Mars Science Laboratory Descent Stage Thermal Batteries

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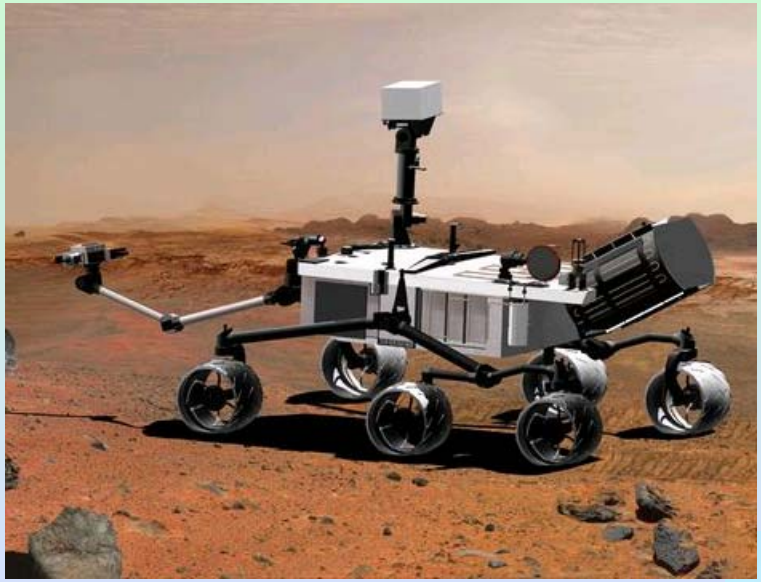
Overview

- Mars Science Laboratory (MSL) mission overview
- Thermal battery general design
- Thermal battery requirements
- Flight qualification test protocol
- Results
- Summary

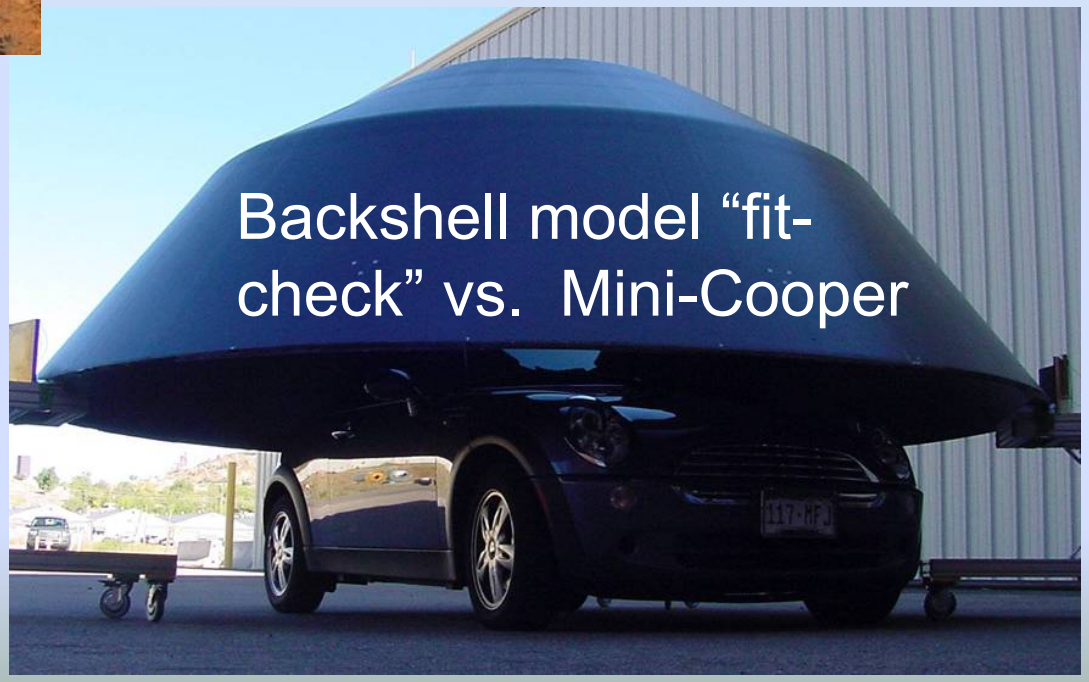


Science Mission

- Science will focus on investigating the past or present potential of Mars to support microbial life
- Remote sensing/contact investigations (e.g. rock crushing for XRD/ fluorescence analyses)
- Suite of environmental monitoring instruments (e.g. pressure, temperature, humidity, winds, ultraviolet radiation levels)

Mission Features

- 10x greater payload mass than previous Mars rovers
- One Mars year surface operational lifetime (669 sols)
- Discovery responsive over wide range of latitudes and altitudes
- Controlled propulsive landing
- Precision landing via guided entry

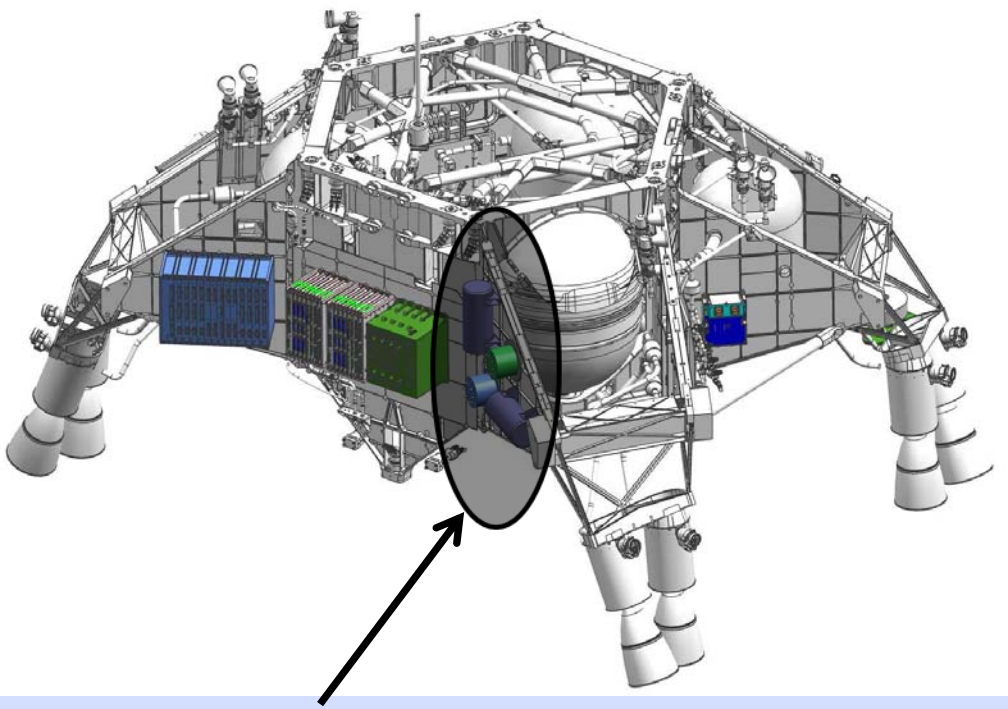


MSL Descent Stage Batteries

MSL Thermal Batteries:

- Reside on outrigger #4 on descent stage
- PWTBs: Provide power to descent stage during Entry, Descent, and Landing (EDL)
- PYTBs: Fire pyrotechnic devices during EDL
- Batteries fabricated and qualified at vendor facility (Eagle Picher Technologies)
- Unactivated testing of batteries including activation circuit resistance, polarity, insulation resistance, etc. performed at JPL
- Survival heaters/PRTs and associated harnesses installed at JPL
- Additional tests to characterize performance carried out at JPL

