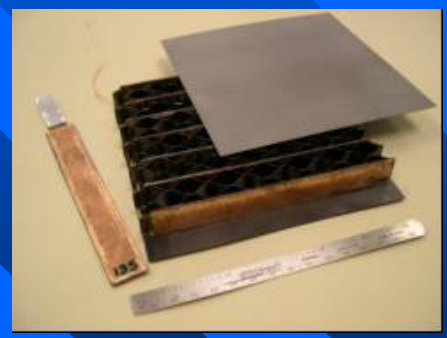
18th Annual AIAA/USU Conference on Small Satellites



Application of Emerging Structural Energy Storage Technology to Small Satellite Systems

Presenter: Phil Lyman (plyman@boundlesscorp.com)

Boundless Corporation & ATK-COI

August 10, 2004

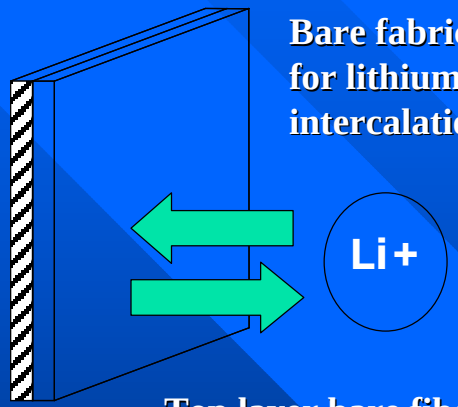
Structural Battery Concepts

- Structure and batteries are both significant items in spacecraft mass properties
- Effective *specific energy and power* of an energy storage device can be greatly improved by configuring battery elements to carry load in structure:

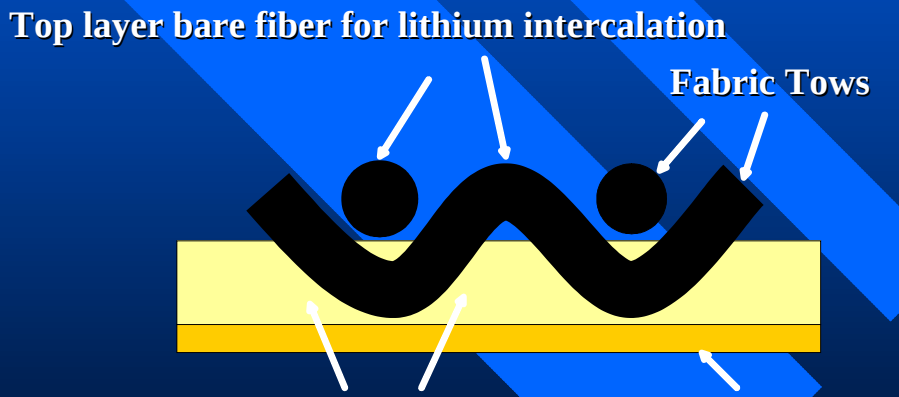
$$\text{Effective Specific Power} = \frac{\text{Power Delivered}}{(\text{Mass} - \text{Mass of Equivalent Inert Structure})}$$

- *Energy and power density* increases dramatically since a battery within a sandwich panel uses no extra space within the spacecraft
- Inactive materials, bulk current collectors & packaging, offer significant opportunity for dual use as structure

Dual-Function Carbon Composite Electrodes



Partially saturated carbon fabric. Fabric on bottom face is fully saturated with resin, while top face is bare fabric.



