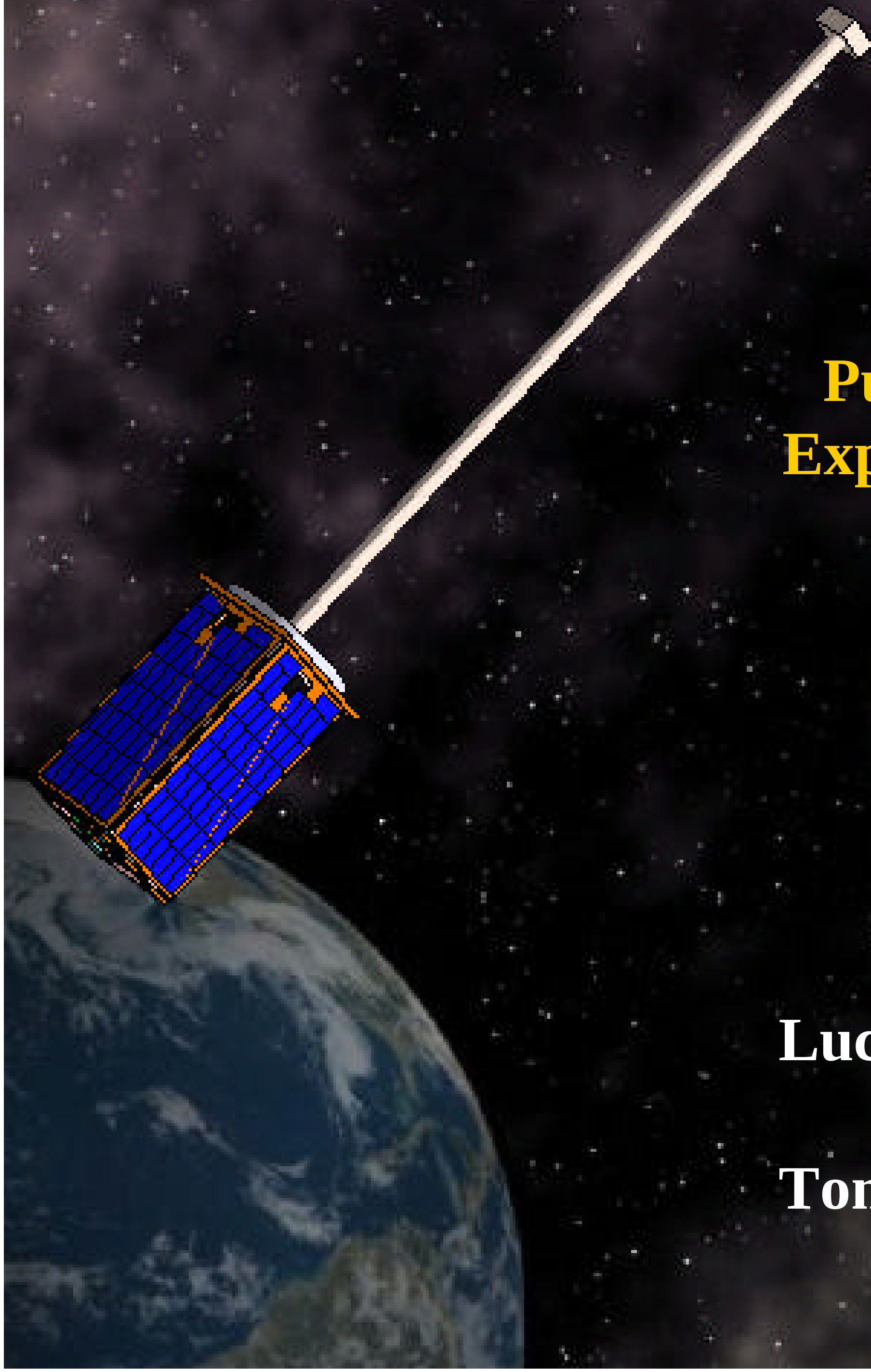


PuTEMP

Purdue University Thermodynamic Experimental Microgravity Platform

Chris Burnside
Javier Lovera
Luca Bertuccelli
Stephanie VanY
Tom Martin
Tim Sanders

Mass Budget

- Mass Budget

  For Total Mass = 40kg

  - Attitude 26%
  - CD&H 7%
  - Payload 3%
  - Power 3%
  - Structure 52%
  - Thermal ?%

Mass Budget

Payload - 1.4kg
SPT 0.5
SPT Fluid 0.7
Insulation 0.2
Heating Strips ?
Thermisters ?

CD&H – 2.9 kg
Antenna 1.4
Transmitters 0.3
Downlink Trans. 0.4
Receiver 0.2
Uplink Receiver 0.3
Modem 0.1
CPU 0.2
Bus 0.2

Structure – 21 .5kg
Frame 5.0
Shelf 0.5
(4) Side Panels 0.8
(2) End Panels 0.1
SPT Support Struc. 7.0
Launch Integration 8.0 (includes additional plate on bottom for Ariane 5)

Power – 1.6
Batteries 1.0
Solar Panels 0.4

Attitude – 1 0.7 kg
Magnetometor1.0
Variable as Tip Mass
(Hor.) Magnetic Torquer 0.3
(Ver.) Magnetic Torquer 0.2
Sun Sensors 1.2
Gravity Boom 2.2
G-G Box 1.8

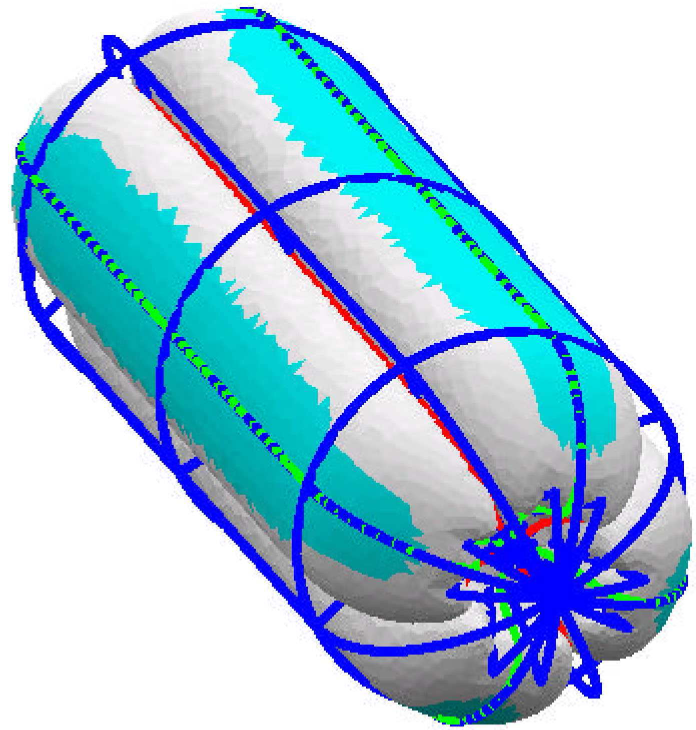
Power Budget

Subsystem	Component	Quantity	Power (Watts)	Voltage (V)
CD&H	CPU	1	0.10	1
	Bus	1	0.00	2
	Antenna	2	7.00	
	Transmitter	1	0.08	V
	Receiver	1	0.08	o
	Modem	1	0.10	l
	Uplink Receiver	1	0.08	t
	Secondary Receiver	1	0.80	s
Payload	A/D Converters	4	2.02	12
	Heater	4	49.50	12
	Sensors	24	4.03	12
Attitude	Magnetometer	1	0.10	5
	Magnetic torquers	2	1.10	5
	Sun Sensor	4	0.40	12
	Total Power (Watts):		**65.38**	
	Total Capacity (W-Hr):		**16.34**	

