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Interaction of Two Micro-Propellers in Coplanar and Coaxial Arrangement for UAV Application

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Abstract: ***In the present work, we have focused on the understanding of the effect of gap between micro propellers in coplanar and in coaxial arrangements on the thrust generation experimentally. In a way it's a preliminary optimization of the spacing and placement of the micro propellers in a multirotor UAV system. APC 12-inch diameter (D) (12X8 E) and Master air screw (MAS) 11-inch diameter (11X6) propellers each 2 in numbers were considered in the study. A static testing rig was built with a provision to mount the propellers in coplanar and in coaxial arrangements. A thrust was measured using a single component load cell. Parameters like current consumption by BLDC motors and propeller RPM were also monitored. For coplanar arrangement, there is no influence of gap (G) between the propellers on the coefficient of thrust (C_T). However, for G/D<0.2 random variation in C_T is observed. Similarly, for propellers in coaxial arrangement, for smaller gap between the propellers along the axis is found to generate higher thrust. This optimization of the gap between the propellers may be lead to a compact multi-rotor UAV system having higher payload carrying capacity or higher endurance.***

Index Terms: ***aerodynamic performance, coaxial, coplanar, coefficient of thrust, gap to diameter ratio (G/D), multi-rotor UAVs***

I. INTRODUCTION

UAVs are gaining prominence in agriculture application like spraying pesticides, crop health monitoring through multispectral cameras etc. Due to vertical take-off and landing capability, these vehicles are also becoming popular in delivering the parcels to the customers. In multirotor UAVs, position of the rotors with respect to each other is important as the overall lifting capacity of the UAV (cumulative thrust generation) depends on it. Also, optimal gap between adjacent rotors gives additional benefit to UAV in terms of compact size of the airframe. Another way to optimize the performance of the multirotor UAVs is to have coaxial propellers. For example, in Octa copter, if the 4 pairs of micro propellers mounted in coaxial manner then the footprint of the UAV would be same as the quad copter.

Aleksandrov and Penkov investigated the effect of gap between the propellers in quad-rotor UAV. Their CFD and experimental results show that there is a 15 % increase in thrust generation when the rotors were placed 0.3D apart, where D being the diameter of the rotor. For smaller gap (<0.3D) they observed reduction in the thrust [1]. Wenwu Zhou however noted that there is no change in the thrust coefficient with respect to the gap between the propellers tip.

They further pointed out that if the gap is below 1D, there are fluctuations in the thrust generation [2]. and Effect of coaxial propellers on the aerodynamic performance was investigated by number of researchers. Ostuka and Nagatani observed the distance between the coaxial rotors have no effect either on increasing or decreasing the thrust generation [3]. Aleksandrov and Penkov showed that with increase in the distance between coaxial rotors, there is decrease in the thrust generation [4]. In the present study, we have experimentally investigated both the effect of rotor-to-rotor interaction on their aerodynamic performance. Both coplanar as well coaxial arrangement of the propellers is investigated based on thrust and power measurements.

II. METHODOLOGY

Fig 1a and 2a show schematic of micro propellers in coplanar and coaxial arrangement respectively. The effect of interaction of micro propellers is characterized by the thrust measurement. A single component load cell (MDB make, series 10, 4.5 kg capacity) was used for the thrust measurement. For coplanar arrangement of the micro propellers, thrust for only one of the micro propellers was measured and total thrust generation was then deduced by multiplying by 2. APC make, 12-inch diameter (D) (12X8E) and MAS make, 11-inch diameter (D) (11X6), each of them 2 in numbers were considered for the study. A gap between micro propeller tips was varied by mounting one of the propellers on the slider for the coplanar arrangement (Refer Fig. 1b). In coaxial arrangement, the gap was varied by adjusting the screw and nut arrangement as shown in Fig. 2b. Two BLDC AXI 2820/14, 860 kv motors were used to drive the propellers. Agilent make DC power supply was used and voltage of 12 V was set across the motors. Another Agilent make DC power supply was used to give 11.8V excitation voltage to the load cell. The load cell was calibrated by recording output voltage against the standard weights. The load cell error was found to be less than 2 % on maximum output voltage. Electronic Speed Controller (ESC) and KV/RPM Meter sensor were used to control speed and measure micro propeller RPM respectively. For all the measurements, micro propeller RPM was varied from 4000 to 6000. Data was acquired using PC based data acquisition system.

