Dumfries Model Flying Club

Electric Flight

The Basics Explained

Contents

Electric Flight - the basics and beyond

This article is written for the benefit of new beginners taking up the hobby for the first time and for those returning to the hobby after several years absence - and also for those experienced aeromodellers who would like to expand their knowledge of what might appear to be the murky and mysterious waters of electric flight!

Introduction - and a bit of history

In the past few years electric-powered flight has become accepted as "mainstream" - a situation very different from just a few years ago. In the early days of electric flight, it was not only regarded as quirky, but its exponents were almost universally disparaged by the wider world of aeromodelling, wedded as it was to the internal combustion (i/c) engine. It seems incredible today, but back then, even in the main modelling magazines, the very word "electric" was printed with asterisks substituted for certain letters, as if it was a dirty word! Hard to believe now, but that is absolutely true!

And because electric flight back then required hauling a heavy NiCd (Nickel-Cadmium) or NiMh (Nickel-Metal Hydride) battery around the sky with inefficient brushed motors, very lightweight airframes were needed, and consequently many electric models were made of styrene foam. So another disparaging term: "foamies", was coined!

It is true of course that the heavy weight of those old metal-cased batteries, did place severe restrictions on electric flying compared to the glow or petrol engine. Not the least of these limitations was that very few were able to do a roll-off take-off from the ground - nearly all had to be hand-launched and belly-landed. The models were necessarily small and lightweight compared to i/c powered models, and this made them more twitchy and more difficult to fly in windy conditions.

However, even in those early days, it was immediately apparent to those of us who were the early "pioneers" of electric flight that, despite its limitations, it nevertheless offered some very distinct and valuable benefits compared to i/c powered models. The first was immediately apparent - it was incredibly quiet by comparison with i/c. (Indeed this was one reason why some of the i/c guys hated it - "aeroplanes should be noisy"). The second, and not insignificant benefit initially seemed lost on the dedicated i/c fraternity, but not so on those of us who were drawn to electric flight. We quickly realised we were getting a lot more flying time per field visit compared with the i/c flyers. We could turn up, stick a battery in the model and go fly! And then a few minutes later do the same again, and again, until we ran out of batteries.

Electric motors, even the old brushed ones, were not only quiet, they were also clean and reliable. They didn't need tuning. The model didn't need to be fuel-proofed, or wiped clean with an oily rag before it could be put back in the car. Although electric flights were of rather shorter duration than i/c models - 5-8 minutes on average, (a lot longer for powered gliders), a lot more flying was done. It was observed that many who flew glow plugs could spend their entire time at the field trying to get their engines to fire and run smoothly. Another benefit was also apparent, and this was especially true of the poor demeaned "foamies". Because they were moulded, and did not need cylinder-heads and exhaust silencers poking out of the airframe, spoiling their looks, scale foamies such as WW2 warbirds were usually far more scale-like in appearance, and as the full-size warplanes had retractable undercarriages, it didn't matter that the foamies were hand-launched belly-landers - they still looked great!

Electric-powered models also launched a completely new model flying experience - indoor flying, something never possible with i/c engines. In many clubs this has become a very popular winter pastime.

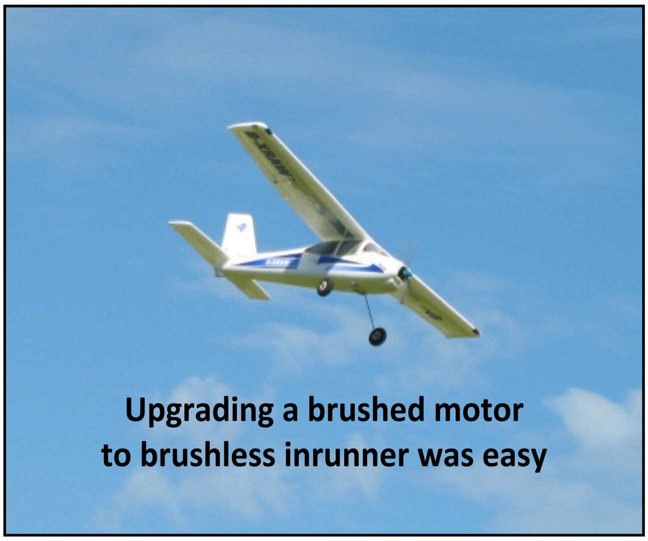
Still, it had to be admitted that most electric models were small and lightweight, less easy to fly, especially in windy conditions, and unable to take off from the ground. It was also argued (not very convincingly) that the initial costs were higher than i/c due to the cost of needing several batteries and ancillary equipment such as a dedicated charger.

But then along came a huge leap in battery technology - the Lithium Polymer (LiPo) - far lighter than the old NiCds and NiMhs, with much higher power-to-weight capacity. Then, around the same time, came brushless motors - far more efficient than brushed, and with no brushes to wear down.

Indoor flying in a sports hall

The combination of LiPo batteries and brushless motors, arriving more-or-less together as they did, absolutely transformed electric flight. Now you could not only upgrade older electric brushed motor models with new brushless motors, but with the right skills you could electrify i/c models too!

With this new-found power, traditional built-up (balsa/ply/film-covered) models could also be electric-powered. And even the electric foamies came of age! Now being made with a new and more durable foam material - EPO or Elapor®, they were also getting better and better. Roll-off take-offs and even electric retractable undercarriages - no problem.



Upgrading a brushed motor to brushless inrunner was easy

In a similar time-scale, with housing encroaching closer and closer to established Club flying sites, the unavoidable noise of i/c powered model flying was becoming a serious issue, and numerous clubs around the UK began to lose the use of their flying fields as a result. Indeed the DMFC was similarly affected, and the club was forced to move from Heathhall to Bankend.

So the scene was set for a massive take-up of electric power for model flying which has increased ever since, and continues to do so, to the point where it is now a mainstream power-train throughout the aeromodelling world, and the preferred power-train of choice for many model flyers.

This is not to say that glow and petrol power are dead - there are still those who prefer it - but there are now no grounds whatsoever for regarding electric power as somehow second-rate. Indeed in international aerobatic (F3A) competitions, electric power has become the norm, to the point where it is now rare to see i/c models in these competitions at all.

To Learn or not to Learn?

For those aeromodellers who are used to i/c, there may be some initial dismay at the apparent complexities of electric power compared to i/c. Consequently, rather unfairly, electric flight initially gained a bit of a reputation as a "dark art".

So, seeking to counter these perceptions, many model manufacturers simply removed these perceived complexities by either supplying their models complete with the electric components all fitted and ready to fly, or selling them separately as complete pre-specified packages of components matched to their models for the buyer to install.

From the earliest days of electric models it was possible to buy the complete deal as a single package: model, with motor and speed controller already installed, and even a 35Mhz transmitter to go with it. It was unusual to find one which didn't need some assembly, but otherwise it was ready to go, and as soon as the aircraft was glued together you could go and fly it.

Today, with 2.4Ghz transmitters, brushless motors and LiPo batteries, things are much the same, except that many models just bolt together with no gluing required at all. Apart from reading the brief manual that came with it, you don't need to understand anything about aerodynamics, airframe design, or the intricacies of an electric power setup.

Even when models arrive without the electrical innards installed, either the manufacturer or the model supplier can usually be relied upon to recommend and supply a suitable electric power train without your having to learn much about the technicalities at all. Modern living seems to demand instant results "straight out of the box", with no need for engagement with how things work.


This model came with everything installed and it just screwed together - no glue required

Nevertheless it has to be admitted that this has brought many people into the hobby who would otherwise never have had the time, the skills or the inclination to delve deeper into the technical mysteries.

