Glider Batteries

Battery technology,
care and feeding

Darryl Ramm (6DX)

Outline

- Battery technology
- Understanding specifications
- Low temperatures
- Glider power requirements
- Battery care
- Battery chargers
- Handouts – battery data sheets

Getting Started

Ohms law:

$V = I \times R$

Power:

$P = I \times V$

$= I^2 \times R$

$= V^2 / R$

Measurement	Units
Voltage, V, v, emf, e, ε	volt, V
Current, I, i	amp, ampere, A
Resistance, R	ohm, Ω
Power, P	watt, W
Battery Capacity, C	Ah, A.h Amp.hr
State of Charge, SOC	%

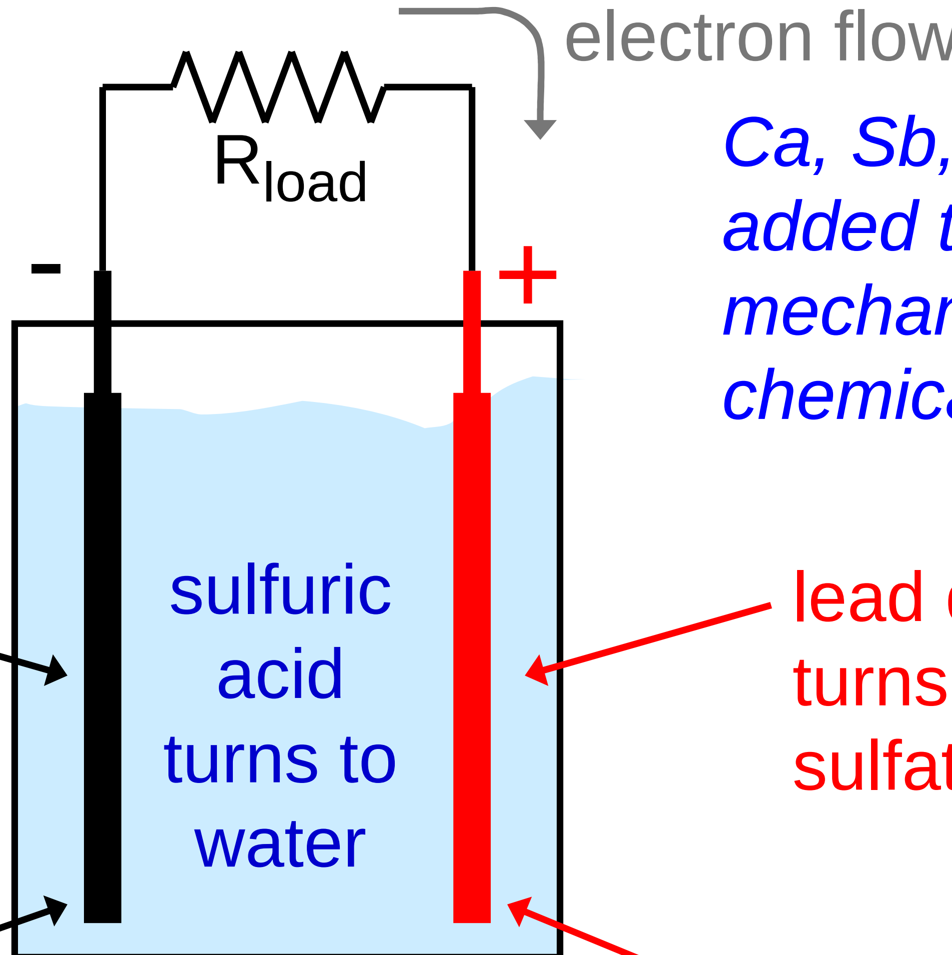
Prefix	Fraction	Decimal	Scientific
micro	millionth	0.000,001	10^{-6}
milli	thousandth	0.001	10^{-3}
kilo	thousands	1,000	10^{3}

State of charge:

SOC = capacity remaining / total capacity (%)

Lead Acid Battery Chemistry

Ca, Sb, Sn, etc. added to plates for mechanical and chemical properties



sponge lead turns to lead sulfate

lead dioxide turns to lead sulfate

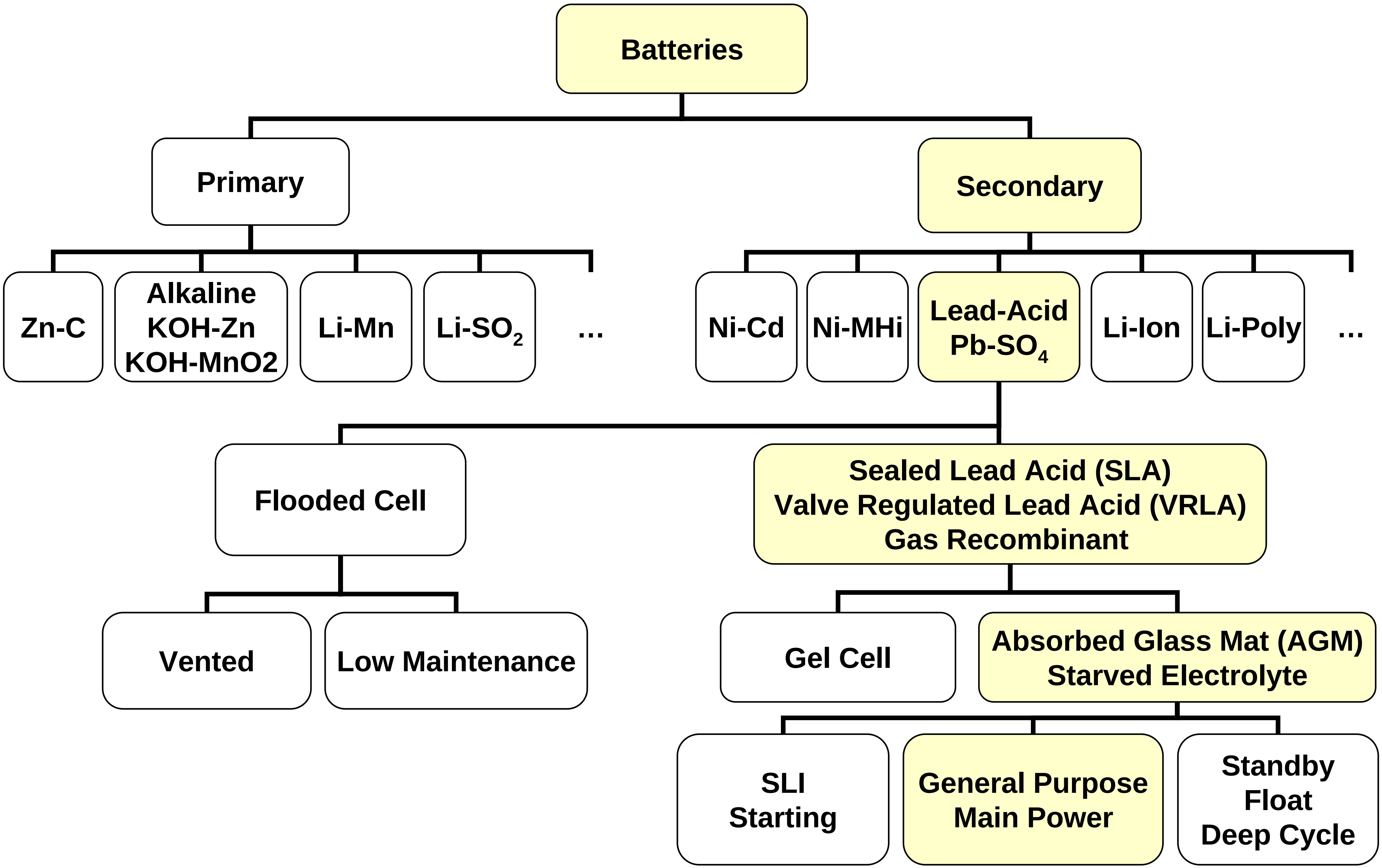
$Pb + SO_4^{2-} \leftrightarrow PbSO_4 + 2e^-$

