Design and Characterization of a Modular Wind Wall for VTOL and Fixed Wing UAV Testing

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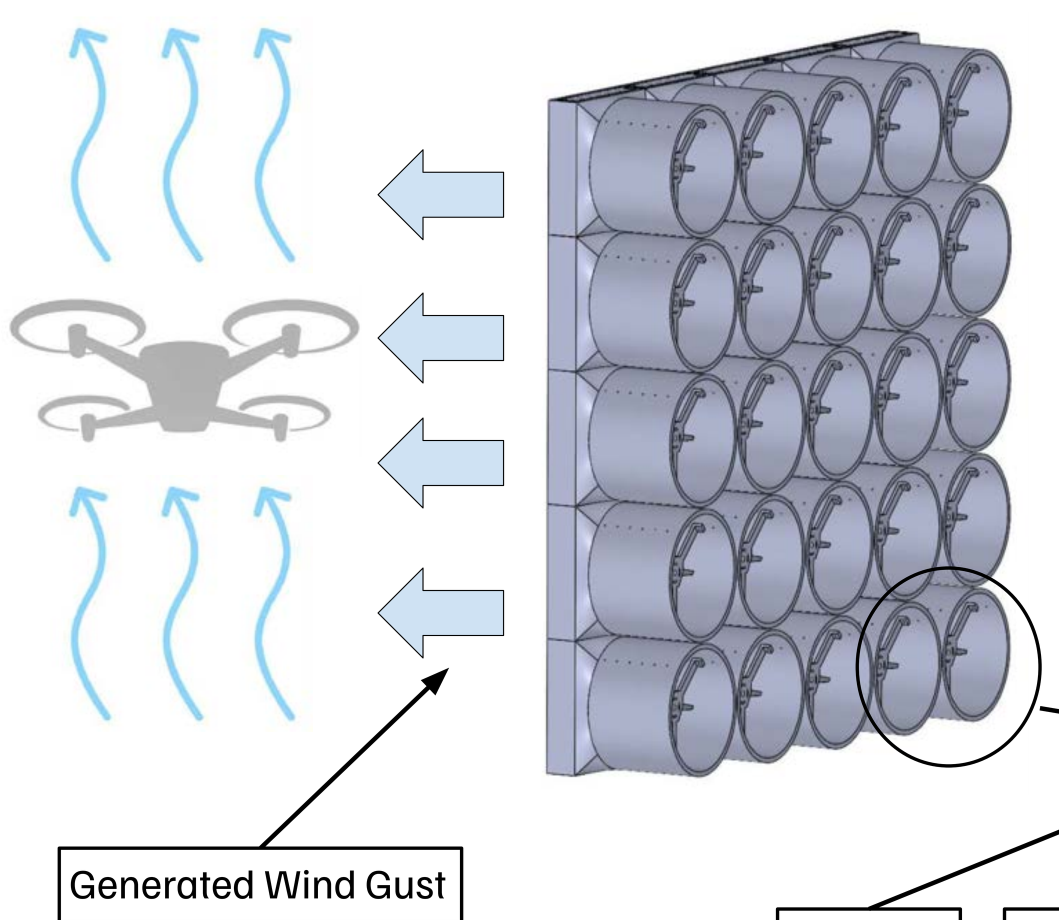
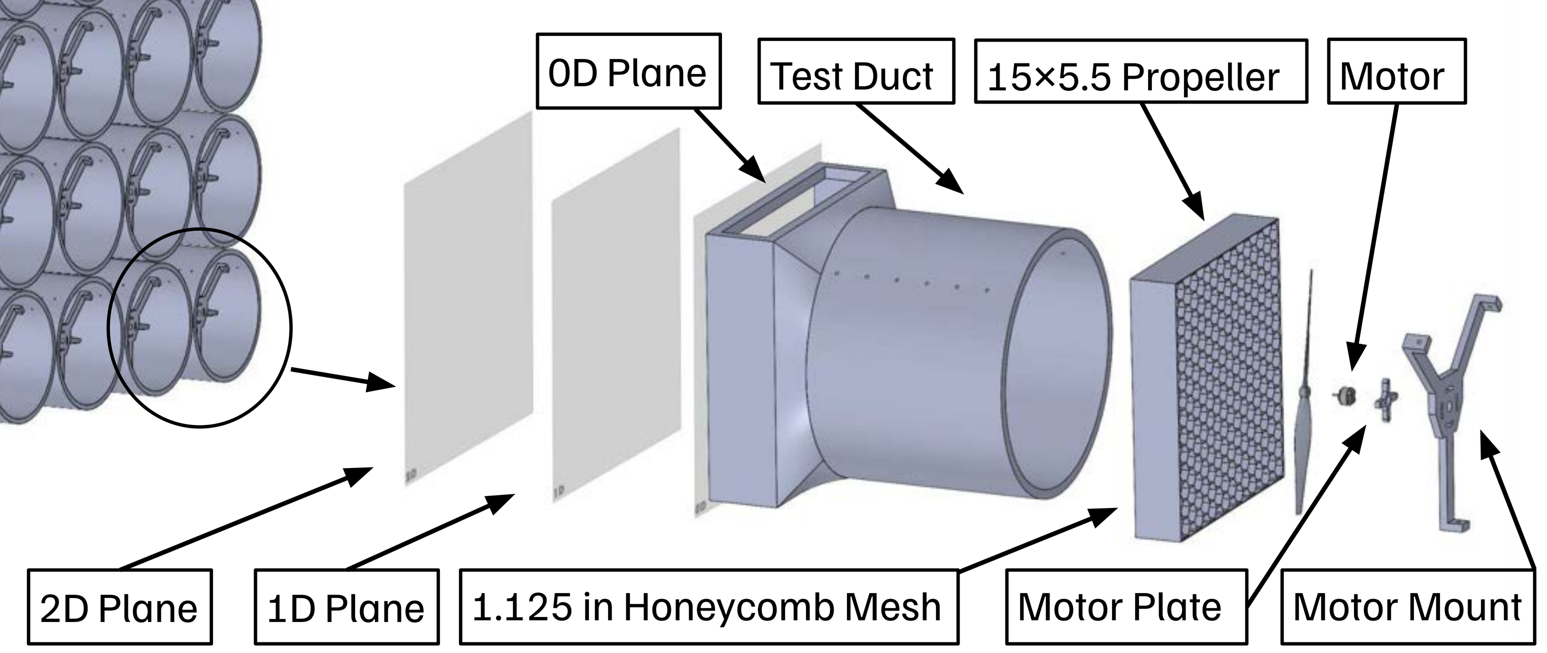
Abstract