But you shouldn't make the mistake of thinking that there is only one "ideal" motor setup for your model. Indeed some manufacturers (Multiplex being one example), often offer a choice of power trains depending on how you want to fly ("Standard" for ordinary sport flying, or the "Power" setup for those who like to fly fast and throw their models around the sky).

This should tell you that in electric-powered flight there are lots of different setups you could choose from if you had the knowledge to make these decisions for yourself. And there can be other very good reasons why this could be of great benefit to you:-

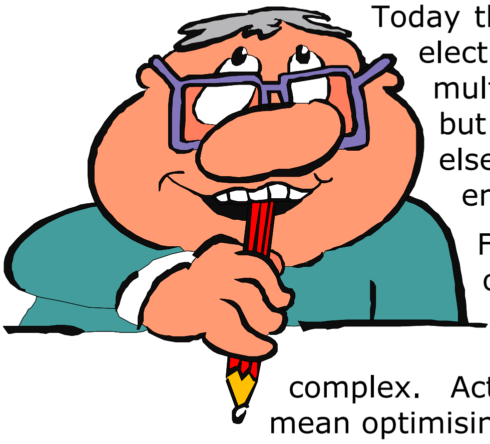
- The first is cost. The packaged power trains offered by model manufacturers can be considerably more expensive than sourcing the individual components yourself, and in any case may not be the most appropriate for the way you like to fly.
- Conversions - you might want to upgrade a model from a brushed motor to brushless. Also, many models designed originally for i/c power can now be converted to electric power, but you need to know what you're doing when it comes to choosing suitable electric power components.
- Building models from kits, or scratch-building from plans. In such cases, you are pretty much on your own, and specifying the power system is just as much down to you as building the airframe.
- Even if you buy models with the electric components ready-installed, they can fail and need replacing, and if the original model is out of production you'll have to source the replacement components yourself.
- As your flying ability improves you might wish to upgrade the performance of a model.
- This last benefit is a personal one. Understanding how things work is interesting and can add a new dimension to your hobby. Of course that means embarking on a new learning curve which might require a little effort, some reading and self-education, but this can be a rewarding experience which can enhance your enjoyment of the hobby.

For all these reasons it is desirable to gain some understanding of how to choose and specify a suitable electric power setup. But if you're new to the hobby and simply want to leave the technicalities until later, that's fine. Or if you're an old hand who's comfortable with your existing level of technical knowledge, that's also fine, there is no need to feel guilty!

The choice is yours: it is possible to happily rely on the knowledge, experience and recommendations of others for your entire model flying career; but if you are interested to learn more, read on ….

An interesting new learning curve

It is not the purpose of this article to cover every technical detail regarding electric-powered flight. It is intended rather to be an introduction to the subject for those new to this form of model power and wanting to understand the basics and perhaps a little beyond. Or maybe to build on existing knowledge, or provide some timely reminders, for those who already "fly electric".



Today there is virtually nothing that an i/c engine can do that an electric model can't. Electric power can now fly large models, multi-engined models, helicopters and multi-rotors and more, but those wanting to fly these will need to do some more reading elsewhere. This information relates only to normal single-engined "club-sized" fixed wing models.

For those who only have experience of i/c models, there are, of course, some significant differences to get to grips with, and some things which seemed simple and straightforward in i/c might initially seem strangely mysterious and complex. Actually it isn't really all that complicated at all, but it does mean optimising four different components to work in harmony.

The Power Train System

It is important to understand that in electric flight the motive power comes from a system of four related and interdependent components. At first this might seem complicated when compared to simply matching an appropriate size of i/c engine to an airframe. The four components of an electric-powered model aircraft are all variables which must be correctly matched to function optimally with each other, and changing any one may necessitate changing the others. This also means that for any given airframe there could be quite a wide choice of options to consider.

The four components of an electric power-train are:-

- the Electric Motor
- the Electronic Speed Controller (ESC)
- the Flight Battery (sometimes called the Flight Pack or Power Pack)
- the Propeller (Airscrew)

The inclusion of the propeller may seem surprising as it is clearly not an electronic component, but electric flight introduces important choices here too - far more so than with i/c engines - and the propeller specification has an integral part to play in the choice and specification of the other components (more on this later).

With i/c, the size of the engine would largely determine the size of the propeller to be fitted, so it was largely a matter of matching the size and weight of the model to the appropriate size engine, and since models were generally advertised as .25 or .40 etc., selecting the right propeller was not complicated. Electric flight is just not like that.

You might find people referring to Ohms Law a fair bit! They'll talk about watts-per-pound or kilogram. Speed controllers have Amp ratings - usually two - one for continuous power and another for short bursts (this applies to motors and batteries too).

Motors can be run with a variety of propeller sizes and pitches, depending on several other factors in the entire power train configuration. And though we've all used batteries for years in torches and cars, the issue of C rating (what's that?) has never come up before!

And just to cap it all, there is no agreed standard for specifying a brushless motor size between the various manufacturers, and even the documentation supplied with motors (if any!) is often minimal so that some calculation (Ohms Law again!) and experimentation is needed to get the performance parameters right for a particular model.

But the fact is that, once you set your mind to it, the electric flight learning curve is really not too long and steep. Even Ohm's Law is a very simple equation that enables you to balance the three different parameters that determine how an electric power-train will perform.

OHM'S LAW

Watts = Amps x Volts

Watts is a measure of power, so if you weigh a model to determine its all-up weight, and then refer to a simple table to determine how many Watts you need the power train to produce for different levels of performance, you're already half way there!

Performance chart for electric power

Watts per lb	Performance	Watts per Kg
< 35	Not adequate	< 80
45 - 60	Slow Fly or Park Fly Models	100 - 135
60 - 75	Trainers, Multi-Engine	135 - 165
75 - 100	Sports Models, Scale Warbirds	165 - 220
100 - 150	Advanced Aerobatics and High Speed Models	220 - 360
135 - 200	3D Models, EDF Jets	300 - 440
200 +	Unlimited 3D Models	440 +

The above table isn't a perfect guide, but it is adequate for most practical purposes. The higher the wing-loading, the faster a model will need to fly to stay airborne. So, the first thing to do is to determine the approximate All-Up-Weight (AUW) of the model. Then, using the chart above, we can see how many Watts the power system will need to deliver. Once we know that, we just have to decide how to balance the other two parts of the equation - Amps and Volts - to deliver the Watts we need.

The easiest parameter to get to grips with is the Voltage. This is determined by the type and number of cells in the battery pack. Let us assume our model is a sports model weighing 1Kg. We want to generate 220 Watts of power and the space in the airframe fuselage will accommodate a 3S 2200 battery pack - don't worry, we'll come back to battery specification later. A fully-charged 3 cell LiPo is rated at 12.6V, although the actual voltage it delivers will reduce somewhat under load, and gradually decrease through the flight duration, so let's assume average voltage under load through the flight will be around 11V. So, using Ohm's Law above, we get 20Amps.

So we might assume that all we need is a motor and ESC that are rated at 20A and we're home and dry. Well almost - but it's not quite that simple - remember there are FOUR components in an electric setup, and we cannot leave the propeller out of the equation.

We must also be sure to build in some "headroom" in the specification of both motor and ESC. By "headroom", we really mean safety margin. In the example above, both motor and ESC should be specified to at least 30A continuous.

Electric motors and ESCs get hot in use and they need to dissipate this heat. By having extra specification headroom they will not get so hot, and will also have the ability to dissipate heat more easily. In fact the data sheet supplied with the motor (or in some cases separately downloadable from a website) will specify the number of LiPo cells it can be used with, and may relate this to various propeller sizes too. The better ones actually tell you the Watts and Amps numbers for some popular propeller sizes and LiPo cell configurations.