← charge – discharge →

$PbO_2 + SO_4^{2-} + 4H^+ + 2e^- \leftrightarrow PbSO_4 + 2H_2O$

← charge – discharge →

Battery Technology

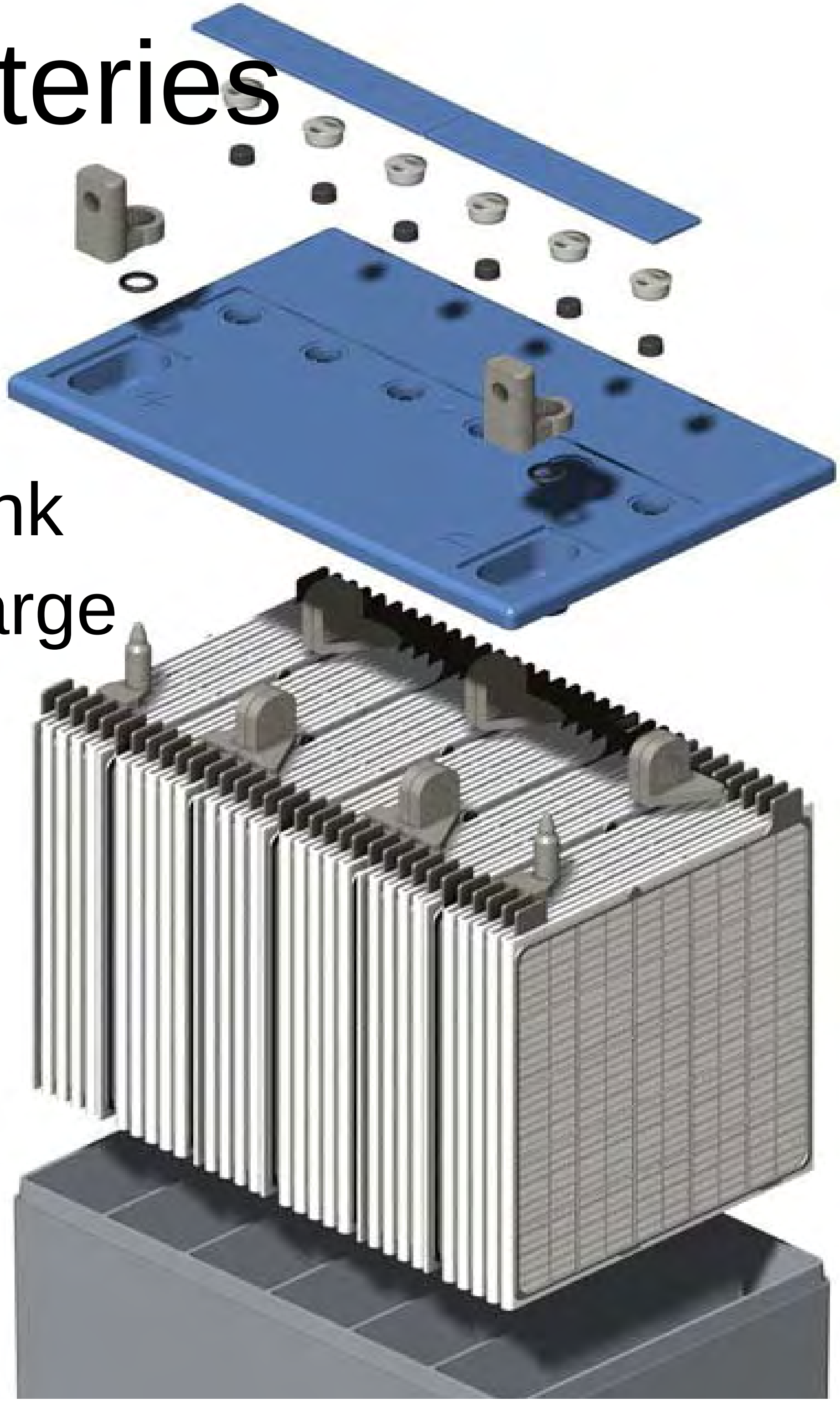


Sealed Batteries

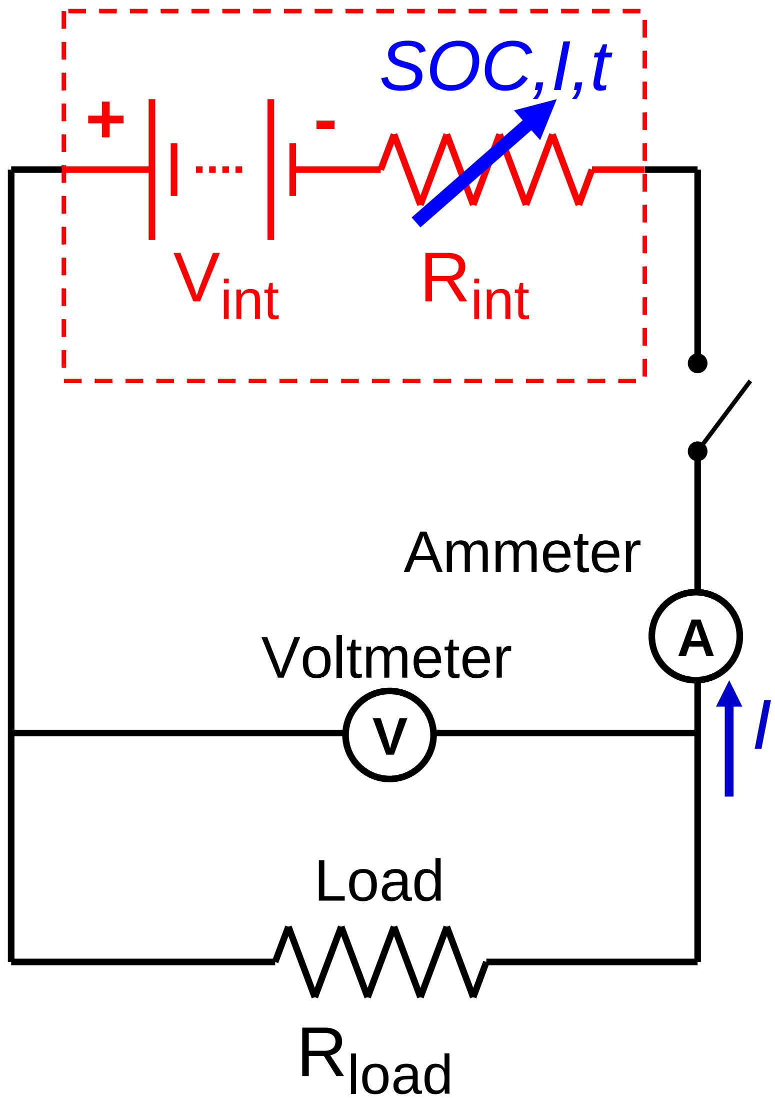
- Sealed Lead Acid (SLA)
- Valve Regulated Lead Acid (VRLA)
  - Gas regenerative
- Gel Cell or Absorbed Glass Matt (AGM)
- Robust won't spill
- Better discharge & cold crank than flooded
- 1-3% per month self discharge (Pb-Ca)
  - vs. 1% per day for flooded!
- Lower charge rate than flooded cell
- Up to 3 x cost of flooded

AGM Batteries

- Absorbed Glass Matt
- Mechanically strong
- Robust won't spill
- Good discharge & cold crank
- 1-3% per month self discharge
  - ~1% per day for flooded!
- High capacity
- Low internal resistance
- Low self discharge
- Need low charge rate
- Charge volts ~ flooded



Simple Battery Model



- Internal resistance (R_{int})
  - Solid metal conductivity
  - Electrolyte conductivity
  - Plate surface/electrolyte contact resistance
- Terminal voltage drop
  - $V = V_{int} - I \times R_{int}$
  - $\Delta P = I^2 \times R_{int} = \Delta V \times I$
- Increases during discharge
- Affected by temperature, current, chemistry, construction, age/abuse
- R_{int} is measure of health

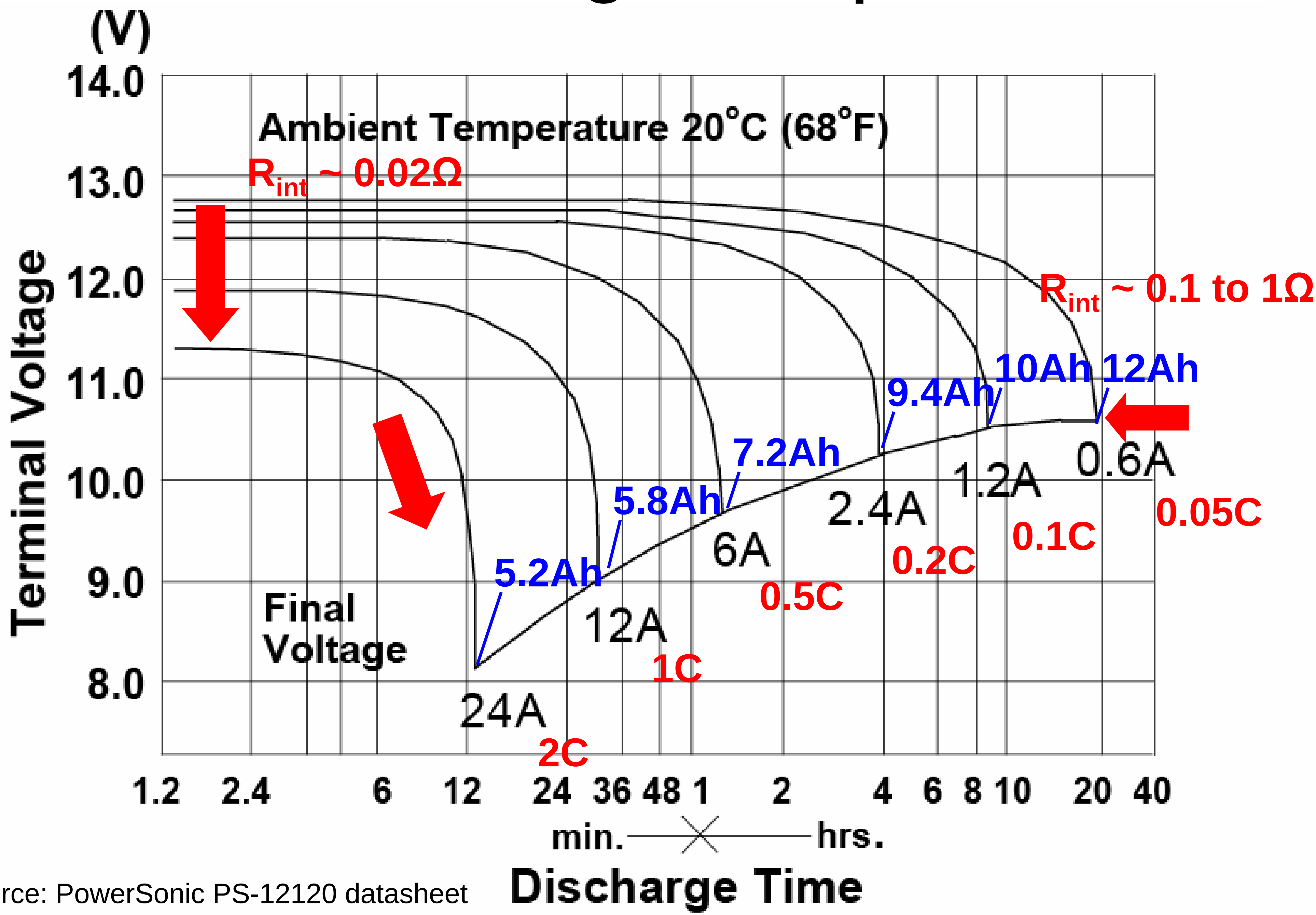
Amp Hours

- Battery capacity
  - Abbreviated as ‘C’, units Amp hours (Ah)
- C = I x time (Ah)
  - Standard is to measure over 20 hour discharge
  - Discharge current = 0.05 x C amps for 20 hours
- C ≠ I x time (Ah)
  - 20 hour C spec is not C amps for one hour

