DARcorporation

Design • Analysis • Research

Electric Ducted Fan Design

1. Introduction

This paper outlines the design process and presents verification testing of an electric ducted fan for small UAV integration. The vehicle is a quad rotor configuration similar to many commercially available platforms. Flight time estimation is made from performance testing results and vehicle weight estimations and compared with the DJI Phantom 4, which has a similar rotor span as the designed duct.

2. Preliminary Design

The design goal is to produce an efficient electric ducted fan design that can produce 2 kg equivalent maximum thrust with an overall diameter including the duct of 10 inches. The duct is designed to be 3D printed and assembled in house.

Using blade element momentum theory and an estimated efficiency from previous designs of similar size and Reynolds number, the shaft power required is estimated at 260 Watts. From this power requirement and accounting for the worst-case losses from both the motor and ESC the center body is sized to fit motors with a maximum rating of 500 W.

3. Detailed Design

The ducted fan is designed with the aid of DFDC as well as DARcorporation in-house optimization and analysis tools. DFDC is a 2D panel code that combines a vortex sheet panel grid and blade element momentum (BEM) theory.

The duct is designed to be relatively short to decrease weight, but is limited by performance hindering flow separation around the lip and duct exit. Figure 3.1 shows the duct and center body geometry and the surface pressure distributions in the DFDC interface. A flow field representation from airflow velocity vectors is shown Figure 3.2.