You might notice that these data sheets indicate that a larger diameter propeller can be used with smaller number of battery cells and vice versa. All will be explained!

Propellers

As we touched on earlier, the choice of propeller has a significant bearing on everything else. It should be obvious that an electric (or i/c) power system delivers actual power by turning the airscrew (propeller) through the air. ***How much*** power is determined by three factors:- the diameter of the propeller arc, the amount of twist (pitch) in the propeller, and the speed at which it is turned (RPM). Of course all this applies exactly the same using i/c power, but perhaps it does not need to be given quite so much consideration with i/c as it does with electric power.

Most manufacturers of propellers produce a range of propellers specifically designed for electric flight and you should always use these. They are usually lighter and thinner than i/c props as they do not (should not!) have to cope with the same degree of vibration that an i/c engine would produce.

With all propellers however, the diameter and pitch is revealed in its specification. A 10x5 prop has an arc diameter of ten inches (metric equivalents are usually embossed or printed on the prop too, although in this context imperial measurements have prevailed). The 5 indicates that there is half a turn of twist in the prop between the hub or boss and the tip. A 10x10 would indicate a full twist. So the larger the second number in the spec, the coarser the pitch of the propeller is said to be. The lower the second number, the finer the pitch is said to be. So what?

Let's deal first with the pitch. This is just like the gearing of a car or bicycle. A fine pitch propeller is the equivalent of low gear. It puts less strain on the motor. It cuts cleanly through the air right from the start to give a good "bite" and therefore good control. But it would have to be turned at a tremendous rate to produce much forward speed. (Think of a cyclist pedalling uphill in low gear - the pedals are whirring around because the cyclist's leg muscles are not meeting too much resistance, but there's not much forward speed).

Electric Propellers

Conversely a coarse pitch propeller with a lot of twist is the equivalent of high gear in a vehicle or bicycle, although with a slight difference. A car would have difficulty moving off from stationary in top gear because the weight and inertia, coupled with the friction between tyre and road would put too much strain on the engine and it would stall. Because air is thin, a motor will still be able to turn a coarse pitch prop, but the motor will be put under more load until higher airspeed is attained. Also, the prop will tend to churn up the air at low airspeeds without producing very much traction - a bit like wheel-spin in a car stuck in soft mud.

So a coarse pitch is what you'd want for a high speed model, but you would need to understand that at lower airspeeds - if you had to abort a landing for instance - you won't get the rapid surge pick-up of airspeed that you'd get with a finer pitched prop. And if you have a heavy or high-drag model for which speed is not required - a powered thermal glider for instance, you would tend to choose a finer pitched prop.

Full-sized prop-driven aircraft usually have the benefit of variable pitch propellers, and although technically possible for models, they are very expensive, add a lot of weight, and consequently are very rare. For most sports and trainer models a medium pitch prop works best (eg. 9x4.5, 10x5, 12x6 etc.).

We've now seen that the propeller pitch has an effect on how hard the the motor has to work and it should be obvious that the diameter of the prop arc has a similar effect. The larger the prop arc diameter the harder a motor must work to turn it. In fact the diameter has a much greater effect on this than the pitch.

What this means is that we must take these things into account when we consider Ohm's Law, because for a given RPM, a motor turning a larger prop will produce more output power but have to work much harder to do it, and similarly (though less so) with a coarser pitched prop.

And of course you don't get anything for nothing, so just as a harder working i/c engine consumes more fuel, so it is with an electric motor - it has to pull more current (Amps) from the Flight Battery, which will reduce the flight duration. But that's not all - by fitting a larger or coarser prop to increase the power output (wattage) and thereby increasing the Amps draw from the Flight Battery, you could burn out the motor and/or ESC by exceeding the Amps rating of these components.

In practice, the RPM would also reduce under load because of air resistance, and could not necessarily be sustained using the same motor. So if we want a larger prop, or a coarser prop, but want retain the RPM, we will almost certainly need a bigger motor. Couldn't you maintain the RPM by increasing the voltage? - theoretically yes, but that would still be likely to burn out the motor, and even quicker! Motors get hotter, the harder they have to work - as we all do!

So the choice of propeller, especially the arc diameter, is a very important factor in specifying a motor/ESC combination.

While on the subject of propellers there are a few more things to cover here. There are several manufacturers of propellers for electric models, but they do vary considerably in quality and performance.

For many years APC dominated electric flight with their APC-E range of props specifically designed for electric flight, and they are probably still the most popular. However, be aware that both APC and other manufacturers offer two types of electric propeller: the so-called "thin electric" and the "Slow-Fly" (or slo-fly). Slow-Fly props are, as you would expect, designed only for slow, very lightweight models, including those designed for indoor flight. If you've been following the above closely, it will come as no surprise that Slow-Fly Props are almost always relatively fine-pitch. They also have a much reduced maximum safe rotation speed and tend to be rather flexible and "bendy". Slow-fly props do have their place in electric-powered flight, but never install one on a normal model for flying at the field.

One of the issues that arises frequently for UK aeromodellers, affecting numerous modelling components, is the relationship between metric and imperial sizes. This is largely because the USA is the largest modelling market and has stubbornly resisted metrification so far. So props are always specified in imperial sizes, though metric equivalents (mm) can be found if you look for them, whereas motor shafts are invariably metric. This has implications for the hole in the central boss of the propeller and not infrequently there is a need for the hole to be made larger or smaller. Some brands of propeller are supplied with collets to make the hole smaller, but even these don't always fit the prop adapter shaft, so an inexpensive prop reamer can be a useful purchase.

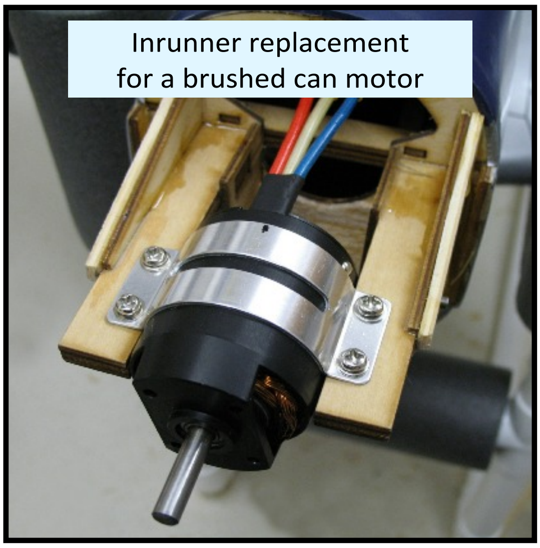
Another tool which is really needed for electric flight is a prop balancer, but make sure you get one for electric propellers as they need to be more finely balanced than i/c props. Some manufacturer's props are much better balanced than others, but it is best to always balance new propellers before flying them. It is useful to keep a stock of props covering the range of diameters and pitches of the ones you use most frequently.

We have hopefully made it clear that the pitch and especially the diameter of the propeller are major factors in determining the size of motor we select, so now we need to talk about motor specifications and designations.

Electric Motors

As we have already seen, RPM plays a big part in all this, so that is a good place to start when discussing electric motors. Although the load it's under will affect the RPM of any given i/c engine, putting more petrol in the tank will not! But with an electric motor, using a bigger (more cells) battery will increase the RPM, but could also burn out the motor, just like putting too much voltage through a light bulb.

Most electric motors these days are supplied with a prop adapter to enable you to fit the propeller to the motor shaft, (or you can buy these adaptors separately). As mentioned motors come in different sizes with different shaft diameters so always use the correct prop adapter for the specific shaft size of your motor.

