DESIGN & DEVELOPMENT OF A FIXED WING VTOL UAV WITH TILT-ROTORS

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ABSTRACT

VTOL tilt-rotor UAVs combine vertical takeoff with efficient fixed-wing flight. This project designs a novel dual-rotor UAV with thrust vectoring for smooth mode transitions.

- Focus areas include:
  - Mechanical design optimization
  - Aerodynamic analysis using CFD
  - Flight dynamics and control modeling

▪The goal is to improve stability, structural integrity, and performance across flight modes.

▪Applications include aerial surveillance, disaster response, and precision agriculture.

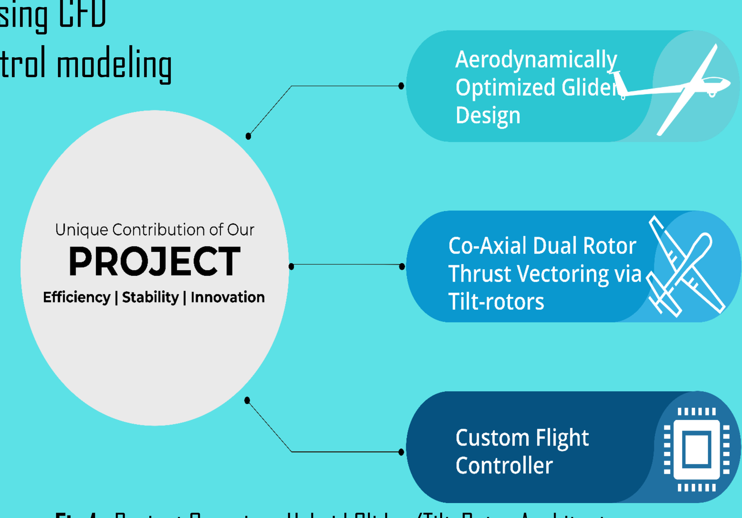

Fig.1: Project Overview: Hybrid Glider/Tilt-Rotor Architecture.

METHODOLOGY

The project began with a review of VTOL UAV designs to set objectives. Key dimensions were derived aerodynamically, and a UAV model with optimized airfoils was developed. T-Motor AS2820 motors, Emax 50A ESCs, and TD-8320MG servos ensured thrust and control. A Teensy 4.0 flight controller managed operations. The carbon fiber structure reduced weight, and control algorithms enabled stable transitions, validated by simulations and ground tests.

