PEAK OF FLIGHT NEWSLETTER

Issue 603 / July 4th 2023

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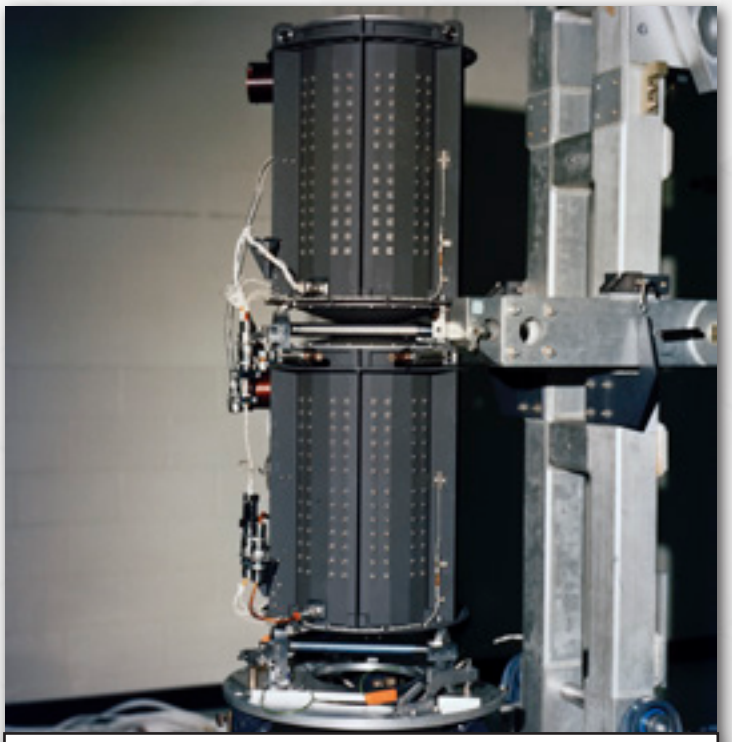
Selecting Batteries for Rocket Electronics

By Martin Jay McKee

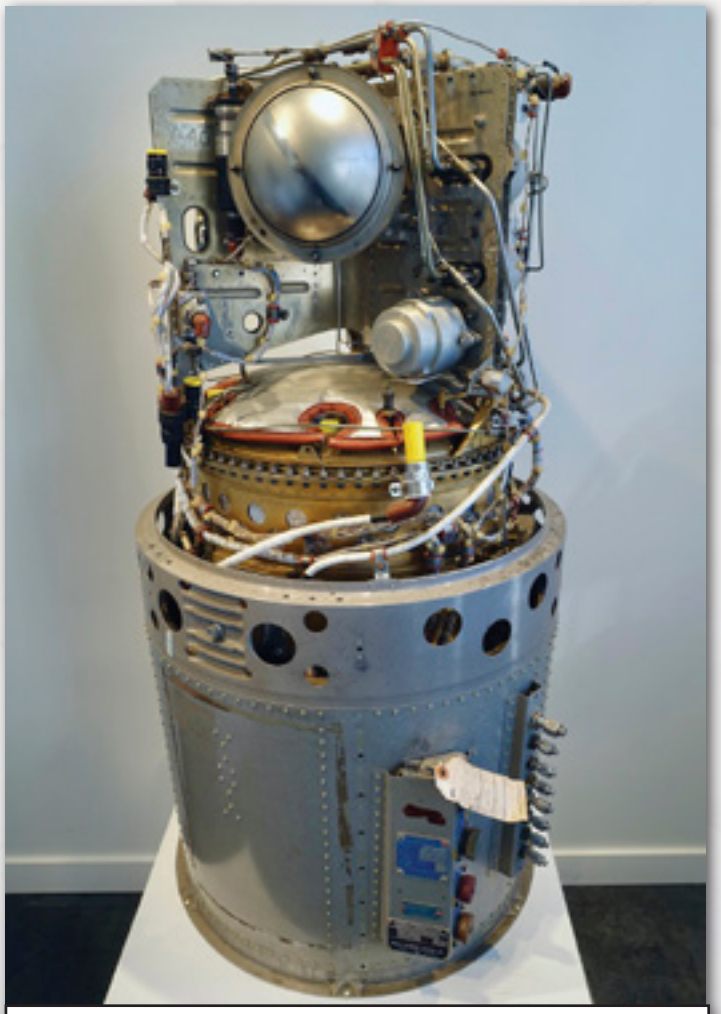
In this article, we are going to take a deep dive into the factors that affect which battery may be best suited for use with rocket electronics. As is so often the case, there is not one right answer to the question, “Which battery should I use for my electronics?” as there are many factors to consider including the size of your payload bay, required power levels (both voltage and current) for your electronics and igniters, the overall environment (temperature, humidity, etc.), the number of flights that can be done per charge, and more. This article examines many of the possible factors in choosing a battery in an effort to assist in making an informed decision.

