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Design of Modified Propeller for Crop and Vegetation Monitoring

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Abstract - *Crop and vegetation monitoring using drone requires a high lift propeller in order to adjust to environment of the forest and farm fields. There are different propellers exist with different specifications the selected profile specification is 11x5.5" according to the motor specifications. Four airfoil sections NACA 2412,4412,23012 and Clark Y is selected for analysis. Three parameters are analyzed viz. drag, lift and thrust force produced. After the analysis in Ansys 19.2 Fluent appropriate airfoil is selected for the propeller design. 4412 is found to be more efficient. The propeller is designed with the selected cross section and performance is tested.*

Key Words: NACA 2214, 4412, 23012, Clark-Y, Propeller, drag, lift, thrust

1. INTRODUCTION

A general propulsion system for a multirotor includes the propeller along with the rotating motor and supporting electronics (flight controller, Battery, Distribution system, fastening bolts ESC's, Control architecture, etc.). Depending upon the thrust required the propulsion system shall be selected. The motor catalogues are available for an individual manufacturer which enlists the thrust and speed of the motor as per the throttle. This is rather an iterative procedure because the motor weight adds to the weight of total assembly and hence requires an overestimation of thrust to obtain the required motor. The supporting electronic architecture is also necessary which adds to the weight of the overall assembly. The major contribution is of the battery.

Usually the manufacturer recommends the type of propeller to be used with certain motor but it is to be optimized by selecting a proper aerofoil section in order to obtain an optimum Cl/Cd ratio. Also, the thrust to weight ratio is considered as an important parameter while designing a drone the higher the thrust to weight ratio, the more manoeuvrable the drone becomes. It is standard to maintain 2:1 thrust to weight ratio but considering the requirement of the application it is decided that the thrust to weight ratio shall be kept as 3:1 in order to have comfortable manoeuvring.

2. LITERATURE REVIEW:

Shubham Yadav et al (2017) [1] In this paper the author is comparing quad copter rand tri copter propeller to check for more efficient propeller in order to find thrust to weight ratio in order to increase performance. The Author infers that those different propeller motors give different amounts of thrust at varying throttle. Large propellers are needed to improve thrust efficiency and to carry more payload. It is necessary to have right motor and propeller combination for stable drone.

Omar D. Lopez et al (2017) [2] Computational Fluid dynamics plays crucial role in aerodynamics of drones. In this paper Spalart Allmaras and k-ω turbulence models used in quad copter hover. Models predict wake generation, thrust and moments coefficients. Thrust, torque and Ct result for model are same but predict given by k- ω model is higher than SA in almost all cases. The k- ω model suggests stronger field of turbulent viscosity induced for the propeller.in this model with increase of velocity turbulent increases. Instead in SA model velocity has a negligible effect on turbulent viscosity field.

Yoon, S., Lee, H., Pulliam, T [3] The author investigates the effects of the separation distances between rotors, wings and fuselage on the performance and efficiency of multicolour systems. Interactional aerodynamic of multi rotor flow were investigated as the part of this study which lead to the conclusion that separation distance has pronounced effect on the vertical component of forces in hovering condition. With the decrease in separation distance between the rotor, efficiency of the system decreases. The fuselage is responsible for little lift whereas the wings decrease the vertical force by generating large downward force.

Echavarria, C. M. L., & Poroseva, S. (2015) [4] The higher propulsive efficient ducted propellers were analyzed as part of this study. The objectives are to optimize the ducted propeller design and discovering the effect of number of blades on flow. The comparison between ducted and un-ducted propellers provide the following result ducted propeller has less intense and complicated wake structure and this creates less noise with improved performance. The un-ducted propeller has higher coefficient of thrust and for the same performance as that of ducted, it requires more number of blades. The author suggests the effect of length, angle of attack, blade twist and duct should be analyzed.