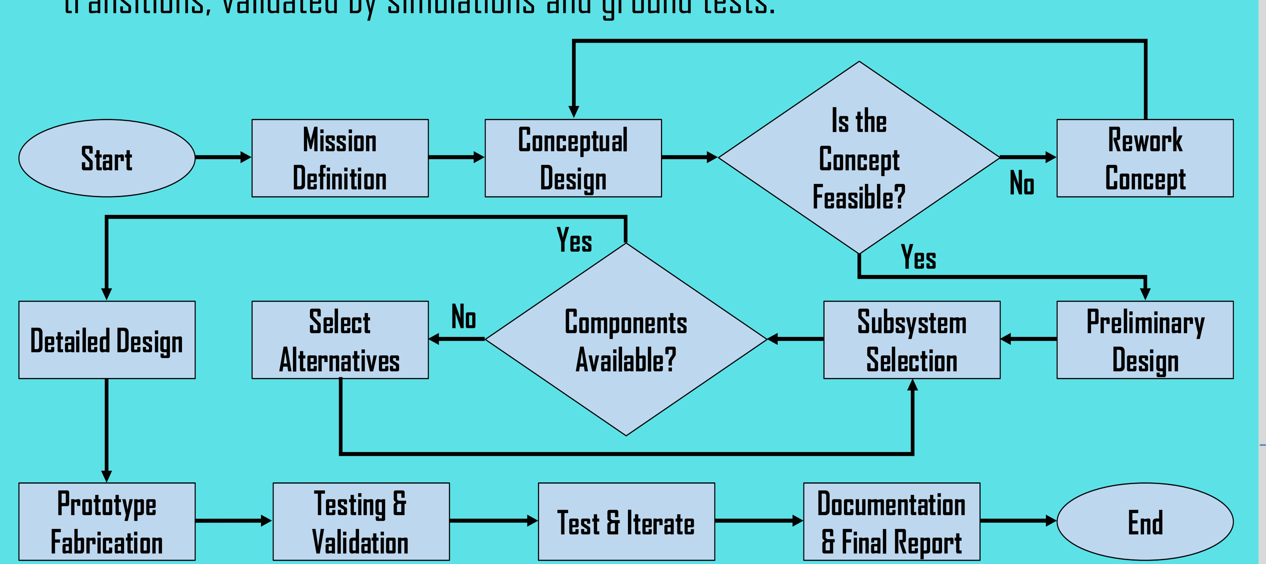

Fig.2: Flow chart of the overall methodology

CAD MODELS

The following assumptions are made while designing:

- Mass and inertia is constant
- The air density is constant
- The ground effect is neglected
- The shear deformation is neglected

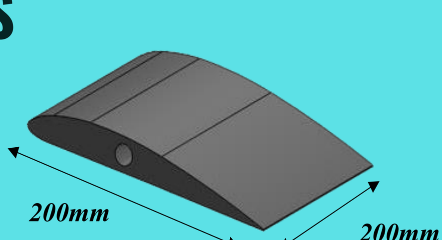

Fig.3: CAD model of NACA 4412 airfoil wing

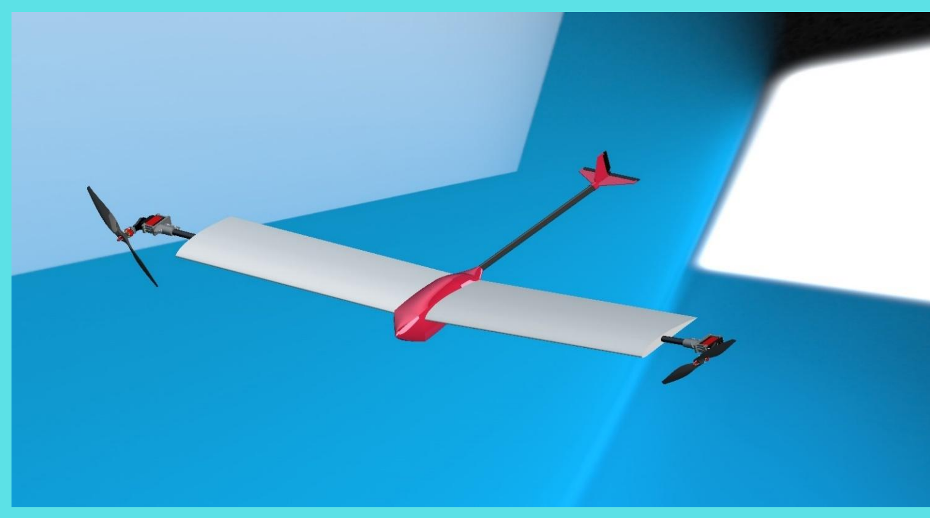

Fig.4: Final render of full model VTOL UAV

The following table is the calculated numerical value of aerodynamic parameters of the selected airfoil (NACA 4412) at 10 degrees angle of attack (AoA) for root chord 0.1428m and tip chord 0.057m.

Lift Coefficient *CL*	Lift, $L=1/2\rho v^2$ SCL	Drag Coefficient *CD*	Drag, $D=1/2\rho v^2$ SCD
1.3	11.46	0.0312	0.275

Table.1: Numerical value of lift & drag

RESULTS & ANALYSIS

Velocity, v (m/s)	Reynolds Number, Re	Critical Angle of Attack, α (⁰)	Lift Co-efficient, C_l	Lift (N)	Drag Coefficient, C_d	Drag (N)
5	28063	10	0.670266	1.47	0.125195	0.27
10	56127	10	1.367024	12.05	0.037991	0.33
S15	84190	10	1.372048	27.2	0.028732	0.57
20	112254	10	1.372784	48.4	0.025486	0.90
25	140317	10	1.372662	75.6	0.023893	1.31
30	168381	10	1.371956	108.9	0.022975	1.82

