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Design and Numerical Analysis of Five Blade Propeller for a Drone

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Abstract. It is a major problem in UAVs to have a better stability in gusty winds and obtaining uniform thrust depend on the various directional and Aerobatic operations. Hence, we have fabricated an X4 model Drone with the existing propeller blade profiles of standard size. Its performance was measured and stability criteria specified by varying the pitch shows that the span parameters of the propeller and the stability can be improved. We designed a propeller and mounted in the fabricated Drone for the real time measurements of the stability.The stability of the Drone was increased by varying the propeller design. The analysis of the propeller blade was performed in Open FOAM platform with the maximum of 10000rpm.

Keywords: Five blade Propeller, X4 model Drone, open FOAM.

NOMENCLATURE

D	=	Propeller diameter
IPTS	=	Integrated propulsion test system
μ	=	Free stream velocity
J	=	Advance Ratio
N	=	Rotationsper second
ηP	=	Efficiency of the Propeller
Ω	=	Radians per second
q	=	Dynamic pressure at Tunnel
Q	=	Torque
ρ	=	Density of air
$R_{0.75}$	=	Radius at ¾ length
Re	=	Reynolds number
R/C	=	Radio control
T	=	Thrust
U'	=	Free stream velocity (air)
Vt	=	Velocity (total)
α	=	Angle of attack
Cp	=	Power coefficient
CT	=	Thrust coefficient
CQ	=	Torque coefficient

INTRODUCTION

According to the economical cost and growth of technology, there are use unmanned aerial vehicles (drones) for civilian purposes has increased during this decade. It has lot of applications for military and commercial purposes. Hence it is in big demand to increase the performance of such UAV systems for the betterment of the applicants. Obviously, the propulsion system plays a major role in the design of UAVs. Hence, it is noted that the increasing interests related to UAV, MAV, and R/C airplanes to use of small size propellers so that it would create the good performance data.[13].

In the smaller UAV's there are not used larger size propellers, although the large size propellers are available. There are operate at low Reynolds numbers, (between 25,000 to 250,000)for smaller in size diameter UAV model aircraft propeller. Designers have generally confided on recommendations from vendors and layman while selecting propellers for their UAVs. In such that limitation ,aUAV and R/C flyers are ableto built coherent performance and improvements. Based on the propulsion systems engine manufacturer preferred propeller pitch and diameter with the help of designer. Again a question, there is no test data is available to the user.The Open FOAM tools with Linux (UBUNTU) platform is used to calculate the propeller performance using theoretical and analytical methods. By using complex systems and propellers with diameters greater than 600 mm testing in wind tunnel are mostly concentrated. In this research, the investigator's are accepted that considering Reynolds numbers regimes.

A five blade Propeller has been analyzed, designed developed and tested at the Sri Ramakrishna Engineering College. Our obtained results were presented and discussed in thispaper.

Factors affecting Propeller Efficiency

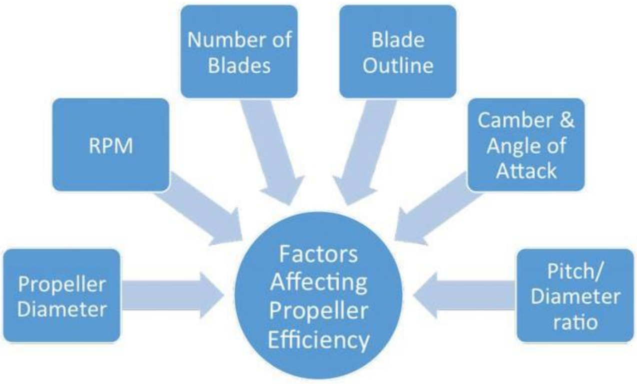

Figure 1: Factors affecting Propeller Efficiency

The factors which has major influence on the blade performance are

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1. Number of blades and
2. Its dimensions.