Why Use Batteries at All?

In the wider world of aerospace, there are innumerable options for sources of electronic power. The Voyager spacecraft (still transmitting after nearly 50 years!) are powered by RTGs – Radioisotope Thermoelectric Generators. These are constructed from a stack of 4.5 kg of Plutonium-238 and hundreds of silicon-germanium thermocouples. While this technology is no doubt reliable and long lasting, there are many concerns (even disregarding the clear regulatory issues!) that make such a power supply inappropriate for model and high-power rockets. Many of the same issues apply to other power supplies which have been used in aerospace. Solar cells are used on basically every satellite in Earth orbit and many of the probes that travel in the inner solar system. Fuel cells were used on the Space Shuttle and during the Apollo era.



An assembled RTG (Radioisotope Thermoelectric Generator) as used in the Voyager spacecraft.



An Apollo era fuel cell.

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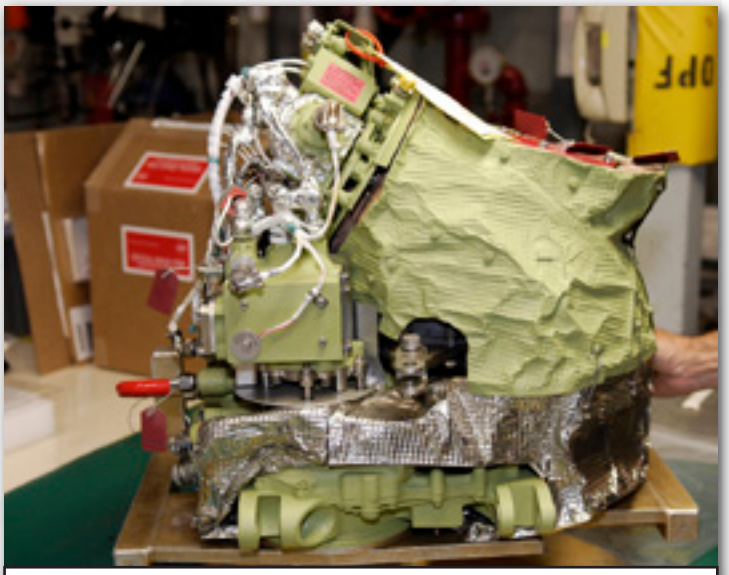
There are even some methods (often referred to as auxiliary power units on aircraft) that convert the chemical energy of propellants into electrical power by way of steam or gas generation and turbines, working in much the same way as a terrestrial coal or natural gas power plant. On the very outskirts of use as a primary power source in professional aerospace systems are batteries. They are used mostly as a buffer for a power source which provides varying energy (such as solar) or as a way to draw large currents from sources that provide long-lasting but low power sources (such as RTGs). Batteries, by themselves, do not power spacecraft. So it is reasonable to begin our exploration of the most appropriate batteries for our application with why we might be looking towards batteries in the first place.

One excellent feature which makes batteries preferable to the previously mentioned power sources is their simplicity. While battery design and chemistry is anything but simple, the use of batteries – when compared to the integration of something like a fuel cell in a high-powered rocket – is almost comically simple. Batteries are properly composed of cells. A single cell is an electro-chemical component that converts chemical energy directly into electrical power. Different types of batteries use different combinations of chemical compounds to make the conversion, but batteries generally require an absolute minimum of supporting hardware. While a fuel cell or gas generator will require fuel tanks and shutoff valves, batteries require none of that. The gas generator further requires metering valves, and control hardware. Solar cells require systems to orient them to the sun as well as inverters or DC-DC regulators to convert the electrical power from the widely varying voltage provided by the solar array to a steady voltage that is usable by the system. A chemical-electric cell, by comparison, is effectively a stand alone power source.



One of the three APUs (Auxilliary Power Units) that converted the chemical energy in Hydrazine into hydraulic pressure.

A model of the Juno spacecraft showing the large solar array required for operation in orbit of Jupiter

A second feature of batteries which makes them nearly optimal as a power source for model rocket electronics is that they are orientation independent. Some power sources (such as the aforementioned solar arrays) require a specific orientation with the environment. Others are simply sensitive to their orientation with respect to the dominant forces. This can even be the case in zero-G flight where fuel may not be properly settled in tanks (due to the lack of gravity) and ullage motors or similar are required for reliable function. Additionally, orientation can be a major issue during launch (which we are most interested in), or while on the surface of a celestial body. Except for batteries such as open lead-acid cells,

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batteries almost entirely ignore the mounting direction, external forces, and their near environment.