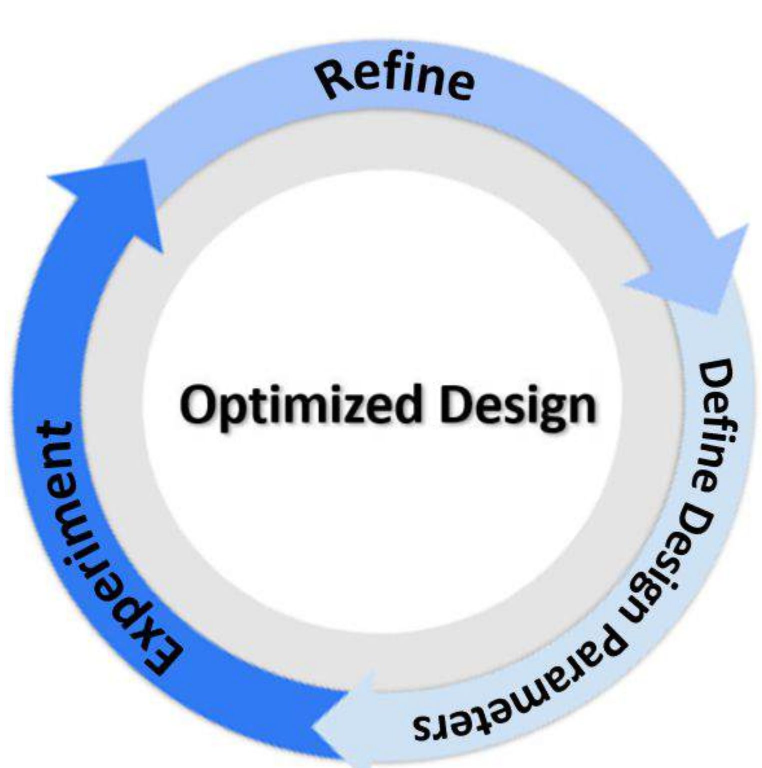
Outdoor flight testing for VTOL and fixed-wing UAVs is often unpredictable due to weather and wind conditions. Low-speed wind tunnels offer more control, but are costly for larger test areas. A modular wind wall, made of stackable propeller-driven units, provides a solution by generating controlled and repeatable wind profiles. These modules can be arranged in different configurations to simulate real-world flight conditions and analyze UAV aerodynamics. To ensure high-quality airflow, a single-duct module tests design parameters such as honeycomb meshes, propeller-to-mesh distances, and duct cross-section geometry. The duct transitions from square to circular at different convergence angles, with each setup evaluated for turbulence and flow uniformity. The design aims to maintain turbulence intensity below 5% to ensure suitable testing conditions. A digital seven-hole probe system, mounted on an X/Y linear traverse, measures wind velocity and flow angularity. This setup ensures accurate and repeatable data collection. The results will help refine the wind wall design, creating a valuable platform for UAV flight performance evaluation and aerospace research.

