ELECTRIC DRIVE SYTEMS

This brief introduction to electric drive systems is intended to just wet your appetite. There is a wealth of knowledge out there concerning electric models and their drive systems available on the internet. Please consider the information presented here as merely guidelines as usual there are exceptions to every rule. Things are changing so fast in the electric flight world and in my opinion this makes it all the more exciting!

Contrary to popular myth any model aircraft can be made to fly with electric power. Unfortunately some planes are easier to convert than others. Luckily for today's electric enthusiast more new aircraft designs are being created for electric than any other power source. Also manufacturers and retailers are beginning to offer package deals with an airplane and matching electric power system it's even easier than ever to make the switch.

Part of the beauty of electric modeling is the ability to go as "deep into the details" as you want. You can keep it simple and enjoy clean/quiet flight or you can design, build, experiment, and tweak to your heart's content. The sheer number of motor choices, gear ratios, prop sizes, speed controllers, battery chemistries, battery pack configurations, battery chargers…well you get the point. All of these choices can make jumping into electrics seem very daunting. Luckily electric designs are now exploding onto the market. The fastest growing segment is the Park Flyer/Indoor Flyer. Park Flyers usually fall in the 10-20oz category while the indoor flyers typically range from several grams to about 15 oz. depending on the size of the indoor area.

Some of the positives of electrics:
- Clean, no mess
- Quiet, potential for expanded venues: backyard, parks, indoor and fewer "lost flying sites" due to noise issues.
- Small inexpensive planes can be built from foam and can rapidly increase your flying abilities, you aren't as attached to a plane scratch built in 8 hours with less than $5 dollars (or <$50 for most kits), smaller size means easier to transport in smaller vehicles or bring more planes to the field
- Ability to tweak to your heart's content or keep it simple, bolt on a prop, charge the battery and fly
- Usually less "fiddling" than with a nitro

And now for some downsides:
- Entry cost will be higher than for an equivalent size nitro aircraft
- More downtime while waiting for batteries to charge (can be overcome with multiple battery packs, but this adds to the entry cost)
- There is slightly more work away from the field to charge the extras battery packs, nitro guys just throw the TX and RX on the charger and go to bed, electrics usually have to charge the TX and several flight packs, but you didn't have to clean the oily mess off your plane at the field either!
- Flight equipment placement can be more critical, electric motors generated EMI (Electromagnetic Interference) which can cause more radio glitches than a nitro engine, keeping things properly spaced usually solves this problem, this can be difficult however since many electric planes are smaller than their glow counterparts
- The smaller electrics are more affected by wind, the larger ones can actually be better in the wind due to there higher overall weight when compared to an equivalent nitro.

Selection of an electric drive system (system is the key word since all of the components work together to produce the thrust) involves choosing either a prepackaged system or mix and match. In either case, all systems will have the following components: prop (or fan if you're going for an electric ducted fan jet), motor, speed controller, battery. A gear drive will also be necessary for many applications and these are usually included when purchasing a motor or complete package. Each of these components will be presented in the following paragraphs in no particular order since they are all an integral part of the system.

Props

Just as in a nitro bird, prop selection is important and must be tailored to the type aircraft, speed of aircraft, and flying style. When working with an electric aircraft it is usually best to use a prop specially designed for electrics. They will be lighter, and can therefore be spun with less power and will have an airfoil designed for the type a specific type of electric flight. For example, if a prop is for a slow flyer it will have an undercambered airfoil shape that makes it more efficient at slow speeds rotation speeds and slow flight speeds.

In the U.S. props are specified using 2 numbers, e.g. 12x6, first number is the diameter in inches and the second number is the "pitch" also in inches. This number is the theoretical distance the prop will move forward with each revolution assuming no slippage.