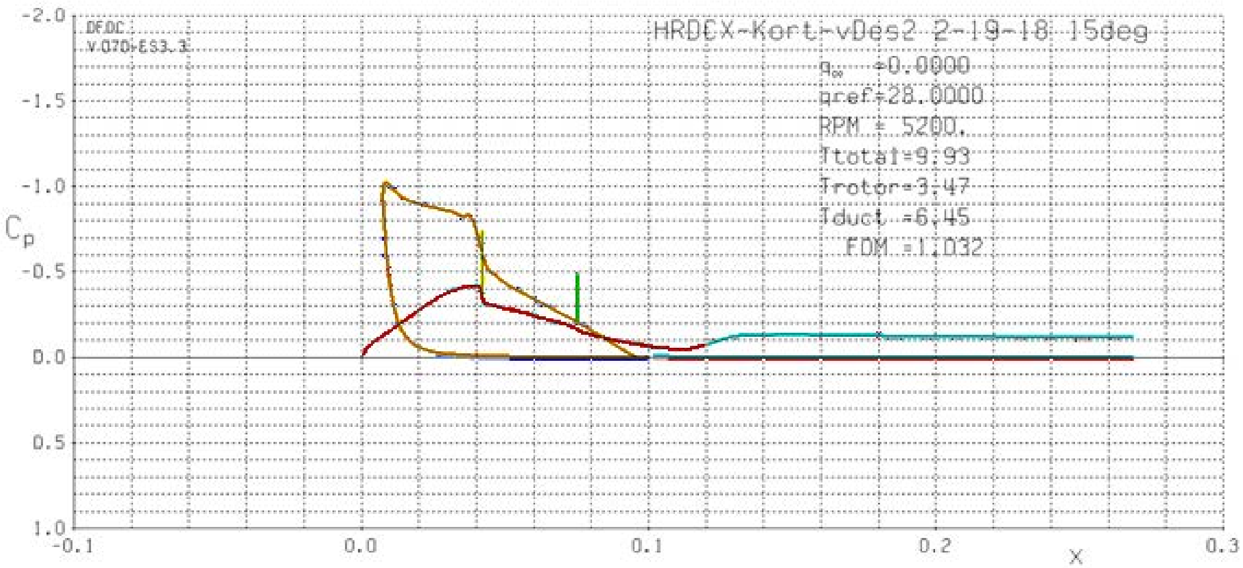

Figure 3.1 DFDC Detailed Design

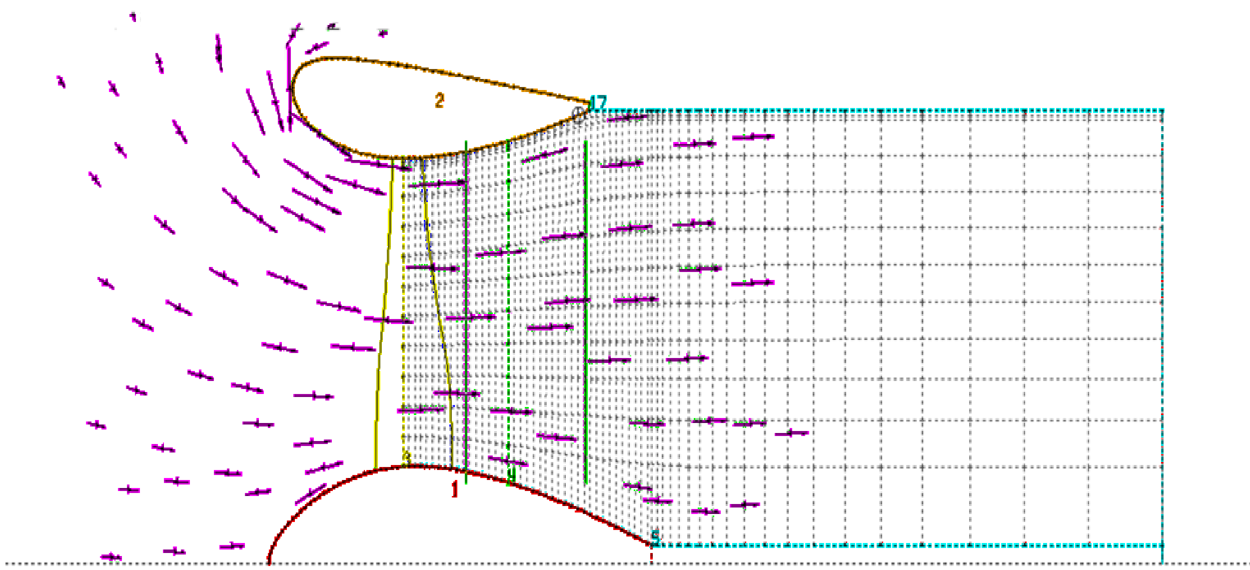

Figure 3.2 Velocity Vector Field Through Duct

4. Motor Selection

Once a rotor torque curve is established, it can be used to predict motor performance based on the manufacturer specifications. The main source of loss in an electric motor is power dissipation from the wire resistance. Other losses are present, but can be estimated from predicted power draw and motor specifications. For motor selection purposes these losses can be considered fairly constant across motors of similar weight and size.

For maximum flight time, a balance must be struck between decreasing motor weight and the accompanying decrease in motor performance with the set maximum load that comes with using smaller motors.

Using the reported winding resistance and idle currents of the motor, the efficiency can be estimated and compared. The KDE 515 motor is selected for use after review of available motors within the selected range. At maximum thrust the efficiency is acceptable at above 80%. This number could be improved, but larger motors that would be more efficient weigh more, which negate their better performance considering increase in required thrust. Estimated motor performance for the duct operational envelope is shown in Figure 4.1.

This analysis also provides the required input voltage to reach maximum thrust. The power supply is set to 6S LiPo at 22.2 Volt. ESC efficiency is predicted through resistance measurement and an estimated switching loss dependent on load. Figure 4.2 shows the prediction as well as the combined system efficiency.

