EaglePicher Technologies

Energy Storage Solutions for Aviation Applications

November 2020
Company Overview
EaglePicher at a Glance

177 years in business
95+ years of research in POWER
80+ years of defense BATTERY development
60+ years POWERING space missions
20+ years track record supplying medical BATTERIES

9 North America manufacturing and R&D facilities

850+ North American team members
160+ engineers, scientists and chemists
60+ veteran and active duty team members

Missiles and Munitions
Energetics
Directed Energy Weapons
Space
Unmanned Systems
Military Aviation

Billions of Cell Hours in Space, Zero Mission Failures

Focused strategic business units:
Defense
Aerospace
Medical
Innovating, Investing and Growing
# Battery Chemistries and Technologies for Diverse Industries

<table>
<thead>
<tr>
<th></th>
<th>Thermal</th>
<th>Lithium-ion</th>
<th>Lithium Carbon Monofluoride</th>
<th>Lithium Thionyl Chloride</th>
<th>Lithium Oxyhalide</th>
<th>Silver Zinc</th>
<th>Energetic Devices</th>
<th>Battery Management Systems</th>
</tr>
</thead>
</table>
EaglePicher’s focus is on advancing the attributes of our core chemistries to allow us to maintain our advantage in the power source arena.

**Innovation Priorities**

**Run-time**
- Next generation CFx
- Next generation lithium ion

**Power**
- Cell design
- Thermal management

**Safety**
- Reduced flammability electrolyte
- Thermal mitigation technologies

**Packaging**
- Pouch cells
- Solid state lithium ion
- Miniaturization
Energy Storage Solutions for Aviation Applications
Market Trends

The driving forces behind innovation in hybrid-electric aviation:

+ Global climate change and concerns over greenhouse gas emissions
+ Initial successes in innovative technologies and business models that challenge traditional models
+ Defense technology spinoffs
+ Technological breakthroughs: chemistries, formats, etc.
+ Government and private investment
## EaglePicher’s Commercial Aviation Heritage

<table>
<thead>
<tr>
<th>Platforms</th>
<th>Capacity (Ah)</th>
<th>Voltage (VDC)</th>
<th>COTS Cells</th>
<th>Weight (lb)</th>
<th>EaglePicher Battery</th>
</tr>
</thead>
</table>
| Main Engine Start  
Light Jet and Turboprop  
Flight Instrumentation  
Test Vehicle | 28 | 28 | 26650 LFP | 38 | ![Battery](image1.png) |
| Main Engine Start  
Rotorcraft (2)  
UAV's (2) | 48 | 2 | 26650 LFP | 54 | ![Battery](image2.png) |
| Emergency Power  
EC170 Stair Actuator | 6 | 24 | 18650 NCA | 6.5 | ![Battery](image3.png) |
| Main Start  
Excalibur UAV | 19 | 19 | Pouch NCA | 6.5 | ![Battery](image4.png) |
## EaglePicher’s Military Aviation Heritage

<table>
<thead>
<tr>
<th>Platforms</th>
<th>Capacity (Ah)</th>
<th>Voltage (VDC)</th>
<th>EaglePicher Cells</th>
<th>Weight (lb)</th>
<th>EaglePicher Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Main Engine Start</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B-2 Spirit</td>
<td>55</td>
<td>28</td>
<td>Prismatic NCA</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>Classified aircraft HALE/Global Hawk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Main Engine Start</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Military aircraft (2)</td>
<td>6</td>
<td>270</td>
<td>Prismatic NCA</td>
<td>107</td>
<td></td>
</tr>
</tbody>
</table>
Joint Strike Fighter (JSF) F-35 Program Battery Development

+ Key driver: support high rate discharges at very low temperatures at end of life
+ Targeting improved chemistry performance and thermal management to allow quick and efficient use of heater power
+ Business case: longer life, design modularity, expanded margin = higher performance and reduced logistical support
Holistic Approach to Safety

Battery management system interface
Protection, optimization, communication

Propagation prevention
Containment, direction, dissipation

Thermal management
Remove heat, manage heat dissipation

Performance, abuse tolerance, response control
Chemistry and form factor
Safety Standards and Testing

Battery requirements fall into three basic categories

- **Electrical**
  - Voltage, current, power, energy, etc.
  - Fault tolerance and redundancy
  - State of health
  - Electrical interfaces

- **Mechanical**
  - Physical dimensions or envelope
  - Thermal performance
  - Mechanical interfaces
  - Environmental constraints

- **Safety**
  - Human
  - Environmental
  - System

Battery requirements address three basic states of hardware

- **Storage**
- **Active or in use**
- **Transportation**
# Key Overarching Documents Cover Battery Design and Safety Aspects