One of the primary reasons that batteries are preferred over something like super-capacitors (which also exhibit the last two advantages) is that batteries can have an exceptionally high energy density either with respect to weight, volume, or both. Modern solar cells are surprisingly efficient at converting sunlight into electricity – up to 40% for space grade multi-junction cells. Even with this high conversion efficiency, however, a 100W power source will need to be at least 2.7 ft^2 (0.25 m^2). By comparison, a small battery can easily provide 100W of power over a short period at a fraction of the size and weight of the solar array. Indeed, the energy density of modern batteries is only exceeded by that of chemical fuels such as gasoline, jet fuel, bi-propellant and solid propellants, and explosives. So, now that it is more clear why we might prefer batteries as a power source for the electronic payloads in model rockets, let's explore some of the characteristics that are important for deciding on which battery to use. By the end, I will argue that for a majority of purposes rechargeable batteries of one of the lithium chemistries will be the best option overall. The remainder of the article will support that assertion.

Glossary

Ah	Unit of capacity with a discharge current in amperes (amps) over the course of an hour. Equal to 3600 Joules of energy per volt.
Ampere	Unit of current flow equal to 1 coulomb (~6.2x10^18 electrons) flowing past a point in one second.
Capacity	The total amount of energy that is contained in a battery often denoted by Ah or mAh
Chemistry	The specific combination of chemicals that are used to create the chemical-electrical storage and conversion of energy in a battery.
Current	A measure of the number of electrons flowing over time. Generally measured in A (amperes) or mA (milli-amperes).
Discharge Current	The current limitation (typically thermally limited) recommended by the manufacturer of a battery. A short across the battery will pull more current but may cause damage
mAh	Unit of capacity with a discharge current in milli-amperes over the course of an hour. Equal to 3.6 Joules of energy per volt
Voltage	A measure of the electric potential difference or the "pressure" in a circuit measured in volts.

Characteristics of Battery Options

There are seven characteristics that we will use in the remainder of this article to compare the available battery options. These characteristics are: ease of use, cost, nominal voltage, capacity, maximum discharge rate, available packaging options, and chemistry specific constraints. Many of these characteristics are not going to be "rated" here. Things such as voltage and capacity are simply parameters that must be appropriate for an application. Generally, a battery with a higher capacity will be preferred – all other things being equal – but given the short duration of the "mission" in model rocketry, capacity in and of itself is rarely the limiting factor when it comes to making the decision about a battery. Ease of use and cost, on the other hand, are certainly subjective measures and I will rate them on a scale of 1 to 5 (best to worst).

Cost will be ranked on a cost per flight basis with the least expensive option receiving a score of 1, the most expensive option receiving a score of 5. The remaining options are then binned proportionally. All batteries, primary (non-rechargeable) cells included, will be allowed multiple flights if they are capable of supporting more than one flight without dropping below 75% capacity at the end of each flight where a flight is defined as a load of 25 mA for a period of 2 hours (to include prep, launch delays, flight time, and recov-

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ery). No estimate of pyro loads is included as the amount of time that igniters are activated is such a small portion of the operation.

The nominal voltage is measured in volts (as might be expected) while the capacity is measured in mAh (milli-ampere-hours). Discharge is denoted using “C” notation which is relative to the capacity. A discharge rate of 1C, for instance, means that the battery can be discharged at whatever its rated capacity is over the period of one hour. A 1C 100mAh battery could, therefore, be discharged at a maximum current of 100mA. This “C” notation is handy for comparing different batteries with different capacities as it is clearly not surprising that a 100 Ah (10,000 mAh) battery for a solar electric power bank is able to provide more current than a small 1000 mAh battery for a drone. The C rating of the drone battery, however, is likely to be substantially higher. That is, it is capable of providing proportionally more current for its size.

The packages that different batteries are available in determine the size and weight of available batteries and therefore can allow or prohibit the use of such a battery in a rocket. Finally, some types of cells have special considerations that are important for their use and should be identified as part of the decision process.

