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DESIGN AND ENERGY MANAGEMENT OF ELECTRIC FAN MOTORIZED (EDF) VTOL UNMANNED AERIAL VEHICLE

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Abstract: *In this study, the design, production and some tests of an unmanned aerial vehicle (UAV) equipped with an electric ducted fan (EDF) propulsion system and vertical take-off and landing (VTOL) capability have been carried out. A tilt-based thrust vectoring system was employed to enable transitions between different flight regimes. During the design process, initial requirements were defined, and a conceptual design was created based on these parameters. The formulas used in the design calculations were transferred to Microsoft Excel, and various technical data-driven tables and graphs were generated to determine the most suitable design values. The UAV's overall dimensions and basic performance parameters were established. A preliminary study for production was completed, and the CAD drawings were adapted to be manufacturing-ready. As part of the production phase, mold designs were prepared for the outer body components of the aircraft, and these parts were successfully manufactured using carbon fiber reinforced composite material. This project was awarded first place in the inaugural year of the "Hangar Campus Innovation Program" organized by Turkish Aerospace Industries (TUSAŞ).*

Keywords: UAV conceptual design, Vertical Take-Off and Landing (VTOL), Electric fan motor, Tilt mechanism, Carbon fiber

1. Introduction

Today, unmanned aerial vehicles (UAVs) are widely used in military, civilian, agricultural, and security applications. While rapid advancements in hardware and software have produced new solutions, widespread use has revealed some operational and structural limitations. UAVs are primarily classified as fixed-wing and rotary-wing systems (Austin, 2010). Fixed-wing UAVs offer advantages such as high speed, long flight duration, and higher payload capacity, but are limited in rugged terrain and confined areas due to runway requirements. Although rotary-wing systems have vertical take-off and landing capabilities, eliminating the need for a runway, they are at a disadvantage in terms of range, speed, and payload capacity. (Bouabdallah, 2007; Austin, 2010).

To balance these contrasting characteristics, VTOL (Vertical Take-Off and Landing) fixed-wing UAVs have rapidly gained popularity in recent years, combining the flexibility of vertical take-off/landing with the efficiency of a fixed wing in horizontal flight (Ozdemir et al., 2014; Dündar et al., 2020; Tyan et al., 2017). However, a significant portion of existing VTOL designs are based on similar architectures; the use of different engines for vertical and horizontal flight on many platforms increases weight and cost, and also results in relatively low cruising speeds. This study presents a unique and high-performance VTOL UAV architecture that aims to reduce these limitations.

2. Design Approach

The UAV has 4 engines. Two of these engines will be located in sections integrated into the leading edges of the wings, while the other two will be positioned on the right and left sides of the vertical tail stabilizer.

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Each engine is designed to be positioned at three different angles using a tilt mechanism:

- 0°: For forward thrust in horizontal flight mode,
- Approximately 65°: For stabilizing thrust during the transition phase,
- 90°: For vertical takeoff and landing, perpendicular to the ground.

The engine placement configuration has been optimized to allow the UAV to both perform VTOL (Vertical Take-Off and Landing) manoeuvres and improve aerodynamic efficiency during horizontal flight (Ozdemir et al., 2014; Tyan et al., 2017).

Stall speed is the lowest horizontal flight speed at which an aircraft's wings can no longer generate sufficient lift, causing the aircraft to lose altitude and cease to stay airborne. Technically, it occurs when the airflow over the wing separates from the surface as the angle of attack increases, resulting in a sudden decrease in lift (Austin, 2010). In this study, the approximate pitching moment slope value for the EDF-powered VTOL unmanned aerial vehicle was obtained through calculations based on Raymer's methods (Raymer, 2012), considering the wing and tail geometry, center of gravity position, and tail volume coefficient. (Table 1)

$$\frac{dC_m}{d\alpha} = -0.1473\, rad^{-1}$$

This value clearly demonstrates that the aircraft is statically stable in the longitudinal direction. The resulting stability margin not only ensures stability but also allows for aerodynamically stable flight performance. This result indicates a reduction in the need for control input, particularly for cruising flights in the fixed-wing segment. (Fig.1)

Tab. 1: Main design parameters of the UAV.

