DETERMINING UNMANNED AERIAL VEHICLE DESIGN PARAMETERS FOR AIR POLLUTION DETECTION SYSTEM

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Abstract: The expansion of the use of unmanned aerial vehicles has developed new ideas and applications. The use of unmanned aerial vehicles has a wide target range from postal distribution to agricultural land inspection. The aim of this study is to design unmanned aircraft systems that can analyze air pollution from specific points, transfer instant pollution information to computer and transfer images to desired points. The important point in the design is that the aerodynamics of the mechanical structure give the most effective results at high altitudes and changing wind speeds. In this study, a quadcopter was designed to be used in instant air measurements. In the computational flow analysis applied on the design, for air flow values of 10m / sec, 15m / sec, 20m / sec and 25m / sec; The effect of pressure, turbulence and velocity variables were investigated. As a result of the analysis, no results were found to affect the vehicle's ability to move in these parameters. As a consequence of the studies and analyzes, it is concluded that this design is suitable for instant air pollution measurements.

Keywords: Unmanned Aerial Vehicles , Air Pollution, Computational Analysis of Quadrotor, Aerodynamics

Introduction

A multicopter is a helicopter with multiple propellers. It may have 2, 3, or more propellers. The most used multicopter versions are: T Copter (2 engines), Y Copter (3 engines), QuadCopter (4 engines), HexaCopter (6 engines).

These systems are powered by rechargeable lithium polymer batteries. Multicopters need a flight controller to stabilize in the air. These controllers contain various sensors. There are several types of sensors depending on the controller to be used such as gyro, acceleration sensor, magnetic field sensor, global positioning system, ultrasonic sensor, and pressure sensor.

The quadcopter, which is a more stable and symmetrical unmanned aerial vehicle, is a 4-rotor vehicle that meets the definition of a VTOL (vertical take-off and landing). Unlike normal helicopters, the quadcopter does not have a tail rotor to correct the inertia created by the engine, instead, coaxial pairs of propellers provide stability by rotating in opposite directions to each other and adjusting the RPM (revolutions per minute) every second.

Quadcopters have some advantages over the helicopters in similar size.
First, Quadcopters do not need mechanical connections to change the propeller angle. This simplifies its design and maintenance. Secondly, the diameter of the engines is small since four engines are used, which means that they have less kinetic energy during flight so that the engines get less damage in the event of a possible collision. Quadcopter chassis is frequently used in amateur model flight projects thanks to ease of construction and control. Another advantage of the quadcopter is that it is more efficient and lighter than real helicopters and other people-carrying vehicles because it works with electrical energy. However, it is a disadvantage that the mechanically full-scale model is quite difficult to construct and fly (Göl, 2019).

Materials and Methods

First of all, if we examine the assembly of the components and electronics of the mechanics to be analyzed; it is produced with carbon fiber structure with a front surface which will slow down the speed of the fluid in dense airflow.

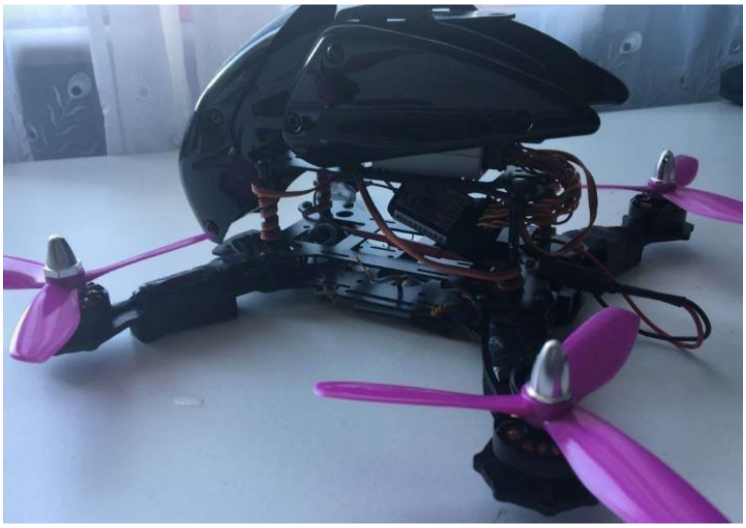

Figure-1: Image of our quadcopter after its assembled

We used drawing in the design stage and Solidworks software for CFD analysis and tensile stress analysis.

Quantity	Hardware
4	Readytosky 2212 920KV Brushless Motor
4	Emax 12A ESC
1	Profuse 25C 2250mAH 3S Battery
1	Flysky FS-R6B Receiver
1	Flysky FS-I6 Transmitter
1	Carbonfiber Frame Parts

Table-1: Hardware Equipments

Quantity	Software
1	DJI NAZA M-LITE
1	SOLIDWORKS
1	ANSYS

Table-2: Software Equipments

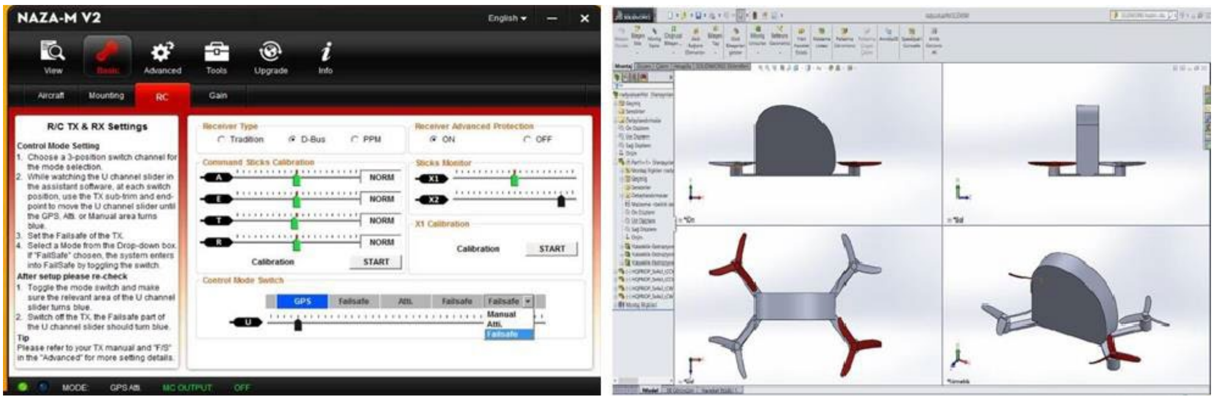

Figure-2: Using softwares

DJI Naza M-Lite Assistant software was used to configure the Quadcopter's flight control.