To begin, we will consider a major functional difference between different types of cells, that is whether they are primary or secondary cells. Simply, primary cells are not rechargeable, while secondary cells are rechargeable. A couple of decades ago, all the batteries used in electronic payloads were primary cells (typically with an alkaline chemistry). Most such cells have a nominal voltage of roughly 1.5v, but rocket electronics were typically powered with 9v batteries (containing 6 cells in series) or 12v batteries (containing 8 cells in series). These are convenient packages, but fail in many of the other characteristics we will explore. They are also single-use batteries. That may mean simply that they are not rechargeable, but given the absolute reliability required out of flight electronics that are in charge of recovery, that single-use may be more literal and many fliers would only fly these batteries once or twice out of an abundance of caution. More recently, secondary cells (particularly lithium based) have become popular. There are many chemistries that are available for secondary cells however, and another good option for rocket electronics is NiMH (nickel-metal hydride). Overall, primary cells are the simpler option rating higher for ease of use, whereas the reusability of secondary cells makes them substantially less expensive in the long run and more ecologically justifiable as they lead to less waste overall.

A selection of primary cells (and batteries) with 9v, AA, AAA, and A23 alkalines on the upper row and lithium primary button (or watch) cells on the bottom row.

The comparisons which follow will be between several different chemistries. The first, Alkaline batteries, are not a single chemistry. Rather, the term alkaline refers to the fact that the electrolyte in the battery has a pH that is in the alkaline (rather than acidic) range. Many of the easily available single-use batteries, such as those traditionally manufactured by Duracell and Energizer are alkaline cells. Alkaline cells are all primary cells. More recently, these well known companies have added non-alkaline cells to their product lines such as the Energizer Ultimate Lithium batteries which are primary lithium based cells. The primary lithium cells will be included as well as they are an interesting option in certain situations that are designed around alkaline batteries.

Following these, we will look at secondary chemistries such as nickel-cadmium (NiCd) and nickel-metal hydride (NiMH). While NiCd batteries suffer from what’s called a memory effect, as they are not readily available any longer and NiMH batteries are either equivalent or superior in every way that affects our exploration, we will consider these two chemistries together using NiMH batteries as our model (an example is the 300 mAh, 4.8v pack for the Gliding Parachute System **https://www.apogeerockets.com/Electronics-Payloads/Electronics-Accessories/NIMH-2-3AAA-Battery**).

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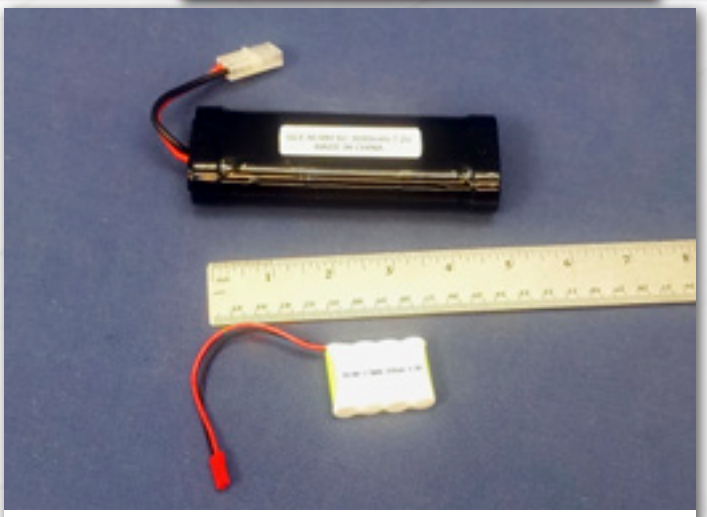

NiMH battery packs in 300 mAh (4.8v) and 3000 mAh (7.2v) sizes.

Also, because lead-acid batteries are so widely available, they will be considered as well, though it must be said that if any project would allow the substantial bulk of lead-acid cells for the flight electronics, the whole project likely warrants further exploration than this article can provide! Lead-Acid is the standard for launch system batteries, however.

Finally, different lithium based options will be examined. The three lithium based chemistries included here are Lithium-ion (Li-Ion), Lithium-Polymer (LiPo) (such as the 120mAh, 400 mAh and 900 mAh cells – all our batteries are listed at https://www.apogeerockets.com/Electronics_Payloads/Electronics_Accessories), and Lithium-Iron Phosphate (LiFePO4). These are all secondary lithium chemistries and they vary only slightly in their properties. Table 1 outlines the properties of the batteries which will be outlined here.

