The Design & Programmatic Considerations of the THEMIS Battery

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- Technical Challenges
  - Thermal Design
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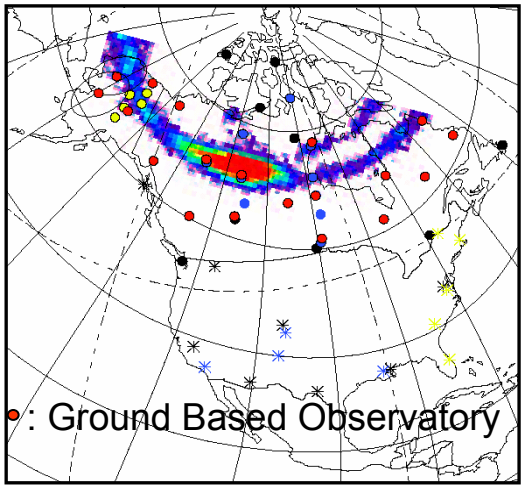
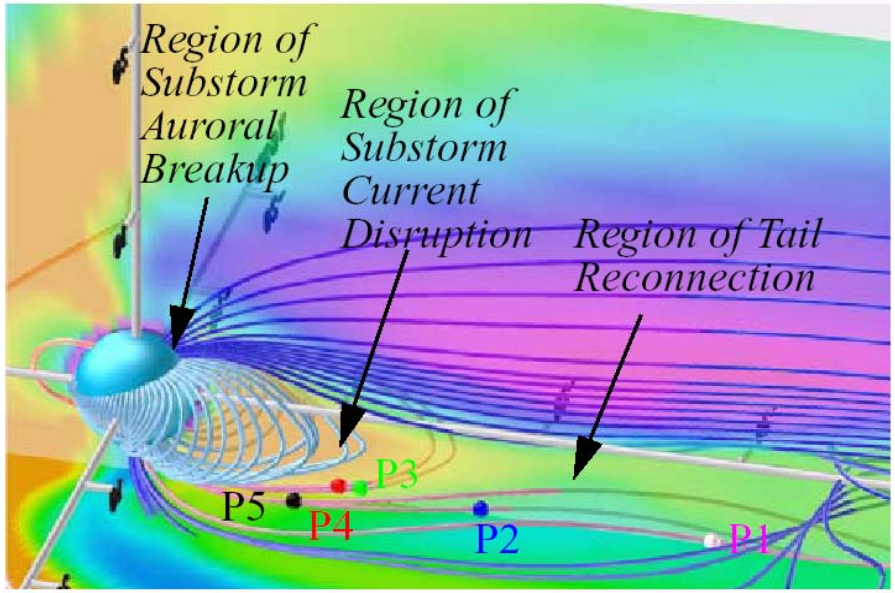
Science Mission Drives the Bus Requirements

THEMIS is NASA Mission that will answer critical questions in radiation belt physics and solar wind - magnetosphere energy coupling

Ground based observatories completely cover North American sector; determine auroral breakup within 1-3s …

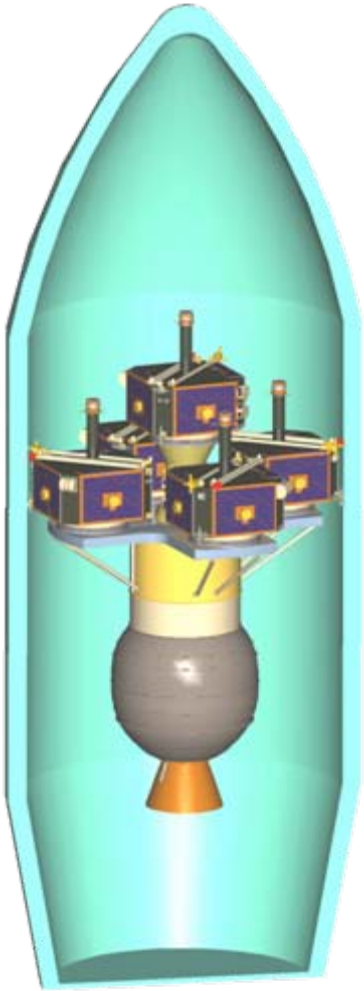


… while THEMIS's space-based probes determine onset of Current Disruption and Reconnection each within <10s.



