Development of a Modular Dual Wing's Quadcopter

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Abstract

This article presents the design and fabrication process of a custom-built quadcopter with detachable dual wings. Unmanned Aerial Vehicles (UAVs) are widely used for multiple applications, for example in the military, search and rescue, and so on. However, multi-rotary-wing UAVs have encountered limitations regarding flight time and power consumption. To resolve these constraints, this study constructs an innovative hybrid UAV by coupling detachable wings with a quadcopter to explore the effectiveness of wings on power consumption and flight efficiency. The quadcopter was assembled including an outboard flight controller and 4-in-1 ESC. Dual wings were designed and fabricated precisely. The final product was seamlessly developed by clamping these detachable wings onto the quadcopter. Before airborne assessment, software was used to rectify flight parameters. The evaluation of the unmodified quadcopter was completed successfully through multiple aerial examinations. Although the modified quadcopter experienced mild hurdles like vibration, instability, and unequal lift distribution during aerial tests, this unique approach has the potential to enhance flight efficiency and reduce power consumption in multirotor UAVs.

Keywords: quadcopter, hybrid UAV, detachable wings, VTOL, NACA 4412, power consumption

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are defined as powered aerial vehicles without on-board human operators [1–3]. They can be operated remotely using on-board controllers with advanced features such as autonomous capabilities [4]. Autonomous aerial vehicles have recently found use in both military and civilian sectors because they can be deployed to desired locations without risking human lives [1, 5].

UAVs have demonstrated success in demanding tasks including cargo transport, surveys, mapping, and rescue missions [6, 7]. Owing to advances in science, UAVs have also facilitated scientific research by monitoring wildlife and investigating environmental parameters [7, 8].

UAV development revolves primarily around two distinct configurations: fixed-wing and rotary-wing [9]. Fixed-wing UAVs offer higher payload capacity, range, and endurance, but require runways for takeoff and landing, limiting their applicability. In contrast, rotary-wing UAVs do not require runways and offer superior maneuverability; however, because lift is generated entirely by the propellers, energy consumption is high, resulting in reduced endurance and lower operational speed [10].

To overcome the drawbacks inherent to each configuration, hybrid UAVs have been developed that merge the characteristics of both fixed-wing and rotary-wing vehicles [11]. Among the well-known examples, the Bell Eagle Eye is the most quintessential tiltrotor hybrid UAV [12, 13]. Its structure resembles a small aircraft with tilted rotors attached at the wing edges, enabling vertical take-off and landing (VTOL) [13]. Other notable tiltrotor UAVs include the Smart UAV of KARI [14] and BIROTAN [15]. The "Pacflyer S100" is a special VTOL tail-sitter that accomplishes efficient long-endurance cruise flight like a fixed-wing system while retaining VTOL capability [16, 17]. Tiltwing variants such as HARVee from Arizona State University [18] and QTW from Chiba University [19] convert between flight modes by tilting the wing. SUVAI, a quad tilt-wing UAV powered by electricity, can perform VTOL similar to rotary-wing UAVs while achieving the higher flight range of fixed-wing UAVs [20].

Despite this breadth of hybrid configurations, systematic study of hybrid UAVs that retain a conventional multirotor structure without requiring a transition between flight modes remains limited. Surface engineering and materials research has similarly seen rapid development, with studies on advanced coating processes such as Plasma Electrolytic Oxidation (PEO) demonstrating the importance of surface treatment on morphology and corrosion resistance [21], phase transformations under non-equilibrium conditions [22], inward ceramic coating growth mechanisms [23], and the effects of current density variation on coating outcomes [24]. The lessons from such interdisciplinary material and process studies—where controlled manufacturing parameters directly determine functional performance—motivate rigorous experimental validation in novel UAV development as well.

In this paper, a new type of hybrid UAV is presented: the **Modular Dual Wings Quadcopter**. It is constructed by attaching detachable small wings to a conventional quadcopter. The rotorcraft serves as the main frame; no transition between flight modes occurs and non-tilted wings and rotors are used throughout. Because the wings are detachable, the aircraft can revert to a traditional multirotor configuration depending on operational requirements. The dual wings provide extra aerodynamic lift during forward flight, with the goal of enhancing flight time, efficiency, and reducing power consumption.