The efficiency of the **number of bladesare** more effective. As it distributes its power and thrust more evenly in its wake, there are slightly better to perform propeller with more bladder. Thenarrow blades with reduced chord length, while for given power or thrust. so practical limits have to be considered here.When decreasing the diameter of the propeller, the chord length can be increased, to keep the power consumption constant. But reduction of the propeller's diameter is usually a bad idea in terms of efficiency, as long as the tip Mach number or tip cavitation is not an issue.

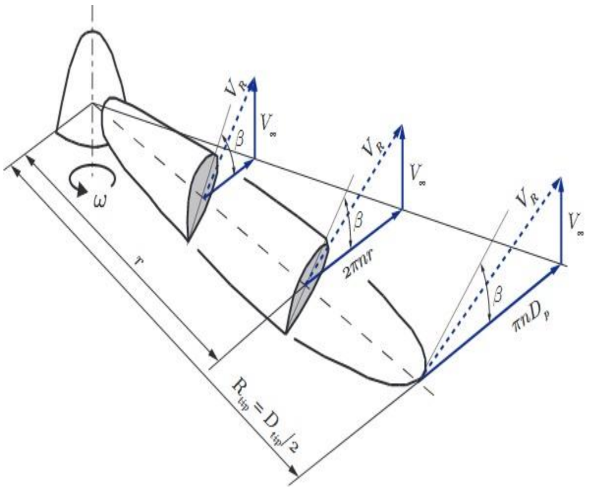

Figure 2: Radial cut section of a Propeller

The Diameter has a vast consequenceon Drone'sperformance. If it catches more incoming fluid and distributes its power and thrust on a larger fluid volumethen, the larger propellerhaving higher efficiency. The lifting surfaces, which results in sailplanes which is having large span but slender wings.[4]similarly the outcome can be shown.

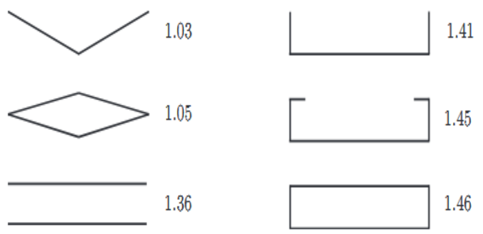

Figure 3: Span efficiency for non-planar wing configuration

From figure 3 it can be noted that, boxing the blade profile reduces the induced drag and improved thrust. Hence apart from aerodynamics few other things related to shape also have the impact on the blade performance parameters

EXPERIMENTAL APPARATUS

The 2 ft x 2 ft Subsonic Wind Tunnel at Sri Ramakrishna Engineering College is an open return type capable of reachingdynamic pressure of up to 32 PSI for 1.12 x 106 Reynolds number per foot. Figure 5showsthe block diagram of wind tunnel. It is consists of a pitot- static probe and a high precision, used for measuring test-section dynamic pressure and calculating J. The transducer along with the propeller balance and RPM sensor are processed through a series of signal conditioners, amplifiers and isolator modules, which are located outside the tunnel's test section and the given output is Signal. The magnetic pickup is powered by an independent 12-volt DC power supply. The power to the motor is supplied by a high amperage/voltage precision control DC power supply.[1]

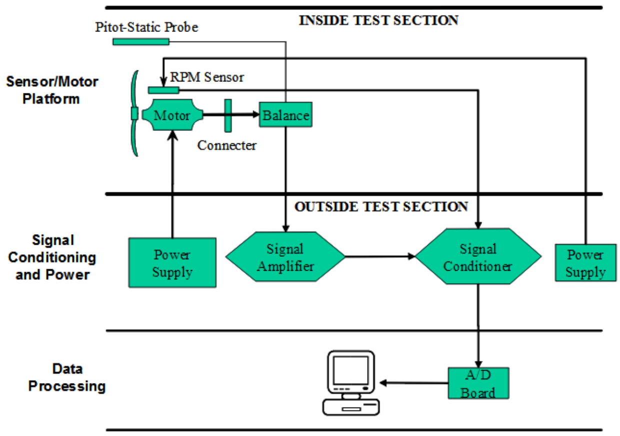

Figure 4. Outline of testing system.

