Dumfries Model Flying Club

Lithium Polymer Batteries

The Safety Issues

Contents

The content of this article is derived from various sources but in no way should this article be considered to be a definitive guide to safety issues relating to Lithium Polymer batteries. It is provided on this website in order to draw attention to these issues and should be regarded as supplementing other sources of information on this subject.

Neither DMFC nor the author will accept any liability whatsoever in respect of this article, including any errors or omissions.

Readers who use Lithium Polymer Batteries do so entirely at their own risk and are encouraged to refer to other sources of information, and in particular to the warnings and other information supplied with these batteries and their chargers, and also to the booklet on Lithium Polymer Battery Safety published by the BMFA and downloadable from the BMFA website.

Lithium Batteries - The Background

Today Lithium batteries are everywhere. You probably have numerous of them in your home, and there is probably one in your pocket right now!

They power every mobile phone and laptop computer of course, but these days they also probably power your electric drill, your hedge trimmers, your vacuum cleaner, even your electric shaver. And in a very short time it seems very likely we will all be driving electric cars powered by them as well. A piloted electric-powered aircraft has circumnavigated the earth, and now there are even electric passenger aircraft being developed and tested in countries around the world.

But all lithium batteries carry risks. They store large amounts of energy in very compact packages, and are all too easily subject to damage and abuse. Consequently, hardly a week goes by without a serious fire or other accident associated with their use. Occasionally there are even fatalities, although most of the accidents and incidents can be traced to equipment failure, impact damage, improper use, or charging errors. Still, many airlines and some postal and delivery services are increasingly averse to carrying them.

Nevertheless, taken in the context of the colossal numbers of lithium batteries there are in gadgets and appliances in homes and work-places all over the world, the number of fires and other incidents directly attributable to lithium batteries, (although sometimes serious and often well-publicised), are relatively very few.

This may be taken as a strong indicator that they are generally safe, provided they are not subjected to abuse or misuse. In fact the vast majority of incidents and fires associated with lithium batteries result from faults, problems and mistakes during recharging. This has important implications for aeromodellers which we will cover later in detail.

There are actually several different types of Lithium batteries, and the correct generic name for them is "Lithium Ion". It is the chemical nature of the ion that differentiates between the different types and gives them different characteristics, including different voltages.

In aeromodelling we have a requirement for the highest possible power-to-weight ratio and capacity-to-size/weight ratio. Ideally we want high voltage to minimise the Amps draw to give us maximum duration and performance in flight. It is probably fair to say that our hobby has been in the forefront of Lithium Ion battery development, and has been used by manufacturers as a kind of test-bed for their developing products and technology.

The are primarily two main types of Lithium Ion battery used by aeromodellers:-

- Lithium Polymer (LiPo)
- Lithium Ferro-Phosphate ($LiFePO_4$ - usually shortened to LiFe)

Of these two, LiFe are the safer as they do not have the volatile thermal runaway characteristic of LiPos. It is possible to buy LiFe batteries in a size/weight format similar to a 3S LiPo, but be careful to ensure that they are designed for flight power, with a high C-rating (25+). Most LiFe packs have a low C-Rating and are only designed to power Receivers or Transmitters which have a low current draw. LiFe batteries are more expensive than equivalent LiPos and also have a lower nominal voltage, so must be charged using chargers with specific settings for them, (which most do). They have slightly lower power-to-weight and capacity-to-size ratios too. Their lower voltage can be compensated for by fitting a motor with higher Kv or a bigger propeller, but might require a higher amp-capacity ESC compared to an equivalent size LiPo.

But the reality today, for the average club flyer, is that if we want to fly electric, we will be almost certainly be using Lithium Polymer batteries. And recently there's a new "kid on the block" - LiHV - a LiPo battery with a high voltage per cell, but these are still rarely seen.

