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Design and Prototype Development of 3D printed Tilt Rotors E-VTOL Aircraft for Urban Air Mobility

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This paper presents the technological advancements in aerial mobility has created a need for innovative and sustainable aerial solutions. 3D-printed technology is developed to meet the growing demand for compact, efficient, and safe aerial mobility capable of vertical takeoff when designed with lightweight materials and electric propulsion systems. This paper Focus to complete innovative design-to-prototype cycle, the use of digital tools and additive manufacturing to construct and test a structurally optimized 3D Printed E-VTOL prototype carrying a 2kg useful payload while ensuring stability and efficiency. It also develops a complete workflow from conceptual design to functional testing addressing additive manufacturing techniques to create airframe in multiple single parts with minimum material waste, high precision prototyping and on 10% density.

This paper conclude 3D printing with the Fused Deposition Modeling (FDM) method improves the innovative design and performance of an eVTOL aircraft. The results show higher efficiency which reduces rework and waste to reduce the prototyping cost by almost 80%. The innovative structure is 70% better durability and a 10% increase in density and stability control compared to normal designs. These improvements allow changes to conventional aircraft structures, making them lighter, stronger, and more reliable with chosen airfoil NACA 2412 results better lift and drag performance with 50% increase in lift helping the aircraft fly more efficiently while using Delta Structure three electric motors for thrust distribution and stable transition from vertical takeoff to forward flight. Additionally, this approach provides a low-cost, durable, and efficient eVTOL system with applications in surveillance, rescue operations, agriculture monitoring, package delivery, and future smart mobility solutions.

Keywords: E-VTOL, Additive Manufacturing, UAM, FDM, 3D Printing, Tilt Rotor Mechanism.

Introduction:

Electric Vertical Take-Off and Landing (eVTOL) aircraft represent a new direction in aviation industry aiming to combine vertical flight capabilities with the efficiency and sustainability of electric power. A variety of VTOL aircraft that uses electric power to hover, take off, and land vertically. This technology came about owing to major advances in electric propulsion (motors, batteries, electronic controllers) and the emerging need for new aerial vehicles for advanced air mobility that can enable greener and quieter flights.

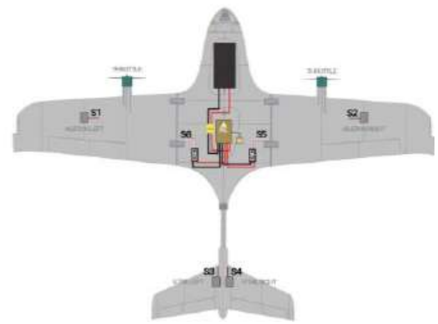


Figure1: E-VTOL Conceptual Sketch

E-VTOL have found a widespread application in both civil and military airspace. They are increasingly used for rescue operations, meteorological monitoring, fish finding, power line maintenance, survey and inspection of various sites and used for urban air mobility. These multipurpose E-VTOL are found in every size, various configuration and complex systems. However, if the E-VTOL are large, they are costly, needing no runways and infrastructure for maintenance. Small E-VTOL are affordable and used for multiple application including civil and Military. Microprocessor and electro-mechanical systems (MEMS) made small E-VTOL design possible. This limitation for runway requirement is overcome through Vertical takeoff and landing mechanism. First built VTOL aircraft was a helicopter which had poor cruise performance such as flight speed, range and endurance. Recently there is a considerable attention given to make fixed wing aircrafts vertically take off and land. These have characteristics of both traditional aircraft and take off and land without requiring a runway. Tilt rotor and thrust vectoring techniques are used in larger and sophisticated aircrafts. However, for VTOL UAVs there are multiple frame configurations. They include mounting rotors in either X-, I- or H- and Delta comparatively easier to fabricate and analyze. Three motors with tilt rotors mounted are placed. This configuration has better stability and lifting capability.