The blade to be tested is placed in the test section area, the speed of the blade is measured by RPM sensor, the corresponding exit velocity of air was received and amplified, then the signals are filtered, then the results are notified in digital display as shown in figure 4.

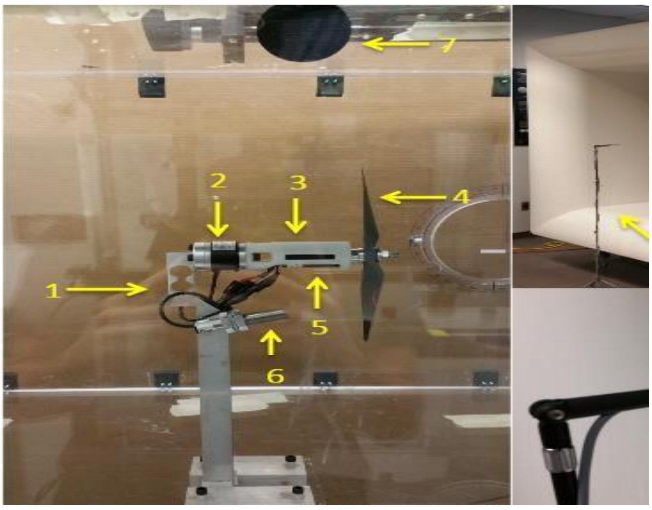

Figure 5: Propeller test stand and 2'x 2' Low Speed Wind Tunnel.

Propeller Design

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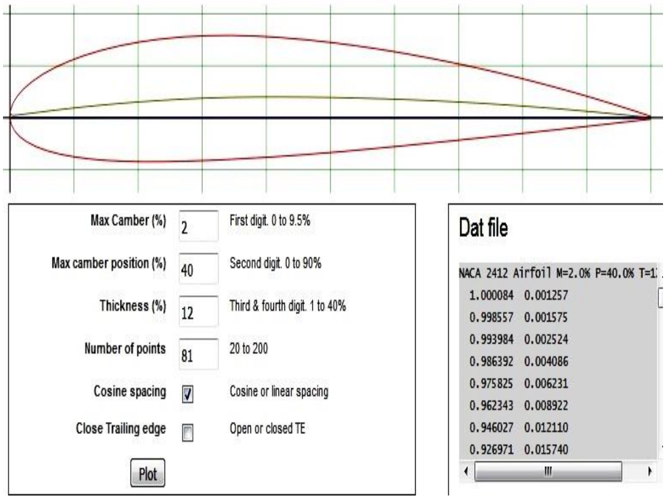

Figure 6: Propeller blade design Generator Software

A software window in Figure 6 shows the parameters of a blade based on the coordinates vice versa. Hence from the designedparameters, the propeller geometry and its coordinates were obtained for modeling.

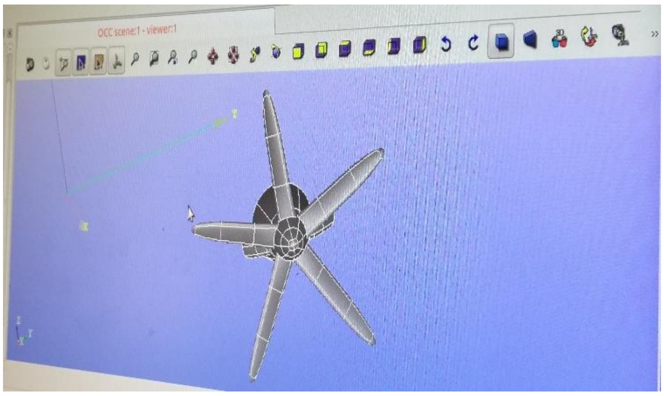

Figure 7. Five blade Propeller modeled and analyzed in Open FOAM.

