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CFD Analysis of Full Quadcopter

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Abstract
The computational fluid dynamics (CFD) simulation is gaining attraction in the development of modern unmanned aerial vehicles (UAV), but few research has been made on quadcopters and the characterization of the flows generated by the propellers, which determine the thrust capacity. Therefore, the purpose of this study is to assess the performance in the 3D flow simulation of the most promising methods: multiple reference frames (MRF) and sliding meshes. The impact of the ground's proximity has also been taken into consideration. Even though there was a clear difference in the measurement of thrust, the results for a single propeller showed that both models were similar in terms of assessing the ground effect. This study examines the effects of steady wind conditions on a quadcopter's capacity to maintain a hovering scenario using computational fluid dynamics (CFD). To evaluate study parameters, preliminary isolated rotor simulations are run using the Improved Delayed Detached Eddy Simulation turbulence model. The mesh that will be utilized in full scale simulations is chosen after spectral analysis has evaluated the meshes of the isolated rotor.

Keywords: Quadcopter, Propeller, CFD, Fluent, Thrust Force, Lift Force, Drag Force

1. Introduction

A unique variety of multicopter, a quadcopter UAV has four propellers. Due to the increased thrust power produced by the four propellers, it can carry a greater weight than a standard helicopter. Add-on to this, Quadcopter has better steering control over the helicopter because, in Quadcopter four propellers help in roll, pitch and yaw motions, whereas in helicopter only two propellers are there. The propellers are designed carefully because they produce the required thrust for the Quadcopter's motion in three-dimensional space. Quadcopter has large range of applications in transportation, spy vision and aerial photography, which creates interest in researchers to improve manoeuvrability and stability of a Quadcopter. In the existing literature on CFD analysis of a Quadcopter, some contributions are described here. Penkov *et al*. studied the shroud influence on lift force by CFD simulation [1]. F. Ahmad *et al*. analysed the Quadcopter body frame based on vibration frequency [2]. The frame was tested under two different boundary condition to find out the resonance failure frequency. M.P. Kishore *et al*. performed the flow simulation on a marine propeller [3]. Furthermore, velocity and pressure distribution of flow around the propeller was calculated. M Anudeep et.al has designed and analysed the quadcopter different parts on the basis of static analysis to find out the optimum design. E. Kuantama *et al*. performed the CFD analysis to find out the power efficient propeller of suitable size [4]. The simulation was performed for different speeds to determine the values of thrust and pressure on the propeller. The simulation results were compared with datasheets of three commercial rotor specifications. S. Wang *et al*. performed the static structural and fluent flow analyses on an agricultural unmanned aerial vehicle [5]. The main wing beam was characterized by calculating the deformation at six different points on the wing surface. F. Ahmad calculated the resonance frequency of a Quadcopter propeller and find out the best suited material for heavy payload application [6].
The main objectives of this study are to achieve following:

- Find out the value of Lift force generated by the propeller.
- Obtain Lift force and Lift Coefficient.
- Obtain Drag force and drag Coefficient.
- Present Pressure and velocity contours and velocity streamlines on one propeller.
- Present Pressure and velocity contours and velocity streamlines on Full Quadcopter at Taking off motion.

2. Quadcopter 3D Geometric Model

The Quadcopter performance is influence by the flying conditions i.e., flying medium density and the Quadcopter geometry specially the propellers. The motion of the quadcopter in three dimensions is controlled by four propellers in an underactuated system. The initial step in using computational fluid dynamics (CFD) to study a quadcopter is to create a CAD model with a variety of components. Using the software Solidworks, a quadcopter's CAD model was produced. A quadcopter with rotors is depicted in Fig 1 as having a matured solid design. Additionally, the propeller is seen in Fig 2 and has been developed with a curved shape to maximise mechanical strength and enhance aerodynamic properties.

