Electric Flight 101 - Version 1.3 05/22/2011

(Red text denotes a change from previous version)

A document to assist in the understanding and selection of electric flight components used in the brushless motor/LiPo battery environment.

Now the disclaimer: The data I present here are my understanding/opinion. Use any of the information at your own risk. I will not be responsible for any of the results you experience. Only you are responsible for the actions you take. The Internet is full of information on electric power. I suggest that you do a search and further investigate any item which you are not comfortable with.

Be sure to read the LiPo Safety section at the end of the document before venturing into any activity.

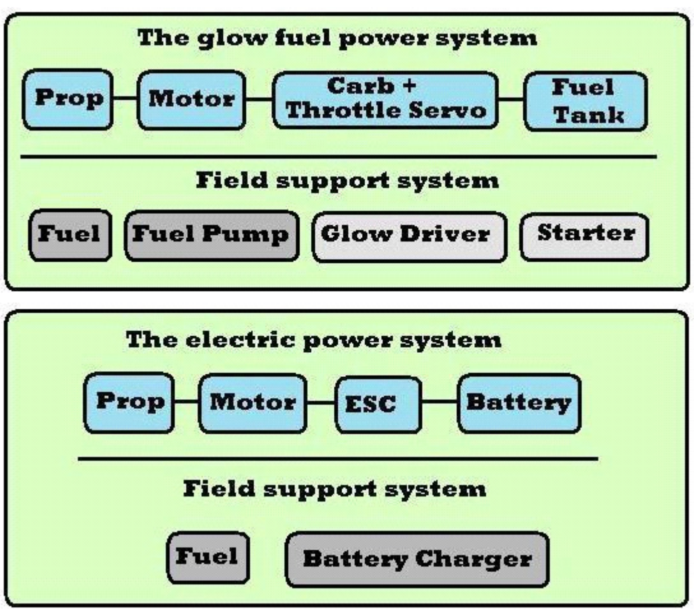
Note: Blue text is a clickable hyperlink

Glow fuel versus electric power systems

The figure at the bottom of this page shows a comparison between the components of a fuel power system versus an electric power system. It also lists the normal field support equipment required for both.

When we purchase a kit, we rely on the manufacturers engine recommendations. Although most kits are defined by engine size, it is really a prop size and rpm recommendation. The aircraft is pulled by the prop. The engine size is just a recommendation on the horsepower needed to pull the airframe.

The actual prop that we fit to an aircraft is usually determined by the type of aircraft and the type of flying that we want to do. For example a 40 size pylon racer versus a 40 size trainer versus a 40 size 3D airplane do not all use the same prop.



The pylon racer will use a smaller diameter larger pitch prop running at a high RPM while the 3D aircraft will use a larger diameter smaller pitch prop running at a lower rpm.

I point this out because when we get into selecting an electric motor for our plane, it is the prop size and RPM that we will use to select between motors of the same horsepower.

So, both systems have a optimum prop and RPM for the aircraft which is driven by a motor of a certain horsepower.

Electric motors do not have carburetors which are driven by a servo to control their output. The equivalent of the carburetor and servo on a fuel engine is the ESC (Electronic Speed Control). Both do the same thing, vary the fuel supplied to the motor.

Both motors require fuel. The fuel tank of the fuel engine is replaced by the battery on an electric system.

Support equipment:

The electric power system eliminates the need for a ignition source and a starter.

If we were only going to fly one flight, neither would require additional fuel as they could be brought out with either a charged battery or full tank of fuel. This is not the norm, so we do need extra fuel.

On the fuel engine, this is normally a spare gallon of fuel and a pump to refill the tank.

On an electric system this could be accomplished in two ways. Bring out extra charged batteries, eliminating the need for field charging, or bring out a bucket of electrons and a battery charger to recharge the flight battery.

Although the bucket of electrons could be a separate battery or a generator, the most commonly used source is you car battery (It gets recharged on your way back home).

What we now see is that selecting our equipment starts with the plane we want to fly.

Then select the optimum prop and rpm for the plane…

Then select the motor which delivers the desired results…

Then select the ESC required to handle the motors requirements…

Then select the battery required to deliver the voltage/current required…

Then select the charging equipment necessary to support the batteries.

We will now investigate the components of our power system.

Motors

There are basically two types of electric motors used for power in our model environment. Brushed and brushless.

The brushed electric motor has been with us for a long time. It consists of a multi polled armature running inside a set of permanent magnets. The armature poles (the center rotating part) are electromagnets which are pulsed with DC power and either attract or repel themselves from the fields magnets.

To control the timing of the pulses to the armature, they have a commutator (a series of contact points on the armature) which make contact with brushes as the armature rotates.

The brushless motor reverses this operation and places the permanent magnets on the rotating part of the motor. It then uses an external controller to pulse the stationary electromagnets. This eliminates the need for the commutator and brushes which are a major wear and interference problem.

In addition to eliminating the brushes, the brushless motor is more efficient and has a higher power to weight ratio.

In our model aircraft environment the brushless motor has replaced the brushed motor in all but the small inexpensive models. (This is just a cost factor as the Brushless motor and it controller are more expensive than a brushed unit.) Because of that, the remainder of this document will address the brushless motor environment.

I will not get into the detail design and operation of the brushless motor as it is of no value in our selection. If you want to understand the details of how a brushless motor works check it out on the internet. (Basically it is a DC stepper motor.)

The brushless motors, available for our environment, come in two varieties, Inrunners and Outrunners. The principle of operation is the same for both.

The Inrunner has the stationary electromagnetic coils on the outside and the permanent magnets attached to the center rotating armature (similar to a brushed motor). The center of the motor is attached to the output shaft and rotates.

The outrunner has the stationary electromagnetic coils on the inside and the permanent magnets attached to the outer rotating shell. The outside of the motor is attached to the output shaft and rotates.

