ELECTRO-ACTIVE

by Tom Hunt tomh@flyrc.com

Power system selection

Part 5—Choosing batteries

Typical cells used for electric flight: L-R, Sanyo NiMH HR-AAAU 720mAh, Sanyo NiCd N-350AAC 350mAh, Sanyo NiCd N-500AR 500mAh, Hi-Cell NiMH AP-1000AH 1000mAh, Sanyo NiMH HR-4/5FAUP 1950mAh, Sanyo NiCd CP-1700SCR 1700mAh, Sanyo NiCd N-1900SCR 1900mAh, Sanyo NiCd RC-2400SCR 2400mAh, Sanyo NiMH HR-SC2600 2600mAh, Sanyo NiMH HR-SCU 3000mAh and Gold Peak NiMH GP330HR 3300mAh. Cells provided by Batteries America.

In part 4 of this series in the July 2005 issue, I explained in general terms, how to select a motor for a particular size model and its mission. This month I will describe how to select the proper battery size and chemistry.

OVERVIEW

A "cell" is a single unit capable of storing electrical energy. A battery is two or more cells connected in a circuit. We generally use three types of cell chemistries to fly our models: NiCd (Nickel Cadmium), NiMH (Nickel Metal Hydride) and Li-Poly (Lithium Polymer). These discussions will only include those types. A single NiCd or NiMH cell is said to have a voltage of 1.2V and a Li-Poly cell, 3.7V. This is somewhat misleading as you will soon find out. A fully charged NiCd/NiMH cell has a no-load voltage of about 1.35V. A fully charged Li-Poly cell has a no-loaded voltage of about 4.1V. A discharged NiCd/NiMH cell reads around 0.9-1V under-load and the Li-Poly cell around 2.7-3V under-load, but all three types can "recover" to a substantially higher value after the load is removed. The voltage listed by the manufacturer is sort of an average between fully charged and fully discharged.

NiCd and NiMH cells come in many "round" sizes, usually in a hard shell "can." These sizes vary in the diameter and length of the cell. Li-Poly cells are flat, rectangular cells in a soft shell. These are characterized by normal length, width and thickness dimensions. All three types of cells have another attribute: capacity. Capacity of a cell is generally expressed in milliamp-hours (mAh). Generally, the larger the cell, the higher the capacity. Do ***not*** associate the size of the cell with power (watts). Sometimes, a smaller cell can be asked to deliver more power than a significantly larger cell! The ability of a cell to deliver power is often associated with the internal resistance of the cell. This is often a consideration missed by the average modeler, mainly because many cell manufacturer/distributors do not list this value in their catalogs. Where NiCd/NiMH cells are often classified as "AAA," "AA," "A" and "Sub C" in size (diameter), there is no such labeling standard in Li-Poly cells to my knowledge.

NICD/NIMH BATTERIES

Until just a few short years ago NiCd and more recently NiMH batteries were the only cells we used to fly our "larger" model aircraft. These "round" cells are relatively heavy but have improved tremendously in capacity and power over the last two decades. When I started flying electric models around 1980, the capacity of a typical Sub C size NiCd cell was 1200mAh. By 1990 this had increased to 1900mAh and by the year 2000, NiCd technology had reached 2400mAh in the same size cell for only a small increase in weight. NiMH Sub C size cells now have reached 3700mAh and are as good if not better than most NiCd cells at delivering modest to high power loadings we need for model aircraft flight. Many European countries are discussing the banning of NiCd cells because the "heavy metal" Cadmium is polluting the ground in the landfills. It is probably only a matter of time before the NiCd cell becomes a dinosaur. Charging a NiCd/NiMH cell is generally referred to as a "peak" function. The charger will charge the cell or battery pack until it "sees" a slight drop-off in the highest voltage obtained in the cell. The cell(s) should feel slightly warm to the touch, but not "hot." A hot cell (or battery) is generally viewed as an overcharge condition and can eventually damage the cell (or battery).

Top: Kokam 3S2P 3000 (two 3-cell Kokam 8C capable 1500mAh packs wired in parallel) shown next to the newest generation cell, the 3S Kokam 3200 (20C capable), bottom. Just a short two years ago, the 3S2P 3000 pack was the only way to draw 25+ amps from a Li-Poly chemistry cell. Now, the high-discharge series of Kokam cells not only outperform the older "parallel" arrangements in power, but in most instances there is also a weight savings. GP-3300 NiMH cell for size reference.

PHOTOS BY TOM HUNT

Three similar size and weight 2-cell Li-Poly cells. Top to bottom; latest generation Kokam 1250mAh pack (15C discharge rate), Apogee 1570mAh (14C) and the older Kokam 1500mAh (8C). All three packs would generally be used on models up to about 12-15 amps, but the older Kokam 1500 (8C) pack would be much happier at 8 amps. The old Kokam cells had a much higher internal resistance and could not sustain the voltage and capacity at these currents. GP-3300 NiMH cell for size reference.