The Tilt mechanism was critically designed to enable smooth transition between vertical takeoff and horizontal flight. This mechanism was integrated into the front motor mounts, allowing uninterrupted and controlled tilting during flight. The back motor remained fixed in the vertical orientation to provide stable lift during takeoff and hovering phases. [2] The design of Fixed Wing Delta shape Tilt Rotors-configuration E-VTOL UAV, its Design analysis and fabrication are the aim of research undertaken. With capability of both a fixed wing and tilting Rotors, this UAV is most suitable for military and civil purposes.

Materials and Methods:

Research aims to bridge the difference between the development of the industry on a large-scale low -cost prototype efforts, which offers a possible and durable approach to EVTOL design using modern equipment's and materials. The Prototype of E-VTOL aircraft refers to the physical construction and assembly of a scaled or full-size experimental electric E-VTOL system based on a predefined design

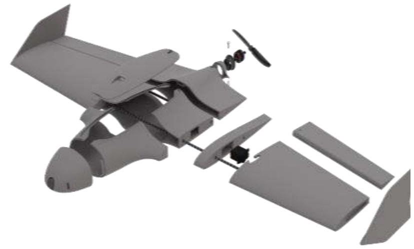
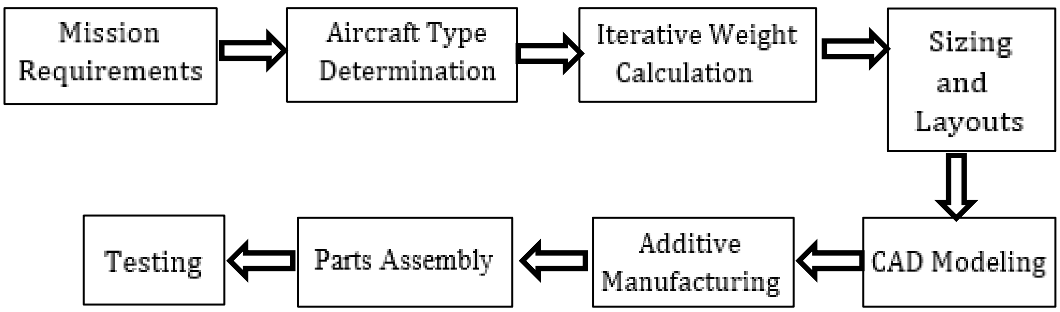


Fig2: 3D Model of E-VTOL



This process transforms conceptual CAD models after Mathematical design Calculations with numbers of iteration and airfoils selection with the using of Java foil software for aerodynamically smooth hovering and transition into a working physical model, allowing for functional testing, design validation, sand performance evaluation in real environment conditions. Material selection is a critical step that affects flight efficiency, durability and total mass. Depending on the design scale and prototype budget.

Figure 3: Fuselage part

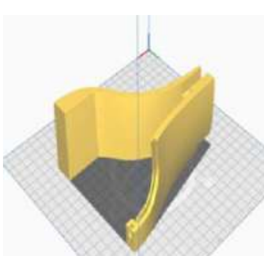


Fig4: Fuselage right part

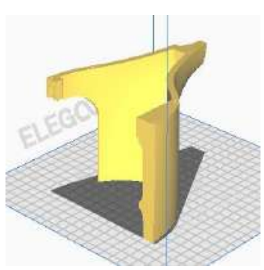


Fig 5: Fuselage left part

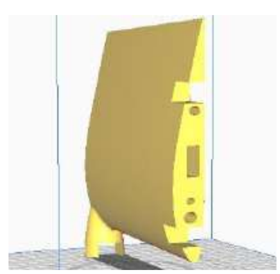


Fig 6: Airfoil wing part

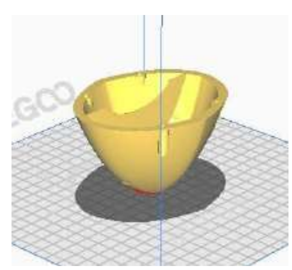


Fig7: Fuselage Nose

Abbreviations:

Wo	Maximum takeoff weight	AR	Aspect Ratio
$Wcrew$	Crew weight	b	Span
$Wempty$	Empty weight	S	Wing Area
L/D	Lift to drag ratio	CR	Root Chord
E	Endurance	CT	Tip Chord
R	Range	MAC	Mean Aerodynamic Chord
CL	Lift coefficient	W/S	Wing loading

The Preliminary design process from initial to defining mission requirements such as payload, endurance, and speed, followed by estimating takeoff weight and selecting a suitable configuration. The design transitions to CAD modeling, where the fuselage, wings, motor mounts are developed. Finally, detailed components are integrated transforming the conceptual design into a validated prototype ready for fabrication and testing.

