Battery Study For
The Shuttle Orbiter EAPU Upgrade

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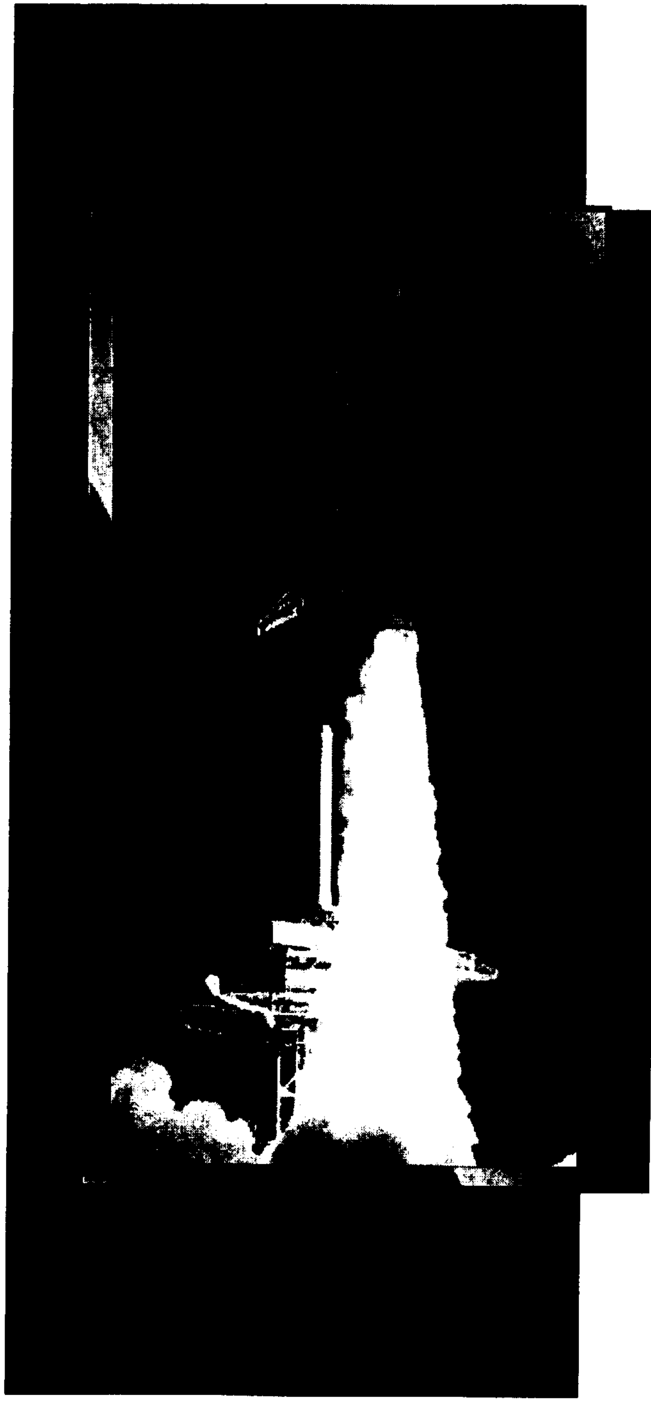

Orbiter Upgrade Electric APU (EAPU) Program

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562-922-0252

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Nissan Electric Minivan

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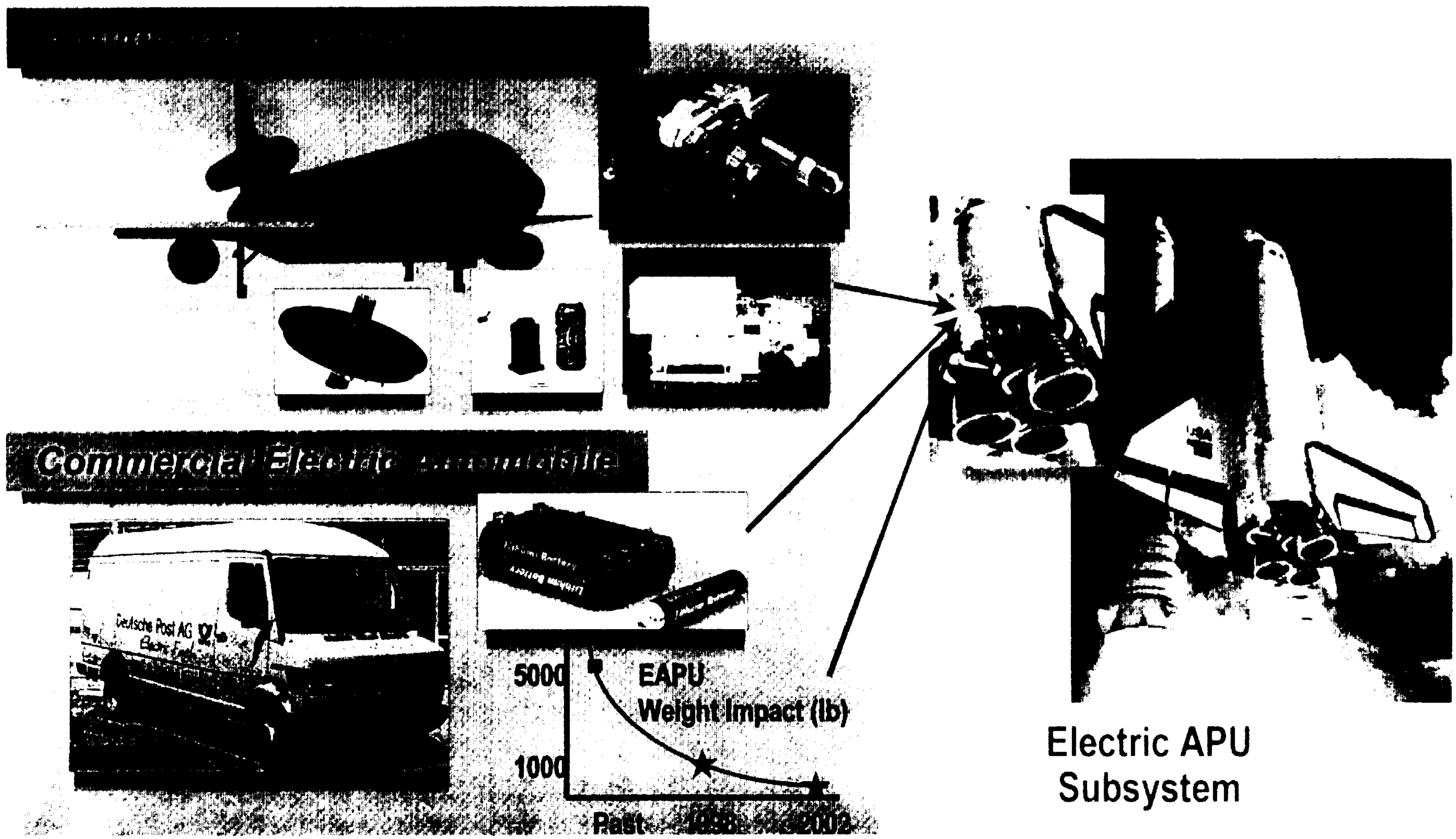
EAPUS Using Mature Commercial Technology