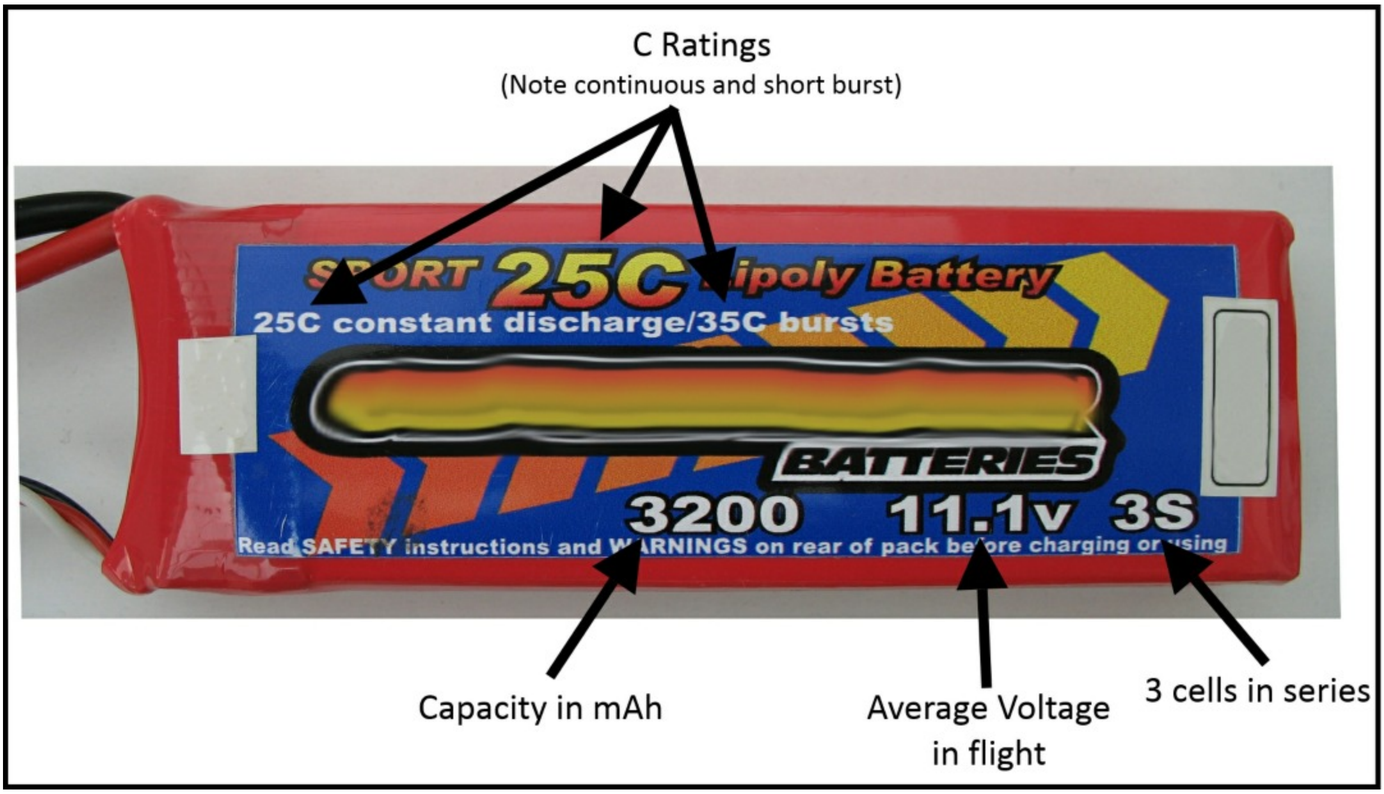
While we enjoy their undoubted benefits compared to other power sources, we must understand the risks associated with LiPo batteries, and must be careful to use, handle, charge and store them in ways that minimises these risks. It is the purpose of this article to draw attention to the specific risks they pose and to outline various ways of managing and minimising the effect of these risks.

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 good habits of safe handling procedures can be adopted by novice aeromodellers from the outset.

LiPo Battery Flight Packs - Basic Configurations and Ratings

Like all batteries, LiPo power packs come in various physical sizes, capacities and configurations. A single fully charged LiPo cell is nominally rated at 4.2V Fully Charged. To make up a flight pack for all but the most micro indoor models individual 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 (or rather, TWO C ratings).

The basic pack configuration is simple to understand - eg. 3S is three cells joined in series (technically this should be denoted as 3S1P, but it 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, then 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.



As mentioned above, LiPo batteries are given C Ratings. The C Rating is simply the maximum rate at which the battery can be safely **dis**charged. Usually there are two C Ratings indicated on a LiPo battery - the first refers to the **continuous** safe discharge rate, and the second, higher rating, is a **short burst** maximum discharge rate that can be safely maintained for only about 10 seconds.