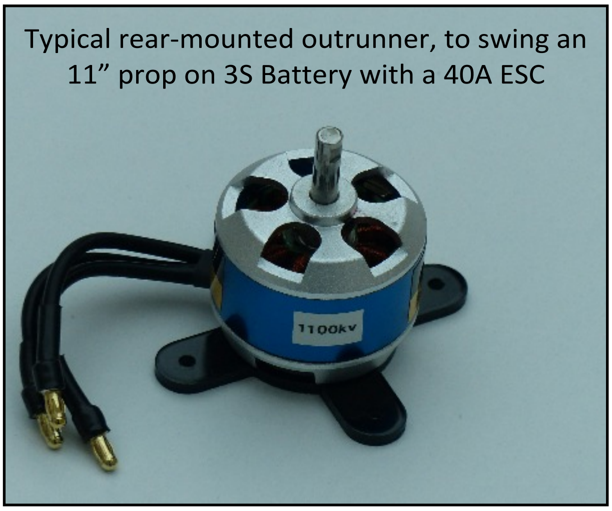

Inrunner replacement for a brushed can motor

Firstly, we should explain that brushless motors come in two main types - inrunners and outrunners. Although rare, there is also a hybrid type called a "canned outrunner" which is exactly what it says on the er … can!

Inrunners are very similar in appearance to a standard "can" brushed motor. The motor is encased in a steel "can", and as all the moving parts are inside the can, these motors are the easiest to retro-fit to models when replacing a brushed motor. They are generally a bit more expensive than equivalent outrunners; they are usually fairly high-revving, and they produce rather less torque than equivalent outrunners too. But inrunners do tend to run very smoothly and quietly, and their ability to run very fast and smoothly means that they are often considered the best power source for electric ducted fan (EDF) "Jet" models.

However outrunners are by far the most widely used for electric flight. The term "outrunner" signifies that the entire outer case rotates and acts as a flywheel, which is what gives it greater torque than an inrunner. They are also generally cheaper, size for size. Of course because the outer casing rotates at high speed the installation in the airframe must allow plenty of clearance for the rotating case.

They come in front-mounted and rear-mounted versions (ie. front or rear of the front bulkhead or firewall) and if the motor wiring has to trail back past the rotating case, great care must be taken to ensure that the motor case cannot chafe the wires. (Which is why canned outrunners were developed). There must also always be a free flow of air on to the motor to help keep it cool.



Typical rear-mounted outrunner, to swing an 11" prop on 3S Battery with a 40A ESC

Unfortunately there are no agreed standards and no significant commonality between manufacturers and distributors in the way they designate electric motors, and therefore it is usually necessary when buying to look at the specification data to get the actual dimensions and other important technical information. But to the extent that some commonality exists, it may look something like this:-

3542/6 1250

The first two numbers (eg. 35) usually specify the diameter of the case in millimetres - important to check that it can be fitted into the fuselage or engine nacelle. Confusingly some manufacturers/distributors use the first two digits to denote an internal dimension, so you might find a 2830/8 1000 also has a 35mm case diameter if you check the detailed specification, whereas it could denote a 28mm outer case from another source.

The second two digits (eg. 42) usually denote the length of the case, front-to-back in mm.

The number after the oblique usually denotes the number of windings the electric motor has, which is getting quite technical - beyond what we need to discuss here. The last number (eg. 1250) is very important, and this denotes the kv.

Kv is the theoretical number of RPM per volt of electricity applied to an electric motor when not under load. This means that a 1000 Kv motor powered by 10 volts would rotate at 10,000 RPM when not under load. Of course the RPM would drop with a propeller attached, but it is nevertheless a useful guide. The most obvious implication of the Kv is the relationship between the voltage of the chosen battery pack and the RPM, and therefore the power (watts) that the motor will produce with that flight battery. Higher Kv ratings may require a smaller propeller or fewer battery cells to avoid overloading the ESC.

We have already seen that the power (watts) produced by any power train is a function of three factors:-

- the propeller diameter
- the propeller pitch
- the RPM

From the table above, we know how to determine the watts we need to produce in order to power a given type and weight of model. We can also relate the appropriate prop pitch to the type of model too. There is a little more flexibility in deciding on the prop size (arc diameter), but this may be determined to within a couple of options, simply by the size of model and the ground clearance of the prop when the model is parked.

A nose-wheeled model may demand a smaller prop diameter than a tail-dragger because of ground clearance. You can't totally ignore the tip-speed of props either. Very few props can be rotated safely above 12000 RPM and an RPM range of 8000 to 10,000 would suit most club-sized models. Larger models tend to swing larger props at lower RPM.

So it's already getting less complicated because the choice of prop diameter and pitch is narrowed down by the parameters of the size and type of airframe. Similarly the airframe will largely determine the maximum physical size and weight of the flight battery pack. At this stage it's worth considering that an electric power system can be designed to give maximum power or maximum flight duration from a given battery size.

Even with i/c engines, using higher power consumes fuel faster than just cruising around, so that shouldn't be hard to grasp.

It is now a matter of selecting a motor that will give us the power we need from the preferred battery pack (as determined by model weight and fuselage space), using the desired propeller diameter and pitch. Hopefully by now some of the fog should be clearing and the myths and murkiness of the "black art" of electric flight should seem less daunting!

For any given model you should now be able to select from a range of motors that will give you the power (watts) you need, and here we remind you of an important principle (mentioned earlier) which should always affect your choice of the electrical components you install in the model.

This is the principle of allowing "headroom" - which is to say you should always over-specify the maximum capacity of each component. Never choose a component specification which will cause it to be operating anywhere near to its maximum capability anywhere in flight, from take-off to landing.

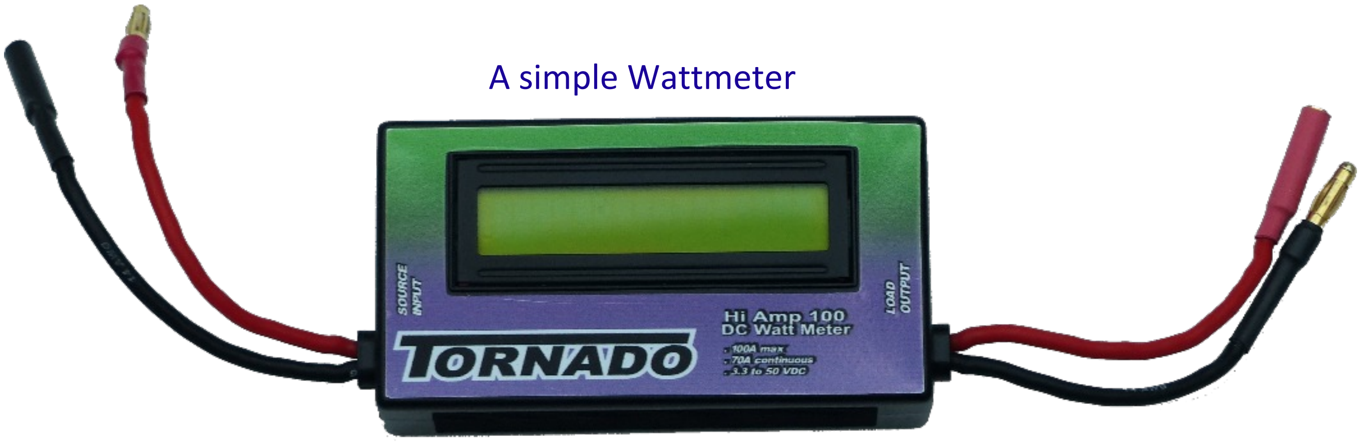
As with the battery, the airframe itself will often limit the choice of motor size and weight you can install. The motor will (usually) be at the front of the model furthest from the centre of gravity, so weight is a consideration, and the space available in the fuselage or cowling will impose another choice restriction. These factors will help to narrow your choice of motor, making it easier to make your decision.