Table 2: Numerical data of aerodynamic parameters at different velocities [7]

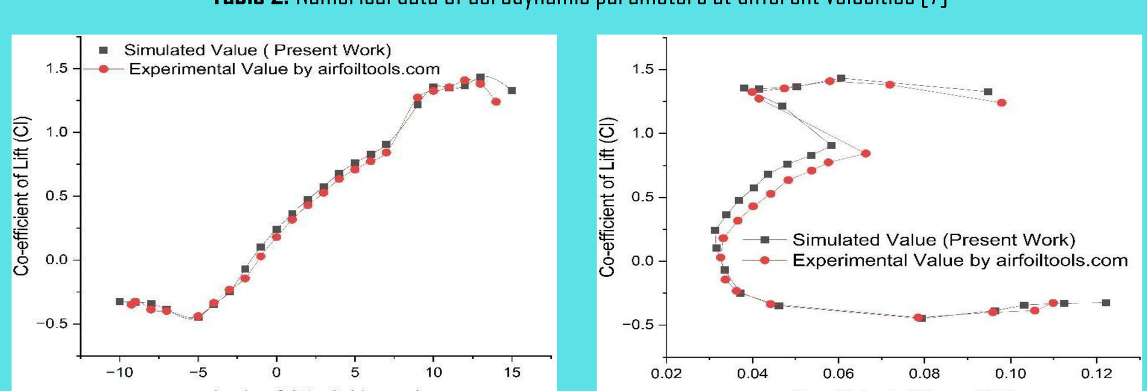

Fig.5: Comparison between computational & experimental data [7].

Validation of Airfoil Data

This table illustrates the lift and drag outcomes for the aerodynamic model at different velocities and critical angles of attack. Simulated results are placed alongside with empirical data to evaluate precision. Simulations presume optimal conditions, whereas experimental outcomes demonstrate wider real-world effects. Significant concordance is visible at angles of attack of 9°, 10°, and 11° beyond these, discrepancies become more evident.

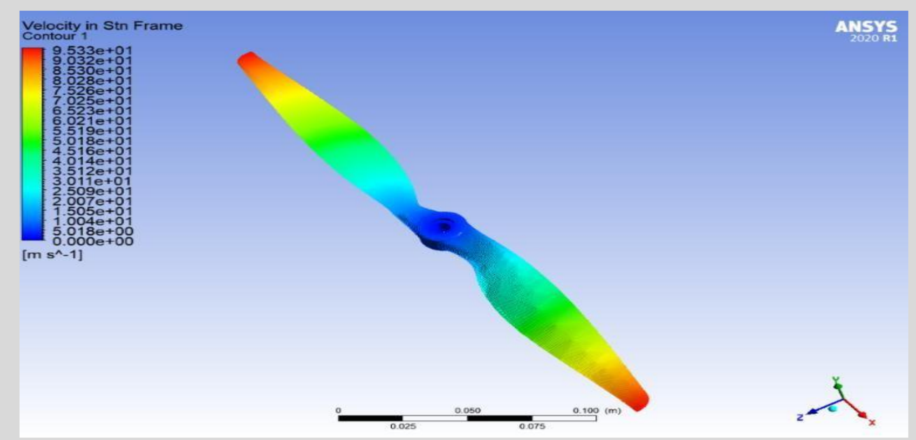

Fig.6: Propeller velocity contour with thrust force

Propeller Thrust Force

At 10 m/s, analytical lift (12.54 N) closely matched CFD thrust (6.51 N), demonstrating strong agreement and validating the simulation's accuracy. Using two APC 12×6 propellers (~85 dB) instead of four 5045 props (~86.02 dB) subtly shifts the acoustic footprint toward a quieter, more refined flight profile.

