Design of Ducted Fans of Small Height for Hexacopter with Long Hover Ability

Sergey V. Serokhvostov,* N. D. Ageev, M. E. Arkhipov
Moscow Institute of Physics and Technology
Department of Aeromechanics and Flight Engineering
140180, Gagarina street, 16, Zhukovsky, Russia

ABSTRACT

Investigated is the ability of the usage of small height ducted fans in multicopters for increase in the hover time and protecting the propellers and surrounding. A set of numerical and experimental investigations concerning duct aerodynamics and efficiency of electrical part (drive, speed controller, accumulator) was conducted. The effects of interference between two ducted fans situated close to each other are also investigated.

1 INTRODUCTION

Multicopters are promising aircraft for the set of applications. The main feature of such a remotely piloted aircraft (RPA) is the ability to hover for a long time over some point. From this point of view one of the main multicopter characteristics is hover time. It implies that the energy consumption from the onboard energy source must be minimized. For a number of reasons, electrical drives are used in multicopters and the energy source is the accumulator.

The energy consumption minimization implies the efficiency maximization of each part of powerplant and a powerplant as whole.

For the set of applications, the multicopter propellers as well as the surrounding evironment must be protected from the contacts with obstacles and from rotating propellers, respectively. One of the solutions is to use the so-called "ducted fans".

On the one hand, the mass of the duct increases with the height increase. In addition, the high duct has worse performance in the presence of wind. On the other hand, with the duct fan height decrease the aerodynamical efficiency of the ducted fan decreases. The ducted fan must also fit the electrical part of the powerplant to provide the maximal efficiency.

The outer diameter of the duct was set as 17 inch for the investigation, and the thrust of the ducted fan was set as 9N.

2 NUMERICAL INVESTIGATION

First of all, the aerodynamics of the "short" duct was investigated numerically. For speeding-up the calculation process the propeller was modeled by "active disk" [1] and only duct parameters were varied. The shape of the duct and disc position were optimized to provide maximal efficiency.

Considering the shape of the duct vertical cross-section as some kind of profile, the type of profile, its thickness and its angle of inclination with respect to the horizontal line (the plane of the active disc) were varied. As for the active disc, its position and gap between the disc and duct were varied.

The computational domain contains multiblock structured mesh. This type of the mesh provides the most reliable and detailed simulation. The size of the cells on the model surface doesn't exceed 1 mm. The general maximum cell size is equal to 1 m. The cell size growth ratio is 1.1, which provides sufficiently detailed simulation. The total 2D grid has 287 thousands elements, that is equal to 34 million in 3D case. The wall cell thickness is about 0.007 mm. The prism layer provides $Y+max \sim 0.53$.

Figure 1 shows the mesh used.

The boundary conditions on the walls of the computational domain are standard: all the walls besides the duct and active disk are free slip walls. Duct is no slip wall and active disk is the interface with the pressure drop of 66.9 Pa. RANS system of governing equations with the SST turbulence model [2] was solved by the solver ANSYS CFX™. Solving is carried out with an incompressible viscous fluid model with parameters corresponding to air at 25C.

The problem is solved in a stationary regime with the approximation scheme of the second-order. One calculation takes 1000 iterations in average. The stop condition is fixation of the third significant digit in magnitude of the aerodynamic forces acting on the model.

Figure 2 shows one of the best duct shapes found, the corresponding location of the active disc and the velocity distribution for the case investigated.

It was found that the main peculiarity affecting the flow near the duct is the vortex on the end of the active disc which can be seen in Figure 2 near the end of disc. It was also proved that the smaller the chink between the disc and duct, the better is flow near the duct.

The second peculiarity is that in contrast to the "long"duct, in the case investigated the inner surface of the duct is convergent (in the case of long duct the inner surface is convergent in the fore-part and divergent in the rear part).

It was also found that for the fixed outer diameter of duct the maximal obtained total efficiency of the "duct+disc" is

*Email address: serokhvostov@mail.ru

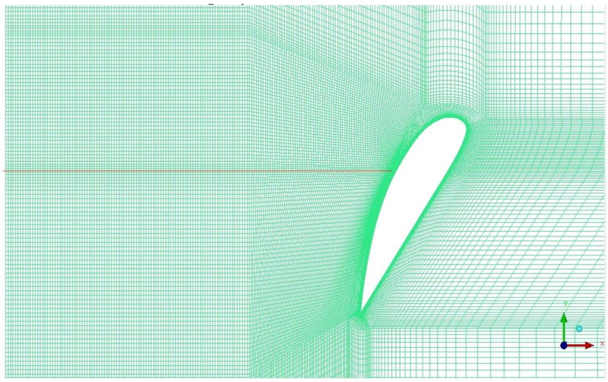

Figure 1: Computational mesh.

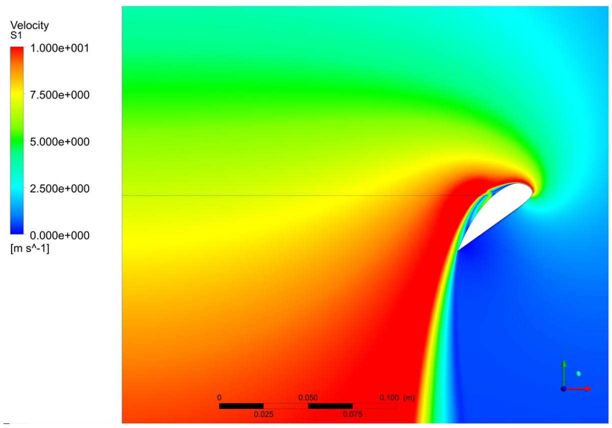

Figure 2: Velocity distribution near the duct for the case investigated.

nearly the same as for the disc with the diameter equal to the outer diameter of the duct.