U.S. Patents Pending

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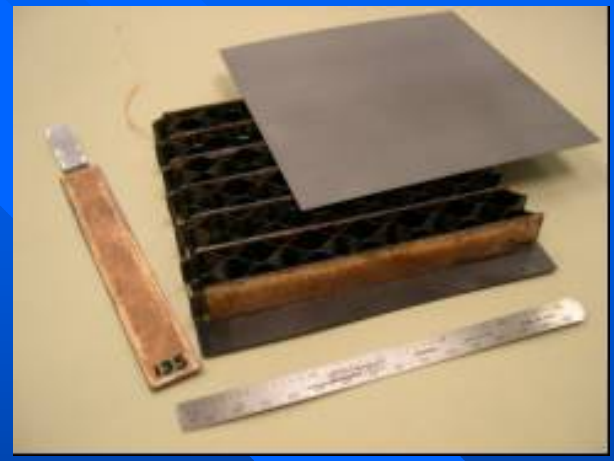
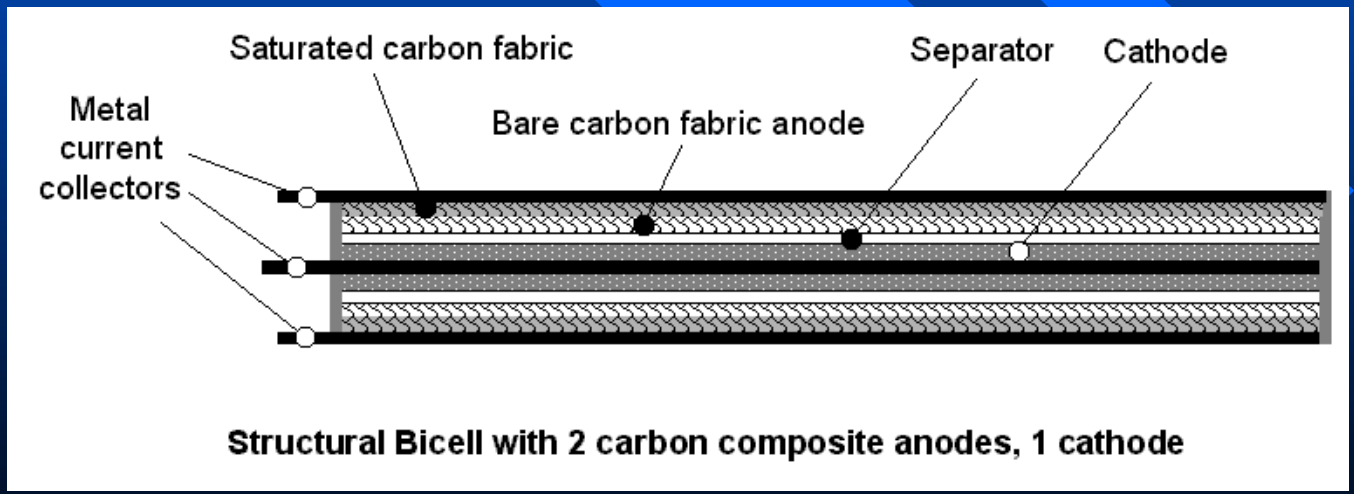
1st Prototype Panel Assemblies Delivered to NASA



Functional structural bicell
First prototype delivered to NASA in 1/03
~ 2 cm x 15 cm
212 mAh capacity
Present specific energy 80-85 Wh/kg not counting structural utility



Structural Bicell with 2 carbon composite anodes, 1 cathode

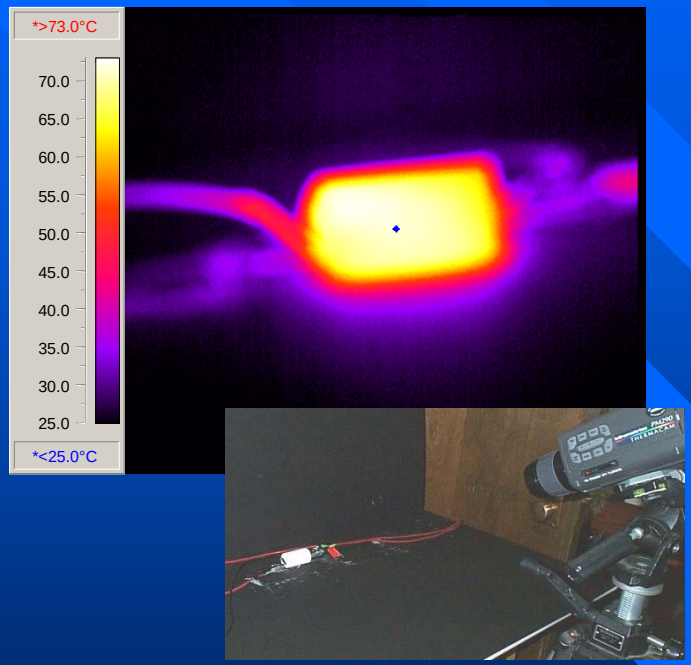
Engineering prototype for NASA uses flat bicells as strengthening ribs mixed with inert core.

