Performance estimation of Twin Propeller in Unmanned Aerial Vehicle

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DOI: 10.13111/2066-8201.2020.12.2.12

Received: 24 December 2019/ Accepted: 30 March 2020/ Published: June 2020

Abstract: *The article deals with the experimental investigation of the thrust performance of a twin propeller used in a typical Unmanned Aerial Vehicle. The propeller is fabricated and tested using low speed subsonic wind tunnel to study the performance characteristics. The results obtained show better performance compared to conventional propellers. The presence of twin propeller has increased the stall characteristics at low Reynolds number. The results indicate a substantial increase in thrust generation of up to 25 percent. The payload carrying capacity and handling quality will improve using this technique during pandemic to spray disinfectants. The results obtained provide an alternate design for future propellers applications. Further it is observed that the endurance of the Unmanned Aerial Vehicle can be reduced considerably, by few alternate solution.*

Key Words: *Twin Propeller, payload, Unmanned Aerial Vehicle, Endurance*

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV) extensively known as 'Drones', have been helping the mankind to take a great step towards advanced technological development.

Drones are a type of aerial vehicles used for surveillance, search and rescue missions. These UAVs come into operation in extreme cases where people cannot cope with terrible and extremely dangerous conditions.

Drones have been used by the military personals for surveillance, detection of land mines, detection and identification of enemy position and many more applications.

They are also used for the search and rescue of individuals trapped under the obstacles caused by natural or man-made disasters.

Drones can easily pass over the debris where the humans cannot have access. Entering into such dangerous locations without having a proper plan can increase the risk of the rescue person to get trapped. These drones help the rescue team in planning their rescue mission by analyzing the structure and position of the debris.

Figure 1 is a typical drone with twin propeller to carry human. The improved propeller design method for the electric aircraft was presented [1].

The numerical simulation of the performance of a Contra-Rotating Propellers (CRP) system for a Remotely Piloted Aerial Vehicles (RPAV) is presented in the article [2].

Fig. 1 - Drone with Twin Propeller

Forest monitoring with UAVs has been proposed for many applications [3]. Unmanned Aerial Systems potentially has been used for the routine transport of small goods such as diagnostic clinical laboratory specimens [4].

2. EXPERIMENTAL PROCEDURE

It has been found that the batteries used for Remote Controlled (RC) fixed wing aircrafts as well as multi rotor aircrafts are costlier than other power banks. The discharge level of Ni-Cd has been much lower than the Li-po batteries. So the batteries play a major role in the flying range of the drones.

The takeoff and landing of the drones have been done by the variation in Revolution Per Minute (RPM) of the brushless DC motor which draws more amount of charge from the batteries. Although Li-po batteries are much smaller in weight than other batteries, they have a shorter battery life. The battery also very limited number of charging and discharging cycles. This increases the manufacturing cost of each drone and also the weight if other batteries are needed. If the power of batteries is increased then the weights increase and obviously the cost. Therefore the batteries cannot be improved and also the flying of UAV is only based on the RPM of motor and propeller.

The variation of motor RPM cannot be performed without a power bank. So the propeller plays a major role in varying the thrust produced. The wind speeds are also very low during flight conditions. The advanced propeller fabrication is needed to produce more thrust force for lower wind speeds for the same battery power and propeller pitch. The increase in propeller diameter produces vibrations in the tip and hence induces drag. Therefore the efficiency of the propeller must be increased so as to produce much thrust than normal propellers for the same working environment.

Fig. 2 - Single Propeller mounted in the wind tunnel load cell

Figure 2 illustrates the Single propeller mounted to evaluate the thrust in the test section of low speed subsonic wind tunnel. The results are obtained for a range of speeds.