- Operating modes are presented in Appendix C

Payload Principle Investigation

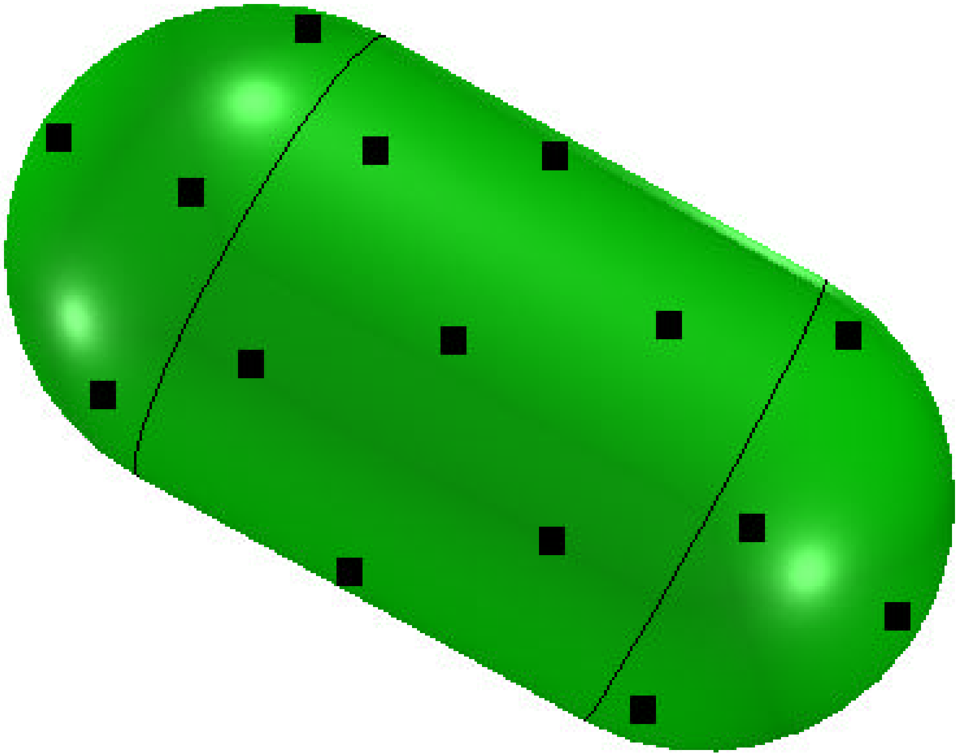
- Develop refined methods for propellant gauging techniques
- Primary experiment: propellant level measurement by measuring temperature change
- Experiment consist of :
  - Measure time needed for 10 degree change in temperature of surface of tank



Courtesy of Dr. Collicott

Payload

- Primary features
  - 5 in x 10 in
  - 25 % fluid fill volume
  - Purified water
  - 22 sensors located on the surface of the tank

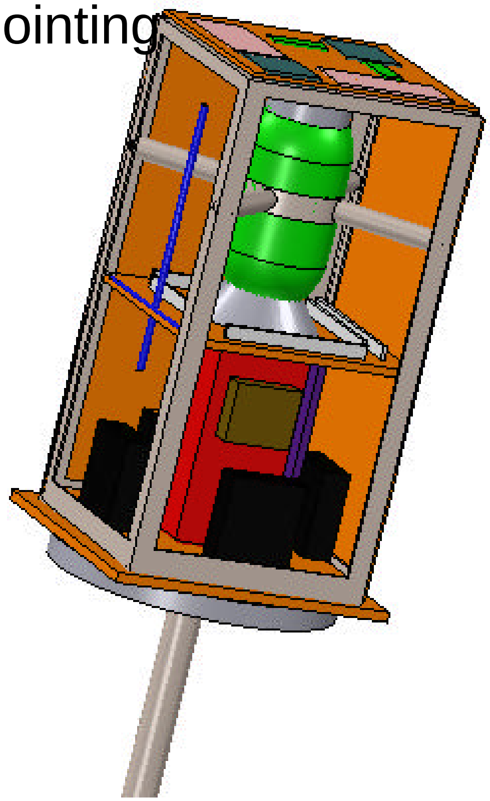


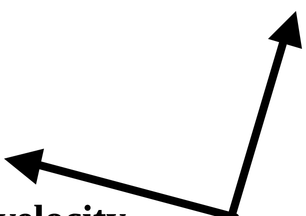
Structural Design

- Major Structural Components
  - Frame (off the shelf)
    - 7072 Aluminum Angle Iron: 2.54cm x 2.54cm x 0.635cm
  - Composite Material
    - Reinforced Carbon Fibre or Kevlar
    - Capabilities of Purdue

Structural Design

- Design Layout Requirements
  - Gravity Gradient
    - Axi-Symmetric - Smallest MOI Nadir Pointing
    - CD&H - Nadir Pointing





EPS Overview

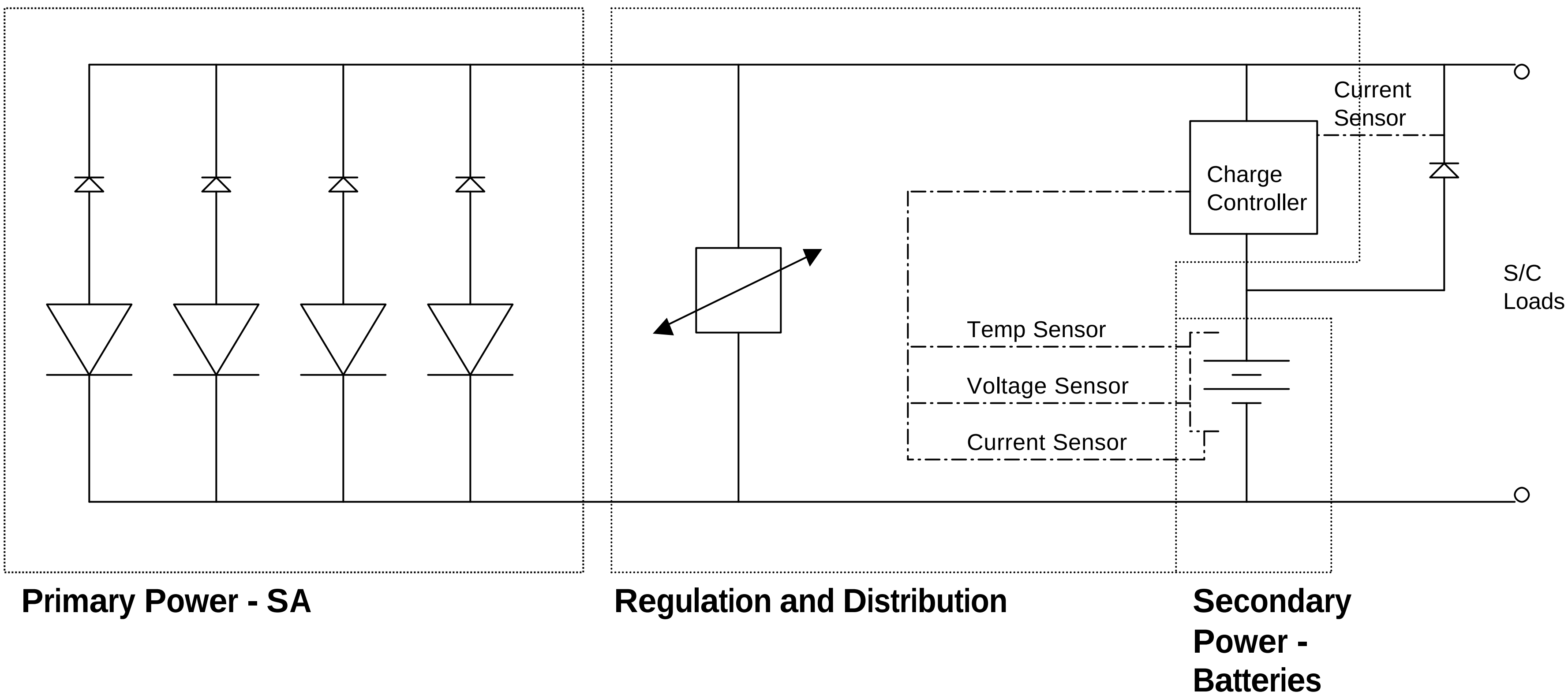
- Based on payload needs, the EPS does not require the capability to recharge the batteries every orbit
- Basic EPS design is Direct-Energy-Transfer (DET)
- A DET system using shunt regulators provides the following advantages:
  - Efficient – Only power not needed by the S/C is dissipated
  - Simple/Reliable – Shunt regulators are self-controlled
  - Low Cost – Shunt regulators are inexpensive devices
- Bus voltage will be quasi-regulated with charge voltage being fixed and discharge voltage fluctuating based on battery DOD.

