Batteries

The least understood components in the airplane?

A little history . . .

- 1800 Volta demonstrates to Napoleon the Volta pile, a primary, non rechargeable battery.
- 1854 Sinstede uses the first time lead plates in sulfuric acid to store i.e. accumulate, electricity.
- 1859 Planté improves the capacity of the lead acid batteries with a technique still in use today.
- 1881 Faure discovers the pasted plate which yields a major breakthrough in capacity. A lead antimony alloy is used the first time to give strength.
- 1882 Gladstone and Tribe describe the so called double-sulfate theory i.e. the basis of operation of the lead acid battery. Tudor operates a lead acid battery factory in Luxembourg.
- 1899 Jungner invents nickel cadmium rechargeable battery. Expensive and limited in useage. New electrodes developed 1930s. 1940s brought a sealed nickel cadmium battery that recombines internal gases produced during charge. Improvements have been made every decade since.

A little history . . .

- **1907 A lead calcium alloy is patented.**
- **1910 The iron-clad or tubular plate construction is introduced**
- **1915 Willard introduces rubber separators.**
- **1918 Shimazu describes the ball mill oxide.**
- **1951 Lead calcium alloys are used in telephone exchange stationary lead acid batteries.**
- **1958 Jache describes the gel valve-regulated, sealed lead-acid battery.**
- **1965 Polypropylene sealed lead-acid battery cases start to be used.**
- **1968 The maintenance free sealed lead-acid battery is developed by Gates.**
- **1980 Stationary valve-regulated, sealed lead-acid batteries based on AGM technology are developed**

A little history . . .

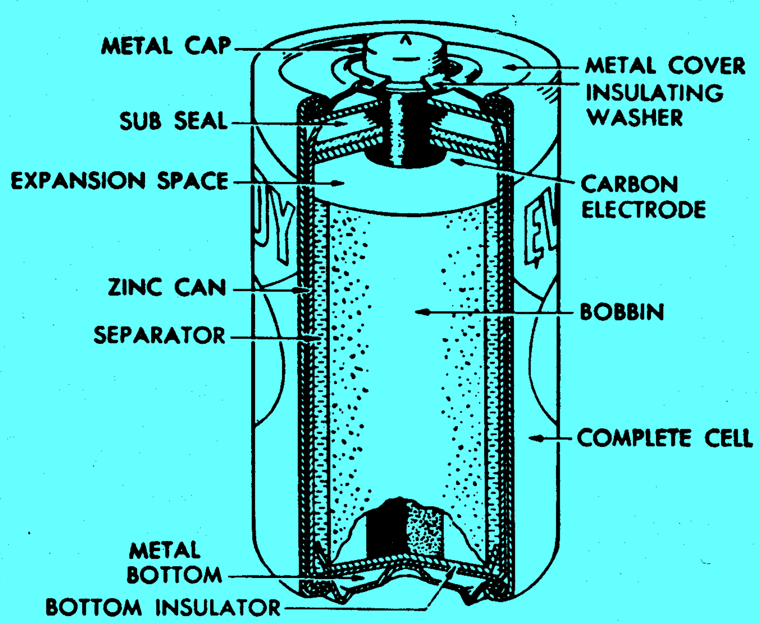
Primary Cells:

- One shot energy sources . . . Chemistry is not reversible

- Typical products:
  - Carbon-Zinc
  - Zinc-Air
  - Manganese-Dioxide (alkaline)

A little history . . .

Carbon-Zinc: Evolved from Leclanché's 1866 patent on a wet cell design using a liquid, ammonium chloride electrolyte. A dry cell version of the Leclanché cell was developed and perfected in the 1880s. The carbon zinc dry cell remains much the same to this day.



A little history . . .

Duracell pioneered the Alkaline Manganese Dioxide electrochemical system nearly 40 years ago.

Alkaline cells have higher energy output than zinc-carbon predecessors.

Other significant advantages are:

- **Longer shelf life**
- **Better leakage resistance**
- **Superior low temperature performance.**

A little history . . .

Secondary Cells:

- Chemistry can be reversed by forcing energy back into the cell via external power supply (charger).
- Typical products:
  - Lead-Acid
  - Ni-Cad
  - Ni-Mh
  - Lithium Ion

A little history . . .

Lead-Acid: A very successful technology with over 120 years of commercial service.

A little history . . .

Ni-Cad: Nearly as mature as the Lead-Acid battery, Ni-Cads were the first to offer drip-free, sealed energy storage technology.

A little history . . .

Nickel Metal Hydride:
Chemically, one of the best cathode materials for battery cells would be hydrogen. Discoveries in late 1960s showed that some metal alloys had the ability to store atomic hydrogen 1000 times their own volume.

NiMh technology is rapidly replacing Nickel-Cadmium as the portable power cell-of-choice.

Electrochemical Energy Storage Basics

(It’s all in the cells!)

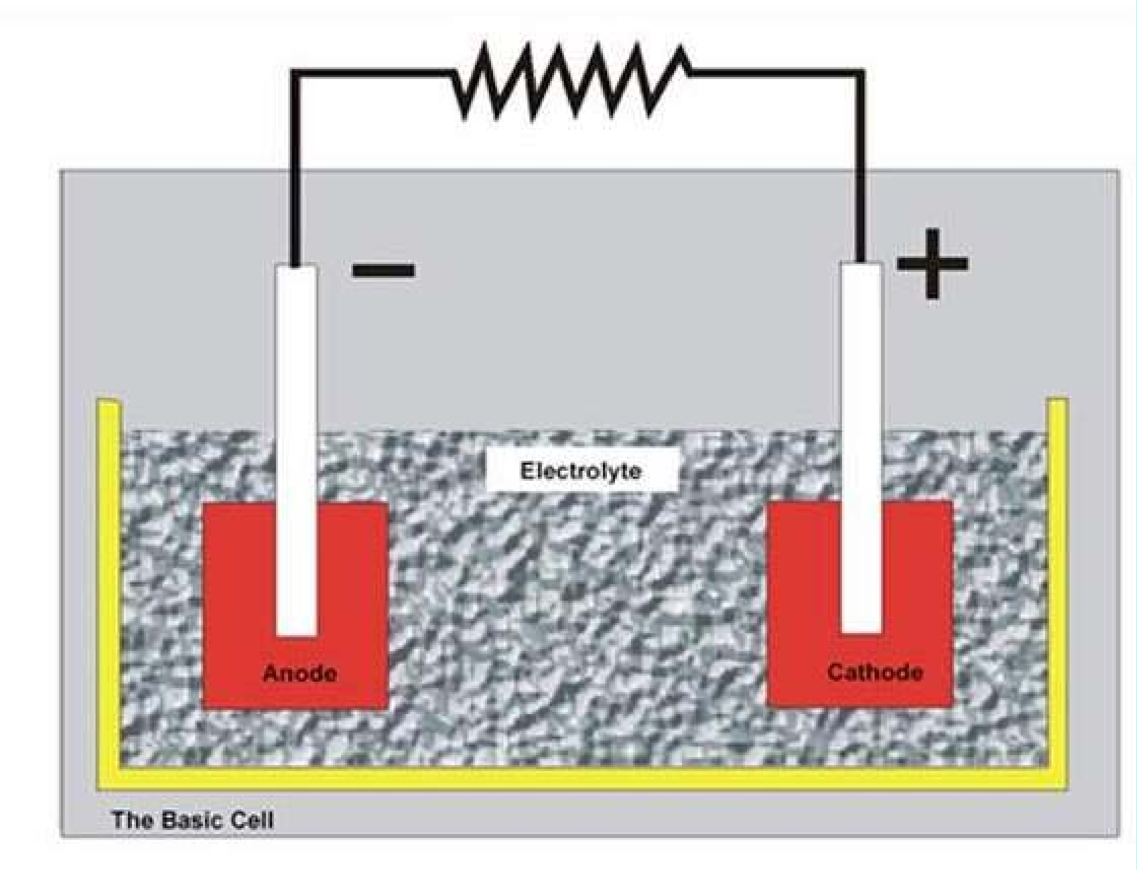
What is a cell?

Definition of Cell:

Anode - Source of electron flow to the outside.

Cathode - Sink for electron flow from the outside.

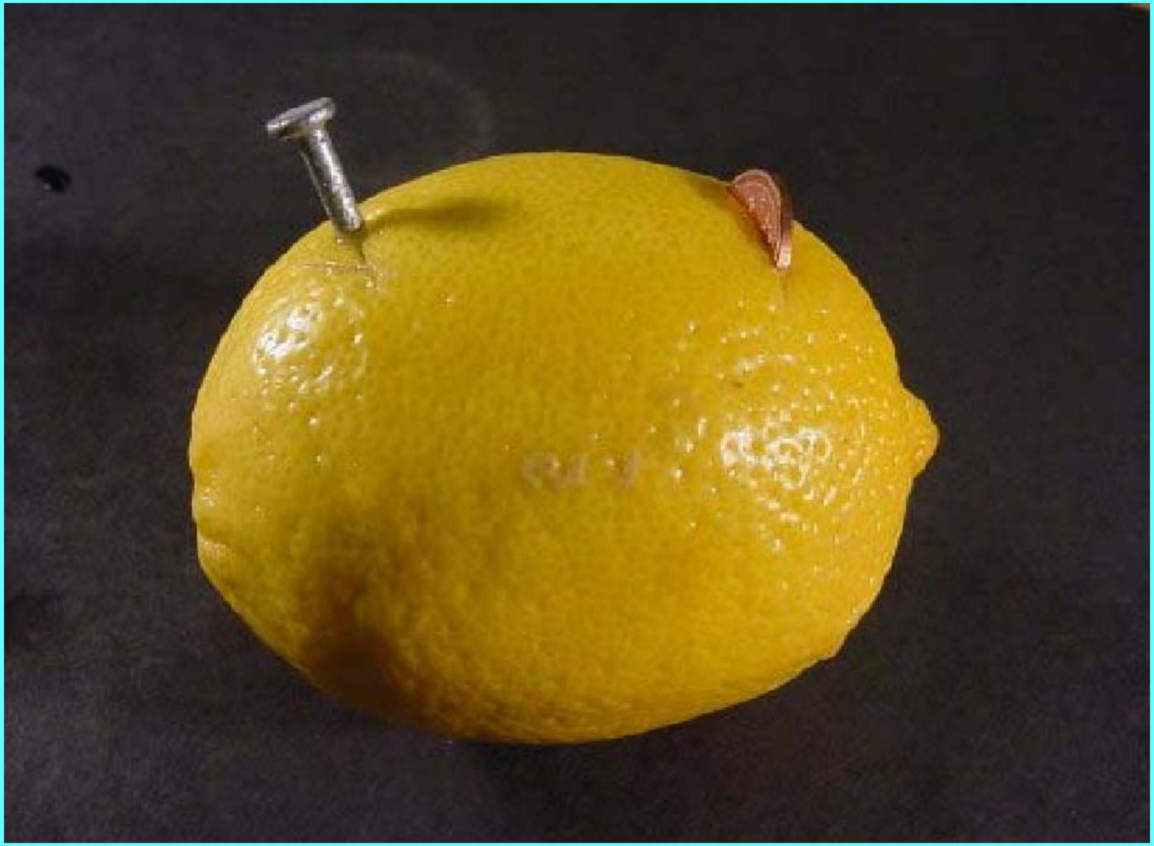
Electrolyte - Media for the exchange of ions in reduction-oxidation reactions at anode and cathode.