The propeller converts the mechanical energy generated by the engine into a propulsion force by accelerating the air mass in front of it in the opposite direction to the aircraft's movement direction. The force that pulls the quadcopter forward/backward and right/left is obtained by increasing the fluid momentum backward according to the aimed direction. This momentum increase is usually achieved by accelerating the air backward using a propeller. Quadcopters have 4 propellers; two clockwise (CW), and two counterclockwise (CCW). The direction of rotation of the engines and propellers facing each other are opposite at the quadcopter, which has a different structure from the helicopter.

The design with the most ideal dimensions for the propeller structure is called aerofoil (wing profile). Aerofoil is a 2D cross-section of objects moving through a fluid such as a propeller. These cross-sections are designed to provide the optimum drag ratio to the vehicle moving through any fluid such as air and water. We wanted to examine the difference in flow analysis by drawing 3 different propellers before the analysis.

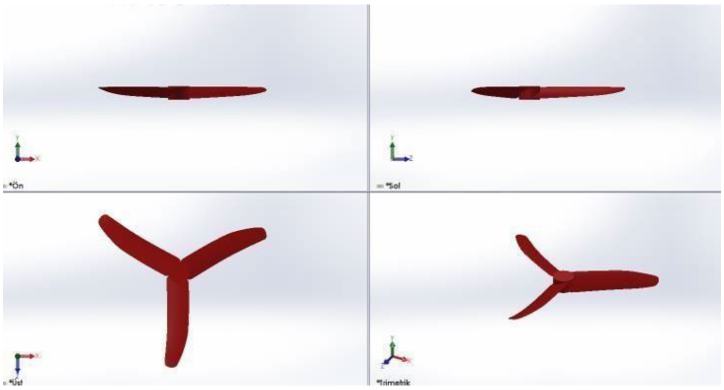

Figure-3: CCW Aerofoil Propeller

In the ideal disc theory developed by Froude, instead of a propeller, an infinitely thin disc of the same diameter is taken and the momentum gained by the air passing through it is examined. However, the following assumptions are made during this examination:
- The fluid passing through the disc gains energy in the form of static pressure increase. The energy gained is the same on all sides of the disc.
- The velocity of the air particles passing through the disc is the same. The flow is constant and irrotational. Vortexes at the propeller outlet are omitted.

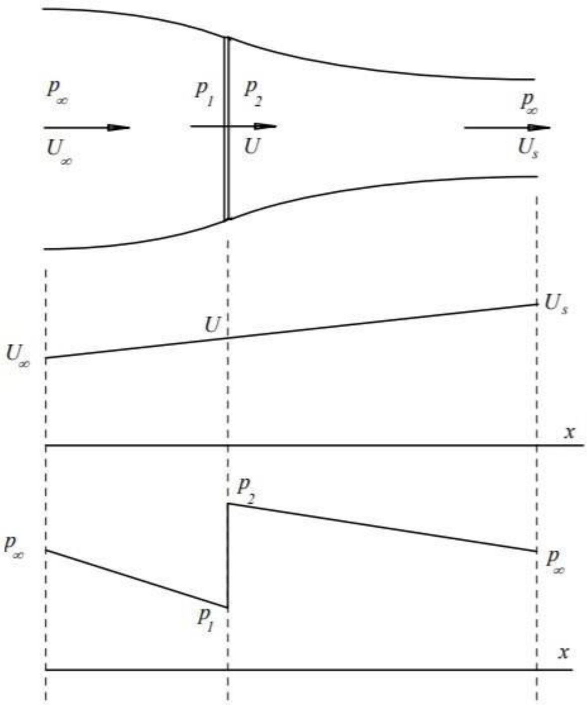

Figure-4: Bearing Disk

In front of the propeller and far enough away from it, the air comes to the propeller with a speed of U∞ equal to the speed of the aircraft and it accelerates as it approaches the propeller, reaching the speed of U on the disc. It continues to accelerate after the disc and reaches the speed of us far enough behind. Parallel to this speed increase, the static pressure of the air decreases as it approaches the propeller and decreases to the value of p1 in front of the disc, increases to the value of p2 behind the disc with the energy it gains from the disc and again decreases to the static pressure p∞ at infinity by gradually decreasing behind the disc. The velocity of the air passing over the disk is equal to the arithmetic mean of the free stream velocity and the advanced velocity of the propeller.

