Electric Propulsion Systems – De-mystified

Electric propulsion systems for airplanes seem like a black-magic recipe in order to get right for the person putting one together, variables like mAh, Kv, number of turns, cell-count, Li-Po, etc add to the mix and confusion. This doesn't have to be the way. Electric power systems are not that much more complex than glow engine systems. The fuel for an electric system is the battery. The ability to fly longer for a glow engine is to have a larger fuel tank; the same is true for an electric powered plane. The capacity of a battery is measured in mAh, or milliAmphours. This rating also has an impact on the ability to deliver power (Current x Voltage) when the full rating of a battery is taken into consideration. Lithium Polymer (Li-Po) batteries are now the common battery for electric power systems. They are described by: Number of cells (1S, 2S, 3S, etc), current capacity (mAh) and discharge capability in XC (times of rated capacity). Breaking these down:

Cells: Li-Po batteries can be configured like any other battery. They can be connected in series or parallel or any combination with other cells. The difference for LiPo packs is when the difference in the cell voltages between the individual cells in a pack exceeds 0.5 Volts. The difference is enough to cause a chemical reaction, which can lead to an increase in temperature and fire. Current-technology batteries have "taps" or balancing leads/connections that connect the battery to a balancer. The balancer is connected between the battery and the charger to ensure that the cell voltages are all effectively the same. The balancer monitors the individual cell voltages while charging or discharging and will adjust the cells to maintain the voltage between the cells. This is not to be minimized, but most chargers and batteries these days are fairly robust; this is less likely to be the cause of demise for your batteries than having a single cell run below 3 Volts or above 4.2 Volts. I have personal experience with batteries that have been brought below the 3 Volts per cell and have not had any ill affects. The long-term effects, however, are not yet known. Preventing reaching these voltages is pretty simple. Before you put your trust in that new charger or balancer, charge your battery once, and check the cell voltages with a multi-meter. The balance taps are the positive and negative connections to each cell, so checking voltage between two consecutive connections will give you each cell voltage. An example is shown below:

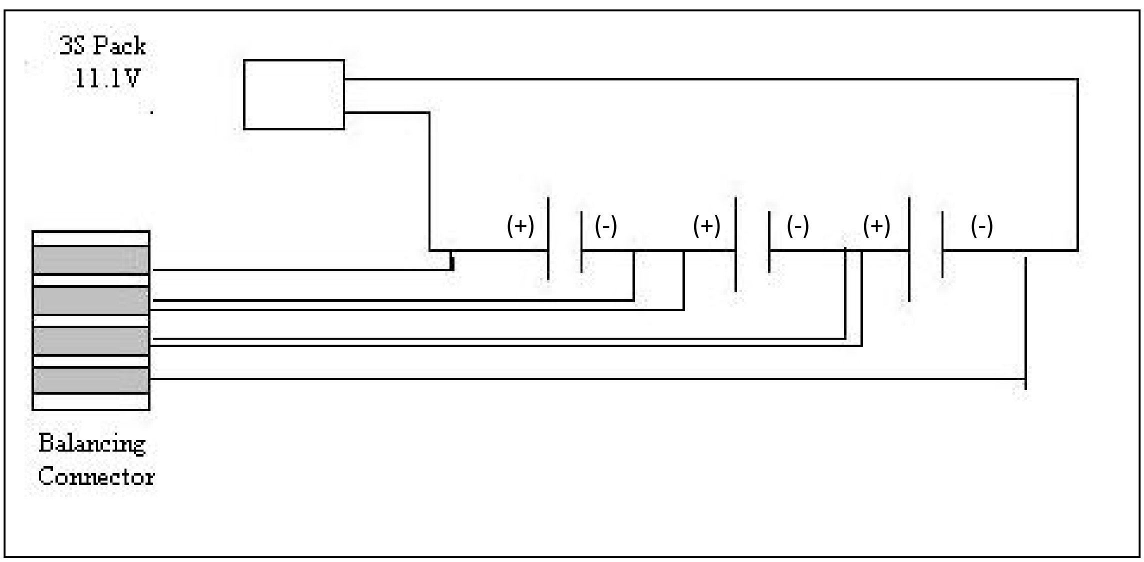

Figure 1: Balance Configuration

Battery configurations are identified with S for series or P for parallel. If there are x cells connected in a series arrangement, the pack will be identified as XS. If there are X cells in parallel, the pack will be identified as XP. Note: connecting packs in parallel must ALWAYS be done with packs of the same voltage. Connecting packs in series do not have the same requirement. Both methods should utilize the same capacity (mAh) to balance the withdrawal of power from the cells. There are two different methods of balancing:

1) Charge an under-charged cell
2) Discharge an over-charged cell

To charge an undercharged cell requires a balancing charger or a balancer. To discharge an over-charged cell, you need a balancer (or charger) with discharge capability, like the Astroflight Blinky or Great Planes balancer.

