EAGLEPICHER TECHNOLOGIES

EaglePicher NASA Battery Workshop 2025/6

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Overview

- In tandem with NASA/U.S. Space Force initiatives, the commercial Space market is seeking to utilize off-the-shelf solutions from the industry where possible. These projects are driving the Space market to shorter development times. The creation of a scalable design for cell packs reduces the risk while shortening the development time along with manufacturing and battery test requirements. Leveraging the extensive heritage of our pack design and manufacturing expertise, EaglePicher has created a “playbook” on how to design modular cell packs that meet both non-crewed Space and crewed Space missions. This simplified design playbook has been validated by the implementation of these design parameters in multiple cell packs, and facilitates providing timely solutions with reduced testing and overall cost.

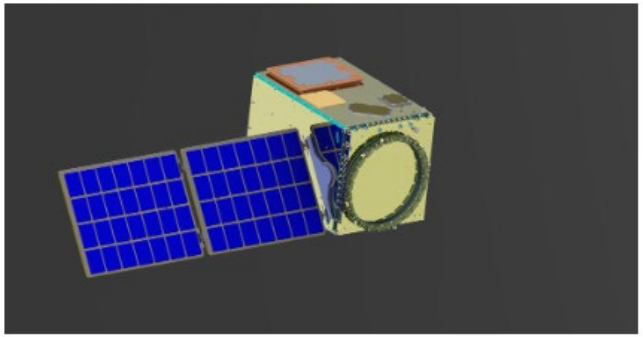
Government Motivators

- Space Force
  - Gen. Stephen Whiting, who leads the command, said the new strategy, which was signed out in November, focuses on SPACECOM's core tasks and how commercial Space capabilities fit within those areas. The update follows the release of two high-level commercial integration strategies earlier this year — the first from the Office of the Secretary of Defense and the second from the Space Force.
  - Last year, for example, the Space Force created a Commercial Space Office and charged it with identifying more opportunities to buy commercial systems and services. (Defense news 12/16/24)
- Air Force plans
  - The 16th Air Force is offering a CSO authorized by 10 USC 3458 and DFARS 212.70 Defense Commercial Solutions Opening. Under a CSO, the USAF may competitively award contracts to proposals received in response to a general solicitation, similar to a Broad Agency Announcement (BAA), to acquire innovative commercial items, technologies, and services, based on a review of proposals by scientific, technological, or other subject matter expert peers within the USAF. Under this CSO, all items, technologies, and services shall be treated as commercial items.
  - The USAF intends to obtain "innovative" solutions or potential new capabilities that fulfill requirements, close capability gaps, or provide potential technology advancements. Solutions may include existing technologies or procedures, not currently in use by the USAF, that would enhance or streamline USAF mission capabilities. "Innovative" is defined as any technology, process or method that is new as of the date of submission of a proposal. It also includes any new application of an existing technology, process, or method. (DOD Notice FA7037-23-S-C0001)
- NASA
  - NASA's COTS (Commercial Orbital Transportation Services) program used public-private partnerships (PPPs) to spur private development of cargo delivery to the ISS, successfully fostering companies like SpaceX and Northrop Grumman to create new launch and cargo systems. NASA also uses COTS components—commercial electronics not built to strict military specs—in Spacecraft, requiring extensive testing to qualify them for Space, enabling lower costs and faster tech adoption, especially in risk-tolerant missions like CubeSats.

Commercial Space

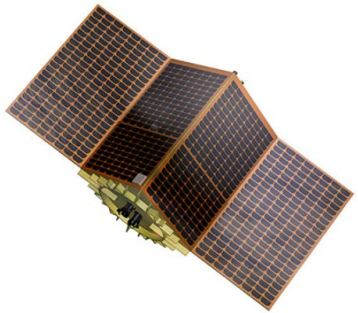
- Move to lower cost small sat
- Increase use of <200kg satellites
- Supplying platforms to US Government projects
- Shortened lead times
  - Was 24 to 36 months from contract to flight integration
  - Now 18 to 24 months contact to integration
  - Future will be less
- Mission duration is less

100 kg-class Small Satellite Platform



Courtesy of SwRI

S-200 Scaled Microsatellite Platform



SatCatalog

Project Timeline

- In the 2015 AeroSpace Corporation presentation, the average program development cycle was length 7.5 yrs