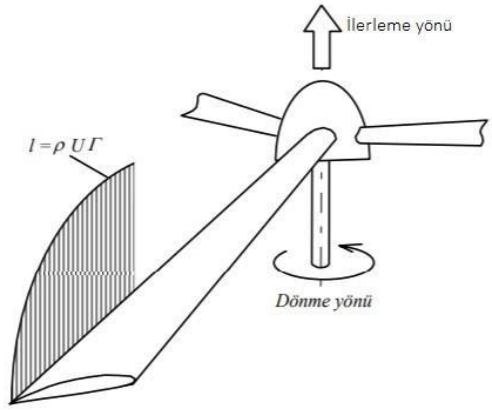

Figure-5: Load distribution through propeller pal[2]

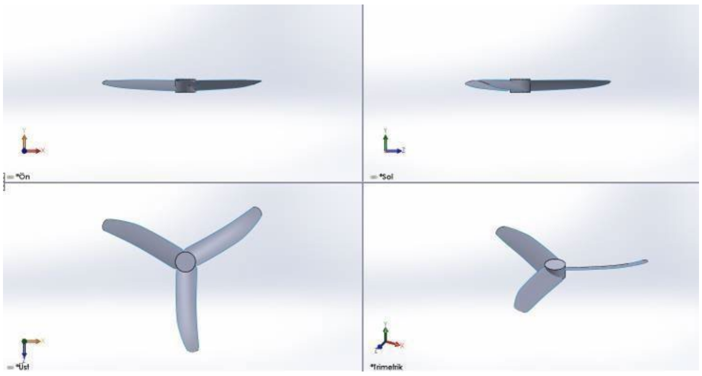

Figure-6: Slenderized Aerofil Propeller

It is possible to consider each blade of a propeller as a three-dimensional wing. However, this wing makes a rotational movement around the root and a propulsion motion in the direction of its trailing edge. Under the influence of these movements, a lift force is generally formed on the propeller blade in the direction of propeller's motion, however, due to tip effect, as in the three-dimensional wing, the lift force which is zero at the blade tip, shows a change along the blade

As a result, evacuation vortices are formed on the trailing edge of the blade, and these vortices roll over each other in the blade to form a tip vortex.Trailing edge vortices formed in the same manner on the track of a three-dimensional wing are spread behind the wing so that they remain in the plane of movement of the wing while they are spread along helical trajectories, due to the common effect of the propeller's rotational and propulsion movements in the footsteps of a propeller.

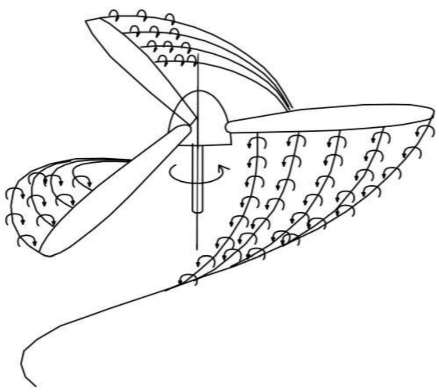

Figure-7: Vortex System around propeller

When the close track of a blade is examined, it is seen that the trailing edge vortices are propagated along the helical trajectories towards the back of the propeller as indicated above, rather than within the blade's rotational plane behind the blade.
In order to better examine the effect of these vortex lines on the stream area around the blade, it is useful to divide them into two components in the plane of rotation and in the direction of propulsion.

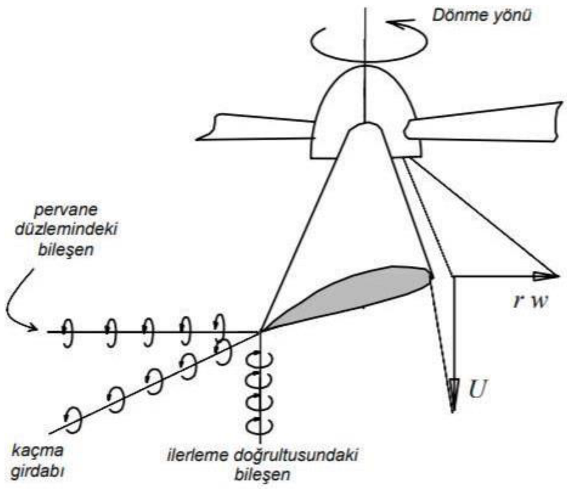

Figure-8: Components of vortex lines(Yükselen,2019)

The vortex lines of the component in the rotation plane induce velocities in the same direction as in the three-dimensional wing in the direction of the blade belly, i.e. in the direction opposite to the propulsion direction of the propeller. These induced velocities are the increase in the flow velocity in the disc plane in Froude momentum theory. It is known that the induced velocity decreases as the wingspan increases in the three-dimensional wing. On the other hand, according to Froude's theory, the faster the stream passing through the disc is, the higher the ideal efficiency is. As a result of Froude's theory, the dependence of the ideal yield on the propeller area and the speed in the track, it is stated that increasing the diameter of the propeller instead of increasing the speed in the track will positively affect the ideal efficiency (Yükselen,2019).

Results and Discussion

Fluid analysis of propellers was examined before the general mechanical structure. After the compatibility of the propellers, the entire structure is examined.
The simulation of the propellers exposed to the air in a closed system was carried out using Flow Simulation extension of Solidworks.
If the steps of computational fluid analysis of the counterclockwise aerofoil propeller are examined;

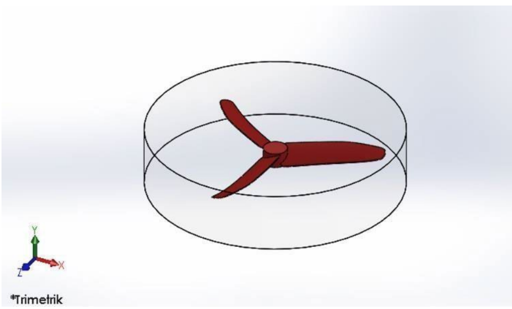

Figure-9: Propeller in the Cylindirical Flow Area

First, the boundaries of the rotating cylindrical field are determined to ensure that the propeller becomes independent of external factors. And the propeller was placed in the cylindrical structure with a volume of 85 cm^3 (h=15 mm, r=75 mm) [Figure 9]. The speed of this rotating cylindrical field is set to (-)1100 rad/sec. The reason is that the angular speed is proportional to the RPM of the engine we proposed to use. The faces to be examined are selected. On each face of the propeller, the effect of airflow on velocity was examined. When we examine the airflow that we sent from the Z-axis;