Some basic rules of thumb (this applies to all props):

- Larger diameter = greater potential thrust and more efficiency, results in a higher current draw for the same gear ratio (shorter flight times), lower RPMs if a higher gear ratio is used keep the current the same.
- Slower turning props mean lower top end speed for a particular aircraft
- Higher pitch = higher current draw assuming the same diameter, less static thrust (poorer low speed performance, prop is stalled or bogged down at slow speeds), more "dynamic" thrust (better top end performance, i.e. higher top speed if the plane doesn't have too much drag) A high pitch prop on a slow flying plane is a poor combination, the prop never really gets to strut it's stuff.
- Lower pitch = lower current draw assuming same diameter (therefore longer flight times), better low end performance (better for 3D work or slow flyers), limits the top end speed of the aircraft

If you beginning to see a connection, all else being equal, a higher current draw results in a shorter flight time, a lower current draw results in a longer flight time. This is one of the governing rules of electric flight!

Gear Box

A Gear Box essentially allows a particular size motor to drive much larger props than would be possible otherwise. As we already know this means that thrust goes up, efficiency goes up, and flying time goes up for the same size battery. The gear box allows a proper match between the optimum propeller and the motor. Gear boxes are available for all common motor sizes and the gear ratios can usually be changed for a particular application. This means that the same drive system could be used on a slow flying Cub, a 3D aerobat, or removed completely for a direct drive pylon racer.

Motor

Several basic types are common in todays electric power systems, brushed motors and brushless DC, both types come in any size imaginable.

Brushed motors have been used the longest in models and are therefore usually less expensive for a given size than their brushless counterparts. Some of the most popular sizes are 280, 400, and 500 can motors (also known as "05" can motors used in RC cars). The number usually refers to the approximate length of the can in tenths of millimeters with each larger size also having a larger diameter and usually a standardized bolt pattern. Basic motors can purchased from virtually all of the electric manufactures (GWS, Graupner..). The crème of the crop in brushed motors is the Astro Cobalt series which uses numbers similar to nitro engines (i.e. 10 20, 40, 60) to "size" its motors (although they don't exactly match up to the equivalent nitro engine, they're actually more powerful).

Sometimes the name "Speed" is placed in front of the sizes but that's just one manufacturers nomenclature and really (Graupner). The can motors are all basically the same, permanent magnets are mounted around the outside of the can, a rotating armature with windings creates a magnetic field when voltage is applied. There are brushes that transfer the current to the contacts (commutator) on the rotating armature. It's the commutator that is responsible for switching the magnetic field at just the right time to keep the motor spinning. Some motors have sealed cans where the brushes cannot be replaced and are considered throwaways when the brushes wear out. Others (usually 500 and up) can be purchased with replaceable brushes since they are more expensive and more costly to just throw away! All of the motor sizes are available with a different number of "turns" of wire around the armature depending on the application. The number of turns sets one of the most important parameters for an electric motor, it's so important that it's everyday name is the "motor constant" or K_V. It is expressed in RPMs/Volt. Fewer turns on the armature means less torque but a higher achievable speed therefore a higher $K_{V.}$ More turns means more torque but a lower top end speed and lower K_V.

In all cases a brushed motor needs to be properly broken in for maximum power output and longest life. This break-in process helps to contour the brushes to the commutator for maximum current transfer and more importantly less arcing! There are two main methods of break-in: dry and wet. The dry method involves running the motor with no load using a reduced voltage. The voltage should be DC (so don't use your models speed controller) and about ¼ to ½ the normal running voltage. Some people use 2 AA alkaline batteries in series to do the break-in. Run the motor without prop (or gear box if possible) for 5-6 minutes at a time (shorter if the motor gets hot, longer if the motor only gets warm). A usual dry break-in requires about 1-1.5 hours of runtime. The break in process is finished when the brushes make constant contact all along the width of the brush. If you have a sealed can motor and cannot inspect the brushes, the break-in should be extended a little longer to guarantee a good mate between the brushes and commutator (Note: The extra time is due to the fact that the sealed motors usually have harder brushes that take longer to break-in, the plus side is that they usually last longer than softer brushes). The wet break-in involves holding the brushed end of the motor in a bowl/cup of water and running it for 30 seconds at a time. Change the water when it turns slightly grey. Repeat until the brushes are properly seated against the commuatator (usually within only a few minutes of running time, i.e. the wet method is much faster). In either break-in method the motor should be blown out with compressed air, sprayed with electric motor cleaner and allowed to dry before being put into service. Proper break-in helps to reduce arcing at the brush/commutator interface which helps to extend the life of the brushes and commutator. All that arcing burns little holes into the brushes! Also less arcing produces less interference with the aircraft control signals (i.e. glitches).

