



# Mechanical Design and System Integration of a Reconfigurable Quadcopter for Aerial and Underwater Operation

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## Abstract

**Background:** Hybrid aerial underwater vehicles offer aerial access and submerged inspection, but fluid loading, buoyancy, enclosure integrity and changing control authority complicate their development. **Objective:** This study developed a reconfigurable quadcopter architecture and examined the mechanical and system integration requirements governing its intended aerial and underwater operation. **Methods:** Three dimensional computer aided design and engineering drawings guided component selection, additive fabrication and preliminary assembly. Four brushless motor channels, stepper actuation, an enclosed central body and a Pixhawk controller were integrated into the architecture. Analytical relationships for thrust, hydrostatic loading, buoyancy and actuator allocation were formulated to interpret design constraints and define subsequent validation requirements. **Results:** The development produced a CAD configuration, printed components and an assembled four rotor prototype. Assembly exposed joint alignment and sealing difficulties that required iterative adjustment. The analytical assessment indicated that propulsion speed, enclosure loading and thrust direction must be coordinated across operating media. Increasing immersion depth raises hydrostatic pressure, whereas increasing propeller diameter strongly affects thrust and shaft loading under constant coefficient assumptions. Four independently commanded rotor channels cannot provide unrestricted instantaneous control of all six body force and moment components. Quantitative flight, submerged locomotion and transition performance were not established. **Conclusion:** The study provides a preliminary mechanical architecture and a physics based framework for developing reconfigurable aerial aquatic quadcopters. Experimental validation remains necessary to establish

propulsion compatibility, enclosure integrity, buoyancy stability and transition repeatability. Future work should combine calibrated measurements, mechanism characterization, mode specific control allocation and repeated bidirectional transition trials under controlled conditions.

**Keywords:** hybrid aerial underwater vehicle; reconfigurable quadcopter; aerial aquatic robotics; mechanical design; system integration; transition control

## 1 INTRODUCTION

Hybrid aerial underwater vehicles (HAUVs) combine aerial mobility with access to submerged environments. This capability is relevant to waterbody inspection, environmental observation and infrastructure assessment, where an aerial approach can complement underwater sensing. Mechanical design becomes particularly demanding because the same vehicle encounters different fluid loads, buoyancy effects and propulsion conditions. Configuration reviews identify these competing requirements as central constraints in hybrid vehicle development [1], [2].

The air–water interface introduces a further operating regime. During entry or exit, different parts of a vehicle can occupy different media, producing asymmetric loading and rapid changes in actuator response. Cross-domain mobility therefore requires coordinated man-

agement of geometry, propulsion and control [3]. A transformation mechanism may improve the orientation of thrust or reduce the exposed area in one medium, but it also introduces joints, additional inertia and sealing interfaces. Its usefulness depends on the resulting system behaviour rather than on geometric transformation alone.

Previous studies have demonstrated biological design strategies, morphing airframes, buoyancy-controlled multirotors and hybrid controllers. The remaining engineering challenge is to translate these principles into a mechanically coherent platform whose propulsion layout, enclosure, actuation and control allocation are compatible across operating regimes. A conventional quadcopter arrangement is attractive for vertical take-off and accessible component integration, yet four motor commands do not independently control every submerged force and moment. Reconfiguration must conse-



quently be evaluated alongside buoyancy, hydrostatic loading and the available actuator authority.

This study addressed that integration problem through the design and preliminary development of a reconfigurable quadcopter intended for aerial and underwater operation. The objectives were to develop a central-enclosure architecture, integrate propulsion and configuration actuation, and formulate the physical constraints that govern subsequent amphibious testing. The contribution is a prototype-oriented mechanical design study that connects hardware integration with propulsion scaling, enclosure loading and control-allocation requirements. The present scope comprises CAD development, fabrication and preliminary assembly; operational performance across both media remains to be experimentally established.