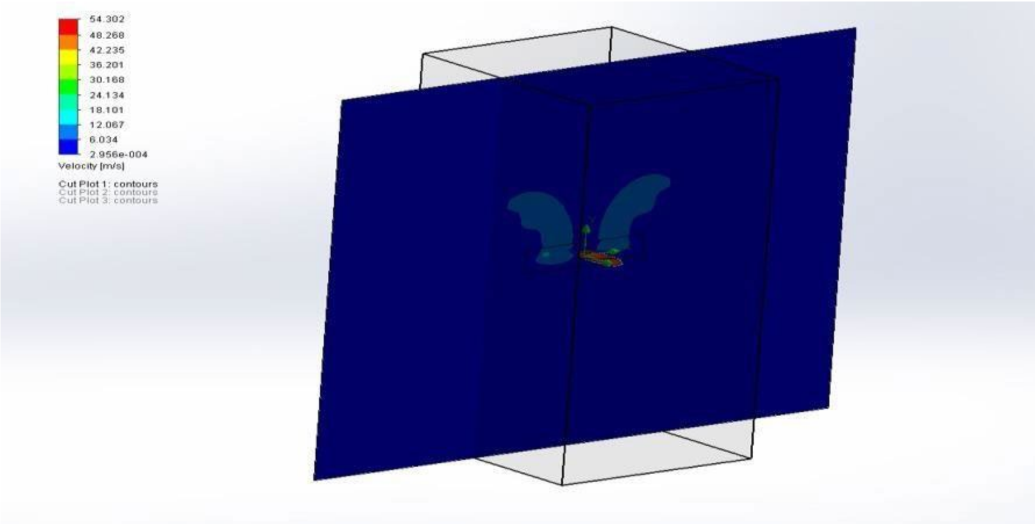

Figure-10: Z axis of the air flow simulation.

When we examine the propeller's reaction to the airflow that we sent from all three axes;

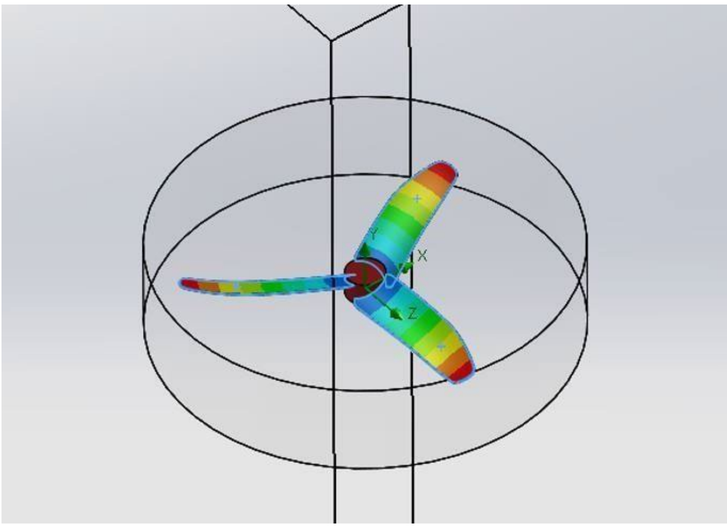

Figure-11: Propeller in the Cylindirical Flow Area

Thus, the hub and the radius points of the propeller are more affected by the airflow. We said that airflow does not occur in one direction in propellers, unlike the airplane wings. Airflow in various directions according to the direction of each blade of the propeller will be monitored. When we observe the airflow direction from a general angle for the counter-clockwise propeller;

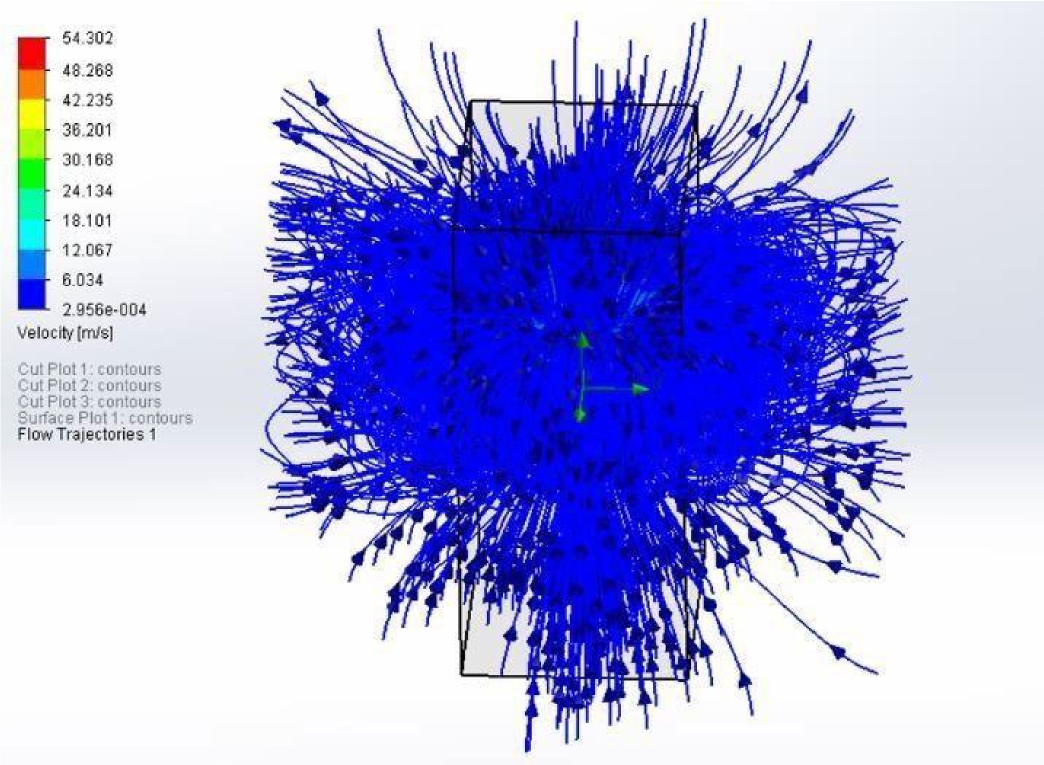

Figure-12: Impulse Force Directions

Usually, we see that the air entering from the (-) Y-axis disperses and move towards the (+) Y-axis, and the air coming from the (+)X direction led towards (-)X direction.