In general the Inrunner is a higher RPM motor and is normally used with a gearbox. The Outrunner is a lower RPM motor which is normally direct drive (Prop attached directly to he output shaft). The Outrunner also has a higher low RPM torque.

Most planes use Outrunner motors.

The power of an electric motor is measured in watts.

What's a watt? Well, a watt is a measurement of electric energy. For our application, watt output of an electric motors can be compared to horsepower in our glow engines.

746 watts = 1 hp

One of the nice things about electric power is that it is not affected by altitude. While the typical 2 stroke fuel engine looses about 4.5 percent of it power for every 1000 foot above sea level, the electric motor puts out the same power at 5000 ft altitude as it does at sea level.

How do we measure watts? For an electrical device the voltage (E) times the current (I) is the watts (W). Commonly written as E * I = W.

So, if I had a motor running on 12 volts and pulling 15 amps it would be using 180 watts (12 * 15 = 180). Which hp wise would be about .24 hp (180/746).

Note: The actual watts/hp output of a motor will be less than the input as motors are not 100 percent efficient. Sometimes a motors efficiency is identified, but for a rule of thumb use 85 percent. So our 180 watt motor is really only delivering about 144 watts of output. Or .19 hp.

There is another formula that calculates the amount of current that a device will draw. This is the resistance of the device, defined as R, and measured in ohms. For an applied voltage (E) the current draw (I) is determined by the resistance of the device (R).

I = E/R

What this says, is that if I place 1 volt (E) across a resistance of 1 ohm (R) I will draw 1 amp (I) (and it will be using 1 watt). Varying any of the values affects the current draw. If we double the voltage to 2 volts, and leave the resistance the same, we will pull twice the current (I = E / R or I = 2 / 1). Double the resistance with the same voltage will cut the current in half (I = 1 / 2).

In a normal electrical circuit R (the resistance of the device) is usually fixed. However, in a motor it is not. The resistance of a motor is determined by two factors. The resistance of the wires used in winding the motor and the Back-EMF (Back Electro Motive Force) generated when the motor is turning.

Motors and generators are really the same but used in reverse. If you drive a motor with an outside source it will generate electricity across its input polls. A brushed motor acts as a DC generator while a brushless motor would act as a three pole alternator. When running as a motor this alternator effect develops an electromotive force which opposes the incoming current.

To simplify this, the amount of Back-EMF (resistance to current flow) increases as the rpm increases and decreases as the rpm decreases.

Why do we care about all this Back-EMF stuff? Well, we really don't but it explains one of the critical parts of selecting an electric motor for your plane. Do not overload an electric motor with too big of a prop for its designed parameters.

Electric motors are different from fuel engines in that if you overload them they will just start drawing more current, trying to maintain their designed rpm, until they burn themselves up.

This occurs based on the fact that if you overprop a brushless motor it cannot obtain is normal operating speed and thus its back-emf (resistance) will be reduced which increases the current draw of the motor. Within limits this is acceptable, however if you exceed the maximum current draw of the motor it will overheat. Exceed it enough and it will burn out.

Under-propping a brushless electric motor does not cause the problems you have with a fuel engine where it will over-rev and destroy itself. An under-propped electric motor will just reach its normal operating RPM easily and maintain it. As the motor rpm increases, the Back-EMF or resistance increases and it will just use less amps.

What we see here is that the brushless motor attempts to self govern its RPM.

When a manufacturer builds a motor they give you the operating characteristics of the motor. The important ones are Kv, volts, nominal and maximum current draw.

Kv – This is the no load RPM (in thousands of rpm) that the motor will turn per volt applied.

Voltage range - This is normally stated in volts, or cell count. This is the range of voltage that the motor was designed to accept.

Nominal current draw – This is the normal WOT (wide open throttle) current draw.

Maximum current draw (Burst current) – This is the maximum current draw that the motor will accept before overheating. It is usually further qualified by a period of time, like 60 seconds.

Ok, now lets apply this.

If we have a 1000 Kv motor and it is running on 12 volts it will attempt to spin the prop at 12,000 RPM. (In actually under load we will only get about 80% of that)

The size of the prop (load) will determine the amperage draw. We would want a prop that loads the motor to the nominal current draw at full throttle.

So what we see is that we select a motor who's Wattage output (hp) and Kv is correct to turn a given prop at the speed we desire.

More on this later under Motor Selection.

<u>The ESC (Electronic speed control)</u>

The ESC is an electronic marvel, full of smoke. Let the smoke out and it quits working.

The ESC is attached between the battery and the motor and connected to the receivers throttle channel.

Basic requirement is that once you have selected the motor, you select an ESC which will handle the voltage and current (amps) that the motor needs.

Although not addressed under motors there are two types, sensor and sensorless. Most all brushless motors available are of the sensorless type and use a sensorless controller (which most all controllers are). A sensorless controller determines the rotors position by sampling the back-EMF on the undriven leg of the motor. Sensorless motors/controllers will utilize 3 wires between the motor and the controller. A sensor motor/controller will have 5 wires with the extra wires connected to a hall effect transistor located in the motor to determine the rotors position.

Motor reversing : On a brushed motor the motor is reversed by switching the plus and minus battery connection to the motor. On a brushless motor the motor is reversed by switching any two of the three wires between the ESC and the motor.

The simplest of ESC should have at least the following preprogrammed or programmable features.

Type of battery: NiCad/NiMH or LiPo

Cell detection: This can be either programmable or automatic but is where the controller determines the number of cells attached to it (Pack voltage).

Cutoff voltage: The voltage at which the ESC cuts off the motor to prevent over discharging the battery. Usually set at 3.0 v per cell for LiPo.

Brake on/off or adjustable. Normally set to off for an aircraft with a fixed prop. For gliders or aircraft using a folding prop the brake would be set on.

This is not a normal mechanical brake. Remember when I said that a motor acts as a generator when driven by an outside force? Well if the ESC applies a load across the motor, when you are not powering it, it will act as a brake.