MSL Flight Descent Stage

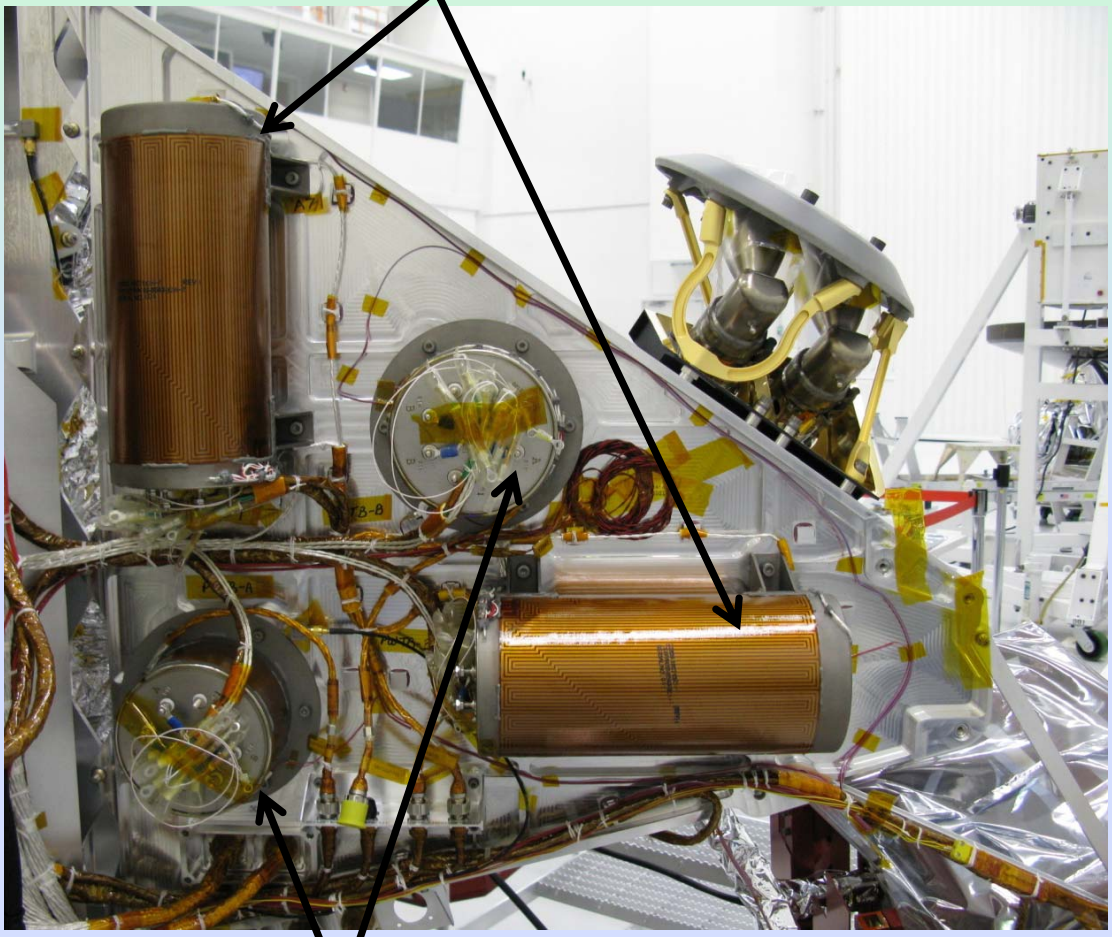


Thermal Batteries (PWTBs, PYTBs)

Thermal Batteries:

- Batteries are single-use non-rechargeable batteries designed to have outstanding shelf life as well as high discharge rate performance
- Nearly indefinitely electrochemically inert until activated (0V open circuit, 0A short circuit, >1GΩ impedance, cannot be discharged or charged)
- Activated with a current pulse across two sets of squib terminals (one set redundant) to ignite the internal heat pellets
- Ignited heat pellets melt the electrolyte which allows the battery to be discharged for as long as the electrolyte is molten (ca. 30 minutes)
- Discharged across two sets of power terminals (one set redundant)

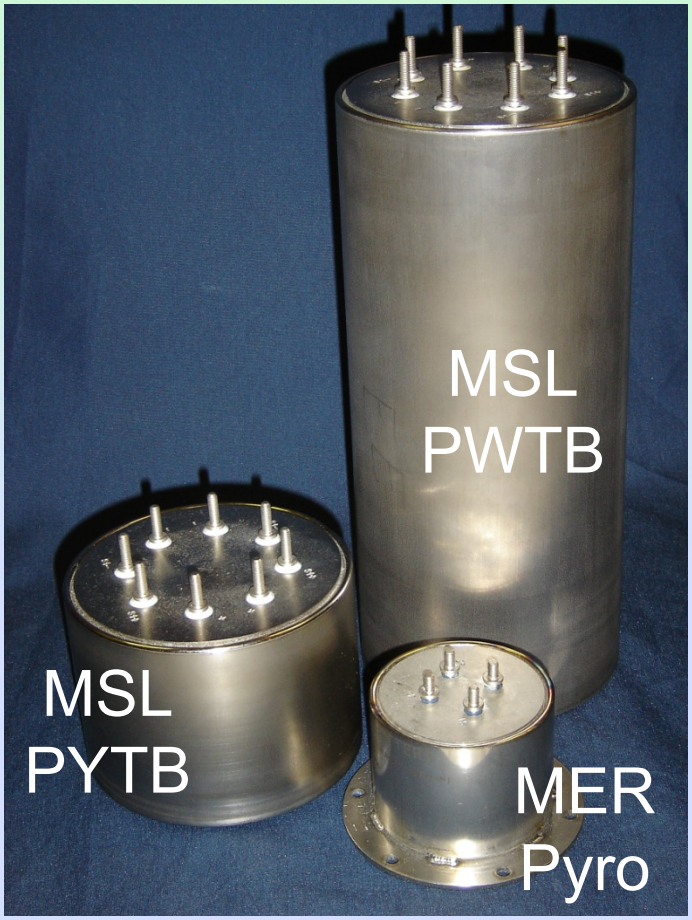
EM Power Thermal Batteries (PWTBs)

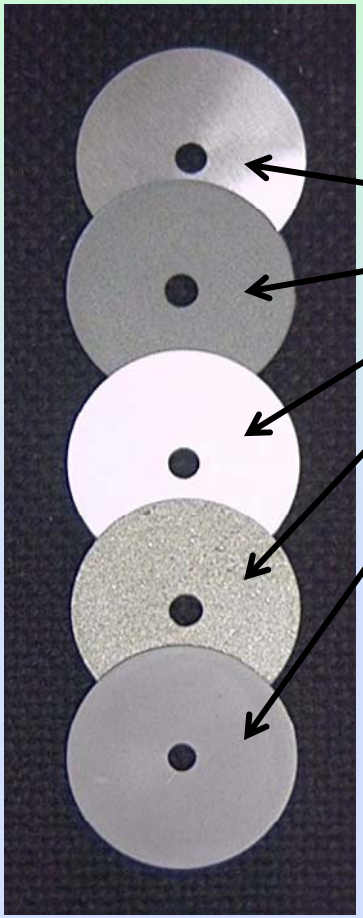


EM Pyro Thermal Batteries (PYTBs)