Battery Data Sheets

- Lots of interesting stuff…
- Self discharge vs. time vs. temp
- Cycle life vs. discharge depth
- Discharge voltage vs. time vs. current
- Discharge time vs. current vs. temperature
- State of charge vs. open circuit voltage

Discharge Graph



Source: PowerSonic PS-12120 datasheet

Discharge Graph

- Constant current discharge
  - Constant resistance would be close
- Graph shows a lot –
  - Volts vs. SOC during at particular current
  - Increasing R_{int} as discharges
  - Increasing R_{int} as current increases
  - Cut off V changes with current (due to R_{int})
  - Need to know curve to use for SOC vs. V_{LOAD}
- Missing temperature dependence
- Really want linear not log time axis

Calculating Battery Run Time

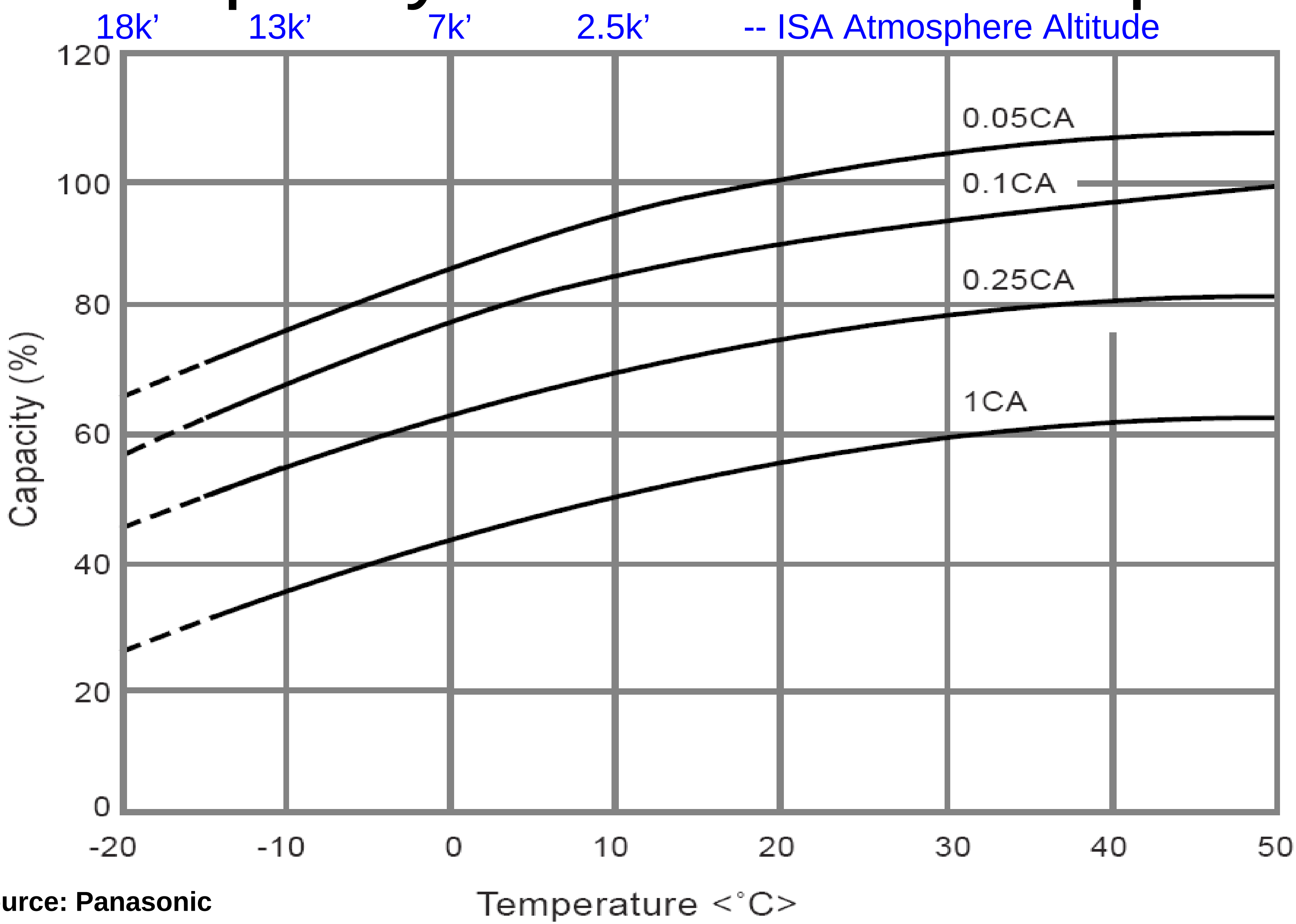
1. Find battery C (Ah) near glider current
2. Divide C (Ah) by glider current
3. Derate 20% for battery aging
4. Derate for low temperature (more soon)

- For example at 1.9 A load
    1. From graph interpolate C ~ 9.6 Ah
    2. At 1.9 A, run time ~ 9.6/1.9 = 5.0 h
    3. Derate 20%, run time ~ 4.0 h (20 °C)
- Incorrect naive calculation
    – 12 Ah / 1.9 A = 6.3 h, Derated ~ 5.0 h

Low Temperatures

- What is battery temperature?
- As temperature decreases
  - Electrolyte conductivity decreases
  - Chemical potential decreases (minor effect)
  - Electrolyte will eventually freeze
- Rule of thumb: capacity halves 25 to -25 °C
- Cold wave flights
  - Solar panels (~ 0.5 to 1.5 A *peak*)
  - Insulate batteries
    - 1” R7 foam = few watt heat leak
    - Self heating = fraction to a few watt
  - Heaters, exotic batteries, ...

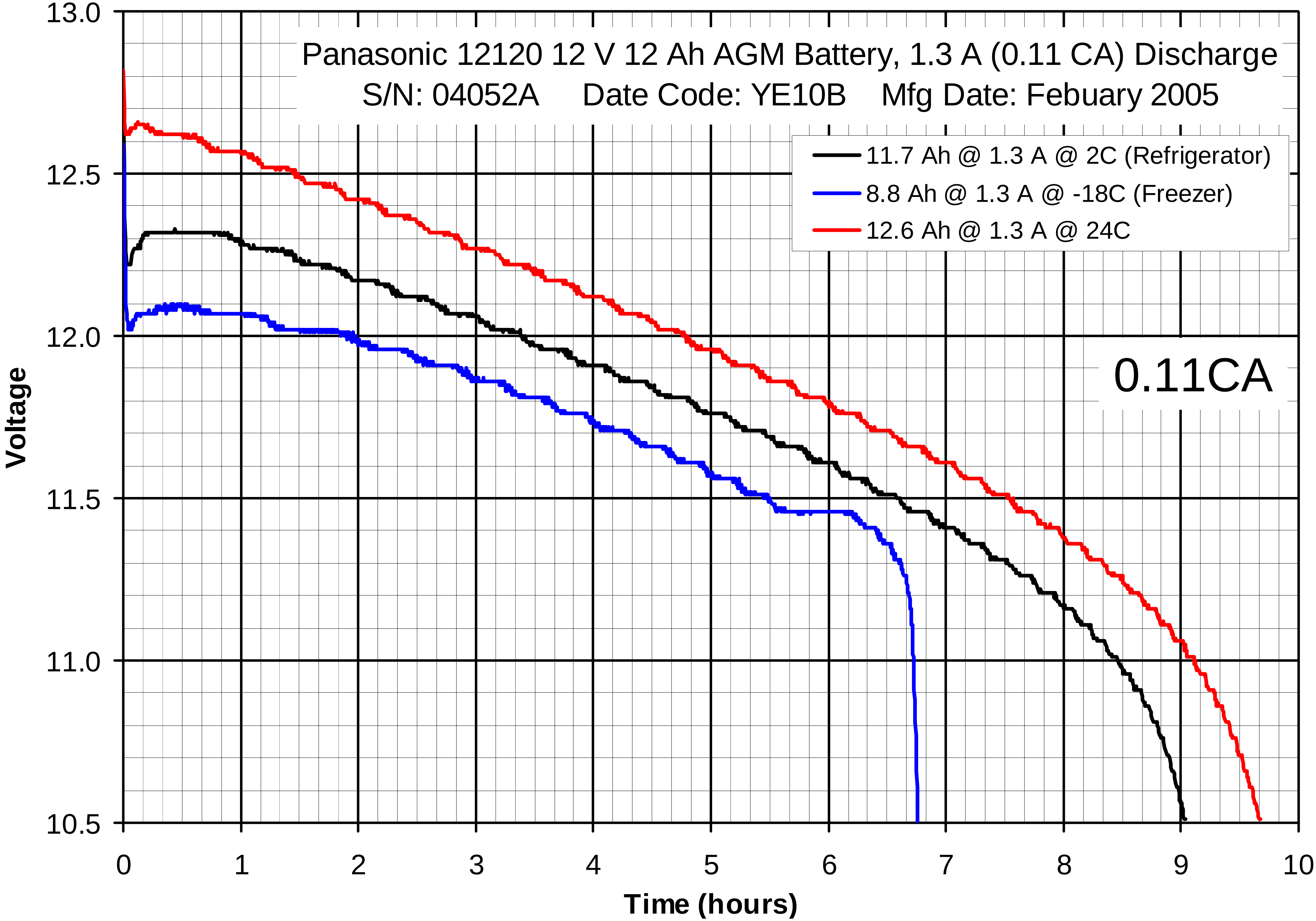
Capacity vs. Load vs. Temp.



