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CFD Analysis of 9 Bladed Propeller for Co-Axial Rotor Assembly of Multi-purpose Drones

Prakhar Nandi Srivastava[1], Abhinav Srivastava[2], Love Kushwah[3] and Prateek Choudhary[4]

[1]Department of Aerospace Engineering, Amity University
[2,3,4]Amity University
E-mail: [1]srivastava.nandi@student.amity.edu, [2]abhinav.srivastava@student.amity.edu, [3]love.kushwah@student.amity.edu, [4]prateek.chaudhary@student.amity.edu

Abstract— *The 9 bladed propeller attached to the rear of the flying vehicles with a co-axial rotor assembly provides extra thrust to enhance the speed of the vehicle. The CFD analysis and further results and discussions using FLUENT provide the numerical computations for the improved velocity near wall effects of the propeller.*

Keywords*: Propeller; meshing; iterations; lift; drag; insert (key words)*

1. INTRODUCTION

This template, The recent advent of Quad-copters and other movement controlled Air-Flying-Bodies have opened a window of opportunity to serve the Civilian, Administrative and Defense purposes alike with necessary modifications incorporated in a single design.

This project utilizes the groundbreaking research and technological advancement to make a Co-axial rotor with an Improved Blade Design(Ref.1-3) so as to increase the Lift, Thrust and efficiency of the air screws alongside diminishing the sound of the blades cutting through the air by a BERP design rotor tip extension inspired by the fins of Blue Whale(Ref 4).

Coaxial rotors configuration in helicopter is one of the technological method for increasing helicopter lift to weight ratio. Since two rotors rotor opposite to each other producing the net thrust larger than the conventional design with single rotor configuration, the diameter of the Helicopter rotors can be decreased to carry the same amount of load with very good maneuvering capability of helicopter as compare to single rotor helicopter(Ref 5).

The most attractive feature of a coaxial rotor design is that the main reaction torque is zero resulting in no need of a tail rotor, which makes this design such a unique and compact. This is done by the converse torsional moments generated by the two rotors cancel each other due to counter rotating directions, so the tail rotor and tail boom can be removed.

Compared to the single rotor helicopter, the aerodynamics and flow property of coaxial rotor configuration is less studied and understood but the research being done. The very first methods to study coaxial rotor were the method of slipstream theory, then the free wake vortex model, predicted wake vortex model, momentum theory, and the blade-element momentum theory generally used to study helicopter rotor dynamics(Ref 6-8).

In our design a nine-blade propeller (fig.5) is attached at the tail boom of the drone thus pushing the drone at the phenomenal speed of 280 knots/hour. The parameters are calculated from numerical modeling and simulation.

2. NUMERICAL MODELLING

Unsteady, axisymmetric and three-dimensional simulations were performed using commercial CFD software FLUENT to obtain the flow field inside and around the propeller with different speeds and direction of flow. Simulations were made using coupled solver adopting standard k-Epsilon turbulence model for chosen for computing near wall effects with 2nd order implicit time stepping. Three dimensional simulations were also performed on propeller, to compare the results with established data. Solution convergence was established by monitoring residuals of density, velocities, turbulent kinetic energy and monitoring few pressures over the upper and lower part of the rotor. A cylindrical enclosure of (Ø=10 m) and length =30 m. The propeller was placed at the centre of the cylinder.

The meshing was done in ANSYS with orthogonal method, with max. size 1 min and min. size 0.1 m. The inflation was set to 1,mesh around the sharp corners and edges were set to Fine and the number of layers were set to 10 on the wall of the rotor.

The boundary conditions were-rotor(wall), enclosure(pressure far-field), Face 1(Pressure-inlet),Face 2(Pressure-Outlet) and cylindrical enclosure(wall).

Ideal gas and viscosity of Sutherland law was selected. The inlet velocity of 200 m/s was given to the pressure inlet. The computation to be done was selected on the propeller wall.