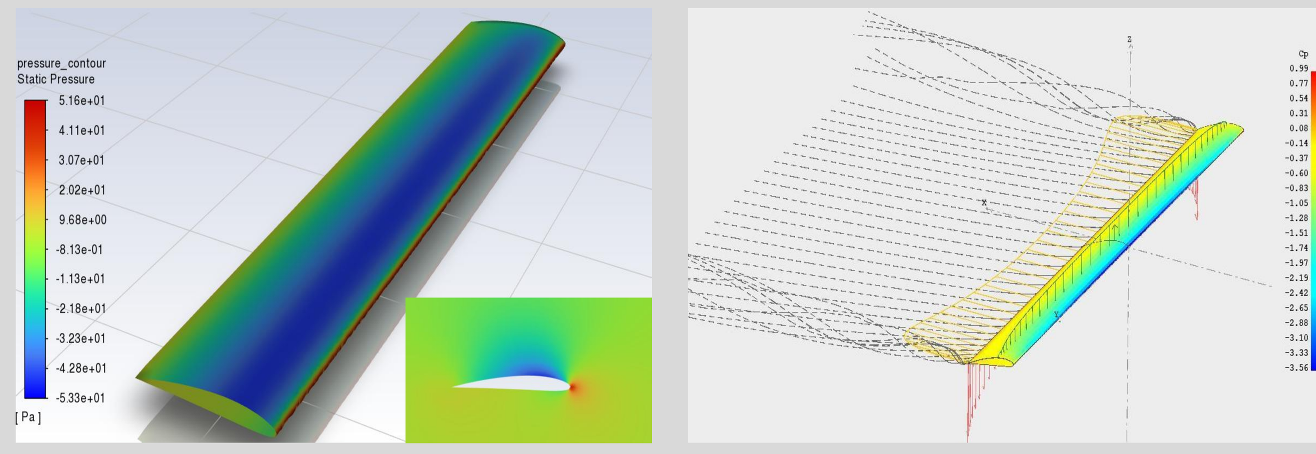

Fig.7: Combined isometric view of Optimized wing

Verification of Optimized Wing

A new wing design with equal chord root and tip (0.2 m) was developed to optimize aerodynamic performance. Lift and drag were calculated using ANSYS Workbench, with refined meshing (150 mm global size, 42 mm body, 10 mm face, 12 inflation layers) and the SST k-ω turbulence model. At 10 m/s and 10° AOA, ANSYS yielded a lift of 13.36 N and drag of 1.13 N. Comparative analysis using XFLR5 under identical conditions estimated a higher lift of 15.61 N. This variation arises from ANSYS's 3D CFD approach capturing complex flow features, whereas XFLR5 uses simplified panel methods.