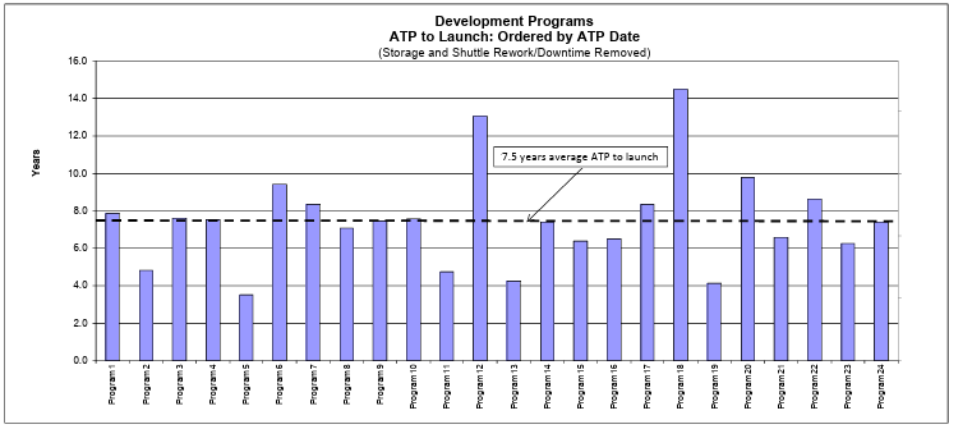
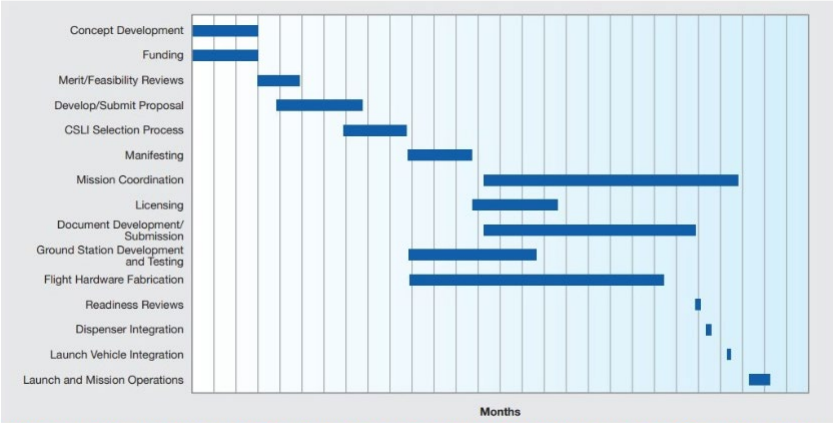


Figure 1. Development programs: authority to proceed to launch.

3. Commercial Satellite Program Development Approach

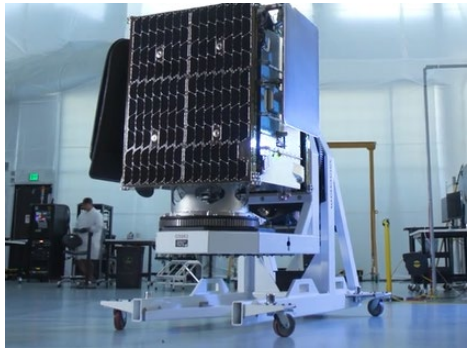
- In 2025, NASA presented
- 25 months from concept to launch
- Hardware development of 12 months



How the potential phases of a project come together. By CubeSat 101 Basic Concepts and Processes for First-Time CubeSat Developers. NASA CubeSat Launch Initiative. Image courtesy of NASA.