More advanced controllers will also allow you to:

Alter the motor timing.

Set the cutoff type, hard or soft. Hard cutoff turns the motor off when the controller senses a low voltage. Soft cutoff will reduce the power to the motor as it nears cutoff voltage to maintain a voltage above cutoff.

Soft/Hard startup: Soft start slows the start-up of the motor. Used highly in helicopters to prevent the sudden surge to the rotor head.

Error detection: A readout (usually a blinking led) that shows if the controller detected an abnormal condition.

Motor reversing through programming.

Some ESC contain a BEC (Battery Eliminator Circuit) which allows you to run the receiver and servos from the motor battery thus eliminating the need for a separate receiver battery.

If the ESC has a built-in BEC then power will be supplied back to the receiver using the throttle channels lead.

The typical built in BEC is a series voltage regulator rated at either 1.5, or 3 amps. In larger aircraft, especially those with high torque servos, care must be taken to ensure that your radio system does not overload the BEC. Many of the higher cell capacity ESC do not have built in BEC.

Note: A BEC may be defined as a 3A BEC, but read the fine print. Most BECs are series regulators and their capacity is reduced as the input voltage (cell count) is increased.

Connectors: ESCs and motors may or may not come with connectors.

The ESC to motor usually use bullet connectors. Bullet connectors are rated for current by their size. (Not all connectors are created equally, check the manufacturers specification before deciding)

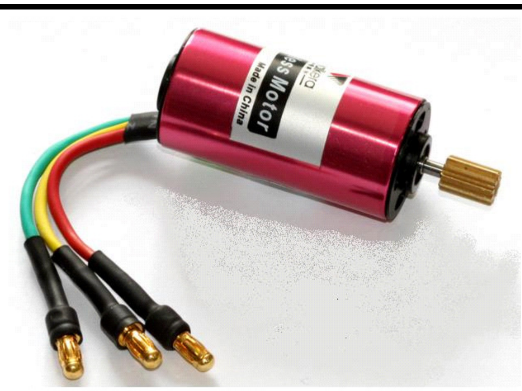
2 mm	30 amps
3.5 mm	60 amps
4 mm	80 amps
5 mm	150 amps

The bullet connector socket side goes on the ESC. The pin side goes on the motor. Connectors are then covered with heat shrink tubing to insulate them.

The ESC to battery will have various connectors . ESC to battery connectors should always be keyed in some fashion to ensure that they are not plugged in backwards.

JST	5 amp
Deans Ultra	60 amp

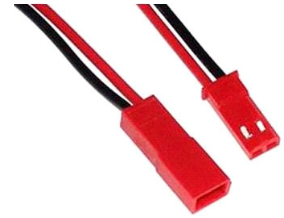
Bullet connectors (Usually in a housing designed to prevent plugging them together backwards.)



Motor with bullet connectors installed

Deans Ultra

Bullet



JST

Polarity standards

Deans Ultra: The half with the sockets go on the battery. The half with the pins go on the esc. The positive connector is normally attached to the horizontal pin and negative to the vertical pin.

JST: The half with sockets goes on the battery. The half with pins goes on the esc. The photo above shows the orientation of the plus and minus leads. (Socket half = flat side down rib side up)

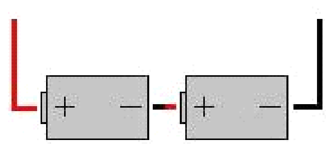
Bullet: Varies based on manufacturer.

Note: If the ESC has a BEC, but you are using another battery to power the receiver, then the red lead (power lead) of the throttle servo connection needs to be removed and taped back. The ESC only needs the signal and ground lead for its input.

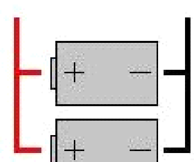
There are also stand alone BECs which can be attached to the motor battery and the receivers power input lead to eliminate the need for a separate battery. Stand alone BECs can usually be found with a higher current capacity than the units built into the ESC. As with a separate battery, if the ESC has a built in BEC it would be isolated when using a stand alone BEC.

<u>LiPo (lithium polymer) batteries</u>

Most of us are familiar with NiCad and NiMH batteries. They are 1.2 volts per cell and vary in mAh capacity by their size.



Series



Parallel

The use of NiCad and NiMH batteries, as a motor power source, has given way to the LiPo battery. This document will concentrate on the LiPo battery.

LiPo batteries are 3.7 volts per cell and also vary in their mAh capacity. As with any other battery, larger capacity batteries are larger in size.

LiPo battery cells can be hooked in series or parallel or a combination of both to make a pack. (See the figure at the bottom of page 4.)

When hooked in series, the voltage of the pack is 3.7 times the number of cells and the capacity of one cell. A 2 cell pack of 1000 mAh cells hooked in series would be 7.4 volts with a 1000 mAh capacity.

When hooked in parallel, the voltage remains at 3.7 but the capacity of the pack is the sum of the number of cells. A 2 cell pack using 1000 mAh cells hooked in parallel would be 3.7 volts but its capacity would be 2000 mAh.

You could also take 4 1000 mAh cells and configure them as two series packs, 7.4 volts 1000 mAh each, hook the two series pack in parallel and come up with a 7.4 volt 2000 mAh pack.

The construction and capacity of a LiPo pack is defined on the pack as #S#P and the capacity in mAh (Milliamp hours). 1000 mAh is 1 amp.

The #S is the number of cells hooked in series and the #P the number of parallel cells

A 1S pack is a single cell, 3.7 volts at its stated capacity. A 3S pack is 11.1 volt (3x3.7) at its stated capacity. To obtain higher mAh capacities from a pack, cells are sometimes hooked in series/parallel as described above. A 3S2P pack would be two sets of three cells hooked in series and then paralleled together.

Important: The mAh capacity written on the pack is the capacity of the pack (not the individual cells) regardless of the cell configuration.

One important thing to remember is that only like capacity cells should be used in the construction of a LiPo pack. This should become apparent later when we look at charging and discharging.