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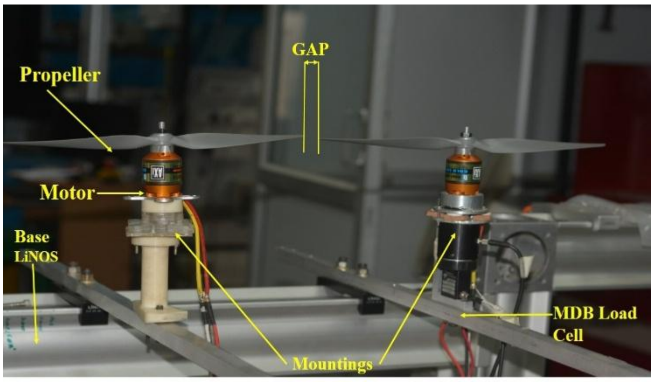
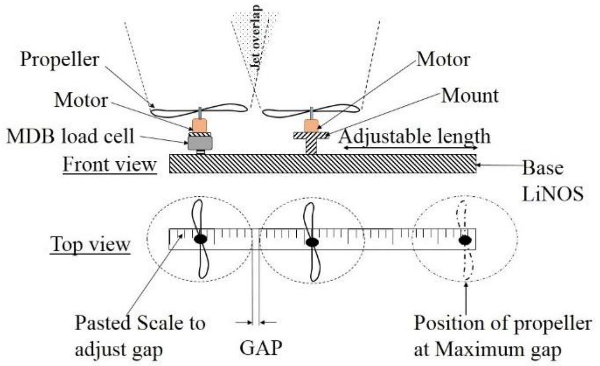
National Instrument USB 6002 card was used along with the LabVIEW program. 1000 data samples were acquired at a sampling rate of 200 Hz. Mean thrust (T) was obtained by averaging 1000 samples acquired for every propeller RPM (n).
Coefficient of thrust (C_T) was obtained using expression 1.



1b

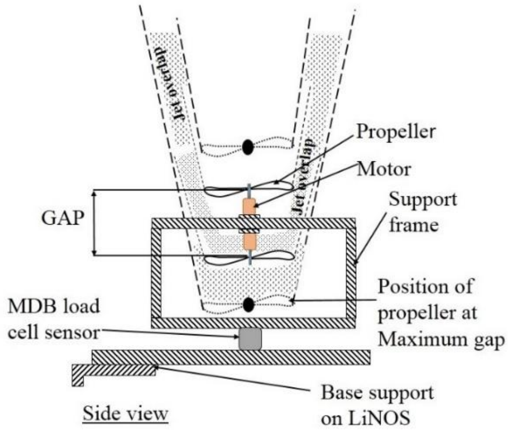
$$C_T = \frac{T}{\rho n^2 D^4} \qquad (1)$$

In coplanar arrangement, for each gap (G) between micro propeller tips normalized by the micro propeller diameter (D), the thrust was measured for the range of RPMs. For coplanar arrangement, for each gap (G) normalized by the micro propeller diameter (D) between micro propeller tips, the thrust was measured for the range of RPMs. 3 sets of measurement were taken for every micro propeller configuration and finally averaged thrust was considered.

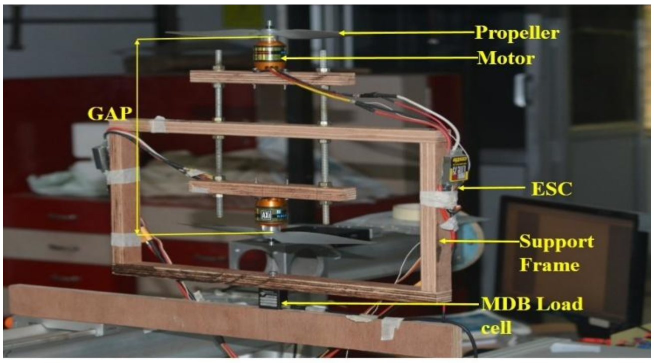


1a

Figure 1: Propellers Mounted In Coplanar Arrangement (A) Schematic Of The Setup (B) Actual Photograph Of The Setup



2a



2b

Figure 2: Propellers mounted in coaxial arrangement (a) Schematic of the setup (b) actual Photograph of the setup

III. RESULTS AND DISCUSSION

A. *Characterization of an independent propeller*

Fig 3 shows variation of coefficient of thrust as a function of micro propeller RPM for both APC 12X8E and MAS 11X6 propeller. C_T found remain nominally constant for the range of propeller RPM.