The swirl rotation velocity was given to be 1000 rpm with Z-being the rotation axis and clockwise rotation(Y axis to X axis)

A validation test was performed on rotor of Y-axis with velocity 100 m/s ,reported by XU Heyong, YE Zhengyin (Ref.1). The comparison of the reported results of mean static pressure along the propeller, and present computed results obtained through adopting various turbulence models is presented in (fig.7). A good agreement can be seen for results obtained through standard k-Epsilon turbulence model. Hence further computations were made keeping similar grids, and turbulence model for the present propeller geometry and

Cases (fig.6).

3. CALCULATIONS

3.1 Solution Set-up

The Gauss-Green Node method was selected.(684216 elements)

The solution controls were set to the 2nd time order in all the 3 parameters.

The Lift, Drag and Moment monitor plots were to be computed from the propeller wall with difference from the upper and lower edges of the blades.

Solution initialization was given to propeller wall with velocity 200 m/s along the z-axis, gauge pressure to 0 and initial/Supersonic pressure to 101325 N/m².

The Courant Number was set to 0.5. The mesh sizing and case data was checked. The numbers of iterations were set to 10000 with time step of 1.

3.2 Equations

The K epsilon model is one of the most general turbulence models used, even though it doesn't perform well in cases of large adverse pressure gradients. It is a 2 equation model, this means, it includes 2 extra transport equations to represent turbulent properties of the flow. This allows two equation model to account for history effects like convection and diffusion of turbulent energy.

The 1st transported variable is turbulent kinetic energy, k. The 2nd transported variable in this case is the turbulent dissipation, ϵ. It is a variable that determines the scale of the turbulence, whereas the 1st variable, k, determines the energy in the turbulence.

Transport equations for standard k-epsilon model

1. For turbulent kinetic energy k

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij}E_{ij} - \rho\epsilon$$

2. For dissipation ϵ

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij}E_{ij} - C_{2\epsilon}\rho\frac{\epsilon^2}{k}$$

In other words

Rate of change of k or ε + Transport of k or ε by convection = Transport of k or ε by diffusion + Rate of production of k or ε - Rate of destruction of k or ε

where

u_i represents velocity component in specified direction

E_{ij} represents component of rate of deformation

μ_t represents eddy viscosity

$$\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$$

The equations also consist of some adjustable constants σ_k, σ_ϵ, $C_{1\epsilon}$ and $C_{2\epsilon}$. The values of constants by numerous iterations of data fitting for a range of turbulent flows. These are as follows:

$$C_\mu = 0.09 \quad \sigma_k = 1.00 \quad \sigma_\epsilon = 1.30$$
$$C_{1\epsilon} = 1.44 \quad C_{2\epsilon} = 1.92$$

4. RESULTS AND DISCUSSION

Simulations were initially performed to obtain the basic flow field around propeller with front wall inclination angle of ∅=90°.

Convergence is obtained in 1335 iterations. The instantaneous Mach contours obtained for flow over propeller is presented in (fig 4).The segregation of internal and external flow through a shear layer extending from front wall tip to rear wall tip and the circulatory subsonic propeller flow can be observed. The corresponding mean static pressure distribution is also presented. There is a peak pressure observed near the wall tip of the propeller.

The comparison of expected and computed density on the bottom surface of the propeller with ∅=90deg is shown in (fig 2).The mass flow rate is also established (fig.7).

Unsteady pressure/density was measured at the middle of the hub assembly,(Fig 2)shows a typical Mach Number time history for propeller with output to be 286.7 m/s.

The presence of pressure fluctuation on the wall can be seen from the figure. The difference in Mach Number Fluctuation from the computed results is due to the location of pressure monitoring point on the propeller along the length of the blade. The variation of Static Temperature along the length of the rotor blade can be observed in (fig 1).

