WATTS UP?

EDDIE CURRENT continues his thoughts on the practicalities of electric ducted fan power

A Dornier Do328 takes to the air with a little assistance

Experience shows that the ideal flow conditions for any fan unit is the 'bare' condition, with no added ducting but a smoothly faired motor. Adding ducting to the intake or efflux, even if perfectly executed, will *always* reduce the thrust available. The longer the ducting, the bigger the losses! The trick is to do it in a manner that keeps the airflow as smooth as possible without unduly restricting it.

As mentioned previously, the thrust from a fan unit is obtained by accelerating the biggest possible mass of air to the fastest possible speed, within the constraints of duct size and motor power. This requires that we must use all the motor power to maximise the acceleration *(Delta-V)*.

Optimised for acceleration, our fan makes a very poor compressor, being incapable of generating a very big *Delta-P*. If we restrict the airflow by excessive length, poor design or poor construction of the ducting, the fan sees this as a pressure rise - and may stall and stop working if the back-pressure exceeds its limited *Delta-P* capability.

The design of fans and their blading is partly to do with the primary *Delta-V* function, and this can be done using well-known techniques. The black art in fan design comes in designing a fan with a good *Delta-V* and also a good *Delta-P*. In general, the larger the fan is for the power (like the *Eco 2* for instance) the more tolerant it is of duct losses. However, the bigger duct for the bigger fan has its own disadvantages in terms of 'wetted area' and other factors - let alone fitting it in a model!

Duct design needs to take account of *Bernoulli's Theorem*, well known to engineering students - but not modellers in general. This states that, for a given mass flow in a pipe or duct, the area times the velocity should be constant, at constant pressure. It's a bit like an internal 'area rule', which many aeromodellers may understand. Unwarranted excursions from this condition cause the fluid (air in our case) to become turbulent and 'choke' the flow. Lets look at the importance of this for a ducted fan unit.

The first thing is that the same amount of air comes out as goes in, thus the mass flow is constant through the unit. Ignoring ram effect (which I'll explain later) the air going in the front is at atmospheric pressure and at the intake velocity - let's say 50mph. As the air passes through the fan, it is accelerated to a higher speed, let's say 100mph. This acceleration produces positive thrust.

Boeing 777 by the highly-productive Dave Chinery

To comply with the Theorem, the cross-sectional area of the duct at this point must be about half that in front of the fan! Very conveniently, most model units have the motor right behind the fan, 'filling up' the centre part of the duct diameter and reducing the area available for the air to flow through to the annular space round it. That is why you

The keep-it-simple approach to jet flying, with a Beriev Albatross, Hawk and a U-2 will rarely see a motor in front of a fan - i.c. or electric.

OK, we've accelerated our air and squeezed it down into a narrow space to keep it happy. What happens when the air gets to the back of the motor? Let's assume that the duct diameter stays constant. When the air gets past the end of the motor, suddenly the cross-section for the air to flow in 'grows' to the full area of the duct.

Conforming to the natural Law discovered by Bernoulli, the air will slow down again to its original speed before the fan, or actually even less!

The extra deceleration is due to turbulence and other losses like the drag of the wires to the motor. All this deceleration causes a force opposing the fan thrust, in the worst case reducing it to zero! We are now burning amps from our NiCad pack just stirring up the air!

In practice, there are several ways to reduce these losses. The simplest way is to just extend the motor with a parallel tube the same diameter, as far as the end of the duct. The passage for the air is thus maintained at a constant cross-sectional area in the parallel annulus. Alternatively, the duct can be tapered (gently) to a diameter at the exit having identical area to the annular space round the motor.