PuTEMP

Purdue University Thermodynamic Experimental Microgravity Platform

EPS Overview

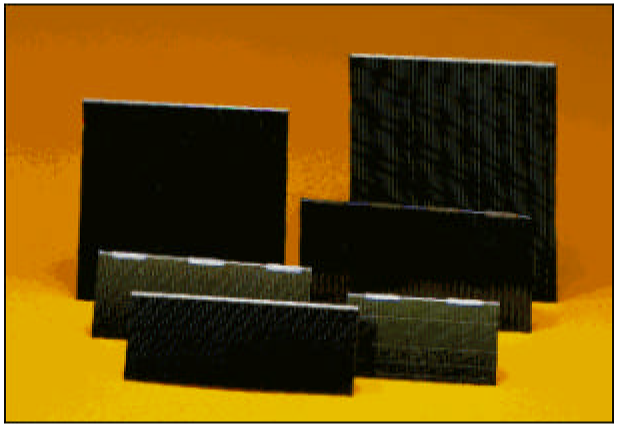
- Below is a schematic of the basic EPS design:



EPS Primary Power

- Overall SA efficiency was not considered a primary design driver based on EPS requirements
- Although silicon cells are less efficient and more susceptible to radiation damage, they are roughly 45% lighter and considerably more cost-effective
- K4702 Silicon Solar Cells from Spectrolab were chosen

(per side)	Series Cells	Parallel Panels	EOL Total Voltage (V)	EOL Total Power (W)
Spectrolab GaAs Triple-Junction	7	7	15.22	43.01
Emcore GaAs Triple-Junction	6	8	14.71	51.65
Spectrolab Silicon	26	2	14.69	23.53



EPS Secondary Power

- Secondary power was sized to provide all power required during peak power operation (Experimental Mode) and to provide sufficient voltage for all S/C loads
- Sanyo Cadnica NiCd battery technology was chosen for secondary power:
  - Flight tested in numerous small satellites
  - Commercially available, the Cadnica batteries are inexpensive
  - Cycle life (<1000) is not a concern for PuTEMP allowing a DOD of 60%
  - Rectangular packaging of cells
- Thermal control of batteries is critical to their performance

Attitude Determination & Control

- Attitude Determination

  - 4 Sun Sensors
    - 2 Orthogonal Axis Sensors
    - Accuracy: 0.5 deg
    - Product of SSTL

  - 1 Magnetometer
    - 2 Orthogonal Axis Sensor
    - Placed in the Tip Mass of the Gravity Gradient Boom
    - Product of Ithaco Space Systems

Attitude Determination & Control

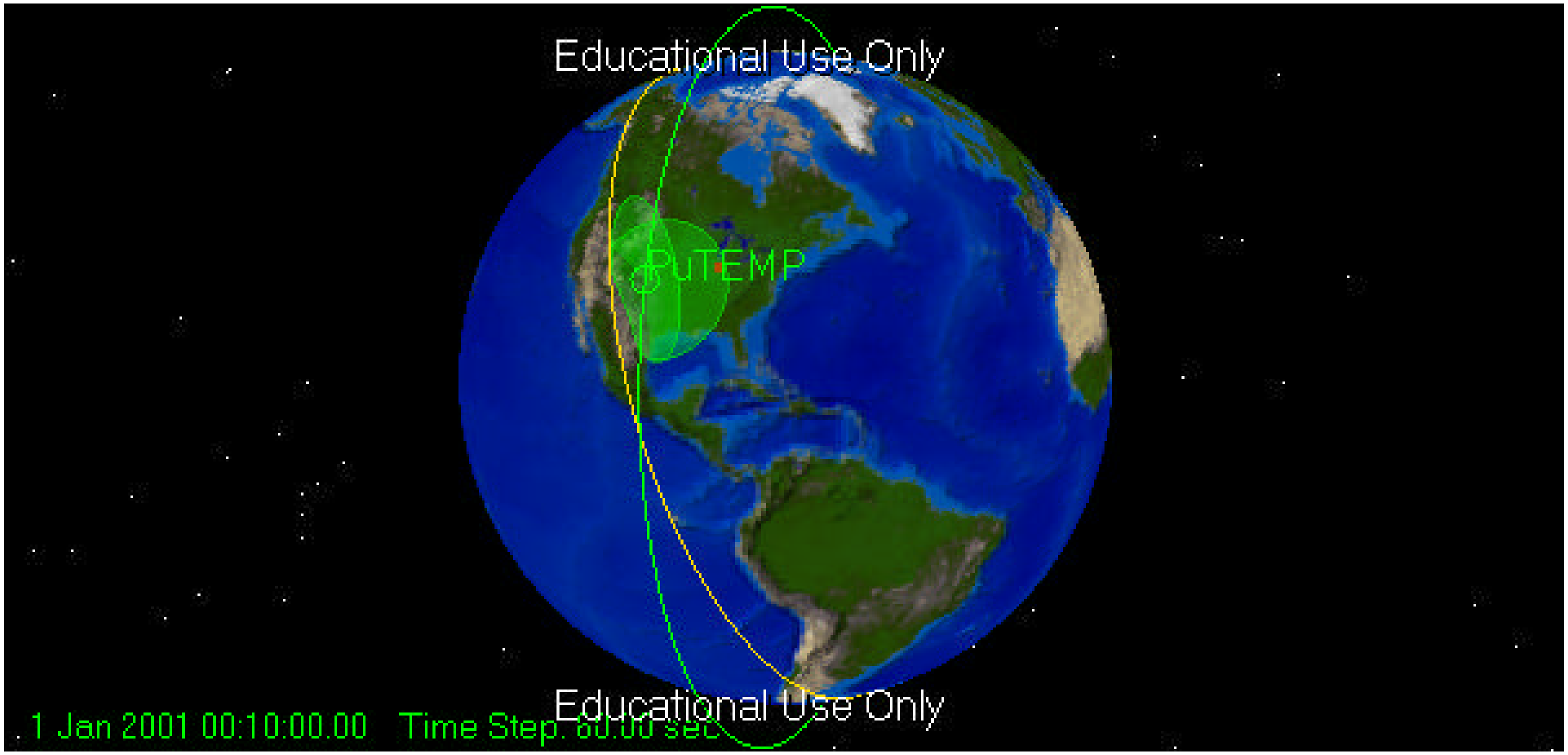
- Attitude Control

  - X m Gravity Gradient Boom with a Y kg Tip mass
    - -Product of Surrey Satellite Technology Ltd (SSTL)