MTOW:	*40 kg*
Wing Area:	*1.045 m²*
Wingspan:	*1.9 m*
Wing Airfoil:	*NACA 4412*
Length:	*2.28 m*
Aspect Ratio:	*3.45*
Taper Ratio:	*0.466*
Cruise Speed:	*22.6 m/s*
Stall Speed:	*16.75 m/s*

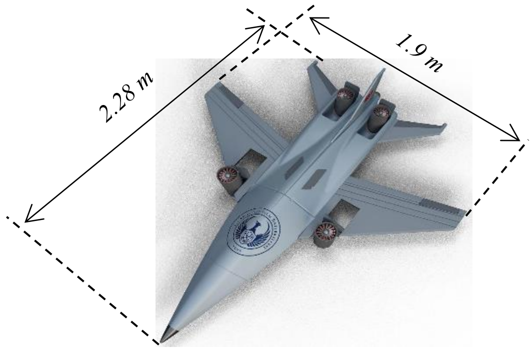

Fig. 1: The sketch of the UAV.

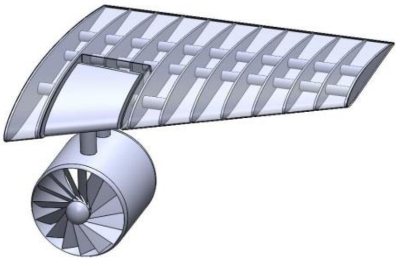

Fig. 2: The second revised wing/engine design.

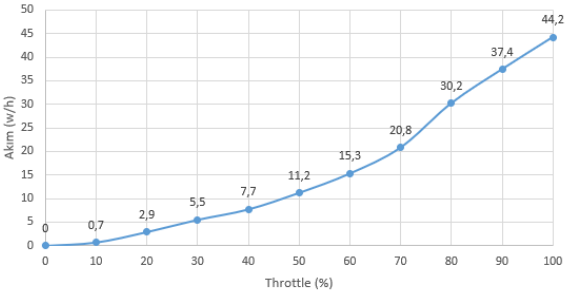

Fig. 3: Throttle adjustment – Electric Current graph.

3. Avionics Equipment

In this study, the Pixhawk Cube Orange+ (IMU V8) ADS-B Carrier Board was used as the flight control unit. The aim was to provide high data processing capacity and safety against sensor failures with a 480 MHz STM32H7 processor and a triple-redundant IMU architecture. The integrated ADS-B capability provides the infrastructure for collision avoidance approaches by detecting surrounding air traffic. The system is configured with ArduPilot in a QuadPlane architecture (CubePilot, 2023; ProfiCNC & Hex Technology, 2022); the switching logic is designed through VTOL parameters (e.g., Q_TILT_* and related VTOL activation/assist parameters) such as motor-servo switching synchronization (ArduPilot Documentation, n.d.).

The integration includes: 4 x Dr. Mad Thrust 120 mm 12-blade EDF (650 kV) motors, 4 x high-torque servos (tilt), 2 x 12S 44.4V 16000 mAh Li-Po batteries, high-current ESCs, PDB, and sensor modules. The ESCs for the EDF motors are connected to the flight computer's MAIN OUT 1–4 lines, and the tilt servos are connected to the PWM OUT 5–8 range; the servos are powered by a 6V BEC. Power distribution is done via the PDB, and the flight computer is powered by an HV power module, incorporating voltage/current monitoring capability into the system (ProfiCNC & Hex Tech., 2022).

RF communication architecture is designed around three channels:

1. RC control: Low latency and long range connection via TBS Crossfire (868 MHz, CRSF),
2. Telemetry: Bidirectional data transfer (TELEM1/UART) with RFD900X (915 MHz) modules, robustness with FHSS/GFSK,
3. Video: 1080p video transmission with low latency (≈40 ms) via DJI FPV HD Air Unit (5.8 GHz). Antenna placements are physically isolated; shielded cabling and ferrite applications are planned for RF/GPS lines to protect against EMI risk from EDF sources (Spitzer, 2007).

4. Engine Energy Management and Battery Evaluation

The EDF motors used were designed for a 12S (44.4V) system with a power consumption of approximately 6.3 kW at around 120A and a static thrust range of 8–10 kg. Due to the limited availability of the manufacturer's datasheet, the motor's energy profile was determined by testing it with a 6S 22.2V 5000 mAh 45C Li-Po battery at different gas levels using a UNI-T UT221 ammeter for current/power measurements; the resulting characteristics were used as a basis for more reliably predicting the requirements of the 12S system (Fig.3).