Hoffmann, G., Huang, H., Waslander, S., & Tomlin, C. (2007) [5] In this paper the effect of quad copter velocity, angle of attack and airframe design on the altitude control. The aerodynamics creates the need of accurate and precise trajectory control. The paper considers aerodynamic disturbances and attempt to improve physical configuration along with control design. The attitude and altitude performance tracking and control done efficiently can be used to get a stable flight at high speed and with severe wind condition.

Sekkwan Yoon et al [6] The paper emphasises of closely spaces rotors at low Reynolds No. The dip in performance is credited to the hypothesized tip vortex cores of neighbouring rotor blades. Also, the field measurements conducted indicated the wake interaction between rotors resulting into a distort and they lose coherent form causing deviation in trajectory.

Erdem Yilmaz, Junling Hu (2018) [7] In this paper two propellers and their aerodynamic performance were analyzed at statics thrust condition. The DJI sparks propeller was analyzed against a new design with winglets. After the stimulation it was found that the thrust generated by the latter is 21% more than the prior under the same rotational speed. The author suggests experimental study to validate this finding.

Brandt, J., & Selig, M. (2011) [8] In this project 79 propellers between 9 to 11 inches diameter where tested at same RPM and changing wind tunnel speed. The tested propellers were operating under range of 50,000 to 1, 00,000 Reynolds number which was calculated at 75% propeller blade diameter. Results indicated degradation in the performance with lower RPM at significant Reynolds number. The efficiency had wide range between 0.28 to 0.65.

Mueller, M. W., & D'Andrea, R. (2014) [9] This paper deals with the quad copter's altitude and position in space with the loss of single, two opposing or three propellers. The strategy of control in each case was to allow the drone to rotate freely about an axis which is fixed with respect to body. The drone's translation was achieved using the forces generated by remaining motor.

Pulkit Sharma et al (2018) [10] In this paper author discusses about drone's landing capability, structural integrity and stress is studied to make sure that structure doesn't get collapse. Multiple tools for various factor like thrust, rpm and forward stress is developed. This model is used to understand flight plan of the drone with gravity considerations in non-linear analysis. The Author conclude that development of MATLAB required for thrust rpm forward speed plot, simplifies the calculation of thrust flight speed as well as it removes test and measures the thrust for propellers, decreases effort and increases precision. Non-linear analysis of drone frame for integrity, landing stability which help in real time insight about the drone frame. Conceptual design of drone helps to eliminate presence of unnecessary components in model, reducing the overall weight of structure. Hence it indicates robustness of frame and amount of payload that can carry without any failure.

Je Young Hwang et al [11] The computational simulation results for aerodynamic interactions were compared for normal overmount and undermount rotors. The undermount configuration comparatively provides no improvements rather an unsteady environment near fuselage, lower thrust for body off rotors and decrease in efficiency in forward flight because of aerodynamic interactions because of downstream and upstream rotors.

3. DESIGN OF PROPELLER:

3.1 Aerofoil Analysis:

The most predominant aerodynamic forces on an aerofoil due to dynamic pressure are lift and drag. The lift and drag force are given by

$$FL=0.5CL\ \rho V02A$$

$$FD=0.5CD\ \rho V02A$$

For subsonic flows aerofoil L/D ratio also known as lift to drag ratio decides the efficiency of the aerofoil. Since the lift contributes to both the thrust and resisting torque and drag contributes to resisting torque, the comparison between the dimensionless parameters of lift and drag called coefficients of drag and lift respectively shall provide a sufficient basis for the efficiency comparison between different aerofoil. Also, a force in Y direction or the upward force will indicate the amount of thrust generated by the aerofoil and hence it is rather convenient to select an aerofoil based on both of them.

The most commonly used aerofoil sections are NACA 2412, 4412, 23012 and Clark Y. All of these air foils are not symmetric and hence the normal comparison using the available charts is under efficient in this particular case hence all these aerofoils are analyzed under Ansys Fluent by creating a fine mesh and inputs were assigned as boundary conditions. The K-epsilon Realizable with Standard wall Function turbulent model was used to compute the required parameter.