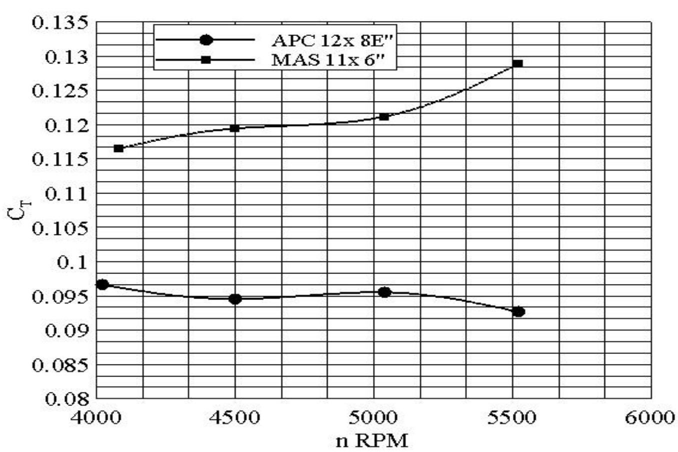


Figure 3: Variation in C_T as function of RPM

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B. *Coplanar arrangement:*

Effect of non-dimensionalised gap between the micro propeller tips on C_T for various propeller RPMs for APC and MAS micro propeller pair have been depicted in Figures 4 and 5. Being a propeller pair, we have multiplied the C_T by 2 as it was obtained from the thrust measured for one of the propellers in the coplanar arrangement. It can be seen that there is a random variation in C_T for G/D up to 0.2. For G/D > 0.2, C_T is found to be remained constant which suggests that the beyond 0.2D, the gap between propellers has no influence on the thrust generation and cumulative C_T is just the sum of C_T of 2 independent propellers. Since the fluctuations in the thrust are more for G/D<0.2 it is recommended that the gap between propellers tip should not be less than 0.2D from the stability of multirotor UAV point of view.

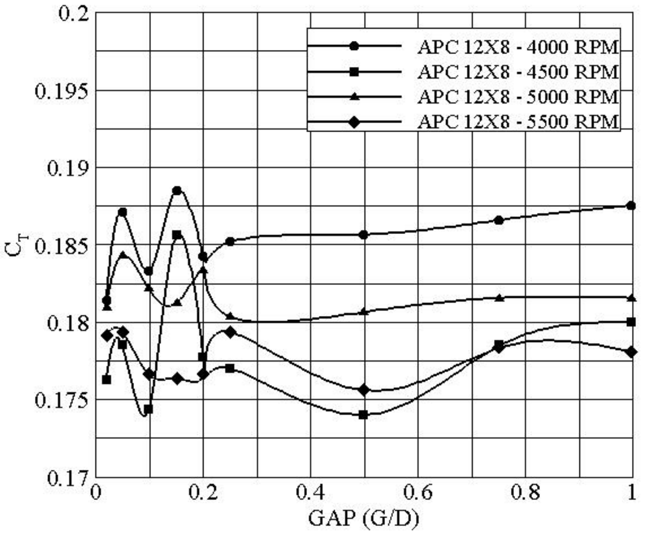

Figure 4: Variation In C_t As Function Of G/D Ratio For Various Propeller Rpms For Apc 12x8e Propellers

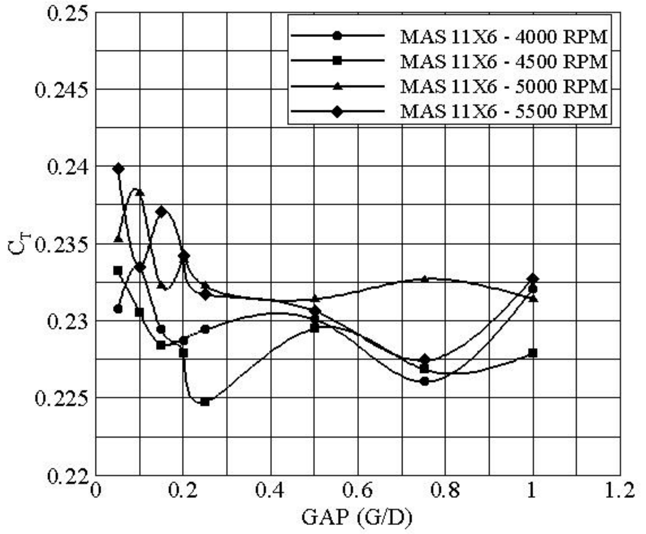

Figure 5: Variation In C_T As Function Of G/D Ratio For Various Propeller Rpms For MAS 11X6 Propellers

C. *Coaxial arrangement:*

Fig 6 and 7 show C_T variation as function of gap between propellers mounted in coaxial arrangement. It can be seen that the marginal increase in C_T by 3 to 4 % is observed when the gap between the micro propellers along the axis is reduced from 1D to 0.5D for both the micro propeller configurations. It appears that even in coaxial arrangement, there is not much influence of the gap between the propellers on thrust generation. However, in UAVs having multirotor, this marginal improvement in the C_T gets multiplied by the number of coaxial rotors in multirotor UAV system and the gap between the rotors plays a significant role in improving overall aerodynamic performance of the UAV.