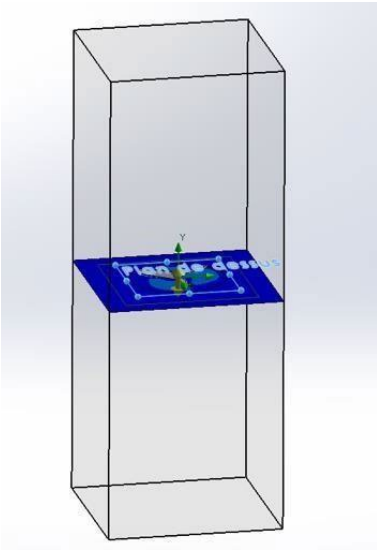

Figure-13: Y-axis air flow at CW propeller

If we examine the flow analysis of the clockwise propeller, we see that there is no change in the flow velocity graph acting on the surface, but only the propulsion forces will be different.

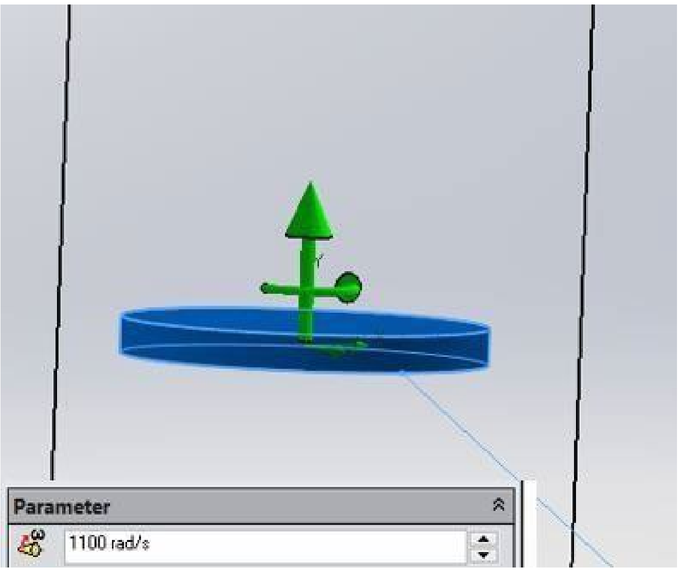

Figure-14: A figure that shows angular velocity is in the (+)Y direction at CW

Computational fluid analysis of the vehicle which was drawn in three-dimensions was carried out using Ansys software. First of all, the drawing was imported into the program and the vehicle was placed in a rectangular closed system of 2x5x2 m3. Airflow was sent to the system at speeds of 10m/sec, 15m/sec, 20m/sec, and 25m/sec respectively.

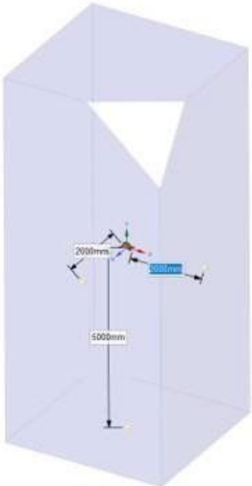

Figure-15: Isolated system that is simulated

3 reference points are taken from the quadcopter placed in the isolated system. These points, which are expected to be the most efficient points in the analysis, are the center of the front right propeller, center of the front left propeller, and the center of the vehicle body.

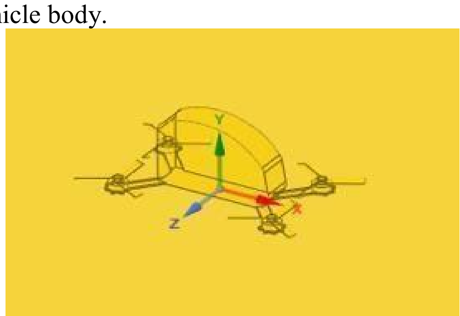

Figure-16: Quadcopter that is in the isolated system

After defining the reference points of the vehicle and selecting the fluid material as air, the simulation is advanced and the network structure of the model is formed. The reference coordinates are entered as indicated in Figure 17.