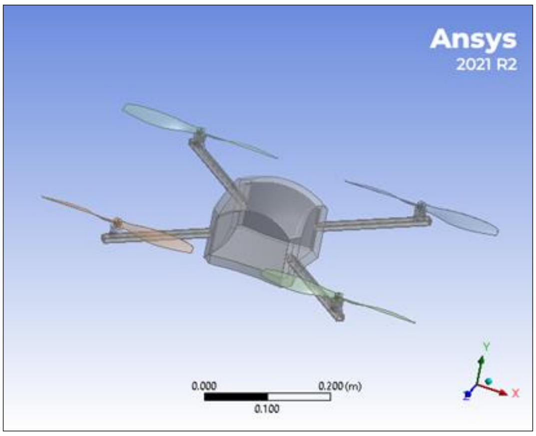

Fig 1: Quadcopter 3D Model

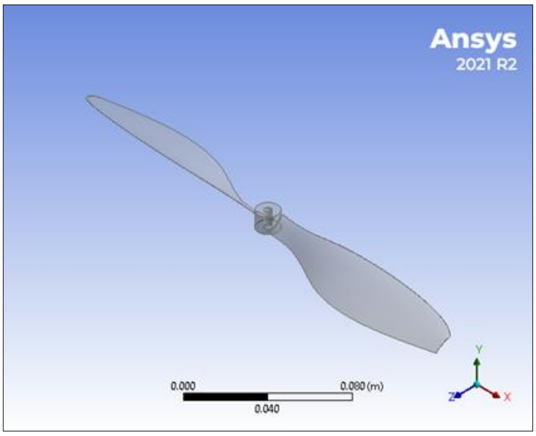

Fig 2: Propeller 3D Model (CCW)

3. CFD Modelling

CFD is a numerical simulation approach which deals with the fluid or fluid-solid interaction. This method relies on the principles of fluid mechanics to address fluid flow-related engineering issues. A user-friendly interface is offered by many simulation tools to study the interaction of a liquid or gas with a solid. CFD is now being used by scientists and engineers to solve engineering issues in areas including aerodynamics, aerospace, fluid flow, heat transfer, mass transfer, engines, and combustion analysis, among others. To analyze the Quadcopter, different steps are presented in the following subsections.

3.1 CFD Model of the Quadcopter's Propeller

The CAD model of the propeller has been imported to fluent flow module in Ansys. To simulate flow, an enclosure has been built around the propeller. The design of the propeller and the flow domain with the applicable inlet and outlet boundary conditions are shown in Fig 3. The mesh size tool was used to mesh the propeller with a maximum mesh size of 5 mm. The propeller is rotating at 6000 rpm while the air velocity at the inlet has been measured at 6 m/s. Table 1 contains a list of the parameters used for the CFD simulation.

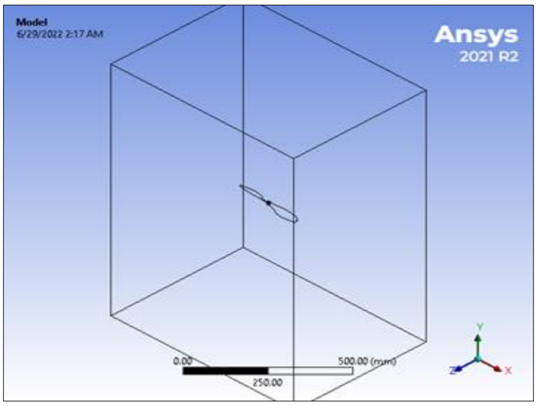

Fig 3: Propeller with Flow domain

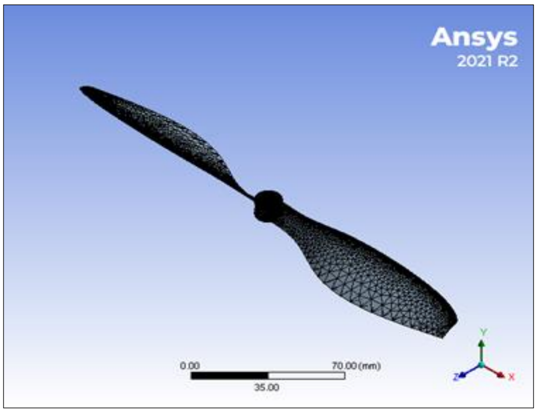

Fig 4: Meshing of Propeller

Table 1: Simulation Parameters of Propeller

Parameter	Value
Propeller Angular Velocity	6000 RPM
Size of Mesh Element	20 mm
Gravity	9.81 m\s2
Time State	Steady
No. Iterations per time step	1000 (0.01 s)
Viscous model	K-Epsilon (Realizable)
Near Wall Treatment	Scalable Wall function
Flow Fluid	Air
Quadcopter Mass	1.4 kg
Flow Density	1.225 kg\m3

