DESIGN AND DEVELOPMENT OF VERTICAL TAKE-OFF AND LANDING UNMANNED AERIAL VEHICLE FOR AIR QUALITY INDEX

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Keywords:

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Introduction:

Every year, air pollution causes millions of premature deaths, making it a serious environmental and public health concern, especially in India's urban areas. Fixed ground-based stations, which are costly, widely dispersed, and unable to record spatial and vertical fluctuations in pollutant concentrations, are the foundation of conventional air quality monitoring systems.

The identification of pollution hotspots, vertical pollutant gradients, and real-time environmental fluctuations is limited by these constraints. A versatile and affordable substitute is provided by UAV-based monitoring systems, which allow for dynamic data collection at various heights and locations.

However, traditional UAVs have drawbacks such low endurance (multirotor UAVs) or inability to take off vertically (fixed-wing UAVs). This project focuses on a Vertical Take-Off and Landing (VTOL) UAV that combines the benefits of both designs in order to get around these limitations.

Using integrated sensors, the system is intended to measure important pollutants as $PM_{2.5}$, PM_{10}, NO_2, O_3, CO, and H_2S. It makes altitude-resolved, GPS-based, real-time AQI monitoring possible.

By providing three-dimensional mapping of air quality, this method greatly improves environmental monitoring and is appropriate for smart city applications, industrial monitoring, and urban pollution evaluation.

Objectives:

1. Create and implement a VTOL UAV platform for environmental surveillance.
2. Combine multiple sensors for $PM_{2.5}$, PM_{10}, CO, NO_2, O_3, and H_2S.
3. GPS-based tracking allows for real-time data collection.
4. Analyse flying parameters and aerodynamic performance.

5. Collect and analyse altitude-based AQI data
6. Create a scalable and affordable monitoring system.

Methodology:

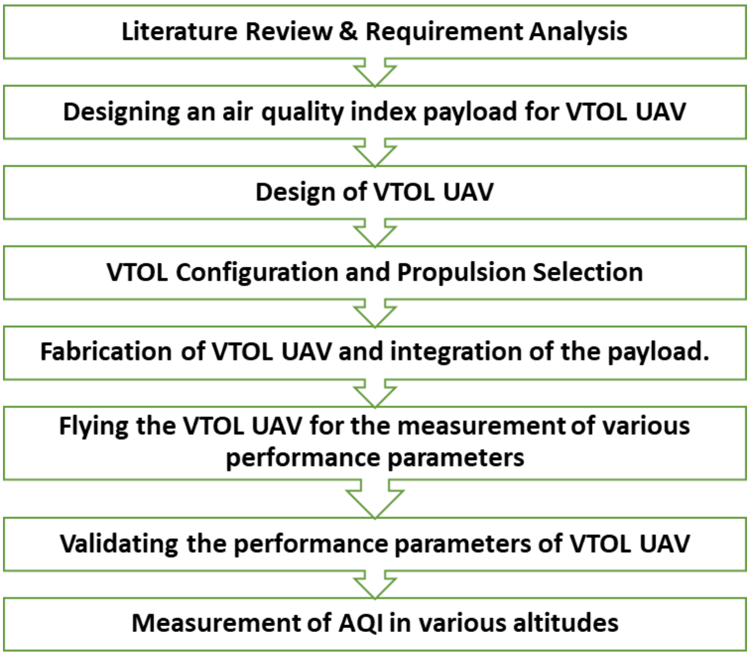

Figure 1: Research methodology of this project

The figure 1 illustrates the systematic approach adopted in the design of the VTOL UAV for AQI measurement. The systematic approach adopted involves a literature review and analysis of requirements to determine system constraints and specifications.

The requirements are then used to design an AQI sensing payload, which is integrated into the UAV. This is followed by the aerodynamic and structural design of the VTOL UAV, as well as the configuration and propulsion system design to satisfy the requirements of the VTOL UAV during hover and cruise flight.

The UAV is then manufactured and assembled, and experimental flight tests are conducted to determine the key performance parameters of the UAV, such as thrust, power, and endurance. The results are then validated by predictions and finally used to determine air quality measurements at different altitudes.

Table 1:Objectives and Methodology Table

Objective No.	Statement of the Objective	Method/ Methodology	Resources Utilised
1	VTOL UAV design and configuration	Conceptual design and layout selection	CAD tools, design calculations
2	AQI sensor integration	Hardware interfacing and placement	PM and gas sensors
3	Data acquisition development	Sensor interfacing with GPS logging	Microcontroller
4	Flight testing	Hover, transition, and cruise tests	VTOL UAV platform
5	Data analysis	Processing and interpretation of data	Logged data, plots

The table 1 summarizes the major project objectives and the respective methodologies used to accomplish them. The table illustrates the logical sequence of activities from VTOL UAV design and AQI sensor implementation to data acquisition, flight testing, and data analysis, and the resources employed in the process. In general, it illustrates a systematic approach to relate project objectives with relevant technical methods.