The airframe design up-front will also determine whether you need a front-mount or rear-mount fitting. Different manufacturers' motors also come with different shaft diameters, and it is a good idea to go for the thicker (stronger) ones where possible, especially if you intend to swing a large diameter propeller. If you are still in doubt, have a chat with a more experienced electric flyer in the Club before you buy, to validate your own conclusion.

If electric flight is the way you plan to go in future, then if you don't already have one, do invest in a wattmeter when you buy the motor (you can usually purchase them from the same source). Be sure to buy a battery checker too (some gizmos do can both jobs).

A wattmeter enables you to check and validate all your calculations when the motor and propeller are installed in the model, and before you commit to aviation with it. Another slightly less useful gizmo, but cheap to buy, is a tachometer to measure RPM.

A simple Wattmeter



A wattmeter is a small gadget with an LCD screen and two wires with connectors protruding from both ends. The wattmeter is connected to sit between the flight battery and the speed controller (ESC), but be sure to connect each set of wires to the right one, and you might need to fit different connectors if they don't match the ones you commonly use.

A healthy sense of danger is most appropriate when working on electric-powered models, as there are some serious potential risks. An i/c engine will never spontaneously and unexpectedly burst into life, but an electric motor system can! You should never ever arm a model at home or in a confined space unless it is either firmly restrained or the propeller has been removed.

However you cannot carry out a wattmeter check without the propeller fitted so great care must be taken to avoid a nasty accident. Remember that as soon as you connect the flight battery the model will be "armed and dangerous".

If an obstacle such as fingers or a hand obstructs an electric propeller in motion, there is actually a rapid surge of power - the motor won't stall as an i/c engine might!

And electric props are thinner and sharper than standard i/c props so an electric prop can reduce human flesh to mincemeat in a moment! And don't imagine that small motors are any less dangerous! Kitchen blenders have small motors! You will need to have the propeller attached to obtain the readings from the wattmeter, so make absolutely sure that the model is firmly restrained, ideally at waist height, and don't forget to tie the tail down too. Beware that the average workshop foam model stand is not adequate for this purpose. The "Safety Compendium" which can be downloaded from the Articles page of the DMFC website contains a simple design which you can adapt for your own needs, using a cheap DIY workhorse.

If you are checking-out a model with a newly-installed power system, do ensure that the motor is turning the propeller in the correct direction. Yes, of course it's obvious, but it is surprisingly easy to forget. If the rotation direction is wrong, just swap over any two of the three connectors between the speed controller and the motor to reverse the rotation.

So with the model firmly restrained, stand behind the model and ensure that no-one else is standing in front or to the side of the model, just in case the prop should come off or a prop blade should break. Keep hands and fingers well away from the prop, (it is highly advisable to remove small children and pets from the workshop when running these tests).

Run the motor up to full throttle for a short time. Allow the voltage to settle to a sustained level and then and take the readings. The LCD screen should tell you the Watts, the Amps and the battery Voltage and some can also tell you the RPM. You will see the voltage reduce as the battery is put under load. The important voltage is the minimum it drops to during this short test. Obviously the voltage would progressively reduce further in a real flight as power is drawn from the battery capacity.

Rig with model "on board" ready for bench-testing

These numbers are all you need to validate your setup. Make sure that the Watts are well within the safe parameters of the motor specification and that the Amps are well within the continuous operating specification of the ESC.

If either of these is too close to the maximum specification, you may have to fit a smaller diameter propeller, which will reduce both, but will obviously reduce the performance of the model in the air.

In a worst case scenario, you may find that your chosen motor and/or ESC are not up to the job and you need to change to a higher specification, but don't despair, they will probably suit a smaller or lighter model very well, sometime in the future.

Do keep the data sheets that usually come with the electrical components you buy for your models. The chances are quite high that at some time you may recycle them into a different model, and then you would need to consult the specification details again.

The Electronic Speed Controller (ESC) - BEC, LVC, OPTO & UBEC

The ESC is a vital part of the power train system in an electric model. They are rated in Amps for continuous power and separately for short bursts of power (usually 10 seconds). They will also be rated to number of cells (ie. voltage) they can handle.

Like most gizmos in the modern world, they have become more and more sophisticated in recent years. There are basically two main types:- linear and switch-mode. Most (though not all) small ESCs are linear, whereas anything over about 30A are likely to be switch-mode.

Simply put, ESCs get hot and have to have a way to dissipate heat, and consequently have to incorporate a heat-sink (and they should also be sited where air can flow over them). Heat-sinks add weight of course, and switch-mode ESCs are now the norm for larger Ampage models as they generate less heat.

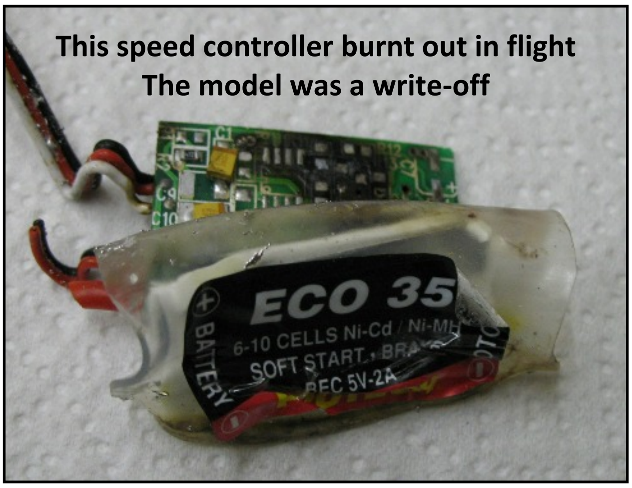
ESCs below 40A are likely to come with a BEC (more in a moment), larger rated ESCs more likely to be OPTO (without a BEC, so requiring a separate receiver battery - and possibly a UBEC voltage regulator to complete the system).

BEC stands for "Battery Eliminator Circuit". With i/c models you still need to install a battery to power the Receiver (RX) and the servos. In electric models, you've already got a battery - the one that powers the motor - but the voltage requirements are quite different. A fully-charged 3S LiPo is rated at 12.6V, but this voltage would burn out the RX and servos which only need 4.8V-6V. So a BEC is actually a voltage regulator, built into the ESC, specifically to enable the flight battery to also power the receiver and servos.

In the old days of heavy NiCd and NiMh batteries, the last thing you needed was to have to add the weight of a separate pack of 4 AA dry cells or rechargeables just to power the RX and servos. So the BEC eliminated the need for a separate RX pack - hence its name.

The problem with that, was that in solving one problem, the BEC alone created another more serious one. In an i/c model, if you run out of fuel the RX pack is still going strong, powering the RX and servos, so that a controlled deadstick landing remains possible. But if the flight duration completely drained the flight pack of an electric model, there would be no capacity left to power the RX and servos for a safe controlled deadstick landing.

And so, as well as the BEC, another bit of technology was added - the LVC - "Low Voltage Cut-Off". What the LVC does is to cut off battery power to the motor before the battery is completely drained, making sure that there is sufficient battery capacity remaining to power the RX and servos for a controlled deadstick landing.



Most ESCs sold today are programmable in various ways, and one of the program options which is especially useful is the ability to ***gradually*** reduce power available to the motor as the LVC point is approached.

The value of this is that the pilot gets some warning that he is close to running out of battery power, and make his landing quickly and normally without being forced into a deadstick situation.