Benefits Amplified in High Power Applications

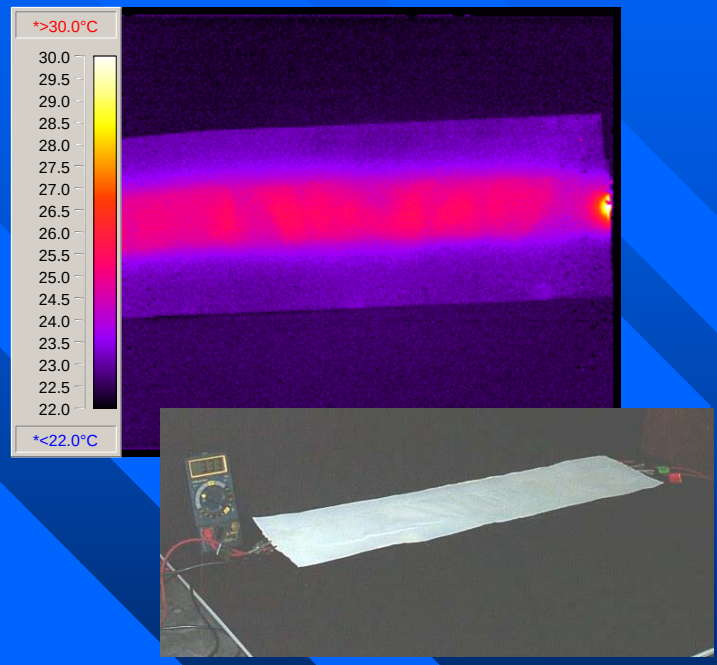
- High power batteries incorporate more inert material than low power batteries – more material to configure to serve as structure
  - To conduct current out
  - To conduct heat out
- Structural connections double as distributed terminals – decreasing current focusing
- Thin, spread-out cells facilitate heat removal

In High Power Versions Advantageous Design Affects *Both* the Numerator and Denominator in Effective Specific Power Equation

Thin Cell Design Allows High Power with Low Temperature Rise



Cylindrical Battery With Low Surface/Volume Ratio > 68 C



Flat Structural Battery With High Surface/Volume Ratio < 28 C

Distributing thin, flat battery elements within large volumes allows cooler operation and safe & reliable operation at higher power levels

Applications Must Be Driven by Performance Demands

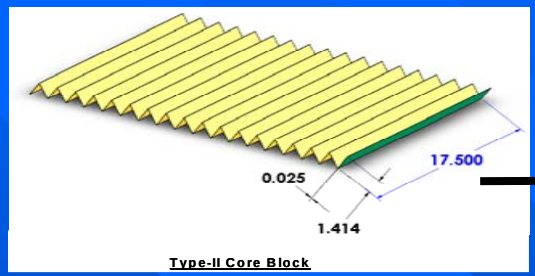
- Power Requirements
  - Energy storage requirement
  - Power – charge and discharge rates
  - Reliability – cycle life and depth-of-discharge
- Mass and volume constraints on system
- Structural Requirements
  - Strength to support launch loads
  - Stiffness to meet launch frequency limits

Multifunctional structures cross traditional subsystem boundaries

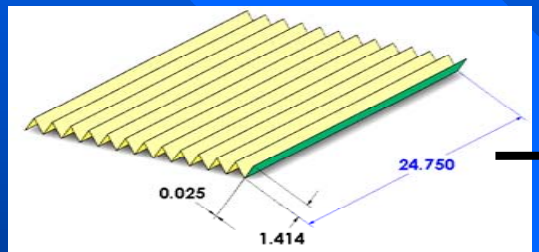
- Structural Energy Primary Effects:
  - Structure
  - Power
  - Thermal
  - Integration and Test
- Secondary Effects:
  - Attitude control
- Tertiary Effects:
  - Telecommunication
  - Propulsion
  - Data Handling & Flight Software

Engineers tackle similar issues of functional fusion for solar array assemblies - sometimes with the added complexity of deployment mechanisms

