Batteries

In this writer's opinion, a battery is the most important component of your electrical system. Without a functioning battery you cannot:

- Crank an engine.
- Effect some mitigation of electrical system noise.
- Expect continued function of critical electrical equipment in case of alternator/generator failure.
- Expect an alternator to come on line after engine start.
- Finally, a rarely needed but exceedingly handy feature of battery functionality is they will “throw themselves under the bus” to slow rate of rise for system voltage at the onset of an alternator runaway event. Batteries offer over voltage protection systems small (100 mS) but comfortable windows of opportunity to do their job.

In spite of a prominent responsibility, batteries tend to languish in the solitary confinement of battery boxes until they simply cannot perform at any useful task. Most consumers of battery technology are ambivalent on battery maintenance. They've come to expect poor or unpredictable battery performance. By the time you finish reading this chapter, I hope your personal awareness of battery responsibilities and limits will be raised a few notches.

HISTORY OF OBSERVATIONS IN ELECTRICAL PHENOMENA

Electro-chemical cells were the very first sources of electrical power that could be made to do practical tasks. Electrical phenomena were observed two centuries before the battery made its debut as a useful power source. In James Burke's book Connections we read how a French astronomer, M. Jean Picard observed a strange phenomenon inside a newly invented instrument called the barometer. Seems he was on his way home from the Paris Observatory one night in 1675 when the partial vacuum space in a barometer he was carrying began to "glow." The glow became brighter as he shook it more. A few years later in 1706, the Englishman Hauksbee produced a machine consisting of a glass globe that could be partially evacuated and spun on an axle by means of a hand crank. When a hand was pressed lightly to the globe's surface, a strange luminosity would appear inside. These gentlemen were demonstrating the visible phenomenon of motion induced static electricity in a partial vacuum.

These events mark the earliest recorded observations of static electricity and subsequent studies of electron flow. In 1729, Stephen Gray demonstrated that the attractive forces of static electricity would propagate long distances. When he "charged" one end of a cord, a feather would become attracted to the other end about 800 feet away! It wasn't until 1800 that the Italian Alessandro Volta discovered that dissimilar metals in the presence of an acid would develop an electromotive potential between the two metals. Further, he showed that by stacking the "cells" together in series, the strength of the force increased. The new source of electron flow was dubbed the "Voltaic Pile." A few years later in 1820, a Dane by the name of Oersted set up an experiment to show that there was no connection between electron flow and magnetic fields. Much to his surprise, the opposite was true. By 1850, alternators and generators using electromagnetic principles were producing practical amounts of electrical energy to do real work like power an arc lamp or generate hydrogen gas from water to fire brighter lamps in lighthouses.

When Edison first began to distribute electrical energy for public consumption, generators turned by steam engines were used to produce DC electricity that was distributed on overhead wires to the backs of peoples houses and businesses. There was a problem with calculating the consumer's bill for electricity used. I recall reading that early "meter readers" were equipped with scales. A single Voltaic Cell was connected in series with a customer's electric service. The cell actually produced a small percentage of the customer's total consumption. As the cell was depleted, one of its plates was consumed. The meter reader simply weighed the plate from time to time. The customer's bill was calculated from the battery plate's weight loss. Of course, the cell would require periodic refurbishment to continue its service as a gauge of energy consumption.

When the automobile industry began to emerge about 1895, many inventors assumed that electric drive would be adopted for most vehicles. From a purely technical perspective, the state of the art of components for electric cars was well advanced at this time. The DC motor, for example, had gone through a decade of improvements with the spectacular growth of the trolley industry. Indeed, most of the circuitry of the electric cars was a scaled-down version of that of the streetcars; e.g., the motor controller, to regulate speed. Lead-acid storage batteries which provided power had enjoyed fifteen years of commercial development. Unfortunately, batteries were the most expensive and recalcitrant technology on the car. Funny thing . . . even today, batteries are the biggest engineering headache in electric car design.

Early batteries, being electro-chemical, lacked the inherent durability of electro-mechanical devices. Nevertheless, fifteen years of experience demonstrated continuous improvement. Inventors in the U.S. and Europe struggled to produce small, transportable batteries for use on self-propelled streetcars. Although the battery streetcar was never successful, the technology of transport batteries received a tremendous boost. The technology advancement was transferred to the electric car and ultimately to a portable power storage medium used in automobiles for the past 87 years.

In the period 1895 to 1900, batteries for electric cars were very unreliable. The first decade of the new century brought us several developments in lead-acid battery technology. By the time C.F. Kettering's work on starter motors for Cadillac came to fruition in 1911, the foundations for aircraft DC power systems were well in place.

Batteries are assembled from individual cells having the ability to convert latent chemical energy into electrical energy. All batteries use a chemical reaction that DOES NOT occur simply because the two reactants are in close proximity. The chemical reaction inside the cell progresses when a flow of electrons occurs external to the cell's chemical system. This flow of electrons is the benefit to be realized; we can make the flow do the work. There are many forms of single use batteries. The zinc-carbon battery used in radios, flashlights and other small appliances dates back to the early 1900's. Some battery chemical systems reverse if the electron flow is reversed; the battery may be recharged. Like automobiles, airplanes also make good use of compact sources of stored, replenishable energy.

LEAD-ACID BATTERIES

The sulfuric acid electrolyte, lead-acid battery is the most common battery used in automotive applications, both airborne and earthbound. Specialty manufacturing of these batteries for aircraft service has been going on for over 40 years. The major feature of this technology is a chemical system that utilizes plates fabricated from lead and compounds of lead submerged in a liquid electrolyte consisting of water and sulfuric acid. Stacks of plates in the cells of early lead-acid batteries were held separate from each other by thin slices of wood. Modern batteries use plastics. Modern designs for lead-acid batteries use thin sheets of Fiberglass mat that looks for all the world like a few layers of tissue.

The form of electrolyte containment in lead-acid battery has been marketed in three flavors:

- "Flooded Cell" batteries are familiar to everyone: they're still the most common battery found in automobiles. These feature loose, liquid electrolyte that can be accessed by removing a filler cap on the top of each cell. If turned upside down, they leak. After a year or so in service, they often grow patches of green fuzz around their terminals.

- "Gel-Cell" batteries have been around for decades and were the first commercially viable products that reduced the hazards and mess associated with portable lead-acid power storage. Cleaner than their sloppy cousins, they still develop green fuzz and don't perform well in cold weather.

- “Starved Electrolyte” also popularly known as "Recombinant Gas" batteries are also decades old but until recently, the RG battery has languished in relative obscurity. Consumer markets for clean, odor free power in portable power systems have mushroomed. The personal computer explosion fed the demand for super clean batteries as stored energy for uninterruptible computer power supplies.