MSL Flight Descent stage with EM PxTBs installed

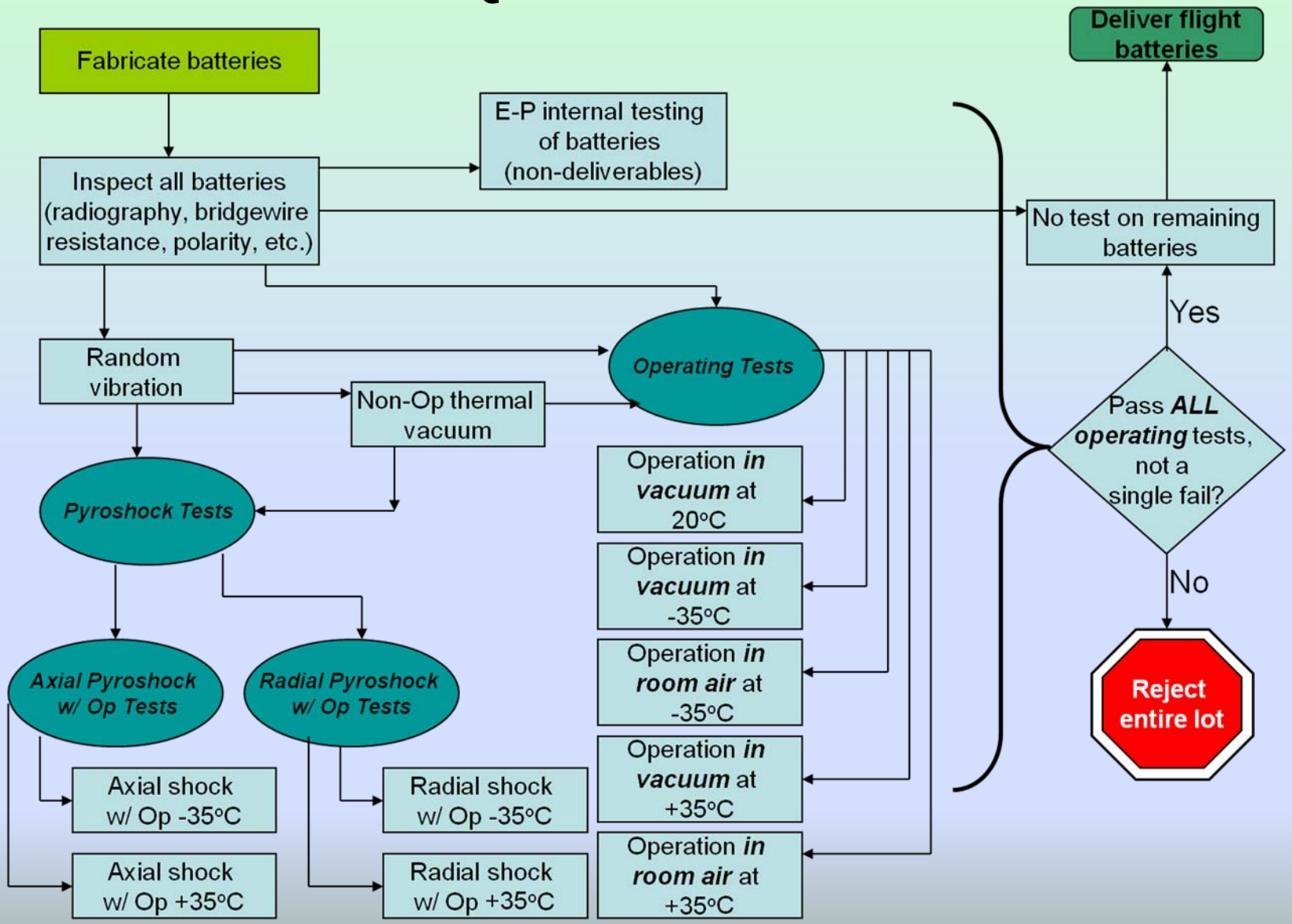
MSL Descent Stage Batteries: Design



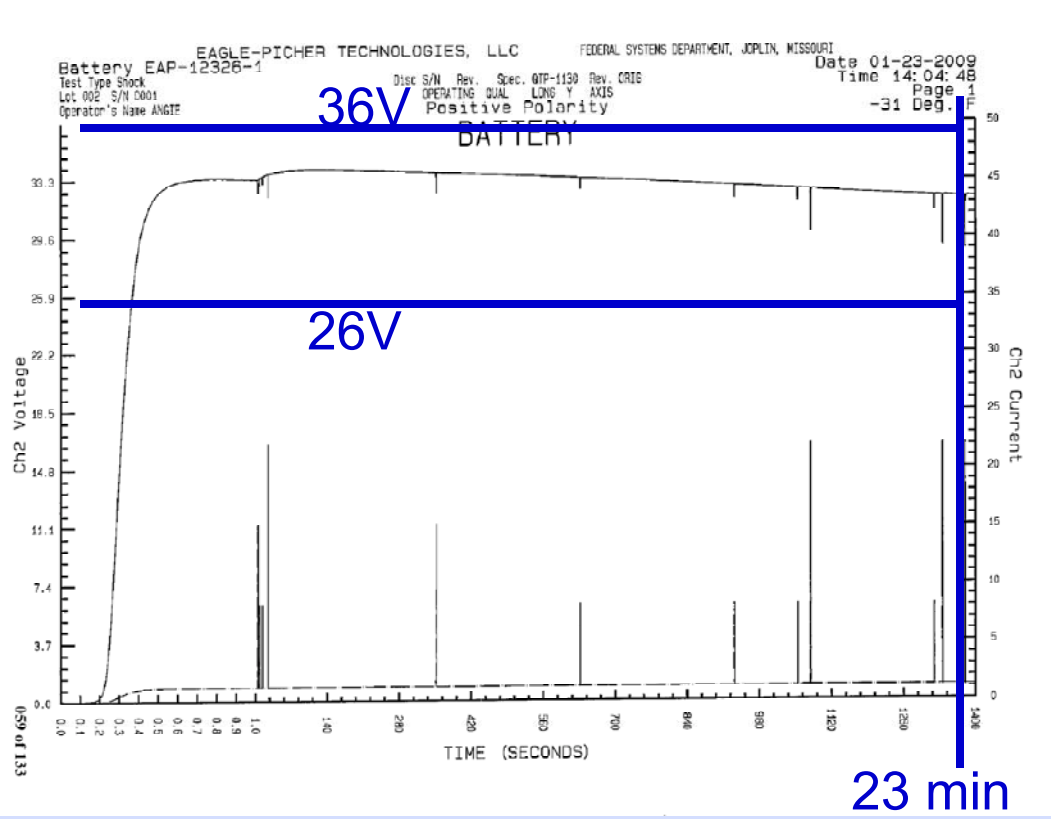


Current pulse through pyrotechnic initiator ignites heat pellets through centerline, activating battery

Qualification



Qualification: PYTB



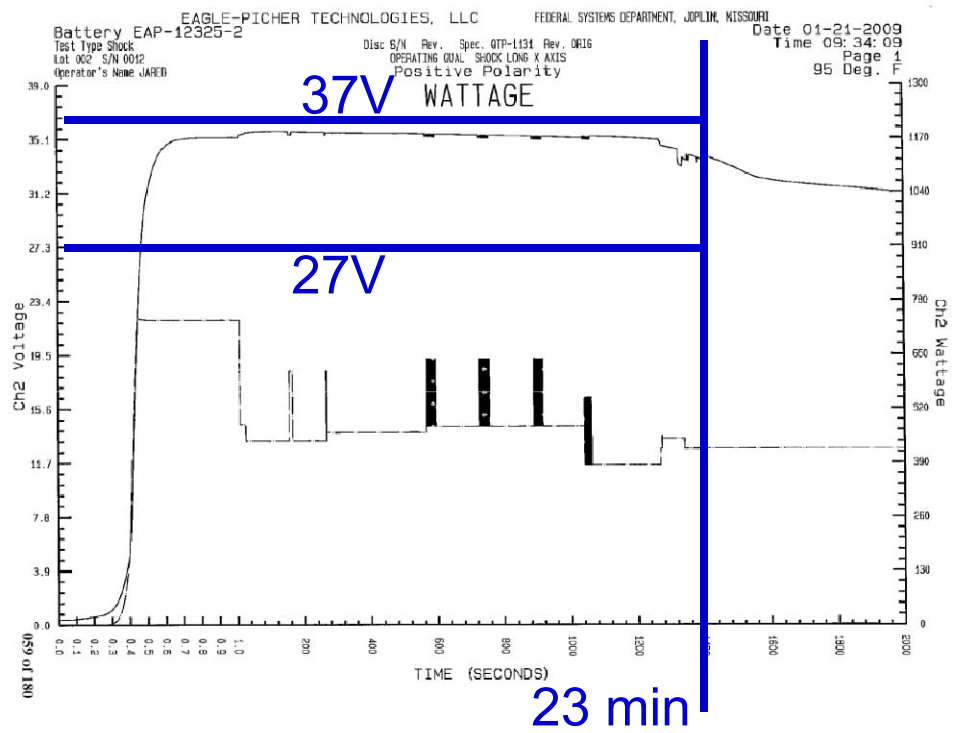
Requirements:

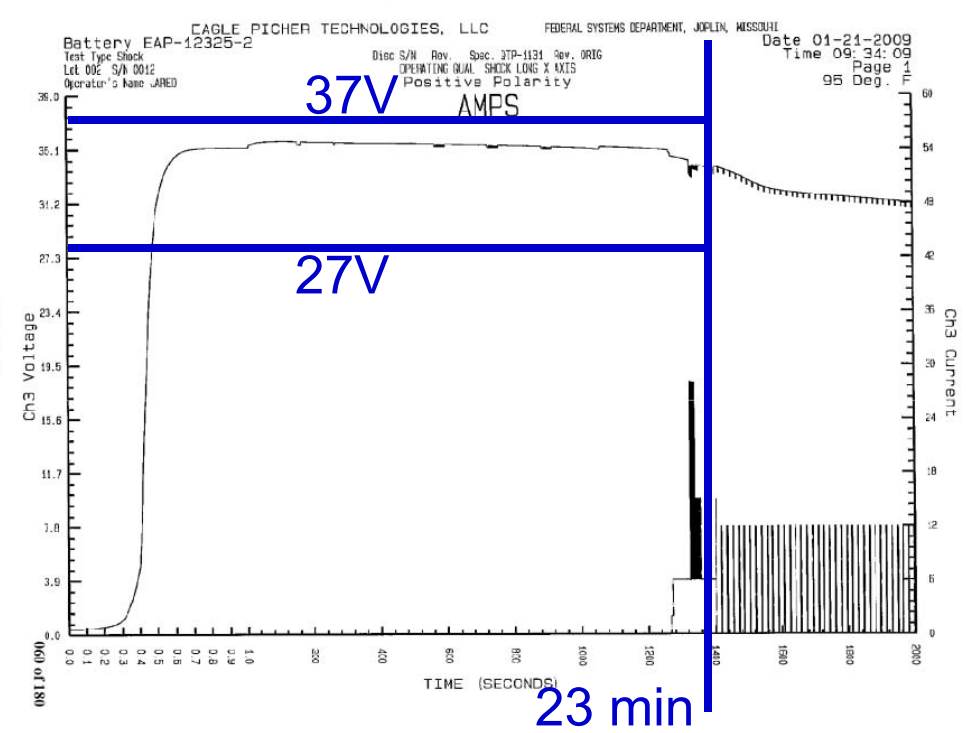
- Voltage: 26 to 36 V
- Rise Time: 1.0 sec max to >26 V
- Operating time after activation: 1380 seconds (min.)
- Shelf Life : > 4 years
- Pulse-type operation required in addition to a continuous load

