Aerodynamic Analysis of a VTOL Fixed-Wing UAV Aircraft With Conventional Control Surfaces

Anusara Wijerathna
Department of Mechanical & Manufacturing Engineering
Faculty of Engineering
University of Ruhuna
Galle, Sri Lanka
rmaswijerathna@gmail.com

Buddhika Annasiwaththa
Department of Mechanical & Manufacturing Engineering
Faculty of Engineering
University of Ruhuna
Galle, Sri Lanka
annasi@mme.ruh.ac.lk

Keywords - UAV, VTOL, Fixed-Wing aircraft, Flow simulation, Aerodynamics

I. Introduction

Vertical Take-Off and Landing (VTOL) Unmanned Aerial Vehicles (UAVs) offer significant advantages in operations requiring both vertical lift and efficient forward flight. However, VTOL aircraft design is challenge in terms of stability, control, and aerodynamic efficiency across flight regimes. Aerodynamic analysis is conducted to determine the variations of pressure distributions, lift and drag forces and center-of-pressure (CP) movement all of which are important towards design optimization and control modeling. This study focuses on aerodynamic analysis of a small VTOL fixed-wing UAV without using any additional actuators or complex tilting mechanisms. The designed UAV only uses the regular control surfaces such as Aileron, Rudder and Elevator of the fixed wing aircraft for maneuverability.

Computational fluid dynamics (CFD) has become a essential tool in aerodynamic design and analysis. Studies of flying-wing VTOL UAVs revealed that CFD is effective in the prediction of stability and flow separation which is critical in transition controllability [1]. The structural and CFD studies were also coupled which showed that aeroelastic effects at high lift and inertia can be critical to performance and safety [2]. CFD has also been useful in wing and fuselage optimization to minimize drag and preserve lift as well as in the prediction of aerodynamic coefficients by use of turbulence models to provide reliable control inputs [3]. In addition to CFD, low-order methods like XFLR5 have been used to facilitate initial design through evaluation of center-of-gravity balance and optimization of wing geometry under structural constraints [4] [5]. On this basis, th present work implements CFD and XFLR5 to examine the aerodynamic forces, pressure field, and CP-CG interaction in a fixed-wing UAV-VTOL.

II. Methodology

The research started with designing of fixed wing UAV aircraft using 3D modeling software. The Fig. 1 presents the 3D model of our designed aircraft. Next aerodynamic analysis was performed to optimize aerodynamic shape and stability. This work involves the analysis of pressure distribution, the computation of lift and drag forces, and optimization of aerodynamic shape and configuration.

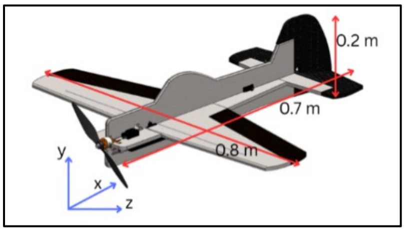

Fig. 1. 3D Model of VTOL UAV

A. Flow Simulation

The modeled 3D UAV model was used to do aerodynamic analysis using the Flow Simulation software. The investigation considered external airflow conditions to represent horizontal flight mode. The simulation was The CFD setup modeled external aerodynamics in air (ρ = 1.225 kg/m³) at 101,325 Pa and 293.2 K, with an inlet velocity of 15 m/s. Gravity (–9.81 m/s²) was included, using a k–ε turbulence model with 2% intensity and refined meshing near wings and control surfaces. From this simulation Lift force in Y, drag force in X, pitching torque about Z, and the location of the center of pressure (CP) was obtained.

B. XFLR5 Simulation

Next stability analysis was performed by using XFLR5. It was used to model aerodynamic coefficients of the aircraft's wings and stabilizers. The Fig. 2. presents the wing and stabilizer placement in the XFLR5.

The aerodynamic analysis was conducted at around 200 m altitude with air density of 1.205 kg/m³ and Reynolds numbers between 141,000–236,000. Angles of attack from –5° to +20° were evaluated using Lifting Line Theory (LLT) and Vortex Lattice Method (VLM2) to capture aerodynamic behavior and stability. The 2D and 3D analyses were done to obtain lift coefficient (CL), drag coefficient (CD), and moment coefficient (CM).

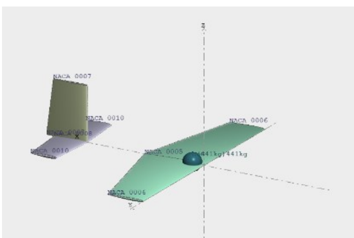

Fig. 2. Aircraft Modeling in XFLR5

III. Results and Discussion

A. CFD Results

The following findings were obtained from the simulation. At lower angles of attack (0–5°), the airflow remained attached, producing smooth acceleration over the wing's upper surface. A minor flow separation was observed near the trailing edge at 5°. The simulations resulted strong suction on the upper surface and increased pressure on the lower surface of the wing, generating sufficient lift. The resulting pressure gradient aligned well with theoretical lift generation trends. The pressure plot at AoA 5° is shown in Fig. 3 and concluded simulation results are shown in the TABLE 1.

Then the forward shift of the CP with increasing AoA indicated that the aircraft exhibited positive static stability throughout the simulated range.