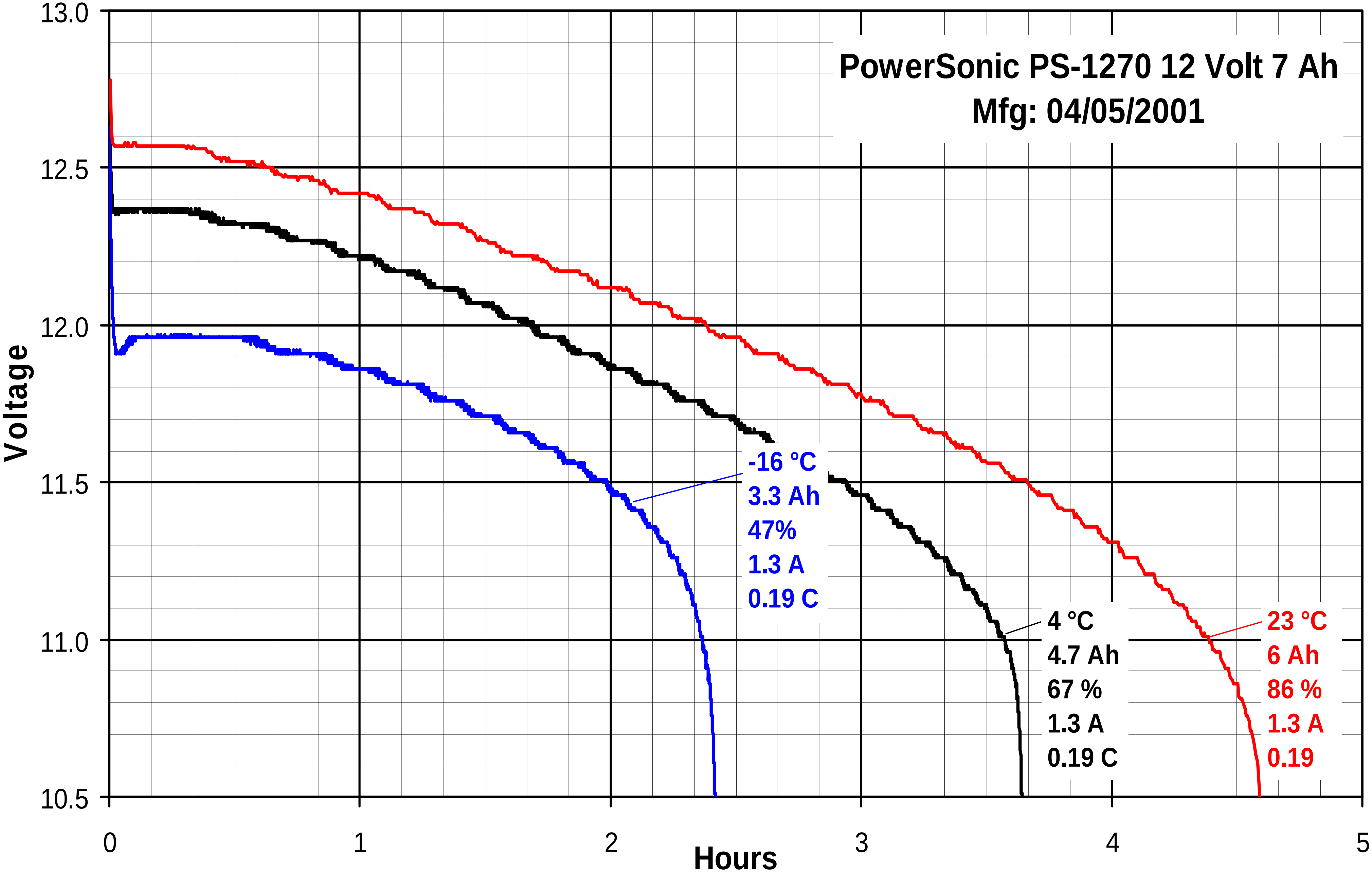
Source: Panasonic


SAUZA
GENERACIONES
BOONVILLE
2006
BEER
Winter Solstice
Seasonal Ale
ANDERSON VALLEY
BOONVILLE
BREWING COMPANY
LIQUEUR
BOTTLED IN FRANCE
Darryl Ramm