For example, 3 cells in a series configuration like the one shown below, would be considered 3S:

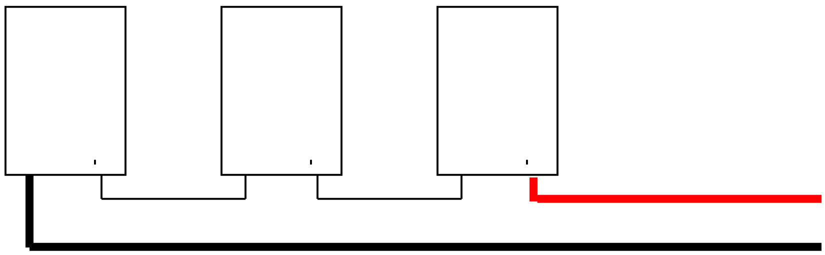

Figure 2: 3S Pack (3 single cells in series)

If we took this pack, and connected it to ANOTHER 3S pack in parallel, with the positive ends tied to each other and the negatives tied to each other, it would yield a 3S2P pack, 2 3S packs in Parallel. This doubles the capacity but NOT the voltage. Connecting packs in series (2 3S packs in series becomes a 6S Pack) will have an additive effect on the voltage.

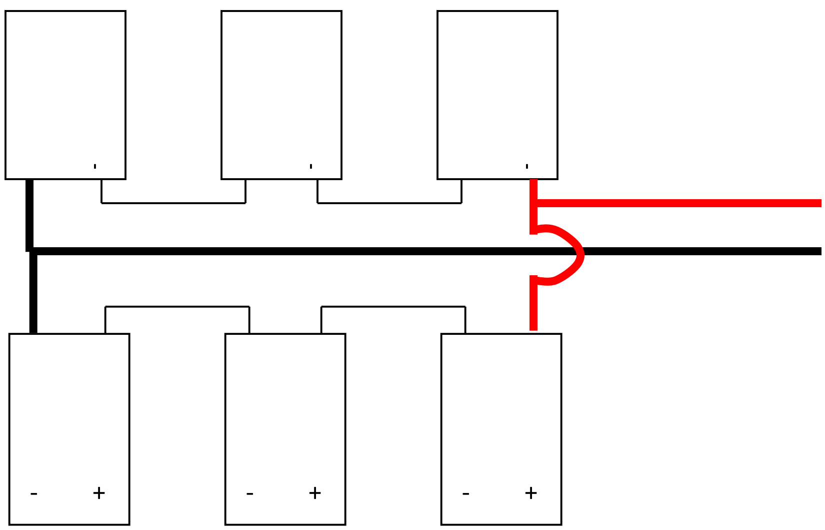

Figure 3: 3S2P Pack

Current Capacity: This is a measure of how quickly the battery can be discharged under certain circumstances. A typical rating for the now-standard 3S 2100mAh pack provides 2100 milliAmphours of use. What does this mean???? Doing some basic math:

$$2100\text{mAh} \times \frac{60\text{ min}}{1\text{-hour}} \times \frac{1\text{ Amp}}{1000\text{mA}} = 126 \text{ Amp Minutes}$$

What this means, we now have a way to estimate, at a particular throttle setting (and therefore current draw or discharge), how long the plane will fly. If we have a motor that draws 10 amps at full throttle, the plane should fly for 12.6 minutes at full throttle with this battery, more with throttle management. Typically, 70% of maximum current draw is a good estimate for judging flying time.

The other piece of current capacity is the C rating. This provides insight as to how much current the battery can safely discharge at steady state and peak rates. Today's packs are normally rated at 20C, or 20 times the capacity. Continuing with this example, a 20C 2100mAh pack, can deliver 42 Amps of current and still function properly. These packs normally have a 30-40C peak rating, which would give 37.8 or 50.4 Amp bursts of power without damaging the battery.

Voltage (V): LiPo batteries minimum voltage is 3 volts per cell. The new ones "can" be run down to 2.7 volts per cell, but it's still not recommended. Fully charged a LiPo cell will be 4.2 volts. A 3S pack will be fully charged to 12.6 volts. Two packs in parallel have the same voltage as one of the packs, since the (+)s and (-)s are tied together, and have double the capacity (mAh). Paralleling 2 2000mAh 3S packs will provide an effective rating of 4000mAh. This also increases the maximum current that can be safely drawn from the packs. A 3S 2000mAh 20C pack can draw 40A, putting two of these packs in parallel allows you to safely draw 80A.