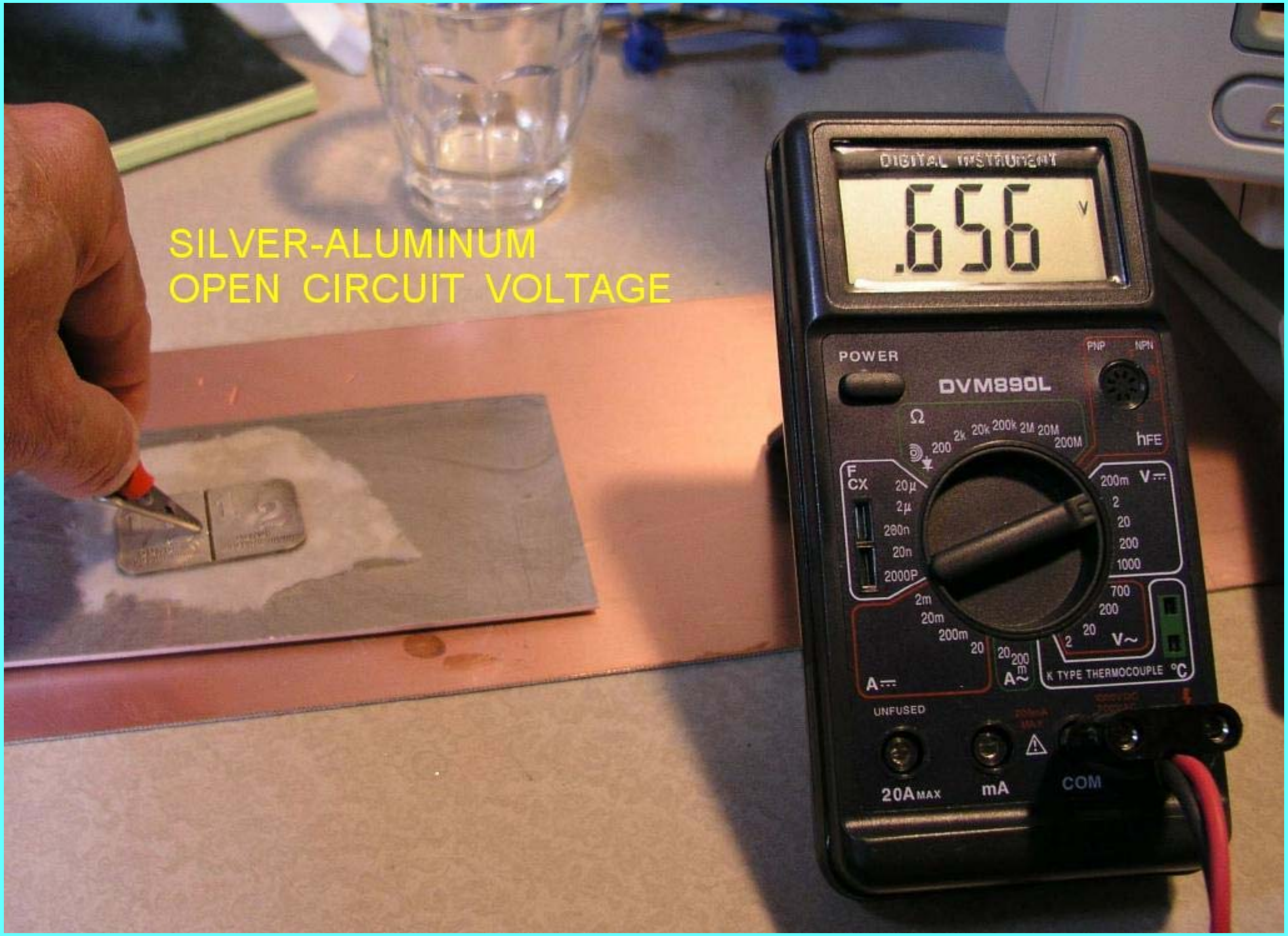
What is a cell?

Classic classroom electrolysis demonstration . . .

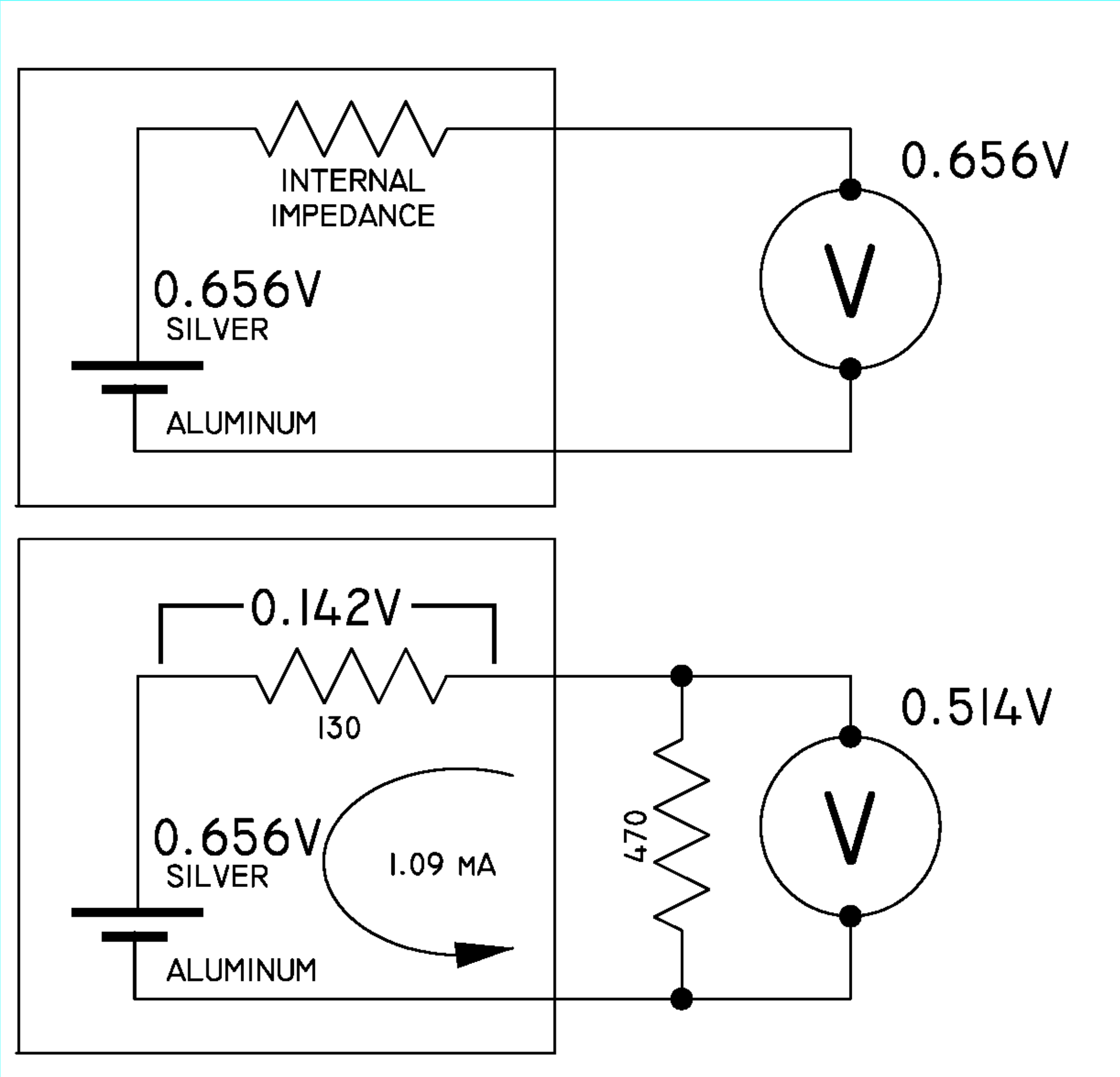
The "Lemon" Cell.



What is a cell?