B. XFLR5 Results

In the XFLR5 simulation CL increased nearly linearly with AoA up to 10°, while CD showed gradual growth, consistent with low-speed aerodynamic theory. Horizontal Stabilizer produced stabilizing negative pitching moments at moderate AoA, supporting longitudinal stability. Analysis of CL, CD, and CM against AoA confirmed overall aircraft stability, with stall predicted beyond 12°. The resulting graphs are presented in Fig. 4.

These results confirmed the aerodynamic compatibility of the designed aircraft to horizontal flight and gave parameters to state-space modeling of the UAV control.

TABLE 1. Simulation Results

Angle of Attack	Lift Force (y-direction)	Drag Force (x- direction)	Centre of pressure
0˚	-0.06 N	0.43 N	484.2 mm
3˚	4.53 N	0.95 N	216.9 mm
5˚	5.08 N	0.54 N	179.9 mm

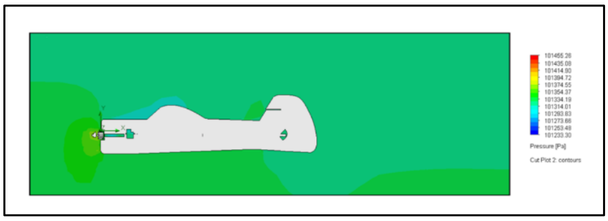

Fig. 3. Pressure Plot for AoA = 5˚

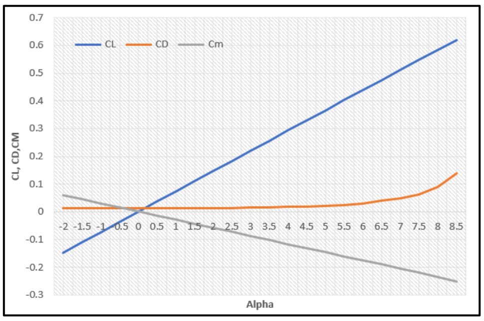

Fig. 4. The Graphs of (a) CL Vs Alpha, (b) CD Vs Alpha, (c) Cm Vs Alpha

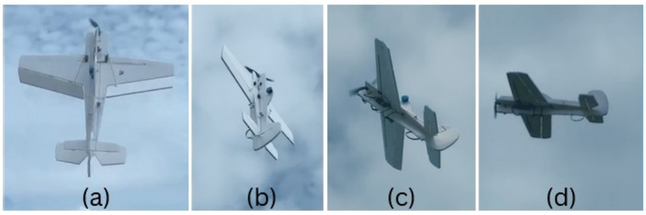

Fig. 5. Test Flight (a)Vertical Take Off, (b)(c) Vertical to Horizontal Transition, (d) Horizontal Flight

IV. Conclusion

Aerodynamic performance of a VTOL fixed-wing UAV with regular control surfaces was tested using CFD and stability analysis in XFLR5. These results indicated that lift improved with the angle of attack, but the drag was not too high to allow the flight at horizontal levels. Distributions of pressure and velocity confirmed the effective lift generation and the forward movement of center of pressure was a sign of positive static stability within the entire AoA range tested.

XFLR5 analysis supported these findings by showing nearly linear lift growth, gradual drag increase, and stabilizing pitching moments from the horizontal stabilizer. The two approaches combined to confirm the design as aerodynamically appropriate to steady horizontal flight, and to obtain aerodynamic coefficients that were used to model the control system. This was the initial analysis for our VTOL UAV. In future work, the simulations will be extended to unsteady conditions, representing the transition dynamics more accurately. Based on these findings, prototype UAV was constructed and flight tested successfully and presents in Fig. 5. And also, the results will be presented in subsequent publications.

Acknowledgment

The authors would like to express their sincere gratitude to the Department of Mechanical and Manufacturing Engineering, Faculty of Engineering, University of Ruhuna for providing the necessary laboratory facilities and resources required for design, fabrication, and testing. We also extend our appreciation to our project group members for their valuable contributions, collaboration, and continuous support throughout the research and simulation process.

References

[1] C. Bliamis, I. Zacharakis, P. Kaparos, and K. Yakinthos, “Aerodynamic and stability analysis of a VTOL flying wing UAV,” IOP Conf. Ser.: Mater. Sci. Eng., vol. 1024, 2021.

[2] J. O. Imumbhon, M. Landazuri, and Y. Cao, “Structural and CFD analyses of a reciprocating-airfoil driven UAV wing,” Drone Syst. Appl., vol. 10, no. 1, pp. 287-308, 2022.

[3] C. Wang, Z. Zhang, and Q. Zhang, “Analysis of aerodynamic characteristics of drone wing based on CFD,” Vibroeng. Procedia, Oct. 2024.

[4] V. A. Campos Rodriguez and S. Yan, “Preliminary design and performance-stability analysis of a fixed-wing UAV using XFLR5,” J. Aircraft Spacecraft Technol., vol. 7, no. 1, pp. 8-16, 2023.

[5] D. S. Körpe and Ö. Ö. Kanat, “Aerodynamic optimization of a UAV wing subject to performance constraints,” Int. J. Aerospace Eng., 2019.