Result and Conclusion:

In conclusion, the prototype VTOL UAV was successfully constructed and tested. Although some flight controller adjustment was necessary during early experiments to ensure stable performance and to test for the transition phase and cruise conditions, the system was able to execute a vertical take-off and steady hover, under controlled outdoor conditions.

Particulate matter ($PM_{2.5}$, PM_{10}) and gaseous pollutants (NO_2, O_3, CO, H_2S) were effectively recorded by the integrated AQI sensor module. The collected data in table 2, showes clear trends rather than exact absolute accuracy, which is expected from low-cost sensors. Following calibration, the data showed minimal variations from ground-level reference values caused by external factors such wind, changes in temperature, and sensor response delays.

The change in pollutant concentration with altitude was one of the most important findings. While some gaseous pollutants exhibited non-linear tendencies, particulate matter levels were often higher close to the ground and declined with altitude. This demonstrates the significance of vertical profiling, which is impossible to obtain with conventional ground stations.

Table 2: AQI Sensor Results

Time (ms)	H_2S	O_3	CO	NO_2	$PM_{2.5}$	PM_{10}
174134	227.54	1.01	10.51	0.13	382	615
176158	54.1	1.02	10.51	0.13	341	560
178184	815.84	1.02	10.51	0.13	298	498
180208	969.46	1.03	10.51	0.13	262	445
182233	1035.91	1.04	10.51	0.13	231	392
184262	44.41	1.04	11.02	0.13	198	348
186286	70.94	1.05	11.02	0.13	167	301
188311	49.11	1.05	10.51	0.13	142	264
190336	54.1	1.05	10.51	0.13	121	238
192361	215.08	1.05	10.51	0.13	108	215
Average	**1548.885**	**0.850202**	**10.44828**	**0.120606**	**225**	**387.6**

The overall air quality conditions experienced throughout the test flight are summarized by the average values at the bottom of the table. The findings validate the efficiency of the sensor integration and data gathering system for vertical and spatial air quality monitoring using a VTOL UAV by confirming that the AQI payload can capture dynamic fluctuations in both gaseous and particle contaminants.

The aerodynamic design technique was validated by simulation results (velocity fields and pressure contours) that indicated patterns that matched experimental findings very well. Simplified simulation assumptions are responsible for the minor inconsistencies that were found.

All things considered, the study effectively shows that a VTOL UAV may function as a useful and adaptable platform for air quality monitoring. The device offers an affordable and portable way to record spatial and vertical fluctuations in air pollution, but it cannot take the place of high-precision monitoring stations.

The findings show that such UAV-based systems have great potential for practical environmental monitoring applications with additional advancements in sensor precision, flight duration, and system optimization.