Before discussing ease of use, it should be noted that none of the options are difficult to use. They are all different levels of ease. That's one of the main advantages (mentioned earlier) of batteries. However, from the standpoint of ease of use, it is difficult to beat primary cells. Because they are not rechargeable, the considerations that must be made for charging disappear. Moreover,

Table 1 - Properties of Batteries

Chemistry	Classification	Ease of Use Ratiing (1-5)	Cost Rating (1-5)	Nominal Voltage	Capacity	Max Discharge Rate	Packaging Options	Specific Constraints
Alkaline	Primary	1	5	1.5v	25 mAh - 1000 mAh	1C	Cylindrical / Prismatic	
Lithium Primary	Primary	1	5	1.5v	500 mAh - 4000 mAh	1.5C	Cylindrical	
Lead-Acid (Pb)	Secondary	2	1	1.5v	3.5 Ah - 1000 Ah+	10C	Prismatic	Non-Sealed Cells Require Venting
Nickle Metal Hydride (NiMH)	Secondary	2	3	1.2v	300 mAh - 3000 mAh	10C	Cylindrical	
Lithium-Ion (Li-Ion)	Secondary	5	2	3.7v	2200 mAh - 5000 mAh	20C	Cylindrical / Prismatic	Multi-Cell Packs Require Balancing
Lithium-Polymer (LiPo)	Secondary	5	2	3.7v	15 mAh - 10 Ah	50C	Cylindrical/ Pouch/Prismatic	Multi-Cell Packs Require Balancing
Lithium-Iron Phosphate (Li/FePO4)	Secondary	4	2	3.2v	700 mAh - 100 Ah	10C	Cylindrical/ Pouch	Multi-Cell Packs Require Balancing

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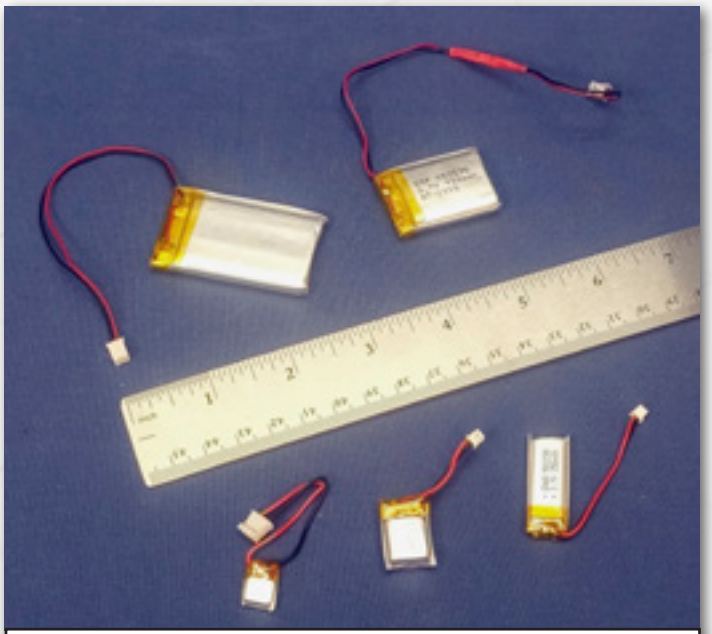
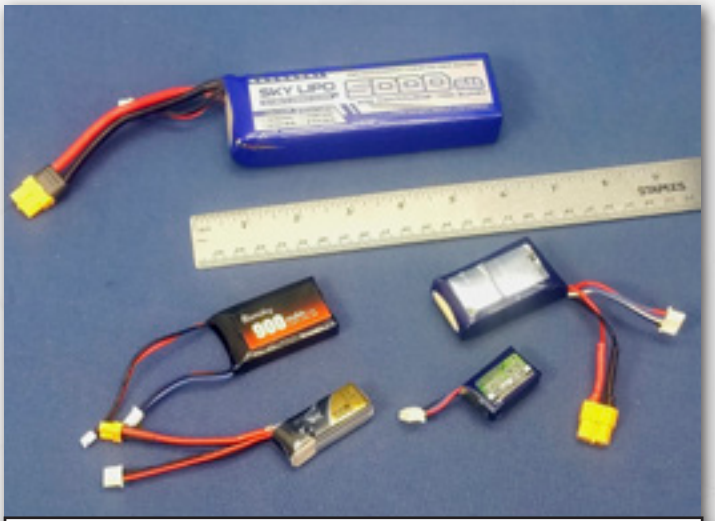


A selection of single-cell LiPo packs with capacities ranging from 15 mAh up to 900 mAh.

Examples of larger 3-cell LiPo packs with capacities of 800 mAh and 5000 mAh.



A large selection of 2-cell LiPo packs with capacities from 260 mAh up to 5000 mAh.

some of the useful styles can be bought at any corner store; and electronics designed for primary cells generally have an included battery holder, so that the batteries can be directly installed.

