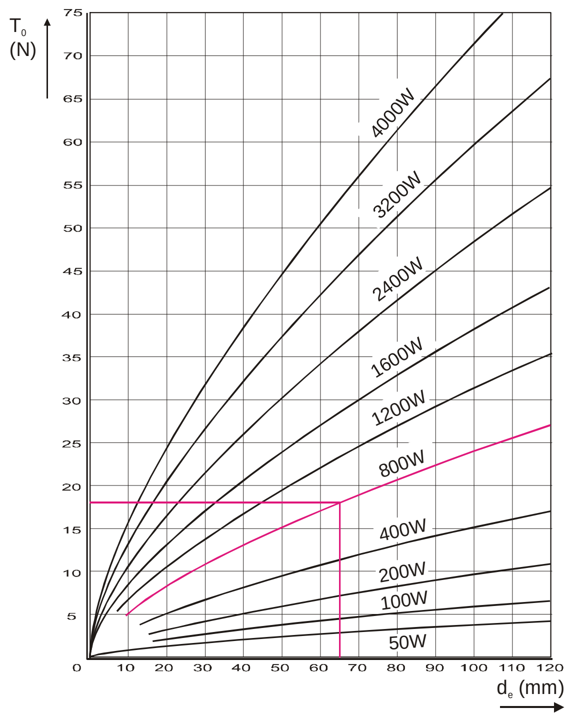
Basics of Electric Ducted Fans

One of the most frequently asked question refers to the thrust which an EDF can develop. This can be answered in different ways dependent on your point of view and fierce discussions usually erupt in discussions about this subject. When all secondary influences have been eliminated however one can find that two major factors are primarily responsible: the motor power and the EXIT AREA of the fan air jet. Under normal circumstances the NOZZLE EXIT AREA will be in the region of 70 to 90 % of the fan ANNULUS area (also called FSA = fan swept area) and if a short piece of conical duct is used to achieve this one can usually neglect the thrust loss associated with the extension, when it is not longer than say one or two nozzle diameters.

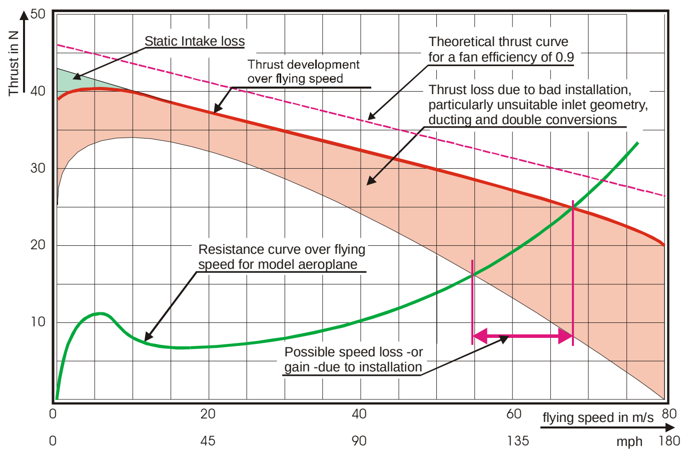


Static thrust T_0 of a ducted fan depending on nozzle diameter d_e for various power inputs

Winchester Models K. R. Scharnhorst ©2006

This rather basic but surprisingly accurate (and therefore useful) interrelation is depicted in the graph to the left. It shows the change of (static) thrust over the exit diameter for various powers. Alternatively for a fixed exit it shows the increase in thrust at various power levels.
If you want to know the thrust of a particular fan installation, first establish the exit area and find the power which the motor provides at the shaft. Where the power line crosses the area diameter you can read off the thrust at the scale on the left side of the graph.
On modern brushless motors the shaft output power can be taken as about 80-90 % of the electrical input power.
As an example let's take the 800W line (=1000W power input). The line is highlighted red in the graph.
The exit diameter of the thrust tube (nozzle exit) has been chosen to be 60mm and the intersection of those two lines indicate a thrust of around 18N ~ 1.8kgf.
Now this is only the static thrust and this will reduce significantly with the flying speed, but as a first approximation this graph can be quite helpful. It certainly puts an end to unrealistic claims of some fan manufacturers.
At the lower end of the power spectrum it becomes difficult to establish reliable values due to the scale of this graph. If there is sufficient interest I could calculate and draw a separate graph especially for this section.

The thrust decay over the flying speed is a fact which can be easily calculated using first principals of physics. There is unfortunately no truth in the often miss-reported hearsay that the thrust increases with flying speed. It may be based on the observed sound effect which sometimes derives from the fan in the start phase.
Basically there is nothing to be done to increase thrust at flying velocity – apart from adding power. But that would then be available for the static case as well, so we are back to square one.



Typical relation of EDF thrust and model drag over the flying velocity (including the influence of inappropriate ducting).
The values apply to a 2-3kW WM1000 system.

Winchester Models
K. R. Scharnhorst
©2006

The graph on the left shows the typical thrust behaviour of a ducted fan installation.
The same applies to smaller EDFs in proportion.
The pink under-laid area indicates the influence of the ducting, be it very well done or rather badly; the velocity gain can be up to around 23% in this case for the same model (apart from the ducting)!
It also shows that there is always less static thrust available in the installed situation as compared with the static thrust measurements done in a test stand. This is caused by the small intake lip curvature compared to the bell mouth shaped intake for testing. The intake loss in the static situation can be more than 50% of the advertised thrust, if the intake is badly designed with sharp edges and increasing cross section downstream (diffuser). This becomes particularly pronounced on small and less powerful EDFs. But one can also see that the thrust in that case can increase with the “flying” speed to a certain extent; and this phenomenon probably has led to the hearsay as mentioned further up.