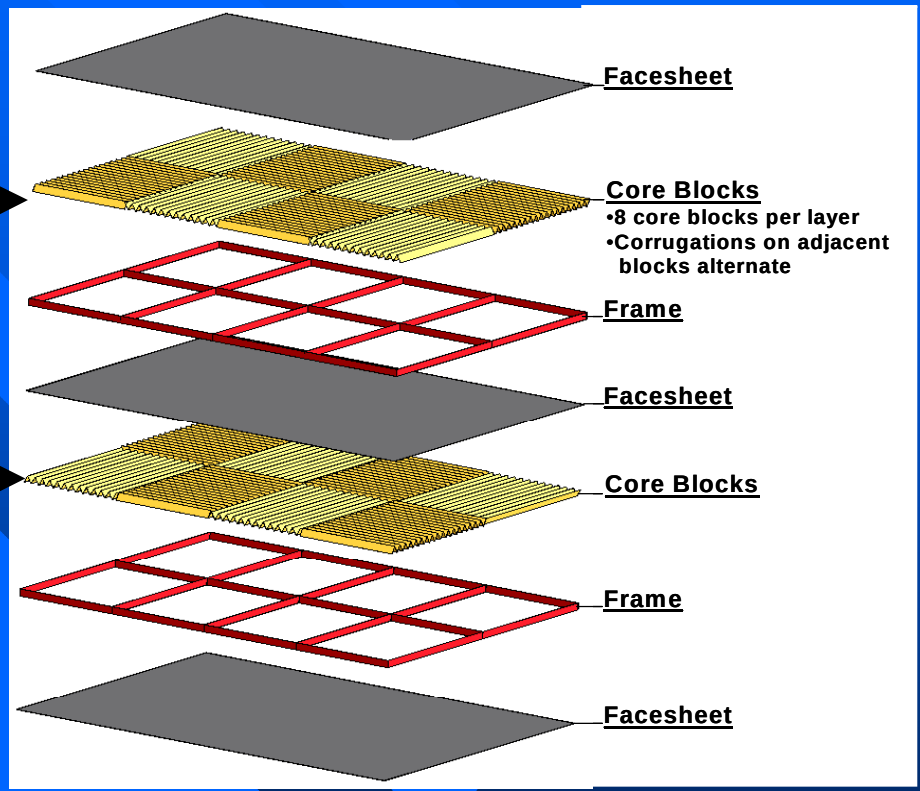
Simplest Implementation is as a Spacecraft Sidewall



Type-II Core Block



Type-I Core Block



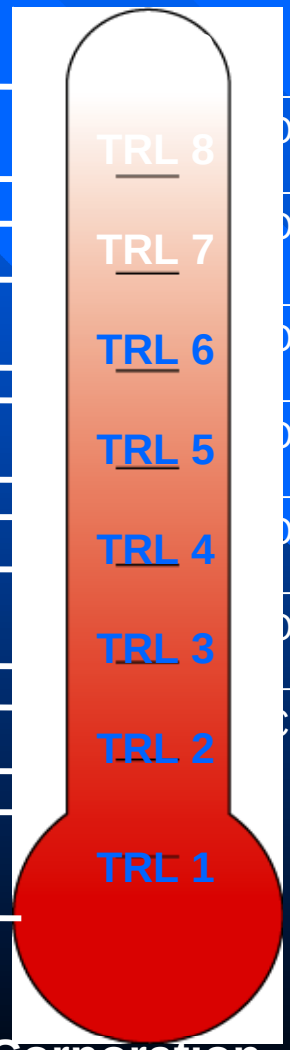
- Similar to many s/c designs having panel dedicated to battery (e.g. WIRE and ICESat)
- Impacts normal I&T flow which has late battery integration

- 50 x 70 x 2.3 cm
- 8 cells in series 28.5 volts, nominal discharge and 12.5 amp-hour capacity

Boundless is Developing Synergistic Technologies

- High-power, low-cost separators for lithium ion batteries: both stand-alone and laminates
- Structural Ultracapacitor technologies
- High-power, nano-structured cathode material
- EV & HEV modular battery systems with distributed fault protection and equalization circuitry

PROJECTION OF TECHNOLOGY READINESS: *AT PRESENT RATE OF FUNDING*



System Test, Launch and Operations

System/Subsys Development

Technology Demonstration

Technology Development

Research to Prove Feasibility

Basic Technology Research

Oct 09

Oct 08

Oct 07

Oct 06

Oct 05

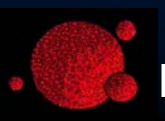
Oct 04

Current

- **System ready for deployment**
- **Actual system completed and "flight qualified" through test and demo (Ground or Flight)**
- **System prototype demonstration in a space environment**
- **Structural energy storage subsystem validation**
- **Environmental (thermal, vacuum) validation, thermal and electrical management components**
- **Prototype for specific high power application and performance verification**
- **Lithium intercalation capacity and partial saturation of carbon fabric shown, low power bicells incorporated into functional panels**
- **Conceptual stage**

Thank You!

We hope to help enhance performance on your future small satellite systems



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