WWW.IJRPR.COM

International Journal of Research Publication and Reviews

Journal Homepage: www.ijrpr.com ISSN 2582-7421

Preliminary Design and Simulation of Mini-UAV for Surveillance and Reconnaissance Mission

Chandrika[1], Chethan A.K[2], Harshitha. N[3], Harshit Devadas Bhandekar[4]

[1-4]Department of Aeronautical Engineering, MVJ College of Engineering, Bengaluru, Karnataka, India.

[1]chandrika0134@gmail.com, [2]akchethan0@gmail.com, [3]harshitdb5255@gmail.com, [4]harshithan20050610@gmail.com

ABSTRACT—

Unmanned Aerial Vehicles (UAVs) are widely used for surveillance and reconnaissance due to their ability to perform aerial observation and monitoring. This paper presents the preliminary design and simulation framework of a mini fixed-wing UAV intended for surveillance and reconnaissance missions. The initial phase involved identifying mission requirements, selecting a suitable aircraft configuration, and studying preliminary design parameters and weight estimation. In the subsequent phase, the flight simulation environment was configured using FlightGear and NALSim. The three-dimensional geometry of the proposed UAV was developed using OpenVSP, and aerodynamic analysis was carried out using VSPAERO to obtain lift, drag, and pitching moment coefficients at different angles of attack. The extracted aerodynamic data were organized for integration into an initial JSBSim flight dynamics model, identified as Garud.xml. Standard aircraft models in FlightGear were also studied to understand flight controls and basic simulation procedures. This work establishes a preliminary framework for integrating the proposed UAV geometry and aerodynamic characteristics into a flight simulation environment. Further model validation, flight performance analysis, and experimental testing are required to evaluate the overall performance of the proposed UAV design..

***Keywords*—Mini UAV, Fixed-Wing UAV, Surveillance, Reconnaissance, OpenVSP, VSPAERO, FlightGear, JSBSim, Flight Dynamics..**

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) are aircraft that operate without a pilot onboard. They are widely used in surveillance, reconnaissance, aerial monitoring, and disaster management. Their ability to perform missions through remote operation makes them useful for various civilian and research applications.

The preliminary design of a UAV is an important stage in aircraft development. It involves identifying mission requirements, selecting a suitable configuration, estimating weight, and studying aerodynamic and propulsion characteristics. Proper preliminary design helps evaluate the expected performance of the aircraft before physical prototype fabrication.

The present work focuses on the preliminary design and simulation of a mini-UAV intended for surveillance and reconnaissance missions. During the initial phase, mission requirements, aircraft configuration, airfoil selection, and preliminary design parameters were studied. The existing flight simulator facility was also restored and configured to support simulation activities.

The three-dimensional geometry of the proposed UAV was developed using OpenVSP. Aerodynamic analysis was performed using VSPAERO to obtain lift, drag, and pitching moment coefficients at different angles of attack. These results were used to understand the aerodynamic characteristics and evaluate the performance of the selected aircraft configuration.

The developed model provides a foundation for further UAV simulation and performance evaluation. Future work includes integrating the visual model into FlightGear, configuring control-surface and propulsion characteristics, and conducting flight manoeuvre simulations. The simulated responses will be compared with analytical results to assess the model's behaviour and support further development of the proposed mini-UAV.

2. METHODOLOGY

The methodology adopted for the preliminary design and simulation of the mini-UAV consists of the following stages.

2.1. Mission Requirement and Preliminary Design

The mission requirements for surveillance and reconnaissance were identified. The basic aircraft configuration, airfoil selection, preliminary dimensions, weight estimation, and propulsion requirements were studied.

2.2. 3D Modelling Using OpenVSP

The three-dimensional geometry of the proposed UAV was developed using OpenVSP. The model included the fuselage, main wing, and V-tail based on the selected preliminary configuration.