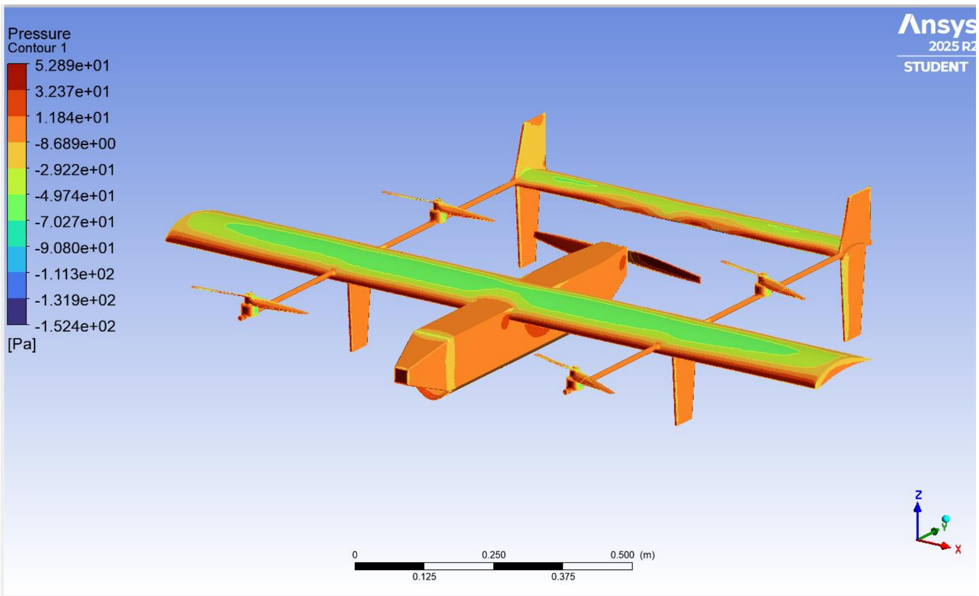

Figure 2 :Pressure contour of Flow over the VTOL UAV

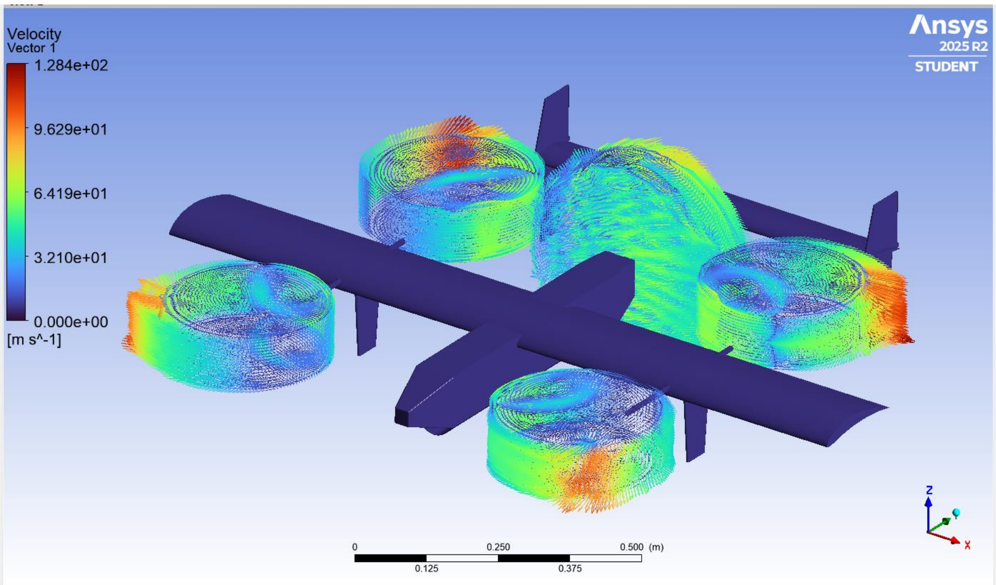

Figure 3:Velocity Vector Analysis of VTOL UAV when all motors are operating

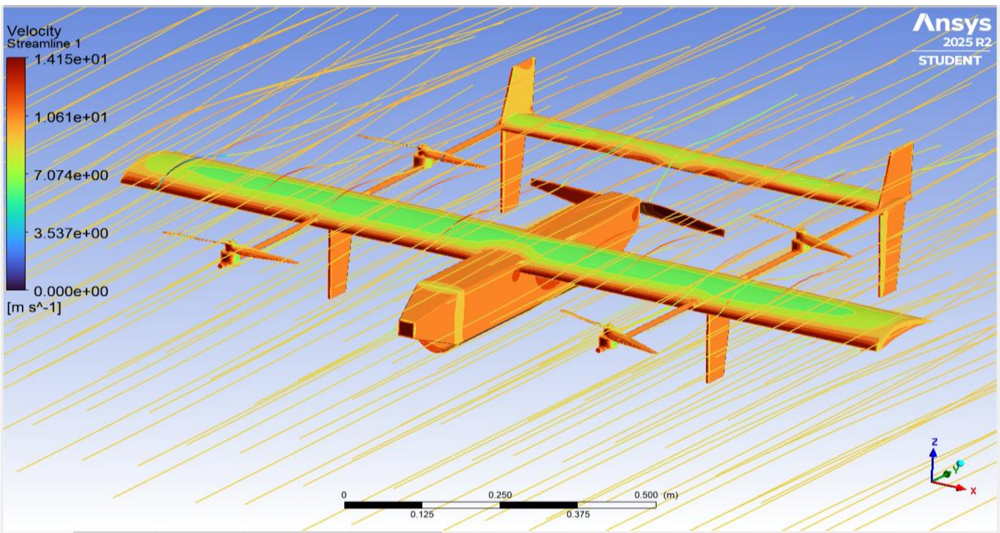

Figure 4: Velocity vector with stream lines for Flow over the VTOL UAV

Project Outcomes and Learnings:

- VTOL UAV design and construction accomplishment.
- Multi-sensor AQI payload integration.
- GPS-tagged real-time data collection.
- Verification of vertical variation in pollutants.
- Aerodynamics and UAV design.
- Integration and calibration of sensors.
- Data logging and embedded systems.
- CFD and simulation validation, flight testing, and performance evaluation.

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Future Scope:

The future scope of this project includes:

1. AI and machine learning methods will be integrated for pollution forecasting and predictive AQI analysis in the future. Dashboards for cloud-based monitoring and visualization can be made possible by real-time data transmission via IoT devices.
2. By combining high-precision industrial-grade sensors with sophisticated calibration methods, sensor accuracy can be increased. Advanced flight control algorithms and obstacle avoidance systems can improve autonomous flight capabilities.
3. For swarm UAV operations, the system can be expanded to effectively cover greater geographic areas. The accuracy of environmental analysis can be increased through integration with weather models and satellite data.