FLOODED CELL BATTERIES . . .

Today's flooded cell batteries are direct descendants of the batteries that whisked Great Grandma to the grocery store in odor free silence. They are strong contenders in automotive markets. In my not so humble opinion, it's sad when they're still the battery of choice for many airplanes. Flooded cell batteries routinely expel explosive gases laden with droplets of sulfuric acid. Because of the requirement to vent these gases while retaining liquids they must be constructed with special cases and filler caps. It is mandatory in airplanes to enclose the liquid electrolyte lead-acid in a separate box for the safe venting of gases and containment of any spills of corrosive liquid.

IMMOBILIZED ELECTROLYTE
-OR-
"GEL-CELL" BATTERIES . . .

Immobilized electrolyte lead-acid batteries have been around for many years and enjoyed wide acceptance in portable power applications. They're still manufactured in special deep-cycle versions for electric wheelchairs. The first widely marketed gel-cells in the US were manufactured by Globe-Union. The gel-cell is not dead but it's sliding fast. I did an Internet search and could find only two major manufacturers of gel-cells. Johnson Controls has the old Globe product line while Sonnenschein in Germany still produces real gel-cell devices.

Both companies produce well known examples of a battery with demonstrated utility in aircraft. The major feature of these batteries is the fact that the water and sulfuric acid used as the active ingredient in the chemical system is not a liquid. Other materials are added to the electrolyte to convert it to a gel. The gelled electrolyte technology was a major breakthrough for reducing the mess and risks associated with flooded cell batteries. The battery is also well sealed . . . it will not normally leak acid-laden moisture. In the gelled state, the electrolyte is somewhat immobilized between the plates but the battery still cannot be operated in any position.

When charged too aggressively, gel-cells will vent risky volumes of explosive and corrosive gases. While much less messy than their flooded cell cousins, they're the poorest performers in terms of cranking power and low temperature operations of any of their close cousins. The true gel-cell battery is very rare. Most of the sealed, lead-acid batteries on the market today are modern recombinant gas designs.

STARVED ELECTROLYTE
-OR-
RECOMBINANT GAS BATTERIES . . .

The first RG batteries appeared on the scene over 20 years ago. A US patent held by Gates Energy Products on early RG battery technology was the basis for their Cyclon series, sealed lead-acid batteries. B&C was offering a 12-volt, 25 AH Gates RG battery when I first met them about 1984. It was NOT a popular battery. At that time it was expensive ($175 retail) and not very suited to aircraft (vibration liked to disconnect the negative leads inside the cells).

These batteries never leak. Their self-discharge rate is a fraction of the best flooded-cell or gel-cell battery. They may be mounted in any position. Best of all, they have very low internal impedance and crank like Ni-Cads. They are often confused with gel-cells. Some distributors even call them gel-cells, thus displaying their ignorance of the product they sell. Nowadays, the RG battery is offered by virtually every major battery manufacturer in sizes from 1 to hundreds of ampere hours capacity.

RG battery technology is characterized by four major features:

- Totally Sealed: Under proper operating conditions, it will never out gas its internal moisture and is truly maintenance free.

- Phenomenal Cranking Ability: I've seen tests where a 10 AH RG battery successfully cranked a high compression IO-360 engine for 5 successive starts without recharging. When we conducted cold cranking tests of the RG battery, a brand new flooded cell aircraft battery was placed alongside a new RG battery in the freezer and cold soaked at about -10F overnight.

  The following day, we applied a 300 amp load to each battery in turn while observing the battery's terminal voltage. ***The RG battery had a higher terminal voltage at the end of 30 seconds than the flooded battery presented at the beginning of the test.*** We didn't even bother to test a gel-cell. Earlier experience with these batteries told us that no useful energy could be expected from a gel-cell at this low temperature.

  Some time later, I conducted a test whereby the multi-kilodollar Ni-Cad battery in a C-90 King Air was replaced with $250 worth of B&C RG batteries. A data acquisition system was attached to the battery to monitor current and voltage throughout a PT-6 engine start sequence. After gathering data on the RG battery, I replaced the Ni-Cad and repeated the tests. When plotted together, the current/voltage curves lay right on top of each other!

- Absolutely Clean: RG batteries are incapable of leaking corrosive liquids. The electrolyte in an RG battery is liquid water and sulfuric acid . . . installed with a calibrated syringe. The Fiberglass mats between plates are about 80-90% saturated with the liquid. To get any of it back out, one would have to wring it out . . . you can drive a nail into an RG battery, pull it out, and continue to operate the battery until it simply dies from having dried out. No liquid will escape the hole.

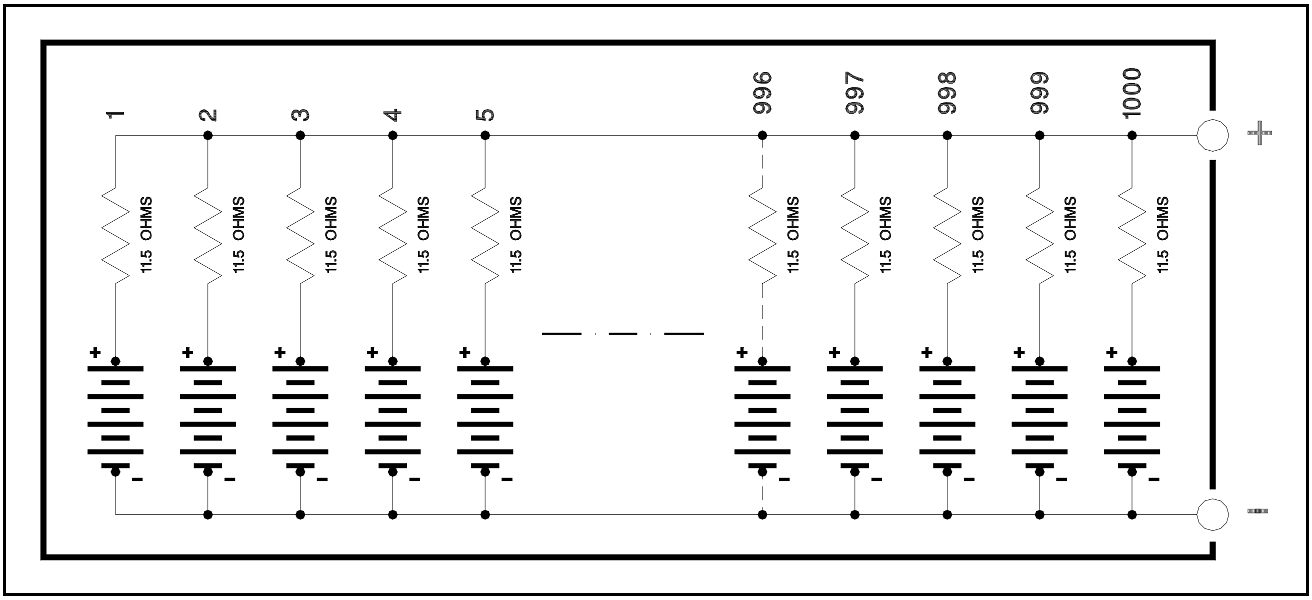

Figure 2-1. The Multiple Cell-Site Analogy for a Battery.