## II LITERATURE REVIEW

### A Morphing architectures and interface crossing

Siddall and Kovač [4] examined biological strategies for aerial-aquatic locomotion and established distinct design demands for flight, water entry, submerged movement and exit. Siddall, Ortega Ancel and Kovač [5] subsequently evaluated a morphing aquatic micro air vehicle using wind and water tunnel testing. Their work demonstrates that configuration changes must be assessed through fluid loading and trajectory behaviour. For the present quadcopter, this motivates treating the orientation and exposed area of motor supports as engineering variables, rather than assuming that a compact submerged geometry automatically improves performance.

Siddall and Kovač [6] investigated water-jet propulsion for impulsive water exit, showing that departure from the surface can require a mechanism distinct from sustained locomotion. Bishay et al. [7] developed printed mechanisms for bird-like morphing drones, illustrating the potential of additive fabrication for integrated actuation and geometry changes. These studies provide useful mechanism principles, although folding wings and water-jet launch systems differ substantially from rotor re-orientation. Their results cannot directly determine the loads, sealing needs or transition behaviour of a reconfigurable multirotor.

### B Multirotor propulsion and buoyancy

Alzu'bi, Mansour and Rawashdeh [8] developed the Loon Copter with active buoyancy control, demonstrating the importance of displacement management in a hybrid quadcopter. Mercado Ravell, Maia and Diez [9] treated aerial-underwater locomotion as a hybrid system, incorporating buoyancy and drag in the dynamics and a switching strategy in the controller. Their work supports explicit treatment of the interface as a transition between operating regimes. It also indicates that selecting an aerial flight-controller board is only one part of implementing a complete hybrid control system.

Propeller characterization is equally important. Brandt and Selig [10] measured small-propeller thrust and torque over different rotational speeds and advance ratios.

Their results show that geometry and operating condition influence propeller performance; a nominal motor speed constant does not specify useful thrust. For a shared propulsion arrangement, separate characterization in air and water is required because coefficient values and operating limits need not remain unchanged between media.

Jin et al. [11] demonstrated Nezha-IV in real ocean environments, providing evidence beyond laboratory integration. Jin, Zeng and Lian [12] developed the tail-sitting Nezha-SeaDart to combine fixed-wing flight, vertical take-off and landing, and underwater operation. These architectures illustrate different approaches to the conflict between aerial efficiency and aquatic mobility. Their operational demonstrations establish appropriate categories of validation, but their measured performance does not transfer to a mechanically different quadcopter.

### C Fabrication and enclosure integrity

MohamedZain et al. [13] linked modelling, material selection, simulation and fabrication in a drone-development workflow. This approach supports early consideration of assembly access and manufacturability. In an aerial-aquatic platform, the enclosure must additionally protect electronics during immersion and accommodate moving interfaces. Romero, Agulló and Molero [14] investigated PETG vessels and electronic housings fabricated by fused deposition modelling. Their results linked watertightness to manufacturing settings and showed that an initially successful vessel test did not establish that a subsequent housing would pass an immersion test.

These findings distinguish material suitability from component qualification. Print orientation, perimeter count, extrusion flow, joining and finishing influence the integrity of a printed enclosure. Dynamic shaft interfaces also require attention because joint movement and shaft runout can challenge a seal that performs adequately at rest. Thus, bearings, alignment and sealing belong to the same mechanical design problem. The present architecture used printed parts and mechanical sealing elements, while quantitative pressure qualification remains a separate validation requirement.

### D Control implications and research gap

Farinha et al. [15] identified unresolved sensing, actuation and autonomy requirements in aerial-aquatic robotics. Wei et al. [16] considered actuator dynamic input saturation in trans-media motion control, highlighting the need to coordinate demanded motion with available actuator response. Marine-craft modelling further distinguishes rigid-body inertia, hydrodynamic effects and hydrostatic restoring forces [17]. Together, these studies show that a mechanically reconfigured vehicle requires consistent actuator mapping and medium-specific dynamics.