  - Two Magnetic Torquers
    1) Aligned with the Z axis (pointing Nadir) of the S/C
       - 6(mA^2) linear Dipole Moment
    2) Aligned with the Y axis of the S/C
       - 5(mA^2) linear Dipole Moment

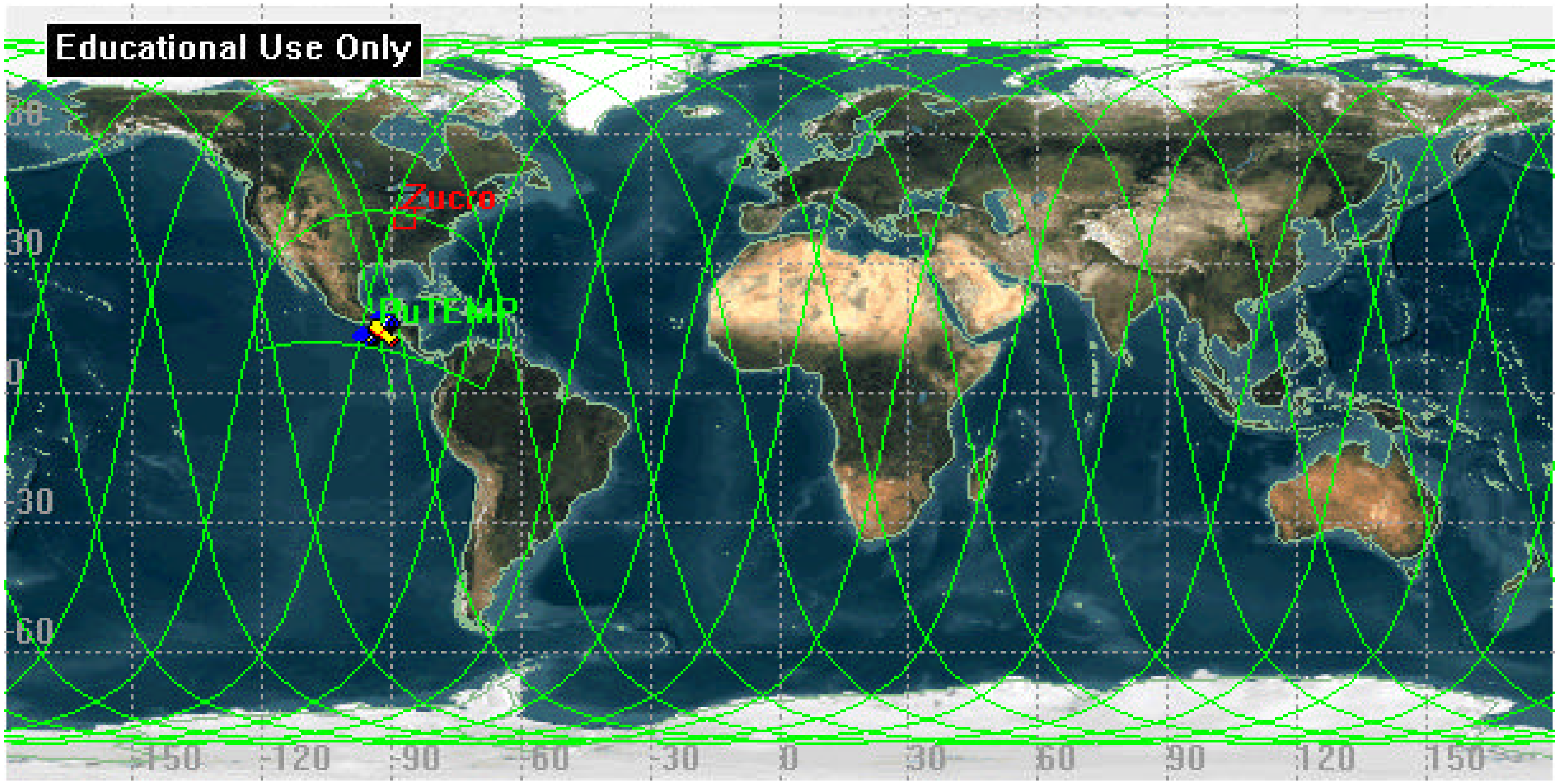
    -Products of Microcosm Space Mission Engineering

Orbit Design



- Orbital parameters:
  - Inclination of 98.7 degrees.
  - Period of 100.9 min
  - Altitude is 800 km.
  - Longitude of ascending node is –90 degrees at start time.

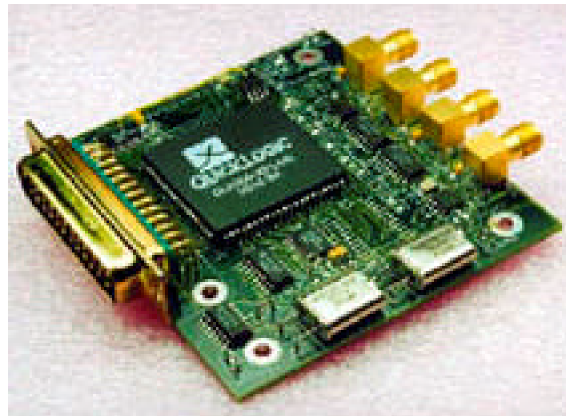
Orbit Design

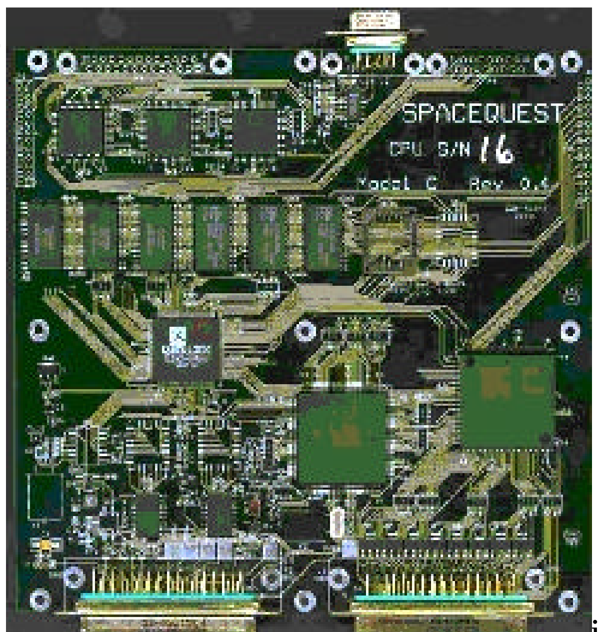


- Ground tracking:
  - Footprint allows a maximum of 14 minutes of line-of-sight time.
  - Up to four passes per day.

