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A Review on Design and Analysis of the propeller used in UAV

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Abstract : *UAV (unmanned aerial vehicle) known as the quadrotor, has more dynamic stability than the helicopters. It is an aerial vehicle which is a remote controlled and does not require the pilot. They are predominantly used in different areas like civilian purposes such as agriculture, logistics, military exercises, fire sensing etc. Propeller is an integrated propulsion device of UAV, generates thrust for vertical take off and landing of the vehicle. Finite element analysis and solid works have been used to estimate the dynamical properties of the propeller.. The concept of propeller having a variable speed is introduced and the techniques of propeller selection is discussed. The process of analysing drag lift and thrust force over propeller through computational fluid dynamics is very complex and intricate. Different CFD methods are used to simulate the full 3-D viscous and turbulent flow for various propeller geometry. This force is important in selecting the motor to be used in the UAV model. Effect of thrust force along with pressure, velocity, and coefficient of viscosity on the surface of propeller can be analysed by CFD and these parameter helps to optimize the geometry, material selection and practicality of using the propeller.*

Keywords: *Aerofoil Structure, Lift-Drag force, computational fluid dynamics, solid works*

INTRODUCTION

At the present time the development of small UAV is under the interest of many researchers and want to discover the application. There is currently a variety of projects and research topics rising in this field. Research has shown that the most versatile and mechanically easy to construct UAV which is a quadrotor helicopter.

Quadrotor aerial robot is an automatic system which is an unmanned VTOL (vertical take-off and landing) helicopter. Quadrotors can be controlled by varying the speed of the four rotors and there is no need of any mechanical linkages to vary the rotor blade pitch angles as compare to a conventional helicopter.

Propeller is a machine element which transmit power by converting its rotation into thrust force. It has a profile of aerofoil shape. This profile utilises Bernoulli's principle to leviate the aerial vehicle. As the fluid flows over the blade, a pressure difference in formed between the rear and front side of the blade. This causes a net force to develop in the direction opposite to the gravity.

The function of the propeller is to change the mechanical energy from the motor (in the electric propulsion system, the chemical energy stored inside the battery) into thrust. Therefore the propeller directly effects the aircraft's performance and drives the design of the propulsion system. Ideally the propeller will be designed such that the required thrust is always produced while being driven by the motor and battery when both are operating at their peak efficiencies, due to the nature of fixed-pitch propellers this is not always possible.

Principle of design of aerofoil:

1.1 Classical Momentum Theory:

Propellers have been used since the earliest attempts at flight to drive powered aircraft. Their operation can be explained by the classical momentum theory

Classical momentum theory assumes that thrust is produced due to a difference in the static pressure across an infinitely thin actuator disc. It is further assumed that

- The velocity and pressure over the disc are constant and uniform;
- The air flows straight through the disc without rotation;
- The flow through the propeller is constrained to a well-defined stream tube;
- The flow is incompressible

1.2 Blade element momentumTheory:

The BEMT was first introduced by Gustafson and Gessow in 1946 and it is a hybrid theory for hovering rotors that combines the basic principles from the Momentum Theory and from the Blade Element Theory (BET), in an attempt to estimate the inflow distribution along the blade.

In this theory the following assumptions are made,

1) Blade assume as actuator disc.

2) Conservation of mass, momentum and energy is applied.

3) Conservation laws are applied to a annulus.

The coefficient of lift force and coefficient of drag force generated over the surface of the propeller blades are calculated and utilised to calculate thrust to power ratio.

A quadrotor is an aircraft heavier than air, capable of vertical take-off and landing (VTOL), which is propelled by four rotors, positioned in the same plane ,parallel to the ground. In contrast with helicopters, a quadrotor make use of fixed-pitch blades in its rotors and its motion through the air is achieved by varying the relative speed of each propeller as is shown in fig 1. In a quadrotor, rotors positioned at opposite ends rotates in the same direction, rotors one and three rotates in clockwise direction whereas rotors two and four rotates in a anti-clockwise direction. This kind of motions in the quadrotor is necessary so that the torque produced by each couple is cancelled by the other, making the control of a quadrotor symmetric.

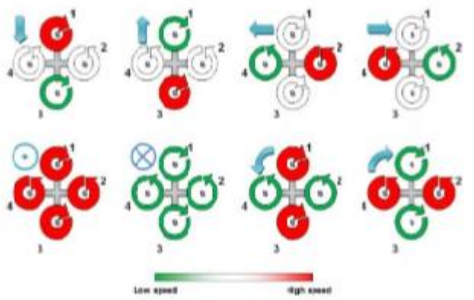

Fig 1: Possible motion of regular quadrotor

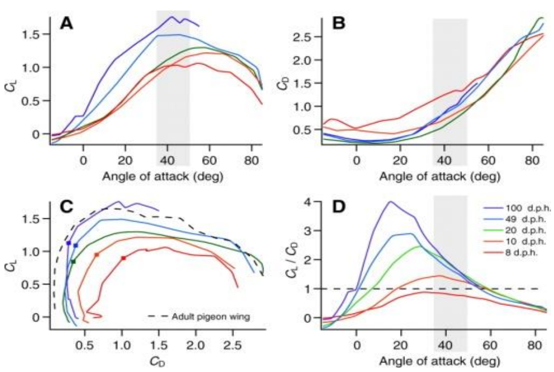

Fig 2: Relationship between coefficient of drag, coefficient of lift with angle of attack

LITERATURE REVIEW:

Pradeep Shetty et al. (2016) [1] This paper predict and correlate the mass flow rate of propeller type axial fan used in condenser unit using Computational Fluid Dynamics (CFD) technique. Computation is done for the axial fan speed of 820 rpm for the steady state condition using moving reference frame approach. The flow rate is correlated with the test results to validate the CFD modelling approach. The correlation level found closer with tested results, hence which will help to improve the futuristic model during conceptual design itself.