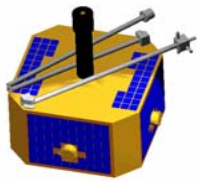
Probe conjunctions along Sun-Earth line recur every 4 days over North America

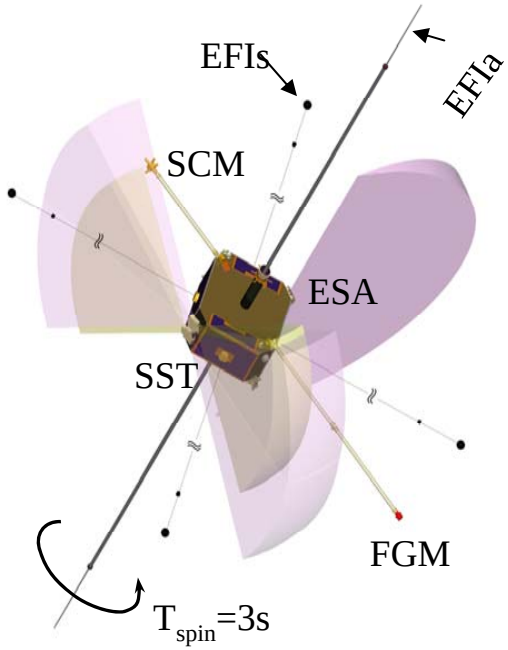
Mission Primary Objectives and Characteristic



Mission Primary Objectives:

1. Establish When and Where Sub storms start
2. Determine how the individual sub storms components interact macroscopically
3. Determine how sub storms power the Aurora
4. Identify how the sub storms instability couples dynamically to local current disruption modes





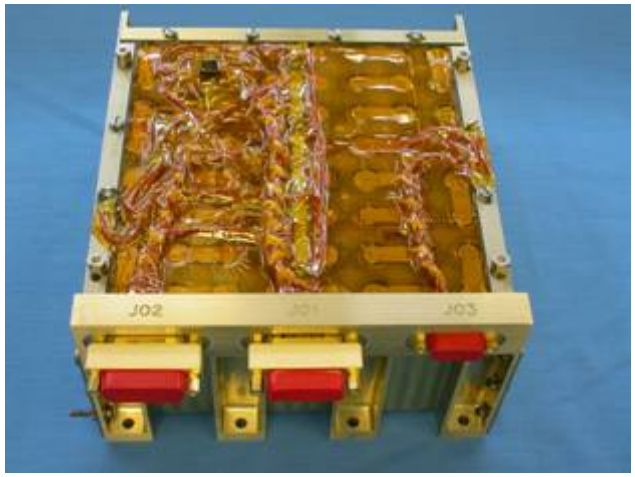
Main Mission Characteristics:

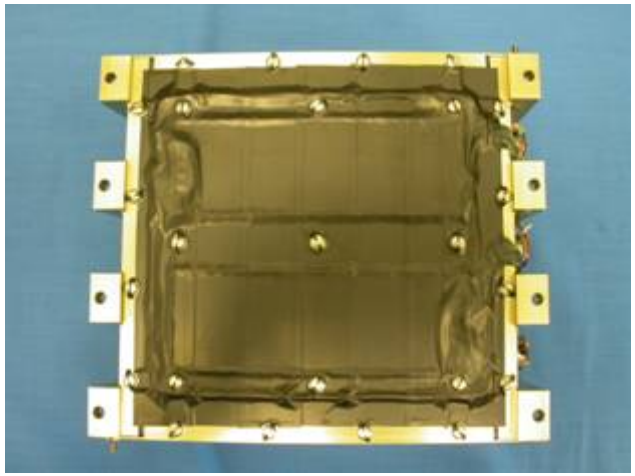
- Five spin stabilized Probes
- Highly elliptic orbits
- 2 years mission baseline

THEMIS Battery Description 1/2

- Li-Ion Battery
- Thermally Conductively de-coupled

Parameter	Value
Configuration	8s8p (single module)
Voltage Range (V)	20-33.6
Capacity (Ah)	*12*
Mass (kg)	*3.4*
Operating Temp (ºC)	*-15 to +45*
Mission Lifetime Requirement	•*6 months AIT* •*1 year storage* •*2 years operation*