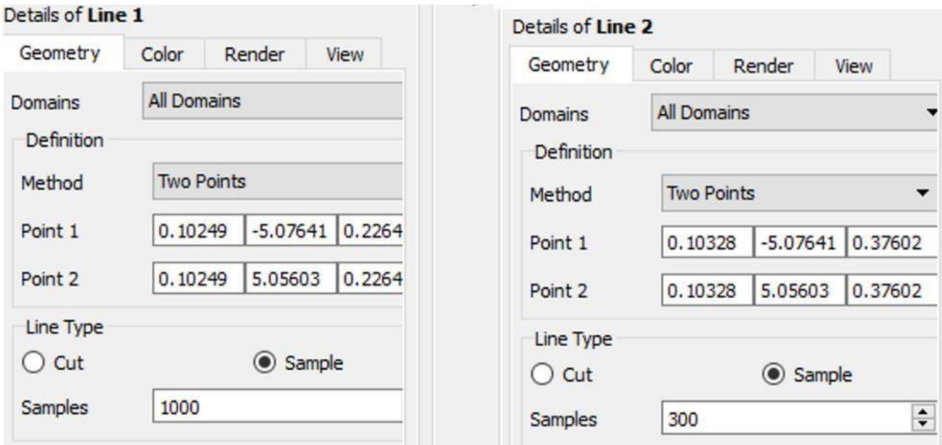

Figure-17: Reference coordinates

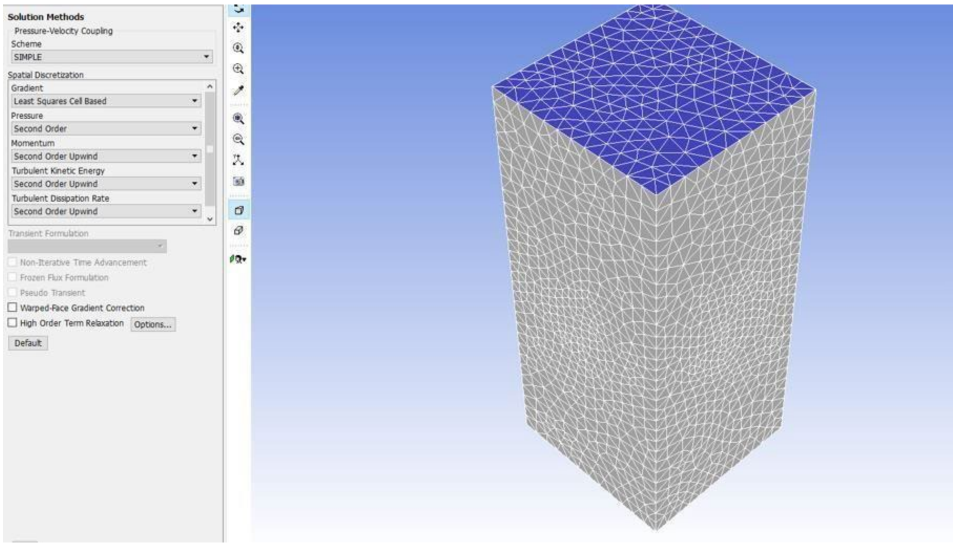

Figure-18: Network Topology of the model

The number of nodes, the number of elements in the model, and the number of network structures divided into tetrahedral are indicated in Table-3.

Table-3: Model's spefications

Domain	Nodes	Elements	Tetrahedra
Model	155572	909851	909851

Three variables were defined to analyze the model. As a result of the analysis, the effects of airflow on velocity, pressure, and turbulence kinetic energy is observed.

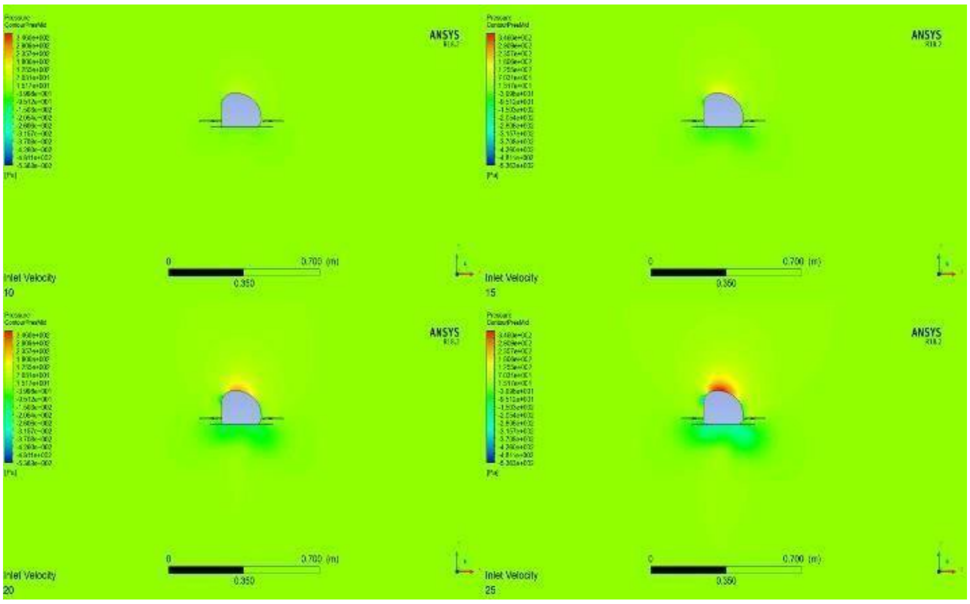

Figure-19: Pressure effect through the center of aircraft

When the above figure is examined, the effect of pressure on the center of the vehicle is increased when airflow rates are increased. However, this pressure level is not enough to prevent the mobility of the system. Only the upper part of the vehicle that is exposed to the air flow of 25m/sec is affected.

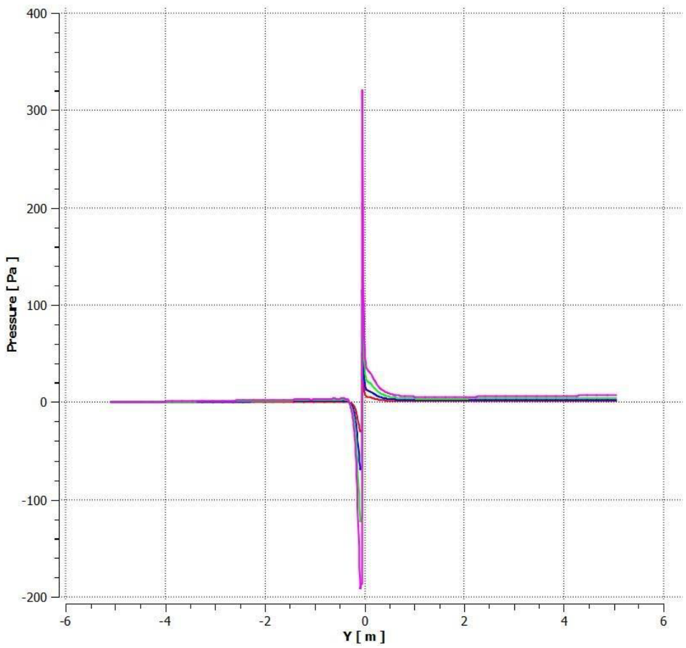

Figure-20: Pressure effect on front-left propeller

When the result in Figure-20 is examined, the increase in the airflow rate does not create a pressure effect at a level that would have a negative effect on the surface of the propeller.