Power (Watts): Measure of Voltage * Current. General rules of thumb for electrics:
For "Sunday Flying" - 75W per pound of plane
For Aerobatic flying - 100W per pound of plane
For Performance flying - 150W per pound of plane

There are a bunch of factors in this that come into play for the power of the electric system though. Maximum current, maximum power and kV rate the brushless motors. The latter kV is equal to the number of rpm per applied volt to the motor. A 710kV motor with a 6S pack (6*4.2=25.2Volts) spins at an ideal rpm of 710*25.2= 17892 rpm. The higher the kV rating, the smaller the propeller and conversely, the lower the kV rating, the larger the propeller. There are a number of ways to figure out what motor/prop combination is best for your application. This is really the main area that people run into issues when selecting a motor for a particular plane. If you look at your plane as if it were going to be a glow powered craft, this becomes easier, providing you have an idea of how you would power it with an engine. For example, let's take a look at a 55" WS sport plane that weighs ~6 lbs. A 46-size engine swinging a 11x6 prop at 13,000 rpm would typically power a plane this size. The top speed would be a little over 60 mph. To figure out the motor combination for this plane, we could work backward from the glow set-up. For the electric set-up:
Prop: 10x6E (electric only)
RPM: 13,000 rpm

Given the weight of the plane and type of aircraft, this plane will need a power system capable of delivering 600W. The following are the options for batteries:
3S – Will draw roughly 54A at full throttle
4S – Will draw roughly 40.5A at full throttle
5S – Will draw roughly 32.4A at full throttle
6S – Will draw roughly 27A at full throttle

This is decision point. If you already have batteries, then you can select the motor based on the battery capacity to figure out the current draw and what is required for a speed control (ESC – Electronic Speed Control). If not, then you can select the batteries based on what you can fit into the plane or what you can afford. Ah yes, the ESC. A quick note or two on the ESC; typically, I will use an ESC that is rated at 25% more than is needed for the set-up. It allows for making changes later without purchasing another ESC later. Also, for battery packs that will have more than 12.6V, either a separate Battery Eliminator Circuit (BEC or uBEC – Universal BEC) will need to be used. ESCs that have switching BECs are another possibility, and more are coming onto the market scene regularly. These are my personal thoughts and there are others out there that set-up differently. Some ESCs have more of a safety margin built-in than others. The ESCs that www.justgofly.com carries are under-rated and you can safely set-up for the exact voltage without issue. Also, if you ARE going to go the route of setting up with an exact match, check to see if the ESC will cut-out on you if you do exceed the current rating or if you can program a soft-cutoff to just reduce the power and get back to a lower current-draw.

Let's say for this example that our charger will only charge up to a 4 cell battery pack, like the older Triton charger. The options here are to use a 4-cell pack, or to use two packs in series to attain the higher cell count to increase the voltage. For simplicity, we will use the 4-cell battery (4S). With a 40.5A current draw the plane will need about a 50A ESC with either a separate BEC or a switching BEC included with the unit. We want to fly for 10 minutes with throttle management. To size the battery pack we will work backward from the equation used earlier:

$$2100\text{mAh} \times \frac{60\text{ min}}{1\text{-hour}} \times \frac{1\text{ Amp}}{1000\text{mA}} = 126\text{ Amp Minutes}$$

To use this to figure out battery capacity we need:

40.5x0.7 (70%) = 28.35A at 10 minutes = 283.5 Amp Minutes

$$283.5 \times \frac{1\text{-Hour}}{60\text{ min}} \times \frac{1000\text{mA}}{1\text{ A}} = 4725\text{mAh}$$

With this knowledge, we need a battery of roughly 4800mAh to achieve our goal. There are a number of batteries in this range, so this is reasonable.

Now, back to the motor selection: Now that we have a battery and ESC we need to select the motor. Knowing that we are going to be running at roughly (3.7Vx4cells) 14.8V and that the goal is 13,000rpm, the kV rating we need is: 13,000/16 = 880. This would be in a perfect world. Motor efficiencies will vary depending on manufacturer and type of motor. A low Kv motor being under propped can be as high as 90% and a high-speed motor over propped can be as low as 60%. For most sport flying, I typically use 80% efficiency. This means that we need a motor with a Kv rating of around 1100. There are motors in this range as well and your preferred shop/vendor should be able to help get a motor that is close to this rating that can handle 600W. Remember, if you go with a higher kV rating, you will spin the motor faster and draw slightly more current, if you use a lower kV rated motor, you will not spin as fast, but can spin a larger prop at the approximately the same current.

One other note on motors; HEAT is the main indicator of whether you are over utilizing a motor. Exceeding 130F is getting to hot and above 150F you will start to smell the insulation between the windings burning.

Chargers: I personally like the Triton by Great Planes. The new one has a nice back-lit display, which is here or there but the charger will charge pretty much any battery and is very configurable for charge/discharge rates. As stated before, TEST your new charger (and balancer) before you put your trust into it blindly. Some balancing chargers will not balance, the SuperMate charger is one example.