Table 3.2 NACA4412: Analysis Results

AOA(α)	Cd	Cl	Thrust	Cl/Cd
0	5.51E-04	4.17E-03	2.02E+01	7.56E+00
	7.45E-04	1.60E-02	88.62	2.15E+01
10	4.99E-03	1.66E-02	95.037	3.33E+00
15	7.22E-03	2.32E-02	133.97	3.21E+00
20	5.97E-03	1.53E-02	90.913	2.57E+00

Table 3.1: Analysis Parameters for Aerofoil

Relative velocity at flow inlet (velocity-type)	96.565 m/s
Outlet (pressure-type)	Gauge pressure (pressure over 101325 Pa) = 0 Pa
The aerofoil (wall-type)	No slip stationary wall
Flow Domain (fluid-type)	Density= 1.1845 kg/m3 Viscosity=1.8444x10-5 N-s/m2
Model	K-epsilon Realizable with Standard wall Function model, double precision and second order momentum equation.

The air velocity at the forest and agricultural terrain is usually around 6 miles per hour while a surge up to 9 miles per hour can be seen in the desired region and hence 9mph i.e., 4.426 m/s is selected as the air velocity. The average velocity at 3/4 diameter of the aerofoil is 92.139 m/s and hence the relative velocity at the inlet is chosen to be 96.565 m/s.

Table 3.3 NACA 2212: Analysis Results

AOA(α)	Cd	Cl	Thrust	Cl/Cd
0	5.32E-04	2.23E-03	1.23E+01	4.20E+00
5	7.49E-04	1.40E-02	7.75E+01	1.87E+01
10	5.78E-03	2.47E-02	139.88	4.27E+00
15	3.89E-03	1.25E-02	72.159	3.21E+00
20	5.84E-03	1.44E-02	85.987	2.47E+00

Table 3.4 NACA 23012: Analysis Results

AOA(α)	Cd	Cl	Thrust	Cl/Cd
0	5.31E-04	1.21E-03	6.69E+02	2.28E+00

5	7.22E-04	1.33E-02	7.34E+01	1.84E+01
10	1.78E-03	1.15E-02	6.42E+01	6.47E+00
15	3.76E-03	1.18E-02	6.81E+01	3.12E+00
20	5.69E-03	1.38E-02	8.22E+01	2.42E+00

4. RESULT AND DISCUSSION

PROPELLER

After the computational analysis of 4 different (NACA 2412, NACA 4412, NACA 23012 and Clark Y) aerofoils it has been that the coefficient of lift to coefficient of drag ratio i.e., Cl/Cd ratio graph has been plotted for angle of attack ranging from 0-20˚. The graph predicts that NACA 4412 is more efficient followed by Clark Y and NACA 2412. The thrust vs Angle of Attack graph shows that NACA2412 generates largest thrust while NACA2412 has more average thrust followed by Clark Y. Hence NACA4412 is selected for aerofoil design.

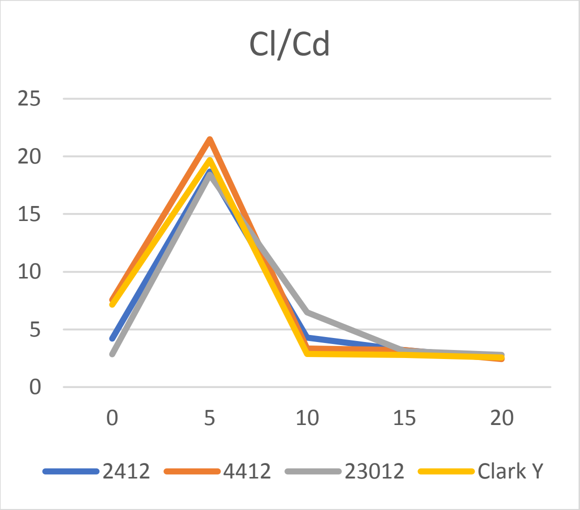
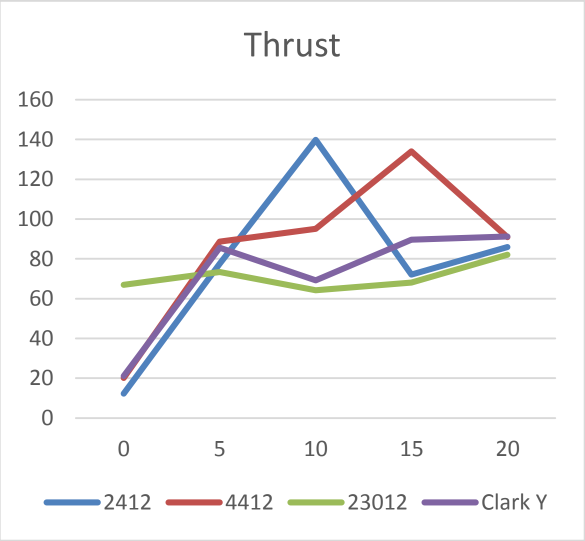