To determine the power consumption behavior of the Dr. Mad Thrust 120 mm 12-Blade EDF 650kV motor under vertical take-off conditions, an experiment was conducted (Fig.4) with a fully charged Gens Ace 22.2V 5000mAh 45C 6S Li-Po battery at 100% throttle. This test aimed to investigate the system's energy consumption and thermal behavior when the motor produces maximum thrust. The experiment showed that the motor could operate continuously for approximately 7.1 minutes at 100% throttle. During the experiment, the motor, ESC, and battery temperatures were monitored at regular intervals, and no overheating that would pose a safety risk was observed. This test provided important data for evaluating the system's energy requirements during the vertical take-off phase and determining the appropriate battery configuration.

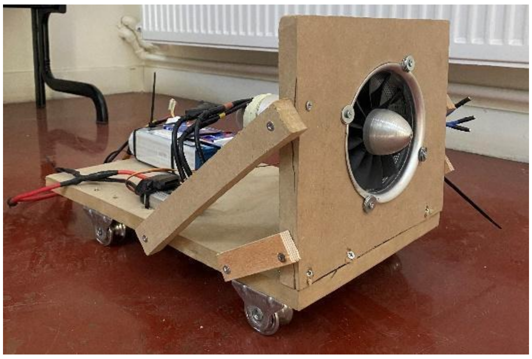

Fig. 4: EDF motor test setup.

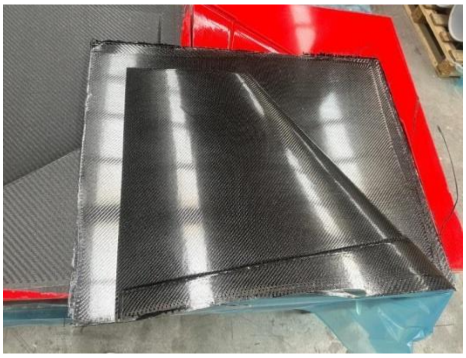

Fig. 5: Carbon fiber vertical tail fin fuselage.

5. Mold designs and production methods

In the design, a square-section carbon fiber tube extending along the fuselage is positioned as the main backbone element; it is structured to carry axial loads and bending moments. Bulkhead profiles are used at different stations to maintain the fuselage geometry and create the interfaces to which the composite outer surface is attached. These bulkheads are planned to be manufactured from laser-cut plywood due to the advantages of rapid prototyping and machinability. Instead of traditional longeron elements, 3D-printed plastic stringer elements are preferred to reduce buckling of the outer covering and contribute to load distribution. Stringer placements are positioned according to load densities along the fuselage and mounted to the composite inner surface by gluing. This method provides low-cost and customizable production while also increasing assembly flexibility (Fig.5). In this study, assembly and integration are planned as the final stage aimed at bringing together the structural, mechanical, and electronic subsystems to make the aircraft flight-ready. The process includes not only physical assembly but also mechanical and electronic arrangements to ensure the compatible operation of the subsystems.

6. Conclusions

This study aimed to achieve vertical take-off/landing capability using four tiltable EDF motors and high lift performance at low stall speeds by using the NACA 4412 airfoil. Flight performance analyses were carried out using Raymer methods (take-off, cruising, range, climb rate, and landing), and parameter optimization was performed using some computational tools. Carbon fiber composite was chosen for the fuselage design to combine lightness and structural strength. During the production phase, the fuselage mold was prepared, the carbon fiber parts were produced using the vacuum infusion method, and the internal frame components were designed and made ready for production before assembly.

The platform's modular structure offers multi-purpose use potential in both the defense industry and civilian sectors. The system is adaptable to reconnaissance and surveillance, disaster relief, environmental monitoring, payload transport, and advanced autonomous mission profiles. In this respect, the study is not only an academic design work but also presents a VTOL UAV platform with commercial potential.

Suggestions:

i. For high-speed missions, the operational range and speed can be increased by developing a gas turbine-powered Version 2.
ii. Prior to flight tests, advanced simulations and control system validation tests should be performed, particularly due to the sensitivities of the center of gravity and stability.
iii. Mission duration and range can be improved by evaluating hybrid propulsion or new generation battery technologies in energy management.

In conclusion, this study has comprehensively presented the design, analysis, and manufacturing steps for an EDF-based VTOL fixed-wing UAV; a feasible and original platform has been developed.

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