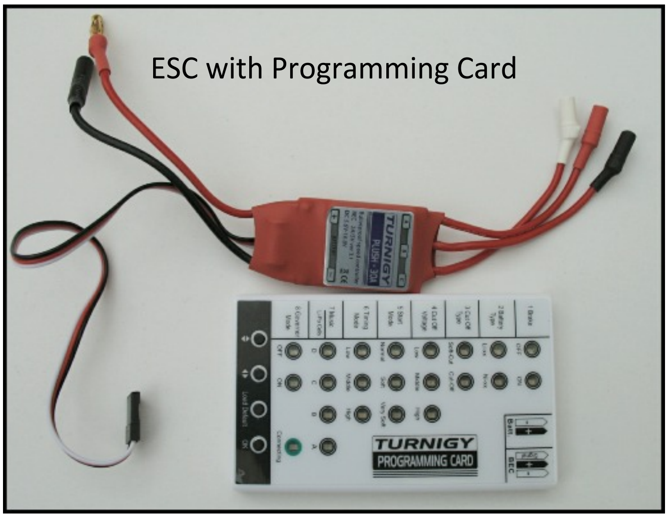
Of course the whole idea of the BEC is to reserve sufficient residual power (voltage and capacity) in the battery to power the receiver and the servos to allow a controlled landing, after the LVC has cut off power to the motor. Nevertheless battery power/capacity is still being drawn off by the requirements of the receiver and servos, and obviously the makers of ESCs have no way of knowing how many servos you may need to power in any specific model. Therefore with larger models and those with more than four servos it is not considered safe practice to rely on the BEC built into the ESC.

Many larger models use higher voltage (more cells) together with a low Kv motor and larger propeller to provide the power needed at a low amps draw on the battery to give longer duration. (Ohms Law again!) A high voltage battery pack would require the BEC to work very hard to provide the low voltage needed for the receiver and servos, and therefore more prone to failure. Consequently if the model requires larger battery packs than 4S it is normal to purchase an OPTO ESC which does not incorporate a BEC. (An ordinary ESC can also have the BEC deactivated by disconnecting the red lead to the Receiver).

The receiver and servos must then be powered from a separate dedicated battery pack, which can be either a 4xAA Dry cell or rechargeable pack, or as is more common these days, a small lightweight 2S LiPo or LiFe pack using a voltage regulator (UBEC) to reduce the voltage to the 4.8-6V required by the RX and servos.

When you install an ESC into the model, ensure that there is sufficient airflow over the ESC heat-sink to keep it cool. Most ESCs incorporate a thermal cutout if it gets too hot, to prevent it bursting into flames, and you really don't want this to spoil your flight!

Most ESCs can be programmed via two methods:- either by a combination of transmitter stick movements, managed via bleeps or blinking LEDs on the ESC itself, (very fiddly) or (much more easily) via a program card which is purchased separately. Most program cards cost around £5 so it makes sense to try to standardise on one or two brands of ESC that you know to be reliable, and buy the programming card for them.



There are usually several different things you can program an ESC to do or not do, and they all come with default settings which may or may not behave as you require. Beware that some may come with helicopter default settings which won't do at all for a fixed wing model.

An important setting is the Brake, which is set to ON or OFF. (Some allow an intermediate setting). For models with a folding propeller (eg. powered gliders) the brake should be set to ON, so that the prop folds back immediately when the power is cut. For all others, the brake should be set to OFF so that the prop is allowed to windmill when the power is cut.

There is also usually a setting for start mode - very soft to hard. Helicopters need a very soft slow start for the main rotors or the gears would be stripped. Normal fixed wings need a rapid response to power on, so you would select a fast or hard start.

Another variable is timing (similar to a car engine). Most ESCs default settings will assume an outrunner motor, but inrunners may require a different timing setting. There may be other variables that can be programmed too, so read the data sheets that come with the ESC and the motor.

Make a note of what settings you've used for each ESC you have in case you later reuse them in a different model. In fact it is highly desirable to create your own data sheet for each of your models, as it is surprising how quickly your fleet of models can increase.

A computer spreadsheet is ideal for this, and you can record model weight and other details, motor and ESC brand and specification and settings programmed. RX and servos fitted - even Transmitter settings are useful to have recorded for if ever your TX is replaced.

LiPo Battery Flight Packs

As you would expect, LiPo battery packs come in various physical sizes, capacities and configurations. A single fully charged LiPo cell is nominally rated at 4.2V. To make up a flight pack for all but the most micro indoor models the cells are joined together as batteries, either in series, or parallel or both. They also have a capacity, usually expressed in mAh (milliamp/hours) and a C rating.

The basic pack configuration is simple to understand - eg. 3S is three cells joined in series (technically this should be designated 3S1P, but is usually abbreviated to 3S). Joining cells in series increases the voltage, but not the capacity. Joining cells in parallel increases the capacity but not the voltage. Basic stuff. So 3S2P is actually 6 cells joined together as two sets of three in series, joined in parallel. The nominal charged voltage of this pack would be 12.6V, but the capacity would be double the capacity of the 3S1P pack.

The C rating is a bit more esoteric, but not really all that complicated. It is simply the rate at which the battery can be safely **dis**charged. Going back to the setup data and Ohms Law we saw earlier, and Amps figure is the one that relates to battery discharge.

We'll come back to discharge in a moment, but it is important to understand the "C" notation in the context of charging first.

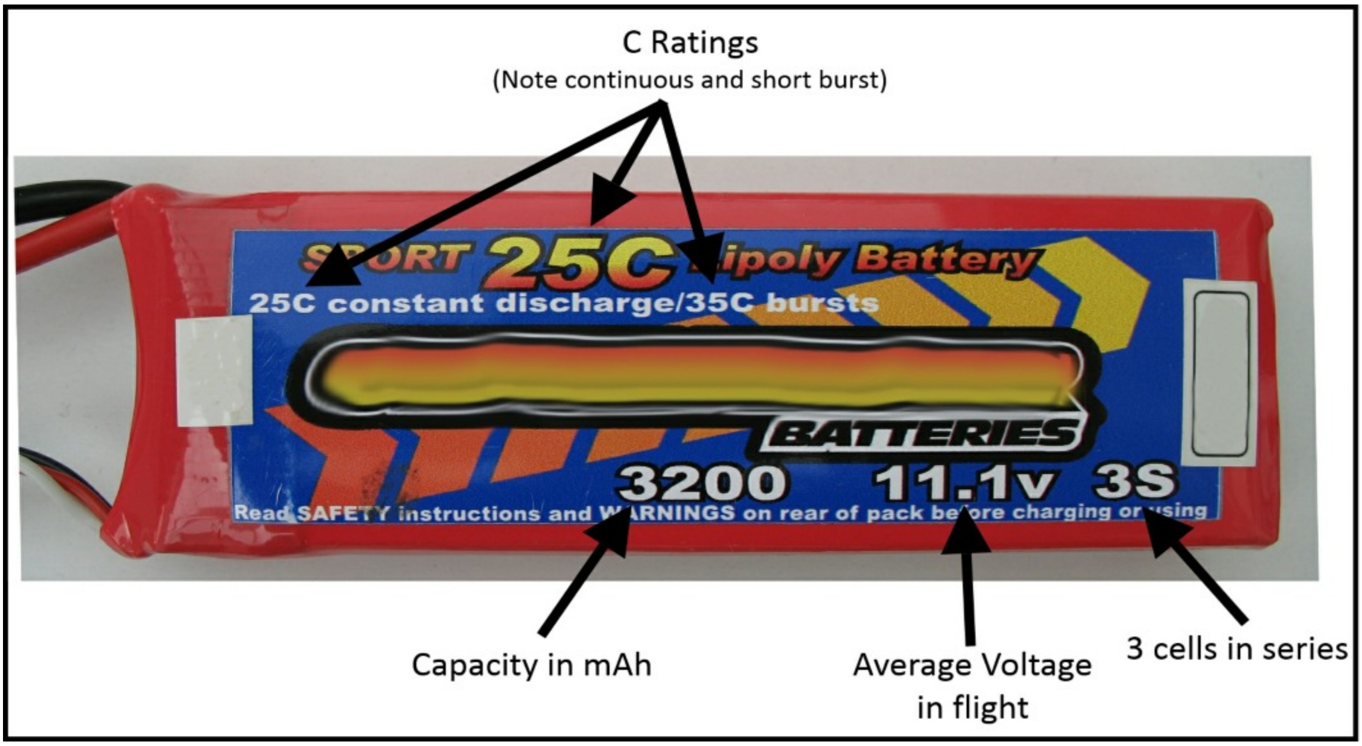
Charging at too high a rate is a significant fire risk, so when charging, for safety reasons, the maximum charge rate should be 1C, **regardless of the battery's C rating**. Although some manufacturers claim their batteries can be charged faster than 1C, this will shorten the battery life and the risk of fire is unacceptably increased.