Unlike NiCad or NiMH batteries, which are limited in the amps that you can draw from them, the LiPo battery has extremely high discharge current ratings. The current rating (maximum amperage draw) for a LiPo is usually defined as a multiple of its capacity and written as 10c, 20c, etc. For a 20c battery you can draw out 20 times its mAh capacity continuously. If we had a 1000 mAh (or 1 amp) battery with a 20c discharge rating you could continuously draw 20 amps from the battery.

Most batteries have both a continuous and burst rating, like 20/25. This battery will deliver 20 times its capacity continuously but will allow for 25 times it capacity for a short period of time (Usually 10 seconds).

In addition to the high discharge capacities, a LiPo pack also retains its charge over an extended period of time. A NiCad or NiMH cell will lose 2 to 3 percent of its charge per day. A LiPo self discharge rate is about 5 percent a month.

Although a LiPo pack will maintain its charge over a long period of time, most manufacturers recommend discharging the pack to 50 percent of its capacity if it is to be stored (The recommended % varies by manufacturer from 40 to 60).

Another advantage of the LiPo cell over a similar NiCad/NiMH cell of the same capacity is that it is about 50 percent lighter.

What the LiPo cell has given the modeler is a light weight battery, capable of providing very high discharge currents. Couple this with the highly efficient brushless motor and we are now able to fly any gas or fuel powered aircraft on electric power.

The down side of this technology is that a LiPo cell must be respected. It has some very strict charge and discharge parameters which if not observed can result in the pack igniting. Furthermore, since it is not in a hard case, it is subject to physical damage from abuse or crashes.

LiPo charging

Never, I repeat NEVER, charge a LiPo battery on anything other than a LiPo battery charger.

The two most critical parameters in charging a LiPo is the maximum charge voltage and the maximum charge current. Exceed either of these and you are asking for problems.

When charging a LiPo battery, the battery is charged at a constant current until the cell reaches 4.2 volts. At that time the charger begins reducing the current, to maintain 4.2 volts across the cell, until the cell no longer accepts any current. (Most chargers cut off when the current drops below .1 amps.)

LiPo chargers never switch to trickle charge. Once the battery is charged, that's it, it's done. Trickle charging would result in the voltage exceeding the maximum 4.2 per cell and may end with disastrous results.

Originally, LiPo chargers were hooked across the entire pack (like NiCad/NiMH) and were given the number of cells (or pack voltage) and the charge current to use. In this setup the charger would charge the pack at the defined rate using the combined pack voltage. For instance, a 3 cell pack has a max voltage of 12.6 (3 x 4.2). The problem is that with age not all cells in the pack are at the same voltage when the pack is discharged. In addition, some cells may accept a charge quicker than others. Using this total pack method of charging, the cells that reach their normal voltage first will be overcharged due to the fact that one or more cells are still low and so the overall pack voltage has not reached its optimum.

Now go back to one of the basic rules, never charge a LiPo cell over 4.2 volts.

To prevent this situation, packs were equipped with a balance connector that says each cell within the pack is brought out independently to a charge plug. During balance charging, the voltage of each cell is monitored and the charge current varied on each cell independently to ensure that no cell ever exceeds the 4.2 volt maximum.

What charge current do I use for a LiPo? The normal safe charge current for a LiPo is 1C or 1 times the battery capacity. For a 1000 mAh cell, that would be 1 amp. A 1350 mAh cell would be charged at 1.35 amps. A 4000 mAh cell at 4 amps and etc. Some manufacturers have developed cells that they say can be charged at a higher rate. If this is true, it will say it on the pack. If in doubt, use the 1C rate.

The state of the art for LiPo chargers has come a long way. The current preferred charger is a balance charger. Most of them also automatically select the charge current. But remember, automatic does not always work correctly. These new chargers usually give you a read out of the % of capacity in the pack, the individual cell voltage as well as the charging current. Be sure to validate that the charging current does not exceed the pack capacity in automatic mode. Most of these chargers have a method for you to manually set the charge current.

Later under selecting a charger we will further address the specific chargers parameters.

LiPo discharge

In addition to having critical charge parameters, A LiPo battery must not be totally discharged or the pack will probably be ruined. As a general rule of thumb, the minimum safe voltage that a LiPo cell should be discharged to is 3.0 volts. So the minimum voltage for a single cell would be 3.0 volts for a 2S pack 6.0 volts a 3S pack 9.0 volts and etc.

When used in an aircraft as a motor source, the motor is driven by an ESC. As discussed earlier, ESCs used with LiPos should have either a preset 3.0 volt per cell cutoff or a user programmable cutoff voltage.

If you use a LiPo battery for a flight pack, usually a 2S pack coupled with a voltage regulator, then just like a NiCad or NiMH pack you must monitor the voltage. Rule of thumb is do not take-off if the battery reads less than 3.0 volts per cell.

Periodic cycling of a LiPo battery is not necessary or desired. LiPo batteries do not develop a memory.

What motor do I need?

We are now at the most difficult part of electric flight, selecting a motor.

The simplest thing to do is to buy a kit and use the equipment that they recommend.

Rule of thumb is that:
100 watts of power will pull a 1 lb plane.
150 watts per pound is required for aerobatics.
200 watts per pound for hard 3D.

The chart at the bottom of this page also provides an example of fuel engine to wattage comparison.

OK, using these two inputs lets try to figure out what motor we want.

A 40 size sport acrobatic aircraft weighs about 6 pounds.

Rule of thumb says 6 x 150 (watt per pound) = 900 watts
Glow fuel comparison says a 40 is about 900 watts

Lets use 900 watts as our desired motor.

What voltage motor do I want to use. Well, I need to calculate the ampere draw for a given voltage and select something within the range of our ESCs.