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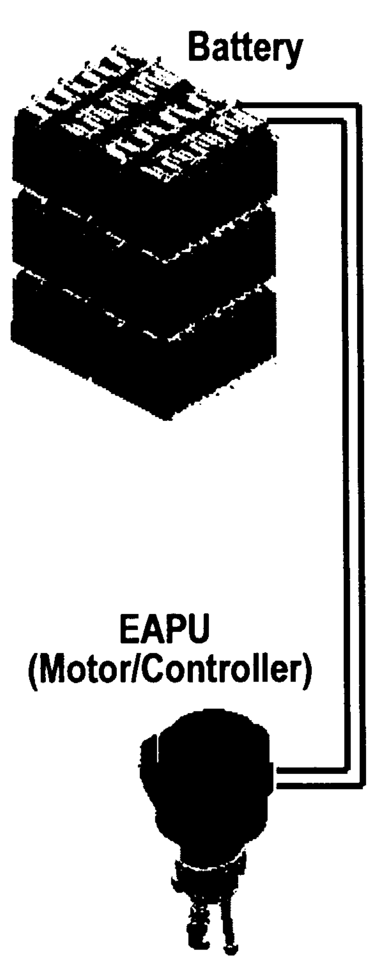
Electric APU Benefits



- Improves safety, reliability and restart capability
  - Eliminate toxic & corrosive Hydrazine fuel
  - Eliminate hazards and CRIT 1 failures (turbine overspeed & N2H4 leakage/ignition)
  - Greater than 1000 factor of reliability improvement
  - Eliminate hot restart system and procedures
  - Potential single EAPU landing capability
- Reduces KSC ground turnaround effort
  - Savings > $ 1.2M per year (APU, hydraulics & WSB)
- Reduces long term program cost
- Continuous infusion/application of commercial progress

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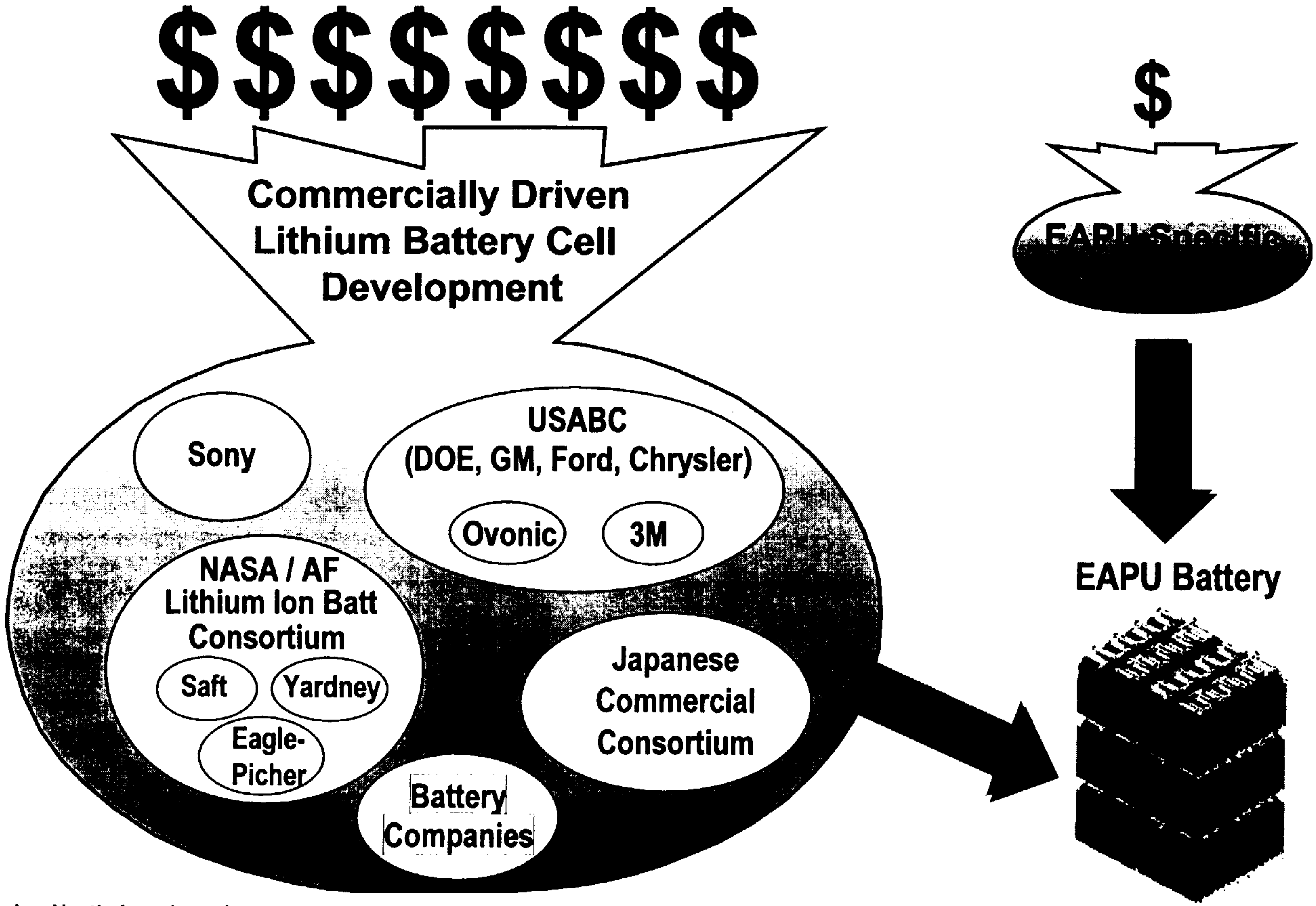
Leverage Commercial Investment In Lithium Cells