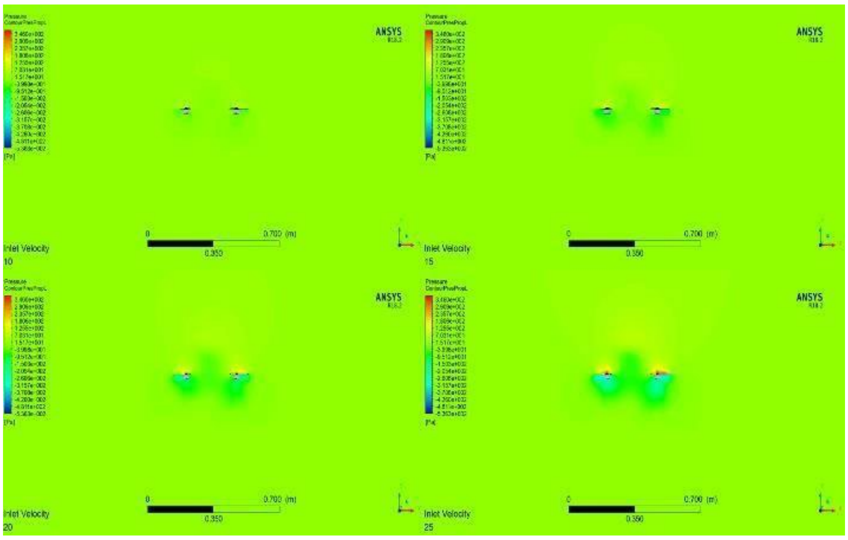

Figure-21: Pressure change for four different velocity values

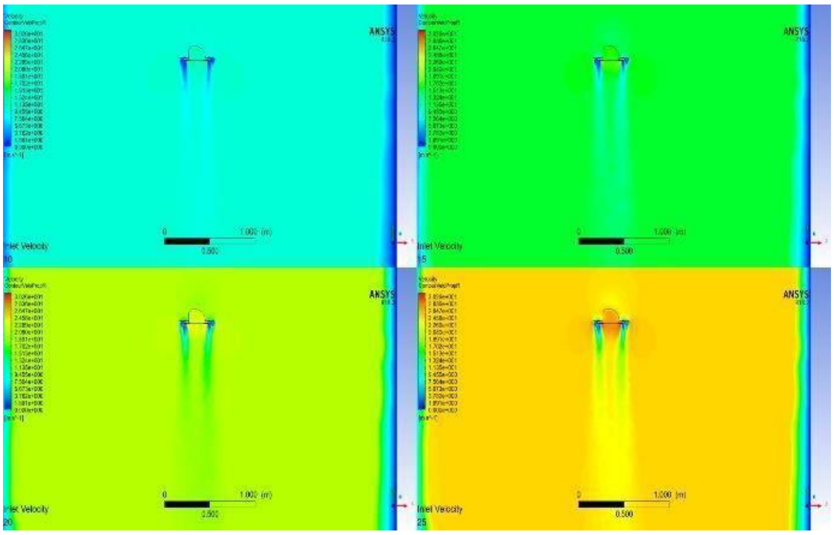

Figure-22: Velocity effect on the center of aircraft

The pressure value reaches its maximum level when the vehicle meets the airflow coming from +Y direction. The airflow, which is not in contact with the vehicle, regains its former stability.

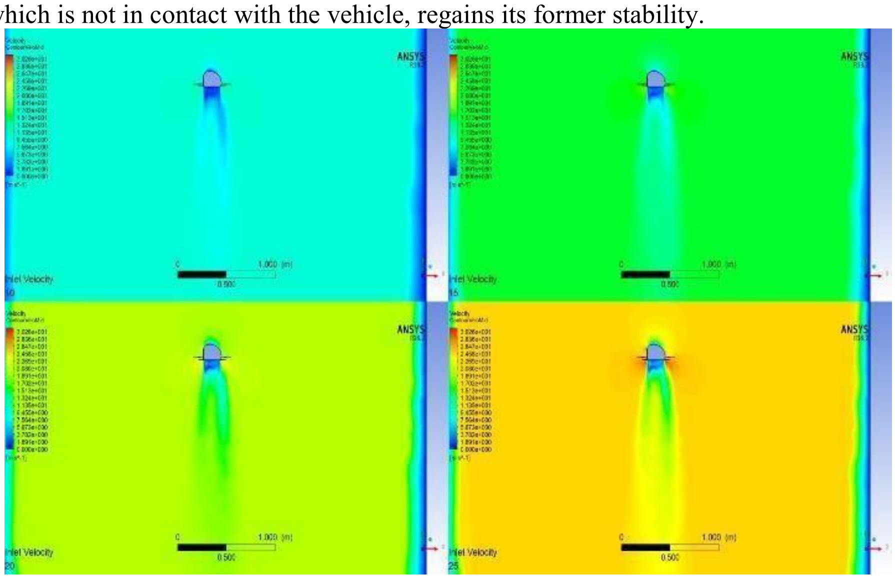

Figure-23: Velocity effect on front-right propeller

When we examine airflow with four different velocity values that effects the center of the body,it is observed that while velocity values increase,reaction of body increases too. The maximum value for this reaction is observed under the body of the vehicle exposed to the wind of 96 km/h.

