EAGLEPICHER TECHNOLOGIES

EaglePicher Technologies

Energy Storage Solutions for Aviation Applications

November 2020

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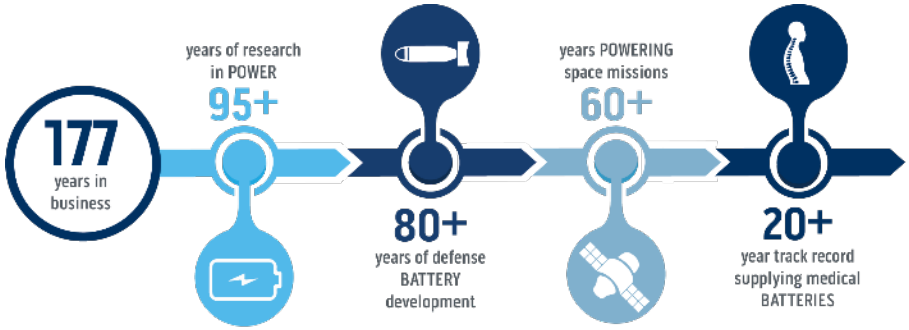
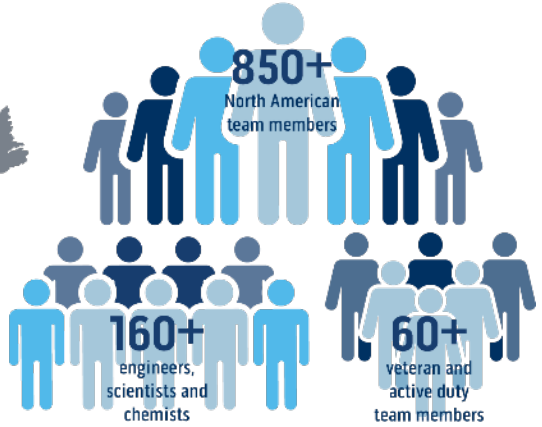
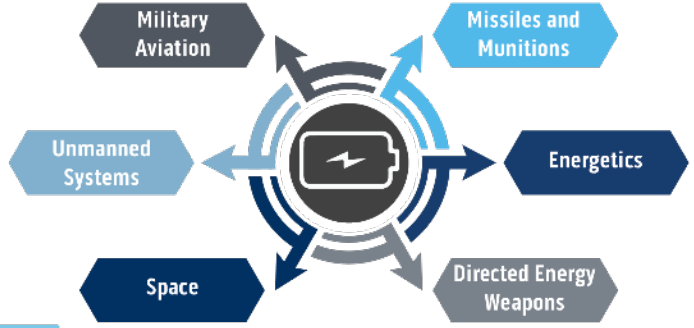
Company Overview