2.3. Aerodynamic Analysis Using VSPAERO

Aerodynamic analysis was performed using VSPAERO over different angles of attack. The lift coefficient (CL), drag coefficient (CD), and pitching moment coefficient (Cm) were obtained to evaluate the aerodynamic characteristics of the UAV.

2.4. Flight Dynamics Model Development

The aerodynamic data obtained from the analysis were organized into tables and incorporated into an initial JSBSim flight dynamics model named "Garud.xml". The model was prepared as a foundation for further flight simulation.

2.5. Flight Simulation Setup

The existing flight simulator facility was restored and configured using FlightGear and NALSim. Standard aircraft models were studied to understand basic flight controls and flight operations.

2.6. Future Integration and Validation

The next stage involves integrating the UAV visual model with the JSBSim flight dynamics model in FlightGear. Control-surface and propulsion characteristics will be configured, followed by flight manoeuvre simulations and comparison of simulated responses with analytical results.

3. UAV CONFIGURATION AND DESIGN

The proposed mini Unmanned Aerial Vehicle (UAV) is intended for surveillance and reconnaissance applications. The preliminary design process focuses on selecting a suitable aircraft configuration and developing its three-dimensional geometry for aerodynamic analysis.

The UAV geometry was developed using OpenVSP (Open Vehicle Sketch Pad). The model consists of a streamlined fuselage, a high-aspect-ratio main wing, and a V-tail configuration. These components form the basic aerodynamic structure of the aircraft.

The three-dimensional model was prepared for aerodynamic evaluation using VSPAERO. The wing and tail surfaces were defined for aerodynamic analysis, while the fuselage was included to represent the overall aircraft geometry. This model provides the basis for studying the aerodynamic characteristics of the proposed UAV.

The configuration developed in OpenVSP was used in the subsequent aerodynamic analysis to obtain lift, drag, and pitching moment coefficients at different angles of attack.

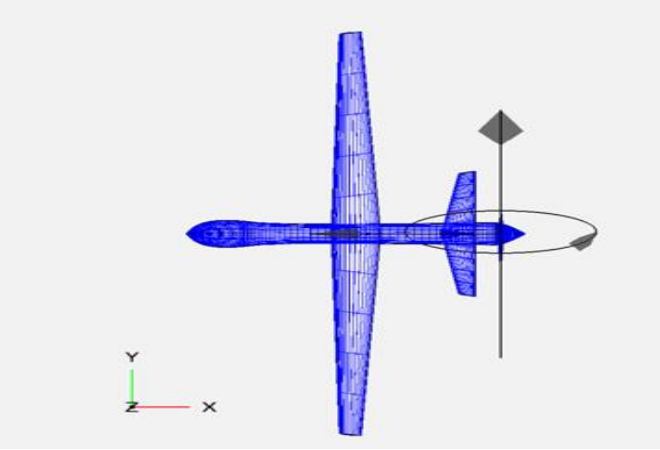


Fig. 1. Three-dimensional configuration of the proposed mini-UAV developed using OpenVSP.

4. AERODYNAMIC ANALYSIS

Aerodynamic analysis is an important step in UAV design because it helps to understand the airflow around the aircraft and estimate its aerodynamic performance.

In this project, aerodynamic analysis was carried out using VSPAERO, an analysis tool associated with OpenVSP. The three-dimensional UAV geometry developed in OpenVSP was used as the input model for the analysis.

The analysis was performed at different angles of attack to study the aerodynamic characteristics of the UAV. The main parameters considered were the lift coefficient ((C_L)), drag coefficient ((C_D)), and pitching moment coefficient ((C_m)).

The lift coefficient represents the lift generated by the aircraft, while the drag coefficient represents its aerodynamic resistance. The pitching moment coefficient helps to understand the aircraft's pitching behaviour. The obtained aerodynamic data were organised into tables and plots for further analysis and use in the preliminary flight dynamics model.

