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Design And Development of a Bi-Plane Tail Sitter VTOL for Enhanced Maneuverability.

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Abstract

The present project focuses on the design and aerodynamic analysis of a biplane tail sitter vertical take off (VTOL) unmanned aerial vehicle intended for enhanced maneuverability and improved aerodynamic performance. Tail sitter VTOL Unmanned Aerial Vehicle combine the advantages of multi rotor hovering capability and fixed-wing forward-flight efficiency, making them suitable for aerospace applications such as surveillance, reconnaissance, inspection and mapping operations. The project was developed based on an existing reference configuration obtained from the research paper titled "A Comprehensive Design and Experiment of a Biplane Quadrotor Tail-sitter UAV." In present work, modifications were introduced in the wing airfoil and wing configuration to study their influence on aerodynamic behavior around the UAV structure. The original NACA 4415 airfoil is used in the reference model was replaced with the NACA 6415 airfoil in order to improve airflow smoothness and reduce turbulence formation during forward-flight conditions. The complete UAV model was designed using Autodesk Fusion 360 and aerodynamic analysis was carried out using ANSYS Workbench to study pressure distribution, velocity distribution and streamline behavior around the aircraft body. Based on the obtained aerodynamic results, its assumed that the smoother airflow behavior observed around the UAV body may contribute to reduce induced drag and improved aerodynamic efficiency during forward flight. CFD analysis showed that the modified NACA 6415 airfoil achieved 13.46% reduction in drag coefficient,11.67% increase in maximum lift coefficient (CL), and 18.86% improvement in lift-to-drag ratio (CL/CD) compared with the reference NACA 4415 airfoil. These modification enhances forward-flight aerodynamic efficiency.

Keywords: UAV, VTOL, Biplane, Range, Endurance

1. Introduction

A drone that can take off straight up, fly like an airplane, and then come back and hover is very useful. This type of drone can be used for many real-life applications, such as checking crops on farms, inspecting tall buildings and other difficult places, and delivering packages quickly in cities.

Normal multi-rotor drones can hover very well, but they use a lot of battery power when flying forward. On the other hand, fixed-wing aircraft can fly long distances using less power, but they cannot stay in one

place or take off vertically. The biplane quadrotor tail-sitter UAV helps solve this problem by combining both types of flight in one aircraft. It can take off and land vertically like a drone and then changes its position to fly forward like an airplane [1],[4].

The biplane wing arrangement is designed for better aerodynamic performance, not just for appearence. Stacking two lifting surfaces shortens the required wingspan while preserving lift area, strengthens the structure inherently, and suits the thrust geometry of a quadrotor layout[1]. The platform transitions between flight modes by reorienting its entire body -no actuated tilting mechanics, no folding components. This simplicity is one of the designs greatest strengths. It is also the source of its greatest engineering challenge, since the aerodynamic, stability margins, and control requirements and change fundamentally as the vehicle rotates from vertical hover to horizontal cruise

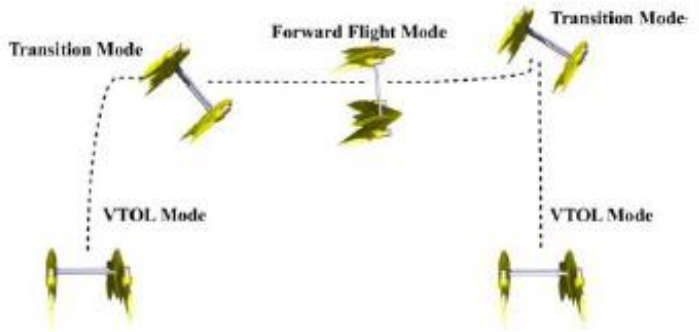


Figure 1.1 Tail-sitter mission profile.