We will look at discharging issues and cover this in more detail later, but first it is important to understand the "C" notation in the context of charging.

LiPo Battery Flight Packs - Charging

The vast majority of lithium batteries installed in gadgets and appliances the world over, are supplied with a dedicated charger, and most are encased in a hard cover. Even more importantly, either the batteries themselves or the gadgets or appliances into which they are fitted, always incorporate electronic circuitry to manage the charging process to prevent over-charging and other charging abuses.

The result is that fires are very rare, and when they do occur it is usually as a result of using a non-standard charger, or failure of the protective electronic circuitry.

Now of course one of the primary requirements of model flying is to minimise unnecessary weight. Furthermore, because we want several flights when we go to the field, we want to take several freshly charged batteries, each of which will be removed from the model after its flight. So all this electronic circuitry to ensure safety during charging is dead weight to us and irrelevant to our actual flying requirements.

We remove our batteries from the model after each flight and we do not charge our batteries while they are still installed in the model (**NEVER EVER DO THIS**) so we don't need the safety charging circuitry to be installed in the model. And we certainly don't want it adding extra weight to the battery itself. The need for clever protective electronic circuitry only becomes relevant to us when we come to recharge our batteries.

Of course we still need the benefit of electronic circuitry to assist us then, but in our case the circuitry is built into the CHARGER, and not into the model or into the battery itself. However this means that LiPo batteries must only be charged using a charger which is specifically designed and programmed to charge this type of battery. A standard car battery charger must never be used to charge LiPo batteries.

All but the most basic chargers are PROGRAMMABLE to allow us to charge numerous different sizes and capacities of battery, and often different types of battery too. This means that before you use a charger of this type you must read and fully understand how to program it, and take great care to program it correctly for the type, capacity and cell-count of the battery to be charged.

As these batteries have no protective circuitry within them, the greatest fire risk with charging LiPo batteries is HUMAN ERROR on our own part. This means that the onus and responsibility for charging our LiPo batteries **safely** rests with **US** individually.

It is therefore vitally important that you thoroughly get to know your charger (or chargers). However complex it may seem, read its manual as many times as it takes to fully understand it, and don't risk trying to charge a LiPo battery unless/until you do. If necessary seek advice from an experienced aeromodeller.

Make sure you know how to ensure that it is set to charge the correct TYPE of batteries. Most chargers can be set to charge several different types (LiPo, LiHV, LiFe, NiCd, NiMh, even Lead-Acid) - and the charge rates, processes and cut-off points for each of these is totally different. Using the wrong Battery Type setting for charging LiPos can cause a serious fire. Make sure you know how to correctly set the charge rate in Amps and the Maximum Capacity in mAh. Getting these wrong for the specific battery you are charging can result in a serious LiPo fire. Also make sure you know how to balance the cells when charging, for this is important too.

Charging LiPos 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 mAh (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 the safe 1C charge rate would be 2.2A.

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 very easy to understand because it is a serious safety issue.

Of course this is all about programming the charger accordingly with the correct battery type, the correct number of cells, the correct charge rate and the correct battery capacity. It also means that if you own several different sizes and capacities of batteries, you must double-check all these settings on the charger ***before*** you connect the battery to be charged. ***For charging - 1C maximum!***

If you don't feel comfortable that you have understood this properly, please ask at the flying field for someone to explain it to you again to be sure you've grasped it, before you ever try charging a battery.

When flying electric models, try not to let the LiPo battery discharge in flight below 10% if at all possible. In most cases a safer margin would be 20%, and this will also help to maximise the working life of your batteries. This means of course that in most case the recharge time for a battery will be less than one hour, although the cell-balancing process can extend the charge time slightly. If you read the safety information that comes with all LiPo batteries and chargers, (and you SHOULD), you will see that they all advise against leaving batteries unattended during charging. This is good advice, but one suspects that it is rarely followed as rigorously as it should be.

For this reason, and because charger circuitry and battery cells can occasionally fail, other measures should be taken to minimise fire risk and also to limit damage to people and property in the unfortunate event of a fire. Risk Avoidance and Damage Limitation measures are covered later in this article.