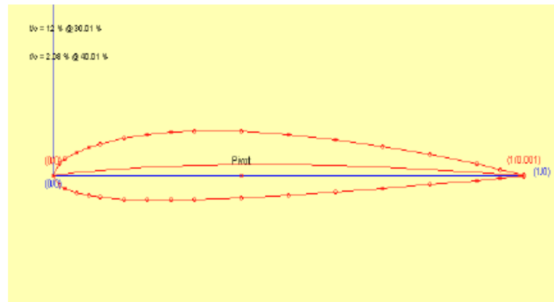
Figure 8: 3D Printed parts

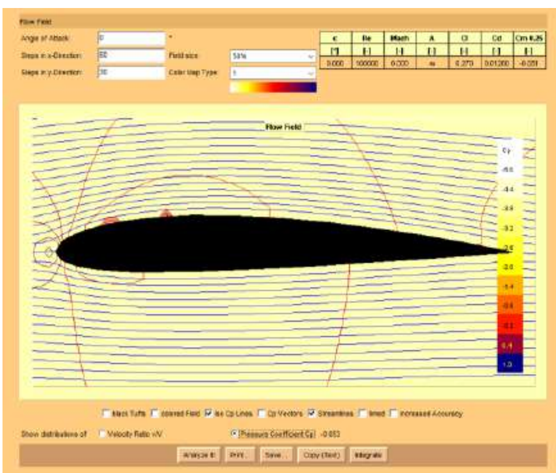
GENERAL AIRCRAFT DATA

Aspect Ratio	6.0
Wing Span	1.48m
Wing Area	$0.265m^2$
Root Chord	0.709 ft
Optimal Cruise Speed	60km/h
Max Range	500 m
Max Payload	2kg
Max Altitude	500m
Airfoil	NACA 2412
MAC	0.709ft
Total Weight	6kg
V- Tail Area	0.538 ft^2
V- Tail Span	0.804 ft.
V-Tail Root Chord	0.886 ft
V- Tail Tip Chord	0.443 ft

Figure 9: Fabricated Model

Java Foil is a computational tool frequently used in aerodynamic investigations for airfoil characterization and performance prediction. The tool computationally generates performance curves, lift, drag, and lift-to-drag ratio (Cl/Cd) and pressure distributions under varying flow conditions. For hovering flight, the primary requirement is to obtain maximum lift at zero angle of attack to ensure efficiency and stability without reliance on high incidence angles. This capability makes it a valuable tool for the design of UAVs and VTOL systems, where stable hover and efficiency are of primary importance.





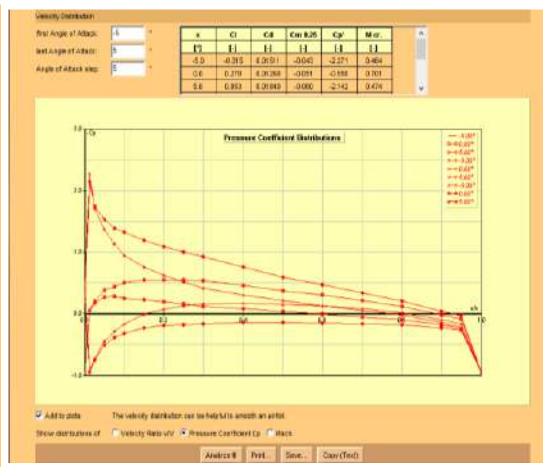
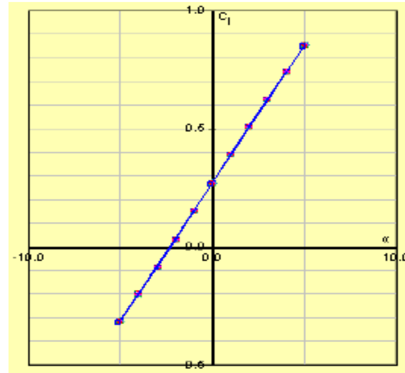