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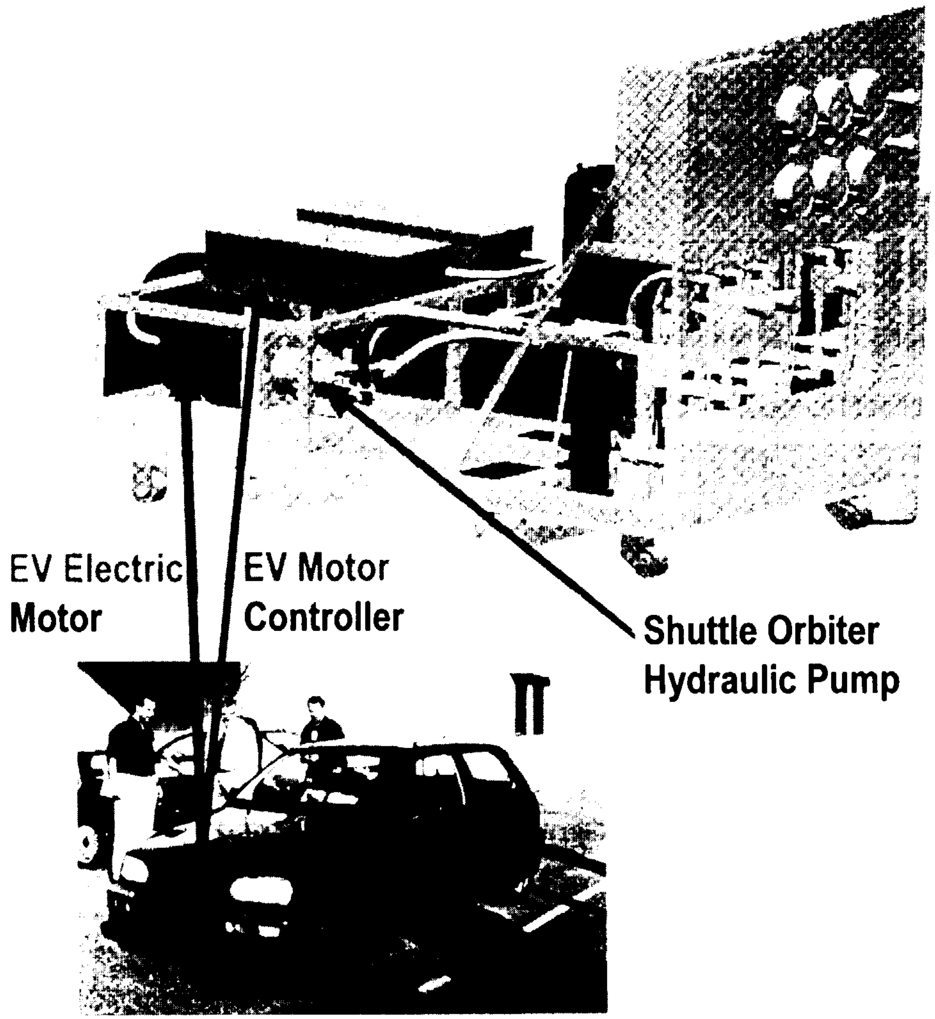
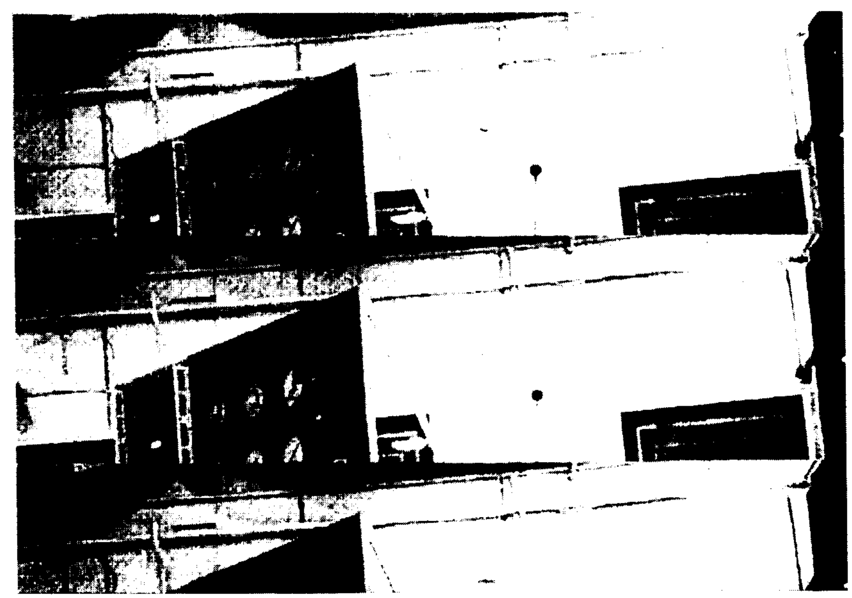
BNA Prototype EAPU Demonstration Testbed (IR&D)



Testbed Under Construction



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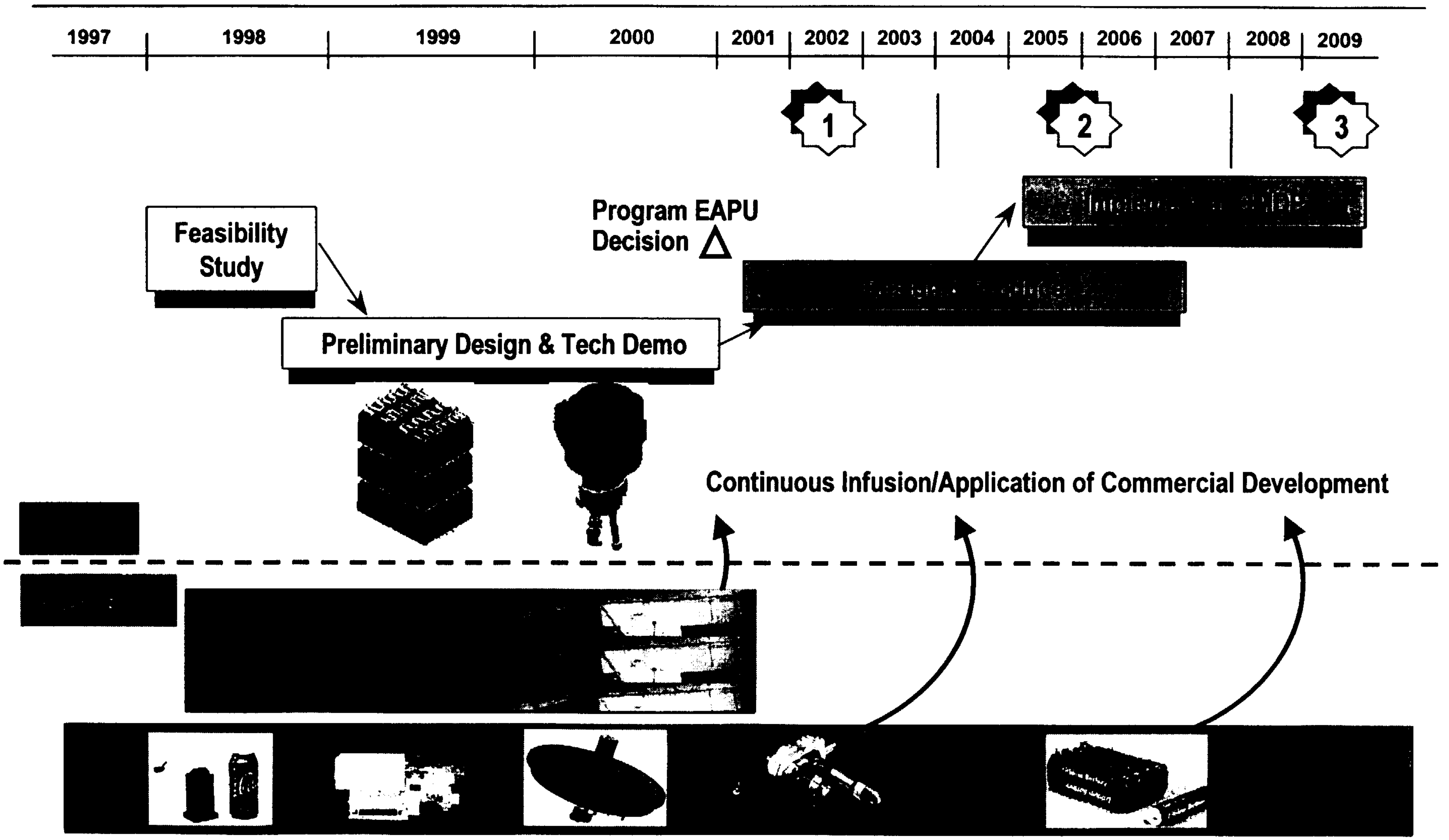
EAPU Program Plan