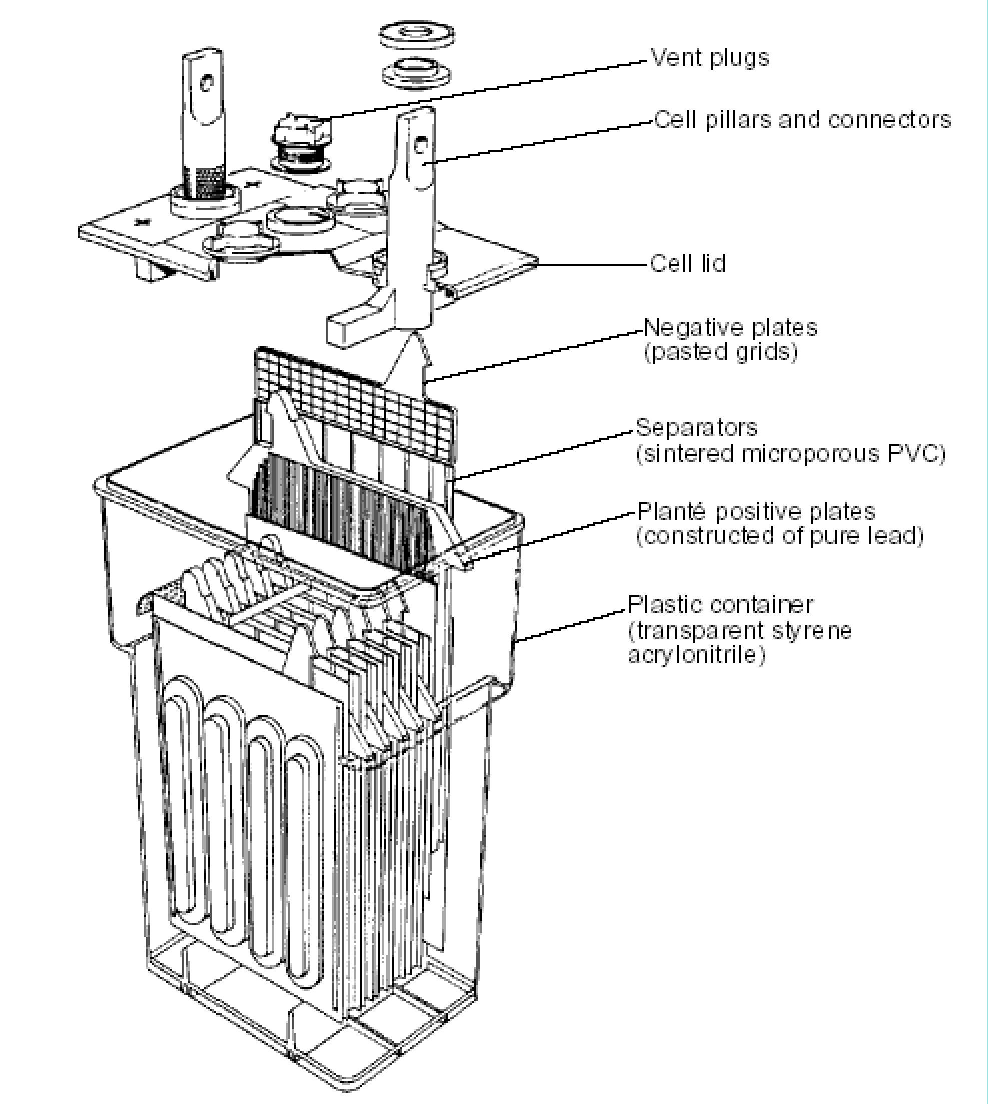
What is a cell?



What is a cell?

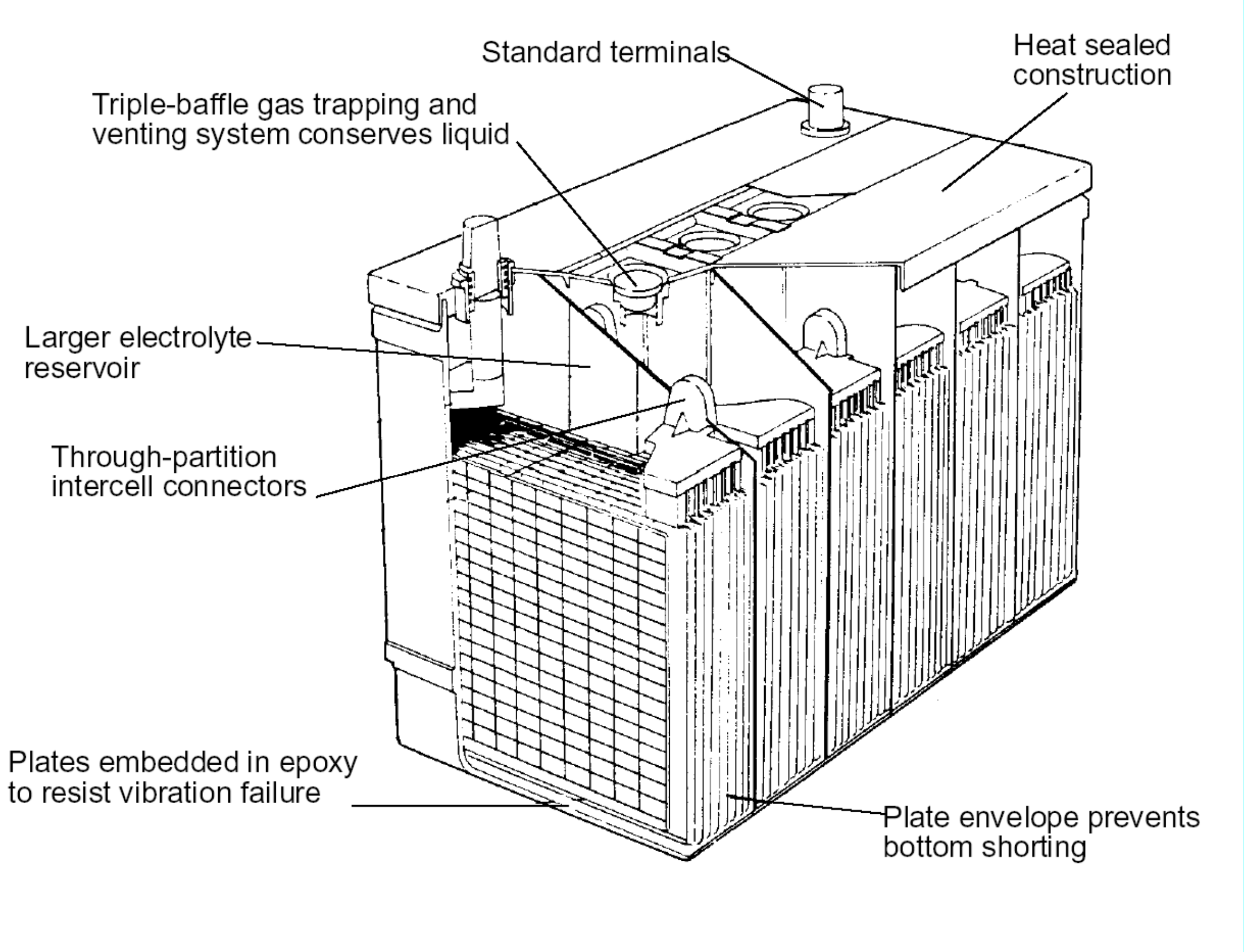
Construction typical of all flooded and "gelled" lead-acid cells.

A "battery" is a array of series connected cells (higher voltage) or parallel connected cells (higher capacity / current)



Two or more cells is a "battery"

An array of cells assembles into a "battery" . . .



Two more cells is a "battery"

What do we expect a battery to do?

- **Crank the engine**
    - **HIGH power (2500+ watts)**
    - **SHORT duration (5 seconds)**
    - **LOW energy (12K watt seconds from total of 500K watt-seconds).**
- **Excite most alternators**
    - **Trivial Duration, Power and Energy**

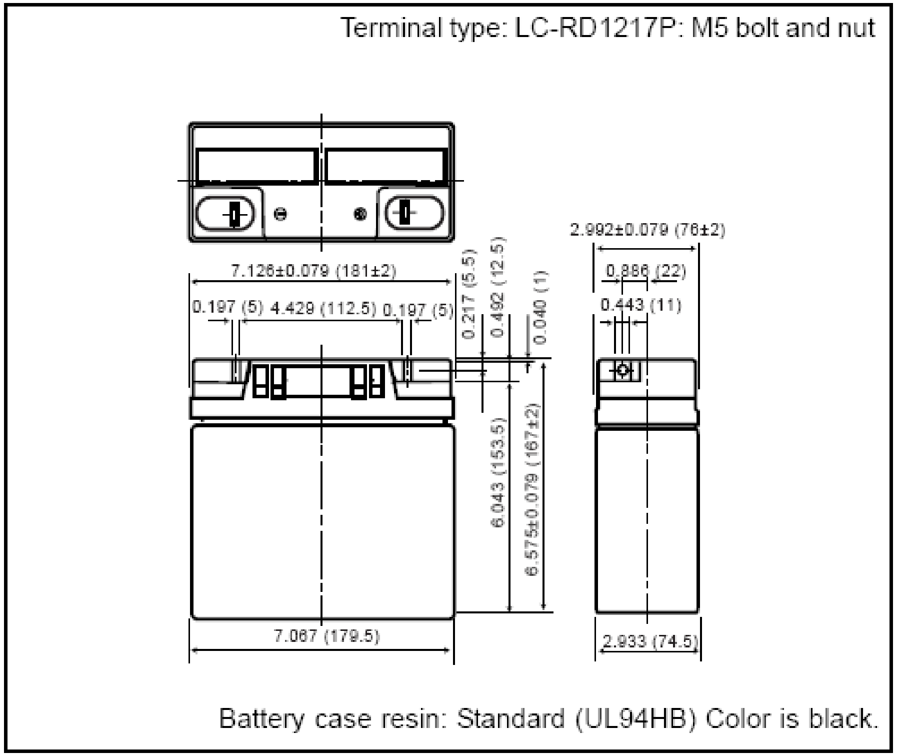
Two more cells is a “battery”

- Provide a source of energy for continued flight in the alternator out (Endurance) mode.
  - LOW power (30-70 watts)
  - LONG duration (hours)
  - HIGH energy (you may need to depend upon all of the 500K watt-seconds).

Two or more cells is a "battery"

LC-RD1217P

Dimensions (mm)



Let's consider a typical sealed, vented, lead-acid (SVLA) product for use in light aircraft . . .

Lead-Acid Battery Operations

Note the a reduction in rated capacity as load is increased.

Internal resistance is the quality that wastes more energy as the load goes up.

As storage temperature goes down, available capacity goes down too (temperature affects internal resistance).