Load:

- 1A constant baseload
- Up to 96 pulses
- 7A, 20 msec pulses
- 22 A (3 simultaneous pulses)
- 120 msec time between pulses

Qualification: PWTB





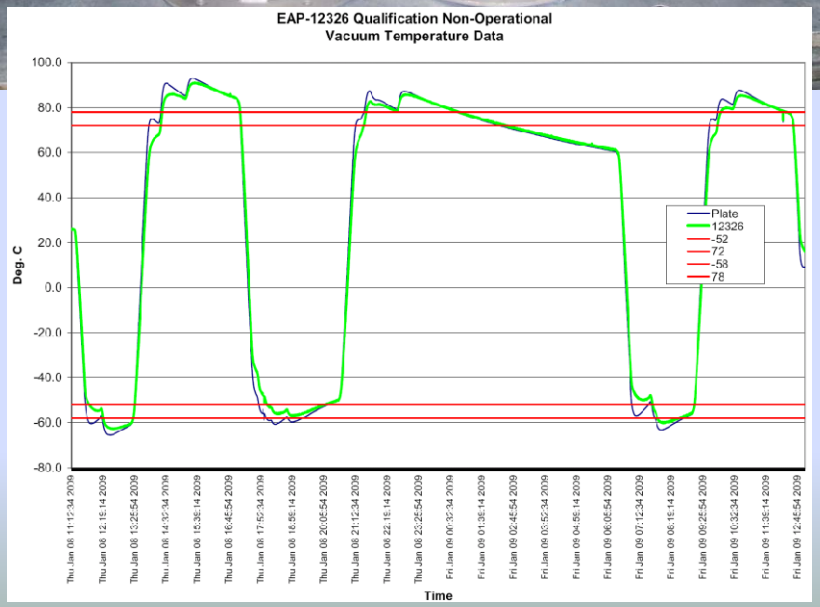
Requirements:

- Voltage: 27 to 37 V
- Rise Time: 1.0 sec max to >27V
- Operating time after activation: 1380 seconds
- Shelf Life : > 4 years
- Capacity (min): 6 Ah at >27V

Load:

- Complex load profile (≈1000 steps)
- Variable power loads 300-650W
- Superimposed 6 – 30A current pulses
- Tolerate a reverse current of 16A for 20 msec

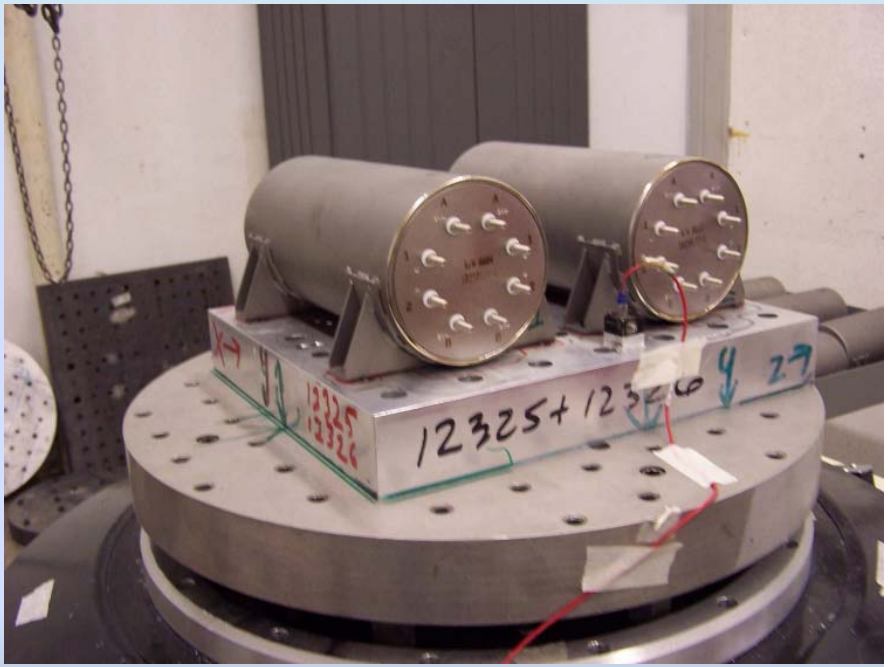
Non- Operational Qualification

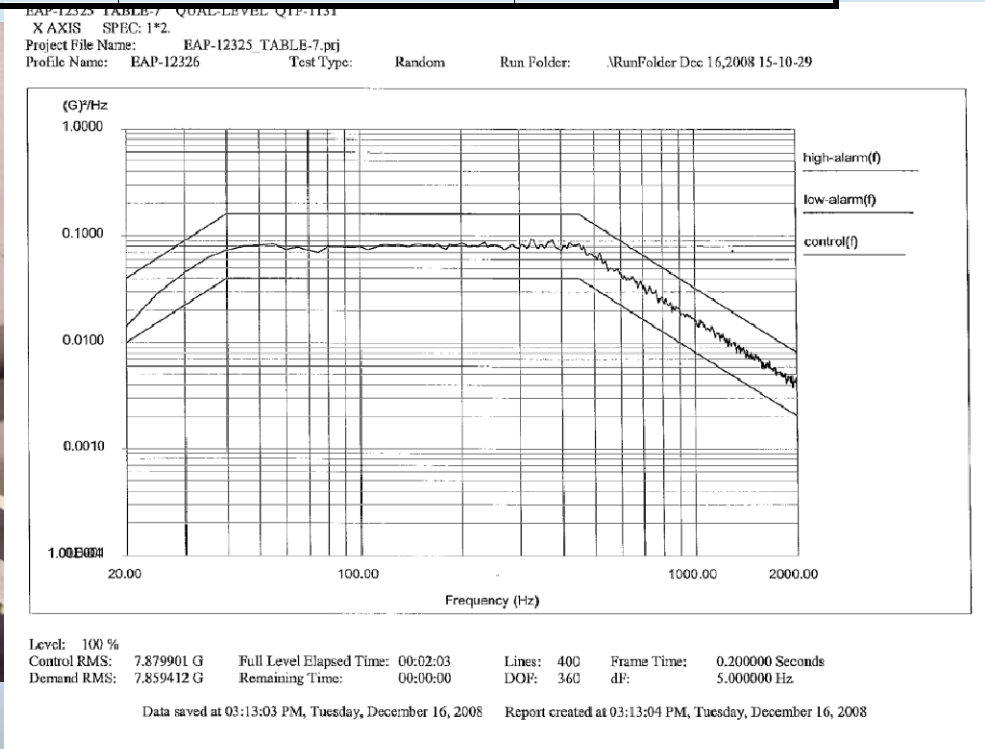


- Visual
- Radiography
- Leak check
- Torque
- Non-op electricals
- Thermal vacuum (min. 3 cycles -55°C to +75°C)

Qualification: Random Vibration

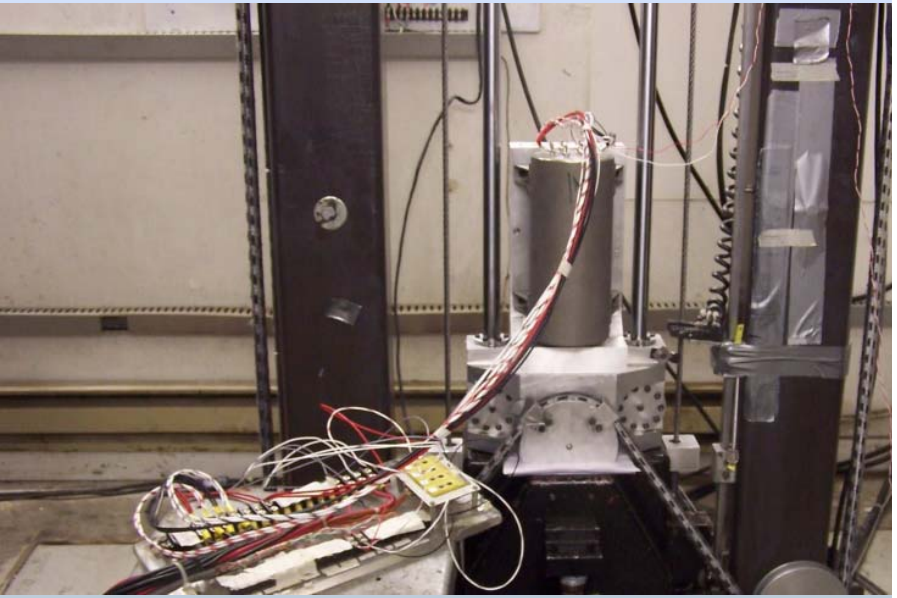
Zone/Assembly	Frequency, Hz	Flight Acceptance Level	Qualification/ Protoflight Level
Descent Stage Mounted Assemblies	20 – 40 40 - 450 450 – 2000 Overall	+ 6dB/octave 0.04 g2/Hz - 6 dB/oct 5.6 grms	+ 6 dB/octave 0.08 g2/Hz - 6 dB/oct 7.9 grms