5. CONCLUSION

The results obtained from the numerical modeling and simulation of the propeller for the Co-Axial Rotor assembly denotes increase in Mach Number (fig.3) and thus the overall speed of the airborne vehicle. The result can be further improved with altered design and variable simulation technique, thereby enhancing the scope for the study.

6. ACKNOWLEDGMENT

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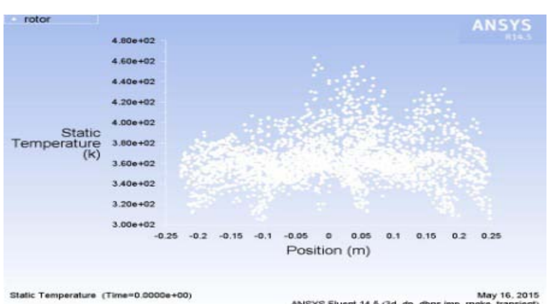
LIST OF FIGURES



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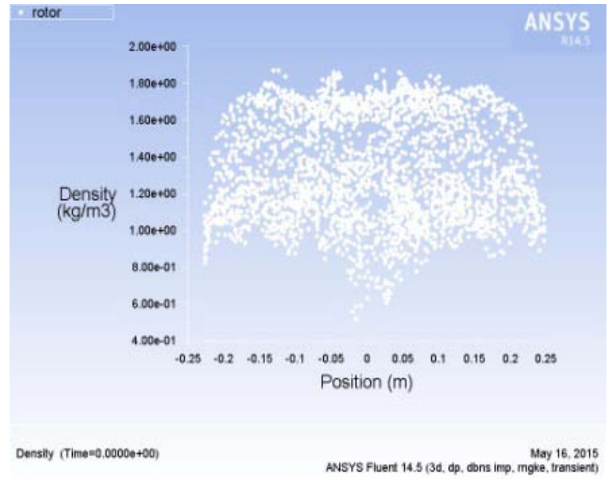

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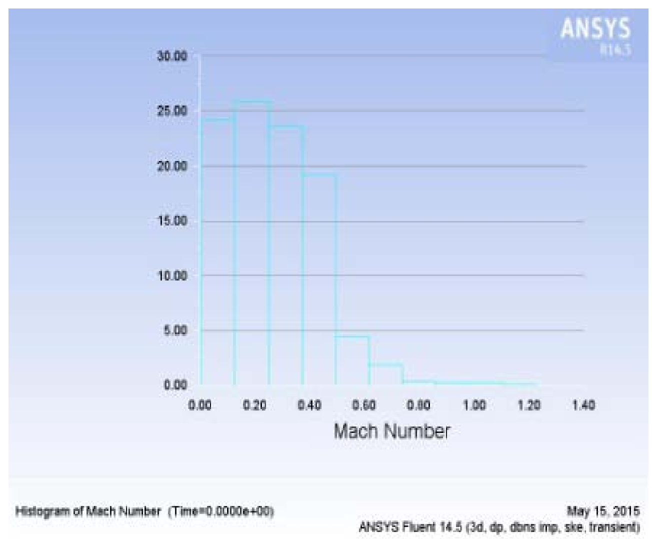

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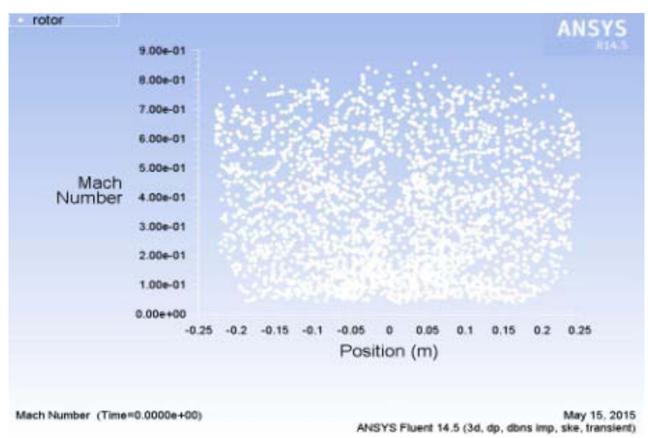