The graphs shown in the work of Qiao et al.[1]. Are based on aerodynamic and structural equations. These equations help us understand how the TW10 quadrotor tail-sitter UAV performs during flight. One important equation used in the analysis is the lift coefficient, which helps us understand how much lift the wings can produce. Lift is calculated using the lift co-efficient formula: As follows:

1. Lift Co-efficient

$$C_L = \frac{L}{\frac{1}{2}\rho V^2 S}$$

2. Drag Co-efficient

$$C_D = \frac{D}{\frac{1}{2}\rho V^2 S}$$

3. Momentum Co-efficient

$$C_M = \frac{M}{\frac{1}{2}\rho V^2 S c}$$

Previous studies have demonstrated the feasibility of tail sitter UAV for VTOL and forward flight. Qiao et al. [1], proposed a biplane quadrotor tail sitter UAV with improved transition characteristics. Wang et al. [2] investigated flight stability during VTOL operations, while Lee and Kim [9] analyzed propeller-wing interaction effects. However limited research has focused on evaluating the aerodynamic performance of replacing the NACA 4415 airfoil with the NACA 6415 airfoil in biplane tail-sitter UAV. It is study addresses the gap through CFD analysis.

2. Methodology

The development of the biplane tail sitter UAV was carried out through a systematic design procedure involving airfoil selection, wing development, fuselage design, propulsion integration ,C

AD assembly and flow analysis.

The overall methodology adopted in this work is presented below

The computational domain consisted of a C-type enclosure with the inlet positioned 10 chord lengths upstream of the airfoil, the outlet 20 chord lengths downstream and the upper and lower boundaries located 10 chord lengths away to minimize boundary interference. A structured quadrateral mesh with approximately 210000 elements was generated to ensure accurate flow prediction. The boundary conditions included a 20m/s velocity inlet, a 0 Pa pressure outlet, a no slip wall condition on the airfoil surface and symmetry conditions at the upper and lower boundaries to represent free stream flow.

2.1 Validation

2.1.1 Design Validation

The aerodynamic behaviour obtained from the flow analysis was compared with aerodynamic trends reported in published literature. The comparision showed agreement with established aerodynamic characteristics of biplane UAV configuration.

2.1.2 CL/CD VS AOA

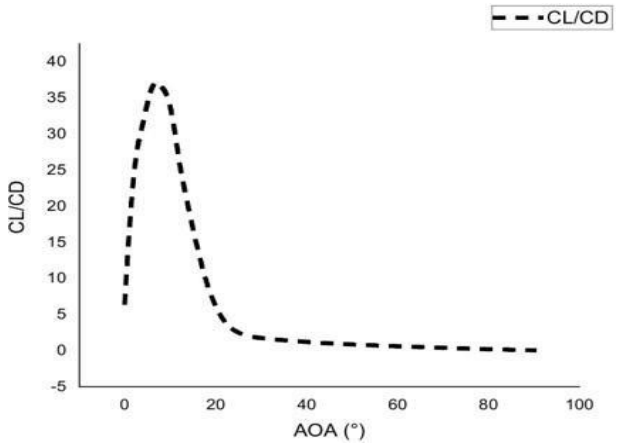


Figure 2.1.2 (a) CL/CD VS AOA

The present study evaluates aerodynamic performance within the cruise flight range of 0^0-20^0 angle of attack. Unlike the reference study, which analyzed the complete VTOL transition up to 100^0, the present investigation focuses on forward flight performance. Future work will extend the CFD analysis across the complete transition envelope.

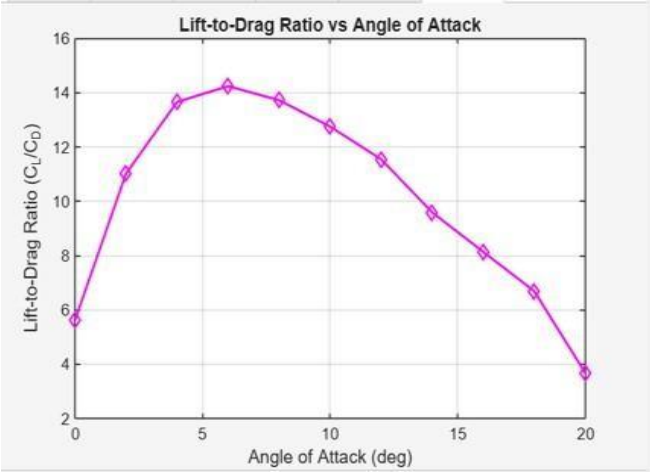


Figure 2.1.2 (b) CL/CD VS AOA

Lift-to-Drag Ratio (CL/CD) Validation
The developed UAV exhibits a similar trend, reaching a peak CL/CD of approximately 14 near 6° AOA before gradually decreasing.