So what is 1C? Well it relates to the battery capacity, and since chargers display the charge rate in Amps, while battery capacities are normally expressed in milliAmp/hours, first we need to reconcile the two. 2200 milliAmp/hours (mAh) is exactly the same as 2.2 Amp/hours (A/h) - all we've done is divide the 2200 by 1000! So for a 2200 mAh pack a safe 1C charge rate would be 2.2A, and you should ***never*** charge at a higher rate for this size of battery. A 3300mAh battery pack would be charged at a maximum of 3.3A. Hopefully this is dead easy to understand because it is a serious safety issue. If you don't feel comfortable that you have understood this properly, please ask at the field for someone to explain it again to be sure you've grasped it before you ever try charging a battery.

It does mean that if you have several different sizes and capacities of batteries that you must double-check the charge rate setting on the charger before you connect the battery to be charged. ***For charging - 1C maximum!***

So, since the C rating of the battery is irrelevant for charging purposes, its importance to us is in its relevance to safe ***discharge*** rate. As with the rating of ESCs, the C rating of batteries is often expressed as two numbers - continuous and short burst. The C rating of a battery pack is important because discharging beyond this rate of discharge will cause the battery to overheat and may burst into flames. If nothing else it may effectively destroy the battery or shorten its life by reducing its voltage beyond the point where it can recover.

Most ordinary LiPo packs will specify a C rating of 20C to 30C and this is adequate for average sport flying. It is best to ignore the higher C rating, as this is only to be used for a short



burst of a few seconds. So, going back to what we've already covered above, it should be straightforward enough to appreciate what the C rating means to us. 20C denotes twenty times the capacity. So our 3S 2200 mAh (2.2 A/h) battery pack rated at 20C can be safely discharged at up to a maximum 20x2.2 - 44 Amps.

However we have frequently alluded to allowing specification headroom when selecting electrical components, and batteries are no different. A battery which is routinely run at close to its C rating will get hot, and may soon start to puff up and have a very short useful life. However, since the C rating directly relates to the capacity (not the voltage) it should be evident that a 20C 3S 2600 battery pack would have a maximum discharge rate of 52 Amps.

Of course this might be too big to fit into the model but if possible it is one way to buy extra headroom. If you've used a wattmeter as mentioned above, you'll know the Amps your power setup pulls so can see if it's within a safe range. For high performance models you may need to purchase higher C rated packs but this can increase the price of the packs considerably.

The other way which might be possible is to increase the number of cells in the flight pack- but again there may not be room in the model to accommodate larger packs. However there are actually other more serious implications and complications with this, which should be evident if you understood Ohm's Law.

Using Ohm's Law it should be apparent that you can use higher voltage with lower Amps to produce the same Watts! Seems simple, but unless you change other things as well, just increasing the voltage will produce considerably MORE Watts. Remember that motors are rated for a certain number of cells, and they turn at a specified Kv. Increase the voltage and you increase the RPM, but with same prop fitted the motor has to work harder to turn the prop faster, and this will also increase the Amps power draw from the battery, which in turn may blow the ESC's Amps rating.

The increased RPM may also push the prop tip-speed above its safe limit too. So to use a higher voltage you must either change the motor to one that can cope with the extra cell and will have a lower Kv, or you must fit a smaller propeller in order to keep the Amps within the ESC safe range and not overstrain the motor.

Finally, a few words about connectors. For a long time the generally accepted "standard" for flight battery connectors was 4mm individual gold connectors, (2mm for very small models). These are still widely used although for larger power systems 6mm should be used.

Great care must be taken not to short-circuit the wires when soldering new connectors on to a LiPo battery or a serious fire might occur.

If these connectors are used, the red (positive) wire should have a female connector and the black a male. Both should be protected as far as possible with heat-shrink, and a system is needed to insulate the negative connector so that it cannot short-circuit by touching positive. (See the Safety Compendium Download).

More recently, Deans connectors became popular for small models and some LiPo packs are supplied fitted with EC3 or EC5 connectors. Multiplex tend to use their own proprietary connectors).

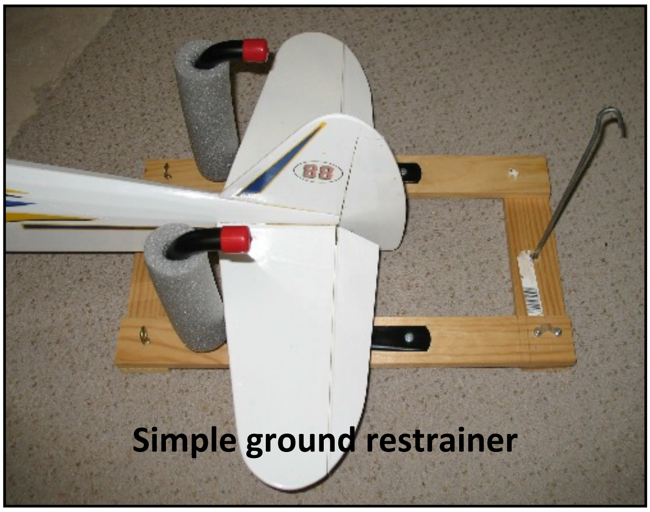
The point is that you need to decide which suits you best and standardise on it. This may mean removing the connectors supplied on the batteries and other items you buy, and soldering new ones on.

Good soldering is important, so get advice if it is something you have no experience of, and you must take great care not to short-circuit LiPos when removing old connectors and soldering on new connectors. (Do the whole process one wire at a time).

The other connector on all LiPo batteries is the Balance Connector, (more on LiPo balancing later), and here again we find that different LiPo manufacturers use different connectors! Some chargers come with a choice of charging leads to suit different balance connectors, or you can buy adaptor leads and/or adaptor boards.

However, don't forget that apart from the different connector types, the actual Balance Connector size is determined by the number of cells in the pack, which is why adaptor boards containing connectors for the different pack sizes is useful.

So perhaps the best solution is to decide which brand of batteries you like best and try to standardise on batteries which use the same balance connector, and use a board or buy the charger leads for the size of batteries you use.



Simple ground restrainer

A corollary of this messy situation is that many aeromodellers try to work with as few different size and types of battery packs as possible, and select new models which can fly on the batteries they already have.

The Sum of the Parts

So we've seen how these components operate together as elements of a single power system comprising motor, propeller, ESC and battery pack voltage and C rating. Each has its own specifications but it is the correct combination of these that produces a successful power train. We have seen that it is very important that each element operates well within its maximum operating parameters, for the system is only as good as its weakest link or lowest specified component.

Sadly, it has to be said that there is another compelling reason to allow headroom in the specified operating parameters. This may come as a shock of disillusionment, but manufacturers sometimes exaggerate the true capabilities of their products. How dreadful! But true nonetheless! And this seems especially true of LiPo battery packs. These can vary tremendously in price, yet it does not always follow that more expensive will necessarily be better, even though generally speaking it is true that you get what you pay for. Over time, experience will tell you which brands you can rely on, and which to avoid.