Brushless DC motors come in two basic flavors: internal rotors and external rotors (or “outrunners”). In either case, no break in is required and no brushes need to be replaced so the motors can last indefinitely. The bad news as that brushless motors cost significantly (usually 2-3 times more) more than an equivalent sealed can brushed motor. The plus side is that they are more efficient, therefore they run cooler for the same power input or can produce more power to the prop for the same amount of heat output. Ultimately it’s the heat output that usually limits the maximum power of a motor.

Internal rotor brushless motors can usually be found in the same basic sizes as brushed motors. A partial list of manufacturers includes Aveox, Hacker, Jeti, Model Motors, HiMaxx...(and is growing by the minute!) The main difference is that the permanent magnets are mounted on the armature and the coils are arranged around the outside of the can. Since the coils are not spinning there’s no need for brushes. Finding a comparable internal rotor brushless motor is most easily accomplished using the K_V parameter and the recommendations of the motor manufacturer, retailer, or someone else who’s gone before.

External rotor brushless motors (outrunners) have the coils situated on the inside of the motor facing outward, the permanent magnets are arranged on the outer can. It is actually the outer can that rotates on an outrunner. That’s right, the shaft is actually attached to the outer can! Since the magnets are further out on the motor, more torque is created therefore larger props can be driven directly. In fact, almost all outrunner installations are direct drive (except in electric helicopter installations, but again that’s another discussion). Unfortunately do to their design there is less standardization in size/part number and comparison between brushed or internal rotor brushless. It’s best to again use the motor constant K_V and the manufacturers recommendations when choosing a motor. Outrunner motors run about the same price as the internal rotor models and manufacturers include AXI, Koehler, PJS… The good news there are some alternatives for truly cheap external rotor brushless motors. These motors are suitable for small aircraft around 10 oz. or so and are available for free if you can find a suitable CD Rom drive from an old computer. Luckily there are people on the internet that have obtained large quantities and they can be had for $10-35 depending on the amount of work you are willing do ($10 buys a motor kit that requires a little bit of assembly while $35 gets you one ready to run). This attractive price puts them in the same price range as sealed can brushed motors which is awesome!

Speed Controller

The speed controller is the device that feeds power from the battery to the motor. As its name suggests it adjusts the speed of the motor. In the early days a servo arm moved a switch to give 2 settings: off or full throttle. Then speed controls progressed to a mechanical rheostat which was also controlled by a servo to provide intermediate speeds. These rheostats would tend to wear out over time. Today a totally Electronic Speed Control (ESC) hooks directly into the throttle servo channel of the receiver so the weight of the speed controller is offset by the loss of a throttle servo.

Another benefit of modern ESCs is the inclusion of a Battery Eliminator Circuit (BEC) which replaces the receiver battery back by powering the onboard RX and servos using the motor battery pack (again helping to reduce weight). Unfortunately a different type of speed controller is required to drive brushed motors and brushless motors. Both types of speed controllers are available in any size to match any aircraft application and are usually rated in Amps of current and also the numbers of battery cells that they can be used with. Again manufacturers, retailers, or more experienced electric modelers can aid in the selection of a proper speed controller. Popular brands of brushed controllers are produced by GWS, Castle Creations, Jeti… Brushed speed controllers are almost always less expensive than the equivalent brushless controllers for a particular application. As stated earlier Brushless controllers are required to drive brushless motors. Castle Creations and Jeti are two of the most popular brushless controller manufacturers.

Battery

Finally the last piece of the system, the battery (actually it's a battery pack since most models need more than one cell to properly power the model). Three main types of chemistries are currently popular for model aircraft power: NiCd (Nickel Cadmium), NiMH (Nickel Metal Hydride), and Lithium (both lithium ion and lithium polymer, usually referred to as Li-Poly). Each type of chemistry has it's advantages and disadvantages. Cells are rated in "current x time" capacity, i.e. "Amp hours" (AH) or "milliamp hours" (mAH). The cell capacity is referred as "C". For example a 1200mAH battery can theoretically supply 1200mA for one hour, at this rate it is said to be discharging at a "1C" rate. If we were to discharge it at higher rates, say 2C (i.e. 2400mA) it would only last for 30 minutes, 3C (3600mA) it would last for 20 minutes, 4C (4800mA) for 15 minutes, 5C (6000mA) for 12 minutes, 6C (7200mA) for 10 minutes, 10C (12000mA or 12Amps) for 6 minutes.