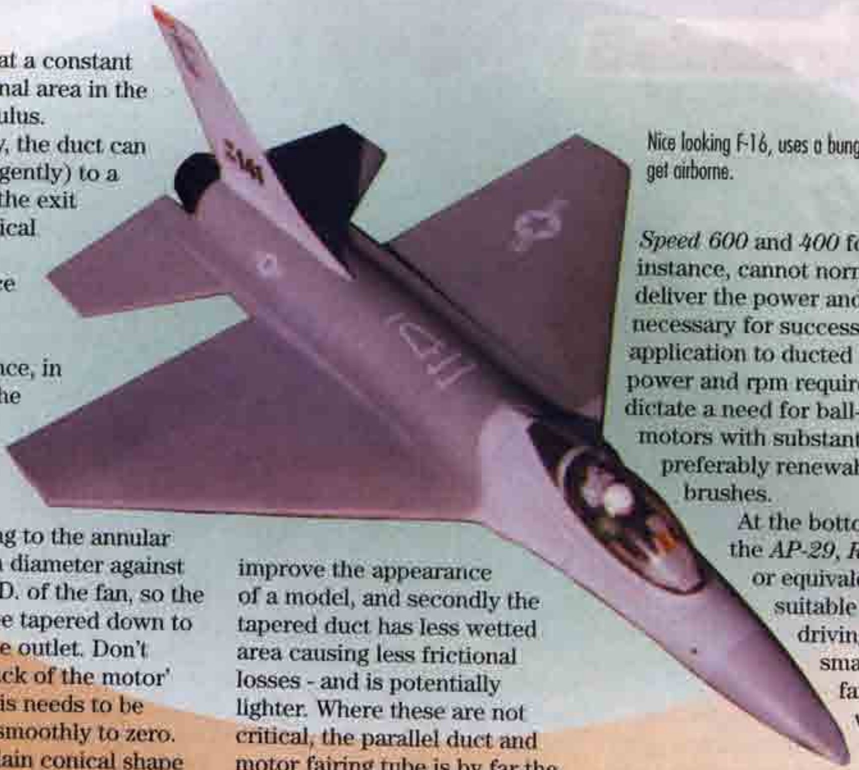
For instance, in the case of the *Jet-Elec* the plain circular area corresponding to the annular area is 50mm diameter against the 65mm O.D. of the fan, so the duct would be tapered down to 2in. dia. at the outlet. Don't forget the 'back of the motor' syndrome: this needs to be faired down smoothly to zero. Although a plain conical shape will do, in theory this needs to be a slightly different shape to a smooth cone to keep the duct area exactly constant along its length.

There are two reasons for using a tapered duct, firstly to allow a smaller efflux hole to improve the appearance of a model, and secondly the tapered duct has less wetted area causing less frictional losses - and is potentially lighter. Where these are not critical, the parallel duct and motor fairing tube is by far the easiest and most effective.

Going back to the intake end, it is important that the air enters the fan smoothly, while some sort of smoothly radiused bellmouth is essential. Once the model is at flying speed, the ram effect will force more air into the fan, increasing the mass flow. Full-size intakes exploit our friend Bernoulli by making the actual intake smaller than the engine intake area.

The increase in cross-section actually uses the ram effect to pressurise the air entering the engine, increasing the power and efficiency in flight. At low speeds on the ground, the small 'hole' would unduly restrict the airflow, and most full-size intakes have 'suck-in doors' which open to allow extra air to the engine. These can often be seen just behind the intake lip, and are especially prominent on the *Harrier*.

Having gained a little understanding of duct design, and fan hardware itself, lets now look at how we drive it.



Nice looking F-16, uses a bungee launch to get airborne.

Yet another twin jet by Dave Chinery: a Martin WB57-F with a pair of home-made fans

Chris Goulds was the designer/bulder of this DH110 Sea Vixen

Motor mouth!

Suitable motors for ducted fans must be powerful for their size and must run at high rpm. Standard *Mabuchi* or *Johnson* type motors, like the *Speed 600* and *400* for instance, cannot normally deliver the power and speed necessary for successful application to ducted fans. The power and rpm requirements dictate a need for ball-raced motors with substantial (and preferably renewable) brushes.

At the bottom end, the *AP-29*, *Race 480* or equivalent are suitable for driving the smaller fans, while for 'standard' size ones, the 'modified'-class *540* motor is the best choice. The best available motor for the smaller sizes is the *Plettenburg 200/20/6*, which is the same size as the race *480* but delivers much more power and efficiency due to its Neodym magnets. However at around £90 each, these will be out of most people's budget! If that doesn't scare you, how about an *Astro .05* brushless motor at about £200?

Select a motor with a 'wind' that will see it free-run at 25,000rpm or more on the intended NiCad pack so it can still turn at about 20K with a fan on it. At the larger end, above *540* size, all motors will be premium ones, it's just a matter of selecting one with the right power and 'wind' for the job.

Cool Britannia?

The motors are going to be running flat out in the fan application, and we should not neglect their cooling. Fortunately air flows over the exposed brushes quite freely, and we must allow for this when fitting a rear fairing cone.

As far as the inside of the motor itself goes, experience shows that air often flows in reverse, entering via the brushgear and being pumped out of the front, by the back of the fan acting in centrifugal mode. The brush carbon found on the back of a well-used *Jet-Elec* fan when removed proves this happens.

Supplies!

The best fan and motor will not perform well unless adequately supplied with power. Whilst you can get away with lower quality speed controllers, connectors, tired NiCads, etc, for soft-fly sport models, ducted fan ones need the best you can afford. The entire supply chain is important, and can be let down by a single weak link like a duff connector or dry joint. Use 4mm 'gold' connectors if possible, with adequately-sized wire, and a good quality speed controller with a generous current rating. Good NiCads are essential.