EaglePicher at a Glance

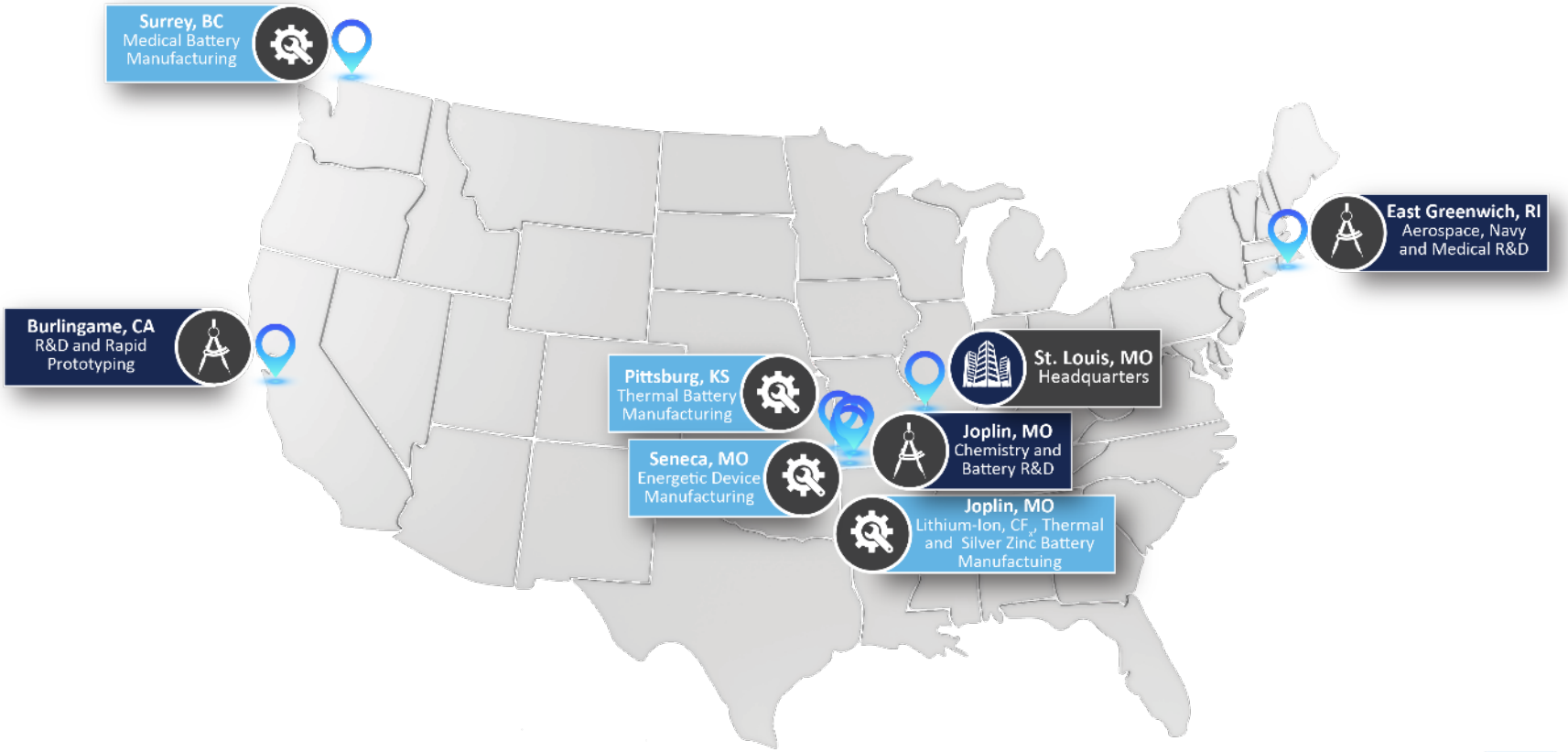






Billions of Cell Hours in Space, **Zero** Mission Failures

Innovating, Investing and Growing



Battery Chemistries and Technologies for Diverse Industries

	Thermal	Lithium-ion	Lithium Carbon Monoflouride	Lithium Thionyl Chloride	Lithium Oxyhalide	Silver Zinc	Energetic Devices	Battery Management Systems
Missiles, Torpedoes and Fuzes	✓	✓	✓	✓	✓	✓	✓	✓
Underwater Vehicles		✓				✓	✓	✓
Directed Energy Weapons		✓						✓
Portable Power		✓	✓					✓
Space Launch Vehicles	✓	✓	✓			✓	✓	✓
Satellites		✓						✓
Space Exploration	✓	✓	✓			✓	✓	✓
Unmanned Aerial Vehicles		✓	✓					✓
Military Aviation	✓	✓	✓	✓		✓	✓	✓
Civil/Commercial Aviation		✓	✓	✓			✓	✓
Medical		✓	✓	✓				