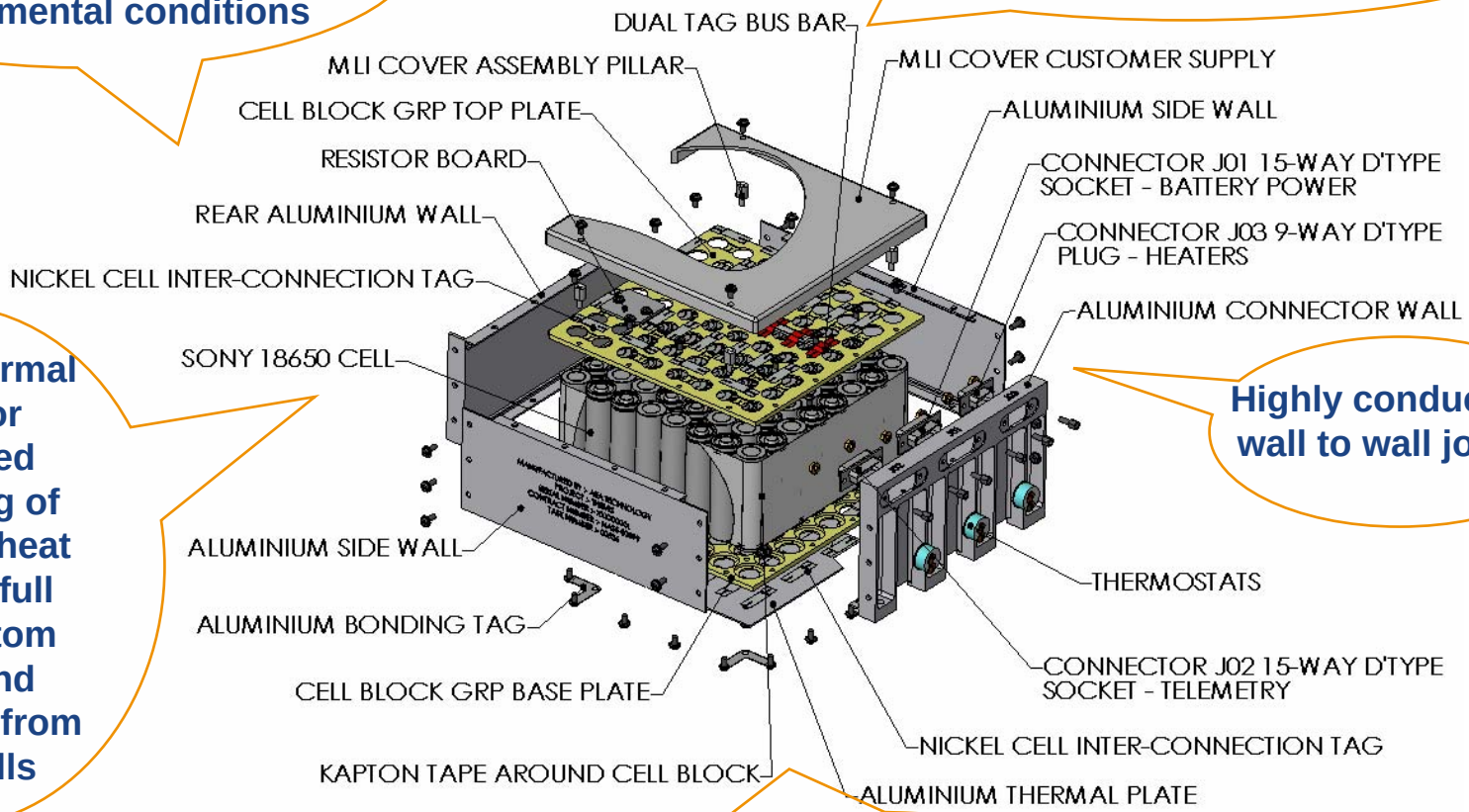




THEMIS Battery Description 2/2

Relatively low emissivity surfaces for the side walls, exposed to various radiative environmental conditions

Very low emissivity on top of battery, using MLI Cover to isolate from highly variable thermal environment



Use of thermal plate for enhanced spreading of localised heat over the full GRP bottom plate, and insulation from side walls

Highly conductive wall to wall joints

High emissivity surface finish on bottom face to take advantage of favourable thermal link during transient case

Themis Technical Challenges

- Thermal Design:
  - Battery radiatively coupled to S/C via several highly variable radiative sources.
  - New customised electrical and thermal analysis software tools developed.
  - Design verified via thermal balance test.

- Magnetic Signature:
  - Low magnetic moment essential [< 0.8 x 10^{-2} (DC) Am^2 during discharge at C/10]
  - Achieved by minimising cell string and wiring (power/heater) magnetic moments.
  - Components (cell and interconnect) magnetic properties measured at start of program by UCLA.
  - Batteries degaussed before integration.