Brian Rutkay et al. (2016) [2] The aim of this research was to develop a process for the designing and manufacturing of propellers for small UAV. This aim was achieved by creating a computer program to design a propeller that meets user-defined aircraft performance requirements within the limitations of the electric motor capacity, user-selected materials, and manufacturing techniques. The feasibility of 3D printing technique in making flight worthy propellers was checked through material testing, manufacturing trials, and by testing the propellers in a wind tunnel. The results shows that the propeller performance generated approximates the predicted design thrust but the efficiency and power consumption could not be accurately measured.

Karna S. Patel et al. (2014) [3] In this paper the lift and the drag forces are obtained using CFD which are also experimently obtained using wind tunnel testing. The wind tunnel experiment is a laborious one and also costs more than CFD technique for the same problem. Thus first the data was obtained through analytical method then it cross checked by experimental testing. The analysis of the two dimensional subsonic flow over a NACA 0012 airfoil at various angles of attack and operating at a Reynolds number of 3×E06 is presented. The CFD simulation results show close agreement with those of the experiments, thus suggesting a reliable alternative to experimental method in determining drag and lift.

Mark W. Mueller et al. (2014) [4] Here the analysis of quadrotor is done under a condition that each propeller gets out of service respectively. This paper has sequentially tried to establish the modalities/capabilities of the quadrotor in terms of its height, position, time of flight etc with limited no of propeller in operation, where one, two and three propellers get down and out. . The stability is analysed using the deviation or the tilt in the primary axis with respect to the stable position control axis, along with the changes in altitude are used to design the quadrocopter with proper validiation from experimental data.

S. M. Mahbobur Rahman et al. (2014) [5] In this paper study of fluid flow characteristics for the flow over a propeller used in vertical takeoff and landing (VTOL) radio controlled (RC) aircrafts. Simulation investigation has been conducted through SolidWorks flow simulation using a propeller model. Design can be modified.

Shlok Agarwal et al. (2014) [6] In this paper structural design and manufacturing of twinrotor AVs has been detailed down. Individual component parts have been thoroughly describe and studied which would help in development of trirotor type unmanned aerial vehicle. Here the cost and dimension constraints are the main design feature that would would provide for practical applications. Thrust vector is directly explained and illustrated . On the basis of rolling pitching and yawing a stable rotor design and propeller orientation has been proposed for the trirotor system.

Kalpesh N. Shah et al. (2014) [7] In this paper payload capacity of UAVs is the area of research. Additional payloads on the accounts of design improvement leads to more functionality in a UAV. In order to do such, different basic design structures of UAVs were compared to developed enhanced payload capacities and choose a quadrotor. On rough estimate a quadrotor has a pay load capacity around 4 kg which gives it additional features for military and other applications. Calculation of aerodynamic drag-lift forces has been done. The stresses generated in the body of quadrotor is not more than 22.5 MPa in "Box" sectional chassis and 22.2 MPa in "C" Sectional chassis as per the practical testing. To validate these results, the stress analysis of two types of body of quadrotor ("Box" and "C" section) is carried out in ANSYS static structural solver. As per the Static Structural solver the stress generated are 15.4 MPa and 16.97 MPa in "Box" and "C" sectional chassis respectively.

S. Subhas et al. (2012) [8] The paper predominantly focuses on CFD analysis of the propeller, forsay ship propeller is used here for CFD. Cavitation and fluid dynamics solution are the parameter are the under consideration. Fluent solution have been implemented here such that the local pressure reduces below surrounding pressure in order to simulate cavitation result. The CFD result are used to establish the design criteria only after experimental validation of the result. The optimization of vibration in flow domain and burrs is done using the above analysis. Varriant boundary conditions, fluid computational domain and grid refinement is considered for improvement in mesh generation methods.

John B. Brandt et al. (2011) [9] In this paper a full scale research on propeller has been done which has earlier been done for aircraft but with growing needs of UAVs, it has highly become imperative to perform such analysis on it too. UAVs use propeller that operate under conditions of low Reynolds number ranging from 5000 to 100000 based on the propeller chord at 75% propeller blade station. Experiments were done at university of Illinios to evaluate the efficiency of propeller under these conditions. 9 to 11 inches was the diameter range for set of 79 propellers under the test. In test conditions at constant rpm. of propeller varied velocities of wind tunnel were used to sweep over a vast range of advanced ratios until a zero thrust condition was reached i.e. windmill state. To study the effect of variable low Reynolds number over the propeller , a range of 1500 to 7500 rpm of propeller revolution, depending upon the nature of propeller was the velocity set used. The results of efficiency varied from 0.68 for best condition to 0.28 under worst possible scenario, implicated that propeller design has a huge impact over the aircraft and UAVs operations.