The flow simulation has been performed successfully using the K-epsilon turbulent model with 20 iterations. Fig 5 shows the value of Lift force i.e., 4.45 N Fig 6, Fig 7, Fig 8 and Fig 9 show the pressure reading on the propeller, while Fig 10, Fig 11, Fig 12, Fig 13 show the velocity on the rotary domain surface and around the propeller, respectively. The considered
Quadcopter has a total mass of 1.4 kg.
Ansys Fluent simulations using the k-epsilon turbulence model were performed on the single propeller. The results showed accurate wake structures when compared to experimental data. The effects of propeller angular velocity

were evaluated using 6000 RPM. Following are the results which have been calculated in this Case.

- Lift force generated by the propeller = 4.45 N at 6000 RPM
- Propeller Drag Force = 0.00223 N at 6000 RPM
- Propeller Pressure Contours = 2441.44 Pa (maximum).
- Propeller Velocity Contours = 70.5523 m/s (maximum).

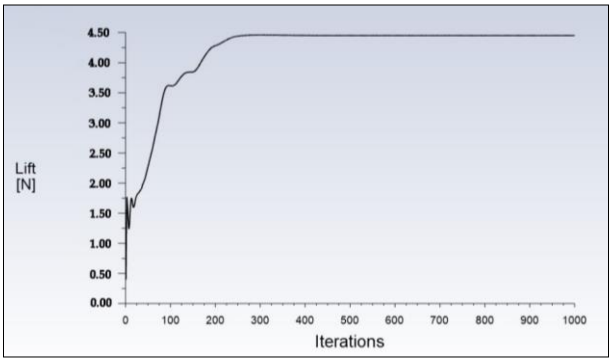

Fig 5: Lift Force Chart for One Propeller

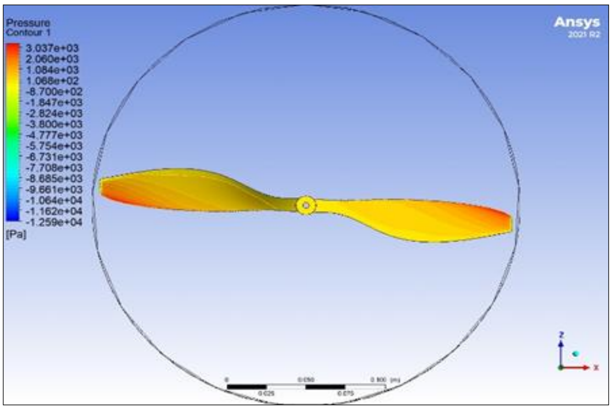

Fig 6: Pressure Contour Bottom blade

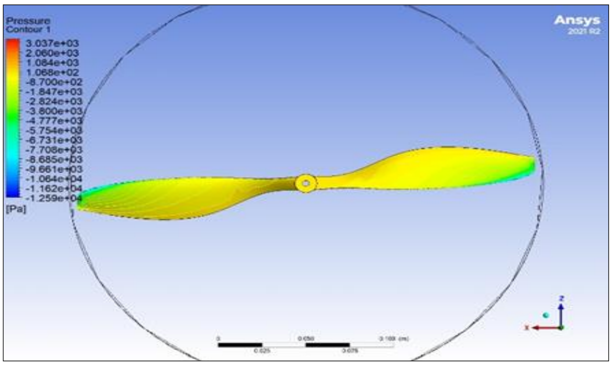

Fig 7: Pressure Contour Top blade

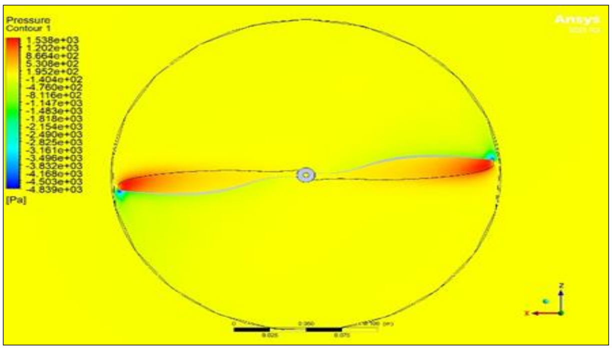

Fig 8: Pressure Contour Intersection (Plan)