This means that the RG battery may be operated in any position. It also means no battery box is necessary. Just strap the puppy down in a tray that captures the footprint. A couple of 1" webbing straps with 6" of overlapped Velcro would hold a 24 AH battery in place for crash safety.

- Very low self discharge rates: The RG battery may be stored for longer periods of time without intervening attention. Sealed cells have very low concentrations of dissolved oxygen in the electrolyte . . . the major antagonist for self discharge.

CHEMICAL SENILITY AND INTERNAL RESISTANCE

There are important characteristics of all batteries that require understanding before we can adequately discuss battery performance and maintenance. Figure 2-1 illustrates an imaginary 12-volt battery composed of 1000 tiny 12-volt batteries, all connected in parallel, each having an effective internal resistance of 10 ohms. Of course a real 12 volt battery is a concoction of thousands of 2-volt cell-sites in series parallel but the simplified model in Figure 2-1 is sufficiently accurate for our needs.

From the battery's terminals looking back inside, this combination appears to have 1000 units of capacity with a net internal resistance of 10 milliohms (one thousand 10-ohm resistors in parallel yields a 10 milliohm equivalent). As the battery ages or succumbs to abuse, the sites for these units of capacity begin to die off, one at a time. At some point, we'll be down to 500 units of capacity or HALF of what we started with. Another interesting thing happens at the same time. Five hundred 10 ohm resistors in parallel have an equivalent impedance of 20 milliohms, TWICE what it was when new. Not only is the capacity of the battery down by half, its ability to deliver energy has fallen to half as well. It is a precipitous slide once the critter starts to roll belly up. A battery that is only half gone may well contain enough energy to crank an engine, but a commensurate rise in the battery's internal resistance stands between what energy is available and the electrical gizmo that needs it! Internal resistance, while seemingly very small . . . (it's expressed in milliohms) can have a marked effect on battery performance as we shall see . . .

BATTERY PERFORMANCE: WHAT'S ALL THIS AMPERE-HOUR STUFF ANYHOW?

To choose a battery for any given electrical application, you must consider three things: a) the rate at which energy must be withdrawn from the battery, b) the total capacity of the battery and c) the ability of the battery to perform in the environment in which it is installed.

Design data is available on virtually every battery as to its total capacity and performance in environmental extremes.

Total capacity should be the first consideration, and there are some things you need to know about published ratings. All battery manufacturers give an ampere-hour (AH) rating for their products. The definition of the ampere-hour is exactly what the name implies.

However, the astute purchaser of a battery will check the manufacturer's data for the product under consideration. For example, one of my favorite products for use in light aircraft is a very common form factor of RG (also called sealed, valve-regulated, lead-acid or SVRLA) in a 16 - 18 AH package measuring about 3.0 x 7.0 x 6.7 inches. This is a popular form factor used by thousands of consumer products . . . virtually everybody who builds RG batteries will build this one.

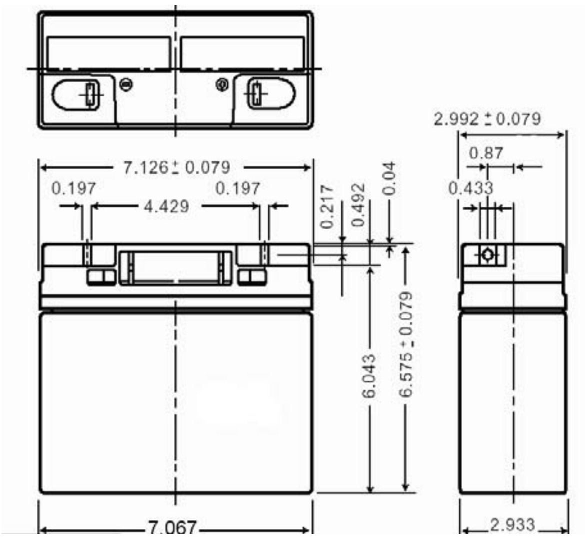

Figure 2.2 Exemplar Dimensions for a
16-18 AH SVLA Battery

A few exemplar brands and part numbers are:

Panasonic LC-RD1217
Odyssey PC680
Power Sonic PSH-12180FR

There are probably dozens of nearly identical batteries, ALL of which are potential candidates for use in your airplane. The only hard requirement for considering any brand of battery are the connections. You need be able to bolt 4AWG wire to the battery's terminals. There may be similar size and capacity of batteries that use the 1/4" fast-on tabs. These are NOT suitable for engine cranking currents.

When it comes to sizing the battery, the device must first crank the engine. There are relatively small batteries on the order of 12 AH that will do that. However, the battery is also your back up source for electrical energy if the alternator fails. Your ENDURANCE under battery-only operations is the primary driver for sizing a battery.

In bizjets, battery endurance is established by regulation to be no less than 30 minutes to end of battery life (80% of new capacity). Hmmm . . . what's YOUR requirement for battery-only endurance? I'll suggest that it could be no less than flight-time-for-fuel-aboard. I.e., fuel should be the only expendable commodity that forces you to put the wheels on the ground.

Time	Watts (W)	Amps (A)	Capacity (Ah)	Energy (Wh)
2 min	1486	143.0	4.8	49.5
5 min	792	78.8	6.6	66.0
10 min	512	49.3	8.4	87.1
15 min	389	36.7	9.2	97.4
20 min	318	29.6	9.8	104.9
30 min	236	21.6	10.8	118.2
45 min	173	15.6	11.7	130.1
1 hr	138	12.3	12.3	138.0
2 hr	79	6.9	13.8	157.2
3 hr	56	4.8	14.4	166.5
4 hr	43	3.7	14.8	172.8
5 hr	35	3.0	15.0	177.0
8 hr	23	2.0	16.0	187.2
10 hr	19	1.6	16.0	192.0
20 hr	10	0.8	16.0	204.0

Figure 2.3 Exemplar 16 AH Battery Performance

Let us hypothesize that we can trim the endurance bus to 4.5A of load. Further, we'd like 3 hours minimum endurance at 80% of new battery capacity. This means that we're looking for a battery offering 3 hours times 4.5 Amps or 13.5 AH Allowing for 20% degradation for end of life, this means that the new battery has to deliver 17.0 AH at 4.5A. So will our 16 AH battery illustrated in Figure 2-2 do the job? Let's see.