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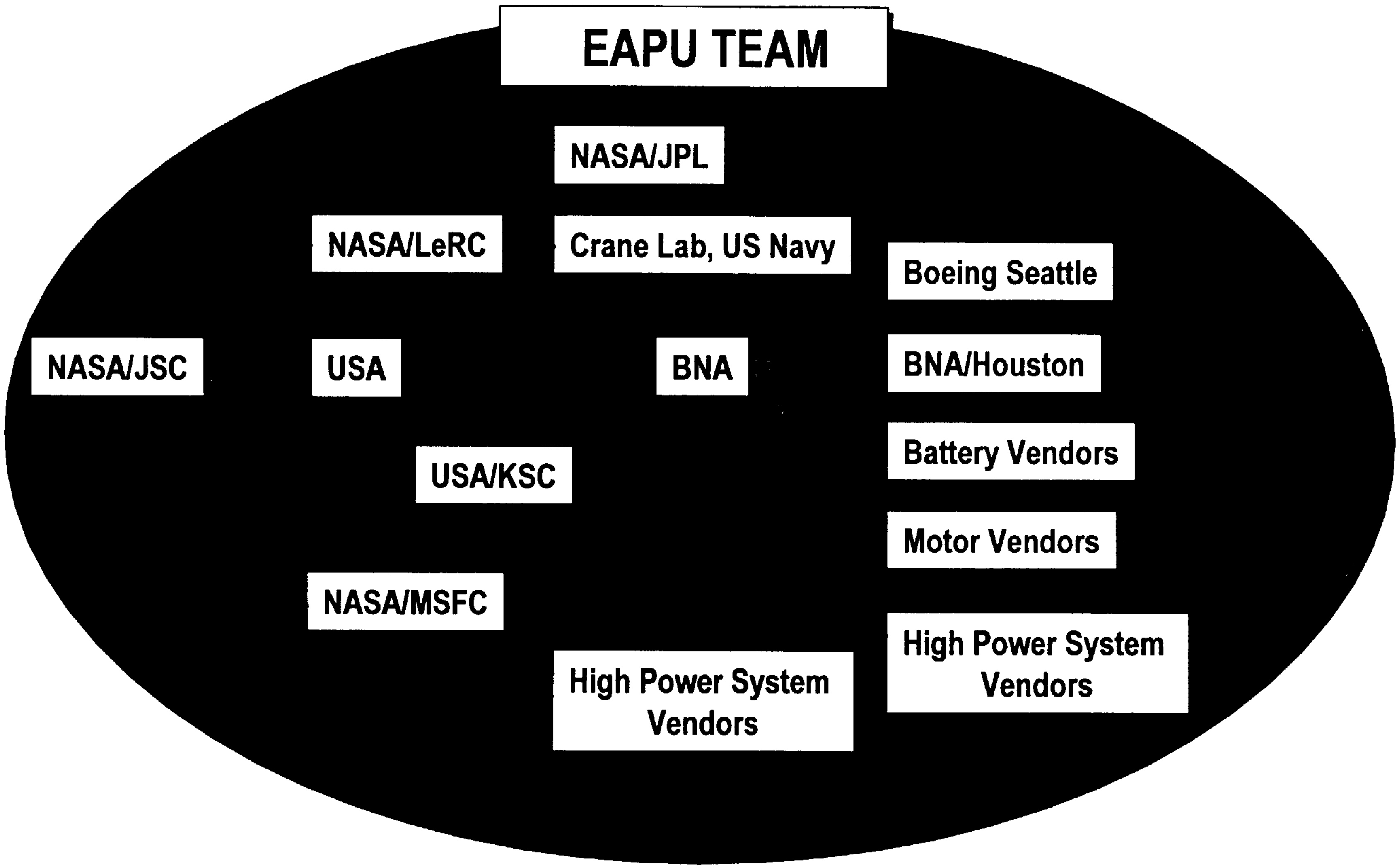
Working Together



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[redacted]

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Battery Design Requirement Definition

- DESIGN POINT ANALYSIS CONDUCTED TO EVALUATE FEASIBILITY
- BATTERY SUPPLIER RESPONSE MID-TERM (1 JULY '98)
- REVISED DESIGN DEFINITION :

  LOAD PROFILE
  FLY-SHEET SPECIFICATION

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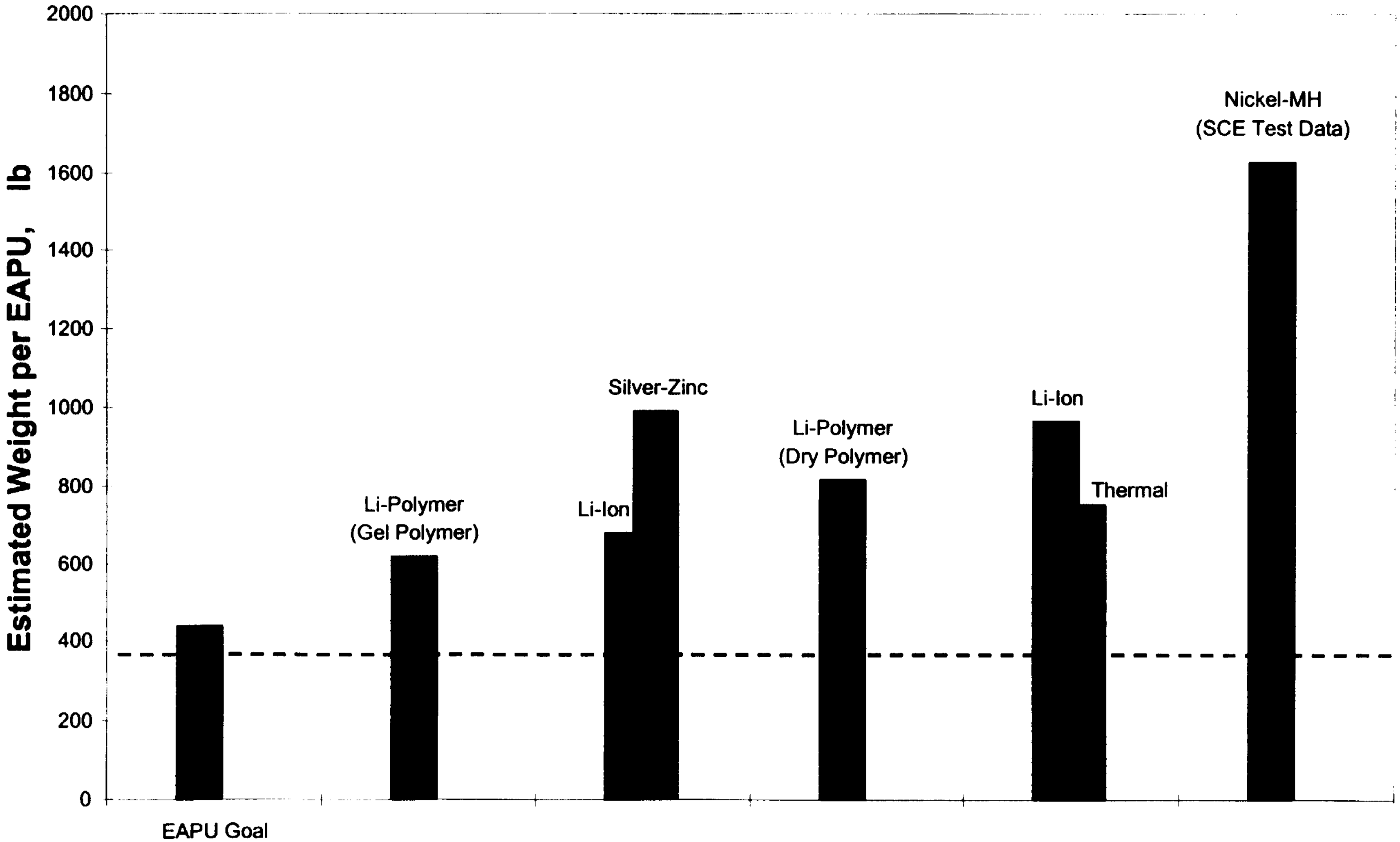
Battery Weight Estimates by Type (July, 1998)
(37 kW-hr Mission)