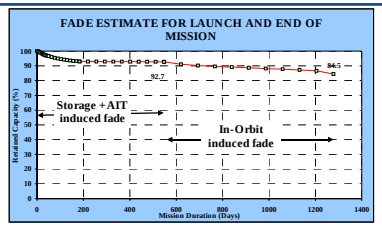
- Battery Electrical Performance:
  - Battery capacity fade predictions made for several AIT, storage and operational scenarios.

Sizing Process

Battery Size

- Max. V
- Power Req./ Energy Req.
- Orbit type

Detailed FADE with LIFE



Detailed Calculation of Fade at various Mission Points based on:

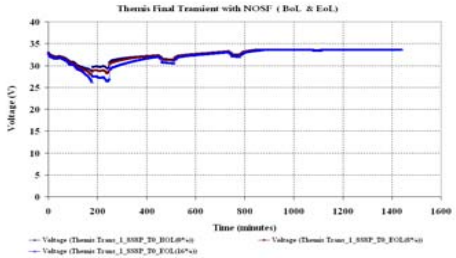
- DoD (Estimates)
- Complex Missions
- AIT activities Definition

Detailed EoL Analysis with BEAST

Detailed Electrical analysis Based on complex input profiles with Fade at various Mission points:

PLOTS:

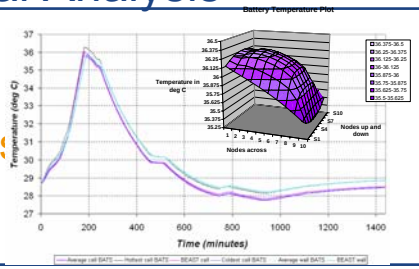
I (A), V (V), P (W), SoC (%), T (deg C), Ω (Ohms)



Detailed Thermal Analysis

Detailed Thermal Analysis

- Time varying Cells temperature mapping



General Electrical Analysis

BEAST 2003 is a "Virtual" battery tester, which allows detailed predictions to be made of battery performance under varying operating conditions based on:

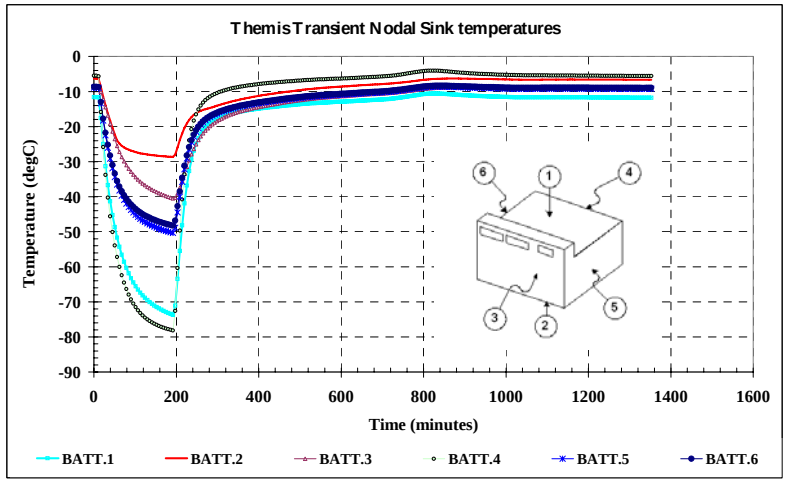
- Battery size
- Time varying current or power profiles
- System voltage limits
- Conductive I/F temperatures
- Cell degradation at time of simulation

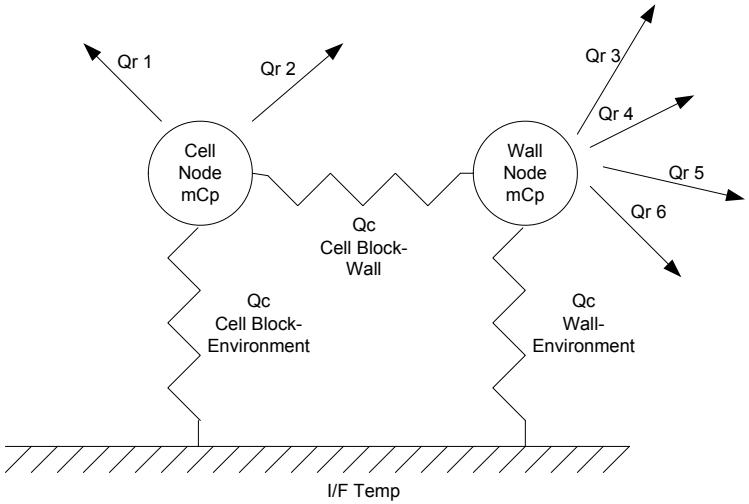
The software contains detailed fundamental performance characteristics of the Li-ion cells. This data is used to perform detailed transient simulations based on specific analysis conditions, including effects such as cell temperature variation, or interaction between power and terminal voltage in operation