CONTROL SYSTEM APPROACH

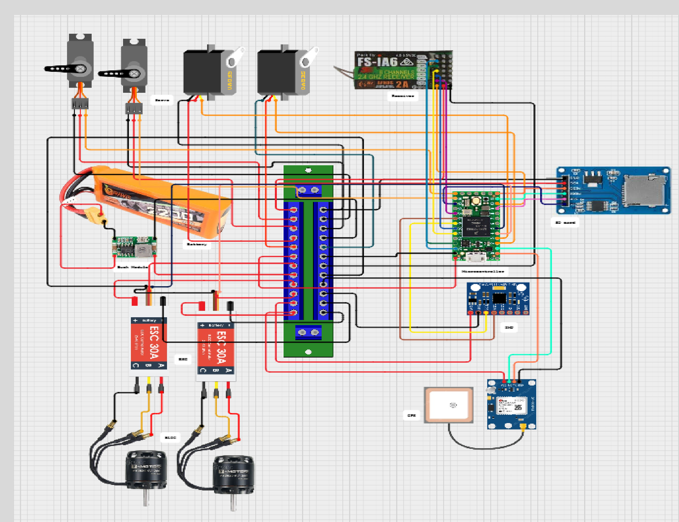

Fig.9: Circuit Diagram Design for VTOL UAV

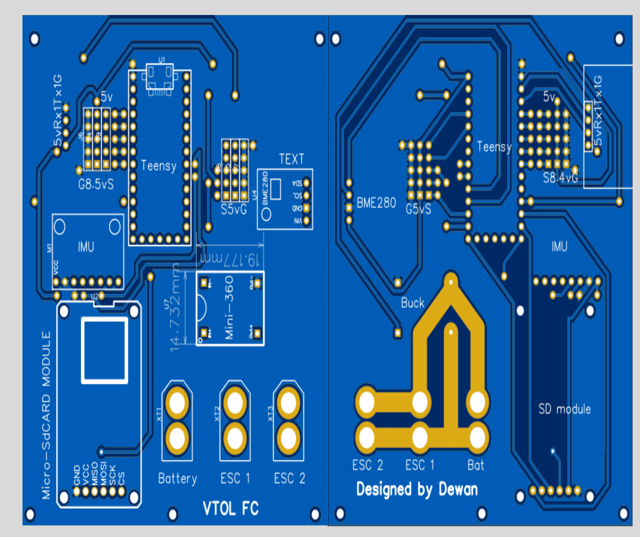

Fig.10: PCB Diagram Design for VTOL UAV

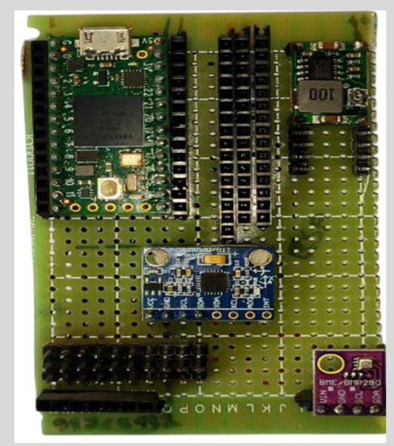

Fig.11: Flight Controller (front side)

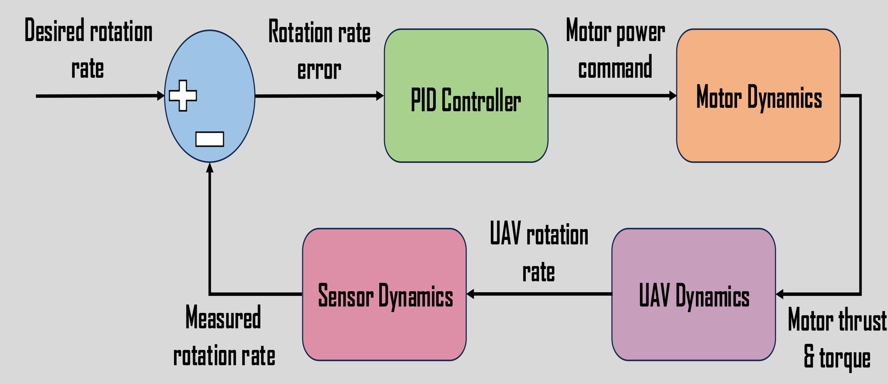

Fig.12: Block Diagram of UAV dynamics and sensor feedback mechanism [5].