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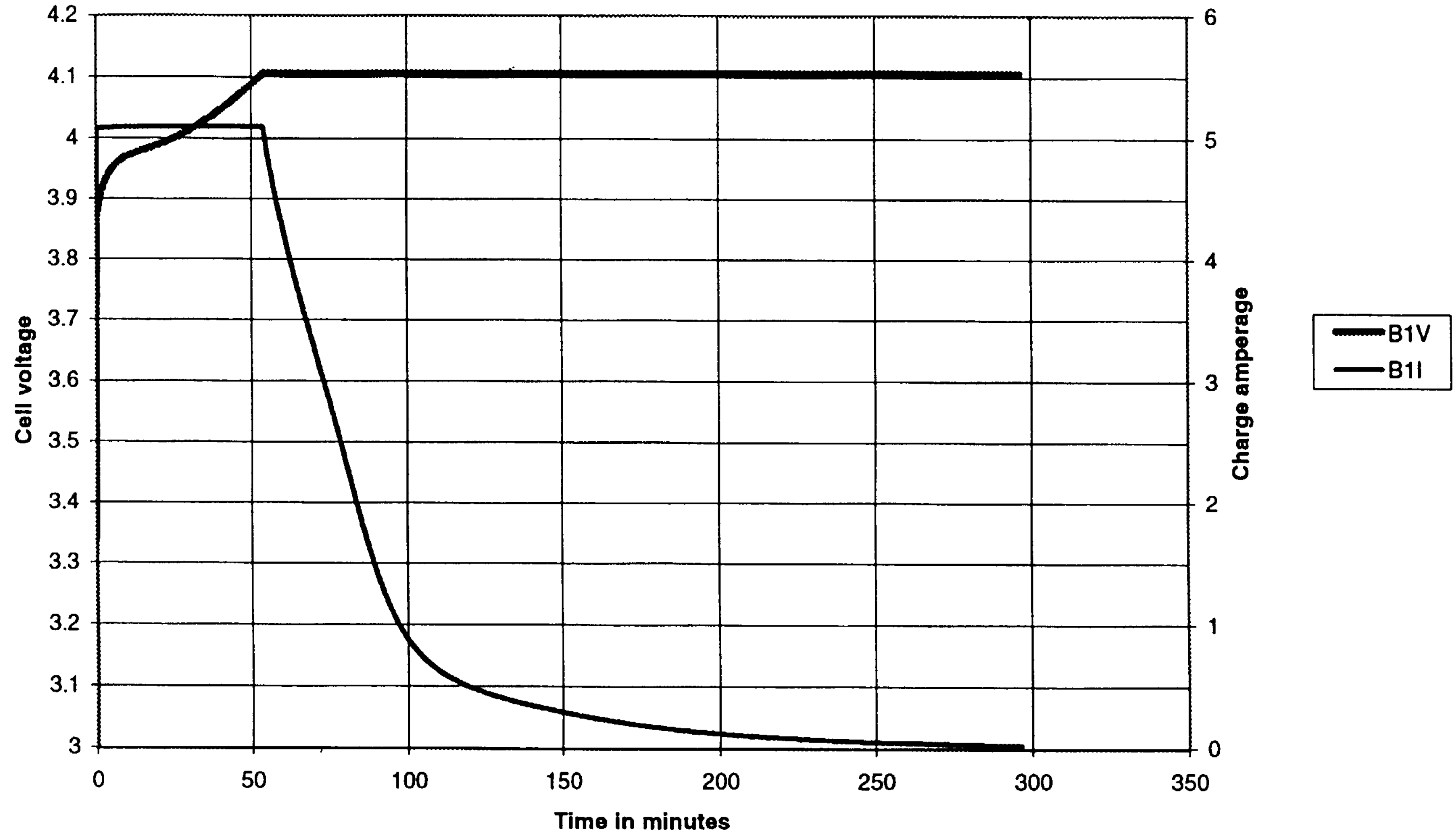
[redacted] 10AH Cells
Charge-up prior to EAPU Discharge Profile
Temperature: 20.2 Celsius
Charge: Imax=C/2; Vmax=4.1; 5 hours



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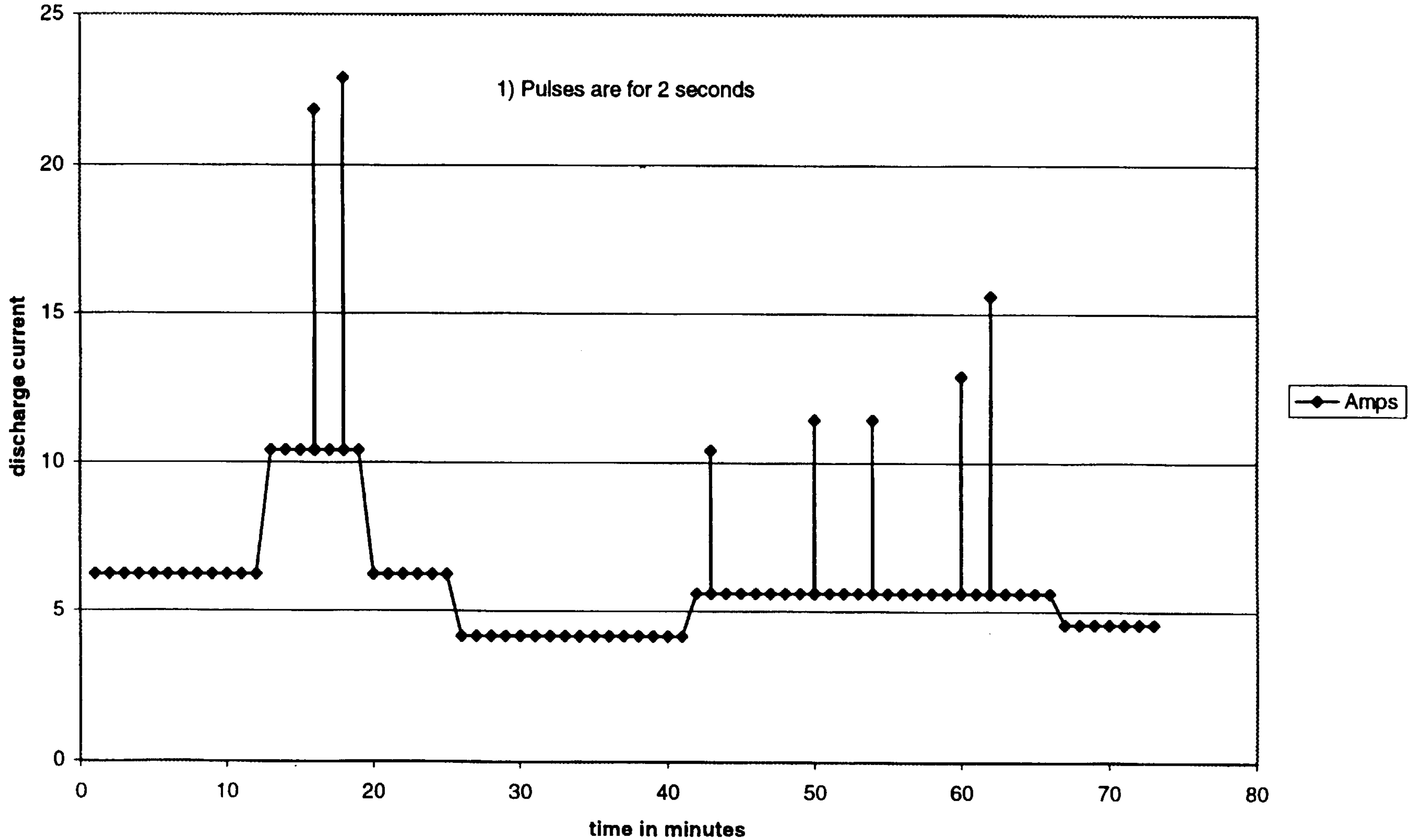
Constant Current Equivalent of Electric APU Power Profile
Discharge Current proportionated to acheive 80% DoD of 10AH Cell Rating