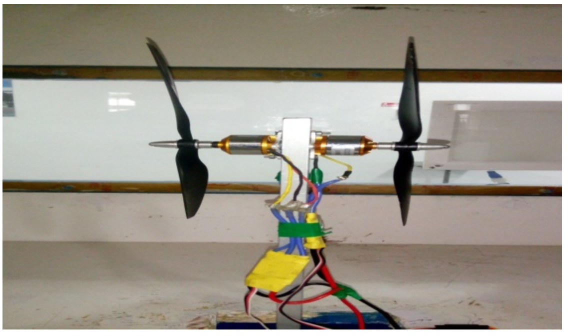

Fig. 3 - Twin Propeller mounted in the wind tunnel load cell

Figure 3 illustrates the twin propeller mounted to evaluate the thrust. The development of twin propellers plays a major role in thrust producing at lower wind speed. These propellers make the airflow to easily pass through the surface of the propeller blades. The most suitable propeller diameter and pitch for RC propellers are 12 x 5.5. So, to produce that much thrust using a small propeller we consume more energy while increasing the RPM of the motor which brings down the UAV faster to the ground. The advancement in the propeller design has made this problem to be solved. As the propeller faces different airflows in the air the maximum airflow of 10 m/s is allowed to pass through the twin propeller and estimated the thrust value. The UAV used with the twin propellers increased the flight time in minimal airflow velocity. The pitch and diameter of the propeller are being kept the same as for the normal propellers. The propellers are being tested firstly in the wind tunnel by varying the RPM of the motor.

3. CALCULATION OF RANGE AND ENDURANCE OF BATTERY

The Range and endurance of Propeller and jet engine aircraft were proposed by Breguet [5]. Unmanned aerial vehicles are also used to transport medical devices [6]. The Bio Inspired propeller has been testes in Unmanned aerial vehicle [7]. The algorithm for monitoring the forest region has been studied [8]. The Forest Fire Detection Using Unmanned Aerial Vehicles has been proposed [9]. For an UAV in steady level flight, the power required (P_{req}) to overcome the drag (D) of the plane at a given flight velocity (U) is given by

$$P_{req} = D \times U \tag{1}$$

The Drag Polar is given by

$$C_D = C_{D0} + kC_L{}^2 \tag{2}$$

The Equation of Drag is

$$D = qS\left(C_{D0} + kC_L{}^2\right) \tag{3}$$

$$P_{req} = \frac{1}{2}\rho U^3 S C_{D0} + \frac{2W^2 k}{\rho U S} \tag{4}$$

Peukert's equation may be written as

$$t = \frac{C}{i^n} \tag{5}$$

Battery is discharged is given by

$$t = \frac{Rt}{i^n}\left(\frac{C}{Rt}\right)^n \tag{6}$$

the output power may be estimated as (where V is volts)

$$P_B = V_i \tag{7}$$

The power output of the battery

$$P_B = V\frac{C}{Rt}\left(\frac{Rt}{t}\right)^{\frac{1}{n}} \tag{8}$$

$$\left(\frac{Rt}{t}\right)^{\frac{1}{n}}\left(\frac{C}{Rt}\right) = \frac{1}{\eta_{tot}V}\left[\frac{1}{2}\rho U^3 SC_{D0} + \frac{2W^2k}{\rho US}\right] \tag{9}$$

Solving for the time t results in

$$E = t = Rt^{1-n}\left[\frac{\eta_{tot}V \times C}{\frac{1}{2}\rho U^3 SC_{D0} + \left(\frac{2W^2k}{\rho US}\right)}\right]^n \tag{10}$$

The condition for maximum endurance is given by

$$C_{D0} = \frac{1}{3}kC_L{}^2 \tag{11}$$

the range is given by

$$C_{D0} = kC_L{}^2 \tag{12}$$

The flight velocity for maximum range U_E

$$U_E = \sqrt{\frac{2W}{\rho S}\sqrt{\frac{k}{3C_{D0}}}} \tag{13}$$

The flight velocity for maximum range U_R

$$U_R = \sqrt{\frac{2W}{\rho S}\sqrt{\frac{k}{C_{D0}}}} \tag{14}$$

The range is

$$R = E \times U_R \tag{15}$$

Minimum power is given by

$$P_{req} = \frac{1}{2}\rho U^3 S\left(C_{D0} + kC_L{}^2\right) \tag{16}$$

Power required in terms of velocity

$$P_{req} = \frac{2}{\sqrt{\rho S}} C_{D0}^{\frac{1}{4}} \left(2W\sqrt{\frac{k}{3}}\right)^{\frac{3}{2}} \tag{17}$$

Maximum endurance

$$E_{max} = Rt^{1-n} \left(\frac{\eta_{tot} V \times C}{\left(\frac{2}{\sqrt{\rho S}}\right) C_{D0}^{\frac{1}{4}} \left(2W\sqrt{\frac{k}{3}}\right)^{\frac{3}{2}}} \right)^{n} h \tag{18}$$

$$P_{req} = \frac{1}{\sqrt{\rho S}} C_{D0}^{\frac{1}{4}} \left(2W\sqrt{k}\right)^{\frac{3}{2}} \tag{19}$$