Apart from the absolute power and the diameter of the exit nozzle the next important aspect which influences the thrust of an EDF (as we have seen above already) is the design of the ducting, which can ruin the performance of an otherwise good fan if not done correctly. The fan shroud resistance is usually incorporated in the fan thrust values and is left out of the calculations here. In total it amounts to about 2-3% thrust loss at normal operating conditions.

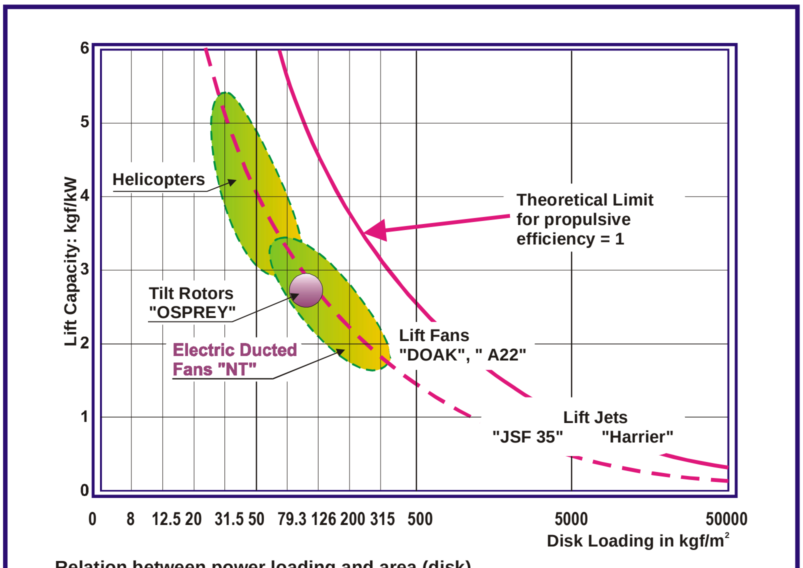
Another one of those ominous questions about ducted fans concerns the efficiency of those machines, absolute and in comparison to normal propellers.
Despite the fact that efficiency is an accurately defined entity one can often see a term – N/W or oz/W (thrust/power) masquerading as such but which is not the efficiency at all, giving an indication of how much thrust is produced per unit of input power. This is a variable figure which depends on the design parameters of the propulsion unit and is not to be used as an indicator of the merits of a device.
The term efficiency for ducted fans (or any propulsion unit) is a measure of how much input power is actually converted into propulsion. The latter is the amount of energy transferred to the mass flow. Efficiency is a factor smaller than “1” (or <100%) without a dimension, whilst thrust/power (N/W or even oz/HP) has a dimension [N/W].

Below is a graph which shows the spread of power loading for various propulsion methods from the light helicopter to the high power Osprey tilt rotor and the even higher powered lift jets Harrier and JSF 35. The vertical scale is the thrust to power ratio, which goes up to 6kgf of thrust per kW, and the horizontal scale is the disk loading, which extends to 50,000kg/m^2.

The disk loading is an entity similar to the wing loading of the whole plane. One can generally say that the higher the disk loading the less thrust can be developed from a unit of power; better understood in the reciprocal form: more power per unit thrust.

A simple equation T=m *dv expresses the thrust in physical notation. T depicts the thrust, “m” is the mass flow and dv the velocity change of the mass flow through the propulsive device. One can see that for a certain thrust value one can use a high mass flow with a small dv, or a small “m” with a high velocity difference. The graph here can be seen as a visual expression of this behaviour using the disk loading to represent the velocity difference: a high disk loading represents a high velocity differential.
A curve of particular interest is the line marked “Theoretical limit for propulsive efficiency = 1”. Any real device would be in the region to the left and below that line. If a particular fan advertises parameters which would place them to the right and above that line the efficiency would be greater than 1 – long live the perpetuum mobile!

I have purposefully drawn the EDF’s power spectrum very wide to cover the reality as I find it in the model world: on one end the low powered smallish fans of the far east GWS provenience and on the other side the high power variety of the “black brigade” exemplified by DS and similar.



Relation between power loading and area (disk) loading for various propulsion methods.

Let’s look at the extreme ends of the covered EDF spectrum: at the low end, left on the red power line we find values of 3.5kgf/kW with the corresponding disk load of 65kg/m^2. Converted to a small EDF this calculates to 70gram of thrust produced by 20Watt of (shaft) power. The corresponding disk load is 65kg/m^2 or 6.5gram per cm^2 which calculates to a nozzle diameter of 37.5mm.
A high performance 90mm EDF exhibits values which are settled at the other end of the bubble:1.7-1.8kgf per 1 kW (shaft) power and a disk load of around 315kgf/m^2 = 31.5 gr/cm^2 results in an area of 57cm^2 which equates to about 85mm exit diameter.

This is a very good tool for performance comparisons; EDFs who’s values are outside the bubble or even lie on the wrong side of the efficiency = 1 curve should be viewed with caution.

In the next instalment we will deal with ducting issues – design and analysis

Have fun with fans!