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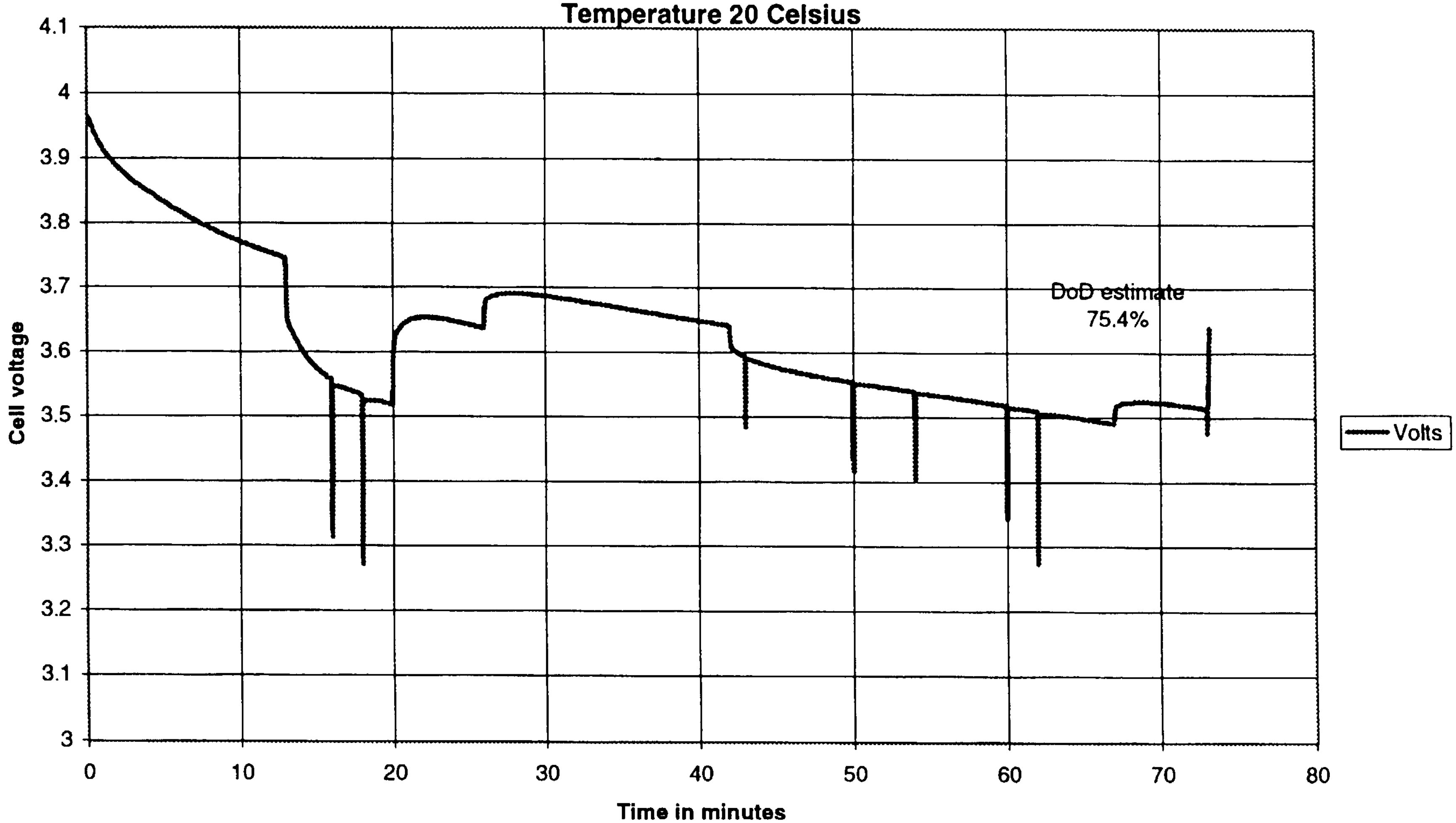
[redacted] 10AH EAPU Test
Discharge voltage vs. time
Charge: Imax=5A; Vmax=4.1V; 5 hours
Temperature 20 Celsius



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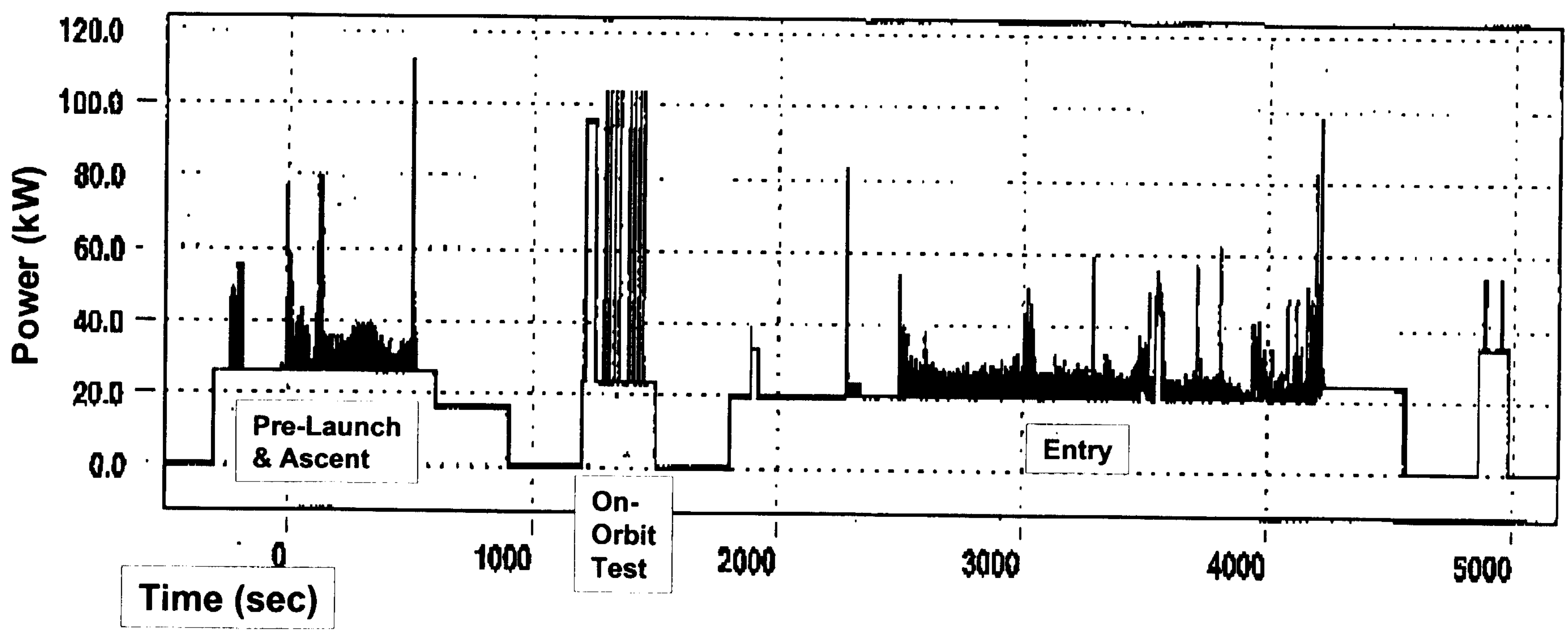
Revised EAPU Power Profile for Battery Vendor Testing