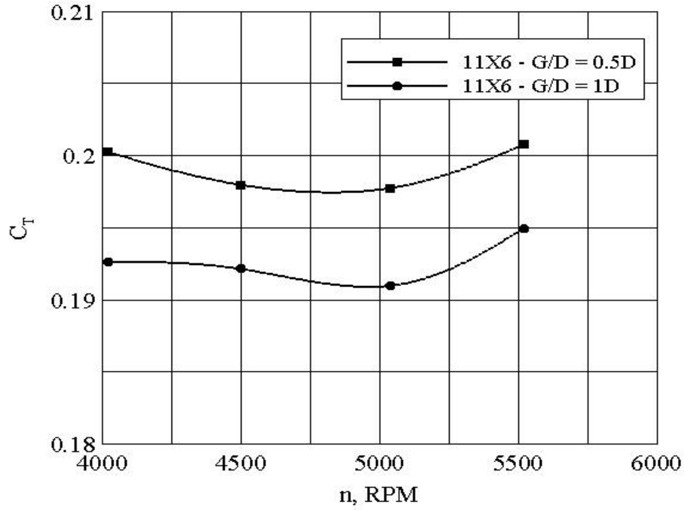

Figure 6: Variation In C_T As Function Of RPM For MAS 11X6 Propellers In Coaxial Arrangement For Two Different G/D Ratios

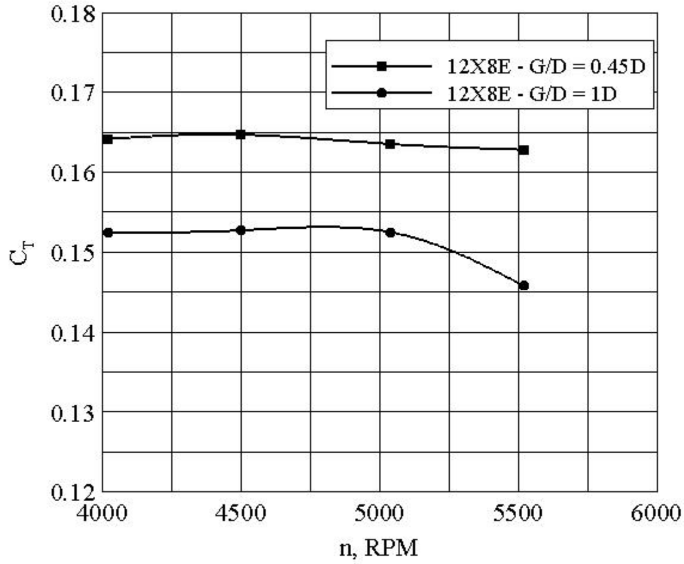

Figure 7: Variation in CT as function of RPM for APC 12X8E propellers in coaxial arrangement for two different G/D ratios

IV. SUMMARY

An experimental investigation was carried out to understand the effect of interaction between two micro propellers in coplanar and coaxial arrangements. In coplanar arrangements, fluctuations in the cumulative thrust was observed when the gap between the propellers was less than 0.2D. For G/D>0.2 the thrust coefficient was found merely independent of the gap between the propellers.

In coaxial propeller configuration the thrust is marginally affected by the gap between the propellers. Thrust found to increase with decrease in the gap between the micro propellers. This preliminary investigation would definitely be helpful in designing airframe with appropriate gap between rotors either arranged in coplanar or coaxial or in both the manners for a multirotor UAV system.

