LV2 Electrical Power System Analysis v1.0

March 31st, 2001

Bus Voltage

We assume a 12V nominal system bus, since most of the radio equipment we have used and will most likely use in the future use 12V. Note that "nominal" usually implies an actual bus voltage of 9V - 15V given voltage droop during discharge and voltage rise during charging. Although we could use higher voltages to reduce I^2R losses or reduce weight in power distribution cables, the tradeoffs for our system small since the power consumed by the entire system is only the 10s of watts.

Load Analysis

The flight profile can be divided into four categories, each of which can be assigned a power level given the required functionality. Since the launch tower will be charging the batteries and running the systems before the flight, it is assumed that the batteries are fully charged before entering the first stage.

Flight Stage	Description	Power Requirement
Pre-Launch	15 minute check of all systems while on the launch tower, as well as countdown and ignition. All systems on.	Full
Launch to Apogee	From ignition until apogee - simulations give 1 minute. All systems on.	Full
Apogee to Touchdown	From the deployment of parachutes at apogee until the vehicle touches down on the ground - predicted to be about 30 minutes. Since the most important flight stage is completed, many of the instruments could go into low power mode, e.g., the IMU and the communications system.	Medium
Touchdown to Recovery	From touchdown on the ground until actual recovery by the recovery team and any necessary transportation back to the operations center. While this time could be as little as 5 minutes, it could be a matter of hours if there is a problem recovering the vehicle. An estimate of 4 hours should cover all but the worst case scenarios. Since the vehicle would be sitting on the ground at this point, only the communications system would need to be active (as a RF location beacon).	Low

Conservative (but not necessarily worst case) power requirement estimates for the different flight stage are:

Subsystem	Power (W)
High speed bi-directional 2.4GHz Communications system	10
2.4GHz Amateur TV transmitter	10
Flight Computer/ Communications Computer	4
GPS/IMU	5
4 Sensor Modules	2
2 Igniter Modules	1
Total	**32W**

Full Power (2.7A)

Subsystem	Power (W)
High speed bi-directional 2.4GHz Communications system (10% DC)	1
2.4GHz Amateur TV transmitter	10
Flight Computer/ Communications Computer (10% DC)	0.4
GPS/IMU (IMU Off, 10% DC)	0.4
4 Sensor Modules	2
2 Igniter Modules (Off)	0
Total	**13.8W**

Medium Power (1.1A)

Subsystem	Power
High speed bi-directional 2.4GHz Communications system (50% DC)	5
2.4GHz Amateur TV transmitter (off)	0
Flight Computer/ Communications Computer (50%DC)	2
GPS/IMU (off)	0
4 Sensor Modules (off)	0
2 Igniter Modules (off)	0
Total	**7W**

Low Power (0.6A)

This profile gives a total power and energy requirement of:

State	Power Level	W	A	Hrs	Wh	Ah
Pre-Launch	Full	32	2.67	0.25	8	0.67
Launch to Apogee	Full	32	2.67	0.017	0.544	0.045
Apogee to Touchdown	Medium	13.8	1.15	0.5	6.9	0.58
Touchdown to Recovery	Low	7	0.58	4	28	2.33
Totals	-	-	-	**4.767**	**43.444**	**3.625**
Rounded Totals				**~5**	**~45**	**~4**

Battery Pack Considerations

This theoretical flight profile requires a 12V, 3.75Ah or greater battery pack that can source a continuous 2.7A. What constitutes an acceptable battery pack? In order of important, some considerations are:

Mass: Given the overall avionics system weight limitation of 2.27kg (5lbs) and the direct tradeoff of altitude to weight, we clearly need a battery system which is as light as possible. Perhaps a reasonable target would be between 10% - 25% of the total system weight (0.23kg (0.5lbs) - 0.57kg (1.25lbs)). This mass requirement obviously rules out chemistries with low energy densities, like lead acid (although for comparison, lead acid batteries are included in this analysis).

Maximum Current Draw: The pack must be able to handle 2.7A loads for up to approximately 16 minutes. Given a 4Ah battery pack, 2.7A translates to a discharge rate of approximately 1.5C which may be conservatively rounded up to a 2C discharge rate. This rules out many types of chemistries with very high internal resistances; for example, $Li/SOCl_2$ (Lithium Thionyl Chloride) batteries, "memory backup" type primary Lithium cells, and Zinc Air.

Primary vs. Secondary Batteries: There is a strong pull towards using secondary battery chemistries because of their convenience. Primary batteries must be strung into packs and replaced every launch, and as importantly, after every test. Primary batteries also usually do not require a power management system, which means the state of the batteries and their health is not necessarily known and bad cells may not be discovered until it is too late.

Acceleration Loads: No data was found on how acceleration loads affected the different types of battery chemistries. One could hypothesize that more liquid-like battery chemistries (e.g., PB Acid, NiMH) would be more affected than the more solid chemistries (e.g., primary Lithium batteries).

Ambient Pressure and Temperature: Eventually, the battery pack should be able to withstand near vacuum so that the vehicle does not need to be pressurized. Temperature is not as important a consideration since insulation along with the thermal mass of the batteries and their internal resistance will contribute to a stable if not increasing temperature. Primary Zinc Air cells are not included in this analysis because they are roughly equal in energy and power densities to primary Lithium cells and because they require air pressure and air circulation to operate.

Pack Construction and Volume: Some consideration should be given to how much volume the pack occupies and what methods (e.g., soldering, welding, etc.) the cells may be connected. Because there seems to be plenty of room in the current avionics module (4.75" x 18"), this does not seems to be an important consideration.