CD&H/COM Items

- GMSK Modem
- VHF Receiver
- UHF Transmitter
- UHF Receiver
- Flight Computer
- Patch Antenna





CD&H/COM Preliminary Link Budget

Item	Symbol	Units	Uplink	Downlink
Frequency	f	GHz	.145	.437
XTR Power	P	W	50	2
XTR Power	P	dBW	17	3
XTR Line Loss	Li	dB	-1	-1
XTR Antenna Gain	Gt	dB	12	0
EIRP	EIRP	dBW	28	2

Thermal Subsystem

- Thermal environment set by batteries:
  - Min/max temp
  - (0/45) degrees C
- "Boom" face radiates heat of spacecraft
- Experiment subsystem has MLI surrounding the tank

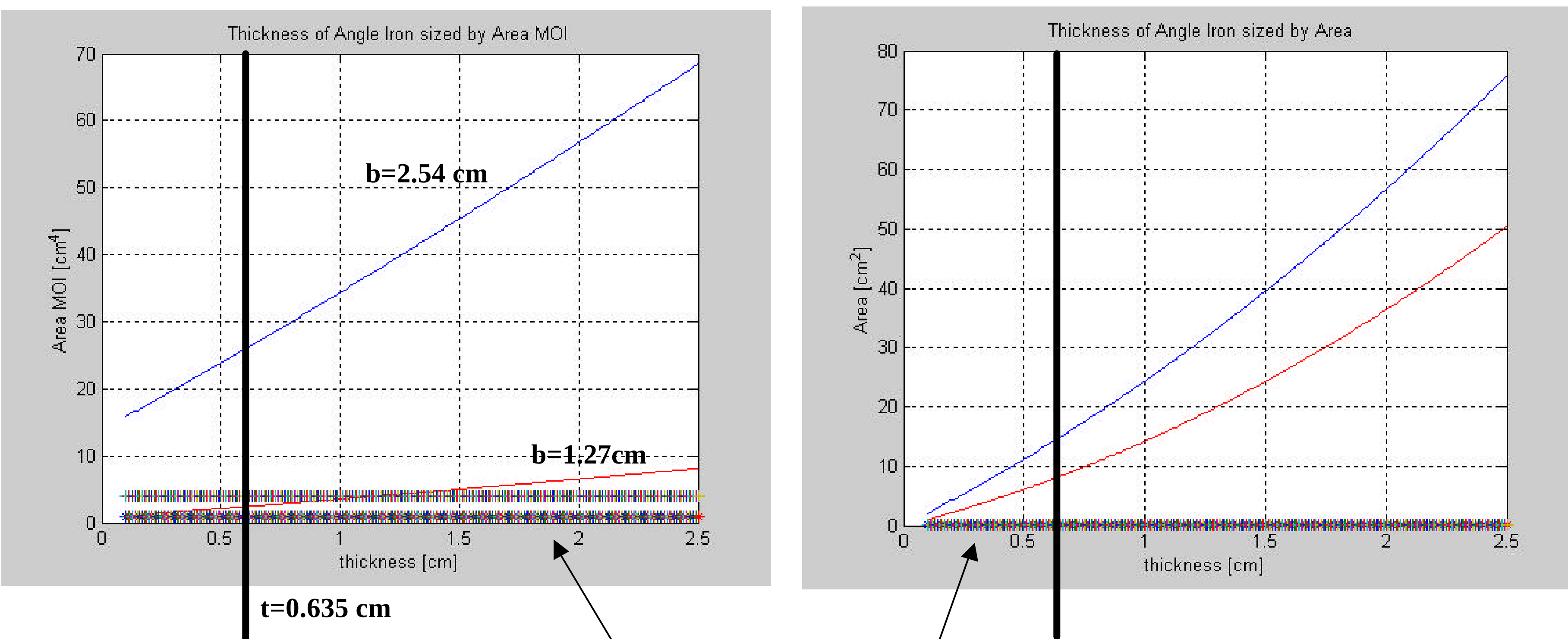
Cost Analysis

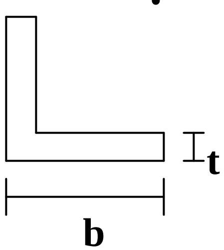
- Parametric cost estimation method
  - Based on Small Satellite Cost Model (SSCM)
  - Fiscal 2000 Dollars
- Why the cost is so high:
  - Expensive Labor
  - Space Qualified Material

- Payload = 1.4 Million
- Spacecraft = 3.5 Million
- Assembly = .5 Million
- Program Level = .8 Million
- Ground Support = .2 Million
- Launch = .2 Million
- Total Mission Cost
- **6.6 Million Dollars**

Appendix A – Structural Sizing

- Load Bearing Structure Sizing





Area MOI and ***Cross Sectional Area***
Required required for Launch Vehicle
(Lateral and Axial)

Appendix A – Safety Limits

- Ariane 5 Launch Vehicle Requirements
- Frequency: Axial 90Hz
  Lateral 45 Hz
- Limit Loads (Transient and Steady State)
  Axial –7.5 to +5.5
  Lateral +/- 6.0

- Margins of Safety for Structure (Aluminum 7072)

$$MS = \frac{\text{Allowable Load Limit}}{\text{Actual Load}} - 1$$

- Ultimate Loading Axial and Lateral : MS = -1
- Axial Compression: MS = -1

Appendix A – Safety Limits

- Maximum Satellite Deflections in Launch Vehicle
- Max Axial Deflections
  .37 cm
- Max Lateral Deflections
  4.1077e-4 cm

Appendix B – EPS Overview

- The EPS is made up of three major components:
  - *Primary Power* – Solar Arrays (SA) convert solar radiation into electrical power for use by S/C loads
  - *Secondary Power* – Chemical batteries store energy provided by the SA and provided additional power when the SA cannot meet S/C loads
  - *Regulation and Distribution* – Energy must be captured, stored and then distributed to other S/C subsystems at appropriate voltage and current levels
- EPS design is driven by payload requirements. Because the payload draws such a large amount of power, the batteries are designed to provide all S/C power while the payload is drawing maximum power. In between experimental runs, the SA will recharge the batteries. No time requirement is specified for battery recharge. As a result, SA size is not critical to overall EPS design.

Appendix B – Operating Modes

- All CD&H components must operate during any operating mode so that the S/C remains in communication

Subsystem	Component	Power (Watts)	Experimental Mode	Recharge Mode	Transmission Mode	Reorientation Mode	Stand-by Mode
CD&H	CPU	0.10	x	x	x	x	x
	Bus	0.00	x	x	x	x	x
	Antenna	7.00	x	x	x	x	x
	Transmitter	0.08	x	x	x	x	x
	Receiver	0.08	x	x	x	x	x
	Modem	0.10	x	x	x	x	x
	Uplink Receiver	0.08	x	x	x	x	x
	Secondary Receiver	0.80	x	x	x	x	x
Payload	A/D Converters	2.02	x	x	x	x	
	Heater	49.50	x				
	Sensors	4.03	x	x (4)	x (4)	x (4)	
Attitude	Magnetometer	0.10				x	
	Magnetic torquers	1.10				x	
	Sun Sensor	0.40				x	
	Total Power (Watts):	**65.38**	**63.78**	**10.919**	**10.919**	**12.519**	**8.23**