Customized Electrical Software Tool

For the purpose of the THEMIS Li-Ion Battery ABSL developed and validated the custom version BEAST THEMIS 2004.

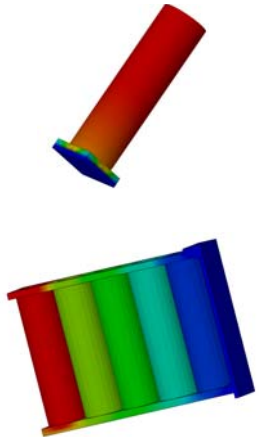
- Battery electrical performances are very strongly linked to the battery thermal behaviour and vice-versa.
- In order to simulate electrical behaviour accurately it is *essential* to include and verify thermal behaviour...
- Move from “Single node” to a sophisticated “Multi-nodes” multiple link nodal network model which allows radiative heat flow and battery thermal dissipation.
- Incorporation of heater operations routines and thermostat control routines.



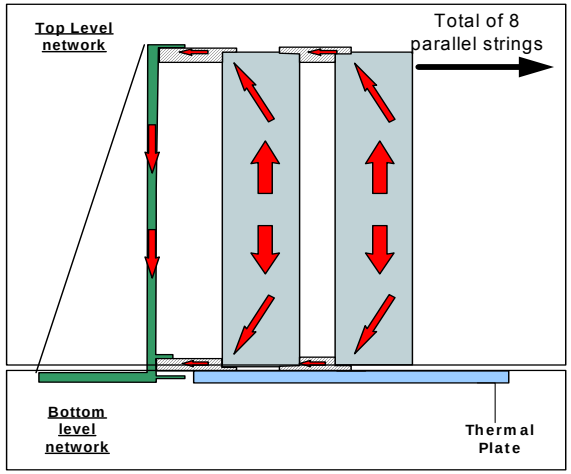


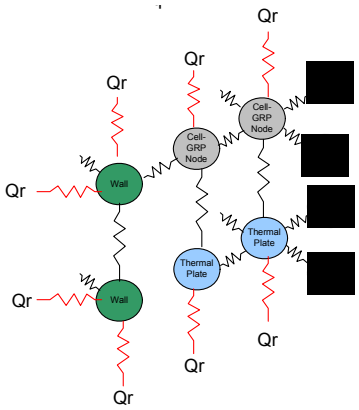
Customized Thermal Software Tool

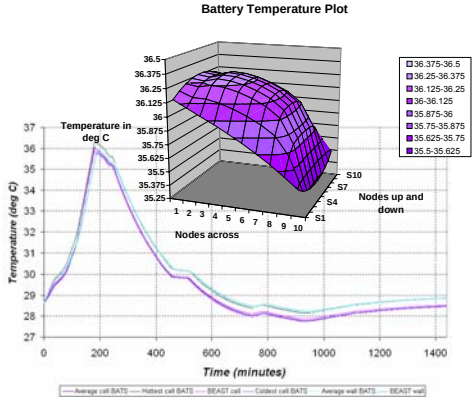
- BATS v2 in house developed tool uses a nodal network to represent the Battery
- A node is used to represent a single cell and the adjoining portion of GRP at the top and bottom
- A node is used to represent a portion of thermal plate associated to every cell
- All the links (conductive and radiative) are well captured within the network model.