I * E = W well here I know E (volts) and W (watts) so the formula would be W (watts) / E (volts) = I (amperes)
So using the packs cell count for a battery we have:

3 cell (11.1 volts) 900/11.1 says we draw 81 amps
4 cell (14.8 volts) 900/14.8 says we draw 60 amps
5 cell (18.5 volts) 900/18.5 says we draw 48 amps
6 cell (22.2 volts) 900/22.2 says we draw 40 amps

OK, now I'm confused, I have 4 separate motors, running on different voltages and amps, and they are all identical in power? Yes, power is watts (I * E = W). The motor designer controls the parameters (voltage/current values) to achieve a given wattage. Basically, double the voltage and you will only need half the current to equal the same power. (Do the math, the 6 cell 40 amps is really 40.54 or half of the 3 cell 81.08.)

Which is best, high voltage/low amps or low voltage/high amps? Within limits, the high voltage/low amps is preferred. (see more under what size ESC do I need.)

Common ESC ratings are up to 80 amp. (There are larger

Engine displacement	HP	Watts equivalent
10	.27	200
15	.41	300
25	.7	525
40	1.2	900
60	1.9	1500
90	2.8	2000
160	3.7	2750

Glow engine/watts equivalent.

but…)

I would throw out the 3 cell option due to the high current requirements , leaving the 4, 5, or 6 cell as an option.

Now I need to figure the Kv I want. Let's say we want to spin the prop at 12,000. (seems logical for a 40 size plane with 11 x 6 prop.)

Note: Check out the software packages listed at the end of this section. WebOCalc may assist you in selecting a prop for a particular aircraft size, type and motor.

RPM = Kv * volts on an unloaded motor. In reality we will only get about 80% of the Kv and the volts per cell of a LiPo under load will be about 3.5.

So **RPM = .8 * 3.5 * series cell count * Kv**

Which says if we know the cell count and the desired RPM then to determine the required Kv would be:

Required Kv = RPM/(.8 * 3.5 * series cell count)

4 Cell = 12000/(.8 * 3.5 * 4) or 12000/11.2 = 1071 Kv
5 Cell = 12000/(.8 * 3.5 * 5) or 12000/14.0 = 857 Kv
6 Cell = 12000/(.8 * 3.5 * 6) or 12000/16.8 = 714 Kv

So, I will be looking for a 900 watt motor with about the following specs:

4 cell	60 amp	1071 Kv
5 cell	48 amp	857 Kv
6 cell	40 amp	714 Kv

What size battery do I need?

This equates to what size fuel tank and what size fuel line do I need in my aircraft. The mAh of the pack is the fuel tank size while the discharge rate is the fuel line size. Too small of a tank and we run out of fuel early. To small of a discharge rate and we cannot supply the amount of fuel the motor wants.

Two of the motor parameters (voltage and current) are used to select the proper battery.

Lets say that you selected the motor rated for a 6 cell battery with a 40 amp, wide open throttle, current requirement.

The first thing we need to figure out is how long a flight we want, or how big of a tank we need. For a battery this is its mAh capacity.

The current used by a motor is the factor we use here. Since we seldom fly continuously at wide open throttle, lets use 75 percent or 40 * .75 = 30 amps. Lets also say we want a 10 minute flight. Using our motors draw of 30 amps a 10 minute flight would require a battery capacity of 30 amps divided by 6 (10 minutes is 1/6 of an hour). That would come out to a 5000 mAh battery.

That is only half of the equation, next we must evaluate the discharge capability of the battery versus the maximum current draw of the motor. In this example the motor will draw 40 amps continuously. For burst current we will use the average 30 percent over norm or 40 * 1.3 which is 52 amps.

This means that our 5000 mAh battery (5 amp) would have to be able to put out 8 times its capacity (40 amps divided by 5) continuously with 10+ times its capacity (52 amps divided by 5) burst. So we need a battery rated at least 8c continuous 10+c burst. Here I would go with at least a 10/15c battery.

LiPo batteries have increased significantly in their discharge current capability. A common discharge of 15/20c or 20/25c are not that much more in cost. Although slightly heavier I would not hesitate in using a 20/25c battery in this application as it gives you more capabilities should you wish to use it with a larger motor later.

Extra discharge capacity causes no problems. An under capacity battery will cause loss of power, overheating of the battery and early battery failure.

Use of two packs hooked in series or parallel versus a single pack:

Just as a manufacturer may choose to series and parallel cells in a pack to achieve a given volt/amperage you may also choose to do the same. For instance, if you need a 6s 3000 mAh pack you could use two 3s 3000 packs in series or for a 6S 8000 mAh requirement you could use two 6S 4000 mAh packs hooked in parallel. If you do use two separate packs, be sure to use matched packs (packs of the same mAh).

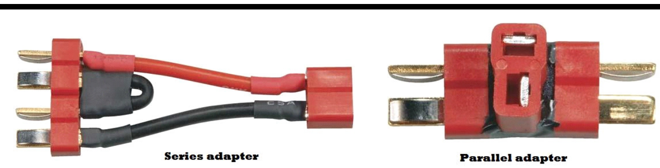
You can either make or purchase battery Y harnesses or parallel harnesses for this purpose. (See photo of sample adapters below.)

Balance charge plugs:

Just like JR and Futaba can't come up with a standard transmitter charging plug, battery and charger manufactures have not standardized the balance plug. Most charger manufacturers offer adapters for different battery plugs however always make sure that the battery and charger plug are correctly wired or adapted.

Battery attachment:

Batteries should be attached in such a manor that they are easily removable for charging.



Sample of Deans Ultra series and Parallel battery adapters

The common method of attachment is to use a self adhesive Velcro strip. The fuzzy half of the strip is usually attached to the battery with the hook side on the mounting surface. On profile models to the side of the fuselage. On full body models to a battery platform. A Velcro strap is then used around the mounting surface and the battery.

What size ESC will I need?

The ESC you select will be based on the battery cell count (voltage) and maximum ampere draw of the motor. The battery cell count (voltage) can be exact, but I suggest you get the next largest ampere capacity unit.