Observations:

- Both graphs exhibit a distinct optimum aerodynamic efficiency region.
- The maximum efficiency is achieved at moderate AOA values.
- Beyond the optimum angle of attack,

drag increases significantly, which leads to a decrease in the CL/CD

Improvement:
The developed UAV achieves a high CL/CD value within its intended cruise region, indicating:

- Better aerodynamic efficiency,
- Longer endurance,
- Reduced battery consumption,
- Improved forward-flight performance

2.1.3 CM VS AOA

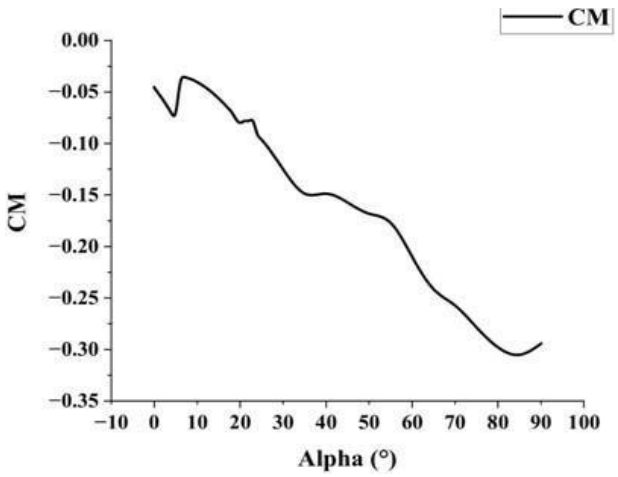


Figure 2.1.3 (a) CM VS AOA

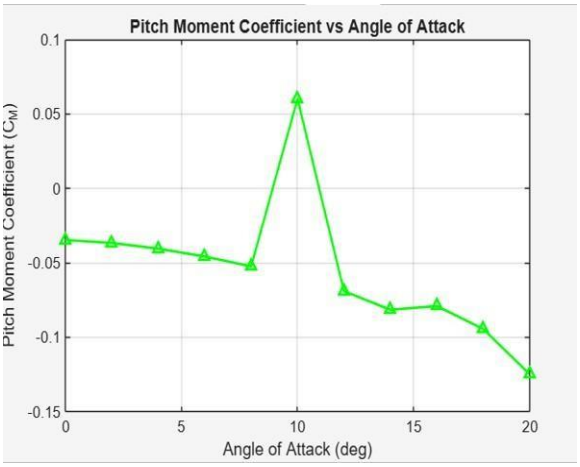


Figure 2.1.3 (b) CM VS AOA

Pitching Moment Coefficient (CM) Validation. The reference graph shows predominantly negative pitching moment coefficients throughout the operating range, which indicates that the UAV has good longitudinal stability.

The developed UAV also exhibits mostly negative CM values, except for a small excursion around 10^0 Angle of attack.

Improvement:

The negative CM values suggest improved longitudinal stability during both hover-to-cruise transition and forward flight. The limited positive peak near 10^0 angle of attack is small and doesn't significantly affect overall stability.