LiPo Battery Flight Packs - Discharging

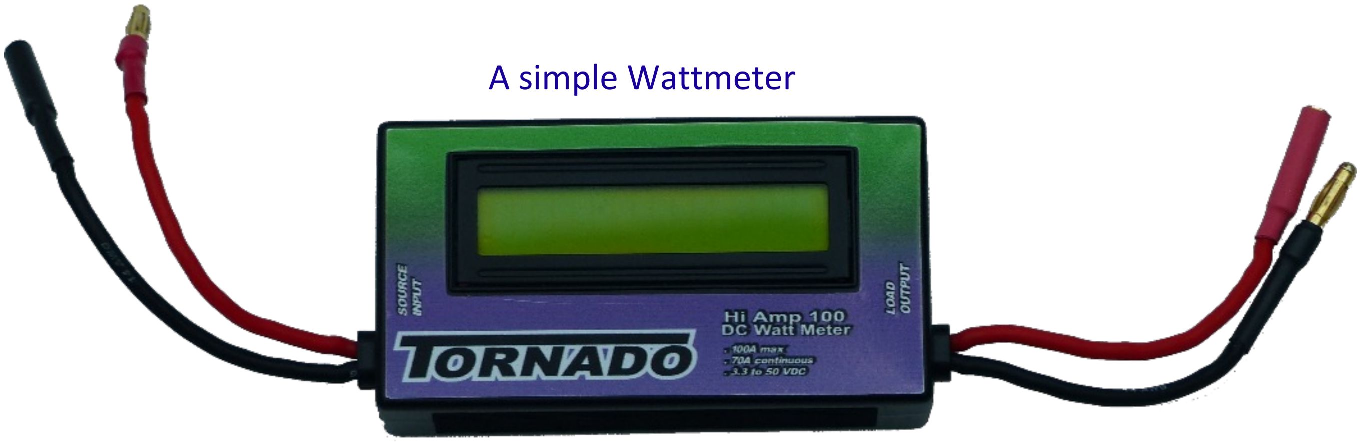
So, since the C rating of the battery is irrelevant for charging purposes, its importance to us is in its relevance to safe discharge rate. As with the rating of the electronic speed controllers (ESCs) installed in models, the C rating of batteries is often expressed as two numbers - continuous and short 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.

Amps is the measure of current draw, and is the factor that relates to battery discharge. The C Rating indicates the highest safe current draw. We have seen that 1C relates directly to the battery capacity - simply converting milliAmp/hours to Amp/hours by dividing by 1000. It should therefore be straightforward to relate this to the C Ratings for discharge purposes.

Most ordinary LiPo packs will specify a C rating of 25C 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 occasional short bursts of just 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, and a 20C 3S 2600 mAh battery pack would have a maximum discharge rate of 52 amps.

However 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. If a LiPo battery puffs up it should be carefully discharged and disposed of properly at your local council facility. Do not put them in general household waste.

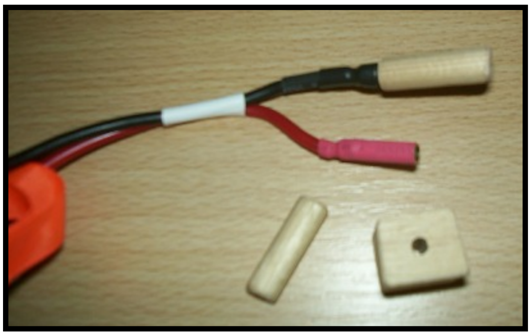


A simple Wattmeter

If you've used a wattmeter to bench-test your model, you'll know the Amps that your power setup pulls, so you 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.

Battery Connectors

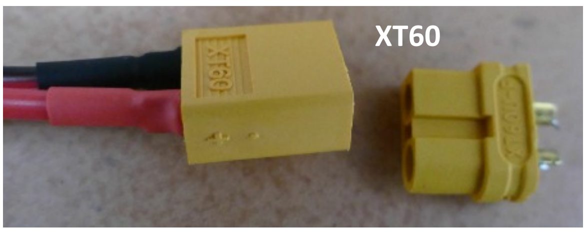
For a long time the generally accepted "standard" for flight battery connectors was 4mm individual gold connectors, (2mm for very small models). These are still widely used although for large power systems 6mm should be used. Great care must be taken not to short circuit the wires when soldering new connectors on to a LiPo battery or a serious fire might occur. If 4mm gold bullet 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 article on the DMFC website).