High voltage/High current ESC

Although not an exact cut, ESCs supporting up to 6 cell or 80 amp are readily available. When the cell count or current exceeds either of these, the selection begins to diminish (and the price goes up). In selecting between various motors, you may want to investigate the available ESCs before making a final decision. For a reference, check out
http://www.progressiverc.com/Brushless_ESC.html

What charger should I get for my batteries?

There are many great chargers on the market today. The charger you purchase should be based on what size batteries you are planning on using. What batteries you are planning on using is based on how big of an airplane you are planning to fly.

If you plan on limiting you aircrafts to the smaller 1 or 2 pound aircrafts then your battery will be relatively small, in the range of 3 cell 1300 to 2200 mAh battery, compared to trying to fly a 40 to 60 size equivalent aircraft where your batteries will get up into the 6 to 10 cell at 4000 to 6000 mAh.

Chargers are rated by their cell and current capacity. Common cell capacities are typically 3, 4, 6, 8 or 10. This number represents the maximum number of series connected cells that the charger can handle. A three cell charger can handle up to a 3S battery, an 8 cell charger can handle up to an 8S battery and etc. The cell capacity is determined by the maximum voltage that the charger is able to deliver.

The other factor is that the charger must be able to provide the charge current required by the battery. As stated previously it is normally 1C, or 1 times the battery capacity.

The #P factor (in the #S#P pack configuration definition) does not come into affect in the charger.

In addition to max cell and max current, chargers have a wattage rating. Two of the common wattage ratings for today's chargers are 50 watt or 150 watt.

A charger may say that it is a 50 watt charger and can charge up to a 6S battery and up to 4 amps, or is a 150 watt charger and can charge up to an 8S battery and up to 7 amps. This does not necessarily mean that it can charge a 6S battery at 4 amps or an 8S battery at 7 amps.

It cannot charge higher than its wattage rating which is volts times amps (I * E = W). On lower cell counts its charge limit will be restricted by its max current rating. As the cell count goes up, it will be limited by its maximum wattage rating.

Since I know the chargers maximum watts, I would divide the watts by the battery voltage to determine the maximum amps. (4.2 is the voltage used here as that is the maximum cell voltage during charging)

Lets look at the limits for a max 6S, max 4 amp, 50 watt charger. Here we see that the 1S and 2S packs could be charged at the chargers max amp rating of 4. The 3S thru 6S however would be limited by the chargers maximum of 50 watts.

1S = 4.2V - 50/4.2 = 11.9A Limit = 4.0A or 1S 4000 pack
2S = 8.4V - 50/8.4 = 5.9A Limit = 4.0A or 2S 4000 pack
3S = 12.6V - 50/12.6 = 3.9A Limit is 3.9A or 3S 3900 pack
4S = 16.8V - 50/16.8 = 2.9A Limit is 2.9A or 4S 2900 pack
5S = 21.0V- 50/21 = 2.3A Limit is 2.3A or 5S 2300 pack
6S = 25.2V - 50/25.2 = 1.9A Limit is 1.9A or 6S 1900 pack

Now for a 8S, 7 amp, 150 watt charger. Here the 1S thru 5S pack could be charged at the chargers max amps, but once again the 6S or above is limited by the chargers maximum of 150 watts.

1S = 4.2V - 150/4.2 = 35.7A Limit = 7.0A or 1S 7000 pack
2S = 8.4V - 150/8.4 = 17.8A Limit = 7.0A or 2S 7000 pack
3S = 12.6V - 150/12.6 = 11.9A Limit is 7.0A or 3S 7000 pack
4S = 16.4V - 150/16.4 = 9.1A Limit is 7.0A or 4S 7000 pack
5S = 21.0V– 150/21.0 = 7.1A Limit is 7.0A or 5S 7000 pack
6S = 25.2V - 150/25.2 = 5.9A Limit is 5.9A or 6S 5900 pack
7S = 29.4V - 150/29.4 = 5.1A Limit is 5.1A or 7S 5100 pack
8S = 33.6V - 150/33.6 = 4.4A Limit is 4.4A or 8S 4400 pack

The above limits are assuming a 1C nominal charge rate. You can charge at a lower rate, however it would take longer to charge the pack. So for example, the 50 watt charger would charge a 4S 6000 mAh pack at 3 amp, however it would take twice as long or 2 hours.

Power supplies: The LiPo charger needs a clean DC voltage. At the field it is common to use your vehicle battery which is normally capable of providing a pure DC and all the current your charger needs.

Although some of the 50 watt chargers may come in an AC/DC version with a built in AC power supply, most of the larger units will not. If you want to use the charger at home, you will need a power supply. When selecting a power supply a "switching" power supply is desired. You cannot run off of a normal battery charger as its output is not clean DC.

What size power supply do you need: Well, based on the wattage of your charger you will need a power supply capable of continuously supplying the voltage/amperage required. Watts is volts * current. Since we know the voltage the charger wants (12 V) and the watts it is capable of we merely divide the watts of the charger by 12 volts.

A 50W charger would require 50/12 or 4.2 amps. A 5 amp supply would be desirable. A 150 watt charger would require 150/12 or 12.5 amps so a 15 amp power supply would be a good choice.

Why a larger power supply? Since chargers are not 100% efficient in converting input to output you should always select a larger amp power supply than the base calculation calls for. Lets use an 80% efficiency rating for the charger. The reciprocal of 80 is 1.25 so it's 4.2A * 1.25 or a 5.25A power supply for the 50 watt charger and 12.5A * 1.25 or a 15.6A power supply for the 150 watt charger.

Lets add a little more confusion. Your charger accepts a voltage range and your power supply may be 13.5v. Now it's 50/13.5 * 1.25 or you only need a 4.6 amp power supply.

Simply stated, your power supply voltage must be within the limits of the charger and its wattage (voltage * current) should be at least 125 % of your chargers wattage. This is the continuous current rating for the power supply.