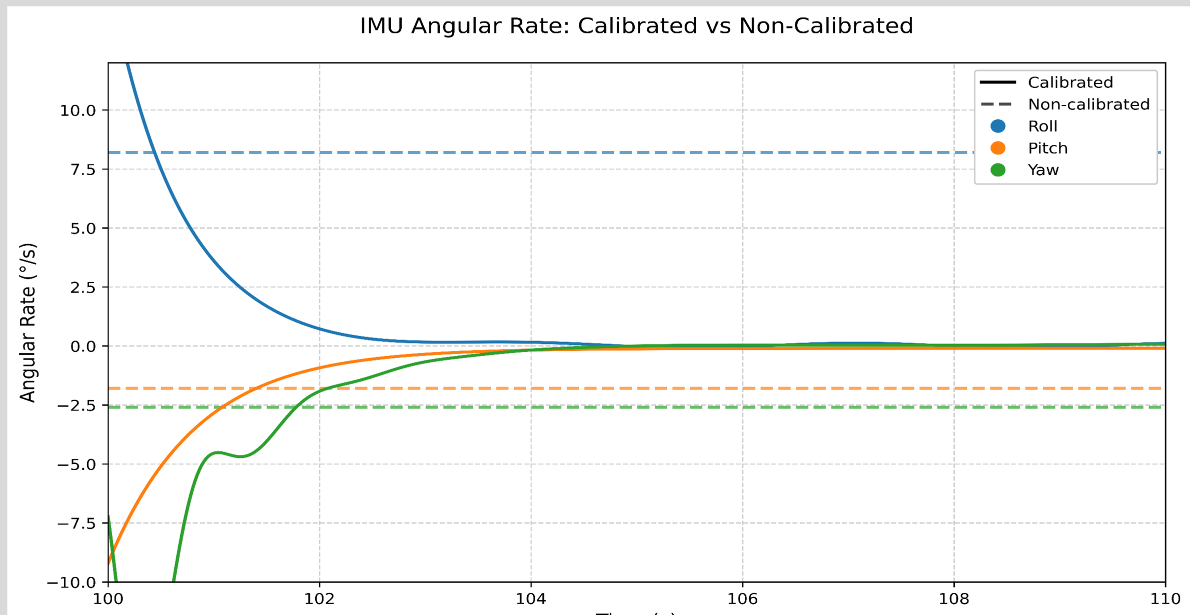

Fig.13: IMU Sensor fusion data with and without calibration.

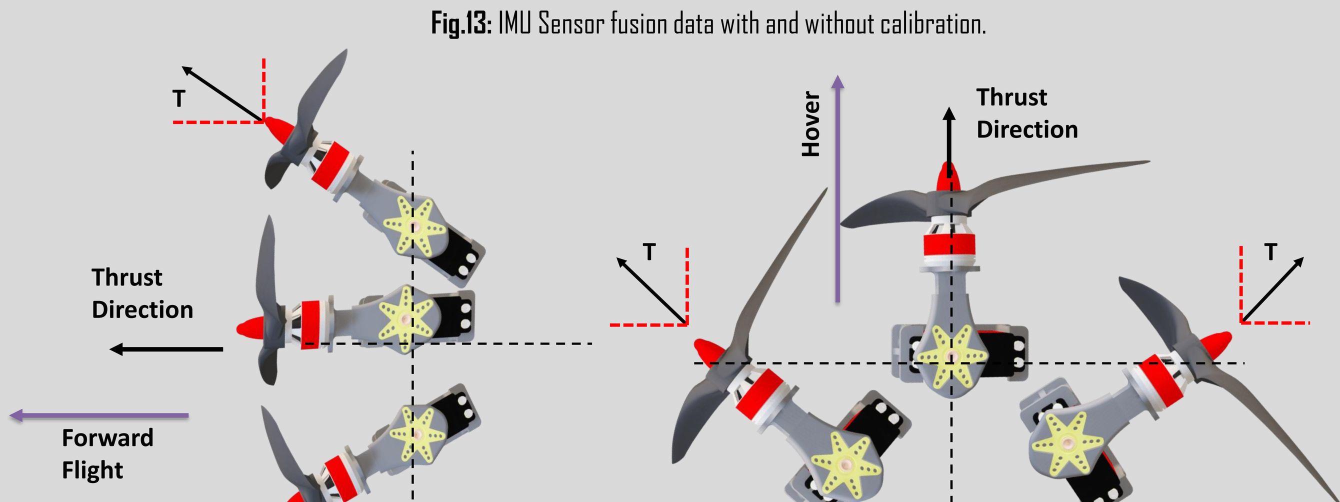

Fig.14: Thrust vectoring mechanism in forward flight and hover conditions.

Microcontroller: Teensy 4.0 (600 MHz Cortex-M7, 1024KB RAM, 1984KB Flash) was chosen for UAV flight control due to its real-time performance, 40 I/O pins, 14 analog inputs, 31 PWM outputs, and multi-bus support (3 SPI, 2 I2C).

IMU: A 6-DOF sensor IMU (MPU6050) with ±250 to ±2000 ⁰/s gyro range and up to 8 kHz output, used for real-time orientation. Offers low noise (0.05 ⁰/s-rms) and drift (±20 ⁰/s) for stable UAV control.

FABRICATION

The UAV body was 3D-modeled in SolidWorks and printed using PLA on an Ender 3 S1 Pro. Carbon fiber tubes reinforced the wings. Components were sanded, finished, and integrated with motors, ESCs, and the flight controller. Final assembly included wiring, mounting, and testing, followed by calibration and controlled test flights for performance validation.