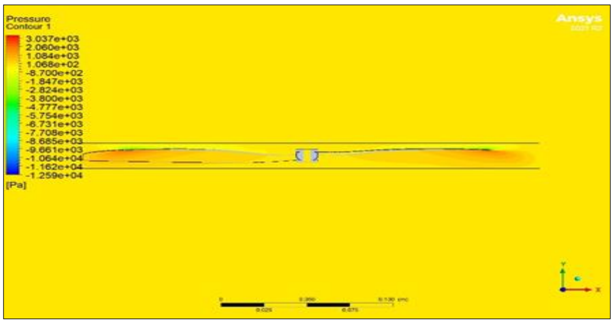

Fig 9: Pressure Contour Intersection (Side)

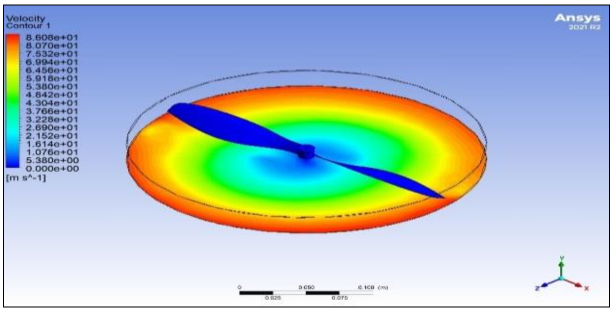

Fig 10: Velocity Contour

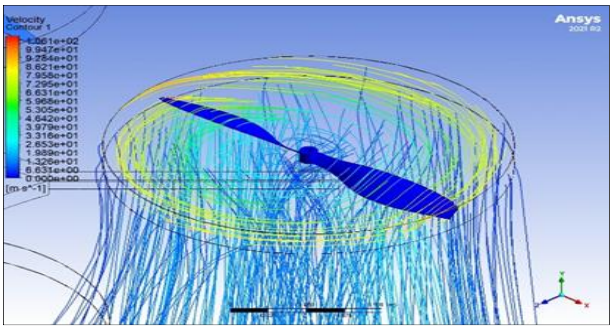

Fig 11: Velocity Streamlines

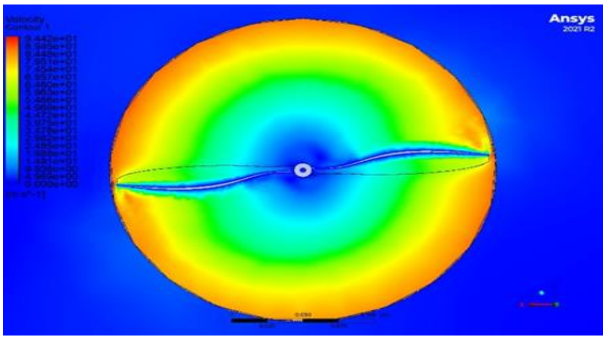

Fig 12: Velocity Contour Intersection (plan)

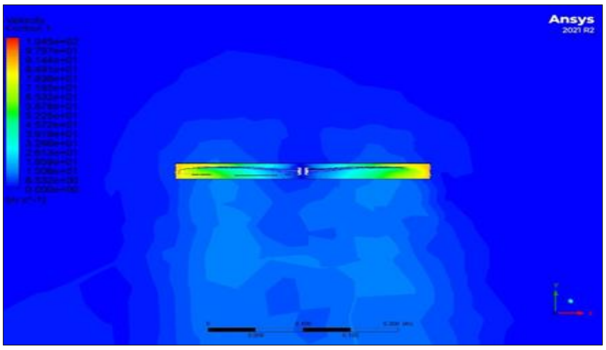

Fig 13: Velocity Contour Intersection (Side)

The Lift force required to fly the Quadcopter F = m x g = 1.4*9.81=13.734 N Hence, the Lift force required per propeller $= \frac{F}{4} =$ 13.734/4 =3.4335 N The simulation Lift (4.45 N) is greater than the calculated Lift (3.4335 N). Hence, for the given flow conditions, the designed propeller can fly the Quadcopter at 6000 rpm.