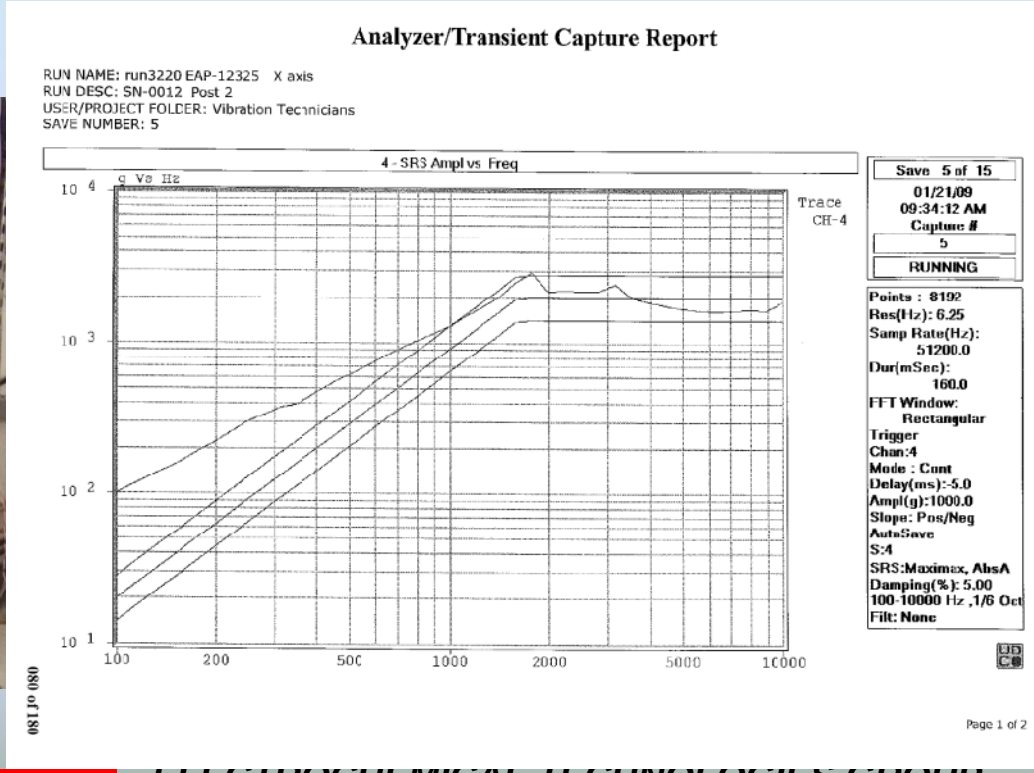




Qualification: Operational Pyroshock

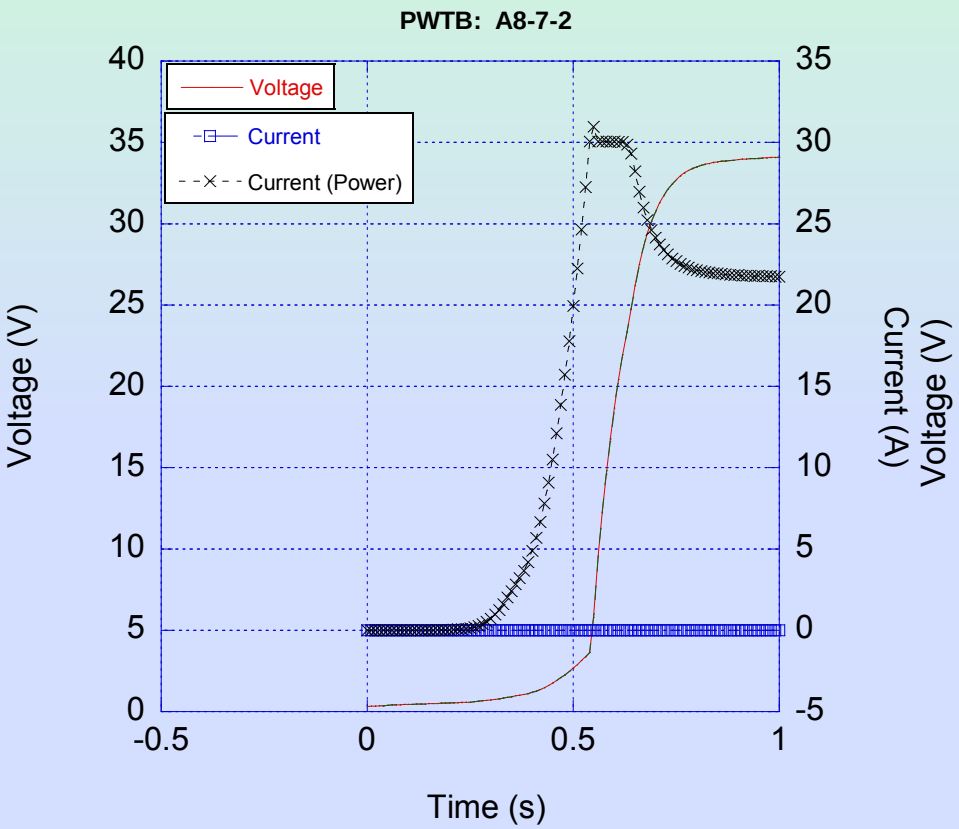
Zone	Frequency, Hz	Qual Peak SRS Response (Q=10)
Descent Stage Zone 2	100 100 – 1,600 1,600 - 10,000	20 g + 10.0 dB / Oct. 2,000 g