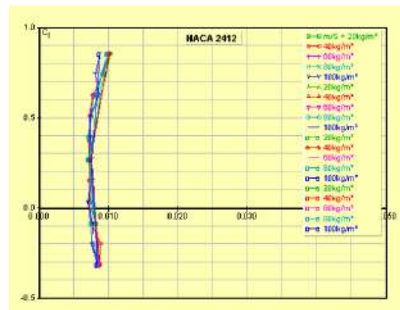
Figure 10: Printed Airfoil

Data Table 3: NACA 2412

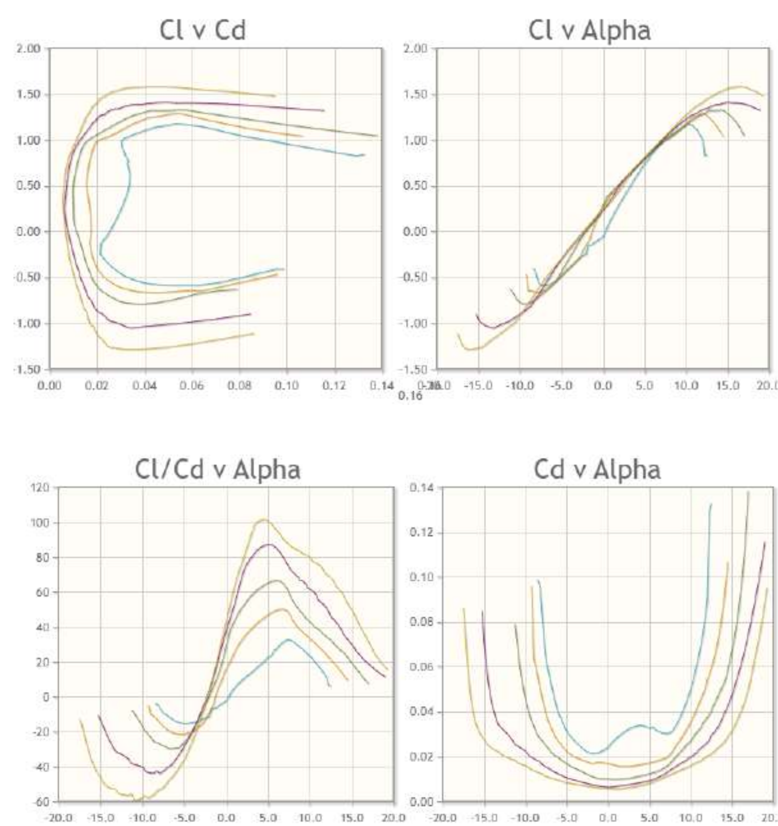
AOA	CL	CD	CM	CP
-5.0	-0.315	0.01511	-0.043	-2.271
0.0	0.270	0.01260	-0.051	-0.550
+5.0	0.853	0.01840	-0.080	-2.143

NACA 2412 airfoil is chosen by keeping design parameters under consideration and to meet eVTOL objectives that's why it is useful to have a fat (around 12% thickness) airfoil because it gives us maximum lift at zero angle of attack which our requirements is meet making vertical takeoff possible in this case exhibits trailing edge stall which is gradual and causes little change in pitching moment coefficient.





Lift	Drag	Weight	Thrust	Thrust
11.53 N	0.55 N	58.84 N	58.84N	58.84N



The Materials Polylactic acid (PLA) and Acrylonitrile Butadiene Styrene (ABS) in the form of raw input for FDM (Fused Deposition Modeling) 3D printers that build parts layer-by-layer. It comes in the form of a long, thin strand typically 1.75 mm and 2.85 mm in diameter wound on a spool. During printing, the filament is fed into a heated extruder nozzle where it melts and is deposited layer by layer to build a 3D object and assembling of all parts Wing, Tail, rods and Propulsion Mounts.