3.2 CFD Model of Complete Quadcopter

In this section the complete Quadcopter has been simulated for analysing the aerodynamic performance. The designed CAD has been imported from Solid works to Ansys workbench for the flow analysis. The virtual wind tunnel type enclosure has been created around the Quadcopter as shown in Fig 14 shows the model of the Quadcopter with the Flow domain, respectively. Fig 15 shows the direction of air from inlet to outlet. The parameters used for the CFD simulation are listed in Table 2.

Table 2: Simulation Parameters of Quadcopter

Parameter	Value
Propellers Angular Velocity	6000 RPM
Size of Mesh Element	20 mm
Gravity	9.81 m\s2
Time State	Steady
No. Iterations per time step	1000 (0.01 s)
Viscous model	K-Epsilon (Realizable)
Near Wall Treatment	Scalable Wall function
Flow Fluid	Air
Quadcopter Mass	1.4 kg
Flow Density	1.225 kg\m3
Inlet Velocity	6 m/s

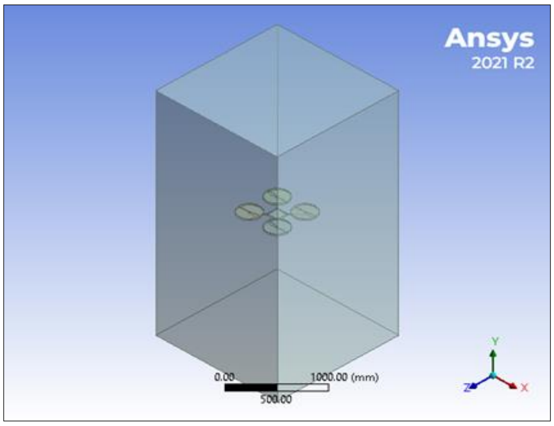

Fig 14: The model of the Quadcopter with the Flow domain

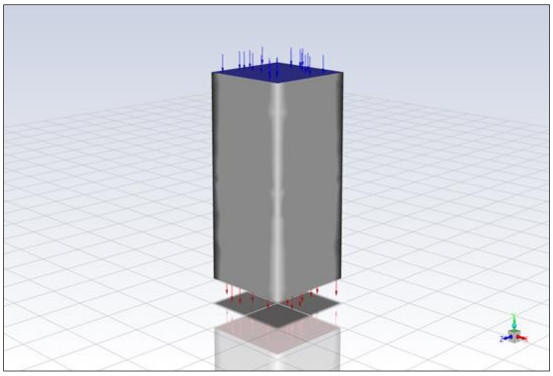

Fig 15: The direction of air at inlet and outlet

Fig 16 shows the drag and lift force exerted by the Quadcopter and we notice, First, the lift force take about 220 iterations until arrives to steady state and value of 17.797 N if divided by four we got 4.449 N which is very close to one propeller lift force (4.45 N). Second, the drag force take about 400 iterations until arrives to steady state and value of 0.0004348 N comparing to one propeller drag force (0.00223 N) we got lower value making better flying stability.

Ansys Fluent simulations using the k-epsilon turbulence model were performed on the full Quadcopter. The results showed accurate wake structures when compared to experimental data. The effects of propeller angular velocity were evaluated using 6000 RPM. Following are the results which have been calculated in this Case.

- Quadcopter Total Lift Force = 17.797 N at 6000 RPM
- Quadcopter Total Drag Force = 0.0004348 N at 6000 RPM
- Lift Coefficient = 0.02905
- Drag Coefficient = 0.00071