NiCd

Advantages:	can usually be rapid charged and peak charged, i.e. (2-3C rate) which results in a 20-30 minute charge, cell voltage of 1.2V per cell allows fine tuning of system performance by adding or subtracting a cell. Packs are usually specified by the number of cells in series, type of cell, and the total capacity of the pack (i.e. 8 AA cells, 1200maH)
Disadvantages:	lowest power density of all cell technologies (i.e. heavier), results in short flight times, cells cannot be connected in parallel for increased current capacity. Larger cells are used for increased current capacity. Packs need to be "cycled" routinely (i.e. complete discharge to 0.9V per cell then slow charged) to prevent a "memory" effect from being set up, the slow charging also has the added benefit of "balancing" all of the cells in the pack (all cells are charged to their maximum voltage).

NiMH

Advantages:	higher power density than NiCd (about 50- 100% more) lighter flight packs result in better performance with same flight time as NiCd or similar performance as NiCd but with slightly longer flight times, cell voltage of 1.2V per cell allows fine tuning of system performance by adding or subtracting a cell. Packs are usually specified by the number of cells in series and the total capacity of the pack (i.e. 8 cell AA, 1200maH).

Virtually no “memory effect” like NiCd but occasionally need to be slow charged to re-balance the pack.

Disadvantages: cannot be charged any faster than the cell capacity (i.e. “1C”), using a peak charge algorithm results in around a 60 minute fast charge, cells cannot be connected in parallel for increased current capacity, larger cells are used instead.

Li-Poly (and Li-Ion)

Advantages: extremely high power density, results in very lightweight packs for greatly increased performance or similar weight packs with greatly extended flight times, nominal voltage per cell of 3.7V results in fewer cells in series to reach a required voltage. Cells can be paralleled to increase current capacity to reach required current. Packs are specified by the number of cells in series and parallel and the total current capacity (i.e. 3s2P, 4200mA). Packs can be recharged when less than fully discharged without fear of “memory effect”.

Disadvantages: can only be charged at 1C on a “non-peak” mode because of the maximum voltage limitation per cell of 4.2V (or they may be damaged), typically charge times for a completely discharged cell is roughly 1.5 hours for full capacity (on the plus side if your pack has extra capacity they can be charged to 80% of full capacity in about 1 hour), cells should not be discharged below 2.75V per cell under load (3V no load) or they may be damaged, charging at rates greater than 1C or to higher voltages than 4.2V per cell may cause these cells to catch fire, it is extremely important to never leaves cells unattended while charging and as an extra precaution they should be placed in a clay flower pot or other fireproof container while charging.

Sanyo and Panasonic both manufacture NiCd and NiMH cells in various shapes and sizes, AAA, AA and Sub C sizes are very popular depending on the size of the aircraft. For Lithium polymer cells Thunder Power imakes packs for all size aircraft and Kokam and E-Tec also make excellent packs for smaller aircraft (park flyers and smaller).

Each battery technology requires a charger capable of charging that particular battery chemistry. **DO NOT CHARGE A BATTERY ON A CHARGER NOT DESIGNED TO CHARGE THAT CHEMISTRY.**