This is another area where asking colleagues in the club for their experience and advice can save money and disappointment, but don't expect them always to agree, especially as it can depend a lot on what kind of models they fly, and how they fly them.

The ones who fly "fast and furious" on full throttle will wear out batteries much quicker than those who fly more moderately, and consequently they may make the case for more expensive higher specified batteries than you might require for more sedate flying or flying for maximum flight times.

Which brings us to another quite important calculation that the aforesaid enables you to do, and that is to predetermine the approximate flight duration your chosen power set up can deliver.

In electric flight, this is important to know, because you should always plan your first landing approach with sufficient battery capacity left to be able to abort and "go round again" if you need to. In any case you do not want to fly until the battery is virtually dead every time, as this will significantly shorten the operating life of the battery pack.

We have seen that battery capacity is designated in milliamp/hours (mAh), and our wattmeter tests will have told us how many amps the power train draws at full throttle - (you can use the wattmeter to give you its results at half-throttle or cruising speed too).

Taking the average amps draw at somewhere between the two, and then calculating how long it will take to drain the capacity from the battery, leaving around 25-30% capacity as a safety margin, and you will get a pretty good idea how long you can fly on one battery. Then set your Transmitter timer to give you a warning accordingly.

Do bear in mind that the duration will be less in windy conditions, and that even carefully used batteries deteriorate over time, so you will need to keep track of actual flight times and check residual capacity after each flight with a simple battery checker, and then adjust your transmitter stop-watch or countdown timer (even better) accordingly. LiPos also perform less well in cold wintry conditions, so allow for that too.

Performance Upgrading

At some point in their model flying career, most radio control pilots wish they could get more performance from their models. This is natural, but there are some practicalities to consider, not least of which is to ask yourself whether the airframe (especially the wing spar and wing joints) are strong enough to cope with the higher forces which faster speed and aerobatic manoeuvres will exert upon it. Many a nice model has been destroyed in a spectacular plummet to earth after "clapping its hands" (its wings collapsed) in a fast loop or tight banking turn which it was never designed or constructed to do.

As far as the electric power train is concerned the easiest (and therefore the most tempting) modification to make, if the airframe has the space, is to increase the battery (voltage) by using a bigger battery with one more cell. But hopefully by now, Ohm's Law should be telling you that this could burn out the motor and/or speed controller UNLESS you compensate by fitting a smaller diameter propeller and then do a wattmeter check to ensure the system is still within safe operating limits.

Electric Flight Safety

Although it may be true that in some quarters, "Health and Safety" concerns and restrictions have been taken to ridiculous limits, it is important not to underestimate the potential danger to life and limb from model aircraft. All model aircraft in flight are missiles which should be subject to responsible and capable guidance at all times.

Largely because model flying is subject to laws, rules and regulations, both at national and club level, it has an excellent safety record. However the unfortunate fact is that most accidents involving physical injury occur through negligent ground-handling of models and equipment, in the pits or at home, and therefore these risks need to be addressed.

The aim here is not to alarm or frighten the reader, but it is important to properly understand the risks so that sensible precautions can be taken, and safe handling procedures adopted by novice aeromodellers from the outset.

Undeniably the fuels used in i/c flight present hazards of their own such as fire risks, and dangers of ingestion or inhalation of fumes, and with both i/c and electric models unrestrained models and whirring propellers have the potential to cause serious injury.

However, although the risks associated with i/c fuels are eliminated in electric flight, electric models pose a few additional and/or different accident risks themselves, compared to glow or petrol-powered models. There are different but no less serious fire hazards. And physical dangers, especially to limbs and digits, are potentially a little greater than those associated with i/c. It is clearly very important not to ignore these risks, and to do all we can to minimise them, but provided we keep our wits about us and observe some basic precautions and safe procedures there is no need to live in mortal fear of them.

Armed is Dangerous!

As stated above, the moment you connect a flight battery to an electric motor, it is truly armed and dangerous. It is extremely important that when you arm an electric model that it is properly restrained and not facing towards anyone or anything that could be damaged if the motor were to start suddenly and unexpectedly. Lightweight model stands do not provide adequate restraint and should never be used for armed models.

Modern equipment has become so reliable these days that we can become blasé about the dangers. But any electrical component can malfunction, and it is not unknown for a

transmitter to be dropped or blown over by wind, pushing the throttle stick forward and causing a serious accident. For the same reason you must restrain and disarm a model as soon as possible after each flight, so don't get distracted by discussing your perfect landing with friends and forget to disconnect the battery. Also, setting up a throttle-cut switch in every model memory is strongly recommended.

Arm the model immediately before flying, and disarm it immediately after flying before you do anything else. And never leave an armed model unattended, even if restrained.

Battery Installation

The idea of a fuel tank falling out of an i/c model in flight seems ludicrous, but it is far from unknown for LiPo flight packs to detach themselves from their model and fall to the ground.

In fact the LiPo battery is usually the heaviest item in an electric model aircraft, so it is extremely important to ensure that it cannot move or fall out in flight. If it can move even slightly forwards or backwards it can adversely affect the centre of gravity and balance of the model and cause a crash.

Even worse, if it falls out of a model, the power to the motor and possibly to the receiver as well is immediately cut off; and even if you use a separate receiver battery the resulting change of centre of gravity may make the model impossible to control.

From the earliest days of electric flight, hook and loop tape (velcro) have been used, and in self-adhesive form it is easy to use. It is especially useful to prevent forward and aft movement of the battery in flight if used in conjunction with a strap to hold the pack firmly on to the velcro.

If applying self-adhesive velcro to a foam, balsa or ply surface, use a glue-spreader to make a thin smear of epoxy resin on the surface, and let it dry before applying the velcro. The shiny epoxy surface gives very good adhesion to the self-adhesive on the velcro. It is usual to stick the velcro with the hard hook surface into the model, and the soft furry part to the flight battery. Do be aware though, that if you allow your batteries to get unduly hot in flight, (not good practice anyway, as it will shorten battery life), the self-adhesive on the velcro may melt and make a sticky mess!

Releasable cable ties can also be a good method. In ARTF built-up electric models, and with the advent of laser-cutting, it has become common for the woodwork in fuselages to be little more than a flimsy latticework. So if you have any doubts whatever about the strength and ability of the battery area to adequately restrain the battery pack firmly in place (even in loops, rolls and bunts), you should have no qualms about reinforcing the area with additional light ply. It might add a little weight, but with modern electric power trains a little extra weight is not the problem it used to be.

Sometimes it is worth making a battery tray, so that you can firmly attach the flight pack to this while both are out of the model, and then slide the tray into the model and fix it using one of various methods such as a bolt and captive nut, or restraining straps, cable-tie etc. depending on the internal design of the model.

You can test battery security very easily by holding the model upside down and shaking it a bit with the canopy or battery hatch removed.

Summary

In just a few short years electric flight has grown from being a quirky and somewhat ridiculed minority-interest in the world of aeromodelling to the point where it has almost totally replaced i/c power in many clubs. It is clean, quiet, reliable, easily available and inexpensive, and it can power a huge range of models from the smallest micro indoor models, to the largest composite aerobats with contra-rotating propellers, to EDF jets, or multi-engined bombers or airliners.

There are a few additional or at least different risks, and some new factors to take into account for those who have only ever flown glow or petrol-powered models.

But what is very apparent is that for many modellers, even in those clubs where i/c is still an option, once hooked into the benefits of electric flight, there is no looking back.


Even the largest models can now be powered by electric motor with LiPo batteries


Small indoor electric model

dmfc.org.uk