LI-POLY BATTERIES

Originally called the "plastic cell," Li-Poly batteries are becoming more popular in electric flight due to their low weight and, more recently, ability to deliver the power of a NiCd or NiMH cell. These soft shell cells must be handled with more care to avoid damage, and in some cases, a fire. Though NiCd/NiMH cells are no stranger to catching fire under extreme circumstances, the Li-Poly cell is more susceptible. One should take great care that the soft shell is not punctured or the cell is overcharged. It is also unwise to try to protect the battery by wrapping it in a harder shell or with foam. The battery must be able to remain cool through exposure to airflow.

Puncturing or physically damaging the cell can cause the battery to suffer an internal short, which in turn can cause the cell to ignite. Always assume that a Li-Poly cell has been punctured during a crash and put it aside in a safe place (such as a concrete slab or in a firebox until you are sure it is not going to catch fire). It can take quite some time after the incident to reveal the danger; in some cases it has been reported to be hours!

Only battery chargers designed for Li-Poly batteries should be used. Li-Poly cells are not charged to a "peak" voltage as NiCd/NiMH cells are. Li-Poly cells are charged to a "set" voltage, usually 4.2V/cell. Whereas the charge rate of some NiCd/NiMH cells can reach five times the capacity (5 amps for a 1000mAh cell), the Li-Poly cell should only be charged at the 1C rate (1 amp for a 1000mAh cell). This does have the drawback of making you wait much longer for the cell or battery to be fully charged. There is one exception to this rule: the new Skyvolt system from FMA charges (and balances) Li-Poly cells in about 20 minutes.

Li-Poly cells should also not be discharged below a set voltage (usually 2.6V, although many speed controls cut the motor power at 3V per cell) or they can become damaged. In normal operation this is hard to do. When a Li-Poly cell reaches about 2.9 to 3V there is so little energy left that the model will generally not be able to sustain flight (except maybe for a sailplane or very lightly loaded indoor model). The danger in over-discharging a Li-Poly cell usually comes from not remembering to recharge it once you get home after a flying session. The self-discharge of a "full" Li-Poly cell is very small; the continued self-discharge of a "spent" cell is much more rapid.

HOW TO CHOOSE THE PROPER NICD/NIMH BATTERY

All too often I have seen a modeler choose a high-quality brushless motor to "improve" the performance of a model when a simple change in battery pack was all that was needed. Though there is no doubt that the change in motor did make a big difference in the flight performance, the poor choice in battery cell type was holding back the model more than the difference in efficiency of the motor.

Draining your battery pack to do the work of flying your model is much like emptying a large water tank. If you wanted to empty a 6,000-gallon water tank in an hour, you would not use a 1-inch diameter hose! You would use a 6-inch diameter hose. The same is true of the "round" cell batteries. The higher the current draw, the larger the cell should be. Generally, though not always, the larger the cell diameter, the lower the internal resistance. The longer the cell, the higher the capacity. Since resistance in any electric circuit impedes current flow, this value should be as low as possible.

Cells designed for high-current applications (power tools) are generally the cells we like to use to fly our "larger" models. These are called the Sub C class. They are generally about .9-inch in diameter and vary in length from 1 to 1.7 inches. They also range in cell resistance from 4 milliohms to 12 milliohms. As the models get smaller and their ability to carry large batteries diminishes

TABLE 1
NiCd/NiMH Cell Characteristics

Brand	Designation	Capacity mAh	Diameter (inches)	Length (inches)	Weight (ounces)	Max Continuous Current (amps)
Sanyo NiMH	HR-SC2600	2600	.88	1.70	2.15	30
Sanyo NiMH	HR-SCU	3000	.88	1.70	2.15	30
Sanyo NiCd	CP-1700	1700	.88	1.30	1.6	40
Sanyo NiCd	CP-2400	2400	.88	1.70	2.1	40
Gold Peak NiMH	GP330HR	3300	.88	1.70	2.2	40
Sanyo NiMH	HR-4/5FAUP	1950	.70	1.66	1.37	30
Kan NiMH	KAN-1050	1050	.66	1.1	0.8	15
Gold Peak NiMH	GP1100	1100	.66	1.1	0.8	15
Sanyo NiMH	HR-AAAU	720	.41	1.75	0.46	4
Kan NiMH	KAN-650	650	.55	1.14	0.5	8

(but also the power requirement), one must be even more "choosy" with respect to cell type. Many of the smaller (AAA, AA, and A) diameter cells do not take kindly to high-amp draws. They overheat quickly and/or the voltage drops so quickly that many "BEC" (battery eliminator circuit) equipped ESCs will shut the motor down seconds after takeoff.