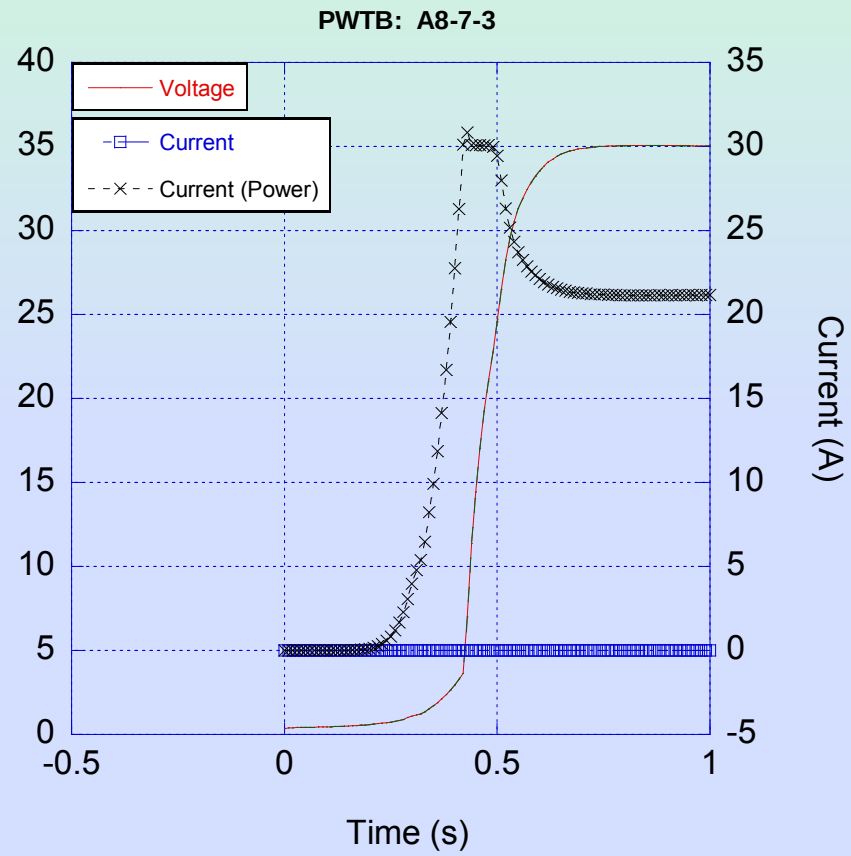


Start-Up

Initiate at -35°C

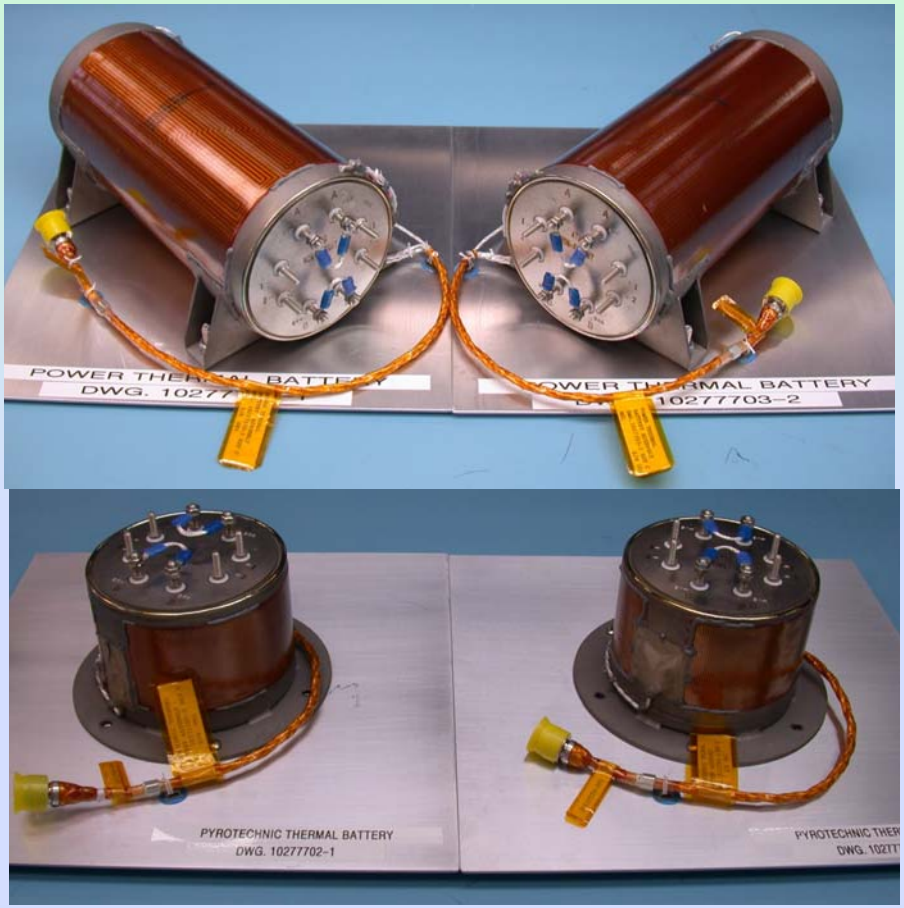


Initiate at +35°C

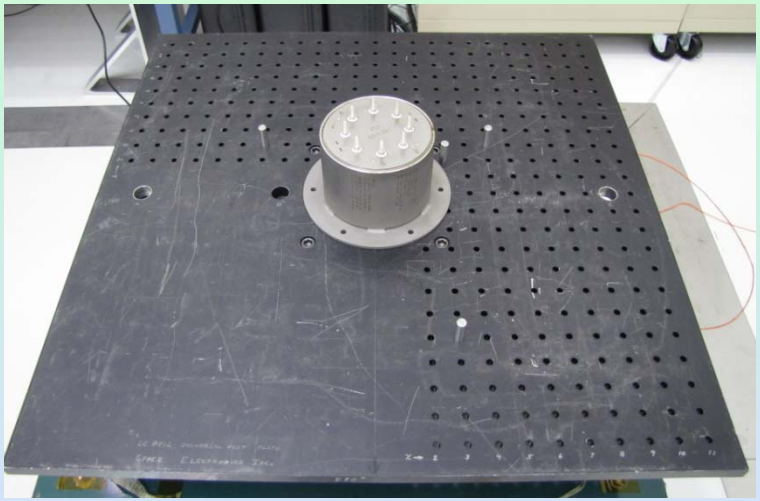


JPL Activities

- JPL Acceptance Tests
  - Visual (burrs, welding flaws, glass-metal seals, activation indicators)
  - Activation circuit resistance
  - Polarity
  - Isolation (case, activation circuit, + and – terminals)
- Heater/PRT installation
- Harness installation
- Mass properties (Center of Gravity, Moment of Inertia)
- EMI sensitivity testing
- ATLO activation and load testing



Mass Properties Testing

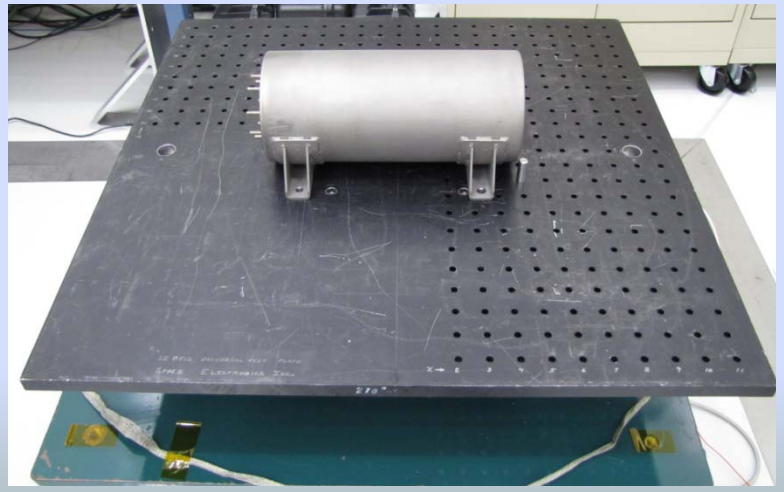


Center of Gravity (CG) test

- Used to identify average mass location of unit
- Precisely weigh unit then mount unit on spin table
- Measure applied moment at 4 positions 90° apart
- Divide by weight to calculate CG

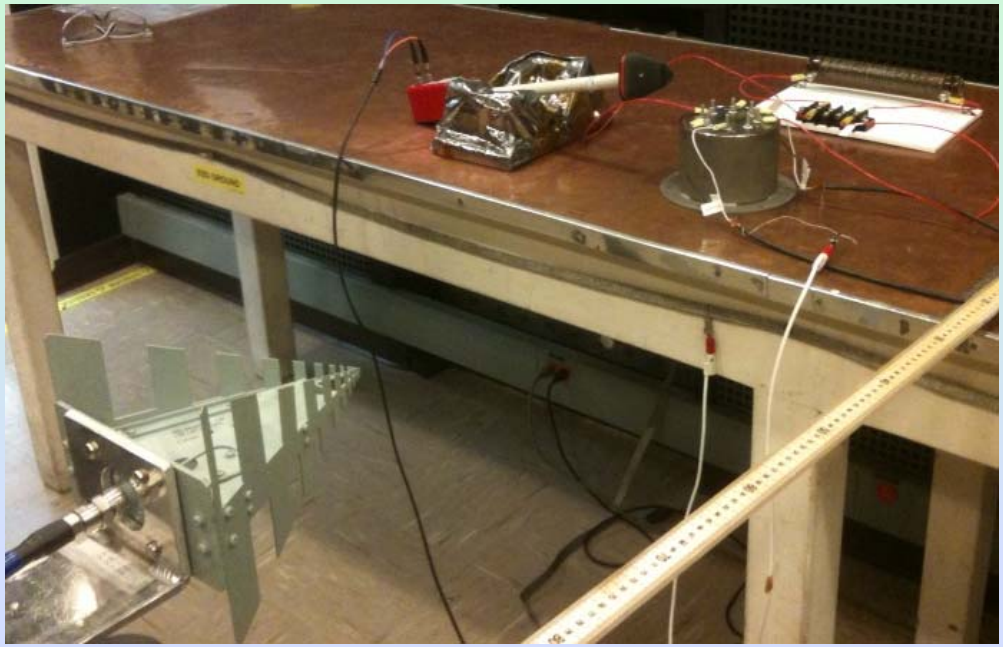
Moment of inertia (MOI) test

- Used to describe unit's resistance to a change in rotation
- Precisely weigh unit then mount unit on spin table
- Lock the bottom of the spin table rotation shaft
- Displace the platform by a few degrees, and then release
- shaft acts like a torsional spring, and the platform will oscillate at the natural frequency of the system
- Period of oscillation is used to calculate MOI



EMI Testing

- At launch, spacecraft will be exposed to tracking radar and other EMI sources
- Question: will the initiator circuit degrade or initiate in EMI field?
- Tests: Expose thermal battery and mock harnesses to pulse modulated 5.4 -5.9 GHz RF at 100 V/m (at 1m, yields ca. 53W exposure)
- Repeat test at opposite polarization
- Record initiator resistance before and after



Outcome:

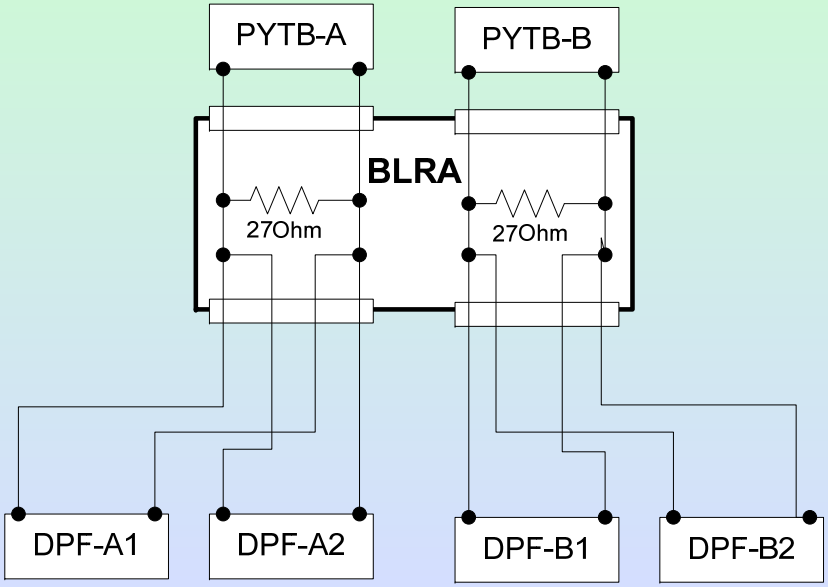
- No battery initiation on RF exposure
- No change in initiator circuit resistance

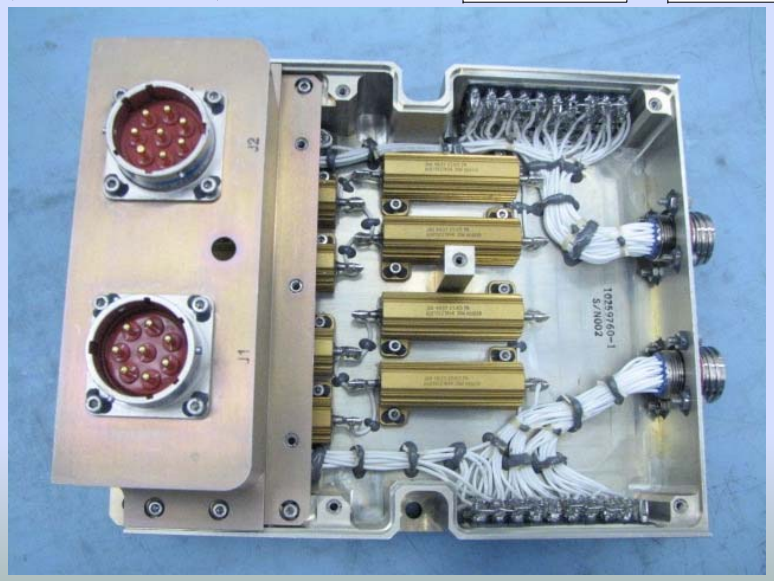
Baseload Resistor Assembly (BLRA) for PYTB

- Thermal batteries, once activated, need to be discharged at some minimum current to prevent safety issues (thermal runaway).
- Self discharge can occur, likely through dissolution of FeS_2 into electrolyte, and/or generation of sulfur via a decomposition of cathode, which would eventually trigger run away.
- The recommended solution is to discharge the battery at small currents, such that the electrode surface is continuously modified.
- Such discharge is required only for PYTB. The PWTBs would not need any such discharge since there a continuous load impressed upon them after activation.
- The base load adopted for the MER batteries in the past was 0.5 A. Based on the larger capacity of the MSL PYTBs, a current of ~ 1 A was recommended.

Baseload Resistor Assembly (BLRA) for PYTB

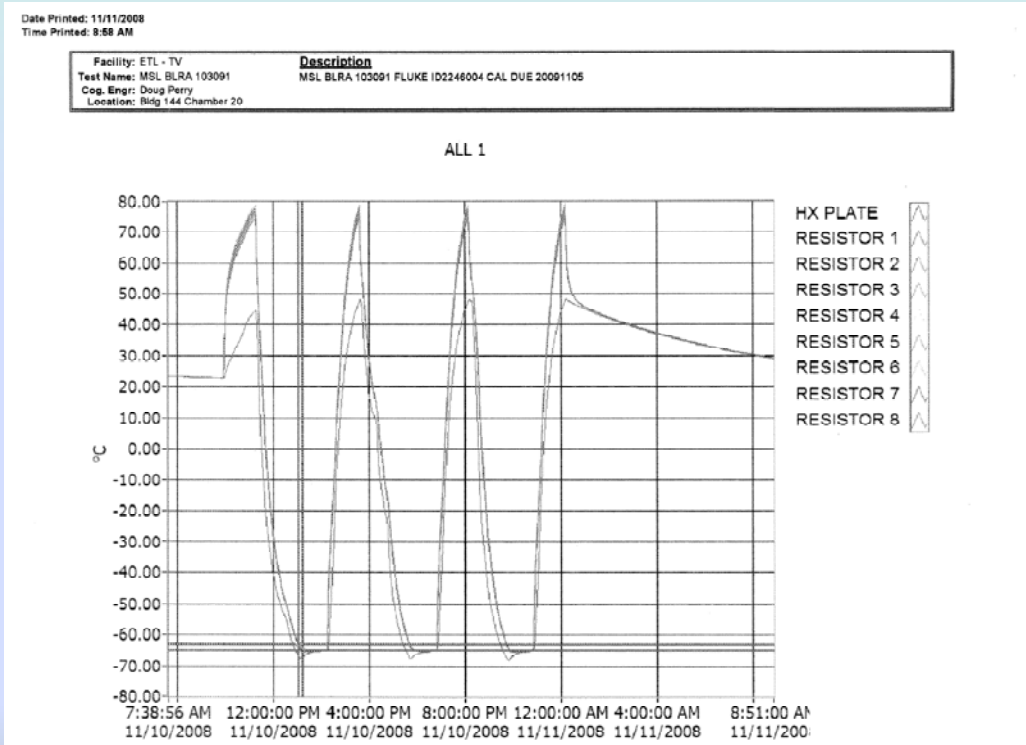
- Baseload Resistor Assembly (BLRA) function in addition to providing a baseload for the PYTBs, also distributes power to DPF, up to 96 NSI firings, 3 simultaneous 7A 18ms pulses
- A 2 x 2 network of resistors can provide the 1 A (nominal) baseload while meeting derating guidelines
  - Four RER75 resistors in series + parallel: offers some redundancy
  - Dissipates 1.31 A BOL (PYTB at 36V) and 0.95 A EOL (PYTB at 26V)
  - Power dissipated < 47 W per resistor bank.
  - Total for box is < 105W





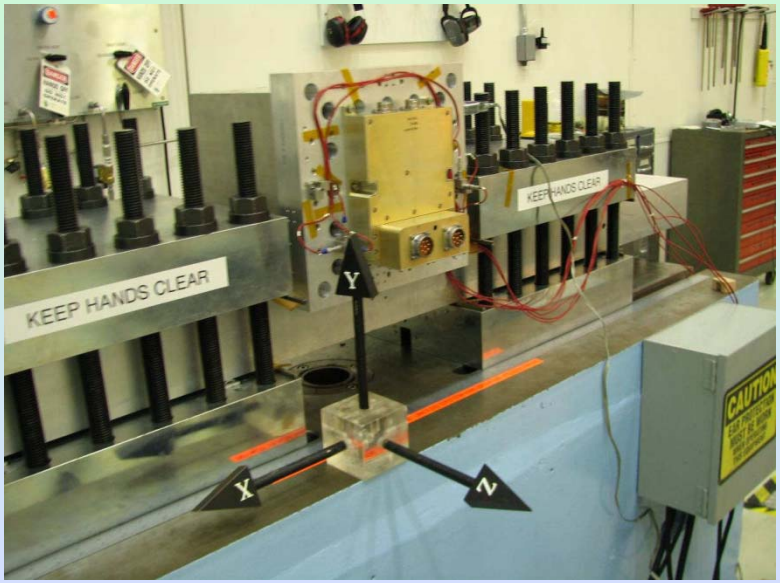
BLRA Flight Qualification

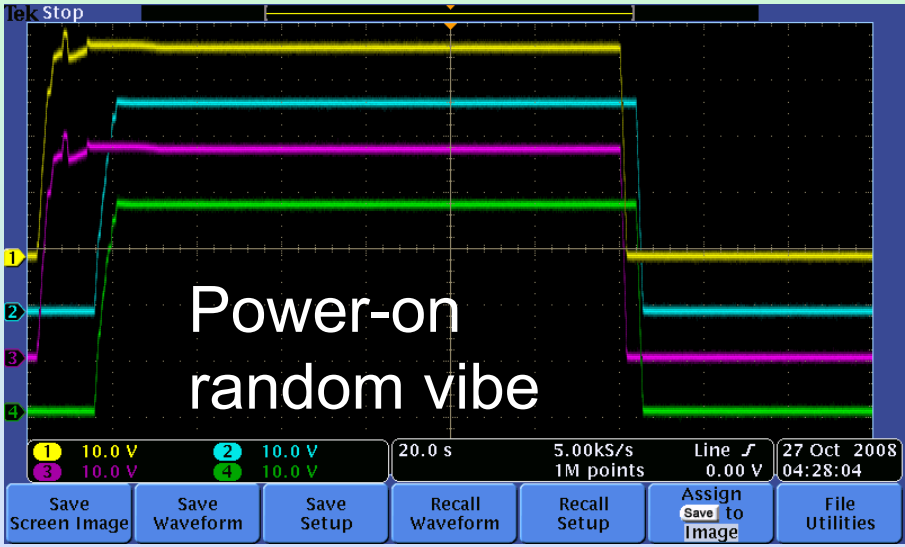
- Visual
- Electrical isolation/resistance verifications
- Power-on 3 axis random vibration
- Power-on 3 axis pyroshock
- Power-on thermal vacuum: 4 power on cycles (20°C→ 75°C, -65°C → 75°C 3x)
- Planetary protection bakeout