Commercial Space

- Projects range from new satellites to crew-rated craft
- These projects can also provide power for lengthening existing Space craft life or de-orbiting
- Our recent move to standard low-cost batteries has taken our NASA heritage and learned how to compete in smaller commercial markets

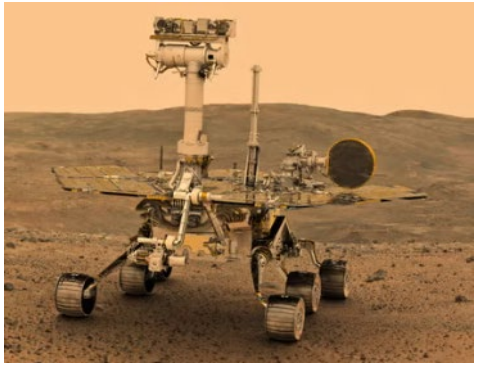


Space News

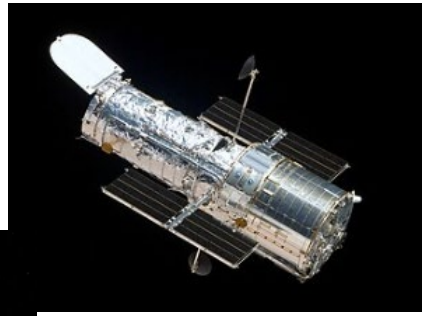
EAGLEPICHER TECHNOLOGIES

EaglePicher Space – NASA - Unmanned

- EaglePicher and NASA have a long history
- From the beginning – Explorer 1
- To Perseverance, and all Mars Rovers
- Breadth of projects includes LEO, GEO, and deep Space
- These are but a few …



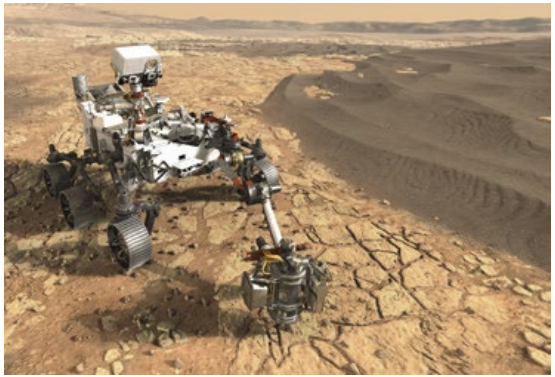
Opportunity



Hubble

Maven

OSIRIS-REx



Perseverance

EAGLEPICHER TECHNOLOGIES

Battery Categories

- Main Bus power (28V, 70V, 120V nominal)
- Crew Rated (typical is 120V nominal)
  - Defined by NASA JSC-20793
- Pulse power for payload
  - Providing 5 kW to 100 kW pulses for up to 2 minutes
  - Charging from craft main bus (typically 28V nominal)
- Short Duration Missions < 90 Days
  - Primary solutions

Path forward

- Use of existing designs
- Use of off-the-shelf products (COTS)
  - Risk review – reliability and mission duration
  - Mission type with the impact of radiation - LEO or GEO or Lunar/Deep Space
- Procurement of “industrial” not Space-rated parts
  - Risk – not rated for Space radiation / limited qualification / limited performance data
- Customization of existing batteries

Battery Platforms Trade Study

Platform-level tradeoffs ...

+ Multiple – Use multiple existing batteries
+ Oversize – Use a battery with excess capacity (also excess mass)
+ Modify – modify an existing battery – requires NRE and time
+ Custom – This is the longest timeline and highest risk