Self discharge rates are low. This battery would still start your airplane after 1 year of storage.

Note charging recommendations that will never happen in real life. More on this later . . .

Characteristics

Capacity (note) 77°F (25°C)		20 hour rate (850mA) 10 hour rate (1500mA) 5 hour rate (2600mA) 1 hour rate (10000mA)	17Ah 15Ah 13Ah 10Ah
		1.5 hour rate discharge Cut-off voltage 10.5 V	7A
Internal resistance		Fully charged battery 77°F (25°C)	Approx. 12mΩ
Temperature dependency of capacity (20 hour rate)		104°F (40°C) 77°F (25°C) 32°F (0°C) 5°F (-15°C)	102% 100% 85% 65%
Self discharge 77°F (25°C)		Residual capacity after standing 3 months	91%
		Residual capacity after standing 6 months	82%
		Residual capacity after standing 12 months	64%
Charge Method (Constant Voltage)	Cycle use (Repeating use)	Initial current	6.8 A or smaller
		Control voltage	14.5V to 14.9 V (per 12V cell 25°C)
	Trickle use	Initial current	2.55 A or smaller
		Control voltage	13.6V to 13.8V (per 12V cell 25°C)

Conditions that affect the magnitude of self-discharge current in batteries:

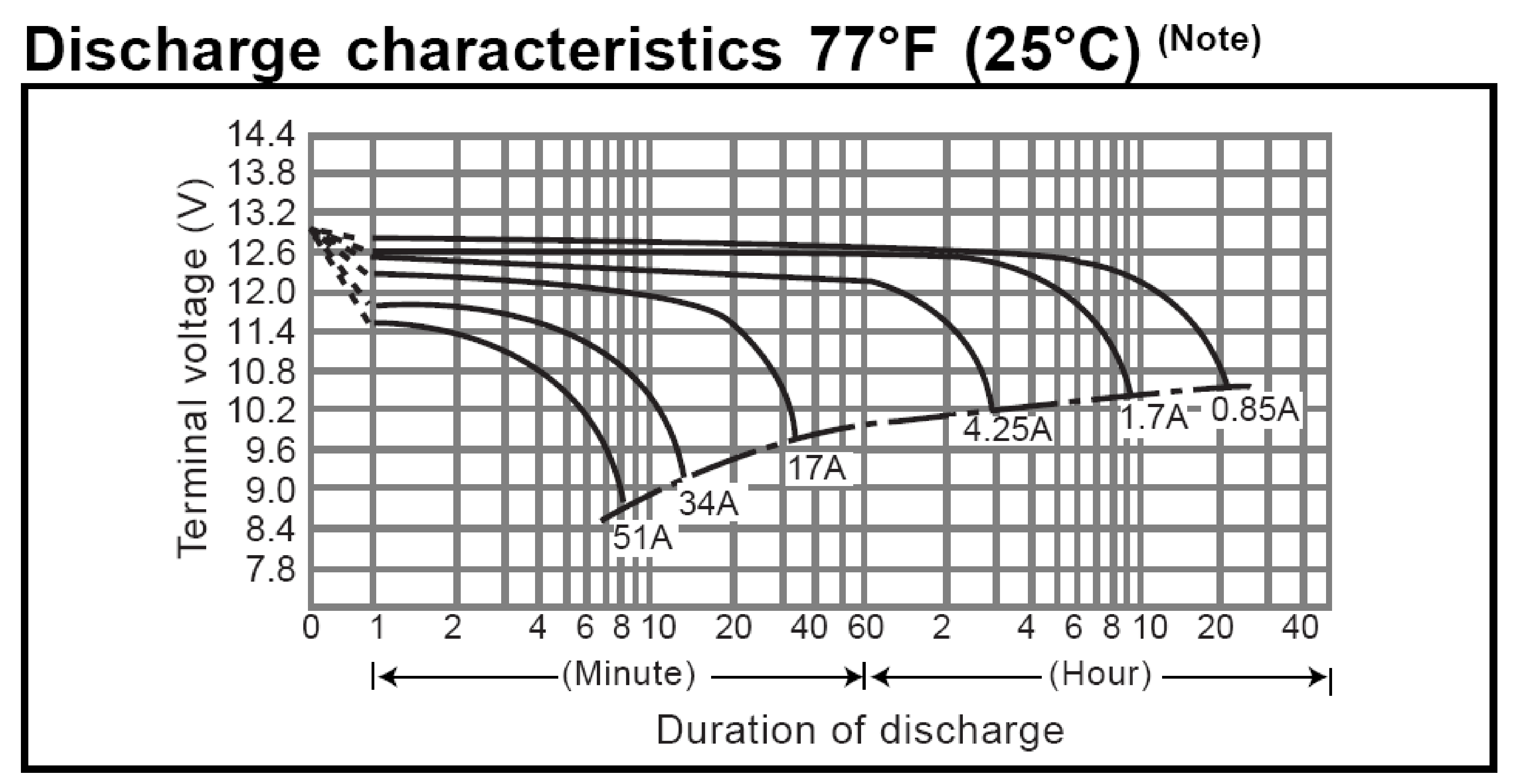
- **Storage temperature**

  Batteries stored in warm climes and un-controlled warehouse environments are especially subject to increased rates of leakage discharge. Batteries stored in Canadian warehouses do very well.

- **Free oxygen dissolved in the electrolyte.**

  When a cell is sealed off from the environment, the percentage of dissolved gasses in the electrolyte drops to a very low value. This simple isolation of the cell environment from ambient atmosphere results in markedly low self discharge rates.

Lead-Acid Battery Operations



Assuming your electro-whizzies quit working at 11.0 volts, we see that a fully charged 20AH battery will carry a 4.25A load for about 2.5 hours. Increasing the load to 17A reduces endurance to about 28 minutes. Cutting load in half will more than double the time.

Lead-Acid Battery Operations

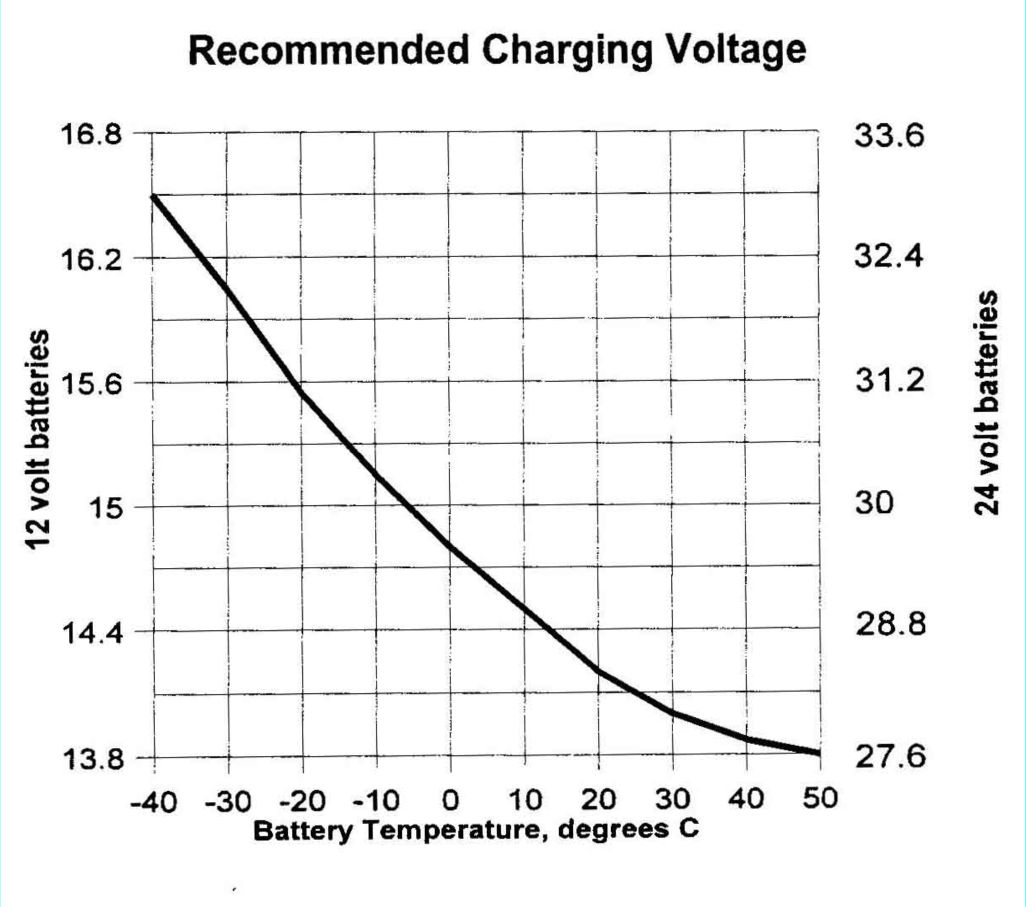
Endurance mode . . .

- **A substantial number of Dark-n-Stormy Night stories include the dark panel syndrome at battery depletion.**
- **It's easy to craft a system where alternator failure does not generate and emergency.**
- **The battery's toughest task . . . Most production aircraft with a standby power storage requirement call for 30 minutes of operation sans engine driven power sources.**
- **OBAM aircraft battery and e-bus loads can crafted to support alternator-out, electro-whizzies for DURATION OF FUEL ABOARD.**
- **Endurance mode operations are all but guaranteed to tax the battery's capacity to the limit.**
- **Aircraft battery capacity cannot be gauged without a capacity test (more on this later).**
- **Depending on your personal endurance requirements, you'll probably find it expedient to replace a battery long before it fails to crank the engine.**

"Ideal" charging voltage for a battery is temperature dependent.

I'm aware of only one battery temperature compensated regulator for aircraft (B&C).

While these "ideal" conditions are part of the published battery data, virtually nobody bothers to schedule voltage with respect to temperature.



Portable capacity tester/chargers do exist but they're not the kind of thing you find in the average mechanic's tool box!