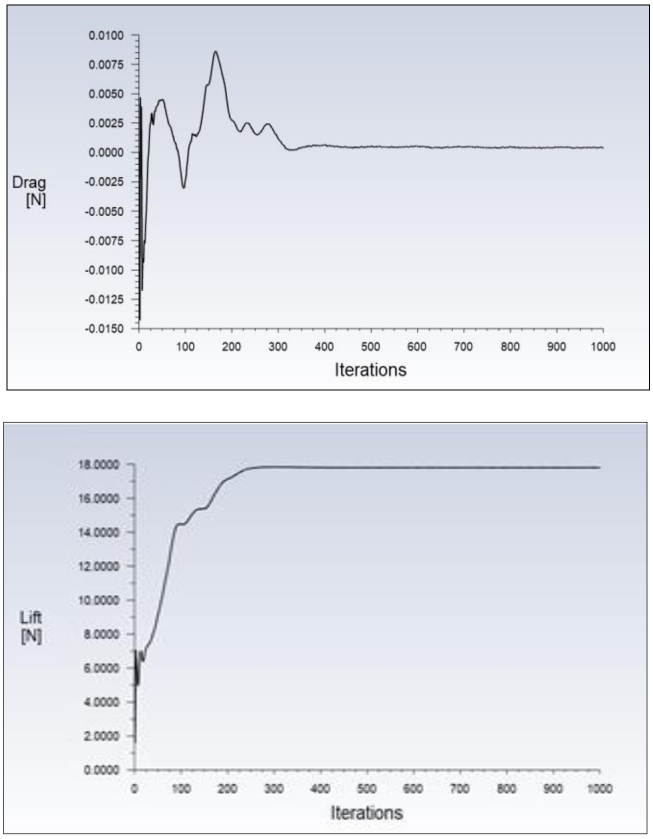

Fig 16: The Drag and Lift Forces Charts

Fig 17: shows Pressure contour of (plan intersection of Quadcopter) from this contour we notice that the maximum pressure (2485.91 Pa) appears at tip of propellers and minimum pressure at the root. Fig 18: shows Pressure contour of (side intersection of Quadcopter) from this contour we notice that the high pressure appears at the bottom surface of propellers and low pressure at upper.

Fig 19 and Fig 20 show velocity contours of Quadcopter from these contours we notice that the highest velocity (109.419 m/s is located at tip of propellers and lowest at root.

Fig 21 and Fig 22 show velocity contour of (side intersection of Quadcopter) and velocity streamlines of quadcopter respectively from these we notice that the direction of air and lift force are forward to the outlet.

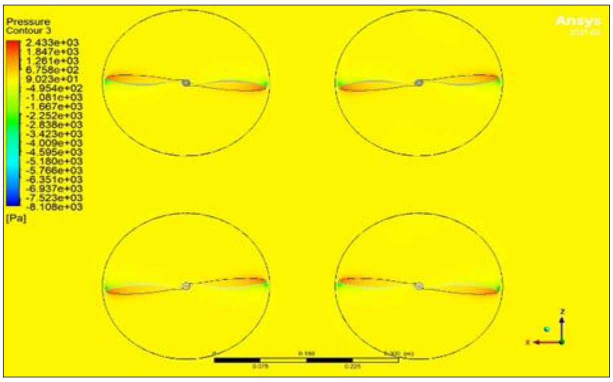

Fig 17: Quadcopter pressure contours (Plan Intersection)

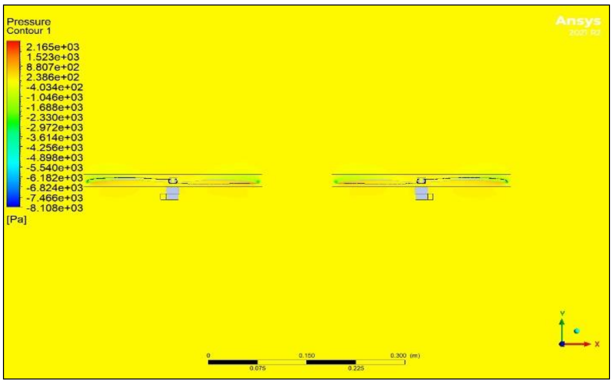

Fig 18: Quadcopter pressure contours (Side Intersection)