The chart in Figure 2-3 depicts typical performance for the PC680 Odyssey battery at various loads. Note that this battery delivers RATED output when loaded to 0.8 Amps for TWENTY HOURS. The 20-hour rate is the most common for batteries of this type. Okay, what's the 3 hour capability? The chart says we can load it to 4.8A when new. Under these conditions, the battery yields 14.4 AH of capacity. This suggests the battery has a high probability of meeting our 3.0 hour requirements when new. At end of life it will only give us 2.4 hours. Is that enough for YOU? Remember, YOU set design goals for this feature. Suppose your E-bus loads are 6.0 Amps. This battery will service that load for just over 2 hours when new . . . and about 1.5 hours at end of life.

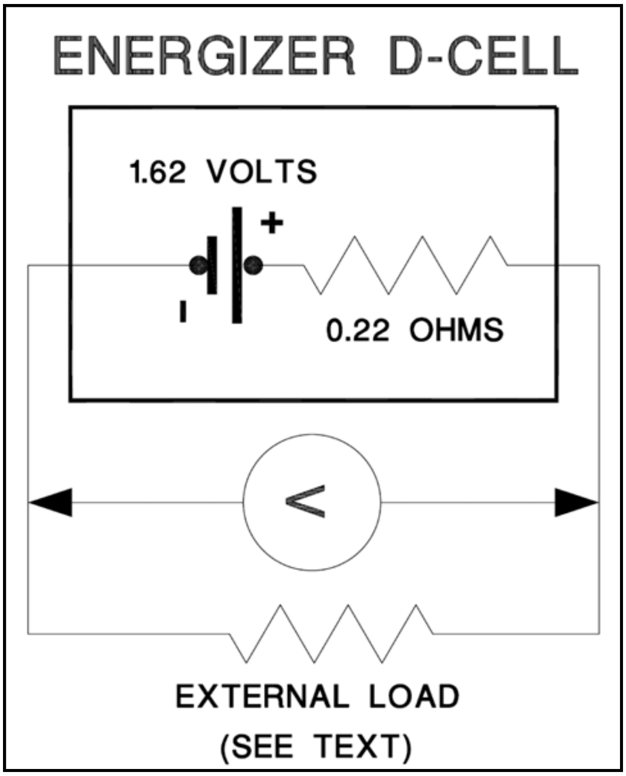

Figure 2-4. D-Cell Experiment

Notice the column for Capacity in AH goes down as the load goes up. This is because the battery's INTERNAL RESISTANCE wastes more energy warming the battery up instead of running your electro-whizzies.

Another example battery resistance affecting delivery of energy comes from the study of the lowly alkaline D-cell for flashlights. These devices have an INTERNAL RESISTANCE on the order of 0.22 ohms. These cells are nominally rated for 4 AH. Suppose we connected 8 cells in series to make a 12v battery. Can we crank an engine at 250 Amps?

$$\frac{4 \text{ AH} \times 3600 \text{ sec/hour}}{250 \text{ Amps}} = 57.6 \text{ seconds}$$

In terms of energy contained within an alkaline D-cell, it would seem that there's more than enough to crank an engine for the few seconds that it takes to get it started. However, if we throw a dead short on the cell, current that flows is

$$\frac{1.5 \text{ Volts}}{0.22 \text{ Ohms}} = 6.8 \text{ Amps}$$

This means that while there's plenty of energy contained within the D-cell to do the job, the rate at which that energy can be delivered is very limited. The cell's terminal voltage drops to zero volts with a paltry 6.8 amp load!

ENGINE CRANKING
A BATTERY'S FIRST TASK

In Figure 2-5 I've illustrated a cranking circuit similar to one I found in a builder's VariEz a few years ago. Where did all the resistors come from? Recall our discussion in Chapter 1 about resistance. You can minimize it but unless you can wire your airplane with super-conductors you have to live with it. I have drawn six resistors on the illustration to represent the following: a resistor inside the battery represents its internal resistance as does the resistor inside the motor. The resistors external to these devices represent the resistance of the wire that makes the interconnections.

The resistance of 4 gauge is 0.00025 ohms per foot. Let us also say that the wire between the battery and the contactor is 2 feet long. The wire between the contactor and the starter is 12 feet long and the one between the starter and the battery is 15 feet long. These are numbers that might be typical of a composite pusher with the battery in the nose. Multiplying out the numbers gives us the resistances shown in the figure. It's unfortunate that we cannot probe the interior of the battery. I include it to remind you that the voltage produced by a battery is a function of its chemical system and is constant irrespective of load. Let us say that the source voltage is 12.5 volts. What can we deduce from these numbers? First, since the terminal voltage of the battery is now down to 10.5 volts, there must be a drop of 12.5 minus 10.5, or 2.0 volts dropped across the internal resistance of the battery.