Battery Pack Chemistry Analysis

The chemistries evaluated here are: Primary Lithium, Lithium Ion, Nickel Metal Hydride, and Lead Acid.

Primary Lithium Cells

Peak Current Requirement	Marginal to unacceptable
Charging Requirement	NA
Capacity	Ok
Weight	Excellent (~200g)

Examples:

Duracell Lithium Manganese Dioxide (http://www.duracell.com/OEM/Primary/Lithium/lithium_manganese_prod.html)
DL123A 3.0V @ 1.4Ah @ 17g = 4 * 3 = 12 cells per pack = 204g (.45lbs)
Max Con. Current = 1.2A, Max Pulse current = 5A
247Wh/Kg

Panasonic poly-carbonmonofluoride (http://www.panasonic.com/industrial_oem/battery/battery_oem/chem/lith/cylin.htm)
DK#P144-ND, pg595,$13.70/ea
3V @ 5Ah @ 42g = 4 cells in pack = 168g (0.37lbs)
Max continus current = 500mA, max pulse = 1A
357Wh/kg

Lithium Ion

Peak Current Requirement	Ok to Marginal
Charging Requirement	More difficult
Capacity	Ok
Weight	Ok (~500g)

Examples:

Valence-Technology Lithium Ion Polymer Manganese (http://www.valence-tech.com/products/Series44/44MDL_1.htm, (888) 825-3623)
Model 44 series: 3.8V @ 4.36Ah @ 121g = 4*1 = 4 cells in pack = 484g
Max current: ??
136Wh/kg

Panasonic Li Ion (http://www.panasonic.com/industrial_oem/battery/battery_oem/chem/lithion/lithion.htm, 877-726-222 Dennis Malac)
Max current: 3.4A on spec sheet - Dennis says 2C is about the limit.
CGR18650HG: 3.7V @ 1.8Ah @ 42g = 4*3=12 cells in pack = 504g (1.1lbs)
158Wh/kg

Gold Peak Industries Li Ion (http://www.gpbatteries.com/industrial/batteries/LiIon/index.htm)
3.7V @ 1.7Ah @ 43g = 4*3 = 12 cells in pack = 516g (1.1lbs)
146Wh/kg

Sanyo Li Ion Batteries (http://www.sanyobatteries.net/NEWliionspecs.html)
3.7V @ 1.6Ah @ 41g = etc.
144Wh/kg

http://tjtechnologies.com/Products/products.html#lithium

Carbon anode Li Ion = 320mAh/g (limit 370mAh/g)
Tin anode Li Ion = 420mAh/g (limit

http://www.hyb-battery.com

http://www.ness.co.kr/prod/prod.htm

http://www.duracell.com/ - no info on rechargeable.

ALSO: PACKS AVAILABLE FROM MOLTECHPOWER.COM

Nickel Metal Hydride

Peak Current Requirement	Excellent
Charging Requirement	Ok
Capacity	Ok
Weight	Ok to Marginal (~ +600g)

Examples:

Panasonic HHR450A (http://www.panasonic.com/industrial_oem/battery/battery_oem/images/pdf/hhr450a.pdf)
(Panasonic NiMH: http://www.panasonic.com/industrial_oem/battery/battery_oem/chem/nicmet/nicmet.htm)
1.2V @ 4.2Ah @ 60g = 10 cells in pack = 600g (1.3lbs)
84Wh/kg

Panasonic HHR650D (http://www.panasonic.com/industrial_oem/battery/battery_oem/images/pdf/hhr650d.pdf)
DK#P019-ND, Pg592,$16.30/ea
1.2V @ 6.5Ah @ 170g = 10 cells in pack = 1.7kg (3.7lbs)
45Wh/kg

Energizer NH50 (http://data.energizer.com/datasheets/library/rechargeables/consumer/nimh/nh50.pdf)
1.2V @ 2.2Ah @ 73g = 10 * 2 = 20 cells per pack = 1.46kg (3.21 lbs)
Great User's Manual: http://data.energizer.com/batteryinfo/application_manuals/nimh_application_manual.htm

Sealed PB-Acid

Peak Current Requirement	Excellent
Charging Requirement	Easy
Capacity	Ok
Weight	Unacceptable (2kg)

Examples:

DK#P077-ND, pg 594, $19.35
12V @ 5Ah @ 1.93kg = 1 battery = 1.93kg (4.25lbs)
31Wh/kg

Design Guidelines:

The above analysis leads to a rough guideline for trading off power consumption (in watts) and weight. The guideline, however, depends on for how long the power is drawn and on the battery chemistry.

In general, a device consumes power for:

Device on only under Full Power	0.25 hours (16 minutes)
Device on under Full and Medium	0.75 hours (46 minutes)
Device on continuously	5 hours

Battery Chemistries (based on the above survey):

Primary Lithium	= 247 Wh/kg
Lithium Ion	= 158 Wh/kg
NiMH	= 84 Wh/kg
Pb Acid	= 31Wh/kg

Thus, adding an extra 1W of power consumption adds the following weight:

Chemistry / Load times	**Full Only**	**Full & Medium**	**Continuously**
Primary Lithium	2g	4.1g	20.2g
Lithium Ion	3.3g	6.43g	31.6g
NiMH	6.2g	12.1g	59.5g
Pb Acid	16.6g	32.8g	161g

Conclusions

Based on this analysis, we chose a 13.2V 4AH Lithium Ion battery pack. Although heavier than a primary Lithium battery, the advantages of recharging the pack - especially when the vehicle is on the launch tower before launch - outweighed the weight savings of a primary Lithium pack.