Table 3.5 Clark Y: Analysis Results

AOA(α)	Cd	Cl	Thrust	Cl/Cd
0	5.33E-04	3.81E-03	2.11E+01	7.15E+00
5	7.88E-04	1.55E-02	8.56E+01	1.97E+01
10	4.18E-03	1.20E-02	6.92E+01	2.87E+00
15	5.51E-03	1.53E-02	8.97E+01	2.78E+00
20	6.03E-03	1.54E-02	9.13E+01	2.55E+00



Graph 4.1: Aerofoil Performance

The performance for the designed propeller shows the uniform thrust over the propeller surface also the pressure variation is minimum. From the stream lines a little vortex generation can be observed at the tip.

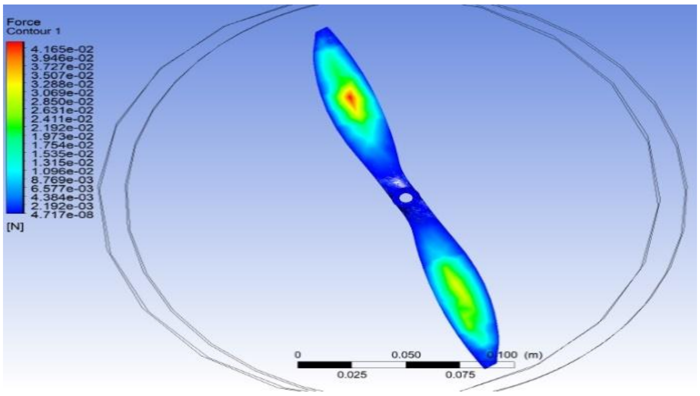


Fig4.1 Thrust on Propeller

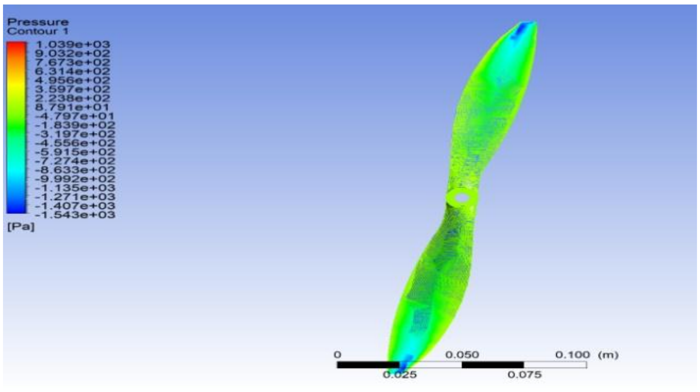


Fig 1 Dynamic Pressure