You could run a smaller power supply. For instance if the 150 watt charger were attached to a 10 amp supply then you would basically reduce the chargers capacity to 120 watts (12V * 10A). If you were not charging large batteries this would not present a problem.

To determine the capacity of the charger at the lower supply amps, merely replace the chargers 150/(volts) with power supplies 120/(volts) and you will see the results. As an example the 150 watt charger on an 8S would drop from 150/33.6 or 4.4A max to 120/33.6 or 3.5 A max. Use of a 10 amp power supply on the 150 watt charger would only affect the charging of packs above 4S as even the 10 amp supply will support all the 4S and below requirements.

In addition to charging the LiPo battery, many of the current chargers will also charge NiCad, NiMH, and even gel cell or lead acid batteries.

A123 cells (Li-Fe or nanophosphate)

One of the newer cells on the market is the A123 cell. Although it has a high discharge rate (up to 35C), it is not a direct replacement for the LiPo and requires special charger settings. Most newer chargers also include A123 as a cell type.

The A123 cell has the following characteristics:

It's voltage is 3.3 volts per cell.
It is enclosed in a hard case similar to NiCad/NiMH
It is less subject to igniting.

Although it has not yet caught on as the replacement for LiPo motor batteries, it is commonly being used as a receiver pack in a 2S configuration with a voltage regulator (or High voltage servos).

When selecting a charger, the option of charging A123 cells would be desirable.

For more information on the A123 cell do a search on the internet.

Li-Ion cells

Many Li-Ion cells charge using the same charger setting as a LiPo. Some early Li-Ion cells were rated at 3.6 versus 3.7 volts and may have a lower than 1C charge rate. Validate the manufacturers specifications before charging. Most chargers have the optional 3.6 volt setting.

Why can't I use Li-Ion cells for my motor pack? Although the Li-Ion cell stores a lot of energy in a small size, it does not have a high discharge capacity. The typical Li-Ion cell has a 2.5C discharge rating.

The Li-Ion is another good replacement for a flight pack. A 2S pack with a voltage regulator greatly reduces the size and weight of your receiver battery. A Li-Ion cell slightly larger than a AA NiCad will have upward to 2500 mAh capacity.

Is my selection correct?

In a proper match, neither the motor or the battery will get hot during flight. Although it may get warm, you should be able to place your finger on the electric motor without burning it. If the motor is overheating, you are probably over-propped.

Check the battery after flying to ensure that it is not overheated or swelling. If either of these conditions exist then the battery you are using probably has an insufficient C (discharge) rating for the system. Overheating or swelling of a pack is a sign of potential danger.

Overheating of the ESC and battery could also be caused by insufficient airflow in a full fuselage airframe. If you covert a fuel powered model to electric operation, you must provide sufficient airflow over the ESC and battery.

Watt meter: The only way to truly understand if your system is operating correctly is to use a watt meter, in combination with a tach, which will measure the operating watts of the system under load. Watt meters attach between the battery and the ESC and ideally measure the volts, amps and watts in real time.

On board monitors: On board monitoring systems are mounted in/on the aircraft and record the critical parameters during flight. The Eagle Tree elogger is one of these systems . http://*www.eagletree.com*

Prop RPM: New prop designations have appeared on the market such as "Slow Fly" and "Electric" in addition to the standard prop. Many of these props have a lower maximum rpm than the "standard" prop. Be sure that the prop you select is suited for your application.

An example would be the popular APC prop which rates their standard prop at 190,000/diameter , their thin electric props at 145,000/diameter versus their slow flyer prop which is rated at

65000/diameter.

Standard 10" prop would be maximum of 19,000 rpm, while their thin electric 10" would be 14,500 and the Slow fly 10" would be limited to 6,500 rpm. Ref: http://www.apcprop.com/v/html/rpm_limits.html

Additional information sources

RC Groups *http://www.rcgroups.com/forums/index.php*

The RC Groups Forum has a wealth of information on electric flight. As with any of the forums, the problem is finding the data you want and weeding out the information which is questionable (Just like this document).

Component specifications: *http://www.progressiverc.com*
A comprehensive list of batteries, motors, esc, chargers and much more… (Click on resources.)

Free Software packages: I know of two free software packages designed to aid you in selecting your equipment. Both may be used either on-line or downloaded to you computer. Although I have not fully used either of these programs, Drive Calc appears to be the most complete and includes a data base of popular components.

Drive Calc *http://www.drivecalc.de/*
Evaluate the complete system.

WebOCalc *http://flbeagle.rchomepage.com*
Recommends a prop for aircraft size, type, and motor.

Try/Buy software:

Motocalc http://www.motocalc.com/
Although touted to be the most comprehensive, it is not free. You may download and try it for 30 days.

Document Change History:

1.0	Initial release	11/21/2009
1.1	Update	12/03/2009
1.2	Update	12/21/2010

LiPo Safety

The above 2 photos have been going around the internet lately as an example of what could happen when something goes wrong in charging a LiPo battery. The only data I know for sure is that LiPos were being charged in the car.

Most battery failures have occurred either during charging or as a result of damage from abuse or a crash, . This however does not mean that an apparently sound LiPo cell could not ignite during storage.

All LiPo manufacturers and resellers usually provide a set of safety precautions to follow when using their batteries. Some resellers even require that you read and signify that you have read their safety warning before they will sell you a battery.

The following is an example of a safety warning given by a manufacturer (From Thunder Power batteries).