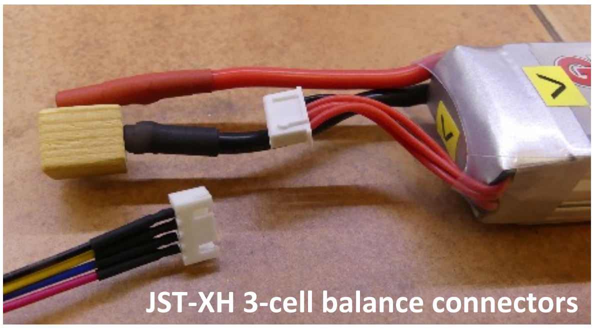
More recently, Deans connectors became popular for small models but these are not really designed to be repeatedly disconnected and reconnected so are not recommended. Much more common these days are XT60 or XT90 connectors or EC3 or EC5 connectors.

These are designed so that the male and female connectors can only be joined in correct polarity which is an important safety feature. 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. If this is necessary it must be done with great care, one wire at a time, to avoid short-circuiting the battery which could start a serious fire. Good soldering is also important, so get advice if it is something you have no experience of.



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 and carefully insulate it so that it is impossible for bare wires to touch.

The other connector on all LiPo batteries is the Balance Connector, (more on LiPo balancing later). There are several different design of these and different LiPo manufacturers may standardise of a particular connector type. Thankfully however, most now standardise on the JST-XH balance connector. Some chargers come with a choice of charging leads to suit different balance connectors, or you can buy adaptor leads and/or adaptor boards.

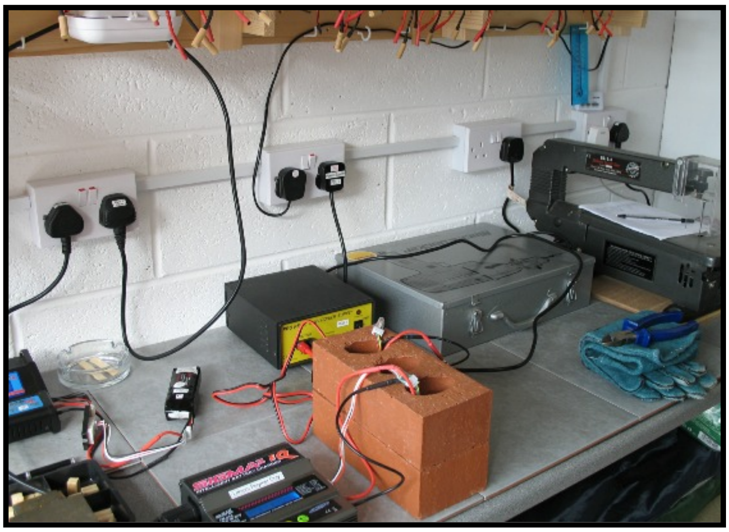

JST-XH 3-cell balance connectors

Each type also comes in different sizes, depending on the number of cells to be balanced, and for this reason adaptor boards containing connectors for the different pack sizes are 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 primary connector and balance connector, and use a board or buy the charger leads for the size of batteries you use.

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. This minimises the storage and management issues and also keeps costs to a minimum as batteries are not cheap.

LiPo Batteries - Treat them with respect



We'll consider the fire risk first. LiPo batteries are the fuel in electric flight, and like all fuels they can be volatile and need handling with care. LiPos have an unfortunate characteristic called "thermal runaway". If they are overcharged, charged or discharged too fast, damaged or short-circuited, a chain-reaction is set in motion which causes an extremely rapid build-up of heat to the point where they burst into flames. The danger is exacerbated by the fact that LiPo fires are very difficult to extinguish as they don't rely on oxygen to burn.

Consequently, if abused or carelessly misused they can cause a very serious fire in your car, workshop or house. The most common causes are overcharging, incorrect charging, physical damage, and short-circuiting. Being aware and conscious of these potential dangers is a great incentive to exercise care to avoid any actions and situations that might cause a fire.