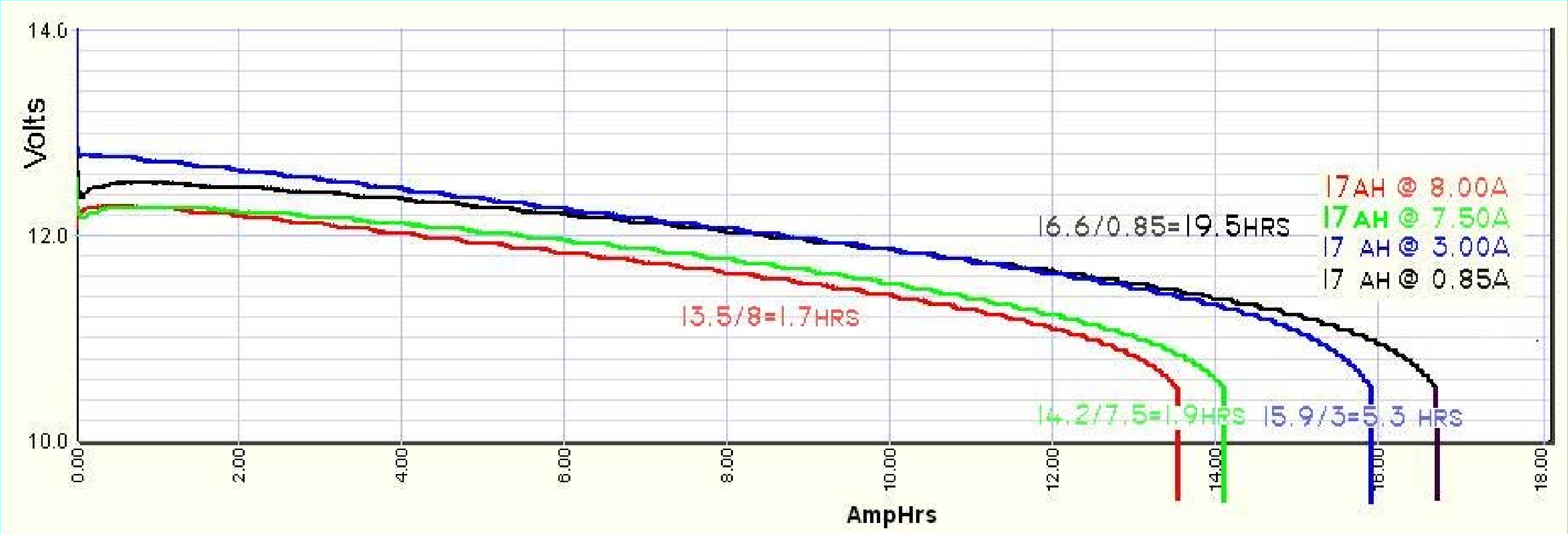
There's a company called West Mountain Radio at . . .

http://westmountainradio.com

. . .that offers a computer controlled and recorded load of up to 150 watts on batteries of 1.5 to 24 volts. This tool sells for about $100 and does some interesting tasks.

Lead-Acid Battery Operations

A Panasonic 17AH, 12V Battery was discharged under various loads ranging from 0.85 to 8.0 Amps. The apparent capacity varied from a low of 13.5 AH to a high of 16.6 AH at the lightest load.



Raising the discharge rate by 10x tosses off 19% of the battery's energy when discharged over 2 hours time as opposed to 20 hour "nameplate" rate. This energy is lost in the internal resistance of the battery.

We observed that a stack of 8, D-sized alkaline cells contain enough energy to start an automobile engine . .

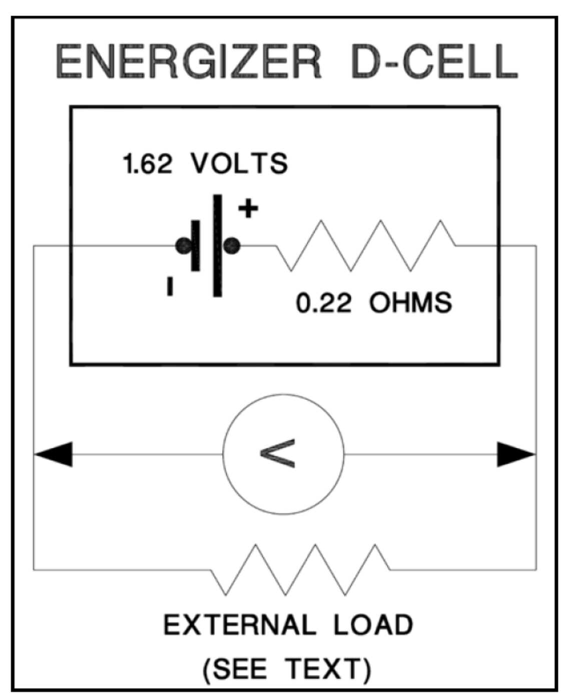
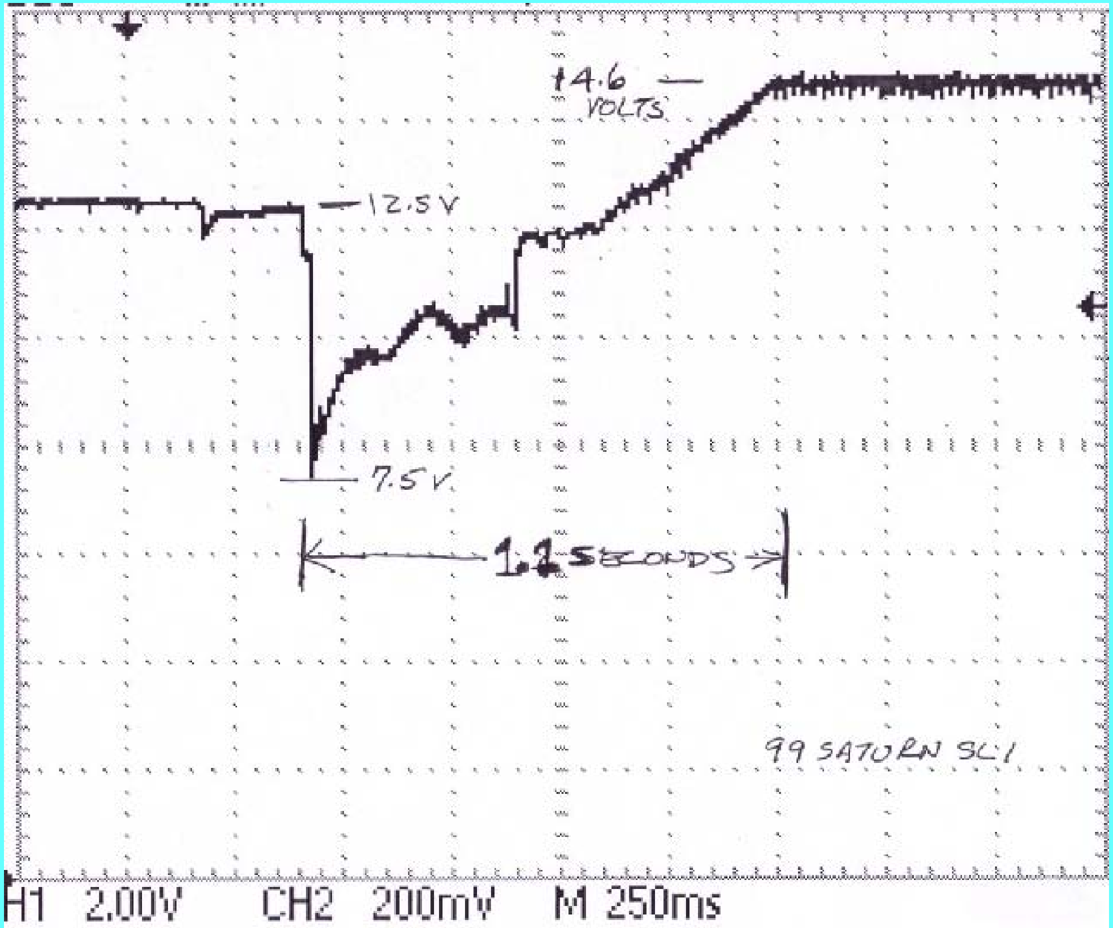


Figure 2-2. D-Cell Experiment

. . . but internal resistance of these cells prevents delivery of that energy at the 200+ Ampere rate necessary to the task.

Lead-Acid Battery Operation

The instant that the starter contactor closes, the battery is loaded with "locked rotor current". This can be many times greater than full load running current often over 1000 amps!



Lead-Acid Battery Operation

Even when the battery is capable of cranking an engine, the effects of internal resistance are still profound . . .