**** IMPORTANT SAFETY INSTRUCTIONS AND WARNINGS ****

• You must read these safety instructions and warnings before using or charging your batteries.
• Lithium ***Polymer batteries are volatile*** . Failure to read and follow these instructions may result in fire, personal injury and damage to property if charged or used improperly.
• Thunder Power, its distributors and retailers assume no liability for failures to comply with these warnings and safety guidelines.
• By purchasing this battery, the buyer assumes all risks associated with this product. If you do not agree with these conditions, please return the battery immediately before use.
General Guidelines and Warnings
1) Thunder Power batteries are NOT charged as you receive them. They contain approximately 50% of a full charge.
2) ***Use Lithium Polymer specific chargers only. Do not use a NiCd or NiMh charger*** - Failure to do so may cause a fire, which may result in personal injury and property damage.
3) ***Never charge batteries unattended.*** When charging LiPo batteries you should always remain in constant observation to monitor the charging process and react to potential problems that may occur.
4) Some LiPo chargers on the market may have technical deficiencies that may cause them to charge LiPo batteries incorrectly. It is solely the responsibility of the user to assure that the charger used works properly. Thunder Power only recommends chargers and balancers made by Thunder Power, other brands may work but are out of Thunder Power's control.
5) ***If at any time you witness a battery starting to balloon or swell up, discontinue the charging process immediately. Disconnect the battery and place it in a safe observation area for approximately 15 minutes.*** Continuing to charge a battery that has begun to swell will result in fire.
6) Battery observation should occur in a safe area outside of any building or vehicle and away from any combustible material. The middle of a cement driveway is a good example of a safe observation area .
7) ***Shorts can cause fires!*** If you accidentally short the wires, the battery **must** be placed in a safe area for observation for approximately 15 minutes. Additionally, be mindful of the burn danger that may occur due to a short across jewelry (such as rings on your fingers).
8) Chemical reactions are not instantaneous, a battery that has been shorted may not ignite for 10 minutes.
9) All crash batteries, even if not deformed, should be placed in a safe area for observation for at least 15 minutes
10) If for any reason you need to cut the terminal wires, cut each wire separately, ensuring the wires do not become shorted across the cutting tool.

11) When soldering connectors, first place a short length of heat shrink tubing over each wire. Then remove the insulating tape from the red wire and strip a short length of the insulation off, exposing the conductor approximately ¼”. Tin the exposed wire as well as the connector terminals. Place the wire in contact with the positive connector terminal and re -flow the solder of both together. Once cool, slide the heat shrink tubing down to cover the joint and shrink. Repeat the process for the black wire. If you accidentally short the battery wires, place the battery in a safe area and observe it for approximately 15 minutes.
12) Never store or charge a battery pack inside your car if the internal temperature will exceed 120 degrees

Before the First Charge

1) Make a visual inspection of the pack. Checking for any damaged leads, connectors, broken/cracked shrink covering, puffiness or other irregularities.
2) Before installing or changing the connector, check the voltage of the pack using a digital voltmeter (not your charger). All new packs ship at approximately 3.80V to 3.9V per cell.
For example: A 2S pack should read approximately 7.60V to 7.8V, A 3S pack should read approximately 11.40V to 11.7V.
3) If any damage to the pack or leads is found, or the voltage is significantly less for your pack than specified above, do not attempt to charge or fly the pack; contact Thunder Power directly as soon as possible.

Charging Process

1) Never charge batteries unattended.
2) Charge in an isolated area, away from flammable materials.
3) Let the battery cool down to ambient temperature before charging.
4) ***Do not charge battery packs in series except as outlined in step 8.*** Charge each battery pack individually. Overcharging of one or the other battery may occur resulting in fire. ***In order to discharge packs in series, the charged voltage of each cell in both packs must be within 0.01V***
5) ***When selecting the cell count or voltage for charging purposes, select the cell count and voltage as it appears on the battery label***. Selecting a cell count or voltage other than the one printed on the label may result in overcharging and fire. As a safety precaution, please confirm that the information printed on the battery is correct.
For example: If a battery label indicates that it is a 3 cell battery (3S), its voltage should read between 11.4 and 11.7 volts. This battery must be charged as a 3 cell battery (peak of 12.6V).
6) ***You must check the pack voltage after each flight before re-charging.*** Do not attempt to charge any pack if the unloaded individual cell voltages are less than 3.3V.
For example: Do not charge a 2-cell pack if below 6.6V
Do not charge a 3 cell pack if below 9.9V

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** DISPOSAL OF LIPO BATTERIES **

Unlike NiCad batteries, lithium-polymer batteries are environmentally friendly. For safety reasons, it’s best that LiPo cells be fully discharged before disposal (however, if physically damaged it is NOT recommended to discharge LiPo cells before disposal—see below for details). The batteries must also be cool before proceeding with disposal instructions. To dispose of LiPo cells and packs:

1. If any LiPo cell in the pack has been physically damaged, resulting in a swollen cell or a split or tear in a cell’s foil covering, do NOT discharge the battery. Jump to step 5.

2. Place the LiPo battery in a fireproof container or bucket of sand.

3. Connect the battery to a LiPo discharger. Set the discharge cutoff voltage to the lowest possible value. Set the discharge current to a C/10 value, with “C” being the capacity rating of the pack. For example, the “1C” rating for a 1200mAh battery is 1.2A, and that battery’s C/10 current value is (1.2A / 10) can be used, such as a power resistor or set of light bulbs as long as the discharge current doesn’t exceed the C/10 value and cause an overheating condition. For LiPo packs rated at 7.4V and 11.1V , connect a 150 ohm resistor with a power rating of 2 watts (commonly found at Radio Shack) to the pack’s positive and negative terminals to safely discharge connecting it to an ESC/ motor system and allowing the motor to run indefinitely until no power remains to further cause the system to function.

4. Discharge the battery until its voltage reaches 1.0V per cell or lower. For resistive load type discharges, discharge the battery for up to 24 hours.

5. Submerse the battery into bucket or tub of salt water. This container should have a lid, but it should not need to be air-tight. Prepare a plastic container (do not use metal) of cold water. And mix in 1/2 cup of salt per gallon of water. Drop the battery into the salt water. Allow the battery to remain in the tub of salt water for at least 2 weeks.

6. Remove the LiPo battery from the salt water, wrap it in newspaper or paper towels and place it in the normal trash. They are landfill safe.