Experimental Setup and Objectives

1. Characterize velocity profile for various honeycomb mesh cell sizes.
2. Analyze flow uniformity at different distances from testing probe.
3. Experimental results will allow for the design and characterization of the final wind wall.







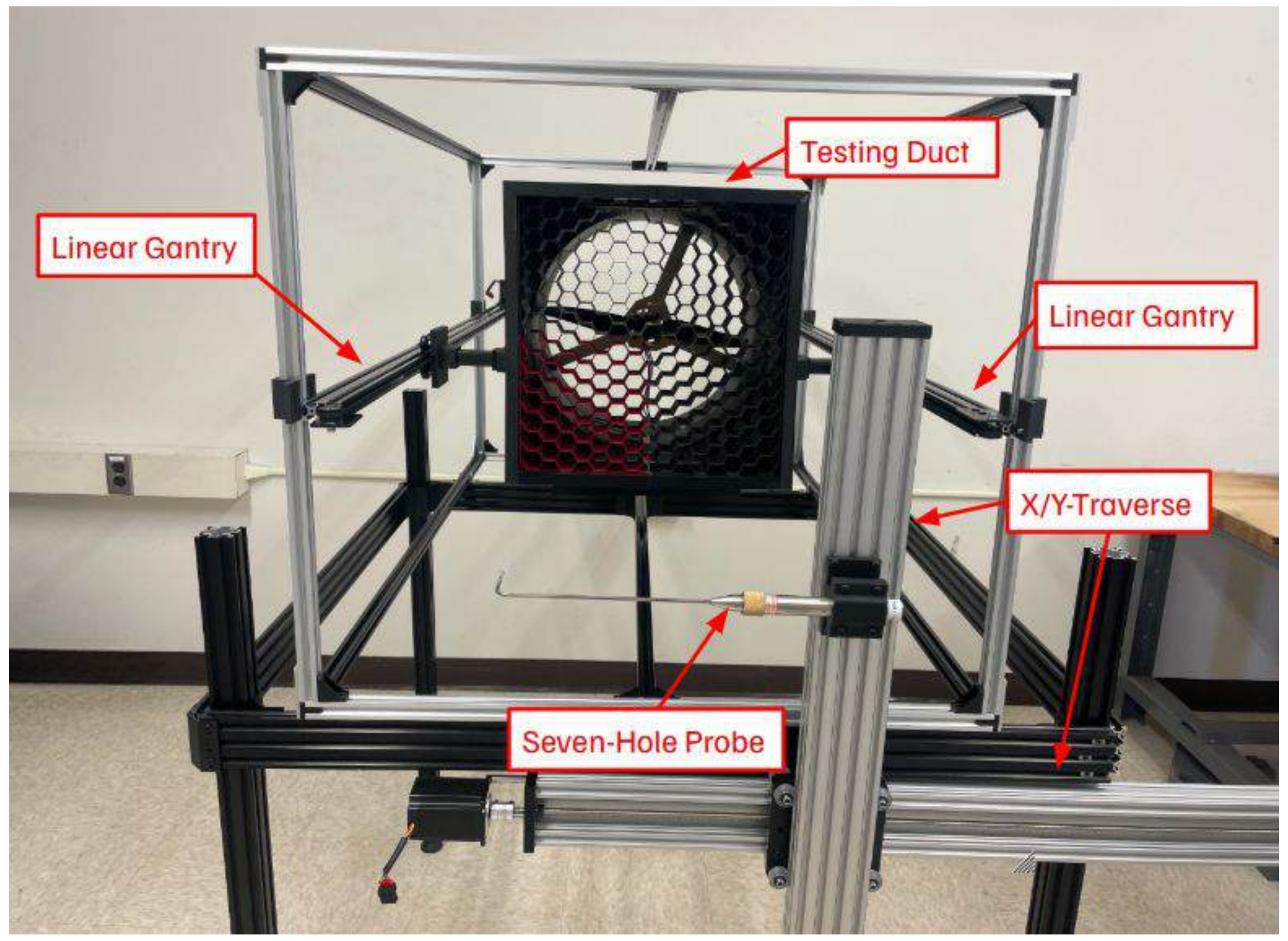


Figure 1. Experimental Setup

Results

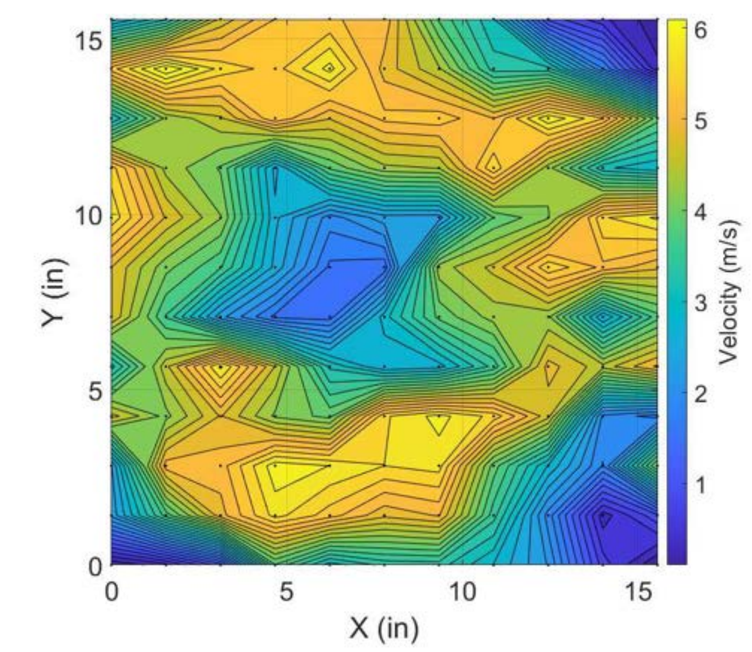


Figure 2. Velocity Contour at 0D Plane

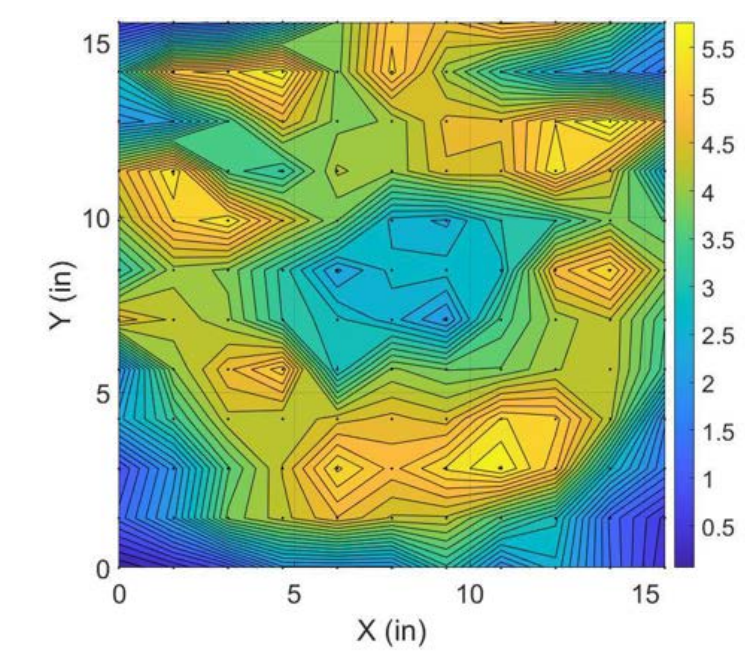