They don't have to be new, but must be able to deliver the high current drawn by most fan units without too much voltage-drop. The comparatively short flight times 'enjoyed' by electric fan models means that it is unnecessary to cool the NiCad pack in flight, just get them out quickly for cooling after landing.

Fairchild A-10 (prototype) by Dave Chinery

Putting it into practice!

Now we've covered most of the factors affecting electric ducted fans, let's return to Mr Carter's problem. The *Meteor* is one of the more difficult subjects because of the (scale) length of the nacelles compared to the size of the `oles. To get the best combination of this, later Marks of *Meatbox* like the F8 are best, although these have the penalty of reduced area 'clipped' wings.

The early Marks with the bigger wings cannot be modelled to true scale as the ducts are far too small to be practical. The later *Armstrong Whitworth* night-fighter *Meteors* may be a better bet, as they have the larger wing and the better nacelles but suffer from a longer and bulkier fuselage instead.

There are several ways to 'cheat' by making the duct size out of proportion to the model. If a semi-scale model is acceptable, then by far the easiest way is to build it with profile 'nacelles' rather like the fuselages of the *Fun-Jets* from Dave's past. The fans, mounted on the front end of the nacelles just blow air over them and the wings. That's a solution which is simple, easy to build - and will fly well if it's the right size.

Size and Weight

Whatever the choice of Mark and degree of scale fidelity, Mr. Carter needs to keep in mind several points about EDF models. Assuming that a good fan and duct installation is matched by adequate power from the motor and supply system, the next one is that of size and weight. It is a mistake to build an EDF model that is too lightly loaded!

For instance, Dave Chinery's early twin-jet models (for two *Jet-Elecs* and up to 14 cells) started out at over 150cm span, and getting on for 3kg in weight, due to the large airframe. Flight performance was marginal to adequate. Recognising that model jets will only fly in the correct manner is they are similarly 'dense', i.e. heavily loaded, Dave's latest models like the *Mega-Jet* seen at Olympia recently, have airframes half the size and two thirds the weight for the same fans and NiCads.

Although the wing loadings have gone up, the ratio between thrust and weight is dramatically improved, as also is the drag of the much smaller airframe. Even using the so-called 'obsolete' *Jet-Elec* fan units, the *Mega-Jet* flies well, is more aerobatic than one might expect from the Biz-jet layout, and can fly for over five minutes on the new Sanyo 3000SCR NiCads.

My recommendation for Mr Carter is to keep the model size to about 1000-1200mm (40-48in.) span (depending on whether is it a 'clipped wing' Mark or not). The quick and dirty solution is to use the profile nacelles with a pair of inexpensive *Jet-Elecs* on the front, driven by two 16-turn *540* motors and supplied by two standard-shape seven-cell packs of NiCads which might be fitted either in the nacelles or spanwise in the inner wing.

Another way would be to power both motors in parallel from a single pack of 3000s, but you will need a 60 Amp or better speed controller!

The later *Meteor* fuselages were long compared to the wingspan, but scale fuselages need not be a great weight burden if care is taken with the design. Alternatively, one could easily design a profile fuselage to match the nacelles!

A closer-to-scale *Meatbox* can be built to about the same size using two *WeMoTec 480*-size fans and appropriate motors. Mr Carter obviously didn't see the May/June 1998 edition of *Flying Scale Models*, which featured a free plan for a *Mk 4 Meteor* designed by Paul Tupker and flown at the *1997 Jet Masters*. The 1050mm (41in.) span model used two Robbe Rojet units powered by two *Race 480* motors supplied from a single pack of eight Nicads, and with careful design and a light airframe the model flies reasonably well. If Mr Carter wants to build one of these models, I'd suggest using the *WeMoTec* units instead of the *Rojets* as they produce more thrust with the same motors.

The accompanying article suggests a range of alternative better and more expensive motors similar to those we have covered above. The builder eventually ditched the inexpensive motors as short brush life was giving frequent (and highly inconvenient) motor failures. The final (expensive) option was two small brushless *Lehner* motors. Whether he is willing or able to pay that kind of money for true 'jet fighter' performance, only Mr. Carter knows!

Thrusting ahead!

That's pretty well covered electric ducted fans for now, and hopefully given Mr. Carter enough information to be going on with. Next month, we'll turn our attention to another area of electric flight technology, and maybe help another reader in distress. Remember, if you have an electric problem, *Auntie (Uncle?) Eddie* is here to help!


Lockheed S3 Viking by John Swain is not for the faint-hearted...