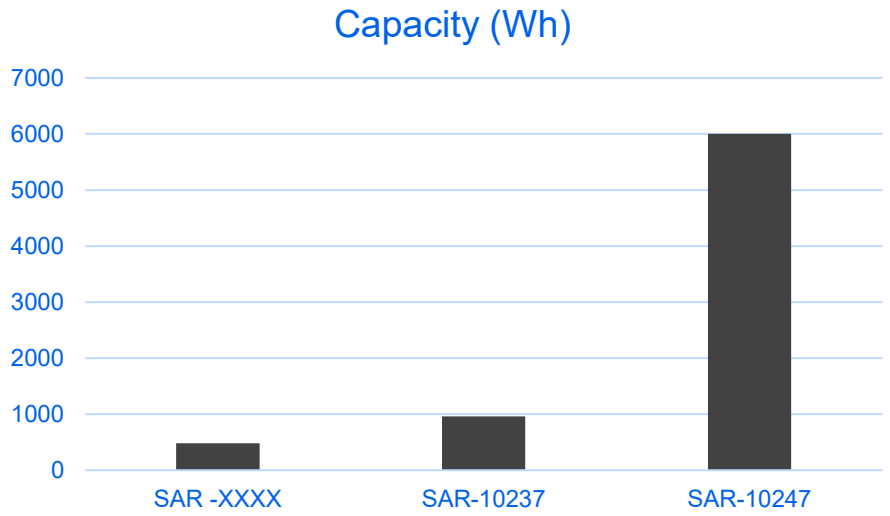
+ NRE vs number of crafts vs timeline

Main Bus Power Battery Architecture

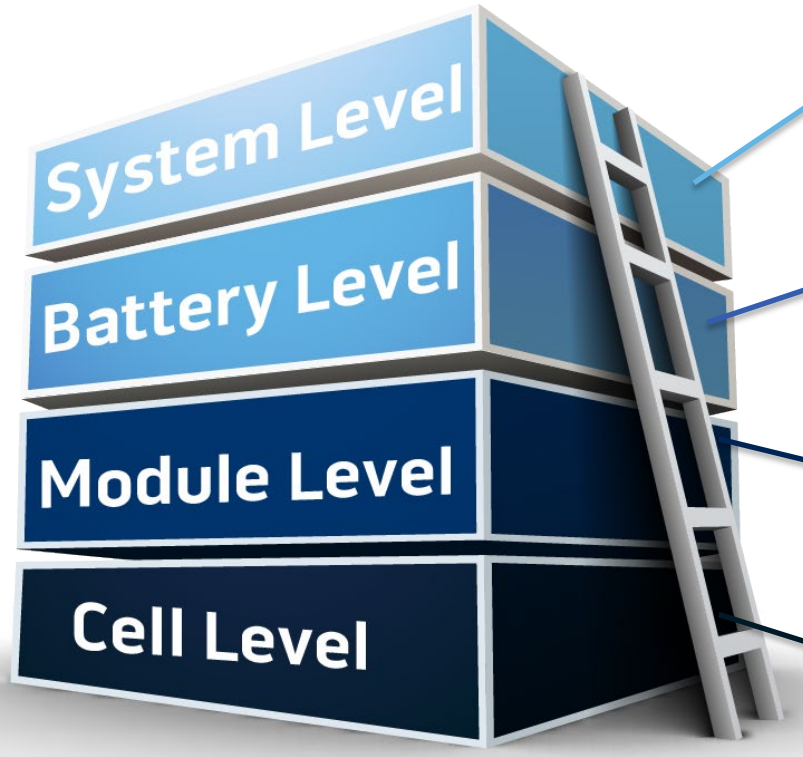
- Path Forward for typical bus power of 28VDC Nominal
  - Application of existing batteries
    - Off the Shelf
    - Prior products
  - Battery blocks
    - Cell Packs
    - BMS
    - Interface
      - Thermal Management
      - Telemetry

Space Qualified COTS Battery

- Standard EaglePicher Space batteries
- Multiple batteries – to meet the capacity or mass distribution
- Space Proven Configurations
  - 2 – SAR-10237
  - 4 – SAR-10237