Some of the NiCd/NiMH cells I have used in the recent past and their corresponding current capability are shown in Table 1. Please be aware that designations and capacities change very quickly in this industry. Often, articles about batteries are out of date before they even get to the newsstand! One also must be aware that two cells of exactly the same size and weight from two different manufacturers may have completely different discharge characteristics. As I mentioned in the very first part of this series, copy someone who knows and understands what he is using in a good-performing model! Don't copy someone who says: "I don't know whose cells they are; I bought them at a discount department store."

HOW TO CHOOSE THE PROPER LI-POLY BATTERY

Li-Poly cells, like NiCd/NiMH cells, have to be chosen based on the current one wishes to consume. Unfortunately, there is no "outward physical" indication of that capability as in the "round cells" (diameter). One must rely on the manufacturer to state the maximum "C" rate of the cell during discharge. A 1000mAh L-Poly cell that is listed at a "10C" discharge rate can be safely discharged at 10 amps for short periods (10 amps/1 amp-hr). If one needs to draw 20 amps to fly the model, then two packs wired in parallel will be required (something we ***don't*** routinely do in NiCd/NiMH cells).

We say that a pack made up of 3 cells all wired in series (nominally 11.1V) is a "3S" pack. A pack made up of 6 cells (two 3S packs wired in parallel) is called a 3S2P pack. This is still an 11.1V pack, but the capacity of the pack (and the discharge rate) is doubled. Many times a manufacturer will not state the continuous running discharge rate that is safe or acceptable. I have found by experimentation that for most "high quality" cells, the continuous discharge rate should be between 50% and 70% of the stated maximum discharge rate. Note that running a Li-Poly cell at or near the maximum C rate will seriously degrade the voltage of the cell and the cell's capacity.

Some cells will deliver less than half their rated capacity when being discharged near the manufacturer's quoted C rate. Li-Poly cell technology is also changing on a monthly basis and it is very hard to keep up. However, the state of the art in the Kokam High-Discharge cells allows one to run series wired packs at discharge rates of 20C. This means that a Kokam 3200mAh cell can be safely discharged (for short periods) at 64 amps! Personally, I do not advocate the drawing of more than 30 amps out of any pack (Li-Poly or NiCd/NiMH) intended for sport flying. Currents as high as 60, even 80 amps can be required for competition and 3D aircraft where the motor runtime at these power levels is brief and well managed.

So, a very simple formula exists for selecting the proper Li-Poly cell. Divide the current expected to be drawn out of the pack by the motor by the capacity you would like to carry (in amp-hrs). This will yield the maximum C rate expected out of the battery. A 30-amp system that desires a 3000mAh (3 amp-hrs.) capacity for long enough flights is 30/3, or a 10C rate. Chose a manufacturer that can supply at least a 10C rate on a 3000mAh cell. This will avoid having to buy twice or sometimes three times the number of packs and then paralleling them together to achieve the proper C rate.

3D Giles-202 (www.giantscaleplanes.com or www.chiefaircraft.com) sport aerobatic model was used to static test four different types of batteries and flight test three of those same batteries. The RCATS flight data telemetry system transmitted and stored the data for analysis on the author's laptop computer. The packs tested were a Sanyo 16-cell RC-2400 NiCd, a Sanyo 16-cell 1950 NiMH, a Kokam 5S2P 4000 Li-Poly and a Kokam 5S 3200 Li-Poly. The data is presented in Tables 2 and 3.

PRACTICAL APPLICATIONS

To demonstrate some of the differences between the current technology NiCd/NiMH cells and Li-Poly cells, I have statically tested and test-flown some "appropriate" packs in my 3D Giles-202 sport aerobatic model. The model was instrumented with the RCATS Data Telemetry System (see article in January 05 *Fly RC*). This data allows me to investigate the performance of each type cell with respect to top speed, rate of climb and duration quite easily. First, let's look at some "static" data; see Table 2.

From this data we

TABLE 2

Static Power/RPM Data Battery Comparison
Giles 3D Sport Aerobatic Model with AXI 4130/16 and APC 15x8 E Prop

Battery	Weight (ounces)	RPM	Voltage	Current (amps)	Watts	Model Weight lbs.
16-cell Sanyo 1950FAUP NiMH	23.4	5800	16.3	25.4	415	5.25
16-cell Sanyo CP-2400 NiCd	35.3	6000	17.1	26.5	454	6*
5S2P Kokam 4000 Li-Poly (15C 2000 cells)	19.8	5930	16.7	25.7	430	5
5S1P Kokam 3200 Li-Poly (20C cells)	15.8	6200	17.8	28.2	503	4.75

* Pack too big to fit inside model, static-tested only.

can make these conclusions. The new 20C discharge Kokam 3200 Li-Poly cells are not only better than either the 1950FAUP NiMH and CP-2400 NiCd cells at delivering power at the 25-amp current level, but are better than the 15C (though 30C capable in a 2-parallel circuit) Kokam 2000mAh cells! The weight savings between the full Sub C CP-2400 cells and the Kokam 3200 pack is 19.5 ounces! Even if the Kokam produced the same power, the weight savings alone would translate into an impressive improvement in performance in a nominally 6-pound model!