Rechargeable batteries are more difficult to use both because they require charging and because they are generally somewhat more difficult to source. If a replacement were to be needed at the last minute, it becomes more difficult to get it. However, while they are somewhat more difficult to use, rechargeable batteries are really not particularly difficult to use overall. NiCd, NiMH, and Lead-Acid batteries generally require a very simple charger unless fast charging is desired. In that case, it is sometimes necessary to sense the temperature of the battery during charging which necessitates a more expensive charger. Single Lithium-Ion, Lithium-Polymer, and Lithium Iron-Phosphate cells can be charged with similarly inexpensive chargers (though the charging process is more involved). This ability to charge inexpensively makes single-cell Lithium attractive. Sometimes more voltage (>3.7 v nominal) is needed however, and then multi-cell Lithium batteries are needed. These increase the complexity and cost of charging because lithium batteries need to have the cells balanced. Balancing is ensuring that each cell is charged to as near the same voltage as possible. While this

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could be done with other secondary cells, it is crucial for lithium cells because fires can break out in lithium cells that are discharged too low, or charged too high. Balancing makes sure that the cells in a battery remain in the safe range. This added requirement makes multi-cell lithium chargers more expensive than single cell chargers. Generally the convenience decreases as well due to the fact that single-cell lithium batteries can often be charged with USB connected chargers, while multi-cell chargers require wall plugs or high voltage (i.e. 12v) DC power.

Table 2 outlines the relative cost of using different batteries with the specified flight profile of 25 mA current over 2 hours. While it is generally possible to find less expensive chargers depending upon chemistry, all costs are estimated using an RC charger balancer that retails for around $40. This sort of charger (there are hundreds on the market in the $30 - $100 range) will charge any of the battery chemistries mentioned here and also do the required balancing, so it is a recommended purchase for anyone that is going to be using rechargeable batteries often for their hobbies. For the purpose of this article, however, using this charger is a simpler approach than attempting to find different chargers for each example battery. While it is also likely that any charger will be used for more than one battery, this article uses a worst case analysis that folds the total cost of the charger into the cost of a single battery. By finding a less expensive charger and taking into account that the charger is likely to be used with many batteries, the cost will only drop. Finally, it is worth noting that the maximum cycles used here are about 1⁄4 of that recommended by battery manufacturers. If batteries are well cared for, they can often be recharged many more times, and again the cost over time will drop.

As can be seen in Table 2, all of the secondary cell options are astronomically less expensive than primary cells if they are going to be used for many flights, even including the cost of a charger. The table shows Lead-Acid to be the least expensive option (~2¢ per flight), but this is mostly just a result of the smallest available lead-acid batteries having such a large capacity (4500 mAh). This

Table 2 - Cost of Battery

Example Battery	Pack Nominal Voltage	Weight	Capacity	Maximum Discharge Rate	Packaging	Maximum Cycles	Flights per Charge	Cost	Cost Per Flight (+including charger)
Duracell 9v (Zn/MnO2)	9v	45g	425 mAh	0.5 C (0.2 A)	Prismatic	1	2	$6.30	$3.15
Energizer Ultimate 9v (Li/MnO2)	9v	34g	700 mAh	1.5 C (1 A)	Prismatic	1	3	$13.50	$4.5
Panasonic 6v AAA NiMH Pack	6v	60g	700 mAh	2 C (1.4 A)	Pack of Cylindrical	100	3	$12.00	$0.17
Power-Sonic AGM PS-640F (lead-acid)	6v	730g	4500 mAh	10 C (45 A)	Prismatic	100	22	$5.40	$0.021
Turnigy nano-tech	7.4v	18g	260 mAh	35 C (9 A)	Pouch	250	1	$5.50	$0.182
ZIPPY Compact (Li/FePO4)	6.6v	40g	700 mAh	5 C (3.5 A)	Pouch	250	3	$6.00	$0.061

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battery is comically large for flight on a typical model rocket, but would work reasonably well for a launch system. Of the remaining batteries – which might actually be flown – the least expensive option is the Lithium Iron-Phosphate battery, mostly because it can be flown three times per change without dropping below the identified 75% target. The LiPo option is much more expensive because it can only be flown once per charge. The NiMH option is around the same cost as the small LiPo. By contrast, the alkaline and primary Lithium options are at least seventeen times as expensive. Moreover, the two primary options have very low maximum discharge currents that may be inappropriate for standard igniters.

The different chemistries produce different voltages per cell. On the low end are NiMH cells that are 1.2v a piece, while LiPo cells are 3.7v each. The nominal voltage only matters insofar as electronics and igniters require a specific range of voltage to work correctly. As such, knowledge of the nominal voltage makes it possible to determine the number of cells a battery requires. In Table 2, the number of cells range from two for the LiPo and LiFe batteries up to eight for the 9v primary batteries. In general 3-6v is sufficient for triggering an e-match, so that a single Lithium cell is sufficient. For other igniters with a standard bridge wire (like the Aerotech igniters), a voltage between about 6v and 12v is necessary and multi-cell batteries are required. Of course, it is possible to purchase every chemistry in the form of a multi-cell battery, so there is little advantage over the others due to nominal voltage alone.