RESULTS AND CONCLUSION

2.2 CAD MODEL DEVELOPMENT

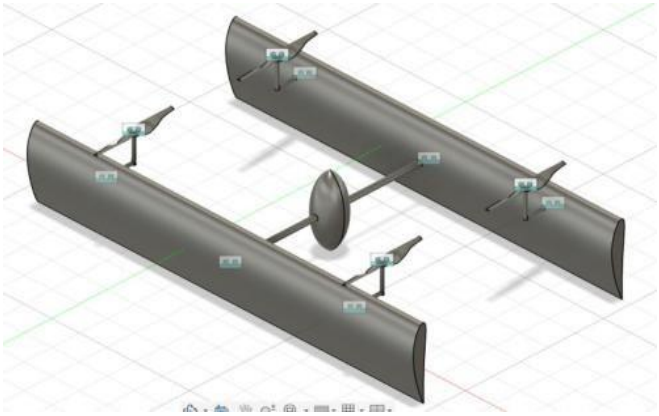


Figure 2.1 CAD Model

AOA (°)	CL	CD	CL/CD
0	0.05	0.030	1.7
2	0.25	0.032	7.8
4	0.45	0.036	12.5

The biplane tail sitter UAV was designed using Autodesk Fusion 360. The Cad model was developed to satisfy the requirements of vertical takeoff and landing (VTOL), efficient forward flight, and enhanced manuverability. The final model consists of an upper wing, lower wing, fuselage, wing support members, propulsion mounting arrangement and control surfaces. Autodesk Fusion 360 enabled accurate geometric modelling and dimensional verification before performing flow analysis. The developed CAD model served as the basis for computational fluid flow analysis and future prototype fabrication.

2.3 FLOW ANALYSIS

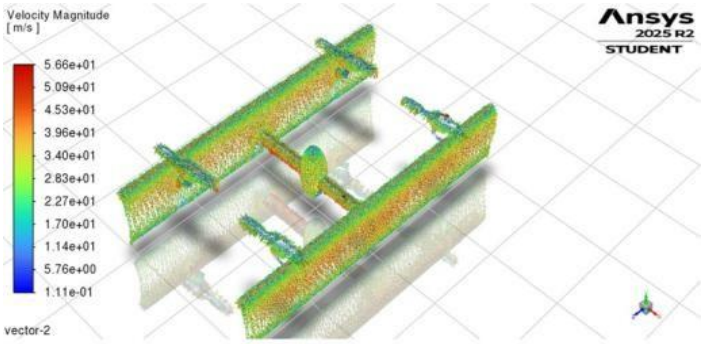


Figure 3.2.1 (a) Velocity Distribution

AOA (°)	CL	CD	CL/CD
0	0.08	0.030	2.7
2	0.28	0.033	8.5
4	0.48	0.037	13.0

Observations:

- Smooth airflow over both wings.
- Uniform velocity distribution.
- No significant flow separation.
- Stable wake region behind the UAV.
- Reduced aerodynamic disturbances.

2.4 PRESSURE DISTRIBUTION

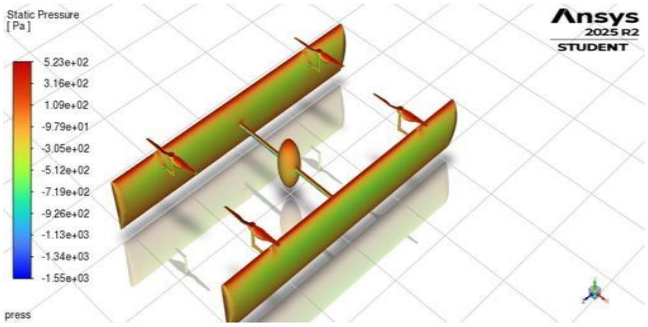


Figure 3.3.1 (b) Pressure Distribution

The pressure contour show a clear pressure difference between the upper and lower wing surface. Higher pressure regions were observed on the lower wing surfaces, while lower pressure regions were present on the upper wing surfaces. This pressure variation confirms the generation of aerodynamic lift.

CONCLUSION

A biplane tail-sitter UAV was successfully designed using Autodesk Fusion 360 and evaluated through flow analysis.

The velocity and pressure distribution results demonstrated smooth airflow characteristics around the aircraft. The velocity contours showed that the flow remained mostly attached over the wing surfaces. The pressure difference between the upper and lower surfaces, which helped in generating the required lift. From the streamline analysis, no major vortex formation or significant flow separation was observed behind the aircraft. This indicates that the proposed biplane tail-sitter configuration provides good aerodynamic performance with relatively lower wake losses The present analysis was carried out using steady-state CFD simulations with passive airflow conditions. The effects of propeller-induced slipstream and the transient flow behaviour during VTOL transition were not considered in this study.

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