Next, it was time to see how these packs performed in the air. Unfortunately, the CP-2400 pack would not fit in the model without a new canopy, so it is not presented in the data. Each battery pack was again tested statically for a few seconds before the flight. The model flight profile each time was accomplished in the following order: take off and a maximum "safe" climb-out angle to 300 feet and maximum throttle passes at constant altitude to assess to maximum speed. Then the model was flown aggressively until the pack was exhausted, in the case of the NiMH pack and in the case of the Li-Poly packs, only as long as the NiMH pack lasted. Since the Li-Poly packs have a considerable amount of charge left in them after only one flight made that way, a second similar length flight was made until the battery was exhausted. The data collected in this manner is presented in Table 3.

This is very enlightening data even if I wasn't testing battery packs! Please look at the data carefully. First, we will look at the rate of climb (ROC). As I mentioned before, even if the Li-Poly packs did not produce any more power than the NiMH pack you would expect

Top to bottom: The following packs were static and flight-tested in the 3D Gile-202 sport model; Sanyo 16-cell RC-2400 NiCd, Sanyo 16-cell 1950 NiMH, Kokam 5S 3200 Li-Poly and Kokam 5S2P 4000 Li-Poly. The data is presented in Tables 2 and 3.

a slightly higher ROC due to the lower weight. The increase from 1080 ft/sec (1950 NiMH) to 1380 ft/sec (5S2P Li-Poly pack) relates to a 27% increase in ROC! This is obviously due to more than the weight reduction of 5%. The additional watts consumed during climb-out for the 4000mAh Li-Poly pack (9% increase) is modest for the substantial increase in ROC. The 3200mAh pack further increased the ROC to 1620 ft/sec for a 50% gain in obtaining altitude over the NiMH pack!

Looking at the maximum speed data shows that the 4000mAh Li-Poly pack fared no better than the NiMH, both pushing the model to approximately 55 mph, consuming 300 watts. Note though that although the rpm of the motor at the maximum speed is not all that much more than the static condition, the current and corresponding wattage is much lower (refer back to Table 1 for the static data). Looking at the data for the 3200mAh Li-Poly pack we can see not only a fair increase in rpm but *not* a large increase in speed. This is to be expected. It takes a substantial increase in input power to increase the speed of the model only a few mph. Note that for a mere 1-mph increase in speed (at 55 mph) took 50 more watts (17%)!

Now let's look at the total mAh consumed out of the pack. The manufacturer's "rated" capacity will never be reached at "flying" currents. The stated capacity of any particular cell is at a very low current compared to flying. The 1950 NiMH pack delivered 86% of its rated capacity, the 4000 Li-Poly pack 92%, and the 3200 Li-Poly 93.5%. All of these are excellent numbers for these types of cells.

CONCLUSIONS

Now that Li-Poly cells (in this case, the Kokam brand) are capable of high-current discharge rates without adding the expense and weight of "paralleling" packs, tremendous gains in flight performance and duration can finally be realized. As you can see, it is becoming increasingly important that you measure current and power in your model systems. Even static data can show you whether you made a good or poor choice in a battery. A $60.00 investment in a good meter is well worth saving just one battery pack from being damaged from an over-current condition.

Next time we meet I will talk about the ESC and radio component selection for our clean and quiet e-powered models. Until then, fly, charge and store your model batteries carefully!

Links

Apogee Batteries, distributed by PFM Distribution Inc., www.pfmdistribution.com, (618) 558-5818

Batteries America, www.batteriesamerica.com, (800) 308-4805

Kokam Batteries, distributed by FMA Direct, www.fmadirect.com, (800) 343-2934

For further information, please see our source guide on pg. 177.

TABLE 3

Flight Testing the Batteries
3D Giles-202 Sport Aerobatic Model with AXI 4130/16 and APC 15x8 E Prop

Battery	Rate of Climb (ROC) (ft/sec)	Maximum speed (MPH)	RPM	Voltage	Current (amps)	Watts	Battery Consumption/ Flight Time (mAh)/Min.
16-cell Sanyo 1950FAUP NiMH	1080	 55.1	5,600 6,060	15.9 17.1	24.3 17.7	387 302	1679/7
5S2P Kokam 4000 Li-Poly (15C 2000 cells)	1380	 55.5	5,660 6,050	16.1 16.8	26.3 18.0	423 303	3666/18
5S1P Kokam 3200 Li-Poly (20C cells)	1620	 56.1	6,050 6,400	17.5 17.7	28.0 19.8	490 350	2992/14