When it comes to capacity, more is almost always better so long as the cell isn't physically too large or heavy. A cell with a large capacity can provide more maximum current and it will also last longer under any specific load (especially comforting when a rocket is sitting on a pad during a slow launch cycle). Capacity is one place where LiPo batteries are much more appropriate than any of the other available options. Lead-acid cells are simply huge. Both their weight and their dimensions make them prohibitive for use in most rockets. Their capacity is generally measured in Ah (ampere-hours). Primary cells as well as NiMH and NiCd cells are more reasonable in size and have plenty of capacity for typical flights. They do not, however, offer many options for smaller applications. LiFe cells are generally targeted for larger applications. As can be seen in Table 2, however, a LiFe battery can easily replace a 9v primary battery with much higher current capability, similar or larger capacity, and no substantial increase in weight. LiPo batteries are the standout here however. Table 1 gives a capacity range of 15mAh to 10 Ah. That is a factor of over 650 in capacity; and across this range it is generally simple to purchase both single cells and assembled batteries. For rocketry applications, batteries under 1000 mAh are generally the most useful and there are hundreds of options with 1, 2 and 3 cells (3.7v, 7.4v, and 11.1v nominal) available all over the place. The smallest LiPo cells available (under roughly 50mAh) are used for consumer goods such as earbuds and are therefore quite inexpensive.

When firing an igniter, the most important thing is the battery's ability to push enough current through the bridge to heat it sufficiently. Some minimal voltage is required to overcome the series resistance of the igniter (the wires and the bridge), but a battery's internal resistance is actually much more important. This internal resistance leads to the maximum discharge rate. Primary cells are terrible when it comes to current capability and should be avoided for anything other than e-matches. This might be fine for electronic deployment, but it makes events such as staging and hotwire cutting for recovery difficult or impossible. All of the other chemistries besides the primary cells are capable of providing a reasonable amount of current in comparison to their capacity. Once again, however, the LiPo batteries excel in this area and are available with truly mind boggling current capabilities. While a primary cell is limited to a rate of less than 2 C (two times the capacity) it is possible to purchase small LiPo batteries with a discharge rate of over 100 C. This allows for the use of extremely small batteries, saving weight and taking less space. The remainder of the chemistries fall somewhere in the middle of these two extremes and while they can be made to provide sufficient current for any

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rocketry application they will not reach the small size and weight of LiPo batteries.

The available packaging of different cells is important as it determines the size and weight of batteries that can be used. The packing of alkaline cells is generally inappropriate for use in rockets as the low voltage per cell (generally 1.5v) is insufficient for rocketry applications. Since these batteries are also designed in such a way that they cannot be assembled into a pack using spot welded bus bars (connections between cells), the cylindrical alkaline cells (AAA, AA, C, and D) are only usable in combination with a battery holder. The spring contacts in such holders work well enough in applications that are terrestrial, but the vibration and acceleration of a rocket flight tends to cause power dropout and overall unreliability. As such, there are only limited packaging options available which are appropriate. The most widely used are the 9v battery and the 12v A23 (indeed, we still sell the A23 **https://www.apogeerockets.com/Electronics-Payloads/Electronics-Accessories/12V-Alkaline-Battery-Size-23A**). Both of these packages were used in early rocketry electronics which had built-in holders. The other primary cells that are sparsely represented in rocket electronics are lithium button cells. These are the small round batteries, sometimes called watch batteries (because the smaller versions were typically used in watches). They are available in several chemistries and may be either 1.5v or 3v per cell, though only the 3v version tends to be used in rocket electronics. Watch batteries have such a low maximum discharge rate that they cannot be used in any application that requires the initiation of pyrotechnics. Like primary cells, the NiCd and NiMH secondary cells are generally only available in cylindrical packages. However, unlike the primary cells, the secondary cells are designed to be assembled into higher voltage batteries by spot welding the cells together with strips of metal. As such, they do not suffer from the same vibration issues that primary cells in spring holders do. Like primary cells, however, the range of available packages is smaller than lithium chemistries.