The focused gap addressed here is the integration of a four-rotor platform with an enclosed body and configuration actuation while retaining a clear connection be-



tween geometry and physical operating constraints. The study does not introduce aerial–aquatic locomotion as a new concept. Instead, it develops a specific preliminary architecture and identifies the relationships that must be satisfied before reconfiguration can be shown to support useful underwater motion and repeatable interface cross-ing.

### III METHODOLOGY

#### A Architecture development

The development sequence comprised conceptual configuration selection, three-dimensional CAD modelling, engineering drawing preparation, component selection, additive fabrication and preliminary assembly. An elongated central enclosure was arranged with four external rotor positions. The enclosure provided a common integration region for power and control components, while external supports accommodated the propulsion units. Stepper-driven actuation was included in the architecture to support changes in configuration. Figure 1 shows the CAD layout.



Fig. 1. CAD architecture with an elongated central enclosure and four external rotor positions.

The CAD assembly was used to organize the relative placement of the enclosure, motor supports and internal hardware. Two-dimensional drawings supported geometry development. This phase established the assembly arrangement rather than a fully qualified manufacturing definition. Configuration travel, mechanical stops, transmission ratio and locking behaviour require detailed characterization before the intended aerial and aquatic geometries can be reproduced as operating states.

#### B Components and preliminary assembly

Four FD4250EVO 800KV brushless motors and four 80 A electronic speed controllers were selected for the rotor channels. The propeller specification was HQProp 15X7X3, with clockwise and counterclockwise variants. Two NEMA17 stepper motors and two DM542 drivers formed the selected actuation hardware. A Pixhawk 2.4.8 controller, vibration-isolation mount, Flysky transmitter–receiver set and pressure sensor were included in the control architecture. Table I summarizes the principal component specifications; these ratings do not represent measured vehicle performance.

Table I. Principal components selected for the architecture

| Subsystem             | Configuration                                          |
|-----------------------|--------------------------------------------------------|
| Rotor channels        | 4 FD4250EVO 800KV brushless motors                     |
| Motor drives          | 4 Readytosky 80 A ESCs                                 |
| Propellers            | HQProp 15X7X3; clockwise and counterclockwise variants |
| Reconfiguration       | 2 NEMA17 motors; 2 DM542 drivers                       |
| Control               | Pixhawk 2.4.8; vibration-isolation mount               |
| Command link          | Flysky FS-i6X and FS-iA10B; 2.4 GHz                    |
| Instrumentation       | Pressure sensor for aquatic instrumentation            |
| Power source          | 6S battery labelled 22.8 V and 16,000 mAh              |
| Mechanical interfaces | Bearings, rotary shaft seals, gaskets and O-rings      |

Printed components were fabricated and incorporated into the preliminary assembly. PETG was selected as an additive-manufacturing material, although part-specific material assignments and print parameters remain to be specified for complete replication. Silicone sealant, O-rings and rotary shaft seals were used in the enclosure-protection arrangement. Joint alignment and sealing were checked during assembly; leakage and misalignment prompted iterative adjustments. These observations were treated as integration findings, without assigning a pressure rating or quantitative improvement.

A bench motor-test arrangement was prepared, and the four-rotor assembly was integrated around the central enclosure (Fig. 2). The bench activity did not establish calibrated thrust, torque or efficiency curves. A distinct underwater thruster set was not characterized in this phase. Accordingly, aquatic use of the selected propulsion channels remains conditional on measurements of fluid loading, electrical demand and component compatibility.



Fig. 2. Preliminary prototype assembly showing the central body, supports and rotor units.