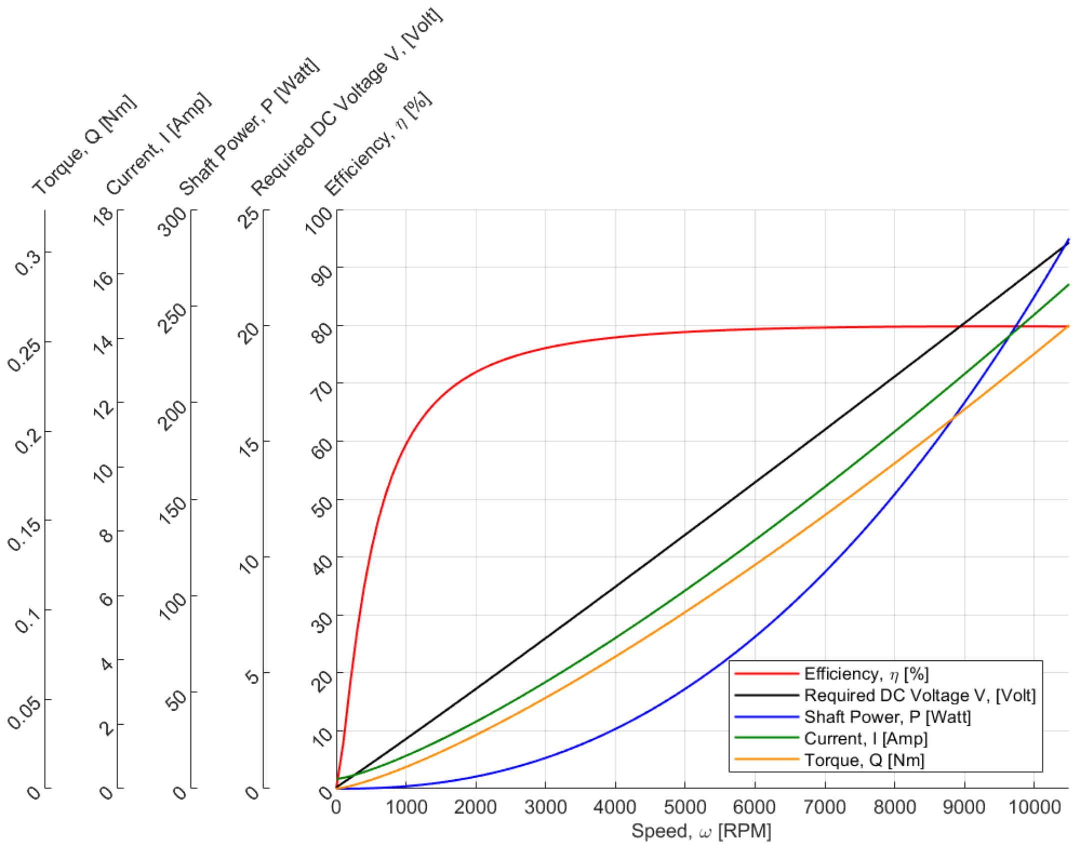

Figure 4.1 KDE 515 Motor Performance Estimations

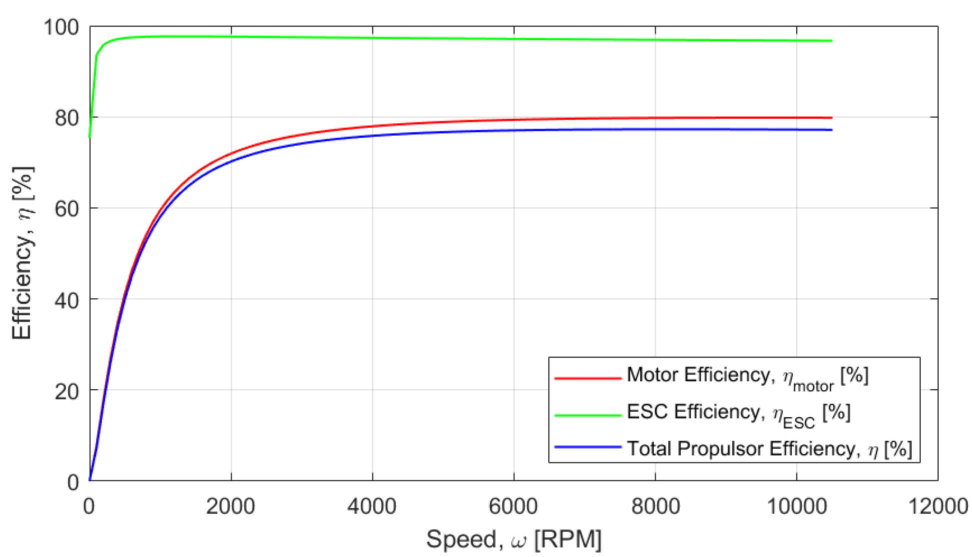

Figure 4.2 Predicted Propulsor Component Efficiency

5. Prototyping and Testing

The duct is 3D printed in sections using the Formlabs Form2 printer. Eight alternating sections are assembled with every other section containing a slot to install a stator. The 4 stators come together to form the center body. Stators are hollow to reduce weight and allow for the passthrough of the power wires from the ESC.