Fig *11*: 3D Printer Filaments

Fig 12: Neptune Elegoo 3 Pro

Table 1. 3D Printing Specifications

Printing Technology	Fused Deposition Molding (FDM)
Print Volume	225 x 225 x 280mm
Layer height	0.1 to 0.4mm
Max. nozzle temperature	260°C
Max. bed temperature	100°C
Printable Filaments	PLA, ABS, PETG, TPU, TPE
Extrusion Type	Direct Extrusion System

The electric propulsion system is the central part of UAVs, which generates thrust to control and hover the UAVs in the air. The propulsion system includes an electric motor, electronic speed controller, power sources, and an energy management system for efficient operation. Components are used to meet the objectives of our research project by integrating power electronics with the UAV's propulsion system. The design achieves low-noise operation, reduced emissions making it highly suitable for applications such as payload delivery and urban air mobility applications.

Figure 13: Controller

Components	Specifications
T-Motor F60 BLDC Motors	920KV Motors
3 Propellers	9-Inch
Battery	Li-Ion, 4S6p 21h
ESC	Electronic System Controllers
Flight Controllers	FS 16 X
Transmitter	FS IA 10 B

Figure 14: Electronic systems

Propellers thrust

Phase	Front Motors (Each)	Rear Motors	Total Thrust
Before Tilting (Hover)	19.61 N (each)	0.01511	58.84 N
After Tilting (Forward Flight)	0.279N (each)	0 (Stopped)	0.559N

Energy Requirements

The Energy requirements are most essential and demanding for aerial vehicle special for electric propulsion systems.

The electric propulsion system (EPS) transforms stored electric power into mechanical power consuming component of the UAVs and generates the required thrust by the motor-propeller system to hover the UAV.

In our case, cruise was found to consume the most energy, while take-off, transition, and descent required comparatively less. This trend agrees with earlier UAV studies. The selected 4S6P Li-ion battery provides much more energy than required, confirming the feasibility of the configuration, though efficient power management remains important to achieve maximum endurance. A brushless DC motor (BLDC) design solution to be used in the hybrid drive for an unmanned aerial vehicle (UAV).

Phase	T. Energy Used
Take-off	6502.36 Joules
Transition	542.95 Joules
Cruise to destination	33934.4 Joules
Descent to Destination	3251.18 Joules
T. Energy Required	**44.23 kJ or 12.29 Wh**

Battery	4S6P Li-ion (14.8V)
Energy Stored	1.12 MJ (310.8 Wh)
Cruise	33 minutes

Figure 15: BLDC Motor

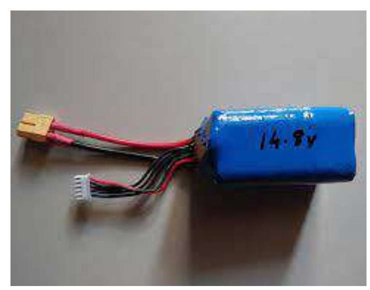


Figure16: Battery

Motor Selection Criteria

Selected Motor	T motor F60 1750 kv
Max RPM (Full Charge)	29,400 RPM
Nominal RPM (14.8V)	25,900 RPM
Total Hover Thrust Needed	58.84N
Total Hover Power Consumption	310.8W
Torque per Motor (Hovering)	1.35 Nm
Motor Efficiency (Forward Flight)	15.7%

Conclusion

The focus of this research work was to design, develop and validate a VTOL UAV prototype capable of transitioning from vertical to forward flight. The reference data is taken from authors similar research work and methods. Fabricated prototype successfully demonstrated these capabilities during testing confirming that the design framework and engineering decisions were effective in meeting mission requirements and objectives. The design was followed by Initial estimation such as payload capacity, endurance, iterative weight calculations and sizing which the required parameters including structure design, wing design and transition capability guided the selection of a tilt-rotor configuration. NACA 2412 airfoil was refined through analytical and computational studies to ensure high lift at low angles of attack finalized. Aerodynamic evaluation confirmed that the selected wing and airfoil configuration results efficient performance in cruise. At an angle of attack +5° degree. The VTOL achieved a favorable lift-to-drag ratio, ensuring lift generation for sustained forward flight. The tilt-rotor mechanism proved effective in transition phase shifting lift from propellers to the wing without losing stability. A complete 3D geometry was developed in CAD modeling software, enabling detailed visualization of the structural and components with the CAD file transformation to Stl for Fabrication which employed additive manufacturing (FDM) producing lightweight durable components, which were then assembled with electronic subsystems to create a functional prototype. The final assembly of airframe, propulsion, and avionics subsystems functioned reliably during both ground and flight trials resulting the effectiveness of the design to prototype workflow.