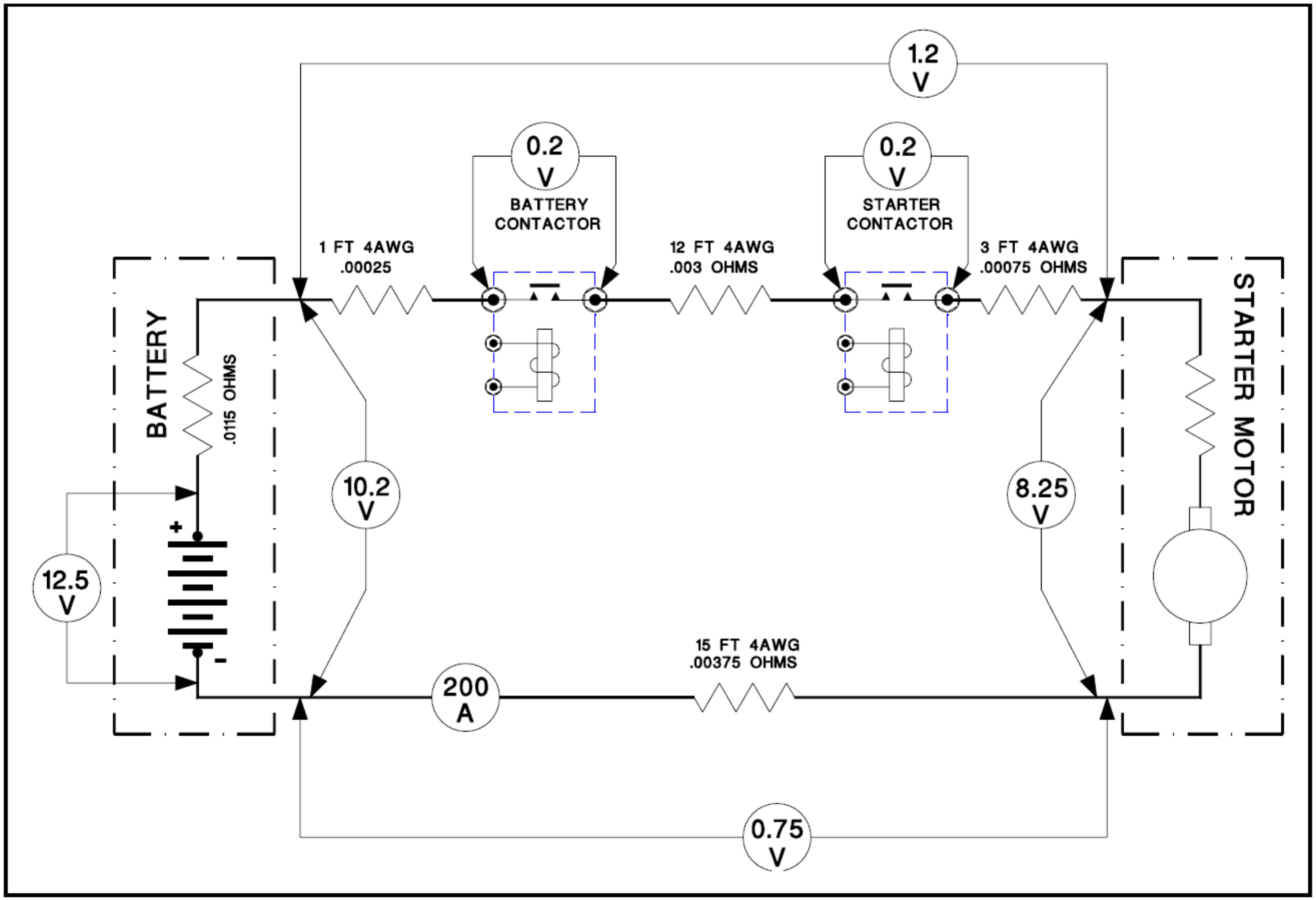


Figure 2-3. Cranking Circuit Analysis.

Battery Operation

At the other extreme of battery performance: The tiny “button cells” used to power wrist watches and computer calendar/clocks contain a great deal of energy relative to their size but internal resistance of these cells makes them suited only to tasks were the energy is extracted over long periods of time ranging from months to years . . .

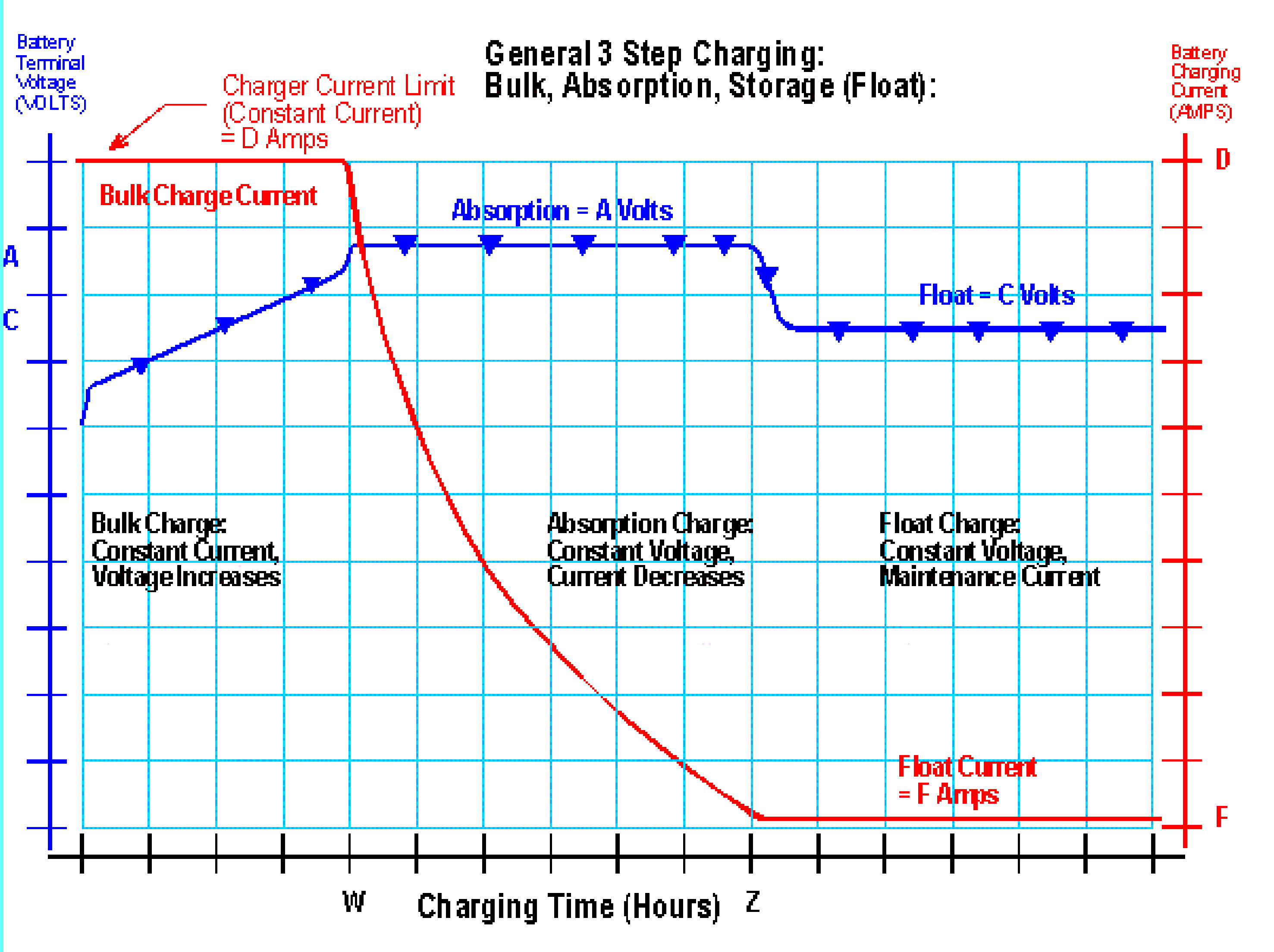
Long Term Battery Storage:

EVERY battery suffers from some degree of internal self-discharging leakage. This manifests itself as a low level “load” on the battery that will eventually discharged battery to a useless state.

0.75A Battery Tender from Deltron
(www.batterytender.com)

A “Battery Tender” type of “smart charger” will charge initially at some level that insures a charge top-off . . . Something on the order of 14.4/28.8 volts. When charge acceptance current drops below some small value, the output voltage drops to 13.0/26.0 volts so that the “Battery Tender” exactly offsets the leakage currents.

Care and Feeding of Lead-Acid Batteries



Portable Power: How BAD can an alkaline cell be?