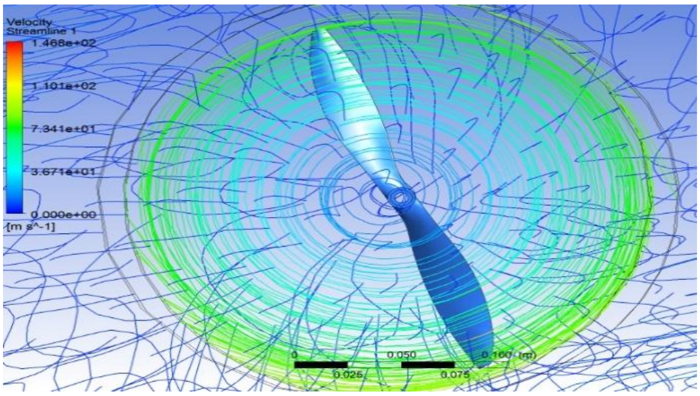


Fig 4.3 Streamline

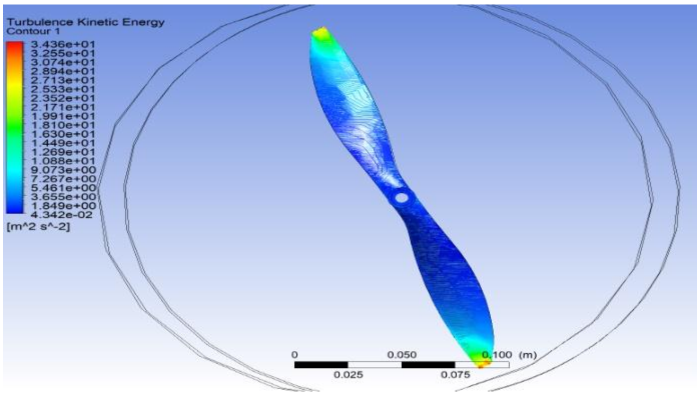


Fig 4.4 Turbulence Kinetic Energy

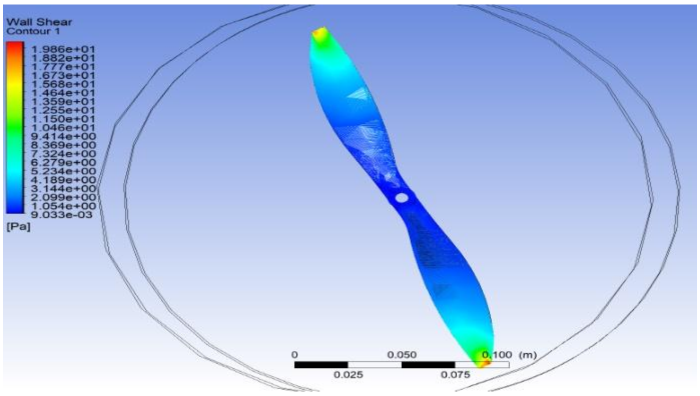


Fig 4.5 Wall Shear Stress

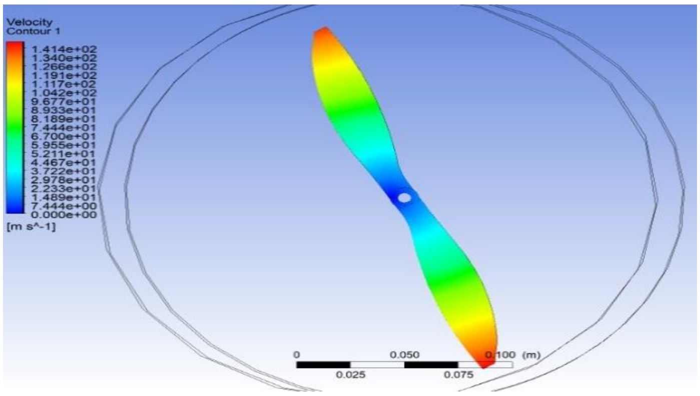


Fig 4.6 Velocity Contour

5. CONCLUSION:

The decline of Cl/Cd ratio can be observed after 10°. Since the section for analysis selected was at the 3/4th of diameter of propeller where the angle generally ranges from 2-10°. Hence the design is optimum. Using NACA4412 has increased the thrust for the propeller and also reduced the tip vortexes making the drone more stable.

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