Off-Nominal Flight Condition and Two EAPU Entry Case



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Battery Design Requirement Fly-Sheet Specification

Battery Type:	**Lithium-Ion** **Lithium-Polymer**
Voltage-	
Nominal:	**270 V.**
Limit:	**250 V Min.**
Discharge-	
Time Line:	**91 Minutes**
Energy (minimum):	**37 kW-h above the 250 Volt. lower limit at 25 °C Min. on the 50th cycle within the 5 year calendar life requirement.**
Delivered Capacity:	**137 A-h (Min.)**
Power Profile:	**See attached chart.**
Peak power capability:	**125 kW with Power spikes 2 Seconds max.**

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Battery Design Requirement Fly-Sheet Specification

Load (Ave.):	**110 Amperes**
Size-	
Envelop (goal):	**0.76m (2.5 ft.) x 0.76m (2.5 ft.) x 0.76m (2.5 ft.)**
Weight (goal):	**200 kg (440 lb.)**
Temperature-	
Operation:	**25 °C to 35 °C**
Non-operational:	**-10 °C to 50 °C**
Heater:	**Maintain 25 °C Min. Temp.**
Life-	
Calendar:	**5 Years**
Cycle:	**50 Charge / Discharge cycles**

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Battery Design Requirement Fly-Sheet Specification

Environment-

Acceleration:	**From 0 to 5 g's, three orthogonal axes**
Random Vibration:	**Constant at 0.70 g^2/Hz from 100 to 400 Hz decreasing at -3 dB/octave from 400 to 2000 Hz.**
Shock:	**TBD**

Other Features-

Cell By-pass Electronics:	**In GSE for charging on ground only. BNA supplied for cell by-pass isolation on discharge.**
Sensors:	**Temperature Thermistors, 2/module.**
Connectors:	**Power, Sensor/heater, Individual cell monitor /charge and Module interconnection.**

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POTENTIAL EAPU BATTERY SUPPLIERS

SUPPLIER	TYPE	STATUS
3M	Li-Ion POLYMER	RFQ, EV BATTERY TEST
ALLIANT	Li-Ion POLYMER	RFQ, 150 AH
SAFT	Li-Ion	EV BATTERY TEST
EAGLE-PICHER	Li-Ion	RFQ, 125 AH
YARDNEY	Li-Ion	25 AH 1ST GENERATION
JAPAN STORAGE BATTERY	Li-Ion	RFQ, 100 AH
BLUE STAR	Li-Ion	RFQ, 100 AH 1ST GENERATION
ULTRALIFE	Li-Ion	10 AH 1ST GENERATION

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BATTERY DESIGN AND DEVELOPMENT

- Battery Assembly Concept
- Flight Battery Development Plan
- Battery Test Activity

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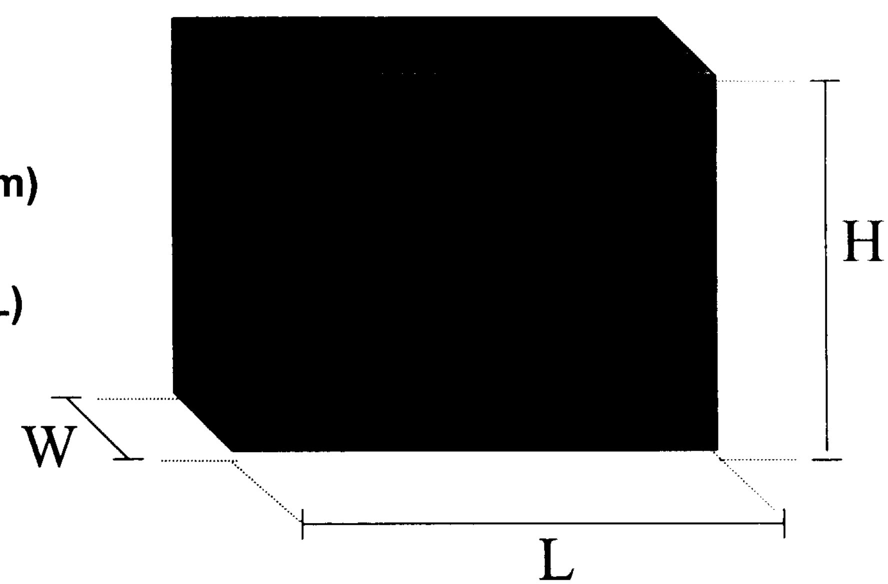
Construction of Battery Module

- Series Connected String of Li-ion Cells
- Series Redundancy Provided By Cell Isolation Switches
  - Isolation Switch Is Configured to Function As Cell Interconnect
- Thermal Path From the Cell Sides to the Baseplate Provided by Lightweight Aluminum Channels ("Taco Shells")
  - Channel Is Also Provides Structural Support to Cell; Similar to NASA Standard Battery
  - Small Gap Between Bottom of Cell and Channel Allows for Venting
- Endplates Hold Channels Together
- Channels Are Held Down By A Common Bracket To Baseplate
  - Baseplate Provides Thermal Management of Cell

Lithium-Ion Battery Cell Dimension for EAPU

- **Lithium-Ion battery cell for EAPU Rev. 10/19/98**
  - **Shape : Elliptic-Cylindrical or Prismatic**
  - **Rated Capacity : 125 A-h (Minimum)**
  - **Mass : 3.6 kg (Maximum)**
  - **Dimensions (mm) : 197 (H) x 180 (L) (Max.) x 50 (W)**
  - **Can to terminal isolation at both seals**
  - **Storage in inverted orientation for 3 years**
  - **Gas vent feature in bottom of cell can**
  - **Cell can sides flush at top and bottom**



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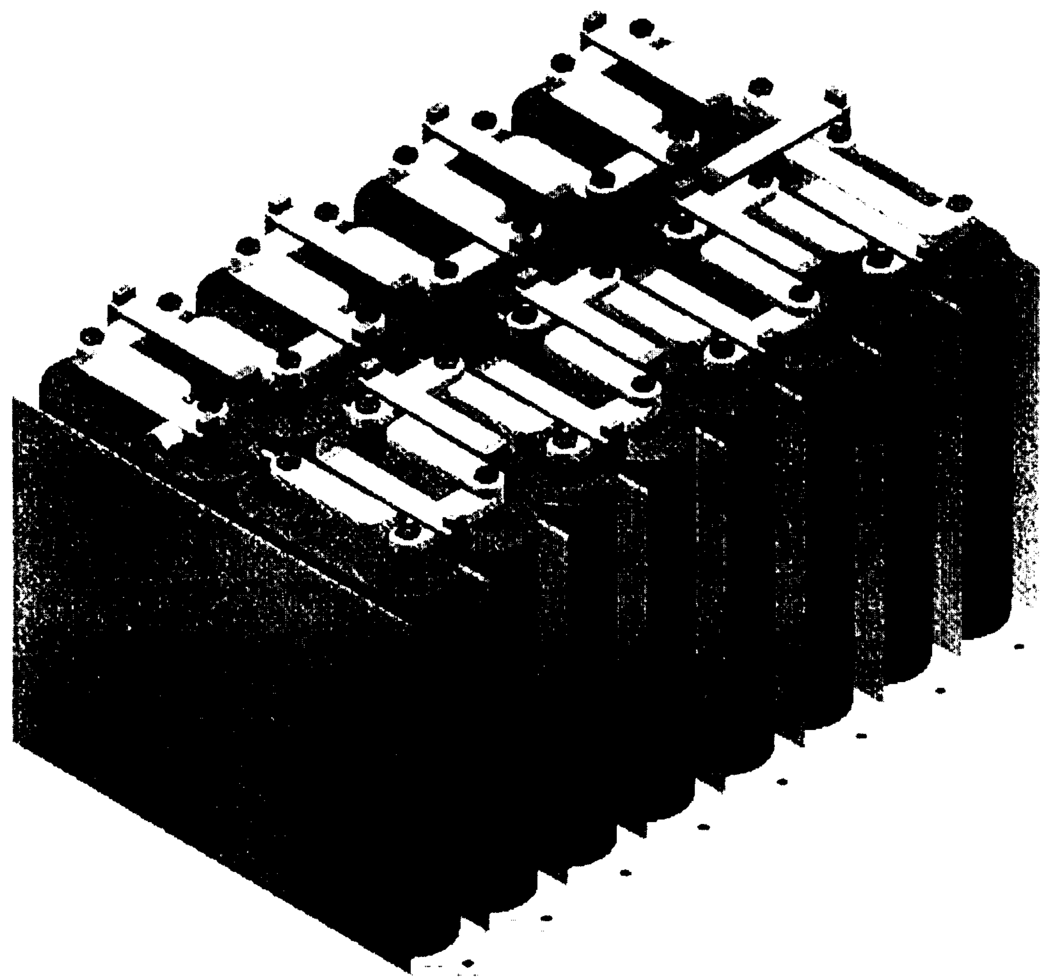
Battery Module Layout



