

Understanding Ducted Fans

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My notes on understanding electric ducted fans for model aircraft.

Table of Contents

| | | |
|-----|--|---|
| 1 | Understanding Electric ducted fans | 2 |
| 1.1 | Assumptions..... | 2 |
| 1.2 | Terminology..... | 2 |
| 1.3 | The basic power equation..... | 2 |
| 1.4 | What do we want to know?..... | 2 |
| 2.1 | Ducted Fans..... | 2 |
| 3 | Thrust and Power..... | 3 |
| 3.1 | The relationship of power to thrust..... | 3 |
| 3.2 | Ducted fan thrust..... | 3 |
| 3.4 | Battery placement in the airframe..... | 4 |

1 Understanding Electric ducted fans

The following short notes are written to summarise what I have learned about the use of electric ducted fans for model aircraft. It is not complete in any sense, but does aim to answer some of the more obvious questions, such as:

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1.1 Assumptions

In the following discussion we shall assume that we are flying a fixed wing electric powered plane such as the ones in the following picture:

1.2 Terminology

The following terms are important to understand.

1.3 The basic power equation

The basic equation for electrical power relates Volts (V) and Amps (A) to Watts (W) in the following way:

$$V * A = W \quad (1)$$

1.4 What do we want to know?

In the following sections we will go through the elements of the system as outlined above and explain why changing or specifying something often changes the decision on something else. For example, changing the propeller can have ramifications on what motor to use, or changing the motor may require changing to a different specification of battery.

The main objective in setting up a plane is to get the optimum set up, which we define as: *the longest flight time, given the required style of flying*, consistent with staying within weight limits for the plane. Because so many factors interact this is not as simple a question as it might seem. Simply using a bigger battery, for example, will not always improve things, indeed it can make it worse.

2

2.1 Ducted Fans

Ducted Fans are basically a small propeller set in a closely fitting tube. The resulting unit

(also called a *fan*, or an *impeller*) is therefore a shrouded propeller which sucks air in at the front and expels it at the back. The objective is to take in slow moving air, and output fast moving air. The force (action) of the expelled air causes an opposite force (reaction) [see Newton's law] which results in the airplane moving forward.

The shrouded propeller system has some advantages over a normal open propeller in that the losses at the propeller tips are lessened. On the other hand there is additional resistance due to friction in the shroud, so the total thrust may or may not be better than an open propeller.

The single most important factor in the amount of thrust a fan unit can produce is related to the size of the fan – the larger the better.

3 Thrust and Power

This section aims to relate the *power* produced by a motor to the *thrust* achieved by the propeller or ducted fan. The reason why we have a motor in the first place is purely to drive the plane forward, which it does by using the propeller to do work (displace air). While the power of the motor is related to the thrust it is mediated by the efficiency of the propeller.

3.1 The relationship of power to thrust

Ultimately, what we want from an aircraft power system is thrust, and to some extent we are not primarily concerned with how the thrust is achieved (at least while piloting the plane). Of course the designer and builder of the plane are more interested in the power system, and try to create a system with sufficient thrust for the pilot to use.

3.2 Ducted fan thrust

Fan units come in a number of sizes (but not as many sizes as open propellers). A typical range of fans is the Wemotec family, which has the following characteristics:

| Name | Diameter in mm | Area in sq.mm | Size ratio | Power range in N | typical power in g | Typical consumption in watts | Thrust rate in g/watt |
|-------|----------------|---------------|------------|------------------|--------------------|------------------------------|-----------------------|
| micro | 50 | 1963 | 1 | 1 – 10 ? | ? | ? | ? |
| mini | 68 | 3631 | 1.8 | 2 - 17 | 700 | 350 | 2 |
| midi | 90 | 6361 | 3.2 | 7 - 22 | 2000 ? | 600 ? | 3 |

Note: 1N = 3.5oz = 102g 1W = 1N m/sec

It will be seen that a small increase in fan diameter results in a significant increase in fan size (area swept by rotating blades). This in turn result in a more efficient conversion of energy into thrust.

Not all fans are equivalent, even if they are of the same size. As the following experiment exemplifies. In this case the battery (a 3s 3200mAh 60C Lipo) and the ESC(Jeti Advance

70) were kept the same, but the fan and motor combination were changed. It is not always easy to try every motor with each fan as the fitting and assembly arrangements can vary between fans. Some manufacturers have evidently designed a particular fan for a specific motor, or vice versa.

| Fan + motor | kv | Diam. | Volts | Amps | Watts | Thrust |
|----------------------|------|-------|-------|------|-------|-------------|
| Wemotec + Mega 16EDF | 3400 | 68mm | 11.1 | 32.4 | 360 | 663g = 6.5N |
| Delta V480 + 1550DF | 4000 | 65mm | 11.2 | 29 | 324 | 601g = 5.9N |
| BRC + Mega 16/15/3 | 3000 | 70mm | 10.6 | 43.8 | 465 | 855 = 8.4N |

Each of these fans is about the same size, but the motors are significantly different, pulling more or less current. The higher current accounts for the lower voltage, so the overall wattage gives an indication of power consumed which translates into thrust obtained.

Fans of this size are expected to produce up to about 15N of thrust.

Most ESCs are shipped with a default timing setting, thought by the manufacturer to be suitable for most average motors. Often this is suitable and no change needs to be made. However, for advanced applications, such as ducted fans, this will need to be changed by using the programming mode.

The timing mode controls the rate at which the ESC attempts to drive the motor:

- Low timing is suitable for high inductance (low kV) motors, such as those used on large propeller driven, slower flying models.
- Mid timing is suitable for average motors, and may be the default setting. It may work, but may not always be the most efficient way of operating.
- High timing is recommended for low inductance (high kV) motors, such as those used for ducted fans.

If the motor speed is observed to be variable, or pulse up and down, then the timing is wrong, and the most likely cause is not setting the timing mode high enough.

3.3

3.4 *Battery placement in the airframe*

It might be assumed that the battery/esc/motor layout in the airframe is simply a matter of choice, and that these elements can be moved around to any extent to suit the airframe designer's needs. Indeed, it is very convenient to be able to move the battery backwards or forwards to help with the overall weight distribution, and therefore the centre-of-gravity placement.

However, it should be remembered that an electrical wire has resistance and that a long lead

will result in a voltage drop due to this resistance. The voltage drop will result in a power loss.

Here is an experiment carried out to test the effect of long leads. A 2ft lead was introduced between the ESC and the fan unit, to enable the fan to be placed at the back of the plane while the battery and ESC were near the front:

| | V | A | W | Thrust in g |
|-------------------|----------|----------|----------|--------------------|
| No leads | 11.4 | 35 | 392 | 1020 |
| Long leads | 11.3 | 33 | 379 | 990 |