To facilitate motor cooling a second rotor inside the spinner is added to pump air through the center body. The completed ducted fan CAD is shown in Figure 5.1.

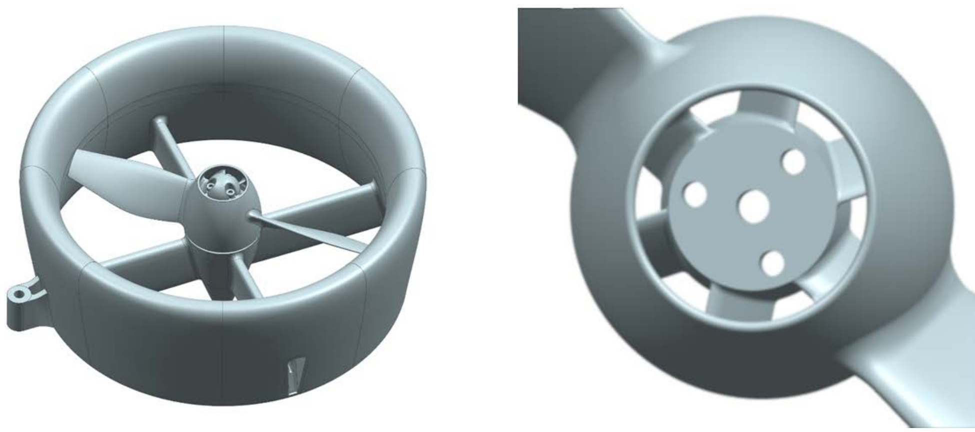

Figure 5.1 Final Ducted Fan CAD

To ensure that the rotor does not fail structurally during operation, structural analysis is performed. Figure 5.2 shows a stress distribution of the first iteration. A safety margin of at least 2 is applied to account for material uncertainties of the printed resin. The highest stress levels are seen in the spinner internal fan blades.

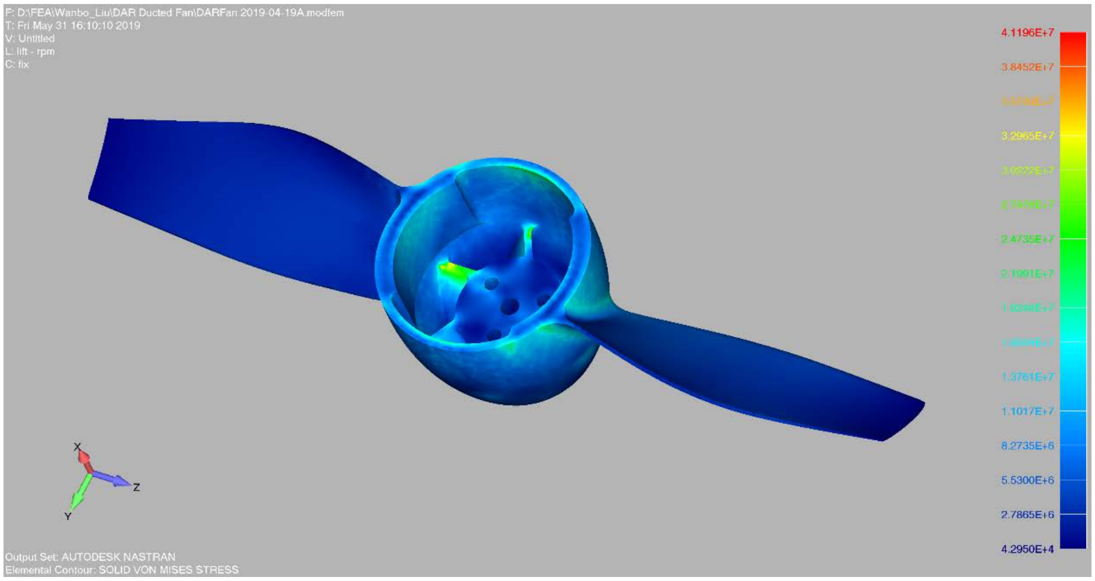

Figure 5.2 Finite Element Analysis of Ducted Rotor

Duct pieces are assembled with a strap clamp jig and bonded together. The end prototype is shown mounted on the test stand in Figure 5.3.