Appendix B – Primary Power

- Three different solar cells that were considered for Primary Power

Ideal Performance								
Spectrolabs GaInP2/GaAs/Ge Triple Junction Solar Cells			**Emcore InGaP/GaAs/Ge Triple-Junction Solar Cells**			**Spectrolabs Silicon K4702 Solar Cells**		
Current Density (mp)	0.0149	A/cm^2	Current Density (mp)	0.0162	A/cm^2	Current Density (mp)	0.0368	A/cm^2
Voltage (mp)	2.275	V	Voltage (mp)	2.565	V	Voltage (mp)	0.585	V
Efficiency (mp)	0.251		Efficiency (mp)	0.26		Efficiency (mp)	0.133	
Weight	0.084	g/cm^2	Weight	0.086	g/cm^2	Weight	0.055	g/cm^2
Thickness	0.0175	cm	Thickness	0.0155	cm	Thickness	0.02	cm
Cell Area*	27.5	cm^2	Cell Area	27.5	cm^2	Cell Area*	27.5	cm^2
Solar Cell Requirements			**Solar Cell Requirements**			**Solar Cell Requirements**		
Number of Cells (Series)	7		Number of Cells (Series)	6		Number of Cells (Series)	26	
Individual Panel Voltage	15.925	V	Individual Panel Voltage	15.39	V	Individual Panel Voltage	15.21	V
Total Panel Area Available	1800	cm^2	Total Panel Area Available	1800	cm^2	Total Panel Area Available	1800	cm^2
Individual Panel Current**	0.410	A	Individual Panel Current**	0.446	A	Individual Panel Current**	1.012	A
Individual Panel Power***	6.525	W	Individual Panel Power***	6.856	W	Individual Panel Power***	15.393	W
Number of Panels per Side	7		Number of Panels per Side	8		Number of Panels per Side	2	
Total Power per Side	45.677	W	Total Power per Side	54.850	W	Total Power per Side	30.785	W
*Chosen to Match Emcore Standard Sized Cell								
** = (Cell Area)*(Current Density)								
*** = (Invid. Panel Current)*(Invid. Panel Voltage)								

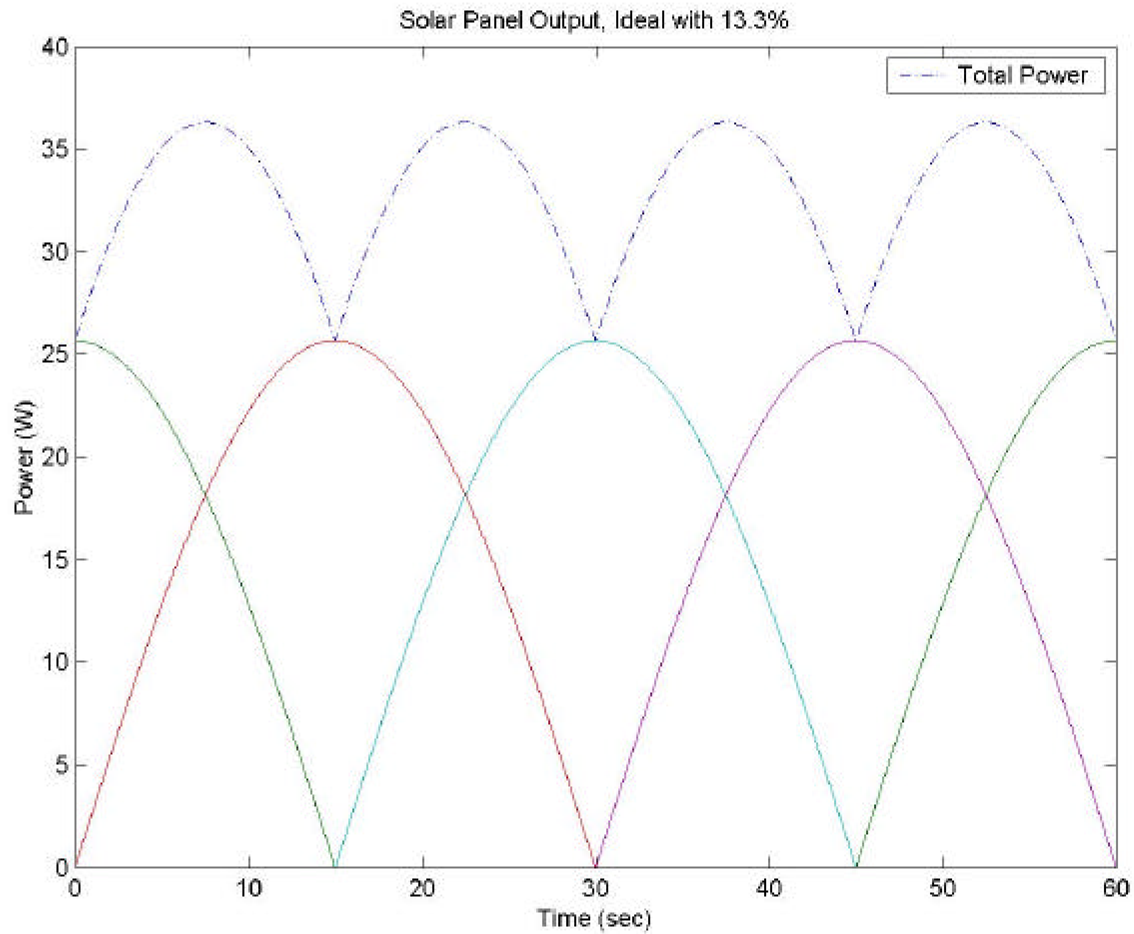
Appendix B – Primary Power

- Below are the voltage and power characteristics once performance degradation from radiation and heat is taken into consideration

Losses										
Radiation (Fluence 10^14 MeV e-)				*Radiation (Fluence 10^14 MeV e-)*				*Radiation (Fluence 10^14 MeV e-)*		
Imp/Imp0	0.99			Imp/Imp0				Imp/Imp0	0.94	
Vmp/Vmp0	0.97			Vmp/Vmp0				Vmp/Vmp0	0.97	
Pmp/Pmp0	0.96			Pmp/Pmp0 (estimated)	0.96			Pmp/Pmp0	0.91	
Temperature (60 degC Operating Temp)				*Temperature (60 degC Operating Temp)*				*Temperature (60 degC Operating Temp)*		
Power Loss	0.9808			Loss^	0.9808			Loss	0.84	
Voltage Loss	15.6946			Voltage Loss^	15.1596			Voltage Loss	15.1396	
Total Power per Side	**43.008**	**W**		**Total Power per Side**	**51.645**	**W**		**Total Power per Side**	**23.532**	**W**
Final Voltage	**15.224**	**V**		**Final Voltage**	**14.705**	**V**		**Final Voltage**	**14.685**	**V**
^Based on Spectrolab losses for Triple-Junction										

Appendix B – Primary Power

- Plot of power vs time as the satellite rotates about its long axes
- These numbers are theoretical based on solar radiation SA efficiency:
  - Input - 135 mW/cm^2
  - SA Eff. – 13.3%
- Minimum power output occurs when one panel is facing the sun