#### C Analytical framework

An analytical framework was formulated to connect the architecture to the principal operating constraints. The relationships represent idealized design analysis, not fit-



ted performance models. No CFD or finite-element results were used to infer vehicle capability. For a propeller operating within a specified regime, thrust  $T$  and shaft power  $P$  are written using dimensionless coefficients [10]:

$$T = C_T \rho n^2 D^4 \quad (1)$$

$$P = C_P \rho n^3 D^5 \quad (2)$$

Here,  $\rho$  is fluid density,  $n$  is rotational speed in revolutions per second,  $D$  is propeller diameter, and  $C_t$  and  $C_p$  are thrust and power coefficients. Their dependence on geometry, advance ratio and operating condition prevents unconditional extrapolation between media. At equal thrust and unchanged diameter, the air-to-water speed relationship follows from Eq. (1):

$$\frac{n_w}{n_a} = \sqrt{\frac{C_{Ta} \rho_a}{C_{Tw} \rho_w}} \quad (3)$$

Subscripts  $a$  and  $w$  denote air and water. Equation (3) defines a conditional scaling relationship; it does not prescribe a safe underwater motor speed. Coefficients and permissible loads must be established separately in each medium.

Hydrostatic enclosure loading and buoyancy were expressed as [17]:

$$\Delta p = \rho_w g h \quad (4)$$

$$B = \rho_w g V_d; \quad W = m g \quad (5)$$

In Eqs. (4)–(5),  $h$  is immersion depth below the free surface,  $g$  is gravitational acceleration,  $V_d$  is displaced volume and  $m$  is vehicle mass. The pressure relation assumes approximately uniform density and an interior referenced to atmospheric pressure; it excludes transient impact loading. The buoyancy difference  $B - W$  defines the static vertical force before propulsion. Positions of the centres of mass and buoyancy determine the corresponding restoring moment.

Thrust allocation was expressed in a body-fixed frame as:

$$u = G(\theta) f \quad (6)$$

The vector  $u$  contains three force and three moment components;  $f$  contains the four rotor thrusts. Each column of  $G$  combines a rotor thrust-direction vector with the moment generated by its position and reaction torque. Configuration variables  $\theta$  change these directions and moment arms. For fixed  $\theta$  and four independently commanded thrust channels,  $G$  has six rows and four columns, so its rank cannot exceed four. Independent configuration actuation can introduce additional motion over time, but full instantaneous six-component control cannot be inferred from four rotor commands alone.

#### D Assessment and validation criteria

Completed development was assessed through CAD geometry, fabricated parts and preliminary assembly observations. No operational means, standard deviations or statistical comparisons were calculated because replicated aerial, submerged and transition measurements were

not established. The analytical relationships were used to identify conditional parameter trends and unresolved design requirements. Table II defines a prospective measurement framework for the next development phase; it is not a record of completed experiments.

Table II. Proposed measurements for subsequent validation

| Requirement     | Measurement and reporting                                                     |
|-----------------|-------------------------------------------------------------------------------|
| Propulsion      | Calibrated thrust, torque, RPM, voltage and current in each medium            |
| Enclosure       | Depth, exposure duration, internal water ingress and pre/post inspection      |
| Hydrostatics    | Vehicle mass, displaced volume, centres of mass and buoyancy, trim            |
| Reconfiguration | Angle, travel time, backlash, position repeatability and loaded actuation     |
| Control         | Firmware, gains, mixing, sensor calibration and synchronized state logs       |
| Transitions     | Entry/exit conditions, time, energy, attitude excursion, success and failures |

## IV RESULTS AND DISCUSSION

### A Mechanical integration findings

Development produced a CAD assembly, additively fabricated components and a preliminary four-rotor prototype. The central-body arrangement concentrated the main enclosure interfaces, while the external propulsion supports separated motor mounting from the internal electronics region. This arrangement offers a basis for modular access and further mechanical refinement, although servicing time and packaging efficiency were not measured. The prototype result therefore establishes integration of the selected architecture rather than validated amphibious operation.

Joint alignment and enclosure sealing emerged as coupled integration difficulties. Misalignment at a moving interface can affect bearing loading, shaft motion and contact at a seal. The assembly adjustments consequently addressed more than a geometric fit issue: they identified the need to control the relative positions of propulsion supports, bearings and sealing surfaces. Quantified tolerances, shaft runout and seal compression are required to determine whether the adjusted interfaces remain effective during reconfiguration and immersion.