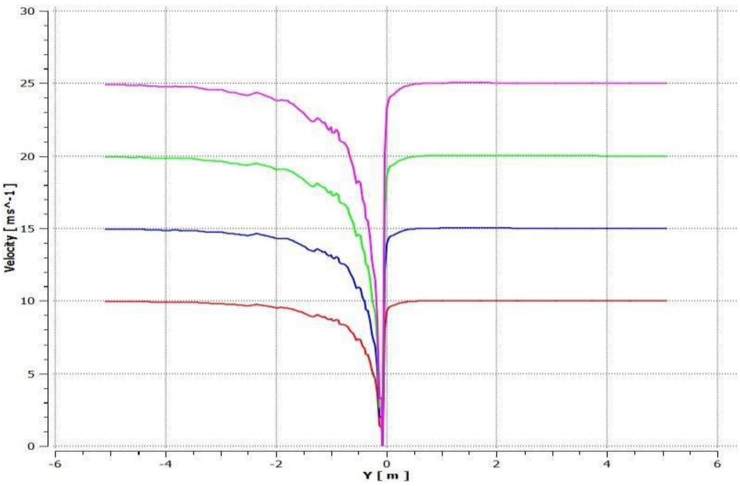

Figure-24: Effect of the four different velocity to the aircraft's velocity

The velocity of the air sent in the +Y direction is damped by the vehicle as soon as it meets the vehicle. After the air contact with the vehicle ceased, it decayed for approximately 4 m and then became stable (Figure-24).

In other words, the vehicle has an immediate damping effect on the air when it contacts with the air. The velocity of the air became exponentially stable after the contact was stopped.

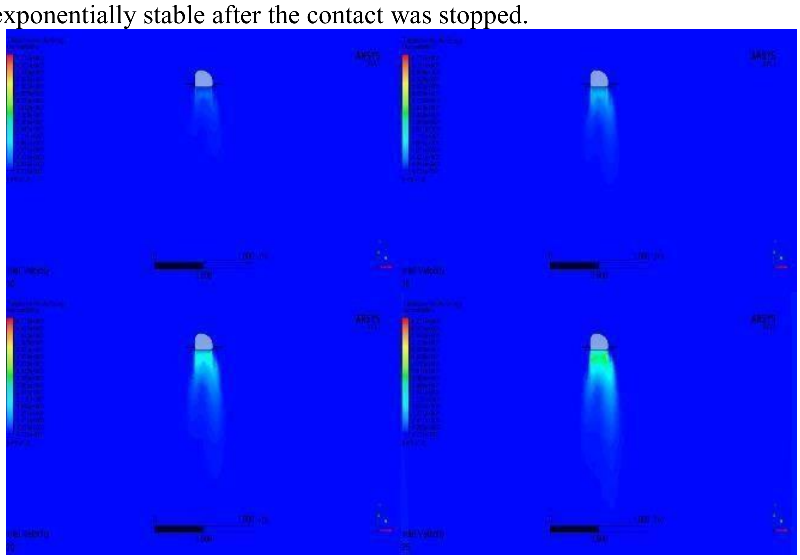

Figure-25: Effect of the kinetic energy on the center of aircraft

The turbulence kinetic energy acting on the vehicle is shown in Figure-25. When the graph is examined, turbulence kinetic energy is increased in direct proportion with increasing velocity values of airflow. This energy is observed starting from the bottom of the vehicle body to an average distance of 2 meters from the lower body. As the airflow moves away from the vehicle, the turbulence kinetic energy becomes zero again. It was observed that the turbulence kinetic energy generated in the vehicle was not at a level that would prevent the movement of the vehicle at the simulated speed values.

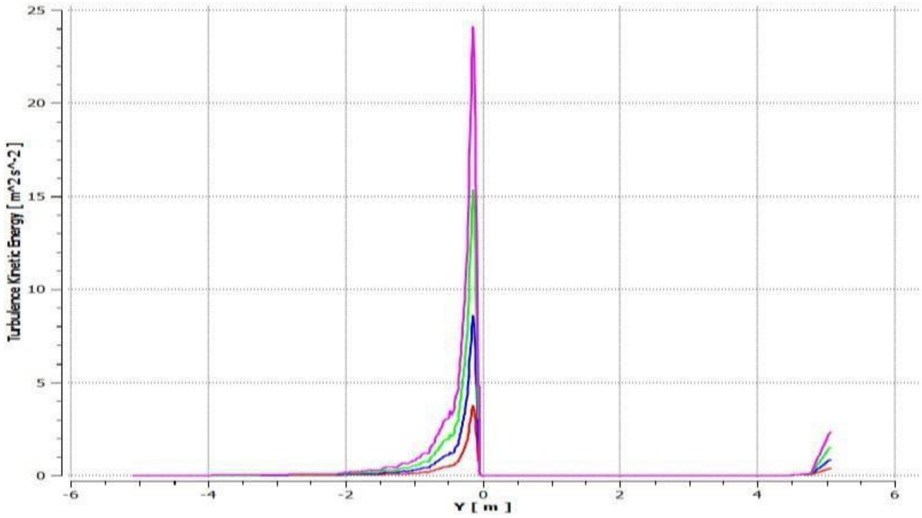

Figure-26: Effect of the four different velocity to the aircraft's turbulence kinetic energy

Conclusion

In this study, a quadcopter was designed to be used in instantaneous air pollution measurements. In the computational flow analysis applied on the design for airflow values of 10 m/sec, 15 m/sec, 20 m/sec and 25 m/sec, the effect of pressure, turbulence, and velocity variables were examined. No results were found to affect the vehicle's mobility in these parameters at the end of the analysis.

As a result of the studies and analyzes, it is concluded that this design is suitable to be used in instantaneous air pollution measurements. The production of the designed vehicle was realized.

Acknowledgments:

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