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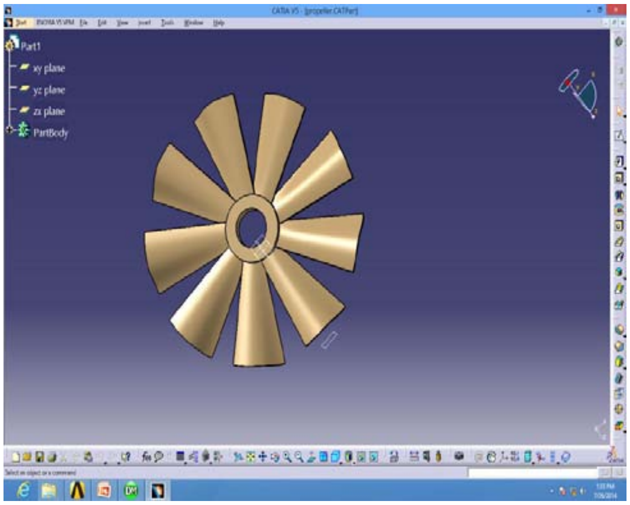
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yz plane
zx plane
PartBody

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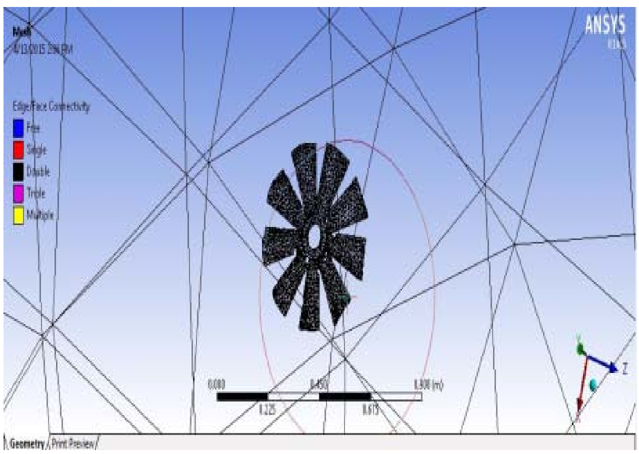
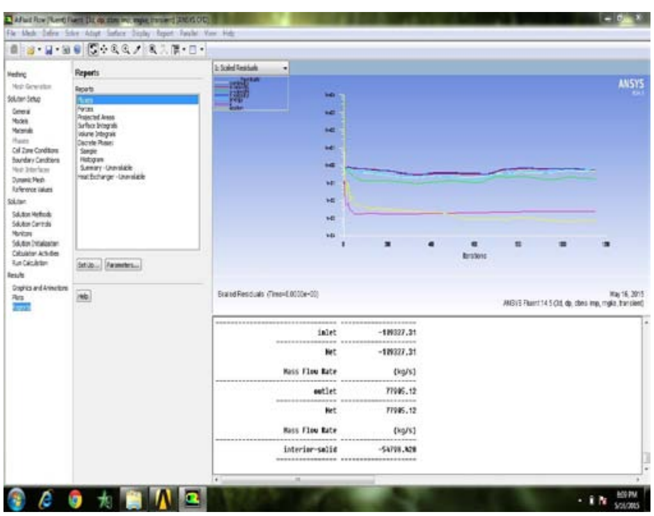

ANSYS
Mesh
Edge/Face Connectivity
Free
Single
Double
Triple
Multiple
0.000
0.450
0.900 (m)
0.225
0.675
Geometry
Print Preview

6.


ANSYS
Reports
Scaled Residuals
inlet
Net
Mass Flow Rate
(kg/s)
outlet
Net
Mass Flow Rate
(kg/s)
interior-solid

7.