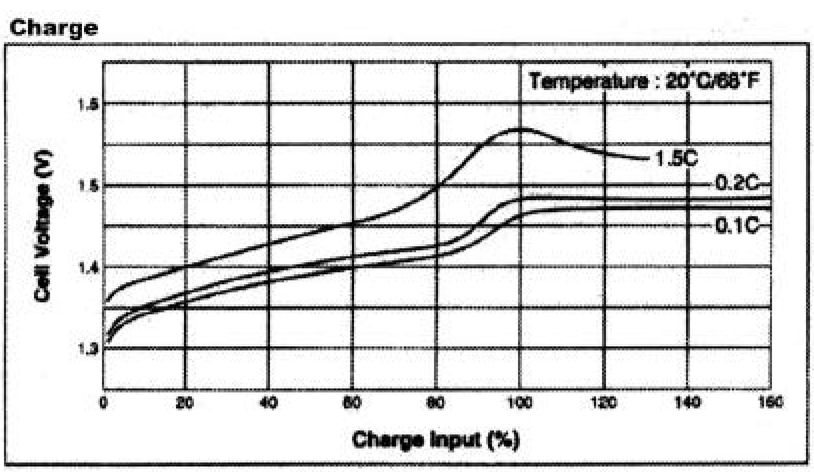
Appendix B – Secondary Power

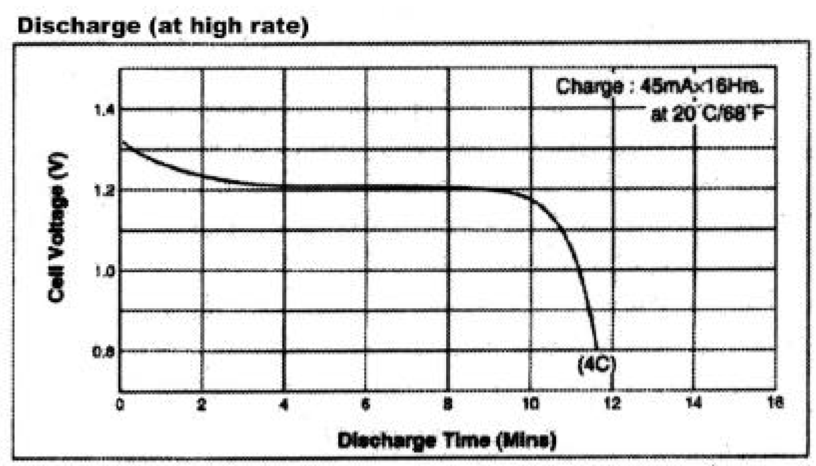
- Sanyo Cadnica KF-B450
  - Five batteries containing 11 cells each
  - Able to provide a capacity of 15.94 W-hr at a nominal voltage of 13.2 V
  - Total Battery weight is 0.935 kg
  - Allowable DOD of 60%

Sanyo Cadnica KF-B450		
Nominal Capacity	0.45	A-hr
Nominal Voltage	1.2	V
Discharge Current	1.8	A (4C)
Charge Temp	0-45	degC
Discharge Temp	(-)20-60	degC
Weight	17	g
Length	4.8	cm
Width	1.7	cm
Thickness	0.61	cm
Battery Requirements		
System Max Power	63.78	W
System Capacity	15.94	W-hr
Number of Cells (Series)	11	
Bus Voltage	13.2	V
Total Capacity (Individual Battery)*	3.564	W-hr
Number of Batteries (Parallel)	5	
Total Capacity**	16.929	W-hr
Total Weight	935	g
Total Volume	273.768	cm^3
*Includes a DOD of 60%		
**Includes a 5% System Loss		

Appendix B – Secondary Power

- Performance curves for a typical KF-B450
  - Higher charge rates require higher peak charge voltages indicating that a slower charge rate is preferable
  - NiCd batteries maintain a relatively constant voltage throughout the majority of their discharge