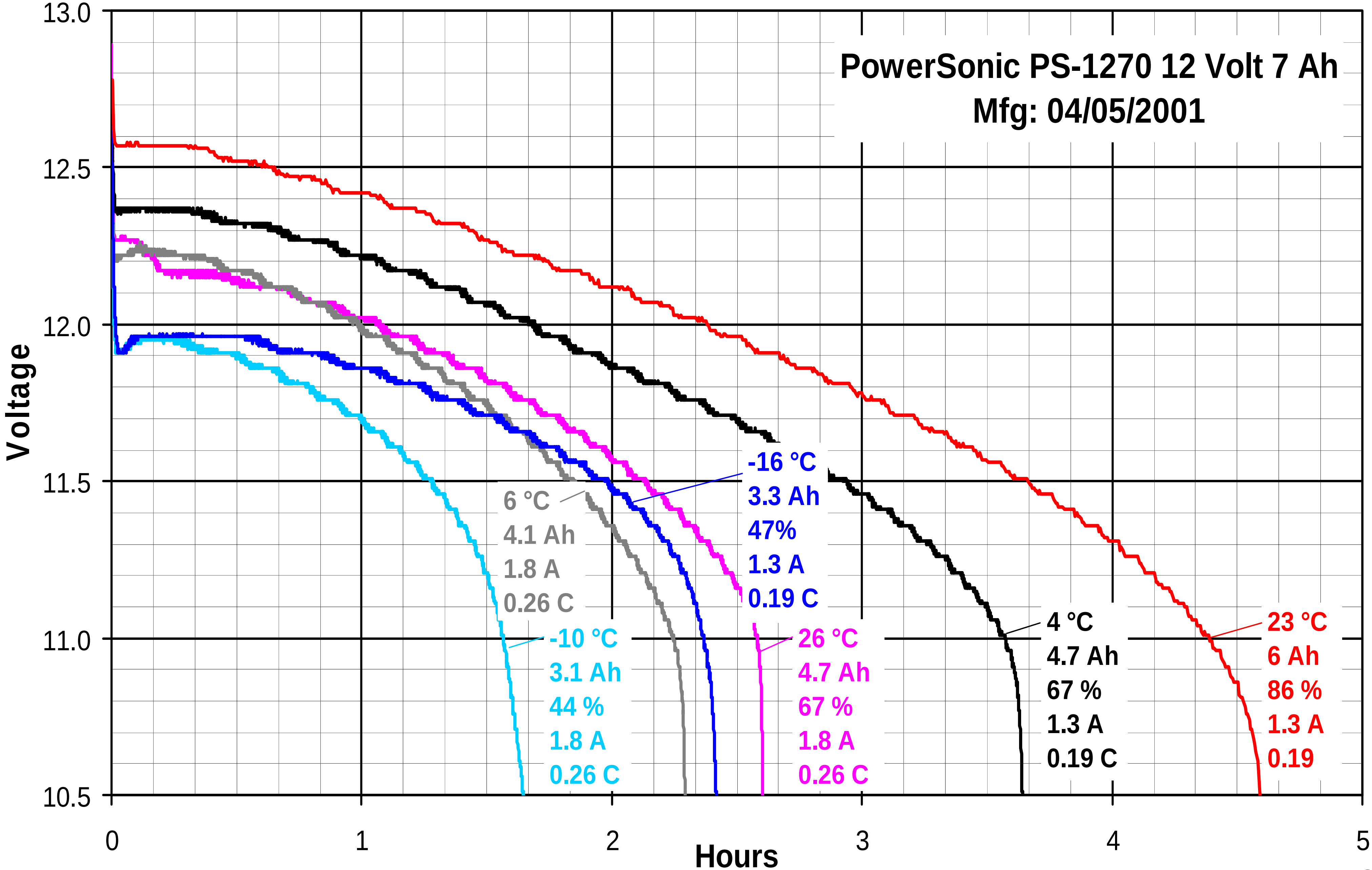
12 Ah AGM Battery



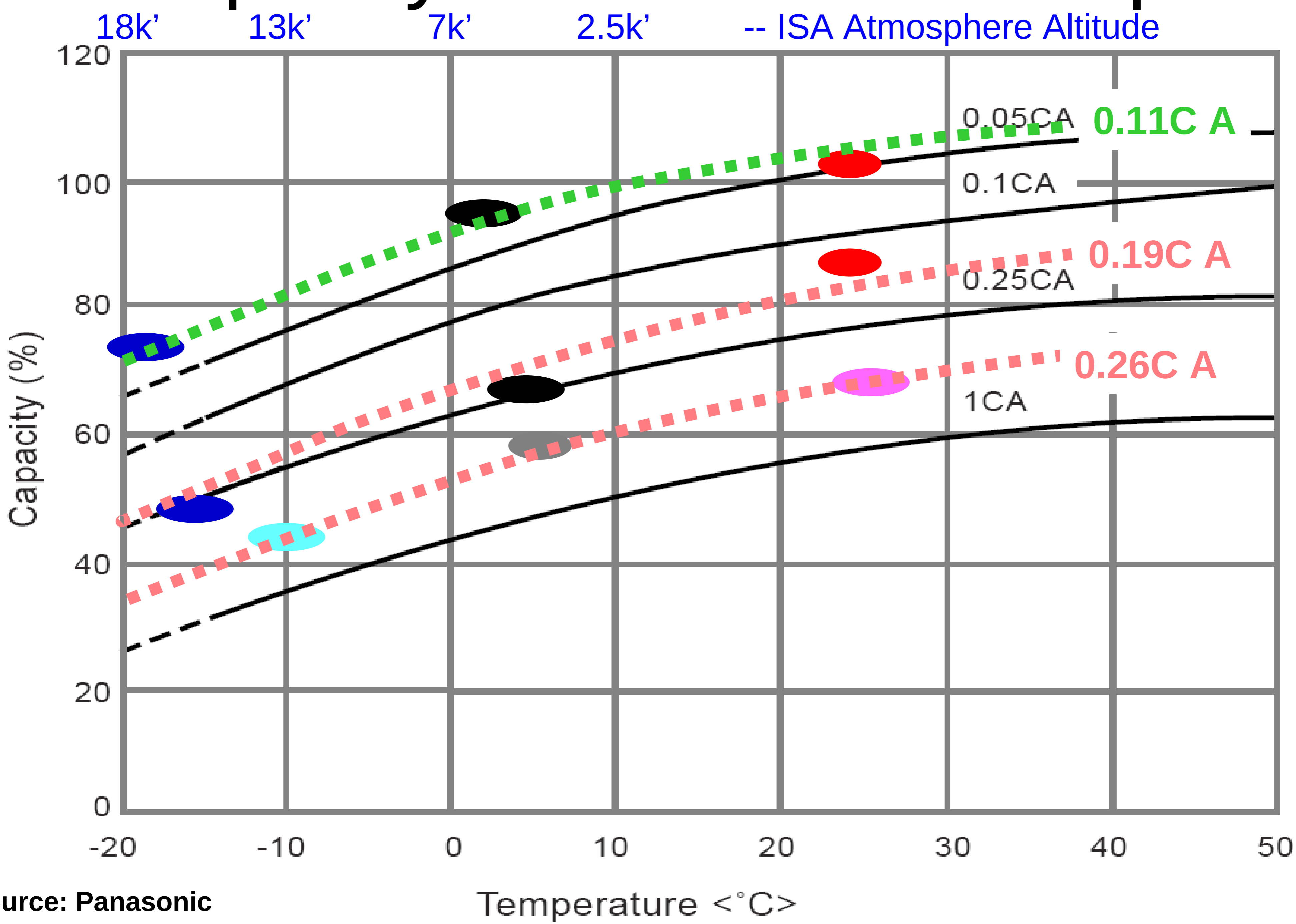
Older 7 Ah AGM battery



Older 7 Ah AGM battery



Capacity vs. Load vs. Temp.



Source: Panasonic

Battery Sizing

- Load sizing – current draw
  - From equipment specs or measurements
  - Transponders hard to measure
  - Don't forget PDAs and other toys
- Load sizing – time
  - Maximum and typical flight duration
- Select battery to account for battery effects
  - Current, temperature, age
- How much redundancy do you want?
  - What if a battery dies, forget to charge, etc.

DG-303 Power Budget

Component	Amps	Duty	Comments
Becker AR-4201 VHF Radio	**0.09**	100%	
Standby	0.07	89%	Measured 0.07 A full squelch
Transmit	1.30	1%	Measured 1.3 A
Receive	0.11	10%	Measured 0.11 A max volume
Transponder and Encoder	**0.49**	100%	
Becker 4401 175 W Transponder	0.40		Manufacturer specs.
ACK A-30 Altitude Encoder	0.09		From E. Greenwell, more if colder
Cambridge 302 Computer	**0.24**	100%	
Audio tone on loud	0.31	50%	Measured 0.31 A max audio tone
Audio tone off	0.16	50%	Measured 0.16 A no audio tone
Cambridge 303 Display	**0.01**	100%	From specs 10mA at 12 V
iPAQ hx-4700 PDA - charged	**0.39**	200%	
CF GPS + Backlight full bright	0.26	40%	Measured
CF GPS + Backlight off	0.18	160%	Measured
Goddard SPS-1	**0.01**	100%	

Total amps	**1.2**	A		
Flight time	**8.0**	h		
Total Ah load	**9.8**	Ah		
20% derate for battery aging	**11.7**	Ah	**# Batteries**	**Comments**
7 Ah battery, 0.21 C at 0 °C	**18.1**	Ah	**2.6**	Derated to 65%
7 Ah battery, 0.21 C at -20 °C	**23.5**	Ah	**3.4**	Derated to 50%
12 Ah battery, 0.12 C at 0 °C	**15.7**	Ah	**1.3**	Derated to 75%
12 Ah battery, 0.12 C at -20 °C	**21.4**	Ah	**1.8**	Derated to 55%

Transponders

- Load = Transponder + Encoder (heater)
- Take care with measurements
  - Transponder needs to be interrogated
  - Encoder heater
  - e.g. ACK A-30 0.42 A for ~minute then ~0.06 A

Transponders			
Manufacturer	**Model**	**Amps**	**Street Price**
Becker	4401-2-175 Mode C 175 W	0.40	$1,800
	4401-2-250 Mode C 250 W	0.50	$2,000
	BXP-6401-2 Mode S 150 W	0.43	$2,500
	BXP-6401-1 Mode S 250 W	0.43	$3,900
Microair	T2000 FSL Mode C 200W	0.15 to 0.20	$1,600
Altitude Encoders			
Manufacturer	**Model**	**~Amps -20 ºC**	**street price**
Ameri-King	AK-350	0.24	$160
ACK Technologies	A-30	0.09	$180
Trans-Cal	SSD-120-30A	0.10 (0.4 Eric?)	$250

PDAs (and Garmin 496, …)

- HP iPAQ hx-4700 example
  - Standard battery: 1.8 Ah at 3.7 V (0.5 Ah at 12 V)
    Full charging ~ 2 hours ~0.4 A to 0.6 A at 12 V
  - Extended battery: 3.6 Ah at 3.7 V (1.1 Ah at 12 V)
    Full charging ~ 4 hours ~0.4 A to 0.6 A at 12 V
- Keep PDAs/GPS batteries charged!
- PDA/GPS turned off can drain glider battery
- Backlights ~ 0.1 A or more

HP iPAQ hx-4700 –12 V Equivalent Currents					
	PDA Off	PDA On			
		Backlight Off		Backlight On	
GPS CF Card		Off	On	Off	On
Charged	0.09 A	0.14 A	0.18 A	0.22 A	0.26 A
Charging	0.44 A	0.49 A	0.53 A	0.57 A	0.61 A

DG-303 Power Budget – Flat PDAs

Component	Amps	Duty	Comments
Becker AR-4201 VHF Radio	**0.09**	100%	
Standby	0.07	89%	Measured 0.07 A full squelch
Transmit	1.30	1%	Measured 1.3 A
Receive	0.11	10%	Measured 0.11 A max volume
Transponder and Encoder	**0.49**	100%	
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Cambridge 303 Display	**0.01**	100%	From specs 10mA at 12 V
iPAQ hx-4700 PDA - charged	**0.99**	200%	
CF GPS + Backlight full bright	0.44	40%	Measured
CF GPS + Backlight off	0.51	160%	Measured
Goddard SPS-1	**0.01**	100%	

Total amps	**1.8**	A		
Flight time	**8.0**	h	4	Hrs. to charge PDAs
Total Ah load	**12.2**	Ah		
20% derate for battery aging	**14.6**	Ah	**# Batteries**	**Comments**
7 Ah battery, 0.21 C at 0 °C	**22.5**	Ah	**3.2**	Derated to 65%
7 Ah battery, 0.21 C at -20 °C	**29.2**	Ah	**4.2**	Derated to 50%
12 Ah battery, 0.12 C at 0 °C	**19.5**	Ah	**1.6**	Derated to 75%
12 Ah battery, 0.12 C at -20 °C	**26.6**	Ah	**2.2**	Derated to 55%