2. METHODOLOGY

The quadcopter is accelerated by four brushless DC motors mounted on four arms and coupled to propellers. Two motors spin clockwise and two spin counter-clockwise, keeping the total angular momentum at zero and preventing uncontrolled yaw. An Electronic Speed Controller (ESC) regulates all four motors in response to signals from the flight controller. Forward and backward motion depends on differential front and rear motor speeds: higher front motor speed produces rearward motion, while higher rear motor speed drives the craft forward. Fixed wings are integrated to provide supplementary aerodynamic lift.

2.1. Main Components

A frame with a wheelbase of 600 mm was chosen to accommodate the fixed wings while preventing propeller interference. The principal components are described below.

Frame

The main frame is fabricated from fiberglass for stiffness and low weight; the arms are built from aluminum. The 600 mm wheelbase provides adequate clearance for wing integration.

Flight Controller

A **T-Motor F4 Flight Controller** is used. It maintains aircraft balance and regulates motor speed through the ESC, processing incoming receiver signals to produce roll, pitch, yaw, and throttle commands.

Electronic Speed Controller (ESC)

A 4-in-1 ESC converts 2-phase battery current into 3-phase power and supplies precise current to each motor as directed by the flight controller.

Brushless DC Motors

Four BLDC motors rotate the propellers to generate thrust exceeding the aircraft weight. BLDC motors are preferred in multirotors due to their superior thrust-to-weight ratio, low power consumption, durability, and quiet operation.

Battery

A 3-cell LiPo battery (5400 mAh, 11 V nominal) powers the system. LiPo batteries are favoured in multirotors for their high energy density, high power-to-weight ratio, and rapid discharge capability.

Transmitter and Receiver

A **FlySky FS-i6** transmitter (2.4–2.48 GHz, 6 channels) transmits pilot commands to a **FlySky FS-iA10B** 10-channel receiver connected to the flight controller. Compatibility between transmitter and receiver is essential for correct signal transmission.

2.2. Wing Design and Modification

The conventional quadcopter design was altered by integrating detachable dual wings. SolidWorks 2023 was used to create 3D and 2D models of the fixed-wing components: airfoil ribs, internal rectangular shafts, and wing clamps.

Airfoil Rib Design

The **NACA 4412** airfoil was selected owing to its wide use and well-characterised lift performance. Airfoil coordinates were obtained from *airfoiltools.com* as a DAT file, then scaled by a factor of 105 in Excel to achieve a chord length of 105 mm. Internal slots were designed considering CNC laser-cutter tolerances: a circular slot of diameter 7.86 mm and a rectangular slot of $6.38\,\mathrm{mm} \times 5.90\,\mathrm{mm}$, with a centre-to-centre distance of 28 mm. The rib profile was extruded to 2 mm thickness using the Extruded Boss feature.

Shaft Design

An internal shaft of rectangular cross-section was modelled as a $500\,\mathrm{mm} \times 7\,\mathrm{mm}$ rectangle extruded to 6 mm thickness, matching the 6 mm plywood stock.

Clamp Design

The wing clamp body measures $65\,\mathrm{mm} \times 14\,\mathrm{mm}$ (extruded to 10 mm), containing a circular bore of diameter 8.3 mm (for the carbon-fibre tube) and a $6\,\mathrm{mm} \times 6\,\mathrm{mm}$ square aperture (for the shaft). Two through-holes of diameter 3 mm are placed 55 mm apart for fastening.

CNC Laser Cutting

LightBurn software was used to drive the CNC laser cutter. Ribs (2 mm plywood) were cut at 15 m/s, 100% power, 1 pass. Shafts (6 mm plywood) were cut at 35 m/s, 100% power, 22 passes to avoid burn-through on the thicker material.