Simplified Heat Flow through battery section







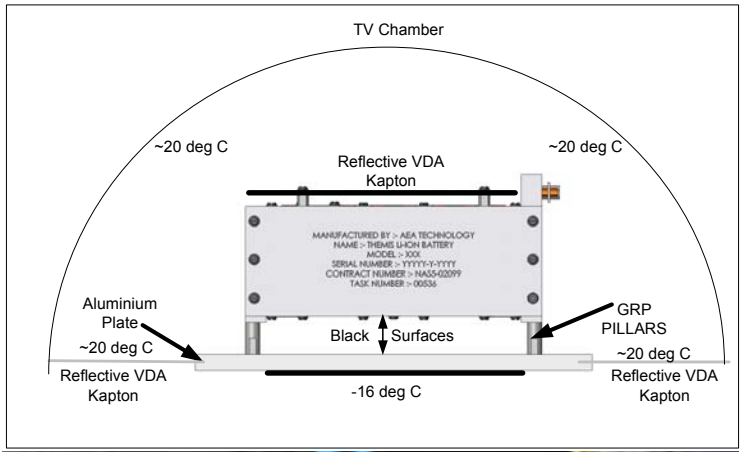
THEMIS
TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS

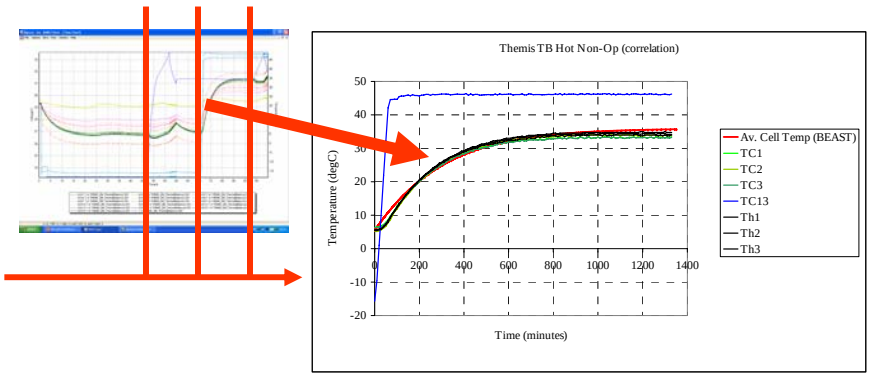
SWALES AEROSPACE

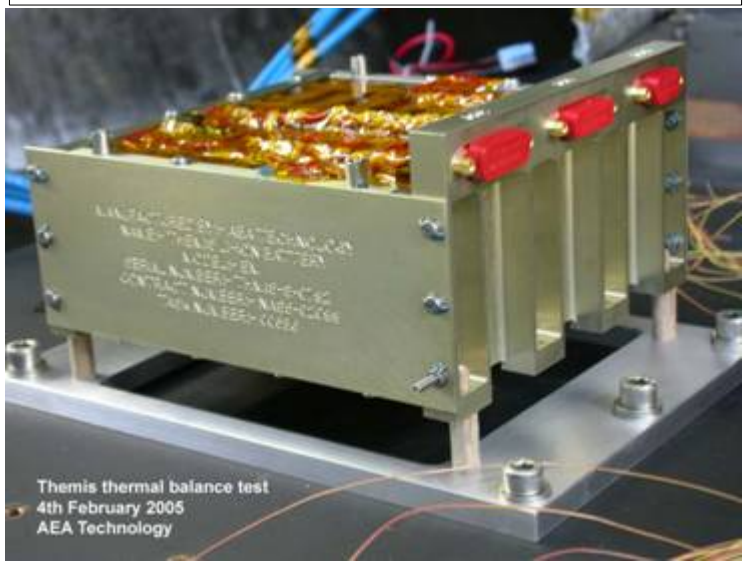
Validating Our Tools and Design

Thermal Balance Test Verification

- Validates battery thermal design (Monolith Brick behaviour), shows insignificant thermal gradients
- Thermal Performance Validation in a complex Environment
- Performed Validation of Software Tools Analysis Results