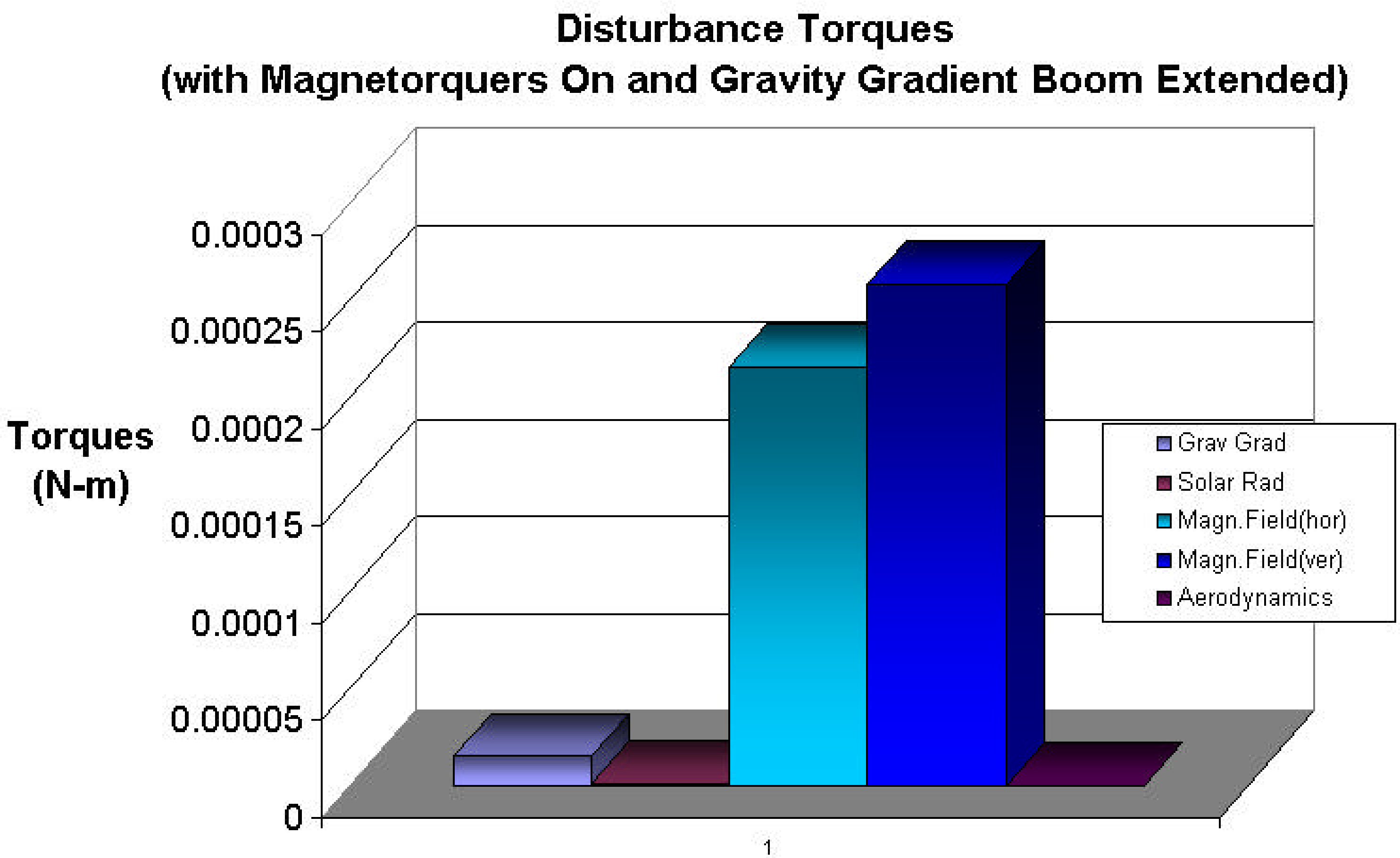




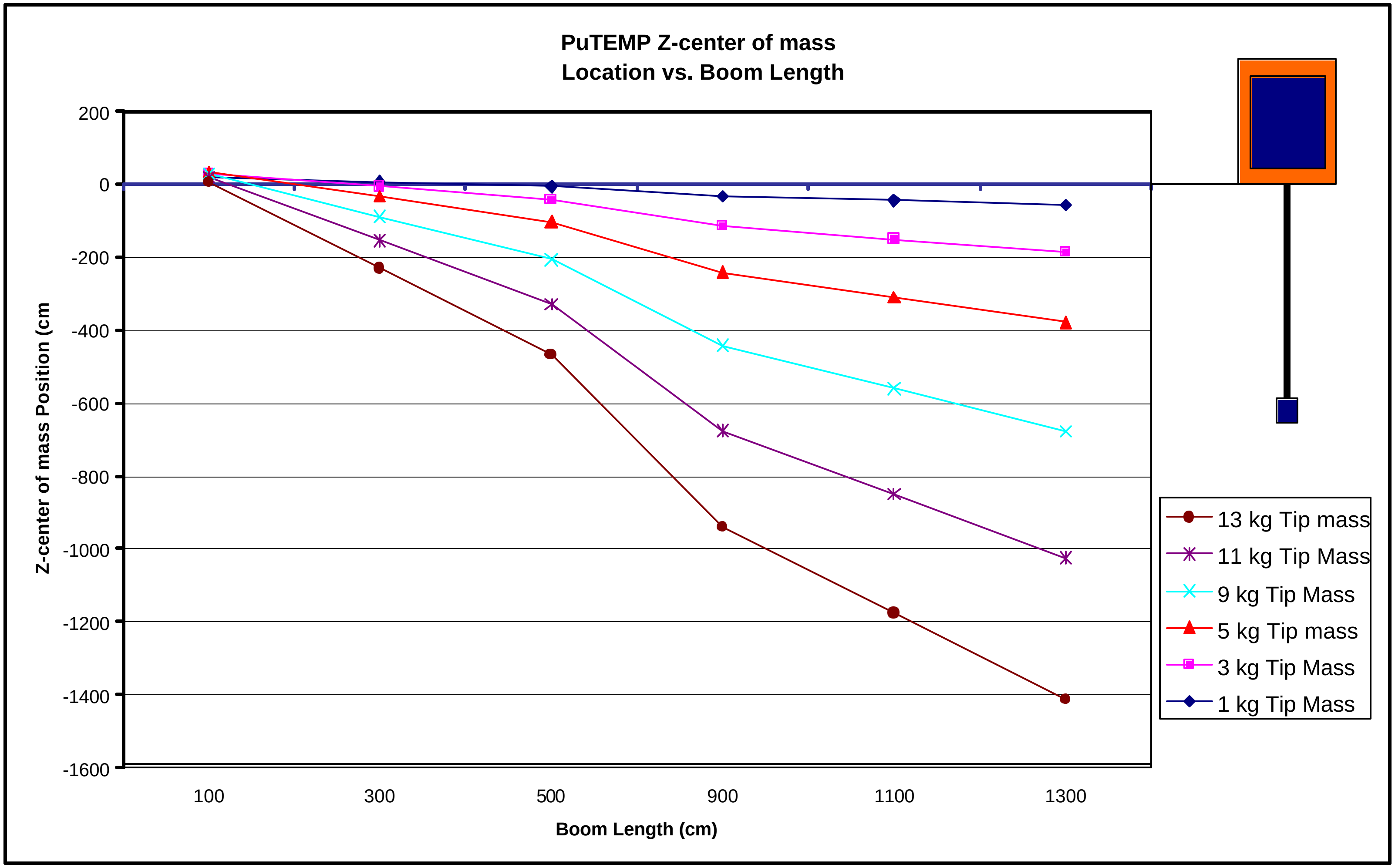
Appendix B – Secondary Power

- Although a nominal voltage of 12V would have been preferable, 13.2V was selected as a compromise between packaging and required capacity
- Batteries must be tested:
  - Voltage characteristics at varying operating temperatures must be captured
  - Cell characteristics must be matched to every cell in each battery to avoid recharging issues

Appendix C – Disturbance Torques



Appendix C – Center of Mass

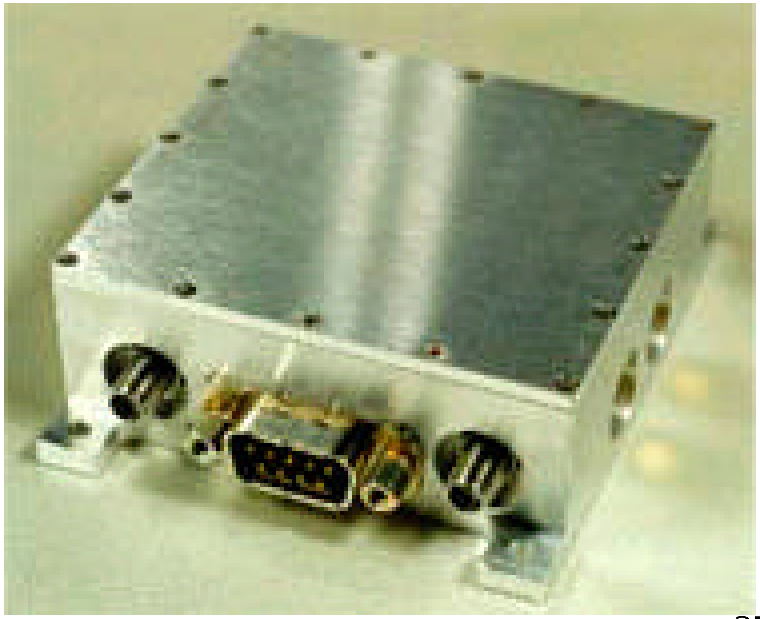


Appendix D - UHF Transmitter

- Frequency range: 400-450 MHz
- Frequency stability: ±5 ppm
- Mass: 300 grams
- Volume: 94 mm x 72 mm x 28 mm
- Power consumption: 77 mW
- Operating Temperature: -10^{o}C to 60^{o}C

Appendix D - VHF Receiver

- Front end noise figure: < 1dB
- Frequency stability: ±5 ppm
- Mass: 198 grams
- Volume: 83 mm x 72 mm x 28 mm
- Power consumption: 77 mW
- Operating Temperature: -10^{o}C to 60^{o}C

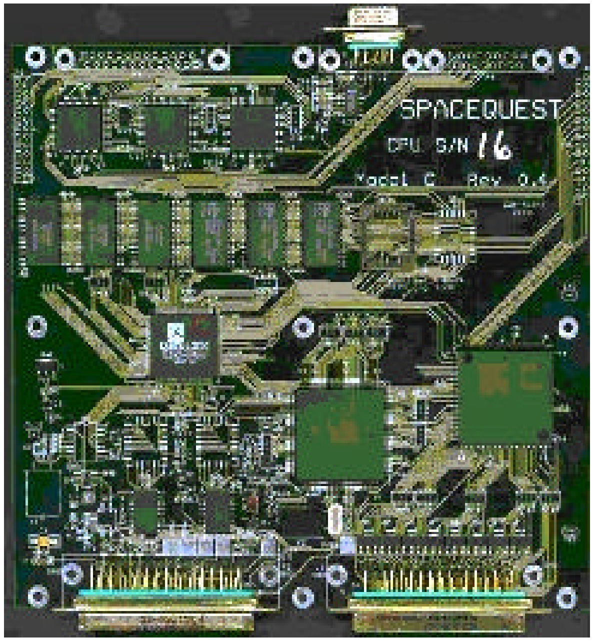


Appendix D - UHF Receiver

- Front end noise figure: < 1dB
- Frequency stability: ±5 ppm
- Mass: 198 grams
- Volume: 83 mm x 72 mm x 28 mm
- Power consumption: 77 mW
- Operating Temperature: -10°C to 60°C

Appendix D - Flight Computer

- Static RAM: 512K
- Mass: 150 grams
- Area: 140 mm x 165 mm
- Power consumption: 10 mW idle
- Operating voltage: 3.3V
- Operating Temperature: -10^{o}C to 60^{o}C
- Data storage capabilities



Appendix D - Patch Antenna

- 150 mm x 70 mm x 30 mm
- Linear polarization
- 2 antennas, one for transmit, one for receive

Appendix D - GMSK Modem

- BER: 10^{-5}
- Fixed channel: 2400 to 9600 bps
- Mass: 60 grams
- Area: 77 mm x 70 mm
- Power consumption: 130 mW
- Operating Temperature: -20ºC to 70ºC