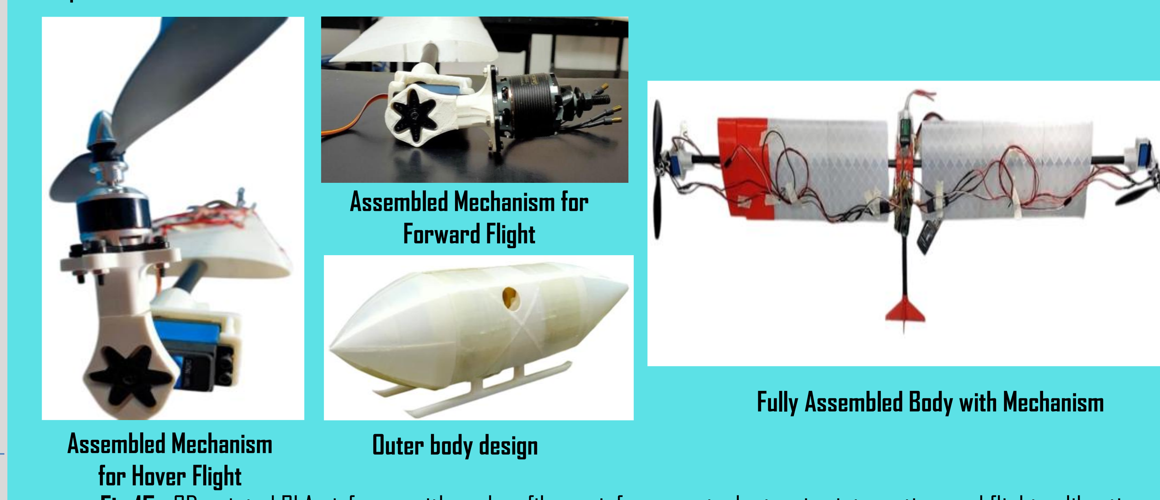

Fig.15: 3D-printed PLA airframe with carbon fiber reinforcement, electronics integration, and flight calibration.

Environmental Impact

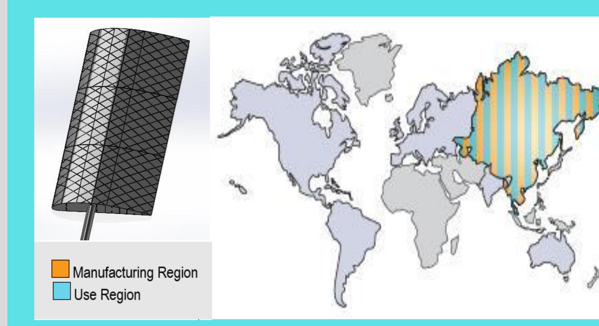

Fig.17: Regional LCA analysis of UAV manufacturing environmental impact.

Table 3: Wing assembly specification and life cycle duration.

Model Name:	Wing assembly
Weight:	293.80 g
Built to last:	10 years
Duration of use:	8.0 year

Component Environmental Impact:

Component	Carbon	Water	Air	Energy
VTOL Wing	1.7	5.1E-4	3.4E-3	30
750mm tube	1.4	4.E-4	2.8E-3	25

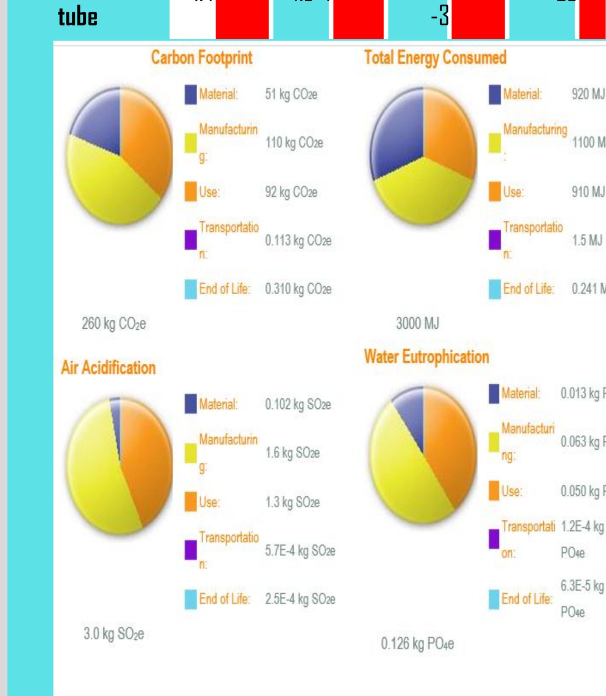

Fig.18: Simulated environmental impact of wing assembly.