Holistic Approach to Design



Battery management system interface

Protection, optimization, communication

Capacity, Size, Mass, Cycle Life

Containment, size, dissipation

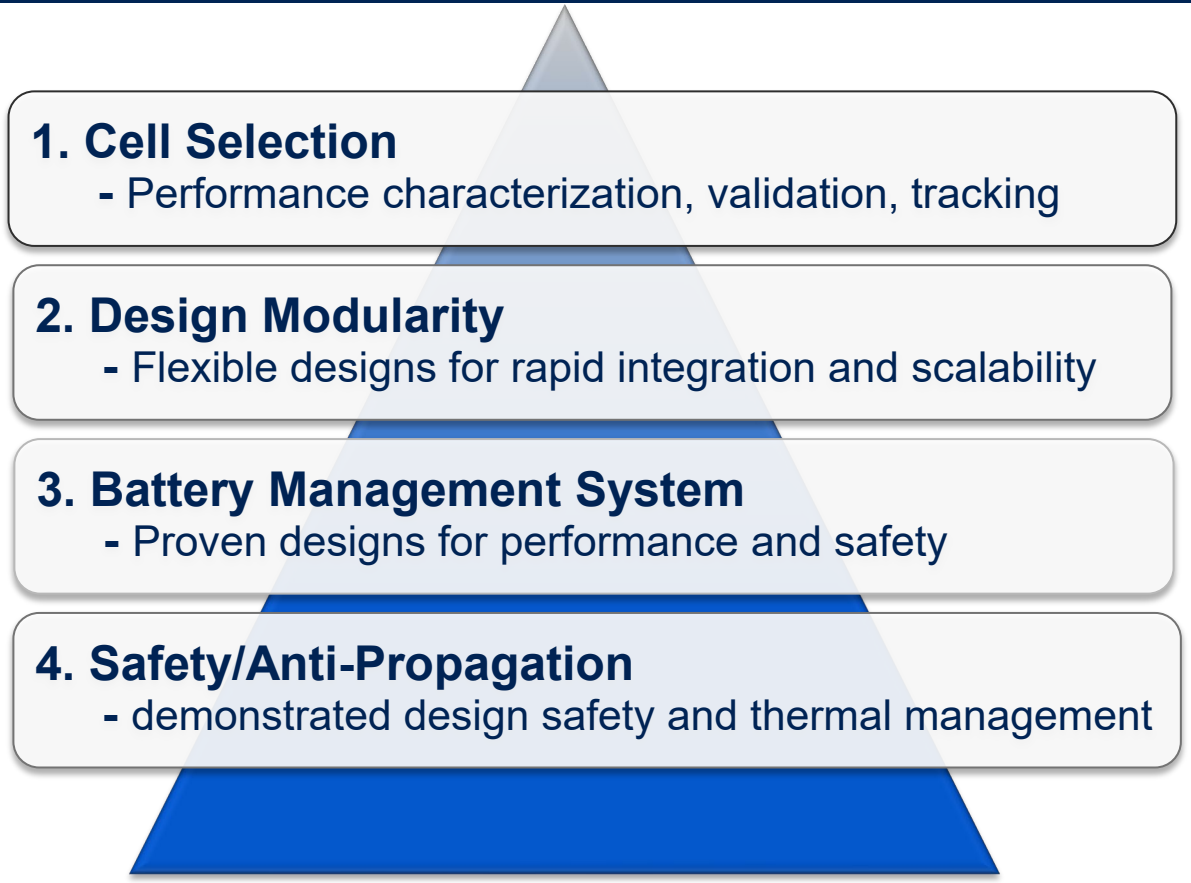
Thermal management

Remove heat, manage heat dissipation

Performance, abuse tolerance, response control

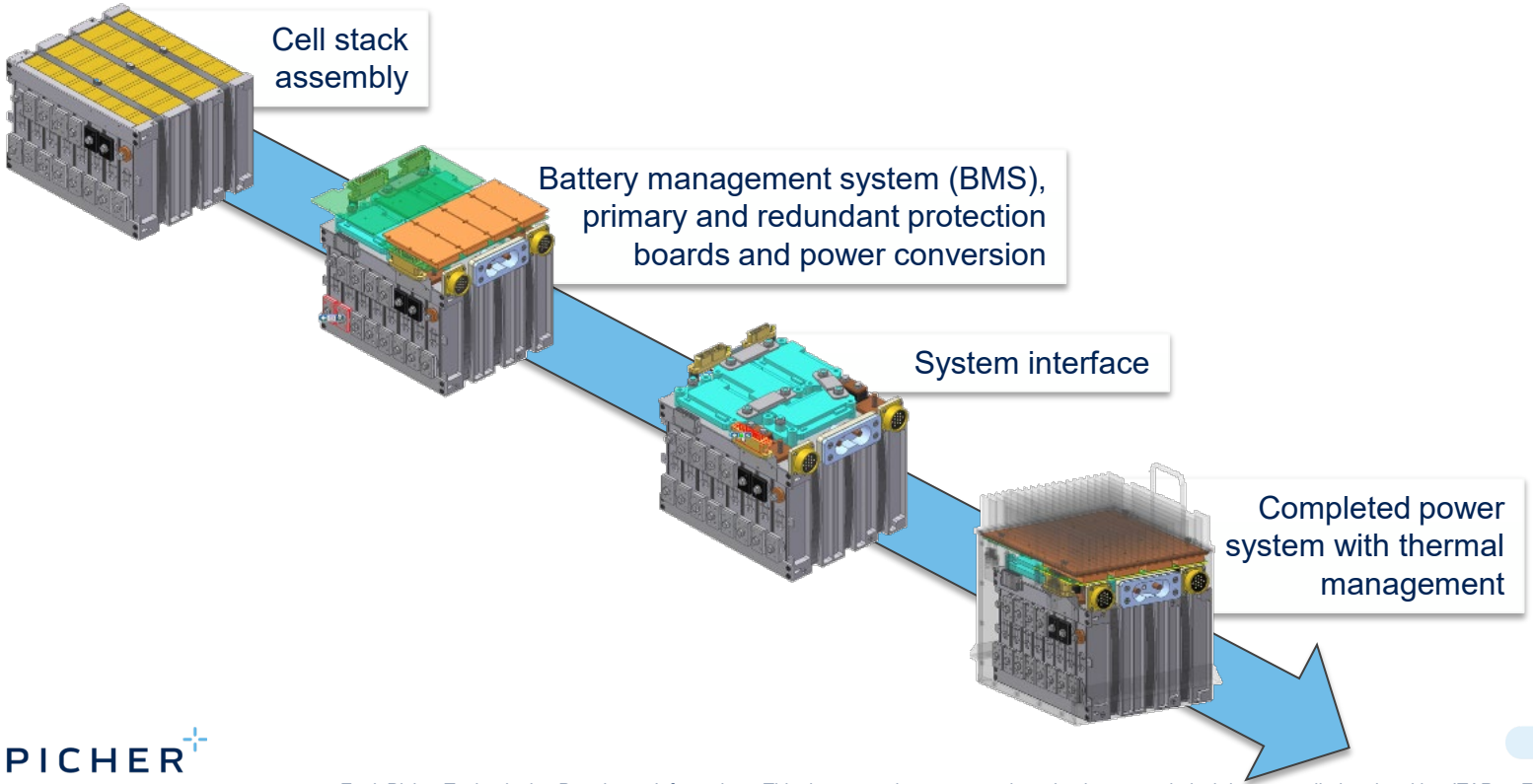
Chemistry and form factor

Flexibility and Safety Foundation of Solutions



System Design Capabilities

Cells + Management + Power Conversion + System Interface = Total Power Solution



COTS Modules

- Use of proven modules that meet the requirements – Lowest risk
- Modification of existing modules to meet the requirements – Medium risk
- Use of existing design blocks reconfigured to meet requirements and perform a limited qualification - Highest risk and schedule

- Risk
  - Each of the above incorporates risk to –
    - Schedule
    - Cost
    - Performance

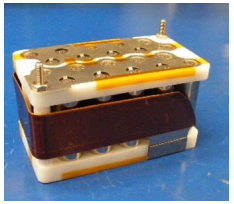
Battery Sizing

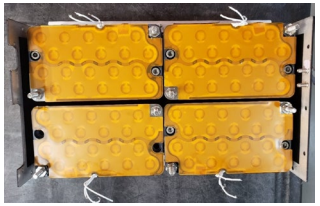
- We analyze cells for …
  - Storage
  - Cycling
  - DoD
  - Temperature