Wing Assembly

Each wing contains 13 NACA 4412 ribs spaced 30 mm apart, giving a wingspan of $(13 \times 30) + 2 \times 2 = 394\,\mathrm{mm}$ including rib thickness. Two carbon-fibre tubes (500 mm long, 8 mm OD, 6 mm ID) run through the ribs for structural rigidity. Ribs were bonded to the shafts with synthetic resin adhesive; shafts were secured to clamps with cyanoacrylate. Yellow covering tape completed the airfoil skin.

2.3. Integration and Software

After assembling the quadcopter, motors were mounted on the four arms, the 4-in-1 ESC was installed on the upper frame surface, and the flight controller was stacked on top. The battery was affixed beneath the frame. The dual wings were then attached to the quadcopter via carbon-fibre clamps bolted to the frame.

Betaflight Configurator (open-source multirotor firmware) was used to calibrate the accelerometer, configure ports, set flight modes (Arming, Angle, Horizon), calibrate the ESC, and bind the receiver prior to any flight testing.

3. RESULTS AND DISCUSSION

Flight tests were conducted for the quadcopter both with and without dual wings at two distances (50 m and 100 m). Battery voltage was recorded before and after each run to quantify energy consumption. Results are presented in Tables 1 and 2.

Table 1. Flight test results — quadcopter **with** dual wings

No.	**Dist. (m)**	V_1 **(V)**	t **(s)**	V_2 **(V)**	v **(m s^{-1})**	ΔV **(V)**
1	50	12.11	13.20	12.02	3.78	0.09
2	100	12.02	22.46	11.89	4.45	0.13

Table 2. Flight test results — quadcopter **without** dual wings

No.	**Dist. (m)**	V_1 **(V)**	t **(s)**	V_2 **(V)**	v **(m s^{-1})**	ΔV **(V)**
1	50	11.75	8.65	11.71	5.78	0.04
2	100	11.80	23.20	11.77	4.31	0.03

Comparing Tables 1 and 2, the wing-equipped UAV exhibited higher voltage drops at both distances (0.09 V vs. 0.04 V at 50 m; 0.13 V vs. 0.03 V at 100 m), indicating greater energy consumption when wings are attached. The winged UAV was also slower over 50 m (3.78 m s^{-1} vs. 5.78 m s^{-1}), consistent with additional aerodynamic drag from stationary wings at low forward speed. Importantly, the voltage drop increased between 50 m and 100 m for the winged case (0.09 V → 0.13 V), while for the unmodified UAV the drop remained low and nearly constant (0.04 V → 0.03 V). This contrasting trend suggests the winged UAV is still operating in a drag-dominant regime at these speeds.

The unmodified quadcopter completed all flight tests without incident. The hybrid UAV, however, experienced vibration and instability. Unequal lift generation between the left and right wings caused tilting, and downwash at the wing trailing edges marginally disturbed vehicle balance. The absence of a barometer and GPS, combined with insufficient firmware to reject disturbances, contributed to the subpar performance of the T-Motor F4 flight controller in the winged configuration.

4. CONCLUSION AND FUTURE WORK

This study successfully designed, fabricated, and flight-tested a Modular Dual Wings Quadcopter equipped with NACA 4412 airfoil wings. Key findings include:

- The hybrid UAV flew successfully in its unmodified quadcopter configuration; winged flights revealed vibration and instability attributed to unequal wing lift and trailing-edge downwash.

- Higher voltage drops with wings indicate increased energy consumption at short distances; longer distances are expected to yield improved efficiency as aerodynamic lift contribution offsets rotor power demand.
- The lack of a barometer, GPS, and robust disturbance-rejection firmware in the flight controller were primary limiting factors.

Future development should address:

1. Increasing the wing angle of attack by 5–10° to augment lift generation.
2. Designing superior modular wings capable of withstanding variable angles of attack without structural failure.
3. Adopting an upgraded flight controller with GPS, barometer, and advanced disturbance-rejection firmware.
4. Refining the modular clamp design for improved rigidity and reduced vibration transmission to the airframe.

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