The CAD and assembled configurations also expose a mass-displacement trade-off. Increasing enclosure volume can accommodate hardware and increase buoyancy, but any resulting increase in structure and sealing hardware adds mass. A submerged configuration must be assessed using both quantities. Without measured mass and displaced volume, neither hover margin nor static underwater trim can be established. This requirement is consistent with the role of buoyancy management demonstrated by the Loon Copter [8].



## B Propulsion trends and shared operation

The conditional trends in Eqs. (1)–(3) show why a shared rotor system requires medium-specific characterization. With density, geometry and coefficient held constant, thrust increases with the square of rotational speed and the fourth power of diameter, whereas shaft power increases with the cube of rotational speed and the fifth power of diameter. These exponents describe scaling within the assumed regime; coefficient changes can alter the practical trend. Larger propellers therefore affect enclosure clearance, support loads and drive requirements as well as nominal thrust.

Equation (3) indicates that greater fluid density generally reduces the rotational speed needed for a specified thrust when other relevant factors remain comparable. It does not imply that an aerial propeller can operate in water at its usual throttle setting. Motor torque, propeller stiffness, controller response and immersion compatibility must be considered together. The present motor and ESC selections establish a hardware starting point, but no measured operating envelope in either medium was established. Thrust-vector reorientation alone cannot resolve an unsuitable motor–propeller combination.

The selected battery ratings likewise describe a power source rather than endurance. Mission duration depends on the electrical demand of propulsion, configuration actuation, control and sensing throughout the operating sequence. Configuration changes may redirect thrust, yet additional actuation and mechanical mass can offset an efficiency benefit. A defensible comparison therefore requires integrated energy measurements for matched trajectories and environmental conditions, including a fixed-configuration baseline.

## C Enclosure loading and hydrostatic stability

Equation (4) gives a linear increase in hydrostatic pressure difference with depth under the stated assumptions. Consequently, a shallow sealing check cannot establish capability at greater immersion depth. Water entry can add transient loading beyond the hydrostatic term. The leakage encountered during assembly is therefore a significant design finding: enclosure qualification must follow mechanical refinement before submerged operation is claimed. Repeated actuation during immersion is especially relevant where seals surround moving interfaces.

Equation (5) distinguishes positive buoyancy, neutral buoyancy and negative buoyancy. Positive buoyancy provides an upward static force but requires downward control authority for submergence; negative buoyancy increases the demand for ascent or depth retention. Near-neutral buoyancy can reduce the static vertical propulsion demand, although it does not eliminate hydrodynamic resistance or guarantee stable attitude. Mass and displacement must be measured before selecting the trim condition, and their spatial distributions must be considered when interpreting pitch and roll response [17].

The additive-manufacturing approach supports rapid adjustment of supports and housings. However, enclosure integrity remains sensitive to the manufactured geometry and joining process, as shown by Romero et al. [14]. The current development does not establish a material-level waterproof property or a pressure-qualified printed housing. Part-specific print settings, surface preparation and inspection should accompany future immersion results so that observed sealing performance can be reproduced.

## D Configuration and control authority

The allocation structure in Eq. (6) provides a further design result: for a fixed configuration, four rotor channels cannot independently generate every six-component body wrench. Reorienting the thrust axes changes the directions in which authority is available, but it does not increase the number of independent rotor commands. Underwater motion may remain possible through an underactuated strategy, constrained trajectories, passive restoring forces or coordinated configuration changes. Which strategy is appropriate depends on the actual mechanism geometry and its verified actuation limits.