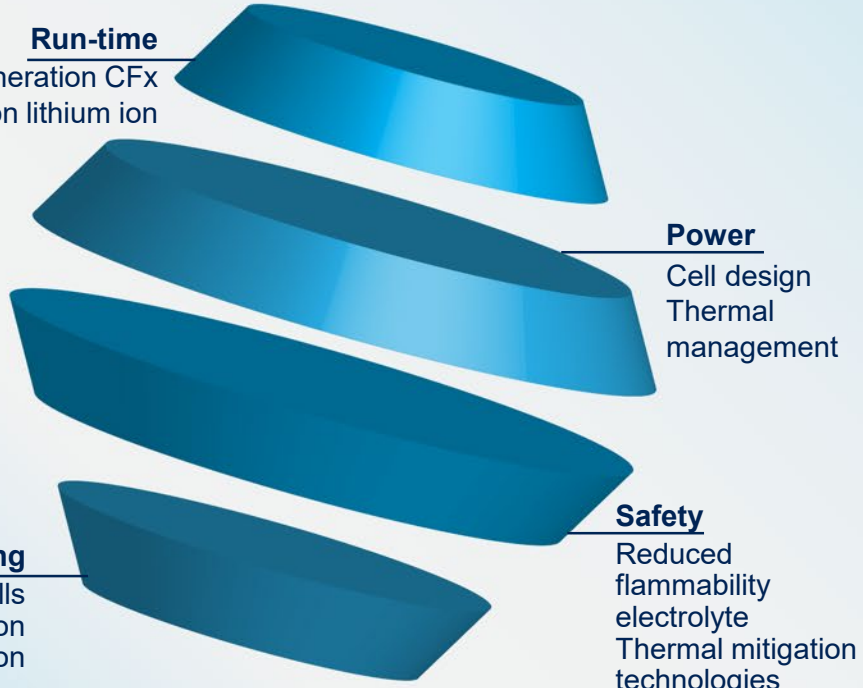
Innovation Priorities

Run-time

Power

Safety

Packaging



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

EaglePicher's focus is on advancing the attributes of our core chemistries to allow us to maintain our advantage in the power source arena

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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

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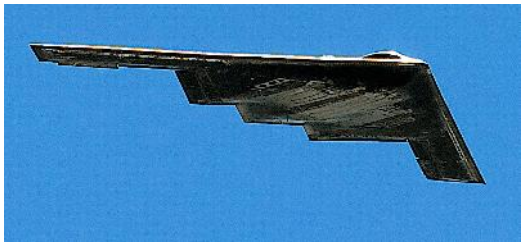
EaglePicher's Commercial Aviation Heritage

Platforms	Capacity (Ah)	Voltage (VDC)	COTS Cells	Weight (lb)	EaglePicher Battery	
Main Engine Start Light Jet and Turboprop **Flight Instrumentation** Test Vehicle	28	28	26650 LFP	38		
Main Engine Start Rotorcraft (2) UAV's (2)	48	2	26650 LFP	54		
Emergency Power EC170 Stair Actuator	6	24	18650 NCA	6.5		
Main Start Excalibur UAV	19	19	Pouch NCA	6.5		

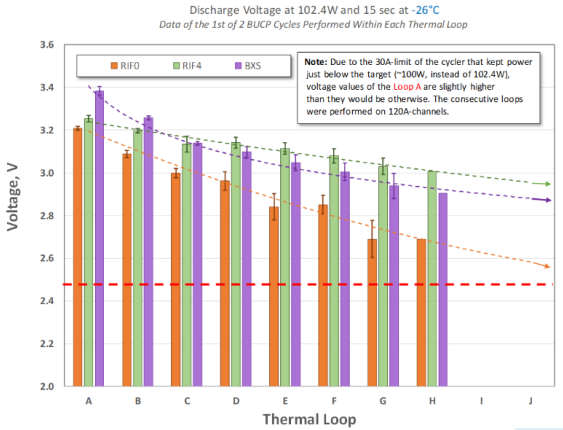
EaglePicher's Military Aviation Heritage

Platforms	Capacity (Ah)	Voltage (VDC)	EaglePicher Cells	Weight (lb)	EaglePicher Battery
Main Engine Start B-2 Spirit Classified aircraft HALE/Global Hawk	55	28	Prismatic NCA	38	
Main Engine Start Military aircraft (2)	6	270	Prismatic NCA	107	



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



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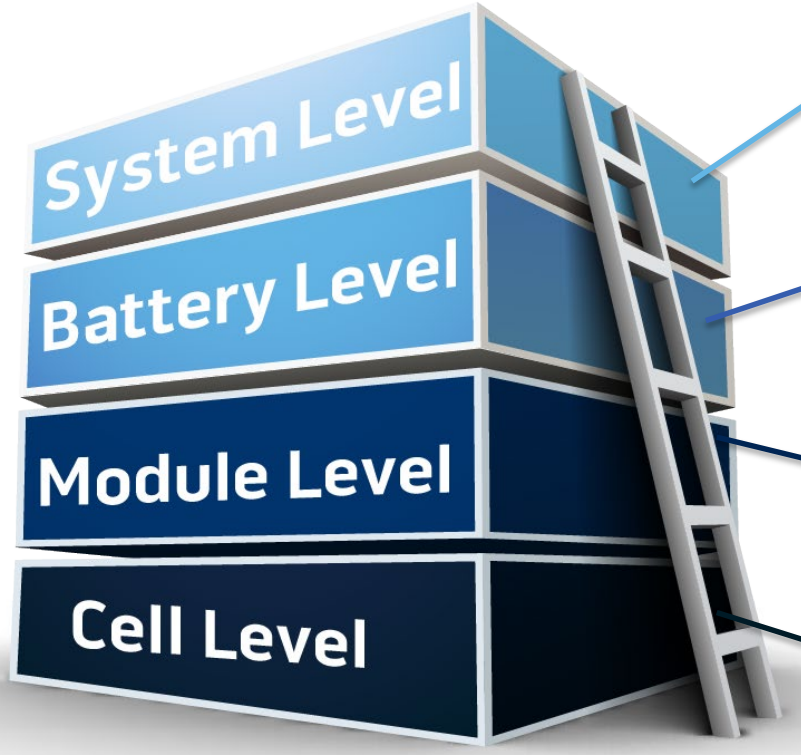
Holistic Approach to Safety