LiPo Fire Risks - Damage limitation

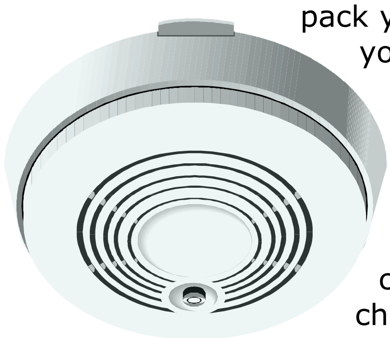
If you search the Internet for "LiPo fires" in a search engine or on YouTube you will see how easily and how fiercely LiPos burn. A LiPo fire does not need oxygen to burn because it creates its own, so such fires can be difficult to extinguish. So planning ahead to contain any damage by use of an appropriate storage system (especially while charging) is a sensible precaution. Similarly making sure you have the means to get a burning LiPo out of your car or premises as quickly as possible is a very good idea.

A fire blanket may be useful for this, but don't keep it near to your LiPos or you'll never find it for the smoke if you ever need it . Same for fire extinguishers. An insulated wire-cutter and a pair of heavy welding gloves can also be also useful aids to getting it off the charger (if necessary) and getting it outside. LiPo fires are thankfully rare, but they can quickly cause considerable damage if they do occur.

Most LiPo fires occur during charging, and therefore charging inside the house is definitely not recommended, and if possible avoid storing them in the house too. If available, an outbuilding is much preferable, and as near to an outside door as possible. But wherever you charge your batteries you should make it a priority to create as safe an environment as you can for charging and storage of your batteries.

Accidental short-circuits can also start a fire, so by placing ceramic floor-tiles on a table or bench you can easily create a non-conductive work surface, and also some heat insulation and fire protection for the work surface. Next it is well worth investing in some method of containing a LiPo fire if it should occur. You can buy purpose-built charging cases for this. They are not cheap but they're a one-off cost, and a lot less expensive than recovering from the aftermath of fire or smoke damage!

But there are other less expensive ways to achieve some degree of protection. How easy this is will partly depend on the size of LiPo pack you use and where you charge and store your batteries. Obviously larger packs are not only physically bigger, but the resulting fire can be bigger too.



The first recommendation is to purchase specially-made LiPo bags, which are useful both for charging and for storage and also for transporting in your car. They are usually made of kevlar or some other fire-retardant material. They are inexpensive and come in various sizes. If you place your LiPos in one of these for charging (with the flap closed), provided you can disconnect the battery from the charger quickly, (hence the value of keeping insulated wire-cutters and welding gloves handy) they will improve your chance of getting the battery outside very quickly in an emergency.

However they won't contain smoke for more than a few moments, so on their own they not a complete answer. You can increase the safety factor further still by creating a little "fire bunker" on your charging bench, using bricks or thermal building blocks. Many of these actually have holes which are large enough to insert smaller LiPo packs into during charging. However, never underestimate the dangers of smoke, and the significant damage it can cause to life and property, so fitting a smoke alarm near the charging area is a good idea to help catch a smouldering battery early.

All the above is really about damage limitation in the event of a fire, and hopefully this has engendered a healthy respect for LiPos, but it is, of course, much more important to take every precaution to avoid a fire in the first place.

LiPo Fire Risks - Avoidance Measures

First of all, be very suspicious of batteries that may have been damaged when a model crashes or by any other means, and be similarly cautious with batteries that have puffed up after a flight or are excessively hot (both most likely due to over-discharging in flight). Don't put a hot or damaged battery straight into your car.

At the flying field it is a good idea to put hot or potentially damaged LiPos on the ground somewhere that they can't do any harm if they suddenly burst into flames, and carry a spare LiPo bag with you to put the LiPo inside, and put it where you can see it as you drive home.

If you have any concerns whatsoever that a battery might have suffered damage, it is recommended that you fully discharge it safely and then dispose of it at your local recycling depot. (An easy way to safely and fully discharge a 3S LiPo is to connect a 12V car headlight to it until it is completely discharged).

Never get blasé about charging LiPos, as this is when most LiPo fires occur. All the documentation you will ever read relating to both batteries and charges states that LiPos should never be left unattended while charging. Even if they're in a LiPo bag - keep an eye on them!

Before charging you should check your packs carefully using a LiPo battery checker (these are cheap too). It is most important that you check each cell of the LiPo pack individually. When fires occur it is often because just one cell of a pack may be dead or have a much lower residual voltage than the others and may no longer accept a charge correctly. So check each cell, and then check the difference between the highest and lowest cell voltage in the pack. If one or more cells has a significantly lower voltage than the rest, or the pack cells are seriously out of balance with one another, (greater than 10% between highest and lowest cell voltage) it is best to discard the pack.