Figure 5.3 EDF on Test Stand

6. Test Results

Results obtained from the DARcorporation EDF design are presented in Figure 6.1. The total system power draw is shown with thrust as the relevant value for calculating vehicle endurance. The power draw at maximum thrust shows a large dip in motor or ESC performance.

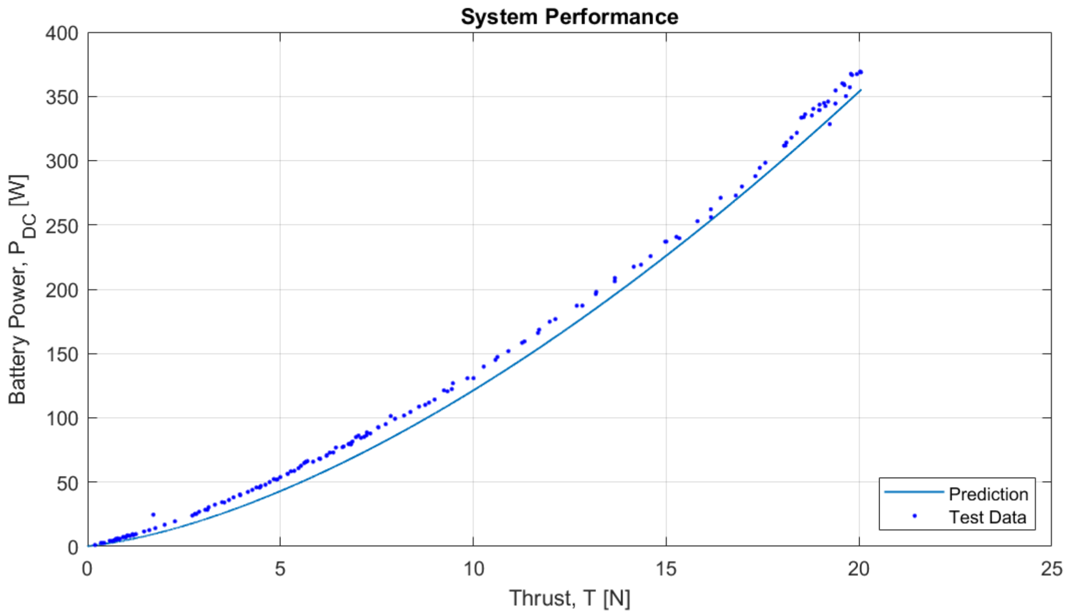

Figure 6.1 Comparison of Test Results with Prediction

7. Vehicle Analysis

Preliminary vehicle sizing of a quad rotor configuration is completed to estimate flight time for a vehicle of this design. Estimated component weight break down is presented in

Table 7.1. Structural weight is based on the actual weight of the test article plus allowances for fasteners and a center body. Electric component weight is compiled from currently available ESCs and motors as well as the wiring to connect them. There is no structural optimization performed and the duct components are oversized for rapid production without detailed structural FEA. Thus, further weight reduction is possible.

Table 7.1 Estimated Vehicle Weight Breakdown

Structures	2.0 kg
Internal Electronics and Motors	0.8 kg
Battery (6S 11,000 mAh)	1.3 kg
Payload	1.3 kg
Total	5.3 kg

Each propulsor unit uses 188 Watts drawn from the battery to produce hover thrust of 1.25 kg. With a currently available, 244 W-hr battery this should allow for around 19.5 minutes of flight time.

8. Conclusions

An all up vehicle weight for a quad configuration is estimated to be 5.3 kg. The battery with 244 W-hr allows for 19.5 min of flight in the same form factor as a DJI Phantom carrying a payload of 1.3 kg. If the 1.3 kg payload is exchanged for a second battery the flight time is doubled to 39 min. Flight time can be further increased through structural optimization.

Thus, the designed ducted fan vehicle has the capability of carrying more payload than the baseline DJI Phantom 4 that typically flies with no payload. This capability augmentation can be reconfigured to extend the flight time of the baseline at 28 minutes by 11 minutes if the design ducted fan vehicle carries no payload.

The use of 3D printing allows for quick turnarounds with lower cost in the design-test cycles. The entire process of design, CAD, prototyping, assembly and testing is completed in only 3 weeks.

9. Further Information

Please contact Design, Analysis and Research Corporation for more information.