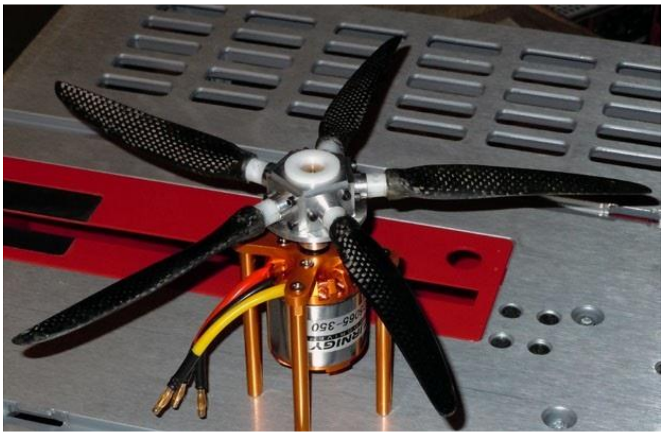

Figure 8. Five blade Propeller fabricated and mounted in the test bench for performance measurement.

In this part briefly summarised described that the detailed process of the conducted experiment of propeller design. The experiment uses a X4 model quad copter to achieve the required amount oftake-off thrust and lift coefficient. Table 1 describes the propeller data obtained by preliminary UAV propulsion system design. Themain driver to obtain STOL capabilities, as defined in,are the take-off thrust and the high-lift performance. For the multi blade configuration the enormous amount of lift during take-off isobtained[3].

The calculations are made by substituting the reference values in computer program, which is based on formulas presented below and compared in Adkins vs Larrabee. It is based on the theory of optimum propeller.

$$C_r = T\rho^{-1}n^{-2}D^{-4}$$
$$C_p = PP\rho^{-1}n^{-3}D^{-5}$$
$$Pp = \Omega.\ Q$$
$$CQ = Q\ \rho^{-1}n^{-2}D^{-5}$$
$$H = J\ .C_\tau^{-1}C_\gamma^{-1}$$
$$J = Un^{-1}D^{-1}$$
$$Re_{0.75} = \rho V_t C_{0.75}\mu$$
$$V_t = (U')^2 + (\Omega.\ R_{0.75})$$

The flow over the single blade was calculated and the corresponding values of flow are measured using the iterative methods and given formulae. The calculation was done by using the online propeller performance calculator

J	n	$v\infty$
Units	1/min	m/s
35*10^{-2}	6000	27
40*10^{-2}	6500	31
45*10^{-2}	6000	31
55*10^{-2}	6400	45
60*10^{-2}	6000	44
65*10^{-2}	7000	52
70*10^{-2}	6500	53
75*10^{-2}	6100	52
80*10^{-2}	5700	52
85*10^{-2}	5300	54
90*10^{-2}	5000	53
95*10^{-2}	5500	61
1	5300	67

Table 1. Investigated advance ratios, corresponding rotational frequencies and freestream velocities