The maximum range

$$E_{max} = Rt^{1-n} \left(\frac{\eta_{tot} V \times C}{\left(\frac{1}{\sqrt{\rho S}}\right) C_{D0}^{\frac{1}{4}} \left(2W\sqrt{k}\right)^{\frac{3}{2}}} \right)^{n} \sqrt{\frac{2W}{\rho S}\sqrt{\frac{k}{C_{D0}}}} \tag{20}$$

These calculations are carried in order to estimate the range and endurance of the battery powered drones. D – Drag, U - Flight velocity, C_{D0} - Zero lift drag, C_L - Lift coefficient, ρ - Density, S - Reference area, T – Time, q – Dynamic pressure, W – Weight, i– Discharge current, n – Temperature, C – Battery capacity, V – Volts, E – Endurance, Rt - Battery hours rating, P_B - Battery output power and η_{tot} - Total efficiency.

4. RESULTS AND DISCUSSIONS

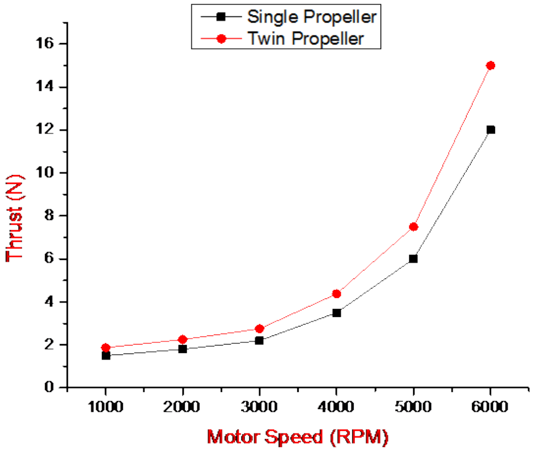

Fig. 4 - Propeller thrust profile comparison

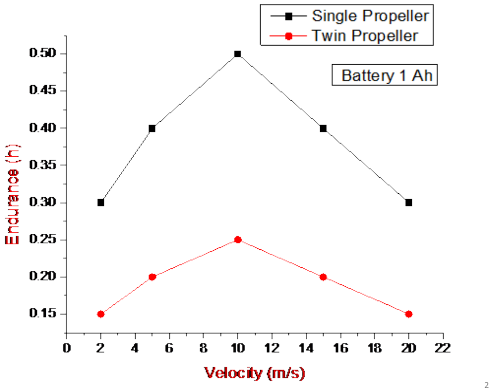

Fig. 5 - Effect of battery capacity on estimated endurance

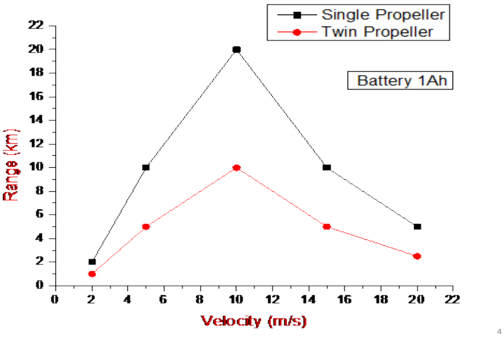

Fig. 6 - Effect of battery capacity on estimated Range

The results are plotted in Figure 4 which depicts the Propeller thrust profile. The twin propeller has produced a higher thrust when compared with the conventional propeller by 25 %. As the Motor speed increases the thrust increases.

The propeller efficiency has been limited by Betz's law, which indicates the maximum power that can be extracted. From the results there has been concluded the twin propeller enhancement in thrust at low Reynolds number by 25 percent. On the other hand figures 5 and figure 6 show that the battery power required is increased twice for maximum endurance and range. Thus the battery power required is increases for twin propeller drones.

5. CONCLUSIONS

The conclusions of the work show that implementing of twin propeller and the ridges to the propeller improves thrust coefficient significantly to a maximum of about 25%. The propeller efficiency increases with higher advance ratios, although lower than the results obtained for the conventional propeller. The major increase in thrust has a significant finding for propeller designers interested in enhancing the raw power output of the propeller. The results indicate that adding the ridges on the surfaces enhances flow separation which has been initiated. This increase in efficiencies makes it possible to select the propellers for motors and increase the flying time and reduce the discharge of battery. Other techniques like hydrogen fuel cells and solar powered drones [10] can be initiated for twin propeller drones which carries high payload. Further during pandemic conditions it can be used to spray disinfectants by carrying large payload.

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