Social Impact

- **Job Creation**: VTOL development drives job creation in engineering, manufacturing, and drone piloting sectors.
- **Public Safety**: The UAV is designed for public safety roles such as search and rescue, disaster response, and surveillance.
- **Economic Development**: The UAV supports economic growth through local manufacturing and efficient data collection for sectors like agriculture, forestry, and infrastructure.

Primary SDGs

- **SDG 7 – Affordable and Clean Energy**: Utilizes electric propulsion to minimize fossil fuel use and emissions.
- **SDG 9 – Industry, Innovation and Infrastructure**: Advances in aerospace innovation and building capacity in smart mobility systems.
- **SDG 11 – Sustainable Cities and Communities**: Supports efficient, low-noise urban air mobility for goods and logistics.
- **SDG 13 – Climate Action**: Reduces carbon footprint with aerodynamic wing design and energy efficiency.

Secondary SDGs

- **SDG 4 – Quality Education**: Provides hands-on STEM learning through real-world UAV development.
- **SDG 8 – Decent Work and Economic Growth**: Creates opportunities in green tech, UAV services, and drone manufacturing.
- **SDG 17 – Partnerships for the Goals**: Fosters collaboration between universities, industries, and government bodies.

Legal & Regulatory Compliance

The UAV was designed in compliance with national and international regulations. Key guidelines from the Civil Aviation Authority of Bangladesh (CAAB), ICAO, and FAA were followed, addressing airframe design, altitude limits, communication, safety, and no-fly zones.

CONCLUSION & FUTURE RECOMMENDATIONS

This study aimed to design a low-cost fixed-wing UAV using parametric analysis, CAD modeling, and CFD tools (ANSYS, XFLR5). The NACA 4412 airfoil was selected for its aerodynamic efficiency and 3D-printing suitability. Initial designs with tapered wings generated 9.6 N lift at 10 m/s, while a rectangular wing (0.2 m chord) improved lift by ~30%. Although theoretical thrust using T-Motor AS2820 exceeded structural limits, switching to dual EMAX 980 kV motors ensured safer, cost-effective performance for a 1.5 kg UAV.

Future Work: Advanced CFD and dynamic system modeling, HIL testing, and composite materials will be used to improve VTOL transitions, structural integrity, and overall efficiency.

REFERENCES

[1] J. Guo, "Fixed-Wing UAV Control via ADRC," *IC2ECS*, IEEE, 2023, pp. 1036–1039. doi: 10.1109/IC2ECS60824.2023.10493358.
[2] S. Sonkar, "Low-Cost VTOL Fixed-Wing UAV for Surveillance."
[3] C. Delarosa *et al.*, "Multipurpose Glider-Quadcopter UAS," *Kennesaw State Univ.*, 2018. [Online]. Available: https://digitalcommons.kennesaw.edu/egr_srdsn/2
[4] F. Wang *et al.*, "Tilt-Wing VTOL UAV Transition Evaluation," *IMCCC*, IEEE, 2018, pp. 1175–1178. doi: 10.1109/IMCCC.2018.00244.
[5] R. Czyba and G. Szafranski, "VTOL Control Impact Study," *Int. J. Adv. Robot. Syst.*, vol. 10, 2013. doi: 10.5772/53747.
[6] G. Ducard and M. Allenspach, "Hybrid VTOL UAVs: Design & Control Review," *Aerosp. Sci. Technol.*, 2021. doi: 10.1016/j.ast.2021.107035.
[7] "Airfoil Tools," *Airfoiltools.com*, 2025. http://airfoiltools.com/ (accessed Jul. 16, 2025).
[8] G. Nugroho *et al.*, "CFD-Based VTOL Arm Performance," *Drones*, vol. 6, no. 12, 2022. doi: 10.3390/drones6120392.

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