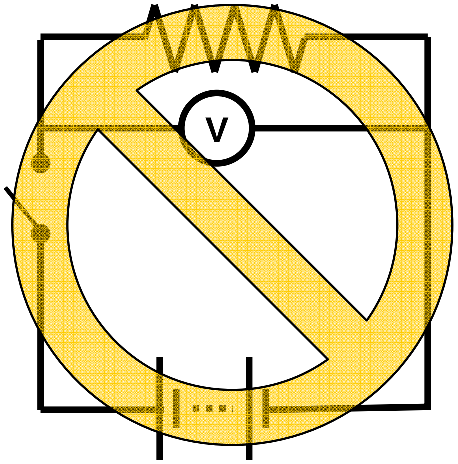
Turn & Bank/Attitude Indicator

- Spin up times (~minutes for mechanical gyros)
- Cold LCD displays and cold gyro spin up be issues
- TruTrak Pictorial Turn & Bank
  - 0.15 A
- Mid-Continent
  - Turn Coordinator 3 1/8” – 14 V 0.28A
  - 4200, 2” AI – 14 V, 1.4 A start, 0.51A run
  - 4300, 3 1/8” AI – 14 V 1.4 A start, 0.6 A run
- Sporty’s Backup Artificial Horizon
  - 14 V, 1.0 A start, 1.2 A running
- MGL Stratomaster Maxi-Single Attitude Indicator
  - 8-18V 0.14 A / 0.22 A Display+IMU (backlight off / on)
- Dynon 10A EFIS
  - 14 V 0.9 A max, 0.6 A typical

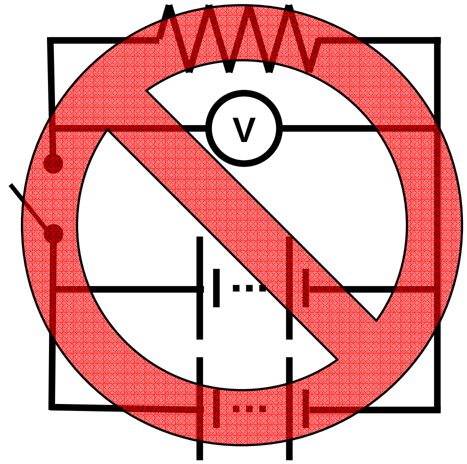
Glider Power Distribution

- What batteries will or can be made to fit?
- How much rewiring is needed?
- Must use master switch
- Redundancy – what if:
  - Battery open circuits, cell shorts,…
  - You forget to charge a battery?
- Flexibility is good
- Simplicity is good – club pilot proof
- Need a voltmeter across load
  - Accurate digital voltmeter
  - Built into some avionics/instruments

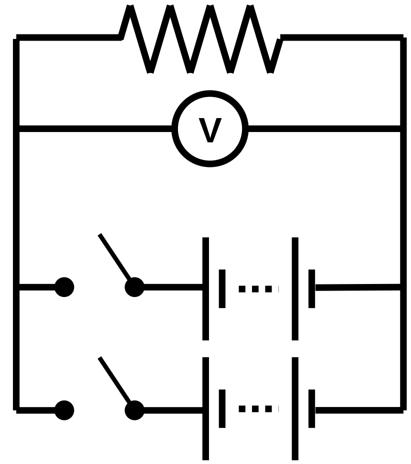
Glider Power Distribution



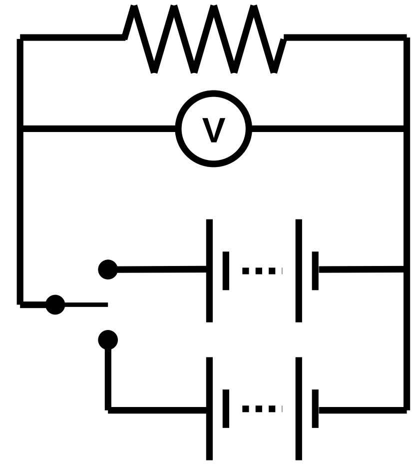
No Redundancy.



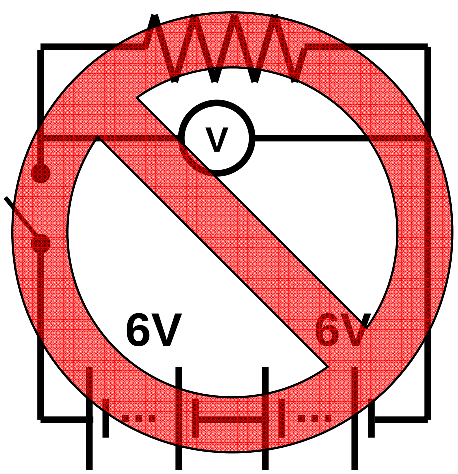
Less redundancy than single battery.



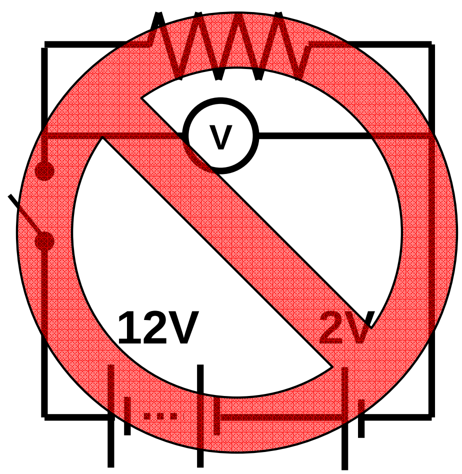
Can avoid glitches switching batteries.



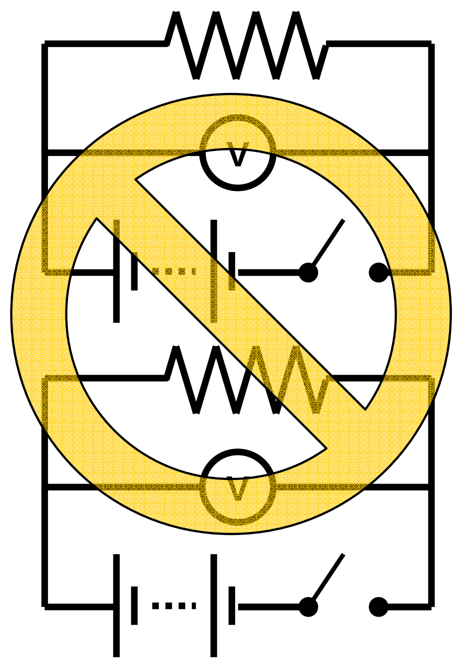
Simple. Idiot proof.



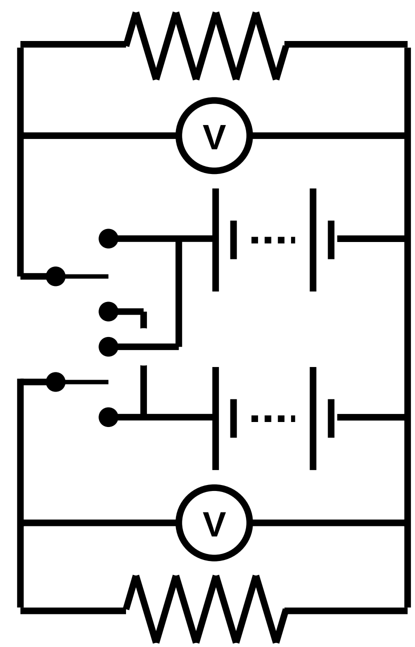
No redundancy. Bad idea all round.



Less redundancy. Bad idea all round.



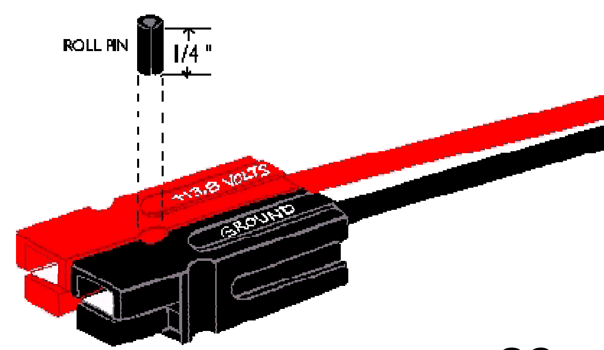
Not flexible. Weak redundancy.



Flexible. Too Complex?

Circuit Breakers & Connectors

- Circuit breaker on the battery
  - e.g. Klixon 5A, 7277-2-5, ~$20
- Anderson PowerPole connectors
  - Standard shells, 15, 30, 45 & 75 A crimp blades
  - www.andersonpower.com
  - Standardized orientation – ham radio
  - www.races.net/powerpole.phtml
  - Williams Soaring
  - www.powerwerx.com
  - www.westmountainradio.com



Battery Life

- Batteries don’t die they are killed!
- Batteries are consumables
  - Few years life at most
- Relatively low cost
- Purchase from a brand name manufacturer
- Purchase where there is a good turnover
- Check date / date codes
- Should come with charge > 11 V
- Record usage start date on battery

Battery Health Problems

- Sulfation
  - Deep discharge
  - Being left at low SOC
  - High temperatures
- Positive grid corrosion, flaking, dendrite growth
  - Over voltage, over charging, wrong or faulty charger
  - High temperatures
- Loss of electrolyte
  - Over voltage, over charging, wrong or faulty charger
  - Decompression of cell, faulty valve, mishandling
  - High temperatures esp. during charge
- Cell poisoning
  - Impurities cause poisoning over time

Date Codes

- Date either plain marked or a code
  - Most manufactures are using plain dates
- Month is indicated by a single letter
  - 'A' for January, etc.
  - 'I' is skilled to stop confusion with numeral one
- Year is indicated by a single digit
- E.g. D3 means April 2003
- Written month first, or year first
  - E.g. D3 or 3D

Battery Tests

- Open Circuit Voltage (V_{OC})
  - Can find gross faults
  - Can give very approximate SOC
  - Does not measure capacity
  - Does not measure internal resistance