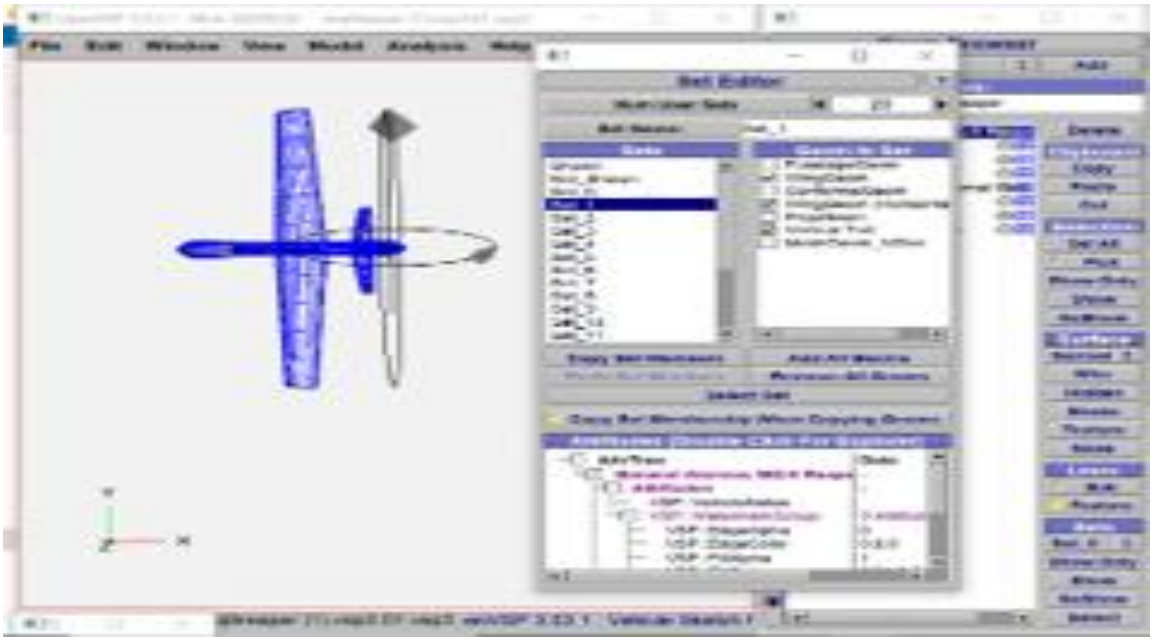
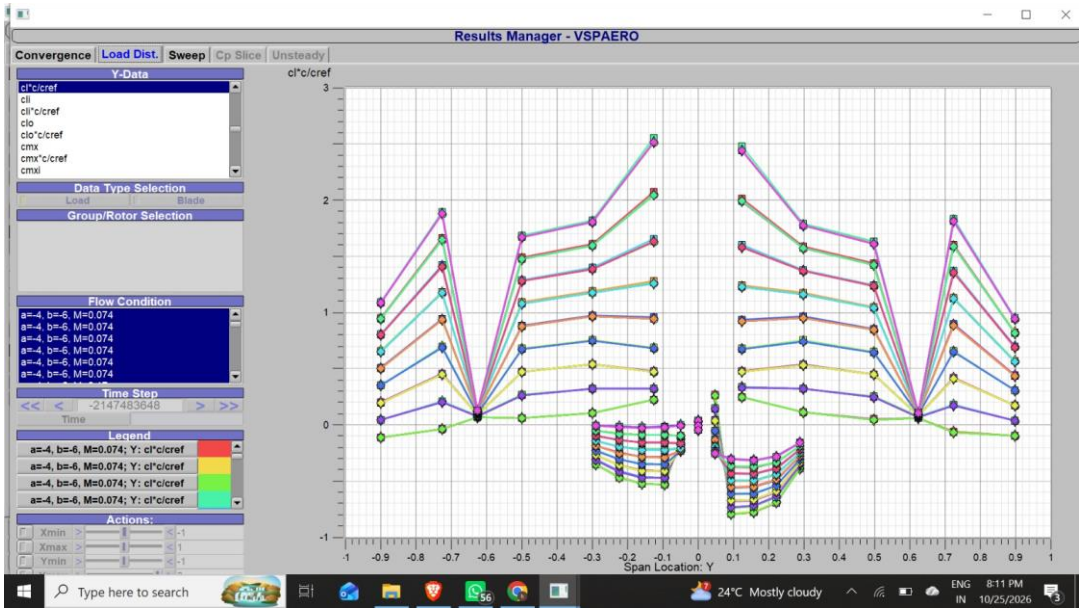