This distinction is particularly relevant during partial immersion. The same rotor command can produce different forces as individual units enter or leave the water, while the mechanical configuration may still be changing. A mode-specific allocation and transition strategy must therefore account for available thrust, configuration position and saturation. Hybrid modelling [9] and actuator-aware trans-media control [16] provide relevant precedents. The Pixhawk board forms an implementation platform, but the selected hardware does not by itself establish the required estimator, switching logic or amphibious controller.

The pressure sensor was included for aquatic instrumentation, whereas the selected radio system provides an aerial command link. An underwater command and data architecture remains to be defined and validated. Configuration completion should also be sensed directly or verified through a calibrated mechanism model before controller switching. The present development did not establish autonomous navigation, transition repeatability or closed-loop tracking accuracy.

## E Study significance and limitations

The main contribution is the connection of a constructed preliminary architecture to the physical requirements of cross-medium operation. The development identifies alignment and sealing as practical integration issues, while the analytical framework makes propulsion scaling, buoyancy balance and actuator allocation explicit. This combination helps prioritize the next engineering decisions without treating an assembled quadcopter as an operational underwater vehicle.

The evidence remains limited to design, fabrication and preliminary assembly. Quantitative mass properties, calibrated propulsion curves, immersion qualification, mechanism kinematics and controller settings are required for full replication and performance assessment.



No flight endurance, underwater speed, maximum depth or transition-success rate was established. The analytical relationships do not capture detailed unsteady interface forces or constitute validated numerical simulations. These limitations prevent direct performance comparison with experimentally demonstrated platforms such as Nezha-IV and Nezha-SeaDart [11], [12].

## V CONCLUSION

A reconfigurable quadcopter architecture intended for aerial and underwater operation was developed through CAD modelling, component selection, additive fabrication and preliminary assembly. Four brushless motor channels, configuration-actuation hardware, a central enclosure and a Pixhawk controller formed the principal system elements. Alignment and sealing difficulties prompted iterative assembly adjustments. The resulting prototype establishes a platform for further development, while amphibious operating capability remains to be verified.

The analytical assessment identifies three central requirements. Propulsion must be characterized separately in each medium; enclosure integrity and hydrostatic trim must be measured; and configuration changes must be coordinated with the available control authority. Four independently commanded rotor channels do not establish unrestricted six-component instantaneous control in a fixed configuration. The benefit of reconfiguration therefore depends on the actual thrust mapping, passive stability and intended motion strategy.

Future work should first establish vehicle mass, displaced volume, calibrated propulsion characteristics and pressure-qualified sealing. Loaded mechanism tests should then determine travel, backlash and position repeatability. Separate aerial and submerged control trials should precede repeated bidirectional transitions with synchronized measurements of attitude, depth, electrical energy and failures. Comparison with a fixed configuration under matched conditions will determine whether reconfiguration provides a measurable operational advantage.