Exceptional Correlation between Test and Analysis

THEMIS
TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS

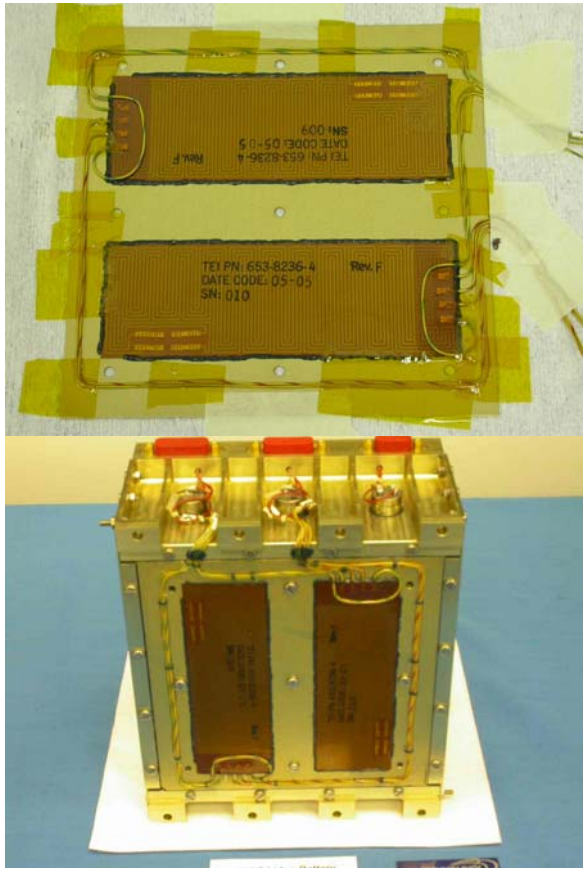
Low Magnetic Signature

- Advantages of small cell approach to reach low levels
  - Our cell configuration allows simple horseshoeing to minimize the magnetic moment contribution at string level.
  - The cells (and battery assembly) can be degaussed to levels aligned to those of a magnetic moment sensitive mission
  - We do not need active electronics

- Custom Designs Solutions Implemented
  - Segmented (magnetic moment self canceling) Bus Bar
  - Self-Canceling Battery Wiring Layout
  - Use of non Magnetic Components
    (or self canceling as far as possible)

- Testing
  - Magnetic Test was performed by UCLA on cells, strings, and various battery assemblies of our own design and proved successful after degaussing.

- Lesson Learned
  - Working with experts at Berkely and Swales helped us further improve our Low Magnetic Battery Design Capabilities



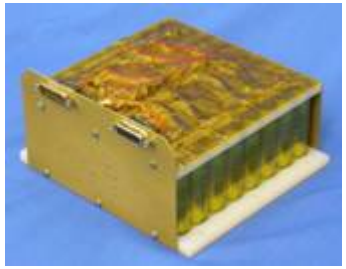
THEMIS Program Deliverables

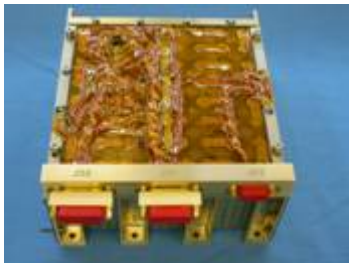
- 1 Laboratory Battery
  - Used for early subsystem check out
  - Electrically representative
- 2 Qual. Batteries
  - 1EM/1QM manufactured
  - Both EM/QM used for AIT
- 6 Flight Batteries
  - 5 Flight Modules

