The Numerical and Experimental Investigation on the Aerodynamics of Quadrotor’s Blade in low Reynolds Numbers

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1-Introduction

In this decade many scientists and researchers paid a lot of attention on Micro Air vehicles (MAV) as a result of which there has been a very sharp growth in this area. Nevertheless, although nowadays MAVs have both military and commercial applications around the world, there is no accurate data about their different parts such as aerodynamic characteristics, mechanics and control. Therefore, according to all of effective issues related to these vehicles, considerable attention must be paid to develop and find a proper database and information for our personal goals.

In accordance with the diversity of existence of MAVs’ blade and their different missions, access to original technology in construction and accessibility of their original information for doing experimental and numerical tests are extremely essential. Based on the trends of previous explorations, a numerical investigation in terms of flow field around the quadrotor blades were not comprehensive and widespread. Furthermore, there is not sufficient data about the process of generating and damping vorticities and also their effects on fluid flow around the blade. Therefore, first of all, a test setup was designed and constructed measuring and analyzing the effect of blade and motor propulsion parameters. Then, a number of different empirical tests on a blade and motor were done. Along the research, the characteristic curves of motor and blade in static condition were recorded. Moreover, a range of numeric simulations in both static and dynamic conditions were analyzed for further exploration about the blade aerodynamic and its flow field. Thereby, the thrust force and process of vortex generation due to the blade rotation were studied based on the different air velocities. Finally, some parts of both methods were compared together which had a proper harmony.

To put it brief, a comprehensive research in both numerical and experimental methods and studying the flow field around the blade in both static and dynamic conditions which was followed by a relevant comparison, can be considered as innovations of this research.

2- Numerical Method

In order to study external flow around a dynamic body, a model of body was constructed in a virtual wind tunnel. Accordingly, the flow had a steady condition and the blade was rigid. In fact, a small single reference frame which had a negligible space from the blade was considered and instead of the blade rotation, the mentioned frame and its inside flow were rotating in the various RPMs. Consequently, the vectors of relative velocity can be subtracted from the frame rotation vectors and because of that a real condition of flow field around the blade can be simulated. Eventually, the governing equations should be applied to estimate the different parameters along the tests. According to the aforesaid stages, Navier-Stocks equations including continuous and momentum equations (1), (2) were employed.

\[
\frac{\partial \rho}{\partial t} + \nabla(\rho \mathbf{V}_r) = 0 \tag{1}
\]

\[
\frac{\partial}{\partial t}(\rho \mathbf{V}_r) + \nabla(\rho \mathbf{V}_r \times \mathbf{V}_r) + 2\Omega \times \mathbf{V}_r + \Omega \times \Omega \times r + \rho \frac{\partial \mathbf{a}}{\partial t} \tag{2}
\]

where \(\Omega, \mathbf{V}_r, r, \rho\) and \(t\) are the rotational speed of the reference frame, relative velocity, displacement vector, density and time, respectively.

In the next step, the discretization of equations and the computation method were selected by finite volume and SIMPLE algorithm. Moreover, due to the measured Mach number in 0.75 of blade diameter, the flow was incompressible and turbulent, so the K-\(\varepsilon\) as one of the popular models was employed. Also, second order upwind interpolation and extrapolation were used in order to compute the convection term in discretized momentum equations. In terms of mesh generation, a tetrahedral grid was used to produce physical domain with a concentrating higher rate of mesh near the blade to have a better computation about vortexes and flow distribution.

Fig 1. Measurement fixture of propulsion force in MAV lab
3- Experimental Approach
As it can be seen in Fig. 1, a test setup was designed and constructed in order to measure the effective parameters of motor and blade propulsion system. Generally, propulsion tests were used find different combinations of motors and blades in supplying the required thrust force for the desired application. The mentioned test setup included the different parts such as electronic load cell, aluminum base, speed controller, radio control, laser tacho meter, battery, voltmeter, data acquisition board, computer, motor and propeller. The selected motor belongs to the EMAX Company with model 6T2215 / 09 which is joined by a propeller with characteristics of 10*4.7 slow-flyer. It is noted that during the static tests, the thrust and power coefficients were the most important parameters which were measured by the fixture.

4- Results and Discussion
Having examined the data from the numerical simulation, it is obviously apparent that the processes of generating and damping the vortexes around the blade have a significant role in the analysis of flow field and its treatment. Therefore, the trends of this process in static conditions are represented in Fig. 2. As it is shown, there are three cases based on the vortexes intervals from the blade’s surface in which A is on the blade surface, B is about one meter behind the blade and C is in a distance of two meters further than the blade surface. It is noted that almost noticeable parts of vortexes in section C were damped.

![Fig. 2. The process of vortex generation](image)

Additionally, to find the propulsion coefficients of blade and motor, experimental tests were done which are depicted by Figs. 3 and 4.

![Fig. 3. The thrust coefficient in Static condition](image)

![Fig. 4. The power coefficient in Static condition](image)

5- Conclusion
In this article, the series of both experimental and numerical tests were studied to find a better view about MAVs propulsion system.
1. Due to the negative effects of vortexes of flow field around the blade, the essential equipment in MAVs such as battery, speed controller, receiver, and camera should be installed at a proper distance from the blade because they lead to a falling trend in the thrust coefficient.
2. The results illustrated that the relevant blade material and its pitch can be estimated based on the velocity and pressure distribution on the blade surface.
3. The experimental tests show that the downstream vortexes should be considered significantly, since if the distance of propeller is lower than a specific value, they can produce a negative thrust that leads to an unsteady condition for the vehicle.
4. From the outcomes of dynamic simulation it seems that the vortexes behind the blade are produced in a further distance of the blade. The distance that these vortexes disappear is unpredictable, unless it is used in a larger physical domain. This matter needs more powerful computers.
5. As it can be seen, the blade (slow flyer 10*4.7) is fallen to the wind milling condition at around 10 m/s inlet air velocity in physical domain.