Support Equipment

Which brings me to support equipment, Astro Flight makes an excellent inline meter called the Super Whattmeter (yes I know Astro Flight can’t spell!) that measures the battery voltage, battery current and battery capacity while running on the bench. This tool can help to fine tune a system. Change a gear ratio, increase/decrease prop size, change batteries cell count or type and see the results. Testing like this can help set the maximum current draw so as not to damage the motor, battery or speed controller. A good charger is vitally important. A multi-chemistry charger that supports all of the battery types you’ll be using is recommended. A programmable charger that can fast charge and slow charge a pack is a necessity for “balancing” a pack (i.e. resetting all of the cells to their maximum voltage). Fast charging tends to unbalance the cells over time and an occasional slow charge will bring the cells back to the same voltage. Orbit makes an excellent (but somewhat expensive) line of chargers called the Microlader series that will charge everything (NiCd, NiMH, Lithium, Lead acid). The Great Planes Triton is also a good choice but it doesn't allow charging of large capacity lithium packs. Hobbico makes a nice field charger that does NiCd, NiMH, and Lithium but is intended for smaller capacity packs. 2A charge current limit for NiCd/NiMH and 1A for lithium. It actually has two chargers in one so you can charge two packs at once which is very handy. It will also charge your transmitter and receiver battery packs. Finally Motocalc is an indispensable tool in designing drive systems from scratch or making modifications to an existing system. You can simulate combinations of props, gearboxes, motors, speed controllers, batteries, and even airframes until you achieve the results you desire.

Drive System Examples

A good rule of thumb for estimating the electric power required to fly a typical airplane (extremely small or extremely large aircraft will have different requirements due to the scaling properties, but that's yet another discussion!):

- 50 W/lb. = Trainer/slow flyer
- 75-100 W/lb. = sport aerobatics
- 100-150+ W/lb. = 3D aerobatics

Usually the more power the better, but these are good starting points. Taking the estimated all-up weight of the plane and multiplying it by one of these factors can give an estimate to the total input power required to fly the aircraft. For example, a 6lb. 3D aircraft like the Hangar 9 Funtana 40 would theoretically take 750Watts of power to perform 3D aerobatic maneuvers (6lb. x 125W/lb.= 750W). Since Power (in Watts) is the Voltage times the Current (in amps) we could estimate that if we used a 3S, 11.1V lithium-polymer battery pack it would have to produce 67Amps for short periods while performing 3D maneuvers. This is a fairly high current draw. In order to reduce the current to something more manageable say 30-45 amps we can increase the number of cells in series in the pack to say 5S, 18.5V results in a maximum estimated current of around 40Amps. Less current will be used when just flying around or setting up for your next killer maneuver. Knowing the required current can help us pick the max current capability of the battery pack (40 Amps), the current handling capacity of the speed controller (40+ Amps), and also the power output capacity of our projected motor (750W). A good choice would be the Hacker B50L or C50L series of brushless motors. The B50L or C50L series of motors can produce the required power and are recommended by Hacker for "40" size 3D aircraft. For the battery, a typical Thunder Power 5S, 2100mAH pack can support 10C continuous discharge rates we would need a minimum of 2 cells in parallel or a 5S3P, 4200mAH pack. In practice, going to the next cell size up (in this case adding another set of cells in parallel to create a 5S3P, 6300mAH pack) is preferable when on the upper edge of performance. This insures that the battery will not overheat and it also lengthens the flight times. 6300mAH pack discharged at 40A peak and say 32A continuous will result in an estimated 5C discharge rate which will provide for 12minute flight times. A good speed controller would be the Castle Creations Phoenix line. The Phoenix 45 would be well suited since it is meant for brushless motors, can provide for 45A continuous current with bursts to 60A, and it is capable of running with our 5cell, nominal 18.5V lithium battery pack. If you feel that 40A is too close to the limits of the Phoenix 45, the Phoenix 60 would be even better, it's rated for 60A continuous and 80A burst!

Knowing that this aircraft will spend a lot of its time performing 3D maneuvers like hovering or harriers we want it to excel at slow speed flight and it's drive system should be tailored for that purpose. Therefore we will pick a large diameter prop with a low pitch. A large gear ratio like the Hacker 6.7:1 will be required to drive the large prop. We could buy several sizes of props and try them on the bench with the Super Whattmeter and select the one which pulls around 40-45A on the bench or we could plug these components into Motocalc and see what it recommends. Motocalc says that an APC 17x9 electric prop would draw 42.8Amps at full throttle on the bench. When the plane is actually in motion the prop will "unload" and the current will descrease. The average current will always be less than the peak current since the plane usually doesn't spend it's time tied down on the ground at full throttle! For example at 35mph the current at full throttle would drop to an estimated 23.3A which results in a 16 minute flight. Even if the plane is hovering (the same as flying at zero mph) only 80% throttle is required to lift the weight of the aircraft.