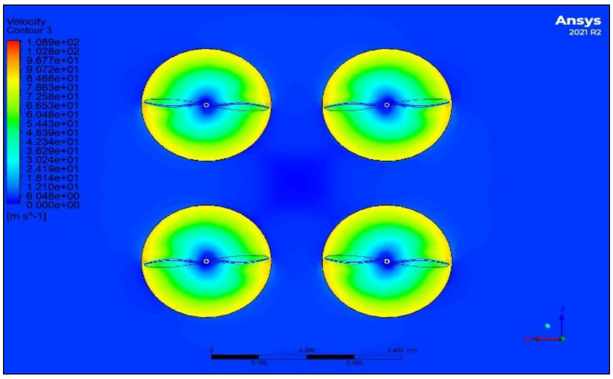

Fig 19: Quadcopter Velocity contours (Plan Intersection)

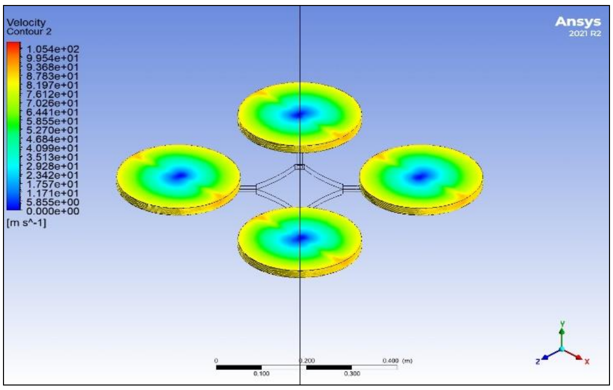

Fig 20: Quadcopter Velocity contours

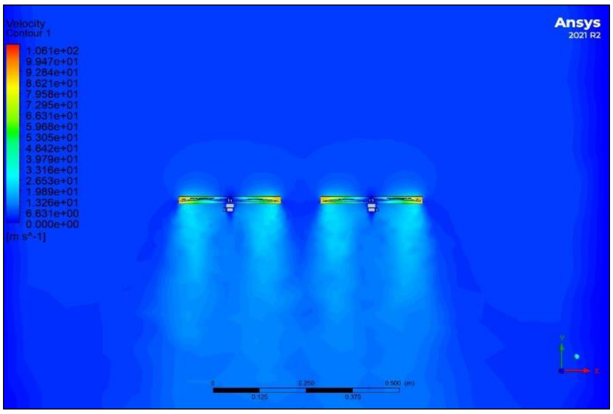

Fig 21: Quadcopter Velocity contours (Side Intersection)

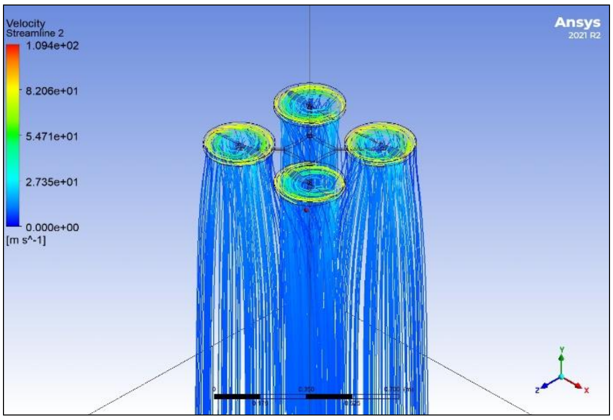

Fig 22: Quadcopter Velocity Streamlines

4. Conclusions

The flight dynamics of a quadcopter experiencing steady wind conditions has been evaluated and presented. Preliminary low fidelity simulations have been performed to validate computational fluid dynamic simulation techniques follow by Single Propeller computational fluid dynamic simulations and finally Full Model simulations. Background on fluid dynamics and turbulence modeling techniques that are used in the present paper have been explained. Previous literature surrounding experimental studies on quadcopter has also been presented and used as a means of validation for the current work's results.

The CAD model of a Quadcopter has been designed in Solidworks and analysed in ANSYS. The flow analysis is performed to observe the behaviour of air on the Quadcopter and its propeller. The value of Lift forces at different angular speeds has been calculated using CFD analysis to calculate the Lift coefficient.

Ansys Fluent simulations using the k-epsilon turbulence model were performed on the single propeller. The results showed accurate wake structures when compared to experimental data. The effects of propeller angular velocity were evaluated using 6000 RPM. Following are the results which have been calculated in this Case.

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- Quadcopter Velocity Contours = 109.419 m/s (maximum).
- Lift Coefficient = 0.02905
- Drag Coefficient = 0.00071

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