Fig. 2 VSPAERO analysis setup for the proposed mini-UAV.



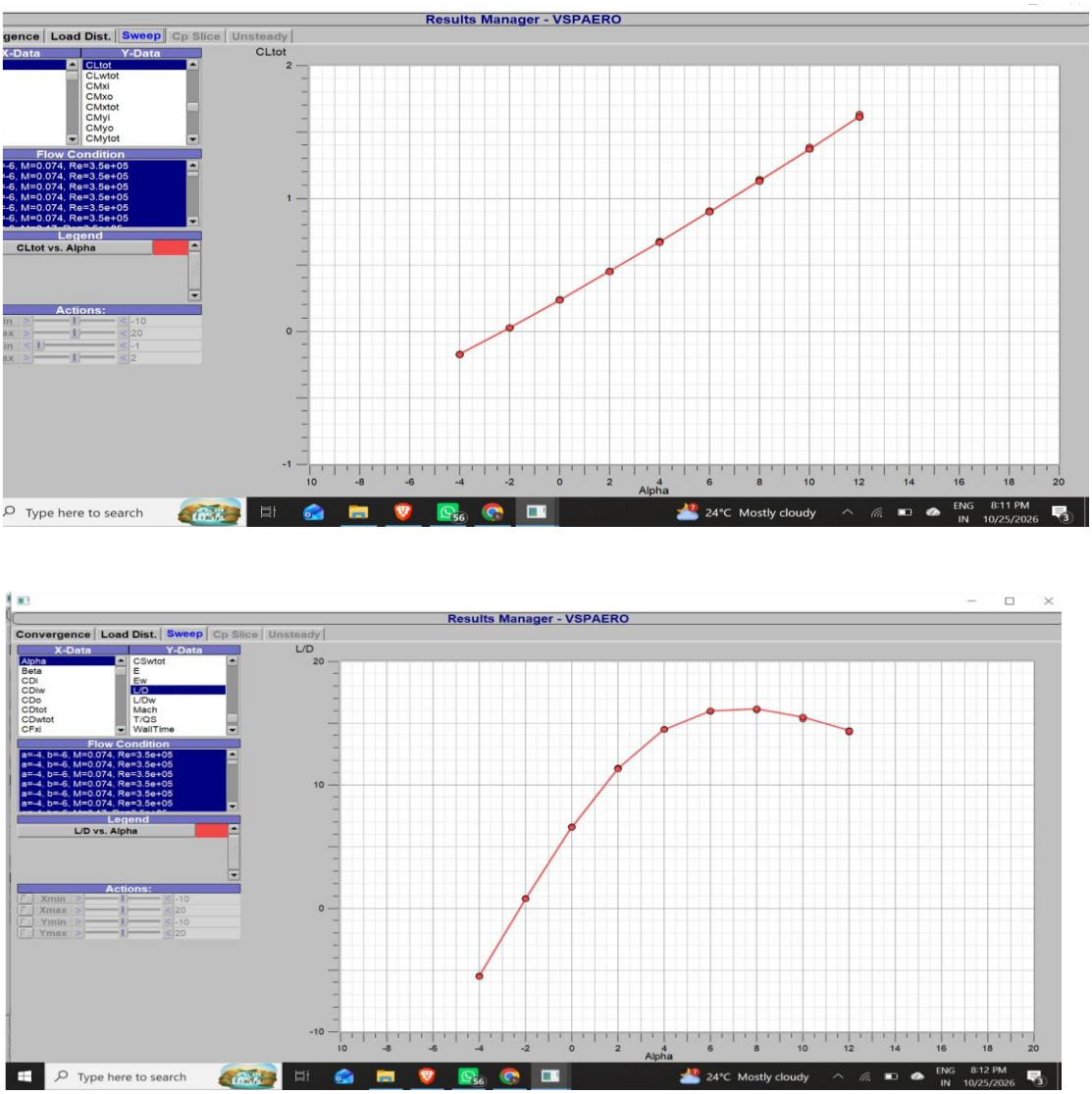


Fig. 3. Aerodynamic coefficient variation with angle of attack.

5. FLIGHT SIMULATION SETUP

The flight simulation setup was prepared to study aircraft flight operations and support the development of the proposed mini-UAV simulation model. The existing flight simulator facility was restored and configured for simulation activities.

The software tools used in this project include FlightGear, NALSim, and JSBSim. FlightGear was used to understand aircraft flight behaviour and basic flight operations.

NALSim was included in the simulation setup, while JSBSim was used for developing the flight dynamics model.

Standard aircraft models, including the Cessna 172P and MQ-9 Reaper, were studied in FlightGear. Basic flight operations such as take-off, climb, turning, level flight, descent, approach, and landing were practised to understand aircraft control and simulation procedures.

An initial JSBSim flight dynamics model named Garud.xml was developed using the aerodynamic data obtained from the VSPAERO analysis. The XML model structure was checked as part of the preliminary development process.Further work involves integrating the UAV's visual model into FlightGear, configuring the control-surface and propulsion parameters, and conducting flight manoeuvre simulations .