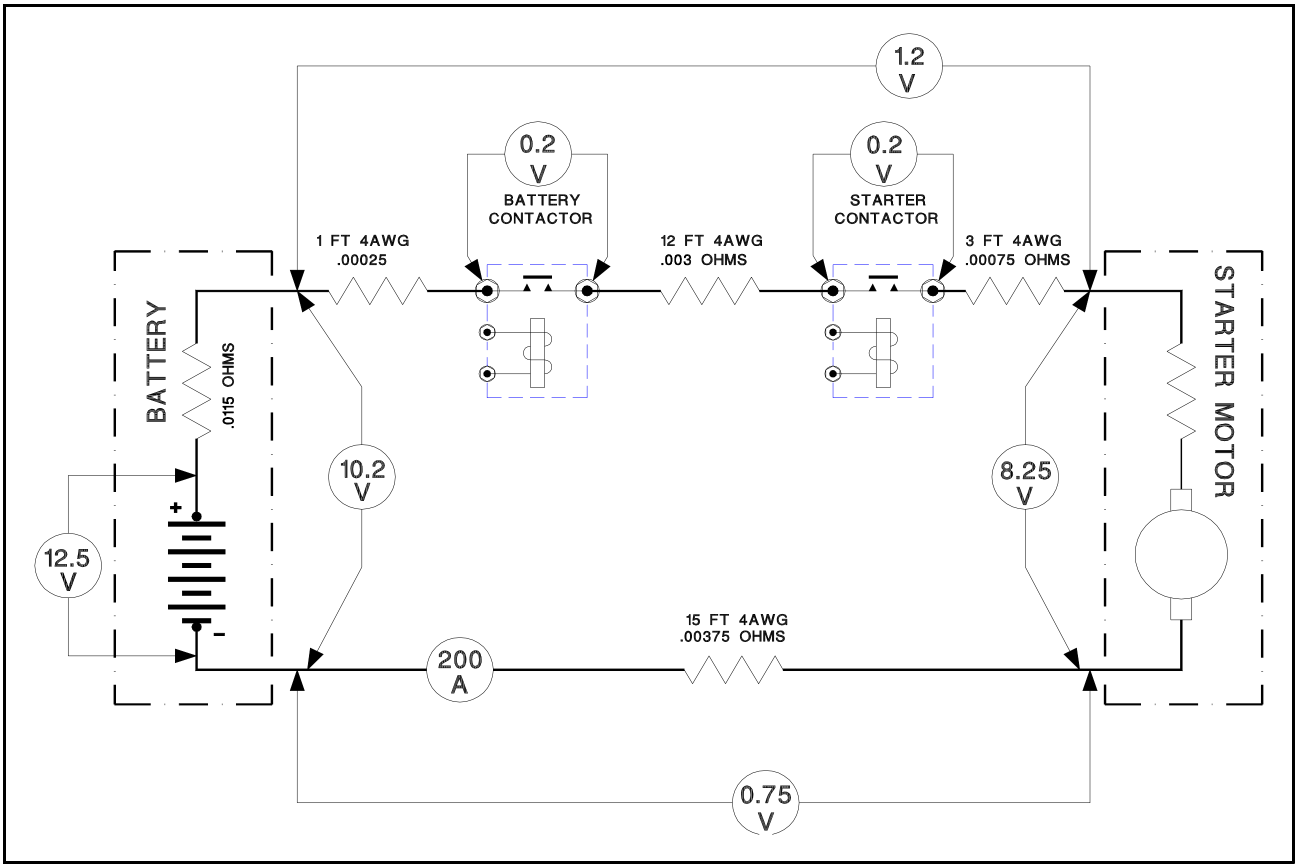

Figure 2-5. Engine Cranking Analysis

We can say:

$$\text{Ohms} = \frac{\text{Volts}}{\text{Amps}} = \frac{2.3}{200} = .0115$$

This calculation shows that the battery has an internal resistance (some call it "impedance" - for our purposes it's the same thing) of 11.5 milliohms. After you account for all the voltage drops illustrated in the cranking circuit, the starter now sees only 8.25 volts at its terminals. This is a fairly typical scenario which also points out the fact that there is no such thing as a 12-volt starter! Starters used in 14-volt systems with 12-volt batteries really need to be characterized for operation between 9 and 10 volts. I did not make any calculations or assumptions about the internal resistance shown for the motor. Motor resistance is a complex combination of features - we'll discuss it in detail in a later chapter on motors. But suffice it to say that the motor has resistance too . . . after you've cranked a recalcitrant engine for too long it is the motor's internal resistance that generates all that heat .

Now, let's repeat the exercise substituting a 4 milliohm RG battery for the 11.5 milliohm flooded device. Wow, cranking voltage at the starter comes up to 9.9 volts! What happens if we put in 2AWG wire instead of 4AWG? We get back some more losses and the starter now sees 10.3 volts. The large demands of a starter make small values of resistance very significant! Our hero's VariEz didn't crank worth a hoot . . . until he replaced the 4AWG wire with 2AWG and the little flooded motorcycle battery with an RG battery.

Remember the 7 amp flow we got from a dead short on our D-cell battery? Let's do an estimate on what happens when you put a dead short across the flooded battery. Looking at a shorted battery scenario we can say:

$$\text{Amps} = \frac{\text{Volts}}{\text{Ohm}} = \frac{12.5}{.0115} = 1{,}088$$

We can also calculate the power dissipated inside the battery:

$$\text{Watts} = \frac{(\text{Volts})^2}{\text{Ohms}} = \frac{(12.5)^2}{.0115} = 13{,}580$$

That's the equivalent heat output of a dozen hair dryers; it would heat a small house very nicely. Except for the small resistance of the 'dead' short, all of the energy is being dissipated within the battery's own internal resistance. Is it any wonder why mistreated batteries sometimes blow up or spray boiling acid all over people? 'Nuf said. Be careful when you work with any battery. They can warm you up in unpleasant ways!

BATTERY SERVICE LIFE

One evening at Oshkosh many years ago we were having dinner with Darryl and Pat Phillips of Airsport Corporation. Darryl made the following observation: "We replace airplane tires when the tread is about gone, overhaul engines when the compression drops below certain limits, change oil and belts as preventive maintenance measures. But why do we flog an airplane battery until it simply dies?" Why indeed?

Generally speaking, the service life of lead-acid batteries is dependent upon how many watt-seconds of energy the battery is asked to transfer and how many times.. Further, depth of discharge on each discharge-recharge cycle will adversely affect battery life. A battery will last longer chronologically if you fly regularly, keep your technique for cranking tuned for rapid engine starting and don't run the battery down by leaving the master switch ON.

If you fly only day VFR, battery life and reserve battery capacity may not be an important issue. In this service, it may be perfectly reasonable to go flying any time you can get the engine to run. Be aware that reserve capacities for running your necessary loads in a failed alternator situation may fade faster than you think. If nothing else, do periodic battery-only, E-bus operations tests as described under Care and Feeding later on.

On the amateur-built side of the aircraft industry, many airplanes are getting dual electronic ignition systems and are operated comfortably even if the ship is fitted with only one alternator. This can be accomplished because a ***properly maintained*** battery can and should be considered the most reliable source of electrical power in the airplane! Some airplanes fly with electrically dependent engines . . . it can be done safely--but only if we view the lowly battery from a new perspective.

The vast majority of batteries in automobiles, snowmobiles, and airplanes receive ZERO attention until they fail to crank the engine. Batteries tend to sit in the solitary confinement of their battery boxes getting cooked, frozen, overcharged, undercharged, run flat and otherwise generally neglected. Of the three technologies we've discussed, the RG battery is most tolerant of abuse. Irrespective of your technology choice, the electrical system's ability to meet design goals will be compromised unless you cultivate good habits in battery maintenance.

The battery industry generally considers a battery to be at end of life when its capacity falls to 80% of new. What practical means do we have at our disposal for making the decision to replace a battery?

CARE AND FEEDING OF RECHARGEABLE BATTERIES

The open-circuit terminal voltage of a battery is related to the chemistry and not to the state of charge. A discharged battery will present a voltage to its terminals that's only 10% or so lower than a fully charged one. To recharge these batteries requires that the flow of electrons be reversed through the battery's chemical system. If you were to connect a 12-volt charger to a 12-volt battery, no recharging would occur since the electrical "pressure" in both devices would be the same. This is the reason why you can't charge a dead battery simply by connecting a fully charged battery to it.