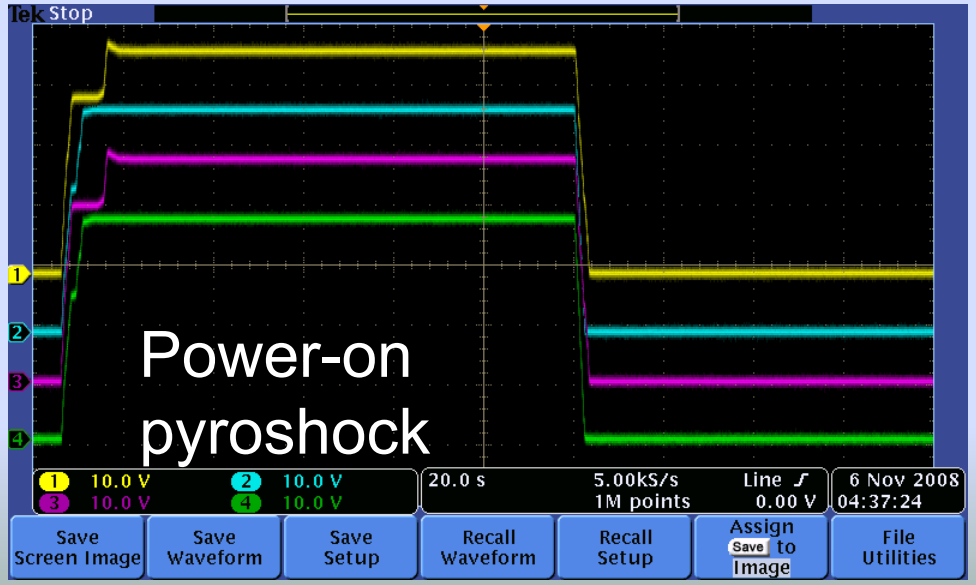


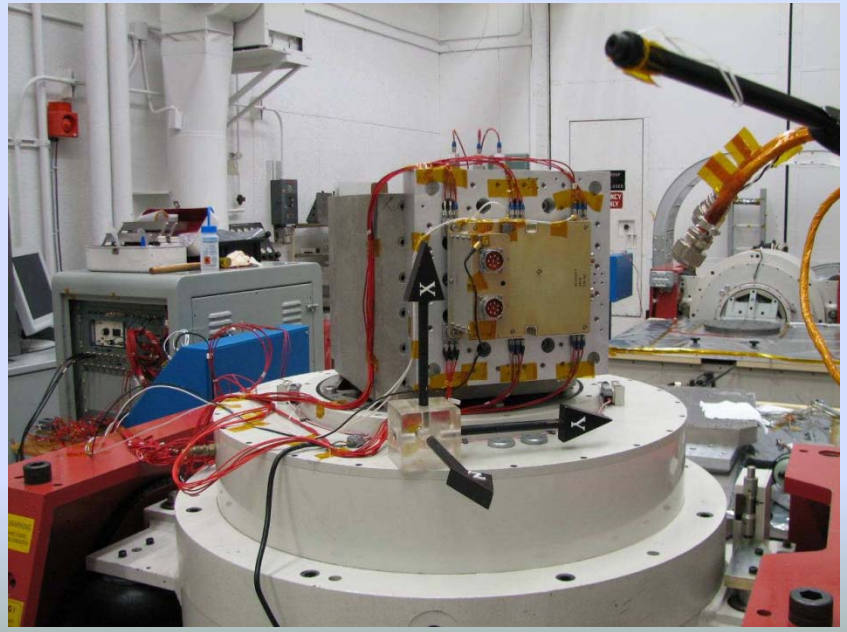
Power-on thermal vac

Mechanical Qualification Tests









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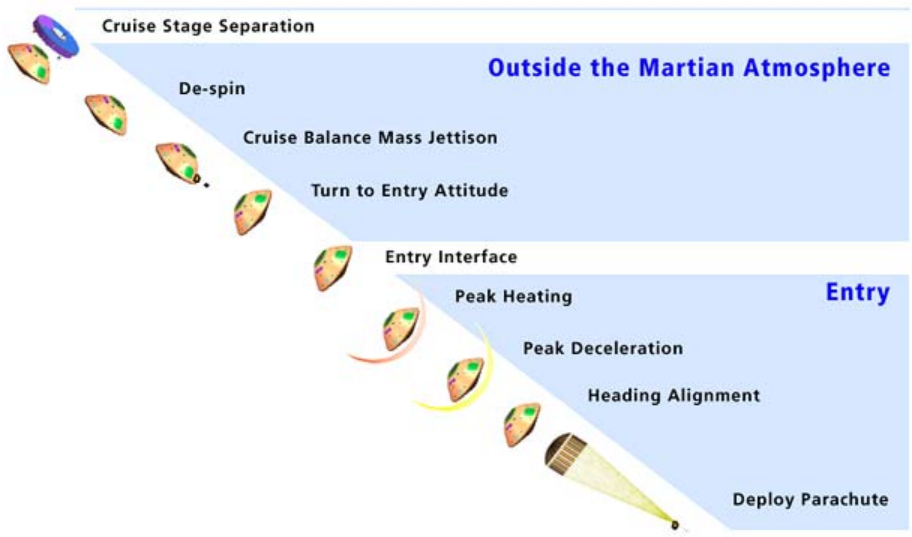
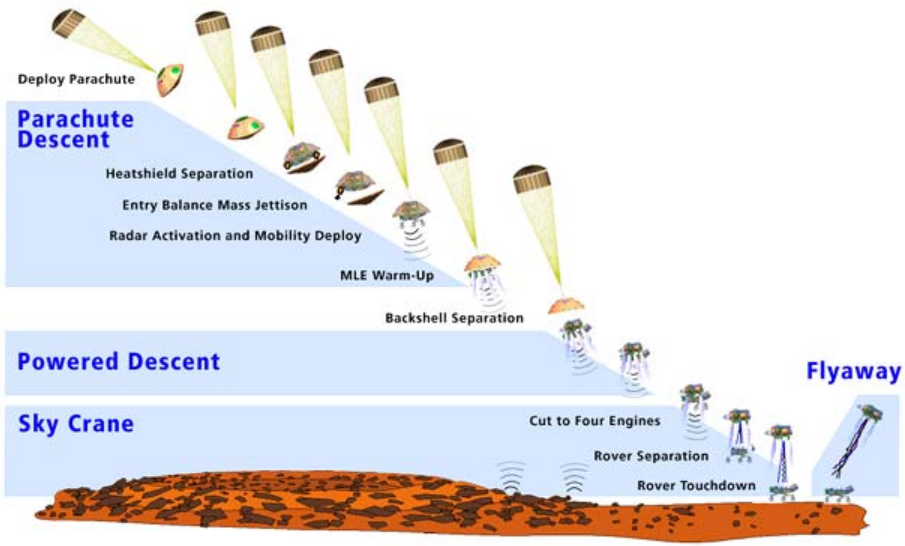
Summary

- Thermal battery and BLRA requirements developed from high-level mission requirements
- EDL requires 23 minutes of power to be delivered to spacecraft bus and pyrotechnic bus
- Based on thermal battery and BLRA requirements, specifications and design studies were carried out
- Thermal batteries and BLRA were fabricated and spaceflight qualified
- Survival heaters, PRTs, and harnesses installed
- Flight model and engineering model thermal batteries and BLRAs delivered to JPL SAF for ATLO activities
- Ancillary tests (mass properties, EMI, EI, ATLO) carried out
- Currently completing final stages of assembly and test
- Launch- Fall 2011, Landing- August 2012

Acknowledgements

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

MSL Entry, Descent, Landing (EDL)