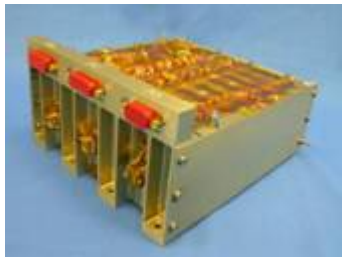
Deliverables:
Customer Service

&

Expertise



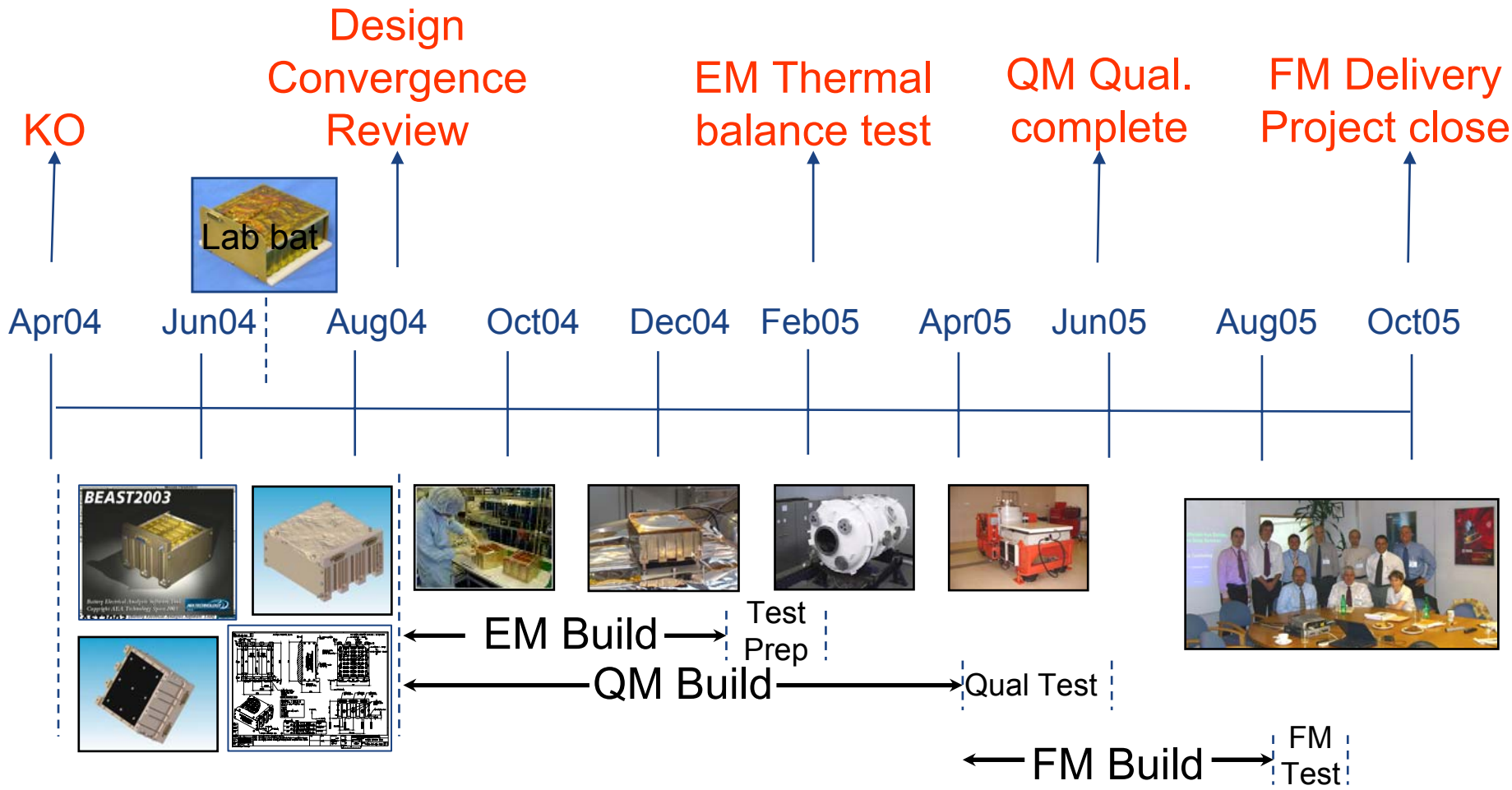




THEMIS Programmatic Challenges

- Very demanding schedule (Flight units delivered 16 months after KO).
- Probes built in pairs in series
  - Delay of a probe component would knock onto entire program
- Early in program, new work packages/issue identified
  - Incorporation of late system change to Radiative Design
  - Forced update of thermal and electrical modelling software
  - Verification of software
  - Late submission of TAA
  - Necessity of battery test hardware ASAP for probe checkout
- ABSL and Swales worked closely to modify program
  - Identified key risk area: novel thermal design
  - New program eliminated this risk ASAP and assumed low-risk of electrical and mechanical qualification

THEMIS Battery Program Timeline



THEMIS
TIME HISTORY OF EVENTS AND MACROSCALE INTERACTIONS DURING SUBSTORMS

Excellent Working Relationship

- Partnership approach
- Leveraged time difference
  - Regular meetings end of day UK/beginning US
  - At start of next day, substantial progress made by partner
- Modelling software used by all parties to speed (battery and system) design iterations
  - Windows based systems (no hardware required)
  - Simple user interface did not require time and training to pick up
- Geographical
  - Distance not seen as issue, no additional meetings
- Able to make up for delayed KO and detailed technical interchange due to TAA ratification
- Good model for future programs

Customer Feedback

"We appreciated the job that ABSL did on THEMIS qualifying and delivering our battery within a tight timeframe.

A lesson learned is the importance of getting Trade Assistance Agreements (TAAs) in place early to avoid delays through ITAR. Even though ratification of the TAA did not happen until some weeks into the program, we were pleased that ABSL was able to adhere to our schedule requirements.

ABSL proved a very professional and responsive supplier of high quality products - we hope to work with these guys again soon."

Mike Cully (Swales Aerospace THEMIS Project Manager)

Acknowledgments