<table>
<thead>
<tr>
<th>Context</th>
<th>Defense Aviation</th>
<th>Commercial Aviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Requirements</td>
<td>MIL-PRF-29595A</td>
<td>DO-311A</td>
</tr>
<tr>
<td>System Safety</td>
<td>3.8 NAVSEAINST 9310.1 (S9310, SG270)</td>
<td>2.2.2, 2.4.5 DO-311A</td>
</tr>
<tr>
<td>Environments</td>
<td>3.6 MIL-STD-810G</td>
<td>2.3 DO-160G, Sections 4-14</td>
</tr>
<tr>
<td>EMI/EMC</td>
<td>4.5.12 MIL-STD-461G</td>
<td>2.3.1 DO-160G, Sections 15-23, 25</td>
</tr>
<tr>
<td>Software Development</td>
<td>6.17.4 IEEE 12207; 12207.1</td>
<td>2.1.2 DO-178C</td>
</tr>
<tr>
<td>Hardware Development</td>
<td>n/a none</td>
<td>2.1.2 DO-254</td>
</tr>
<tr>
<td>FMECA</td>
<td>6.17.3 SAE ARP5580</td>
<td>App C SAE ARP4761</td>
</tr>
<tr>
<td>Transportation</td>
<td>6.18 49 CFR 173.185 invokes UN/DOT 38.3</td>
<td>2.3.1k UN 38.3 T4 in-lieu of Crash Safety</td>
</tr>
</tbody>
</table>

Both invoke, either directly or via supplemental specifications

- Design approach, including software/hardware development processes
- Performance and environments
- Safety expectations, including testing methods
## Safety Contrasts: DO-311A vs MIL-PRF-29595A Expectations

<table>
<thead>
<tr>
<th>Test Description</th>
<th>Military MIL-PRF-29595A / S9310.1</th>
<th>Commercial DO-311A / DO-160G</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nail or Bullet Penetration</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Battery Crush</td>
<td>None</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Crash Safety</td>
<td></td>
<td></td>
<td>DO: DO-160G Section 7.0 - allows UN/DOT T.4</td>
</tr>
<tr>
<td>Short-Circuit</td>
<td></td>
<td>Less stressful than MIL</td>
<td>DO: less time, &amp; can be higher load/less current</td>
</tr>
<tr>
<td>Overcharge</td>
<td></td>
<td>Less stressful than MIL</td>
<td>MIL: requires at least 20 cycles</td>
</tr>
<tr>
<td>Overdischarge</td>
<td></td>
<td>Less stressful than MIL</td>
<td>MIL: requires at least 20 cycles</td>
</tr>
<tr>
<td>High Temperature Test</td>
<td>Optional</td>
<td></td>
<td>DO: optional in place of overcharge</td>
</tr>
<tr>
<td>Electrical Device Safety</td>
<td>None</td>
<td>None</td>
<td>MIL: tests effectiveness of subsystems to stress</td>
</tr>
<tr>
<td>Aging</td>
<td></td>
<td>None</td>
<td>MIL: tests cumulative cycling effects on failure</td>
</tr>
<tr>
<td>Propagation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Explosion Containment</td>
<td>None</td>
<td></td>
<td>DO: tests battery container resiliency</td>
</tr>
<tr>
<td>Off-gas Analyses</td>
<td></td>
<td>None</td>
<td>MIL: SG270 scenarios to be based on CONOPS</td>
</tr>
</tbody>
</table>
Electric Power Innovations
Commercial of the Shelf (COTS) Cell Modular Systems

+ Scalable cell pack designs for 18650 and 22710 cylindrical COTS cells
+ Proven cell propagation mitigation across all pack sizes
+ Designs meet latest NANSA standards for manned space (JSC20793) and recent UL lithium-ion cell safety seminars
+ All packs include thermal management and redundant cell isolation to mounting surface
+ Cells are individually fused and thermally stabilized
Battery Management System Architecture and Safety

+ Usual battery management system (BMS) functions and protections:
  + Charge and discharge control
  + Telemetry (voltage, current and temperature)
  + Status (state of charge, state of health and failure status)
  + Fault protection (voltage, current, temperature, leakage current and short detection)

+ Redundancies to ensure continued operation
  + Microprocessor utilization
  + Built in dual memory
  + Analog redundant parallel monitoring

+ Additional Attributes
  + Cell Balancing: Passive or Active (processor controlled)
  + Charge cycle counting
  + State of health projections
  + Local data storage and trending
  + Local bit error and self test modes

+ “Battery Compartmentalization” MIL-PRF-29595 requirement to isolate cells from other functioning subsystems

BMS is NOT just electronics but it is a way to maximize the battery life and cost efficacy.
Conformal Batteries

- Using EaglePicher pouched cells, form-fitting batteries can be made that flex in the final configuration.
- This design will migrate battery (cell) capacity to the existing area within the wing where liquid fuels are presently contained.
- The use of this technology, moving the cell mass, into the wings will allow existing airframe and flight stability system to migrate to electric flight with ease.
Hybridization of power and energy solutions to provide optimized performance

- Bus voltage stabilization reduces strain on generators and other equipment
  - >80% reduction in peak to peak voltage transients
- Power for take-off and flight surfaces, Energy for long duration flight
- Increased life by reducing stress on energy source
- Reduced size and weight by increased energy and power densities
- Independent solutions are replaceable for maintenance and upgrades
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