Figure 17: Fabricated Prototype of E-VTOL

The Results was achieved to select appropriate motors, propellers, and batteries to meet thrust and energy requirements. The T-Motor F60 BLDC motors (1750 KV) with 9-inch propellers were chosen, powered by a 4S6P Li-ion 21 Ah battery pack. Energy calculations across mission phases confirmed a total requirement of 44.23 kJ (12.29 Wh), well within the battery's capacity of 310.8 Wh, enabling a cruise endurance of ~33 minutes. In forward flight, the UAV exhibited reduced power demand, though measured propulsion efficiency of **15–16%** indicated an area for further optimization. Energy analysis further demonstrated the feasibility of the system. Across the complete mission profile, the UAV consumed approximately 44 kJ (12.29 Wh), while the 4S6P Li-ion battery (21 Ah, 14.8 V) supplied 310 Wh yielding a significant safety margin. This enabled an endurance of about 33 minutes, validating the energy management strategy and ensuring mission feasibility under payload conditions.

In conclusion, the UAV successfully achieved its design objectives, demonstrating vertical take-off, stable transition, and efficient forward flight with sufficient endurance. While forward-flight propulsion efficiency offers scope for refinement, the results highlight the potential of lightweight, electrically powered VTOL UAVs for payload delivery and short-range aerial mobility.

Recommendations

Improving the performance of E-VTOL requires development in three major areas, propulsion systems, aerodynamics and control capabilities. To enhance the propulsion and energy systems by using higher energy-density batteries or hybrid systems. These upgrades can increase flight endurance and reduce power losses during forward flight, allowing the aircraft to operate more efficiently over longer distances. The second area of focus is on improving aerodynamics and structural design. By optimizing the shape, using lightweight materials, and refining the structure, the overall strength-to-weight ratio and efficiency of the UAV can be improved. This leads to better flight stability and reduced energy consumption. The third key area is the advancement of control and mission capabilities. Incorporating fault-tolerant systems can improve safety and reliability while flexible payload configurations make the VTOL suitable for multiple applications. These improvements will help achieve higher performance, reliability, and operational versatility in future VTOL designs.

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References

[1]. Daniel. Raymer, “Aircraft Design a Conceptual Approach, (American Institute of Aeronautics and Astronautics, Washington D.C. 20024, 1992), p.110

[2]. Namrata Deka Baruah, Dimmability Deka, and Kalyan Kumar Das, “Aerodynamic Analysis of NACA 2412 airfoil using ANSYS,” International Research Journal on Advanced Engineering and Management (IRJAEM), vol. 03, no. 173-177, 10.47392/IRJAEM.2025.0030, 2025.

[3]. Dhaval Joshi, Dipankar Deb and S. M Muyeen[2], “Comprehensive Review on Electric Propulsion System of Unmanned Aerial Vehicles,” Frontiers in Energy Research, vol. 10, 752012, 2022.

[4]. Darshan Kumar Jayaram, Vijayawada Raja and Beena Stanislaus Arputharaj “Design, Multi perspective Investigations and Performance Analysis of Multirotor Unmanned Aerial Vehicle for Precision Farming,” International Journal of aerospace Engineering, Forward Series, vol. 2024, ID 8703004, 2024.

[5]. Ranjit Bhairavnath Satpute, Omkar Pradeep Shitole, “Design and Development of Vertical Take-Off and Landing (VTOL) Drone for Surveillance,” International Journal of Modern Developments in Engineering and Science, vol. 2, pp. 2583-3138, 2023.