A battery will accept charging only if connected to a source that is of a higher voltage than the battery. In systems which use 12-volt batteries, the required higher voltage is on the order of 13.8 to 14.5 volts. With 24-volt batteries, the charging voltage is twice that--about 27.6 to 29 volts. Battery charging voltages are responsible for the 14-volt and 28-volt numbers used to identify electrical systems. When the alternator is running, the system is operating at or about 14.2 volts. When the alternator is not running, the system voltage quickly falls to the level at which the battery can deliver energy - at 12.5 volts or less.

From time to time someone asks,"where should my voltage regulator be set?" On the Internet I've seen this discussion go on for days with numbers ranging from 13.8 to 14.8 volts. Manufacturers are not particularly helpful in this regard either for they sometimes give two recommended voltages for charging their products: a "float" or "standby" charging voltage and a higher "cycle" voltage.

The reason for two regulator set points centers on the fact that it takes time to fully recharge a battery. Recall that batteries are rated in ampere hours of capacity . . . amp is a rate of electron motion. A unit of rate (Amps) x some unity of time (hours) is a ***quantity*** of electrons. This translates to a finite quantity of battery chemistry molecules having changed from a charged to a discharged state. The goal is to reverse the flow of electrons at some rate (Amps) for some time (hours) to replace the energy taken out.

When the battery is used in short "cycles," like most vehicular situations, the probability of getting the battery topped off is much better if the voltage is boosted a tad above the idealized charging level. In any case, all lead acid batteries at room temperature eventually acquire 100% of their capacity when charged at 13.8 volts if you can wait around long enough.

There's a design goal in airplanes for having a battery replenished a short time after takeoff. Since day-one, the popular set-point for generator and alternator regulators has been 14.25 or 28.50 volts DC. Yes, this is slightly abusive of the battery . . . but while setting the voltage lower might get us a slightly longer service life, it prevents realization of more critical design goals for timely recharge.

BATTERY REPLACEMENT: A PLAN FOR THROWING IN THE TOWEL

When configuring a system it is not sufficient to simply select a battery that is adequate to the task when new. The capacity of a battery begins to decline from the time it is first placed in service. The fade is slow at first but increases with age and abuse. The life of the battery in flight cycles will be a function of how much excess capacity the battery has when new and how well the battery is treated during its service life.

Monitoring battery condition becomes important when the battery is small and of limited life to begin with. If your engine starts in a few blades, then the battery never gets a chance to demonstrate its true capacity. I consider it good practice to shut down the alternator on long VFR day flights and drop to E-bus loads only. Simulate a loss-of-alternator condition. Measure the length of time that the battery supplies adequate power to the aircraft systems and record this number in your log. When the battery-only ops endurance drops to your minimum acceptable value, it's time to replace the battery irrespective of how well it cranked the engine that day. Other chapters in this publication will describe system monitoring and bus structuring techniques to make capacity evaluation procedures easy and informative.

BATTERY CAPACITY TESTING

Figure 2-6 shows a nifty product by West Mountain Radio (westmountainradio.com) for testing batteries of all sizes, chemistries, and voltage. This device sells for about $100 and drives out of the USB serial data port of a computer. Software provided with the product allows you to set up a discharge rate in amperes and allow the tester to deplete the battery to a cutoff voltage of your specification. For aircraft parts we use 10.5 (21.0) volts as end-of-battery-charge.

Figure 2-6. West Mountain Radio's Model CBA for Capacity Testing of Batteries

Using the model CBA Battery Capacity Tester to discharge your ship's battery at the e-bus power consumption rate, you can test exactly how long your battery will service ***your*** E-bus during alternator-out operations.

Come back in a few hours and you will find the battery depleted and the computer will display the discharge voltage curve for the battery under test. If you've stored previous tests of the battery on the same computer, you can bring those old plots back and overlay them on the current data for comparison. The CBA can also be used as a single-channel data acquisition system to measure and plot some voltage of interest over a period of time.

BATTERY LOAD TESTING

A second consideration of battery condition and the test most often used by battery stores, is to measure the ability of a battery to carry a heavy load. They hook a tester to the battery that contains an ammeter, a voltmeter and a heavy duty variable resistor known as a 'carbon pile'. With the tester connected, the pile is tightened down until the voltmeter reads some test value (usually 9V for a 12v battery). Then the load is adjusted manually to keep the voltage at the test value. At the end of 15 seconds, the ammeter is read for an indication of available cranking current for the battery under test.

Figure 2-7 shows an inexpensive load tester offered by Harbor Freight. These sell for about $50 and are a good value for the money. Your local friendly battery store will probably be glad to do the test for you periodically with its fancy tester, especially if it thinks it can sell you a new battery. Write the numbers down and track them with the age

Figure 2-7. Exemplar Battery Load Tester

of the battery. In any case, you should probably replace a battery that tests below 300 Amps for large engines, and 150 Amps for engines like a Rotax.

AC POWERED BATTERY CHARGERS

Automotive stores have lots chargers designed to 'work with' (read minimally abuse) an automotive battery. You get what you pay for here. I've looked at chargers that claimed all manner of automatic and fail-safe features that just were not there when I looked inside.

If you've found yourself with a "dead" battery, then any charger will suffice to replenish the energy so you can go flying. The big variable is size . . . bigger chargers (higher output ratings) will recharge a battery faster than a smaller device. The capability of low cost, off the shelf battery chargers has blossomed in the past ten years or so. A host of companies offer charger/maintainer products that behave in concert with the graphs in Figure 2-8. The bulk charge cycle begins with a constant current based on size of the charger. When the battery terminal voltage reaches the “absorption voltage” level appropriate to the battery, voltage is not forced any higher . . . and the charge current beings to taper off. As soon as the current drops to the anticipated float/maintenance level, the charger’s output voltage drops to some level just above the battery’s open circuit terminal voltage . . . but lower than the voltage necessary to push more charge into it.

Figure 2-8 graphs were provided by the folks who make Battery Tender brand of chargers. Other companies that offer low cost charger/maintainers are Battery Minder and Schumacher. One of my favorites is the Schumacher 1562 series devices offered at many stores including Walmart for about $20.