Lead-Acid batteries are generally only available in a prismatic package that is a rigid rectangular package. Non-sealed lead-acid batteries are wholly unsuited to rocketry applications as they can spill corrosive acid when tipped. Sealed lead-acid batteries can be used in many orientations and so could be used in rocketry if it were not for the fact that even the smallest lead-acid batteries are massive on the scale of typical model rocketry applications. As it stands, small lead-acid batteries could be used in very large rockets. Lead-Acid batteries however – in the form of car batteries – are widely used in launch systems. As such, they are applicable to rocketry though rarely to flight systems.

In contrast to the previous options, rechargeable lithium chemistries provide a massive range of packages and, as mentioned above when discussing capacity, a wide range of sizes. The three main types of packing for lithium chemistries are pouch, prismatic, and cylindrical. Cylindrical cells are very similar to the primary cells and are sometimes even available in the same sizes though the 18650 cell (similar in size to a longer “C” cell) is the most widely available. Prismatic cells are rectangular cells in a rigid case. These cells and cylindrical cells are more rugged than the final packaging type, but they are heavier due to the weight of the case. The final packing style – pouches – are little more than a plastic bag surrounding the cell materials. There are a few advantages of such packaging. First of all, they have the best energy density and generally have some of the highest volumetric density as well. These advantages make pouch style cells ideal for rocketry. Another advantage of this style is that it is easy to manufacture cells of a new shape and size. The result of this is that pouch cells are available in a massive range of capacities.

In addition to the physical and electrical characteristics outlined above, there are special considerations required for some cell chemistries that might affect choices. For instance, lead-acid cells can require venting and NiCd cells can require special charging procedures to deal with the so-called “memory effect”. The most important special consideration is the fact that rechargeable lithium cells require chargers that are capable of individually adjusting the voltage of each cell in the battery. This is called balancing. While the process of

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Different types of chargers that may be used for secondary cells. A large hobby charger (upper) that handles many different configurations and chemistries, and two versions of USB chargers for single-cell LiPo packs.

balancing does improve the overall performance of the battery, the reason it is necessary comes down to safety. It is well known that Lithium batteries can be dangerous. The many videos of Hoverboards, laptops, and cell phones bursting into flames amply demonstrate what a lithium cell can do when handled poorly. Lithium Iron-Phosphate cells are actually much safer overall, which is why they are used for things like backup batteries in solar-electric installations (the main reason that such large Li/FePO4 cells are manufactured). Lithium-Ion and Lithium-Polymer cells still have the highest power density and are still less expensive, so they are more likely to be used in a rocket. Balancing prevents any cell from becoming overcharged. Depending upon the batteries, charging them with a balance charger may require plugging in a specific balance plug, and it always requires a more expensive charger. As such, it's easier to avoid multi-cell lithium batteries when possible. That said, while balancing is important, it is not difficult or expensive enough to be a reason to avoid lithium cells.

Having examined the characteristics of many battery chemistries, it is not possible to review the battery recommendations. For old electronics that were developed to use alkaline primary cells, it may certainly be beneficial (or even necessary) to continue to use such batteries or replace them with lithium primary cells. Indeed, those electronics with built-in battery holders are unusable – without invasive modifications – with any other options. For any new electronics that allow the connection of external batteries, there is little argument against using LiPo, Li-Ion, or Li/FePO4 cells in rocketry applications. Charging of lithium based secondary batteries is simple given an appropriate charger and such chargers are widely available for one or more cell battery packs. Alkaline cells (along with other primary cells not mentioned in this article) end up being substantially more expensive and wasteful in the long run with very little advantage in modern electronics, while older secondary cells such as NiMH, NiCd, and lead-acid impose a moderate to substantial weight and size penalty that is not balanced by any other advantages in our specific applications.

There are, of course, many special applications that require different battery choices (such as the lithium primary "button" cells that are used for the MicroPeak altimeter (https://www.apogeerockets.com/Electronics-Payloads/Altimeters/MicroPeak-Altimeter)) either due to physical or electrical constraints. Generally, the manufacturers of these payloads are well aware of the special requirements and make it abundantly clear what sort of battery is needed. In the absence of such information, the characteristics examined in this article are generally more than enough to decide upon a flight battery. That said, I have ignored many characteristics of cells including series resistance (and the related voltage drop under load), the shape of the discharge curve, dependence of other characteristics upon temperature, and many more. The nice thing though is that none of them is important enough to change the fact that readily available LiPo batteries have become the most appropriate power source for hobby rocket electronics in the past decade.

About the Author:

Martin has been designing and building rockets for as long as he can remember. After originally toying with the idea of pursuing a career in Aerospace Engineering, he did a double major in Computer Science and Fine Art then spent a decade working in K-12 math and science educa- tion. Only recently did he land at Apogee Components as the Product Designer.

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