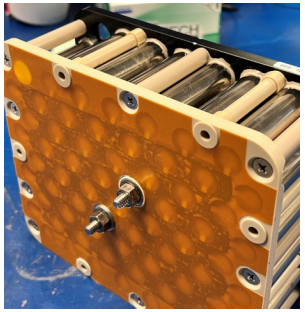
MJ1		
Orbit period (500km Altitude)	94.47	minutes
Eclipse duration	33	minutes
Sunlit duration	61.47	minutes
Sunlit operation duration	18.5	minutes
Nominal Voltage	28.8	Volts
Worst Case Battery Energy Draw	201	Watt-hours
DOD of Cell Nameplate	20.0%	
Cell voltage at 24.1% DOD	3.99	VDC
Battery voltage at DOD	31.88	VDC
Total Mission Energy Throughput Battery	9333213	Watt-hours
Total Mission Energy Throughput Cell	116665.2	Watt-hours
Cell Type	MJ1	
Cell Energy Nameplate	12.6	Watt-hours
s-configuration	**8**	
p-configuration	**10**	
Battery Energy Nameplate	1008	Watt-hours
Pre-Launch Degradation	5.3%	
Mission Degradation	13.8%	
Total Degradation	19.1%	
Battery Energy available at 4.1V/cell charge voltage	93.5%	
EOL Total Energy available at 4.1V/cell charge voltage	762	Watt-hours
EOL Operating DOD for worst case eclipse	26.4%	
EOL Operating DOD for worst case eclipse Batt Voltage	31.36	VDC
Round trip efficiency	95%	
Total Recharge Required for worst case cycle	211.4	Watt-hours
Worst Case Recharge Power	295.1	Watts
Worst Case Recharge C-rate	**C/3.4**	