Figure 3. Velocity Contour at 1D Plane

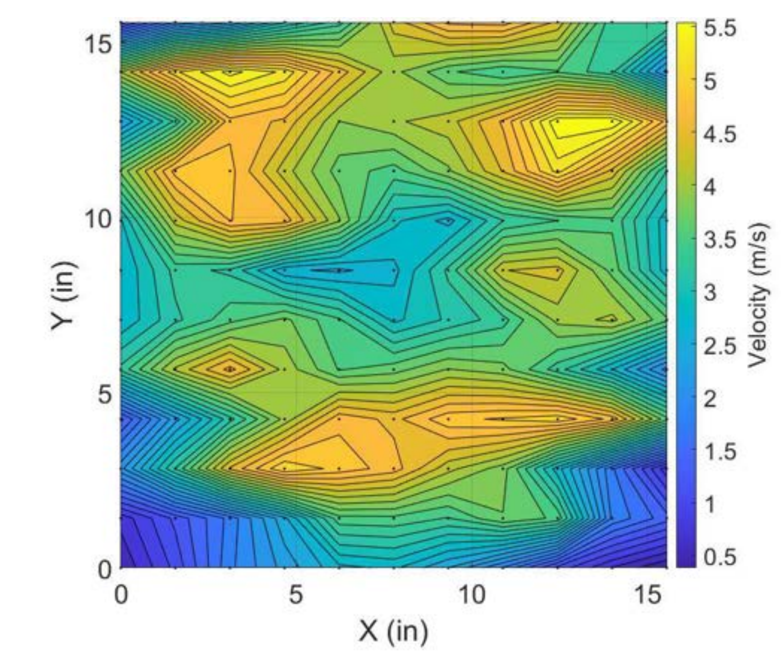


Figure 4. Velocity Contour at 2D Plane

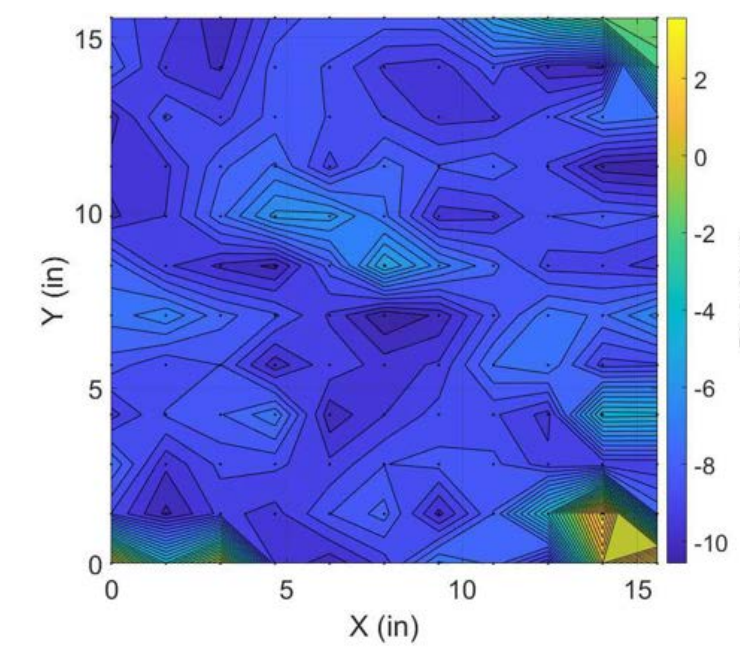


Figure 5. Pitch Angularity Contour at 0D Plane

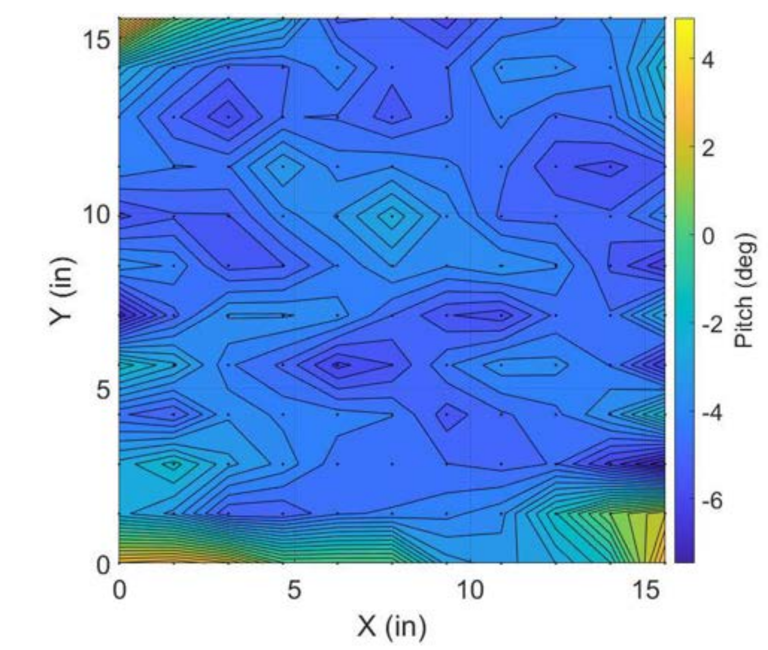


Figure 6. Pitch Angularity Contour at 1D Plane

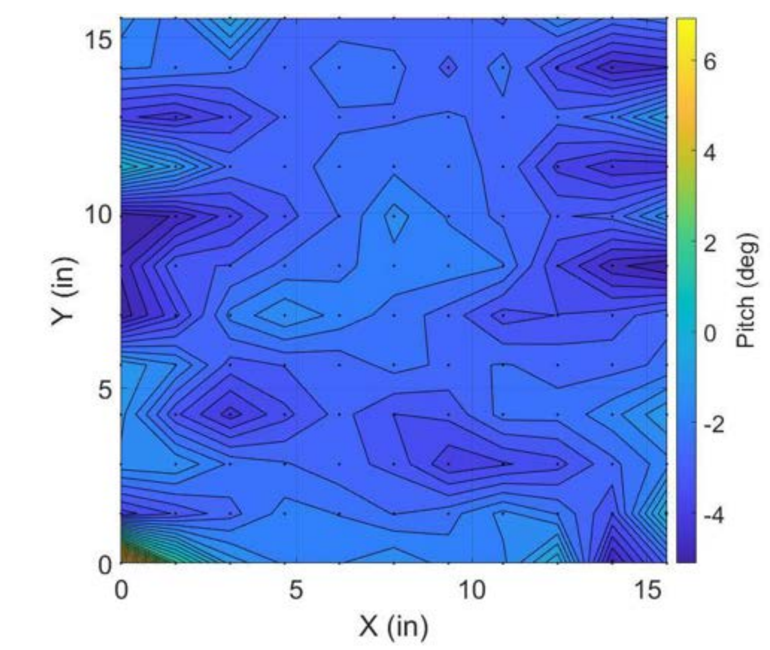


Figure 7. Pitch Angularity Contour at 2D Plane

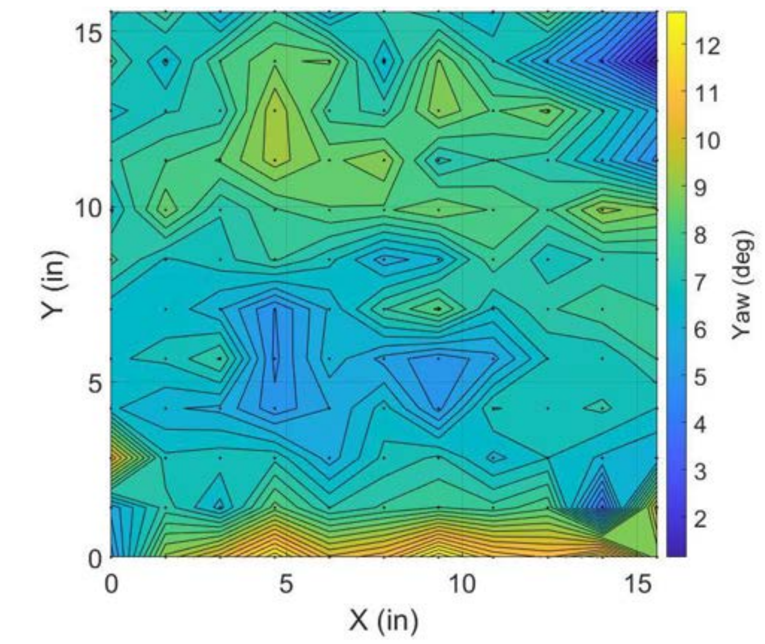


Figure 8. Yaw Angularity Contour at 0D Plane