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REFERENCES

1. Aleksandrov, D. Penkov "Optimal Gap Distance Between Rotors of Mini Quadrotor Helicopter" 8th International DAAAM Baltic Conference "Industrial Engineering" 19-21 April 2012, Tallinn, Estonia
2. Wenwu Zhou1, Zhe Ning, "An Experimental Investigation on Rotor-to-Rotor Interactions of Small UAV" 5-9 June 2017, Denver, Colorado 35th AIAA Applied Aerodynamics Conference AIAA 2017-3744
3. Hikaru Otsuka, and Keiji Nagatani, "Thrust Loss Saving Design of Overlapping Rotor Arrangement on Small Multirotor Unmanned Aerial Vehicles".
4. Aleksandrov,Penkov "Increasing of Power Characteristics of Mini Uav Helicopter by Changing of Its Geometrical Parameters" Estonia Department of Mechatronics-Tallinn University of Technology, Estonia.
5. https://m-selig.ae.illinois.edu/props/propDB.html

AUTHORS PROFILE

Naveen Kumar has done BE in Mechanical Engineering from Visvesvaraya Technological University Belagavi Karnataka in the year 2017 has done BE project solar operated groundnut harvesting machine related to Agriculture field and also pursuing M.Tech in Thermal power engineering from VTU. His research interests are Thermal power generation, Advanced and computational fluid dynamics, thermodynamics and IC engines and also interested in small UAV/MAV propulsion system.

Dr. Parag has done BE and ME in Mechanical Engineering from University of Pune in 2003 and 2006. Subsequently, did his PhD in Aerodynamics from Department of Aerospace Engineering, Indian Institute of Technology Bombay (IIT Bombay, Mumbai) in 2012. Dr. Parag worked on number of government sponsored projects related to fixed wing UAVs and flapping wing MAV development. Primarily he is involved in wind tunnel characterization of fixed and flapping wing MAVs using various types of force balances, surface pressure measurements, flow field mapping and flow visualization technique. Apart from the sponsored projects, he is involved in knowledge generation and knowledge development in the area of UAVs/MAVs. He defines different research potential problems and execute them through independent project proposals or define them as a M. Tech or summer intern projects depending upon the quantity and degree of challenge involve in solving the problems. His research interests are fluid-structure interaction problem in flapping wing MAVs, atmospheric turbulence and its effect on UAVs, flow control, low Re flows etc.

Roshan Antony completed BE in Mechanical Engineering from Dayananda Sagar College of Engineering under the Visvesvaraya Technological University, Belgaum in 2003. He joined CSIR-NAL in 2006 as Junior Scientist in the Propulsion Division to work on development of MAV technologies, which was very nascent back then. He along with Suraj C S designed CSIR-NALs first micro air vehicle called Black Kite 300, which was a 300mm span MAV that was successfully flown in fully autonomous mode. Black Kite 300 was a benchmark MAV for research activities of different divisions of CSIR-NAL over the following years. Following the success of Black Kite, many other projects and programs were undertake at CSIR-NAL. He is actively involved in the development of mini UAVs, MAVs and Flapping wing MAVs related technologies at CSIR-NAL. He has worked on national programs on development of MAV technologies like NP-MICAV, NAL-ADE MAV Program, 12th FYP on MAV Technologies, CSIR FTT Program and the SIGMA Panel of AR&DB. Roshan Antony is a good team player and enjoys his work. His interests are Product Design, Propulsion System Configuration, Design of flapping wing MAVs, Design of Rotary UAV for agricultural and mining applications.

Ravi Dodamani's is a mechanical engineer with interest in MAV/UAV design, wind tunnel testing and advanced composite fabrications. He joined CSIR-NAL in 2008 and has contributed to many ongoing and open-ended research projects. He was taken into the MAV unit team to support the small team with his skill set. He was given the task to set up a national wind tunnel facility specifically for Micro Aerial Vehicles that would address the Low Reynold number problems associated with MAVs and the low loads that these vehicles encounter. The outcome of which the Micro Air Vehicle Aerodynamics Research Tunnel or MART. He took part in the design of the 3D model positioning system with automation that is currently installed at MART. Ravi Dodamani has handled many government sponsored project related to fixed wing & flapping wing MAV / UAV development. He handles many instruments like force balances, pressure measurements instruments, Time resolved Stereoscopic Particle Image Velocimetry (TRSPIV). He has the capability to handle activities that involve both the inhouse fabricators and outside vendors and deliver goods on time. His research interests are Mechanical design, wind tunnel model design, Low speed wind tunnel testing, flow diagnostic experiments, Gust response studies and advance fabrication techniques for MAVs/UAVs.

Girish Prasad M has done M.Tech in Thermal power engineering from Visvesvaraya Technological University Belagavi Karnataka in the year 2016, he also published paper on Thermal Analysis of Aero Gas Turbine Blade in IJMPE Journal during his M.Tech study and presently working as Assistant Professor and coordinator in Mechanical Department in NMIT Bengaluru. And he teaches subjects like Heat Transfer, Turbomachines, I.C.engines, and Thermodynamics and shares his knowledge, guidance in doing research-oriented projects for both UG and PG students. Also Pursing his PhD from VTU on Nano composite polymer thermal.