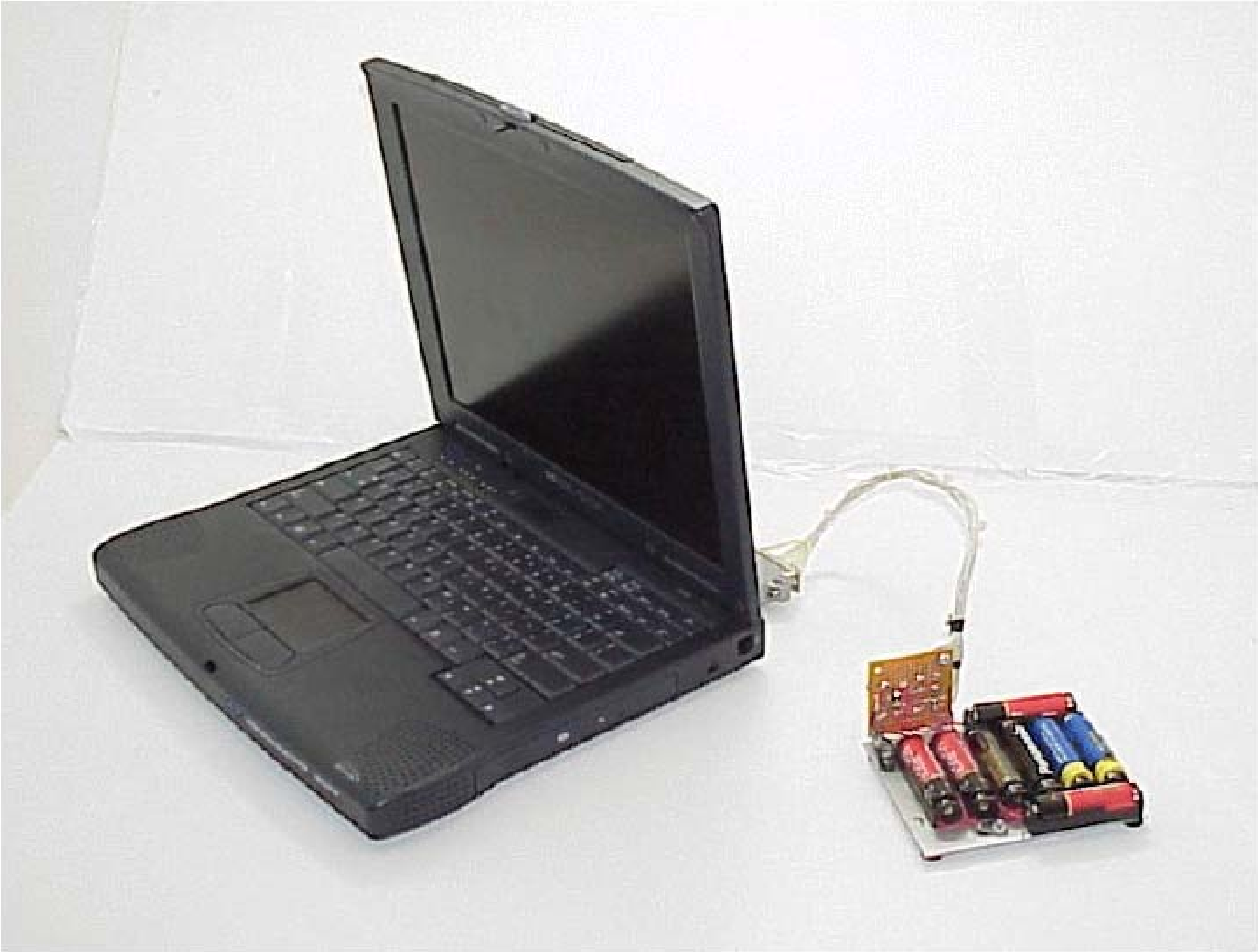
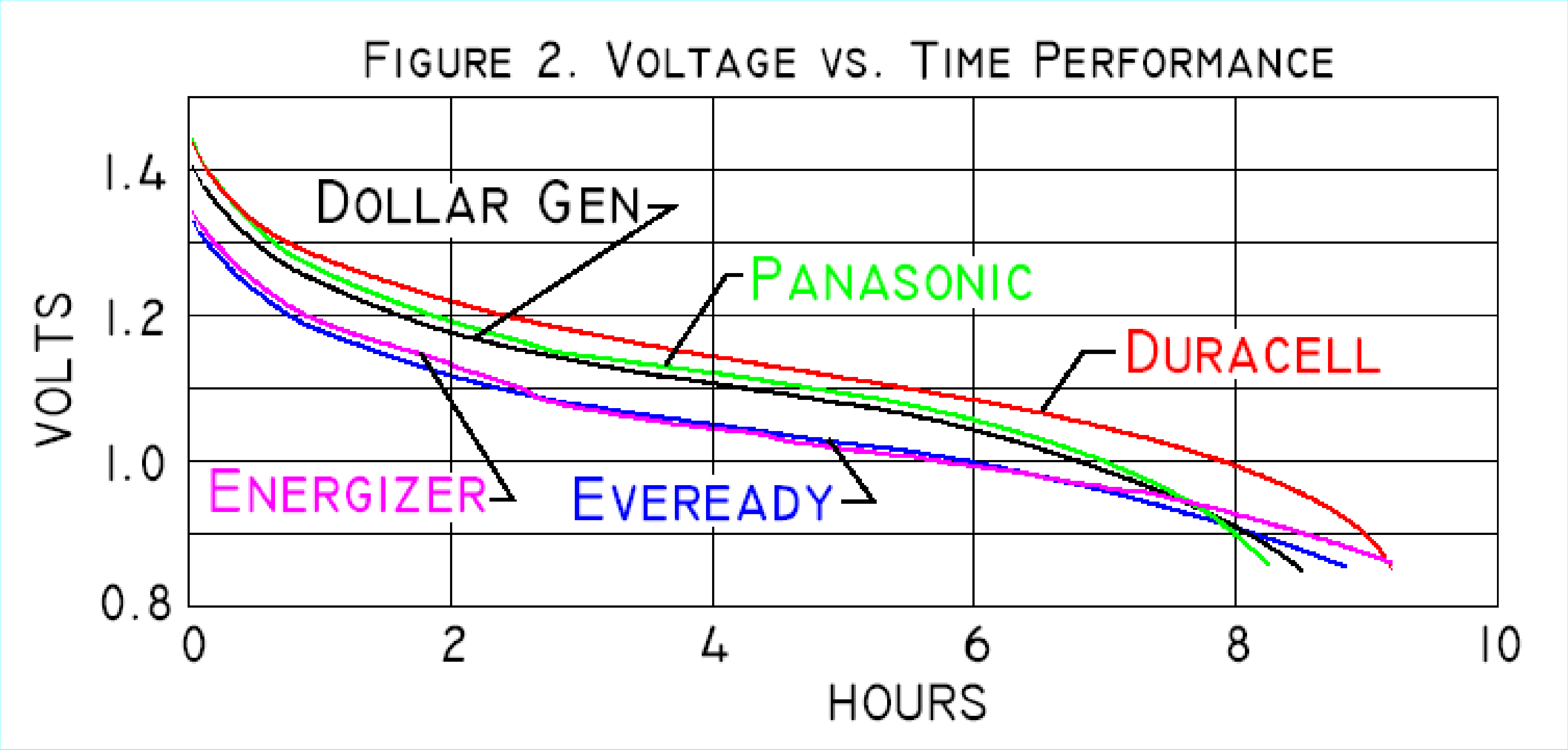


Figure 1. Bob's Computer Driven Battery Killer.

Portable Power: How BAD can an alkaline cell be?



Performance of various AA cell brands at room temp

Table 1. Numerical Performance Data					
Brand	Depletion to 1.0V w/5 Ohm Load		Depletion to 0.85V w/5-Ohm Load		
	Time (Hours)	Energy (Watt-hours)	Time (Hours)	Energy (Watt-hours)	Cost $/watt-hour
Duracell Ultra	7.95	2.13	9.24	2.36	$0.33
Panasonic	6.99	1.87	8.27	2.09	$0.18
Dollar Gen	6.78	1.78	8.50	2.08	$0.12
Eveready	6.03	1.63	8.88	2.05	$0.19
Energizer	6.00	1.14	8.22	1.99	$0.37

Bottom line of study on AA Alkaline batteries: Irrespective of intensity and flavor of marketing hype, the “best” isn’t a lot better than the “worst” and the “lowest cost” is not the “worst” yet offers the best “value”.

Portable Power: How GOOD can a cell be?

- It is not uncommon to see secondary cell products offered with . . . shall we say . . . astounding ratings?

! ! ! ! !

- **The laws of physics are rather firm. When tested for usable capacity, the NiMh cell above tested just above the industry average for Sub-C cells at1600 mAh; the 18650 Li-Ion to the right tested at the industry average of 1000 mAh.**

In a nutshell . . .

• **Batteries are like houseplants: Peak performance is achieved with optimized control of deleterious and helpful environmental conditions.**

• **Irreversible damage may occur when a battery is allowed to sit in a fully discharged condition . . . Not all batteries can be recovered from this kind of abuse.**

• **Service life is strongly influenced by owner, pilot and maintenance behavior. A battery "likes" to be moderately challenged often. Batteries stored for long periods of time will do better with considered attention from battery maintainers**

• **Unless you're willing to spend the $time$ necessary to maintain a battery in a state suited to your needs, then buying cheap and replacing often may offer the *lowest cost of ownership*.**

• **SVLA batteries do not need a battery box. You can lay them down if it makes sense for optimum mounting.**

In a nutshell . . .

• Batteries with lead posts fitted with thru-bolt holes need to be pampered. The preferred attach philosophy suggests very soft and flexible, 4AWG welding cable jumpers from battery (+) to contactor and battery (-) to ground.

• Avoid star billing in your own "Dark-n-Stormy Night" story:

(1) Establish personal requirements for flight endurance during alternator-out operations then . . .

(2) Size and maintain your battery such that you can confidently meet those expectations.

Lithium-Ion Batteries

- **Here's a 24v True Blue Power lithium battery flying on General Aviation Aircraft**
- **A substantial portion of this battery's volume is filled with ELECTRONICS that manages cell balancing, overcharge, over-discharge, fault protection.**
- **The last time I looked inside one of these batteries, I saw a huge series-parallel array of 14650 cells.**

- **This battery enclosure has been tested to withstand pressures and heat of a battery failure while venting gaseous products of failure overboard.**

Lithium-Ion Batteries

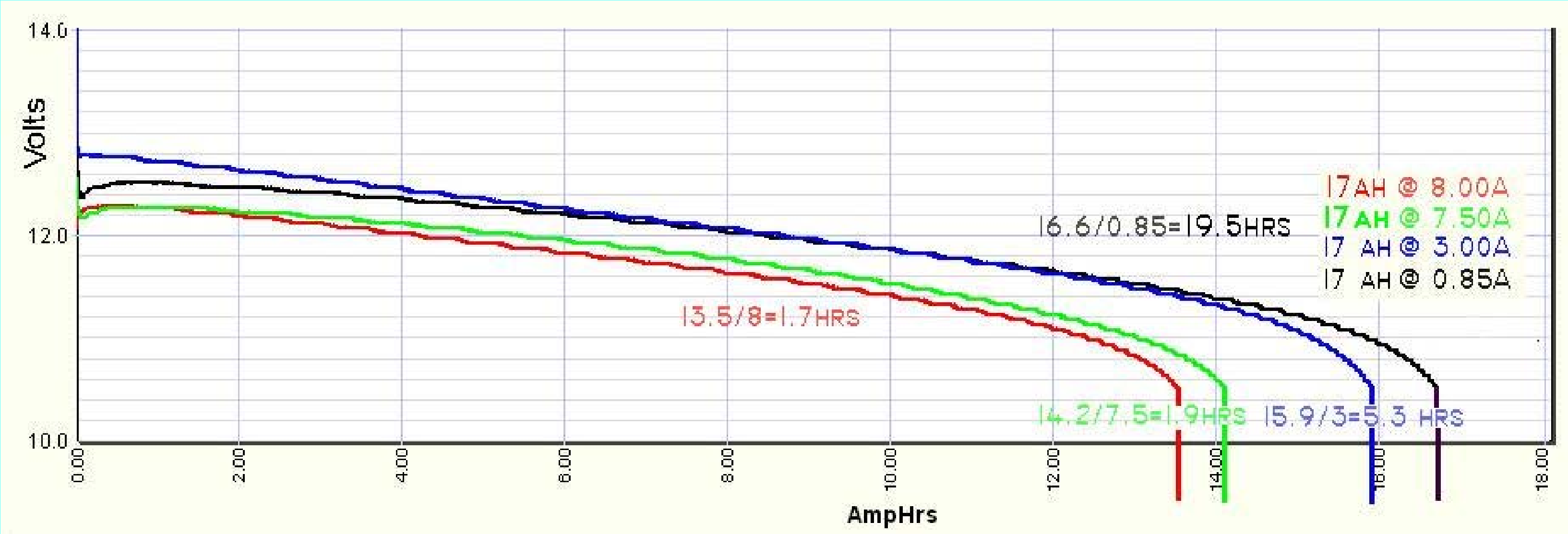
- BEWARE of less-than-forthcoming adverts for replacing an SVLA battery with lithium.
- Suppliers are fond of citing a new ratings term that was created for the lithium market . . . "Lead Acid Equivalency" or "PbEq."
- The idea behind this rating is supported by the notion that "this battery cranks an engine like a 24 a.h. lead-acid". Few sellers are cognizant of the special needs in aircraft to offer back-up energy alternators.
- This particular battery DOES feature a Watt-Hrs rating. A step up from a few years ago when a lot of batteries were being hyped as a 'drop in replacement' for an existing SVLA battery.