## REFERENCES

- [1] Z. Ma, D. Chen, G. Li, X. Jing and S. Xiao, "Configuration design and trans-media control status of the hybrid aerial underwater vehicles," *Applied Sciences*, vol. 12, no. 2, Art. no. 765, 2022, doi: 10.3390/app12020765.
- [2] G. Yao, Y. Li, H. Zhang, T. Wang, F. Sun and X. Yang, "Review of hybrid aquatic-aerial vehicle (HAAV): Classifications, current status, applications, challenges and technology perspectives," *Progress in Aerospace Sciences*, vol. 139, Art. no. 100902, 2023, doi: 10.1016/j.paerosci.2023.100902.
- [3] Z. Zeng, C. Lyu, Y. Bi, Y. Jin, D. Lu and L. Lian, "Review of hybrid aerial underwater vehicle: Cross-domain mobility and transitions control," *Ocean Engineering*, vol. 248, Art. no. 110840, 2022, doi: 10.1016/j.oceaneng.2022.110840.
- [4] R. Siddall and M. Kovač, "Launching the AquaMAV: Bio-inspired design for aerial-aquatic robotic platforms," *Bioinspiration & Biomimetics*, vol. 9, no. 3, Art. no. 031001, 2014, doi: 10.1088/1748-3182/9/3/031001.
- [5] R. Siddall, A. Ortega Ancel and M. Kovač, "Wind and water tunnel testing of a morphing aquatic micro air vehicle," *Interface Focus*, vol. 7, no. 1, Art. no. 20160085, 2017, doi: 10.1098/rsfs.2016.0085.
- [6] R. Siddall and M. Kovač, "A water jet thruster for an aquatic micro air vehicle," in *Proc. IEEE International Conference on Robotics and Automation (ICRA)*, 2015, pp. 3979–3985, doi: 10.1109/ICRA.2015.7139755.
- [7] P. L. Bishay et al., "3D-printed bio-inspired mechanisms for bird-like morphing drones," *Applied Sciences*, vol. 13, no. 21, Art. no. 11814, 2023, doi: 10.3390/app132111814.
- [8] H. Alzu'bi, I. Mansour and O. Rawashdeh, "Loon Copter: Implementation of a hybrid unmanned aquatic-aerial quadcopter with active buoyancy control," *Journal of Field Robotics*, vol. 35, no. 5, pp. 764–778, 2018, doi: 10.1002/rob.21777.
- [9] D. A. Mercado Ravell, M. M. Maia and F. J. Diez, "Modeling and control of unmanned aerial/underwater vehicles using hybrid control," *Control Engineering Practice*, vol. 76, pp. 112–122, 2018, doi: 10.1016/j.conengprac.2018.04.006.
- [10] J. B. Brandt and M. S. Selig, "Propeller performance data at low Reynolds numbers," in *Proc. 49th AIAA Aerospace Sciences Meeting*, AIAA Paper 2011-1255, 2011, doi: 10.2514/6.2011-1255.
- [11] Y. Jin, Y. Bi, C. Lyu, Y. Bai, Z. Zeng and L. Lian, "Nezha-IV: A hybrid aerial underwater vehicle in real ocean environments," *Journal of Field Robotics*, vol. 41, no. 2, pp. 420–442, 2024, doi: 10.1002/rob.22274.
- [12] Y. Jin, Z. Zeng and L. Lian, "Nezha-SeaDart: A tail-sitting fixed-wing vertical takeoff and landing hybrid aerial underwater vehicle," *Journal of Field Robotics*, vol. 42, no. 1, pp. 137–152, 2025, doi: 10.1002/rob.22399.
- [13] A. O. MohamedZain, H. Chua, K. Yap, P. Uthayasurian and T. Jiehan, "Novel drone design using an optimization software with 3D model, simulation, and fabrication in drone systems research," *Drones*, vol. 6, no. 4, Art. no. 97, 2022, doi: 10.3390/drones6040097.
- [14] P. E. Romero, A. Agulló and E. Molero, "Manufacturing of watertight housing for electronic equipment by fused deposition modeling," in *Fused Deposition Modeling Based 3D Printing*, H. K. Dave and J. P. Davim, Eds. Cham: Springer, 2021, pp. 363–376, doi: 10.1007/978-3-030-68024-4\_19.
- [15] A. Farinha, J. Di Tria, R. Zufferey, S. F. Armanini and M. Kovač, "Challenges in control and autonomy of unmanned aerial-aquatic vehicles," in *Proc. 29th Mediterranean Conference on Control and Automation (MED)*, 2021, pp. 937–942, doi: 10.1109/MED51440.2021.9480342.
- [16] T. Wei, Y. Bi, Z. Zeng, L. Lian and Y. Dan, "Trans-media motion control of a hybrid aerial underwater vehicle considering actuator dynamic input saturation," *Journal of Marine Science and Engineering*, vol. 12, no. 12, Art. no. 2169, 2024, doi: 10.3390/jmse12122169.
- [17] T. I. Fossen, *Handbook of Marine Craft Hydrodynamics and Motion Control*, 2nd ed. Chichester: John Wiley & Sons, 2021, doi: 10.1002/9781119575016.