W.Shawn Westmoreland et al. (2008) [10] In this paper propeller modelling using CFD is done to simulate fluid flow condition over it. Research with the support NLOS-T (Non Line Of Sight Transportation) is published here. The NLOS-T is a conceptual vehicle that will be canister launched, deploy wings and control surface, and then fly to a destination within approximately 15-20 minute of the launch point. The scientific investigation was undertaken over the propeller i.e. spinning geometry of UAV, excluding the rest of air frame structure. The result of CFD over the rotorcraft propeller structure is validated with the help of experimental data.

K.C. Wong et al. (2006) [11] This paper includes the instrumentation of off-the-shelf Remote-Controlled flight platforms, the design development and operation of flight research platforms, innovative airframe concepts, of Micro Air Vehicles (MAVs), and exploring commercial applications for UAV.

Bruno Herisse et al. (2008) [12] In this paper a controller of nonlinear nature to control flight and touchdown operations of a vertical take-off and landing unmanned aerial vehicle is presented. The VTOL is a rigid body equipped with only a camera and IMU circuit which moves over textured flat plane. Stability of hovering flight and automatic landing of the unmanned aerial vehicle using optical flow feedback system is achieved. Results shows that the proposed control strategy is a successful one.

Abdellah Mokhtari et al. (2006) [13] In this paper, a nonlinear quadrotor unmanned aerial vehicle is combined with a feedback linearised controller. The most unfavorable case of control is analysed by introducing Actuator saturation and by constrain on state output. Parameter uncertainities and external disturbances causes performance issues of a controller which is shown through a simulation study. The results shows that the system becomes robust depending upon the selection of weighted functions.

Peter G. Ifju et al. (2002) [14] This research shows the effects of windy environment and unsteady aerodynamics over the micro air vehicle. The introduction of flexible wing on this vehicle improves its flight stability and durability and its performance in adverse weather conditions. The flexible wing has a operating range wingspan of 18 inches to 5 inches. In addition with the concept of flexible wing, aerodynamic assessment, and flight data analysis, fabrication method are also shown in this research.

T. A. Maitre et al. (1991) [15] Circulation around **lifting** body is modelled through a non linear function in this paper. The circulation potential is well defined inside the body and evaluation is made for the flow over the body. This method is well suited for the flow analysis over the propeller of UAVs which are consider to be extremely thin. This method is applied over non cavitating fluid flow condition in a marine propeller. Here the researcher deeply tried to solve the problem pertaining to Joukowski condition, problem of propeller mesh, wake region analysis and the influence of wake region over the hub is numerically analysed.

Jonathon Bell et al. () [16] This project has undertaken the task of designing and constructing a test rig for the purpose of experimental analysis of SUAVs coaxial rotor system. The focus is led on the importance to highlight aero mechanical components and variable that dictate the co-axial flight performance with the aim of optimizing the propulsion system to be used for HALO coaxial SUAVs manufactured by Middlesex university. The chief contribution of the paper is to design and optimize the co-axial configuration with respect to motor and propeller variation. Inter rotor spacing has been detailed out with the help of H/D ratio that is in between 0,41 to 0.65.

Pierre Jean Bristeaue et al. (2009) [17] Here different models of quadrotor UAV have been studied. Aerodynamic effects of the propellers and their interaction with rigid body motion of the UAV has been modelled. The main assumptions are the twisting of the propellers in such a way that the local angle of attack is constant along the blades in stationary flight and, secondly the local induced velocity is invariable along the blade, these conditions are used to optimize the hovering rotor and hence conclude that the dynamics of the UAV is prominently dependent on the flexibility propeller design (location of centre of gravity) thereby playing important role in designing close loop controller**.**

S. Norouzi Ghazbi et al. (2016) [18]This paper reviews and gives an overview of various works done on quadrotor with dynamic modelling and control features.

A.V. Javir et al. (2015) [19] This paper focuses on the aerodynamic effects of quadcopter. It addresses all the aspects of quadcopter ranging from mechanical design to electronics used. It provides backup to the selection of different components with the help of various formulas from research papers. It also gives clear results with respect to weight of components and their corresponding costs. Along with this, finite element analysis is done on the frame so as to sustain the loads generated in the vehicle and concluded that small deformation occurred on the center plates are safe and within the limit.

CONCLUSION

In this paper we have tried to cover the recent research in the field of propeller specially design for usage in quadrotor with payload capacities of 4kg and above. This review paper has tried to chronologically illustrate the development of propeller advancement in the field of quadrotor. Here optimum design and stability features has been reviewed by researchers is compiled together. This review revealed that the performance of a propeller degrades at low RPM values when the significant value of Reynolds number is used. Numerical Simulation using CFD methods proves to be the most effective method to stimulate full three-dimensional viscous and turbulent flow for various propeller geometries.

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