How do you "balance charge" a battery that never needs charged?

- 3.5 pounds
- 28 aH Pbeq
- 9.2 aH Stored Energy
- No internal electronics
- External Cell Balancing Charger

If the ship's alternator replenishes energy used during cranking and the airplane is parked with a "fully charged" battery . . . Then what is the opportunity for a hangar-bound cell balancing tool to work effectively?

Recall our 17AH SVLA capacity test cited earlier. This 15# battery would run an 8A endurance load for 1.7 hours . . . Approx 0.11 hour per pound of battery.



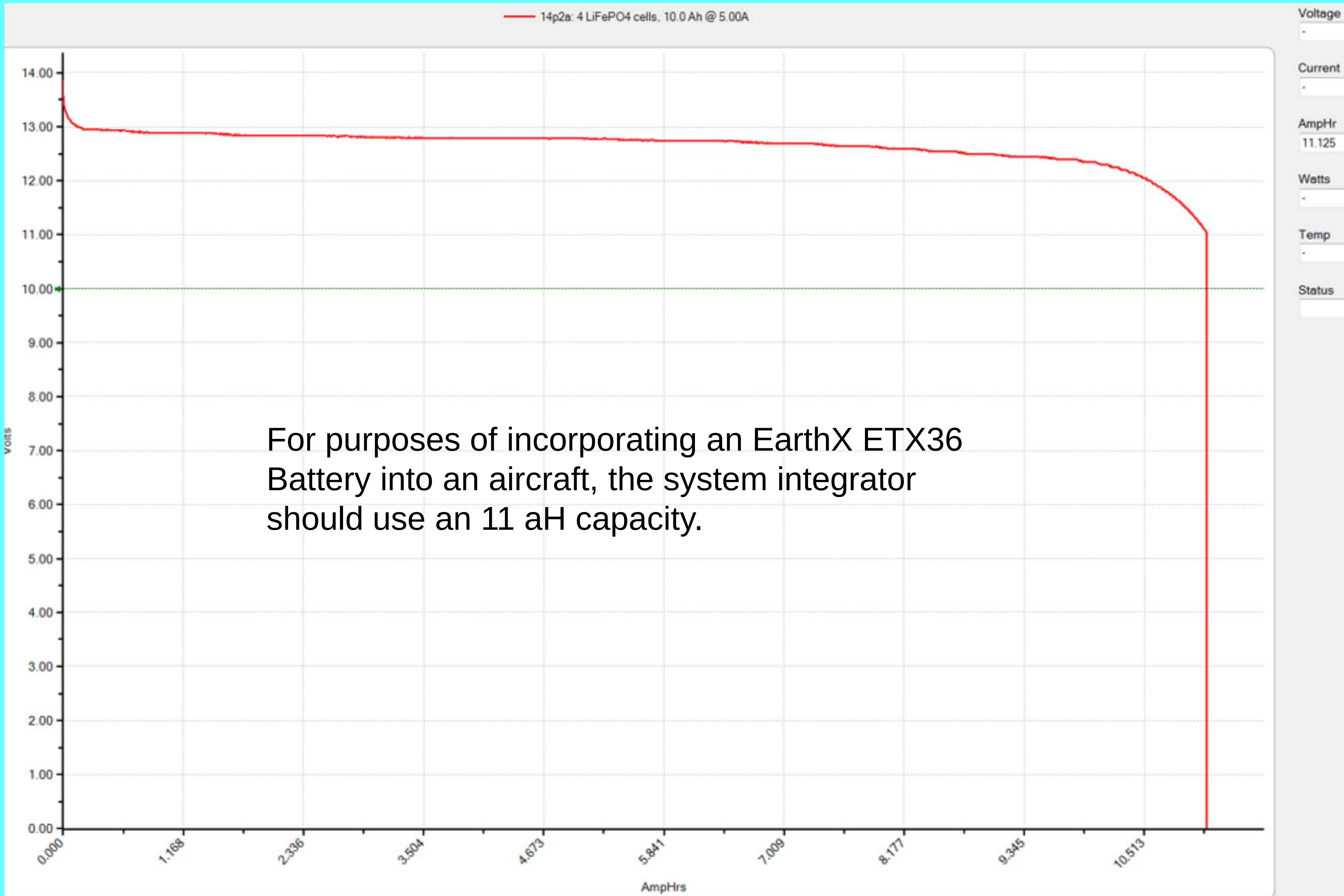
The AeroVolts 16-cell would carry the 8A endurance load for about 1.1 hours . . . Approx 0.32 hour per pound of battery. In round numbers, it would take an AeroVolts style battery weighing in at about 5.5 pounds to offer the same battery only endurance as the 17 a.h. SVLA. Hence the savings of about 2/3 the weight over Lead-Acid

Lithium-Ion Batteries

- **One manufacturer of lithium products is EarthX. I have one of their ETX36 batteries.**
- **This product strives to offer operational features and protections not unlike the type certificated products being offered by True Blue Power (Mfgr Data to follow).**

- **While about the same volume as an 18 ah SLVA battery, it is indeed much lighter. Further, it's offered as with a PB-Eq rating of 36 while in fact . .**

Lithium-Ion Batteries



For purposes of incorporating an EarthX ETX36 Battery into an aircraft, the system integrator should use an 11 aH capacity.

EarthX Automatic Protection Features

- Over-discharge protection
- Over-charge protection
- Cell charge balancing
- Excessive cranking protection
  (cell temperature protection)
- Short circuit protection

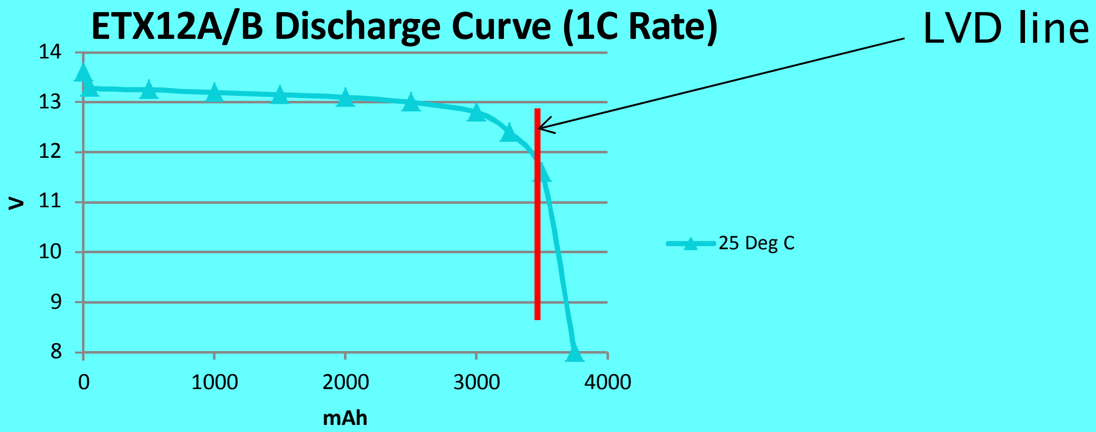
Over-discharge protection:

- Cells that have been drained; voltage less than 2V per cell, are considered over-discharged
- Cells that have been over-discharged are permanently damaged
- Cells damaged from over-discharge display elevated temperatures on subsequent charging and discharging

Over-discharge is a big deal!

Over-discharge protection:

- Low Voltage Disconnect (LVD) point is a approximately 95-98% Depth of Discharge (DoD) or 11.5V (2.8V/cell) at a low discharge rate (<1C)



The discharge control MOSFETs turn off, and remains off until voltage recovers (>12V).

Over-discharge protection, RESET:

- To reset the BMS (re-energize the MOSFETs) after over-discharge event, the battery must be charged
- A battery charger with a BMS reset feature must be used, for the battery terminal voltage will be 0V and appear as a "dead" battery
- When the voltage recovers (>12V), the MOSFETs will reconnect

Over-charge protection:

- Over-charge protection is designed to limit individual cell voltage to < 3.9V (single cell of 4 cell battery)
- If any individual cell voltage exceeds 3.9V the charge MOSFETs disconnect (turn off)
- The charge MOSFETs automatically re-connect if the voltage drops below 3.85V

Cell charge balancing:

- Cell balancing logic is active at any time a cell’s voltage is over 3.35V
- Resistive type cell balancing method is used; cell current is shunted across a resistive load
- Heat from the resistive load is transferred to the battery’s brass terminals

Excessive cranking protection:

- Continuous engine cranking can cause cell damage due to high internal cell temperature (typically > 60 deg C)
- Excessive cranking protection logic limits “high current use” (engine cranking) to 10 seconds in any 60 second period (factory adjustable)
- High current use is defined as >30C discharge rate. The discharge MOSFETs are turned off when excessive cranking protection is active

Short circuit protection:

If a low impedance load is connected to the battery, which causes the battery volts to instantaneously dip below 5V, the discharge MOSFETs will turn off to disconnect the load

The take-away for this study suggests that there's a huge array of configurations for multi-cell, Lithium-Ion vehicular engine cranking batteries. Features and performance can range from a simple packaging of 4-fat cells up to an including devices like True Blue and EarthX that offer protections for what has proved to me a relatively fragile technology. STUDY WELL BEFORE YOU BUY.