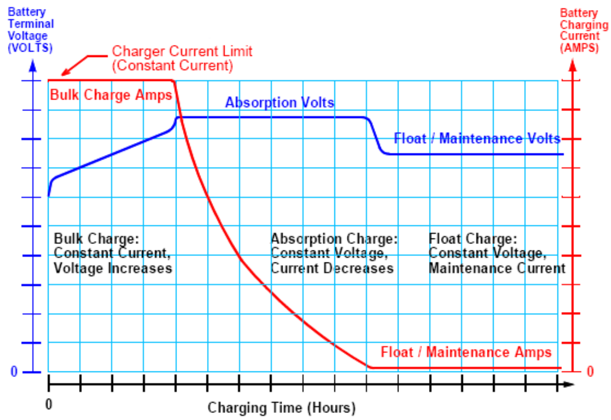

Figure 2-8. Battery Charge and Maintenance Profile

These chargers are designed to drop to a maintenance float voltage after the battery is topped off in the “absorption mode”. These chargers may be connected to any battery indefinitely without concern for harming the battery.

Do the following checks on any charger you may use on your own battery. Monitor the battery voltage at the 'end of charge' as defined by the charger's front panel indicators or by the fact that the charger has simply been connected long enough to accomplish the task. If the "float" voltage is greater than 13.8 volts for a lead-acid, the charger is slowly cooking the battery.

A quick note on 'trickle' charging. Virtually all battery technologies have some very small internal drains or losses inherent to their construction. In time, even the best rechargeable batteries will discharge themselves. The idea of a trickle charge is to simply replace the energy being lost internally to the battery while it is being stored. The internal losses are very small, hence trickle charge rates should also be very small and appropriate to the size and technology of the battery. Once a battery is "topped off" at 13.8 volts, it's entirely practical to drop and hold the float voltage to something on the order of 13.0 volts.

Recall that a battery DELIVERS energy at 12.5 volts and below . . . this includes energy lost in the battery's internal mechanisms. It stands to reason that if the battery is held at 13.0 volts via an external source (battery charger) then it's incapable of using its own stored energy to satisfy internal losses. Further, at 13.0 volts float voltage, the charger is incapable of overcharging the battery.

If your charger does not appear to meet these criteria then you will experience the best battery life if you use the charger only to recharge after a “run it down” capacity test or to recharge it after and accidental discharge in the airplane. Don't store the battery for long periods of time on a charger that does not meet the requirements for long term storage at a float voltage just above the battery’s own open circuit terminal voltage.

PROGRAMABLE CHARGERS

There’s a class of chargers that feature lots of buttons on the front for setting recharge rates and perhaps selecting the type of battery. Some battery manufacturer’s are quite adamant that you conform to some special recharge criteria for the purpose of getting the most from your battery.

But recall this, once you take the battery off some super-whippy charger and put it in your airplane (or any other vehicle) programable recharge rates and voltage profiles are no longer an option. We set the regulators for 14.2 and watch for alternator failure . . . and that’s it. Spending extra dollars to have a programmable charger has a limited and perhaps non-existent return on investment. I have some of these devices. However, if I have a simple charger-maintainer handy (Figure 2-8), I’ll stick it on the battery to be serviced and not worry about it.

WHEN ARE TWO BATTERIES BETTER THAN ONE?

Most automotive conversions are very difficult if not impossible to adapt to dual alternators . . . yet automotive conversions are always electrically dependent engines. Many builders are installing all electronic ignition systems . . . some electronic controlled fuel injection.

First, let’s keep in mind that modern alternators are exceedingly reliable compared to their ancestors popularly used on aircraft. Assuming that the owner/operator takes battery preventative maintenance seriously, then the probability of facing an unmanageable alternator failure is quite low. But the risk is never zero.

Further, the owner/operator has an opportunity to deliver on design goals that are seldom featured in type certificated aircraft; i.e. designing for battery-only endurance that is much longer than the 30 minute target deemed adequate for some certified designs. In my book a 30 minute battery-only endurance limit sets you up for an emergency. Some of the places I like to fly over don’t have attractive landing sites within 30 minutes flying time.

Your ability to navigate and communicate with a totally dark panel should be backed up by hardware carried in your flight bag. A $100 GPS, a $200 nav/com and a flashlight will get you there. Keeping the engine running is another matter.

While crafting an architecture tailored to your electrically dependent airplane and the way you plan to use it, the first task is decide how much energy must be in storage to meet your personal battery-only endurance requirements. Electrically dependent engines should be wired directly to an always-hot battery bus such that the DC Power Master switch can be turned OFF and the engine runs unaffected.

It’s sometimes advisable to replace one "fat" battery with two smaller ones. For example, a pair of 17 AH batteries can be run in parallel under all normal operations. This technique is illustrated in the diagrams in Appendix Z. The combined batteries give 34 AH of cranking power. The ship’s electrical system should include a low voltage warning system set for 13.0 volts. If bus remains above 13.0 (or 26.0) volts, the alternator is working and carrying ship's loads. Should the voltage drop below this value, the alternator has failed. The two batteries are then split into separate tasks. Perhaps one is assigned to keeping the engine running while E-bus loads are carried by the other battery.

If you do periodic capacity tests, it’s easy to determine when one of the batteries requires replacment. Alternatively, with a dual battery system, one battery is replaced every annual. This means that after the first annual, a two-year-old battery gets rotated out of the airplane. It also insures that one of the batteries is always less than one year old. This measure adds about $50 to the cost of an annual but it affords a measure of assurance that can only be matched or exceeded by installing dual alternators.

Keep in mind that it’s a very rational plan to operate from one well maintained battery of KNOWN capacity to keep the engine running and drop to flight-bag-backups for the purpose of completing the flight at an attractive destination without breaking a sweat.

Suppose you're flying certified iron and still fly two mags . . . how does this discussion affect you? Please consider this:

I recently downloaded a batch of service difficulty reports using "battery" and "alternator" as keywords. The resulting collection of data read like the opening lines to a Dragnet episode on the radio, "There are 150,000 airplanes in this country, each has a story to tell." Indeed. The stories ranged from benign to hair-raising but a common thread was obvious: Timely notification of alternator failure -AND- judicious utilization of battery capacity should have made most episodes into ho-hum events. In most cases, the pilot was UNAWARE of alternator failure until the panel started going black . . . which meant the battery was gone too!

In certified ships, options for reducing loads on a battery in a certified aircraft are limited even when the pilot is immediately aware of alternator failure. Numerous articles on the website along with Chapter 17 of this book speak to architectures designed for failure tolerance which translates into flight-system reliability. I won't belabor those issues in this chapter.

A FEW LAST WORDS ON BATTERY SELECTION

Choosing batteries for amateur built airplanes is pretty easy: 15 years ago, “real” aircraft batteries were expensive, lackluster performers. Automotive batteries were cheaper but heavy and messy. Motorcycle batteries offered built-in manifolds for mess-control but are suited for cranking only the smallest engines. A few gel-cell products helped control mess (they leak only occasionally!) but didn’t even come close to matching performance of the poorest of flooded-cell battery. Today, the field of consumer grade, sealed, valve-regulated, lead-acid batteries are the products of choice from which the most practical systems will be crafted. Further, we’re free to choose the product that best suits our need.