Another useful investment is a temperature probe for your charger. Many chargers have the socket for one of these, but few actually come with one. But they are cheap to buy and have a velcro strap to clamp them to the LiPo pack during charging. If your charger can use one of these you can program it to stop charging if the probe registers above 50°C. Well worth the very few quid they cost!

When you charge, it is best to balance the cells within the pack at the same time, and NEVER charge above 1C (as explained above).

ALWAYS make double-sure that the charger is set to charge LiPos (not other battery types) and set to the correct number of cells. Then, when the charge is completed, always check the cells again with the offline Battery Checker. Check again balance of the cells, and the difference between the highest and lowest cell voltage within the pack - if it's much more than 10% the pack should probably be scrapped.

LiPo Fire Risks - Storage

Of course storage of petrol or glow fuel for i/c engines is not without risk so having to think about how to mitigate fire risk is not new.

For storing your LiPos, here again purpose-made LiPo bags are very useful but it is probably best not to rely on these alone. A stored LiPo quietly minding its own business is most unlikely to burst into flames, but if it did, the smoke damage alone could be considerable.

You can buy special fire-proof cases to store your LiPos and even use them while charging, but they have quite limited capacity so are not ideal for storing more than a very few batteries. Some people use old ammunition boxes or steel filing boxes and these are fine, but beware of the short-circuit risk in a steel box. If the LiPos are in a LiPo bag inside the box, then that risk is minimised. You can also line the interior of the box with non-conductive material. However do NOT airtight seal the box lid shut - there must be a way for gases to escape in the event of a fire inside, or there could be a very nasty explosion!

You should also consider how you store LiPos in transit from home to the field and back. LiPo bags are useful for this, but when travelling be sure to put them where you can see them (eg. the front foot-well) so if they start to fizz or smoke you can stop the vehicle and remove them quickly. LiPo bags come in various sizes, so a smaller one inside a larger one gives double protection! Make absolutely sure that the battery leads cannot short-circuit - so carrying them in a metal container is not necessarily a great idea unless extra precautions are taken.

It is not uncommon to see people tie one lead back along the body of the pack using an elastic band, but this is not to be recommended, as elastic bands perish and break. Shrouded connectors such as XT60 are becoming more common, but even if bare connectors are used there are simple solutions to avoid short circuit. It is easy to drill a blind 4mm hole into a short length of wooden dowel or square-section wood, and push the male connector into this for storage and transit.

Flying with LiPo Batteries

One rarely considered danger in electric flight is the possibility of mistaking a used (discharged) battery from a freshly-charged one. Installing a discharged battery in a model will result in a very short flight! If you use 4mm gold connectors, you can use different insulating plugs - eg. round dowel for fresh and square blocks for discharged batteries, which is a good way to differentiate between them Another method is to use short lengths of different coloured fuel tubing to achieve the same insulating effect. (See the Safety Compendium on the DMFC website).

Obviously you cannot use this method with XT and EC type connectors so if you standardise on these you'll need to adopt some other sort of consistent method for identifying fully charged batteries from used (discharged) one - as they look identical. Clearly it is potentially dangerous to launch a model aircraft with an almost exhausted flight battery installed, so some means of indicating and differentiating freshly charged batteries from discharged ones is very important. Of course you can always use a Battery Checker every time before installing a battery in a model and this is very good practice provided you do it before every flight, and never forget to do it.

Summary

Lithium Polymer Batteries have proved to be of huge benefit to the aeromodelling community. Combined with the efficiency of brushless motors, they have brought electric flight into the mainstream of model flying, and because electric flight is so much quieter than the infernal combustion engine, it has actually saved some Model Flying Clubs from losing their flying field facilities due to noise.

Electric power using tiny LiPo flight packs has also made indoor flight possible, and opened up a whole new flying experience for aeromodellers - especially through the winter months when weather conditions for outdoor flying are often not favourable.

But, like all fuels, there are volatility issues to be considered, and careful handling, charging and storage procedures and arrangements to be adopted. Complacency or a hurried approach to charging can be costly. But provided they are used, charged and stored properly, there is no need for an irrational fear of LiPo batteries, and many of us have used them for years without incident. But never treat them casually without the care and caution they demand, or they can bite back with serious consequences.

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