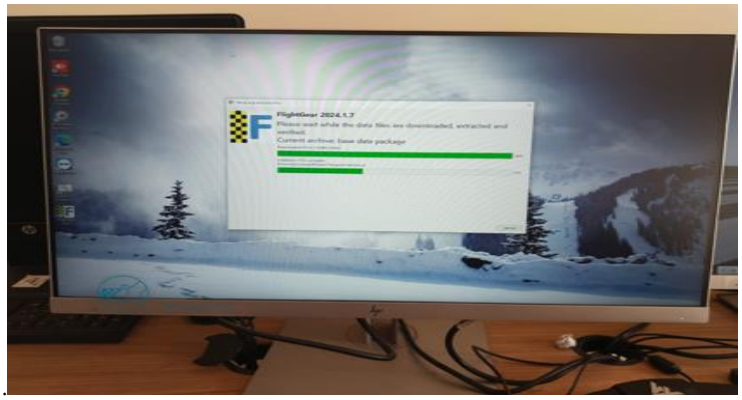


Fig 5.1. FlightGear installation



Fig. 5.2. Flight simulation environment using FlightGear.

Requirements check: Garud actual v2

Requirement	Target	Result	Status	Basis
Cruise at 25 m/s	CL required below CLmax	0.96	**Pass**	CL required = W / (q S); CLmax 1.2 estimated
Static margin	5% to 15%	12.8%	**Pass**	-Cm_alpha / CL_alpha
Cm-alpha negative	< 0	-0.82	**Pass**	Pitch stability
Trimmable at cruise	|Cm| within tolerance	0.014	**Pass**	Tolerance is my criterion (about 1 deg elevator)
Horizontal tail volume	>= 0.30	0.37	**Pass**	Estimated from the recommended tail
Vertical tail volume	>= 0.02	0.023	**Pass**	Estimated from the recommended tail
L/D at cruise	>= Phase-I L/D	16.3	**Pass**	VSPAERO; conservative case in PerformanceIF12
L/D, conservative	>= Phase-I L/D	14.5	**Pass**	e = 0.85
Endurance (full battery)	>= mission endurance	68.5	**Pass**	Minutes; Phase-I method with eta_p
Endurance, conservative	>= mission endurance	60.8	**Marginal**	Marginal when within 10% of the requirement
Endurance, 85% usable	>= mission endurance	58.2	**Marginal**	Allows for depth-of-discharge
Stall speed	<= 20 m/s	22.4	[redacted]	CLmax 1.2 estimated
Rate of climb 3 m/s	Motor power >= need	957	[redacted]	Fill in the motor power on the Inputs sheet