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

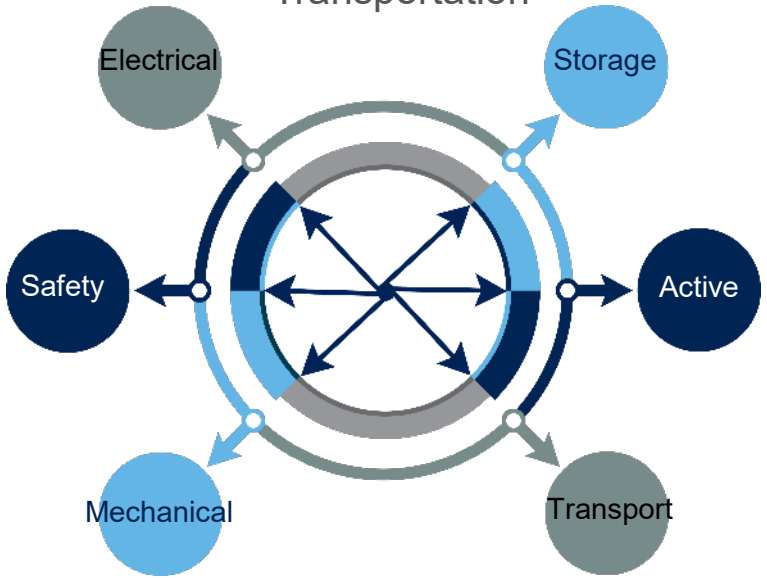
Safety Standards and Testing

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



Aviation Minimum Operating Performance Standard (MOPS)

Key Overarching Documents Cover Battery Design and Safety Aspects

- Military Aviation: MIL-PRF-29595A general specifications for batteries and cells, lithium, rechargeable, aircraft
  - NAVAIR, April 2011
- Commercial Aviation: DO-311A minimum operational performance standard for rechargeable, lithium batteries and systems
  - RTCA, December 2017

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

- 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

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

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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 sub-systems

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

Pouch Cells

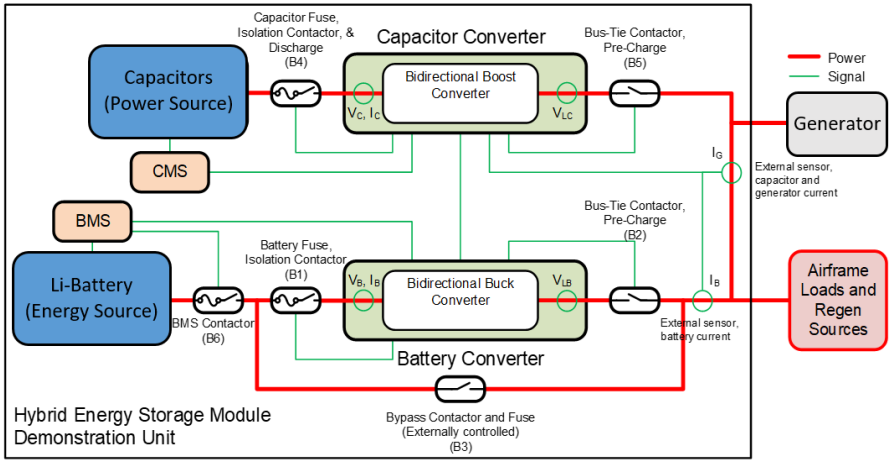
Batteries

Conformal Batteries

Hybridization

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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