Most of our brothers building airplanes are able to craft failure tolerant systems with 16-17 AH batteries. Further, since many projects are going all-electric, the use of a vacuum pump pad driven alternator provides at least 8 Amps of continuous power during main alternator failure. This means that your E-bus loads can be at least 8 Amps while holding the battery’s stored energy in reserve for descent and approach to landing.

If you're running two batteries, making them the same size allows a yearly swap-out of the oldest battery during annual inspection. Your design study should strive for an E-bus powered by the primary battery which is always less than a year old. When rotated into the secondary slot, its alternator-out tasks should be smaller . . . carry a single ignition system and perhaps a boost pump as needed . . . much smaller loads than the E-bus. A year later, it's outta there. **This eliminates the need to do periodic capacity checks.**

Most aircraft accessories and components have practical limits to service life. The problem with batteries is knowing when conditions for continued airworthiness are no longer met. It would be very nice if batteries just had dipsticks or "gas" gauges for making their condition known. Unfortunately, the most qualitative thing we know about a battery in most vehicles is derived from a general sense of how well it cranked the engine. When the alternator comes on line, we busy ourselves with other matters and the battery is left to fend for itself. By the time a battery is down to just a few more engine starts, its capacity as a standby power source has long since fallen below useful values. This is the saddest and most hazardous aspect of our ignorance of battery condition. I hope this chapter has given you some better tools for battery selection, operation and maintenance that will raise your confidence levels for electrical system integrity.

BATTERY INSTALLATION

If your project is designed to use a flooded battery, then a full surround battery box, drained and vented to the outside is in order. Most kit suppliers recommend or even supply this type of enclosure. Aside from the extra expense and weight of the full surround enclosure, I find the concept disturbing. If you WANT to build a bomb, you first provide an enclosure to contain the explosion as long as possible before bursting. A few years ago, a Glasair pilot experiencing electrical system difficulties was offered a surprise when the battery box built into the back of the right hand seat exploded. A series of failures precipitated out-gassing of his battery sufficient to load the bomb. A spark from a battery contactor INSIDE the box provided the ignition source. Fortunately the bomb's outer shell was not robust. The energy release was too low to cause severe damage to the airplane. The story ends well.

In my not so humble opinion, the RG battery's limited ability to generate explosive gasses combined with its lack of need for a battery box makes it one of the safest batteries ever manufactured. My first advice for installing a battery is NOT to use a battery box. Pick a battery that doesn't need one! If you do plan to use a flooded battery, at least keep the battery isolated in the enclosure. No other components of the electrical system should share the box with the battery. The box should have positive venting to avoid accumulation of explosive gasses.

Lead wires coming off of a battery's terminals can provide a challenge . . . especially when the airplane is wired with 2AWG battery and starter path wiring. Connections to the battery terminals are generally made with short pieces of wire: one from the battery (+) to battery contactor, the other from battery (-) to ground.

Even if the rest of the airplane is wired with stiff, Mil-Spec fat wires, consider making the two short battery (+) and (-) jumpers from 4AWG welding cable. We'll speak of this product again later. Suffice it to say now that welding cable is designed to lay on gravel roads and be routinely run over by dump trucks. It's also made from a bazillion strands of very fine wire . . . QUITE flexible. Much easier to work with in the narrow confines and short bend radii around the battery and its terminals. If you do use a full-surround box, be sure to use grommets to protect the (+) battery wire from damage and shorts to the battery box. Some extra layers of heat shrink over the wire where it penetrates the battery box is a good idea, too.

If you don't have a battery box, the exposed terminals need protection from inadvertent contact that might draw sparks. Rubber terminal booties are available and sometimes suited to this task. I've seen some nifty shields fabricated from PVC sheet. I once saw the efforts of an enterprising builder who cut the bottom from a Tupperware container to make a shield for his battery's terminals.

In terms of mounting strength, the battery should not become a hazard in a crash. If the battery is behind the cabin, I like to see sufficient strength in the hold downs to withstand in excess of 10 times the battery's weight, 20x is even better. This doesn't have to be titanium steel . . . a series of nylon web straps and companion plastic tensioning buckles (or even 6 square inches of overlapped Velcro per strap) can be used to provide hold-downs good for 1,000 pounds.

The limiting factor of most hold-down schemes is NOT the materials used for grabbing the battery but the structure to which the hold-downs attach. Modern aircraft structures pride themselves in lightness or thinness . . . many a 1000+ pound webbing strap has ripped loose from its mooring at a few hundred pounds. If in doubt, consult the kit manufacturer should you wish to install a battery in some manner other than the original recommendations.

Batteries mounted in front of people are not so critical. For example, batteries mounted either front or back side of a firewall do not become missiles launched against folks hoping to survive a crash. Major loading vectors for this installation are forward and down . . . a simple tray with a couple of nylon straps would be sufficient for about any size battery.

COMING OVER THE HORIZON . . .

The hey-day of Thomas Edison’s DC power generation and distribution was shared by the sulfuric-acid-water-lead plate and lead-oxide battery technology. Who would have guessed that over 100 years later, lead-acid is still the low-cost-of-ownership choice for storing DC power.

The sealed batteries are technologically old-hat but there’s still a great deal of interest in taking some of the weight out of lead-acid batteries. A new composite and lead foam plate under development promises to lower the internal resistance of the battery, increase capacity while taking out more than half the weight contributed by pure lead plates.

A number of wanna-be suppliers are stroking lithium ion batteries in one form or another. Some have been approved for use aboard airplanes. They’re not ready for prime time in our little ships. The energy density of these cells is seductive but it’s like trying to figure out a way to burn nitro-glycerine in your engine. The power density is really great but there are obvious hazards to overcome. I’m involved in a number of development programs that promise much lighter Li-Ion batteries with great power density . . . but there are significant manufacturing and system integration issues to be solved.

At the time of this writing, my best recommendation for battery selection in the Owner Built and Maintained (OBAM) aircraft venue can be made from the corner “Batteries R Us” store. Just recall that batteries have a lot in common with house plants. Most little potted beauties liberated from the Walmart garden shop sit on a shelf and get watered when they look wilted. They may never bloom and finally get tossed when too many leaves have fallen off. We’ve probably all met individuals who enjoy lush green leaves and prolific blooms from the same plants. These folks understand the plant’s balance of requirements for optimum performance. Like house plants, batteries are not complex but they do demand some study and effort to implement a considered preventative maintenance program. The outcome assures the satisfaction of meeting design goals and no in-flight disappointments. Learn how to stroke your battery well and it will be there when you need it. What’s more, it will let you know when it’s time to retire!

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