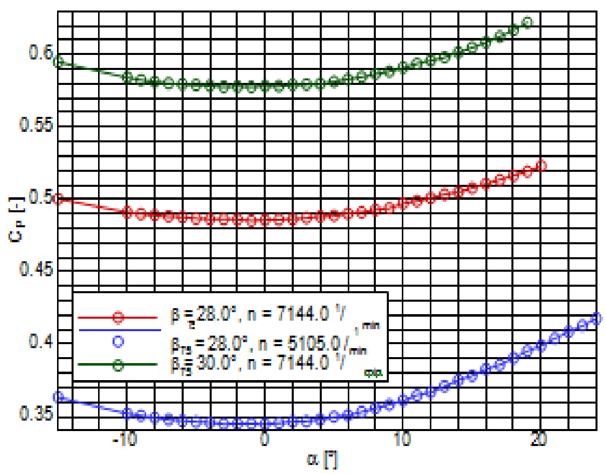

Figure: 9 CoefficientofpowerandangleofAttackat free stream velocity*v∞=45m/sec.*

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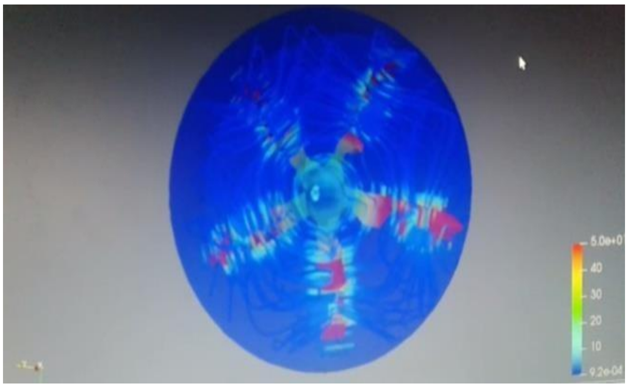

Figure:10 Velocity distribution for free stream velocity *v∞=45m/sec.*

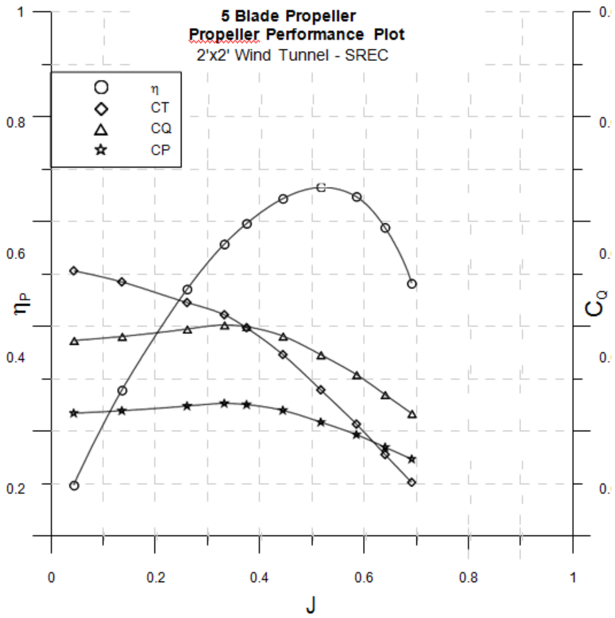

Figure 11: Performance Plat for five blade propellers

Experimental Procedure

The Sensors of the measuring systems are calibrated as per its standard conditions and the supporting stands are mounted inside the wind tunnel. The propeller is mounted in the test stand fixed in the test section. The pitot static tube is to extended to measure the pressure velocity values at tailing portion of blades.[3]Velocity of the incoming free stream air is varied from 70 to 120 m/s and the corresponding values are measure and substituted in the formulae and the resultswerefound and tabulated. The corresponding graph shown in Figure 11 showcases the performance of the designed propeller.Similarly, the propeller blade designed for the new coordinates are fed into the Open FOAM for the CFD analysis and the corresponding results were found as shown in the figure 10.

RESULTS AND DISCUSSION

Performance details for a five-blade propeller, has the pitch varied as per the objectives, wereobtained. Thus, all the data cannot be given in this article, only a few important results aregiven for illustration.

From above figure 9 when the angle of attack increases the power increases at high angle of attacks, from the figure 2the velocity distribution is uniform and no shocks on the blade surfaces and better air flow at the hub sections also because of uniform separation at multi levels as the number of blade increases.

From the figure 11 the performance factors increaseup to J= 0.6.

CONCLUSIONS

The newly designed Propeller blade with Five blade propulsion system has better efficiency and uniform thrust factors.The Drone with five-blade propeller operates quieter and generates lower amplitude vibrations. Hence there is an improvement in stability of the drone. As the number of blade increases, the diameter required for producing same level of thrust reduces.

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