- Discharge test
  - Accurately measures battery capacity
  - Can estimate time remaining in flight
  - Heavy discharge looks for early weakness
- Other testers and analyzers

RC Model Power Meters

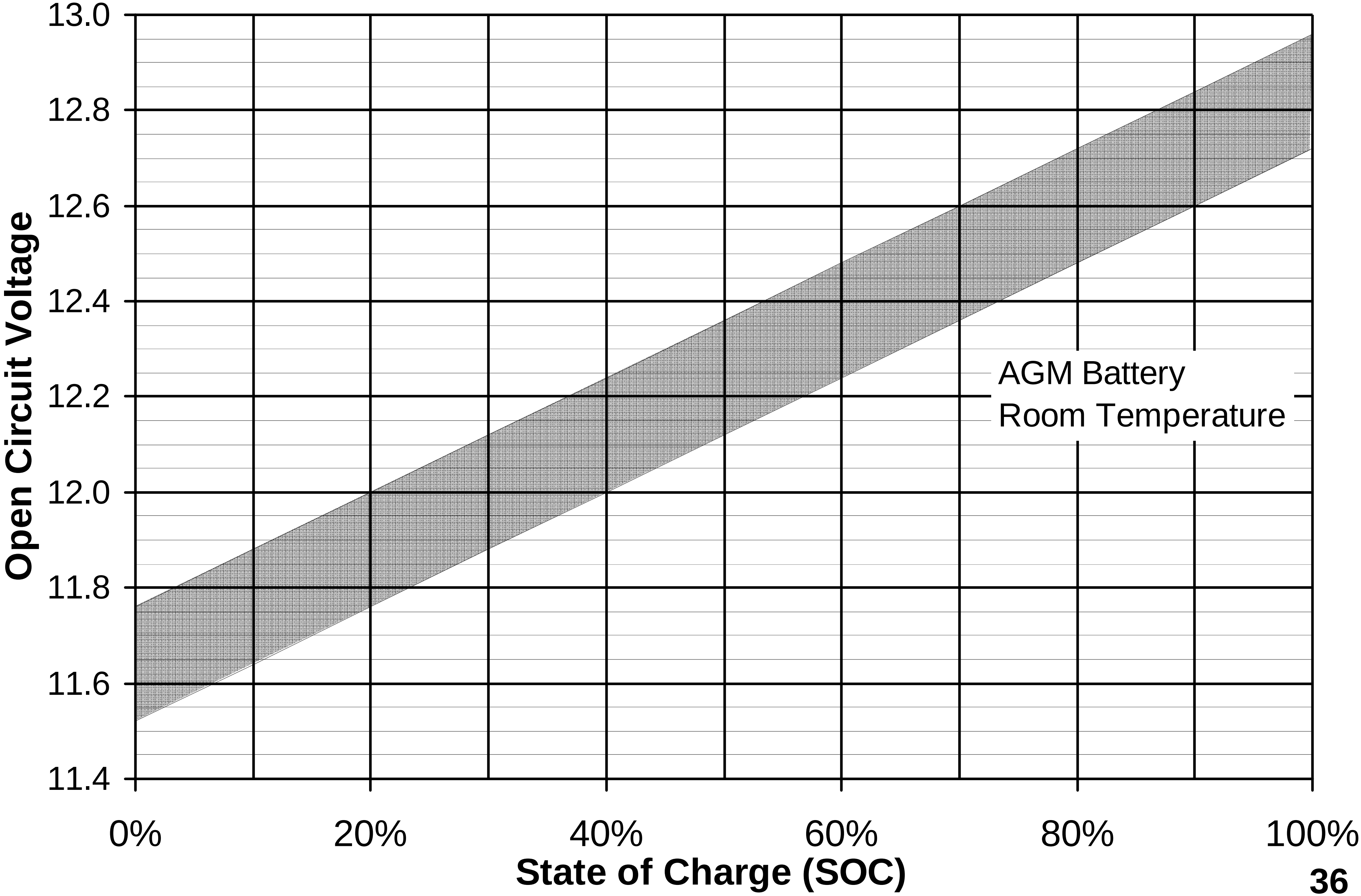
- RC Electronics
  - Watt's Up? ~$55
- Medusa Research
  - Power Analyzer–II ~$60
  - Power Analyzer Pro ~$90
- AstroFlight
  - Super Whattmeter ~$45

Open Circuit Voltage - V_{OC}

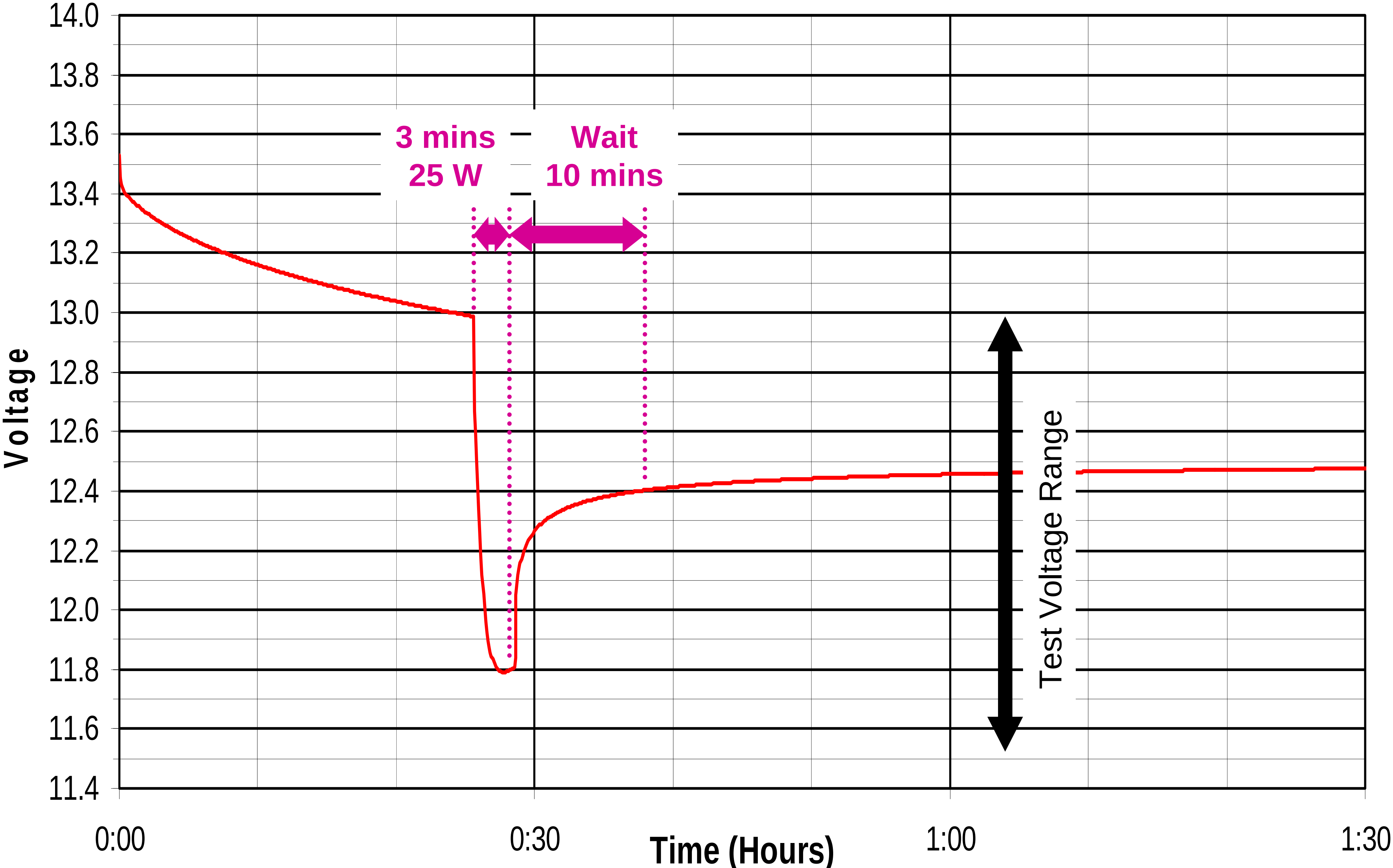
1. Remove surface charge
   – Wait up to 12 hours, or…
   – ~25 W bulb for ~ 3 minutes, wait ~10 minutes
2. Measure V_{OC}
   – Digital multimeter or power meter
   – Use chart to calculate SOC

- Test measures SOC only
  – Faulty battery can have 100% SOC but much less capacity than specifications

V_{OC} vs. SOC


13.0
12.8
12.6
12.4
12.2
12.0
11.8
11.6
11.4
Open Circuit Voltage
AGM Battery
Room Temperature
0%
20%
40%
60%
80%
100%
State of Charge (SOC)

Surface Charge



Discharge Test – Constant R

- Calculate or measure glider current
- Test close to this current (< ±50%)
  - Light bulb or power resistor
  - Combine, series or parallel if needed
  - Check actual current
- Cut-off voltage from spec sheet
- Measure V during discharge
- Calculate run time at glider battery load
- Also do test at high current (~1 to 0.5 C A)
  - Need headlight or big resistor, different cut-off