Fig.5.3.Requirements check: Garud-uav

6.**RESULTS AND DISCUSSION**

The preliminary design and aerodynamic analysis of the proposed mini-UAV were carried out using OpenVSP and VSPAERO. The three-dimensional UAV geometry was developed, and aerodynamic analysis was performed at different angles of attack.

The analysis provided lift coefficient ((C_L)), drag coefficient ((C_D)), and pitching moment coefficient ((C_m)) data. These results were represented using plots to study the aerodynamic behaviour of the proposed configuration.

The aerodynamic data were organised into tables and used as an input for the initial JSBSim flight dynamics model, Garud.xml. The model's XML structure was checked as part of the preliminary development process.

The existing flight simulator was also restored and configured. FlightGear was used to study standard aircraft models and practise basic flight operations. This helped establish the simulation environment for future UAV testing.

At the current stage, the preliminary aerodynamic analysis and initial flight dynamics model development have been completed. Integration of the custom UAV model into FlightGear and validation of its flight characteristics remain future tasks.



Fig.6.1. Garud mini-uav

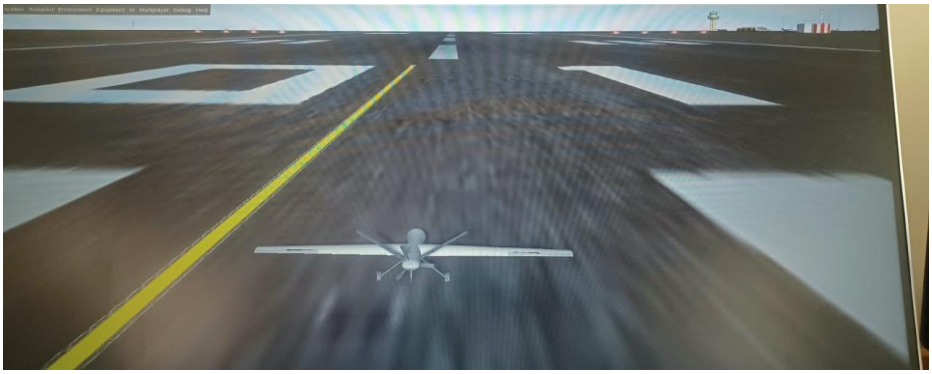


Fig.6.2. Three dimenstional visualization of the proposed

7. CONCLUSION

This paper presents the preliminary design and aerodynamic analysis of the proposed Garud mini-Unmanned Aerial Vehicle (UAV) for surveillance and reconnaissance applications. The three-dimensional UAV configuration was developed using OpenVSP, and aerodynamic characteristics such as lift coefficient ((C_L)), drag coefficient ((C_D)), and pitching moment coefficient ((C_m)) were evaluated using VSPAERO at different angles of attack. The obtained aerodynamic data were organized and incorporated into the initial JSBSim flight dynamics model, Garud.xml. The FlightGear simulation environment was also configured, and standard aircraft models were studied to understand basic flight operations. These activities establish a foundation for further development and simulation of the proposed UAV. Future work will focus on integrating the Garud UAV model into FlightGear, refining the flight control and propulsion parameters, conducting flight simulations, and validating the simulated performance against analytical results.

The Garud mini-UAV was designed for surveillance and reconnaissance applications. Its three-dimensional model was developed using OpenVSP for preliminary design. Aerodynamic characteristics were analysed using VSPAERO at different angles of attack.

The obtained aerodynamic data were incorporated into the initial JSBSim model, Garud.xml.

We further focused on flying the custom UAV model in FlightGear and validating its flight performance.

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