Now if this all seems a little too difficult, checking with the aircraft manufacture you can find their recommendations for equipment. The manual I have lists a Hacker B50-10L motor, a 5S4P lithium polymer pack, and a 17x10 electric prop. All very similar to the ones we chose. (Note, since the printing of the Funtana manual I have, the Hacker C50 series was introduced and has a slightly stronger armature design and an integral heatsink, although an optional heatsink can be purchased for the B50 and is highly recommended when producing 750W in a cowled aircraft like the Funtana. You'll also note the manufacturer suggested 5S4P lithium polymer pack is slightly larger than the one we specd at 5S3P. This is due to the fact that since the manual was printed the Generation 2 Thunder Power lithium cells we chose have hit the market and can support the 10-15C discharge rate listed in the example. Previous generations could only produce around 6C continuously which is why the extra cell was needed. They also recommend a 17x10 electric prop which will provide for a slightly higher top end speed at the expense of a slightly higher current draw. Low end performance will be identical to the 17x9). Both props will get the plane into the air and let you wring the plane out, final selection is definitely personal preference based on flying style). Whew, That's a lot of information in one sitting, I need a break!

Good Luck, hope this helps get you interested in trying electrics. If so try checking out some of the websites out there on the Internet dedicated to the advancement of electric RC modeling.

Electric RC Links (just a sample of what's out there!)

Discussion Groups

www.rcgroups.com – General discussion forums for all things RC! Check out the electric forums especially the Foamies group. There are links there to free downloadable plans for planes that can be built at home for next to nothing! Also many of the foam kits currently being manufactured are built and test flown by fellow modelers and "reviewed" in the forum. Also interesting are the 3D and the Electric helicopter forums.

www.rcuniverse.com – More discussion groups!

Electric Suppliers

www.hobby-lobby.com – Has many electric ARF and kits, large selection of motors, speed controllers, props, some batteries, misc. electric accessories.

www.aeromicro.com – Good for motors, batteries, speed controllers, servos for Park/Indoor/Slowflyers.

www.radicalrc.com – Electric kits, motors, batteries, speed controllers, props for Park/Indoor/Slowflyers, Orbit chargers, connectors.

www.towerhobbies.com – No explanation needed. They have everything Glow but are playing catchup in the electric arena. Not bad for ARFs, kits, motor combos, speed controllers, battery chargers, connectors.

www.maxxprod.com – Misc. electric accessories, motors, speed controllers, props, good source for custom made NiCd and NiMH battery packs.

www.tppacks.com – Thunder Power Lithium Polymer packs.

www.helihobby.com – Site for Electric (and Glow) helicopters kits, parts, motors, speed controllers, batteries

www.fxaeromodel.com – Site for Electric helicopter kits, parts, motors, speed controllers, batteries.

www.fmadirect.com – North American distributor for Kokam Lithium Polymer cells and FMA Radio equipment like micro receivers.

www.gws.com.tw/english/english.htm - Grand Wing Servo Tech., makers of many Park Flyer aircraft kits, inexpensive micro servos, brushed motors/gear boxes, speed controllers.

www.castlecreations.com – Maker of the Pixie and Pegasus Brushed speed controller lines and the Phoenix Brushless speed controller family.

www.nikitisaircraft.com – Club member Ed Nobel's website for aerobatic foam models.

www.foamyfactory.com – Download some plans (both free and for purchase) for easy to build foam models. Lots of info on build and outfitting aerobatic foam aircraft.

www.3dfoamy.com – Tons of foam aerobatic models in kit form plus lots of information on building and outfitting.

www.quicktechhobby.com – Source for Tanic Lithium Polymer battery packs and other supplies.

www.espritmodels.com – Source for all sizes of Thunder Power Lithium Polymer battery packs and other modeling supplies (motors, kits, speed controllers)

www.nesail.com – Northeast Sail. Sailplanes, electric aircraft kits and ARFs both foam and traditional built up, speed controllers, motors, combos, batteries.