Example Test – Constant R

- Light bulb simulating 1.3 A load

  $P = I \times V = 1.3 \times 12 = 16$ W

  Use two 25 W tail light bulbs in <u>series</u>

- Resistor simulating 1.3 A load

  $R = V / I = 12 / 1.3 = 6.7\ \Omega$

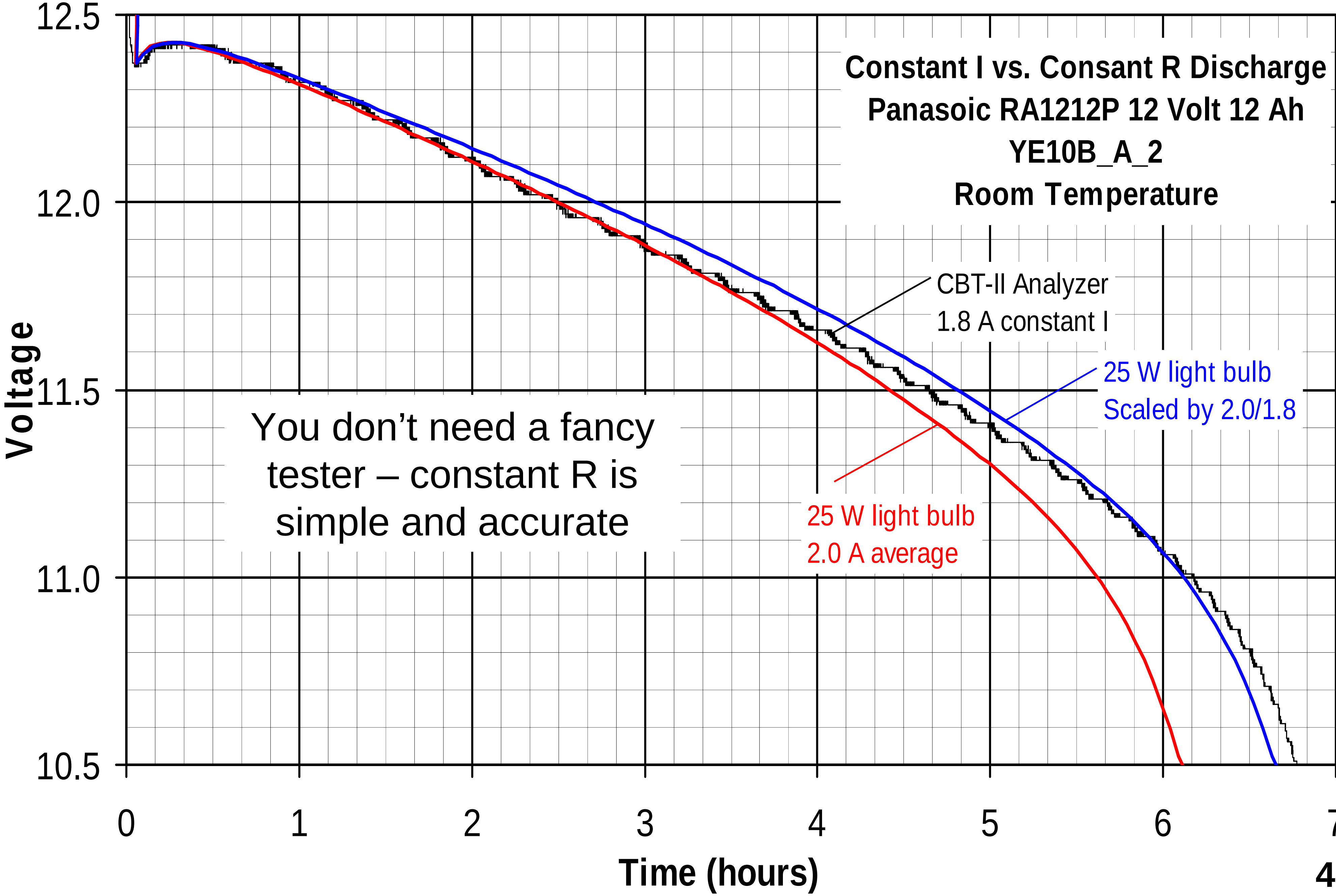
  P = 15 W (want several times this rating)

  Use a 10 Ω, 65 W power resistor

- 50 W car headlight or two in parallel

  $I = P / V = 50 / 12 = 4.2$ A per light

Constant R Discharge



Discharge Test – Constant I

- Most accurate discharge test
- Usually done with battery analyzer
  - Convenience more important than accuracy
- Suitable for club, FBO, repair station, etc.
- Automated battery analyzer
  - West Mountain Radio CBA-II (~$120) www.westmountainradio.com
  - Vencon UBA4 (~$600) www.vencon.com

AGM Battery Chargers

- Need lower charge rate than flooded
- Charge voltages may differ from flooded
- Smart chargers are dumb
  - Do not know battery size, do not adjust
  - Look for bulk current ~ C/5 to C/10
- Two or three charging steps
  - Bulk → Absorption → Float or Bulk → Float
  - Different names, same thing

Selecting a Charger

- Current in range C/5 to C/10
- Charge time
  - Bulk+Absorbtion, 90% SOC ~ 1.2 x C / I hours
  - Float ~ few hours to 100% SOC
- Designed for AGM (flooded may be OK)
- Described as 2 or 3 stage, with “float”
- Status lights – float, errors, etc.
- Fault protection
  - Reverse battery, short, and over temperature
- Temperature compensation
- Cut off timer (most don’t have this)

Chargers

- Some good chargers
  - Xenotronix HPX-30, 2 A, ~$80
  - Xenotronix HPX-10, 0.8A, ~$40 (wall wart) www.xentronix.com (OEM'ed by PowerSonic)
  - VDC BatteryMINDer Plus, 1.3 A, ~$50 (wall wart) www.vdcelectronics.com
  - Deltran BatteryTender Plus, 1.25 A ~$50 (not wall wart)
  - Deltran BatteryTender Jr., 0.75 A ~$30 (wall wart)
  - www.batterytender.com
- Only charge one battery at a time
- Carry spare fuses for charger
- Provide adequate cooling
- Replace DC connectors with PowerPole

RC Model Chargers

- Better than battery to battery or AC inverter
- Very sophisticated & high performance
  - Some do not charge lead acid batteries
  - Make sure you have correct settings
  - Select charger or program for I ~ C/5 to C/10
- Great Planes Triton
  - www.greatplanes.com
  - www.towerhobbies.com
- Graupner Ultramat
  - www.graupner.de
  - www.hobby-lobby.com

Solar Panels on Glider

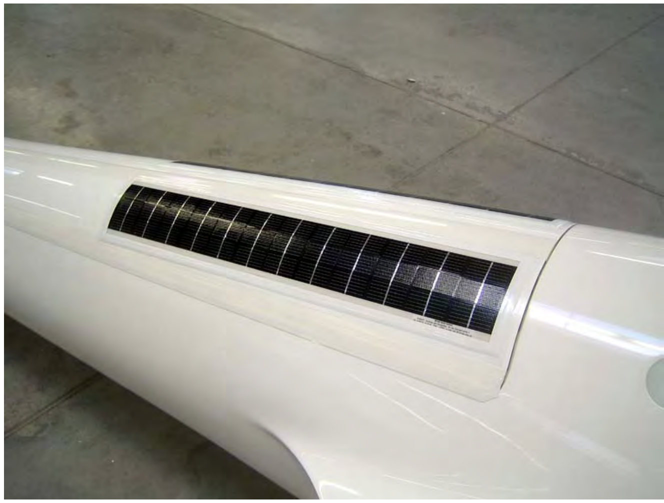
- Beware of over simplistic & optimistic specs
- As assist to battery
  - ~0.5A to 1.5 A *peak* currents
- As a battery charger in air and on ground
- Sunlight up to ~1 kW/m^2 at equator
- Technology
  - Amorphous silicon panels ~6-10% efficient
  - Crystalline silicon panels ~ 30% efficient
- Important for cold flights
  - ~10% efficiency increase from +20 °C to -20 °C

Solar Charge Controllers

- Not needed on < 5 W panels
- PWM (Pulse Width Modulation) better than shunt
  - e.g. MorningStar – www.morningstarcorp.com
- MPTT (Maximum Power Point Tracking) best
  - e.g. Solar Converters – www.solarconverters.com
- Look at self consumption specs
- Hermetic sealed?
- May not charge very flat battery (~< 8 V)
  - SunGuard will not, SunKeeper and SunSaver will
- Don’t use low voltage disconnect (LVD) in glider

Strobl-Solar Solar Panels

- www.strobl-solar.de
- From glider manufactures or add on kits
  - Includes charge controller, etc.
- Bonded to fuselage or engine bay door
- Semi-flexible, monocrystalline cells
  - Appears 2-4 times the best amorphous cells
- 7.5 W per module
  - 660 x 108 x 1.3mm
- 2 modules 15 W peak, 0.86 A peak
- 3 modules 22 W peak, 1.2 A peak
- 4 modules 30 W peak, 1.6 A peak
- ~$1,500-$3,000 for kit
- CA / NV guess ~ 1-4 Ah/day/module



Summary

- Do an energy budget for your glider
- Look after your batteries
  - Avoid deep discharge
  - Never leave a battery flat
  - Keep batteries cool
  - Use a smart charger, sized for batteries
- Batteries are consumables
- Test your batteries
  - VOC test
  - Discharge test batteries at start of season
  - For capacity and heavy discharge for health

The End

Lange Antares 20E

- 9,020 ft climb
- 728 ft/min
- 123 nm saw tooth range
- 42 kW (57 hp) motor
- 72 x Saft VL41M Li-Ion
- 2.1”diam x 8.7” length
- 39 Ah at 3.6 V per cell
- ~ 840 Ah 12 V total
- 76 kg = 13% of 600 kg
- ~1,500 cycles, ~11 years
- 8 hour charge