3 Experimental Setup

On the basis of the mathematical model of the duct the experimental test duct was made with the help of 3D-printing technology, see Figure 3. In addition, a "thin" duct was made as the "inner" part of optimized duct (in this case the "experimental test duct" was used as mould), see Figure 4. The weight of the "thin duct" is about 45–50 gram. Then the experimental setup was designed and made to measure the characteristics of the ducted fan, drive, speed controller and accumulators which enables to measure propeller rotational frequency, thrust, current from accumulator, voltage at the input of the speed controller.

4 Experiments and Results

All the necessary data were obtained to calculate the total efficiency of a system and to define the efficiencies of its components. Experiments show that within the accuracy of the measurements there is practically no difference in the efficiency between the ducted fan and the propeller of the same

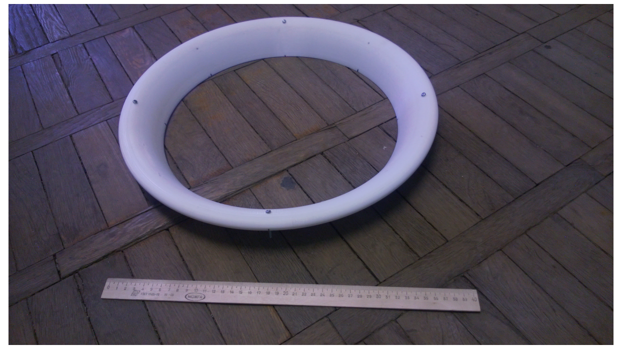

Figure 3: Duct made by 3D-printing technology.

Figure 4: Thin duct.

diameter. However, it should be mentioned that the authors are not sure that the elements of the ducted fan (propeller, fan and their combination) really have the best efficiencies among all the possible variants.

The interference influence of the two ducted fans was also investigated. The situation was modeled with the help of the "wall" situated in the vicinity of the duct. It was found that within the experiment accuracy there is no effect of interference.

After that, a set of experiments was conducted to define the dependence of the speed controller efficiency on its maximal current and voltage permitted and voltage of power source. A set of controllers (see Figure 5, Table 1) were tested for the case of 9N thrust of the powerplant for the different input voltages (12–18 Volt). First, it was found that for the current much more lower the maximal permitted (less than 30%) the controller efficiency is practically independent of the value of the maximal permitted current. This means that one can utilize the controllers with maximal permitted current of about 2–3 times higher than nominal current.

Second, the characteristic of the maximal permitted voltage does not affect the efficiency of the controller (at least for low current). Third, the efficiency of the controller decreases with voltage increase. For example, the increase of the voltage from 12V to 18V gives the increase of the current of about 10Finally, it was found that the mass of speed con-

	Max. current, A	Max voltage, Li-Po
Jeti Advance 40 Plus	40	6
Multiplex Multicontrol 40	40	6
ZTW 40A	40	6
Hornet	60	6
Hobbywing Flyfun 60A	60	6
Maytech 50	50	6
T-Motor T40A 400Hz	40	6
Scorpion 45	45	3
Scorpion 35	35	3

Table 1: Controllers tested.

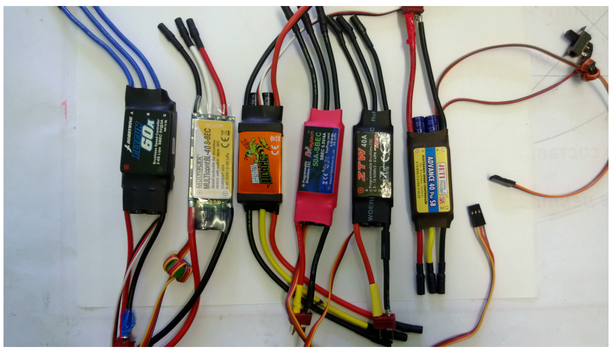

Figure 5: Controllers tested.

troller is proportional to the maximal permitted current and practically independent of the maximum voltage. The coefficient of proportionality is roughly about 1 gram per 1 Amper.

5 Conclusion

1. Numerical investigations of small height ducted fan were conducted. Optimal duct shape and propeller position were found. It was obtained that the efficiency of ducted fan is practically the same as for the propeller of the same diameter.

2. Experimental setup was made. All necessary characteristics of ducted fan were obtained. It was found that the efficiency of ducted fan is nearly the same as for the propeller of the same diameter.

3. The characteristics of speed controllers were investigated. The dependence of controller efficiency on the maximal permitted voltage and current and input voltage were estimated.

References

[1] H. Glauert. *The elements of aerofoil and airscrew theory*. Cambridge Science Classics Series. Cambridge University Press, 2 edition, 1983.

[2] F. R. Menter. Zonal two equation $k-\omega$ turbulence models for aerodynamic flows. *AIAA Paper 93-2906*, 1993.