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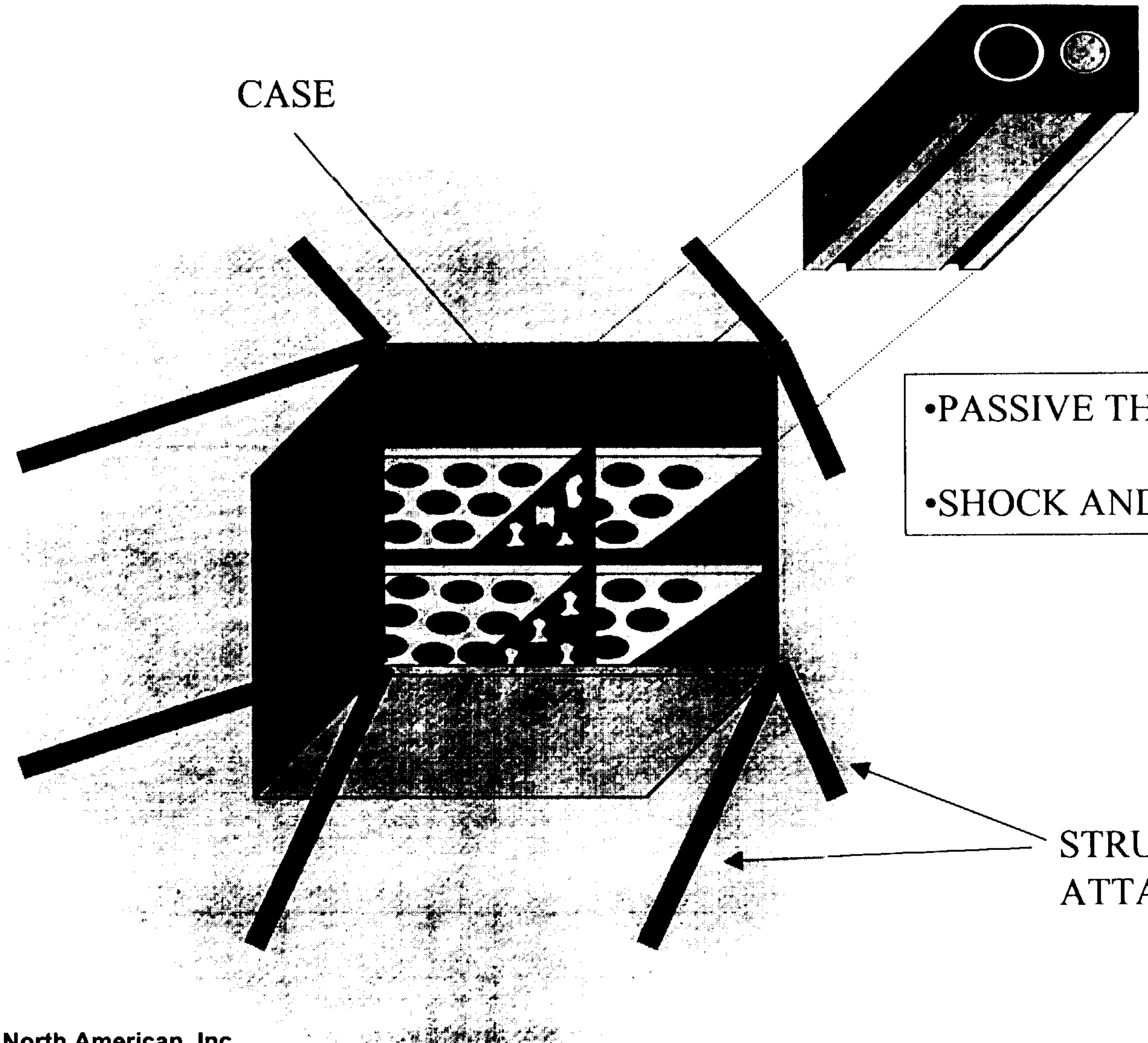
BATTERY ASSEMBLY CONCEPT



- •PASSIVE THERMAL CONTROL
- •SHOCK AND VIBRATION ISOLATION

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FLIGHT BATTERY DEVELOPMENT

- **Phase I** **Test Battery (100-150 Ah)**
  - 345 V Battery To Support EAPU System Demonstration
  - Cells Mounted On Three Thermal Control Plates, 32 Li-ion Cells/plate
  - Cells Are Demountable To Facilitate Configuration Changes
  - Plates Can Be Stacked In 2.5 X 2.5 X 2.5 Ft. Configuration
- **Phase II** **Module Configured Battery**
  - Fabricate Cell Modules
  - Complete Inter-cell, Connector And Instrumentation Wiring
  - Demonstrate Operation With Inter-module Connection Concepts
- **Phase III** **Integrated Battery Operated**
  - Assemble Battery Case Mockup
  - Demonstrate Module LRU Feature
  - Demonstrate Completed Battery Operation To EAPU Requirements

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BATTERY TEST ACTIVITY

LOCATION	TEST SAMPLE	*TYPE TESTING
PHANTOM BOEING WORKS	CELLS/ MODULES	MISSION ASSURANCE TECHNOLOGY ASSESSMENT
BNA	CELLS	BATTERY/MODULE FABRICATION
BOEING WASH.	CELLS	THERMAL PROPERTIES
SOUTHERN CALIF. EDISON	BATTERY	EAPU SYSTEM TEST BED
JPL	CELLS	SELECTED 50 AH CELL TESTS
LEWIS RESERARCH LABORATORY AT CRANE TEST FACILITY	CELLS	SAFETY ASSESSMENT

*CELL TESTING LIMITED TO SUPPLIERS THAT WILL PRODUCE LARGE CAPACITY CELLS SUITABLE FOR EAPU APPLICATION

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Battery Reliability And Safety Features

- Flight Energy Margin Confirmation.
- Battery Cells Are Series Redundant.
- Battery Cell By-pass Isolation During Discharge For Short And Open-circuit Conditions.
- Battery Cell Charge Current By-pass Provided In GSE Non- Flight Hardware.
- Shock And Vibration Isolation
- Passive Battery Heat Rejection With Heater Maintaining 25 ^{o} C Minimum Operating Temperature.

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Acknowledgment

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