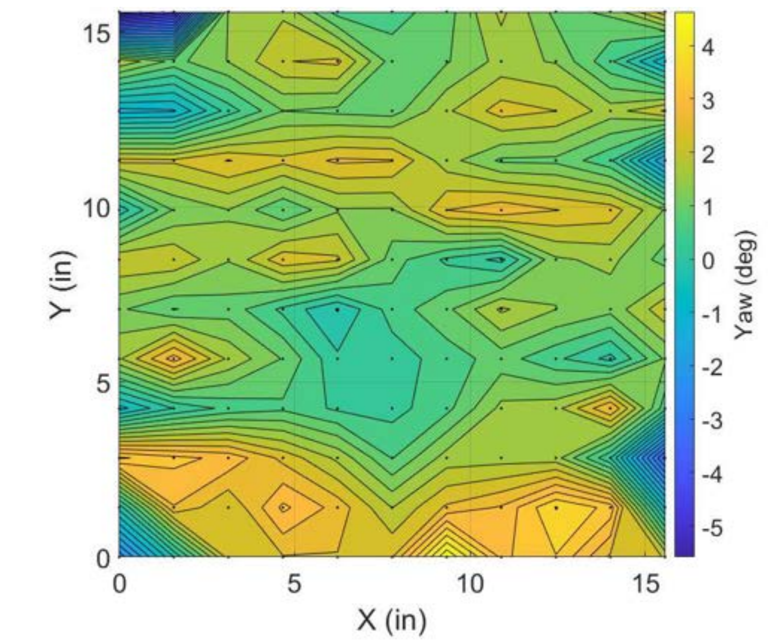


Figure 9. Yaw Angularity Contour at 1D Plane

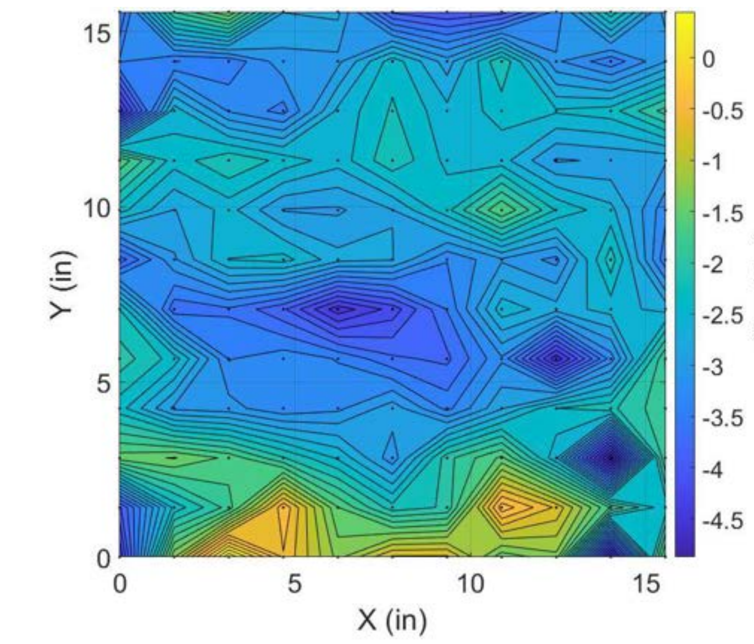


Figure 10. Yaw Angularity Contour at 2D Plane

Discussion and Future Work

Discussion

Results indicate that the velocity profile in the center of the honeycomb and at its corners is significantly lower than in the surrounding areas. The central low-velocity region appears to correlate with the motor's location, which creates a distinct dip in the velocity contour. As expected for initial trials, turbulence levels are high. However, by optimizing the design of the honeycomb cells and incorporating additional flow straighteners, such as guide vanes, it is anticipated that turbulence can be considerably reduced. Additionally, the observed slight pitching and yaw in the flow calls for further investigation to determine its underlying cause.

Future Work

- Continue testing various honeycomb cell widths to refine flow characteristics.
- Incorporate guide vanes to reduce angularity.
- Explore different duct geometries by varying convergence angles to enhance performance.
- Investigate alternative methods for generating wind gusts, such as EDF ducted fans.
- Implement a control system using VFD and LabVIEW to better manage operational parameters.
- Employ a PIV system for a more detailed characterization of the wind wall.

Acknowledgements

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