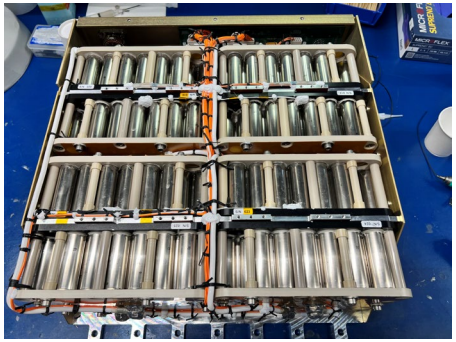
COTS Battery Packs

- Battery designs using commercial 18650 cells for either energy or power
- Cells are 100% tested and matched per NASA guidelines
- Cell pack designs exist and are scalable from 400Wh to 10kW – 28V bus
- Existing standard qualified designs for 400Wh and 5.5 kWh
- EaglePicher has built and shipped over 250 of the 900Wh solution





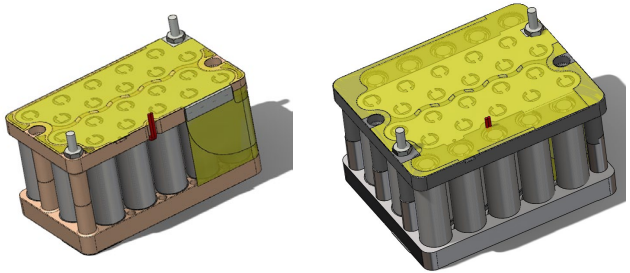




Cell Pack

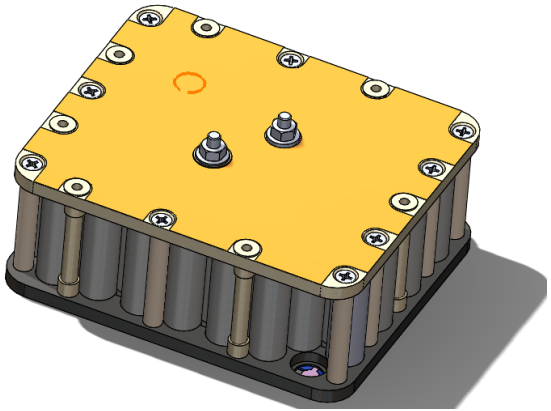
High Volume

+ Moldable material selection for capture plates
+ Thermal transfer rates for cells to housing
+ Thermal transfer material that is electrically isolated



Low Volume

+ Cell Capture Machined Parts
+ Cell Electrical Attachment
+ Assembly Mounting
+ Vibration / Shock Tested
+ Standard Mounting



Cell Type

- Small – off-shelf commercial (185650 / 21700)
  - Cell Qualification data and cycle/calendar life performance
  - Use of a cell using the Manufacturing Limited data sheet
- Prismatic – EaglePicher
- Large cell – GS Yuasa, Saft, Enersys

18650 Cells cells being evaluated (259- 276 Wh/kg and 704-735 Wh/l)

Batch 1 cells	Batch 2 cells
• LG M36	LG M36
• LG MJ1	LG MJ1
• Panasonic BJ	Panasonic/Sanyo GA,
• Samsung 35E	Samsung 35E
• Sony VC7	Samsung 36G

Performance Characteristics

Characteristic	LG MJ1	Samsung 35E	Panasonic GA	Sony VC7
Capacity at C/10 at RT, Ah	3.41	3.49	3.34	3.5
Energy, Wh	12.46	12.7	12.16	12.72
DC Internal Resistance, mOhm	33	35	33	31
Mass, g	46.9	46	47	47.4
Specific Energy, Wh/kg	266	276	259	269
Energy Density, Wh/l	720	733	704	735

Types of Tests

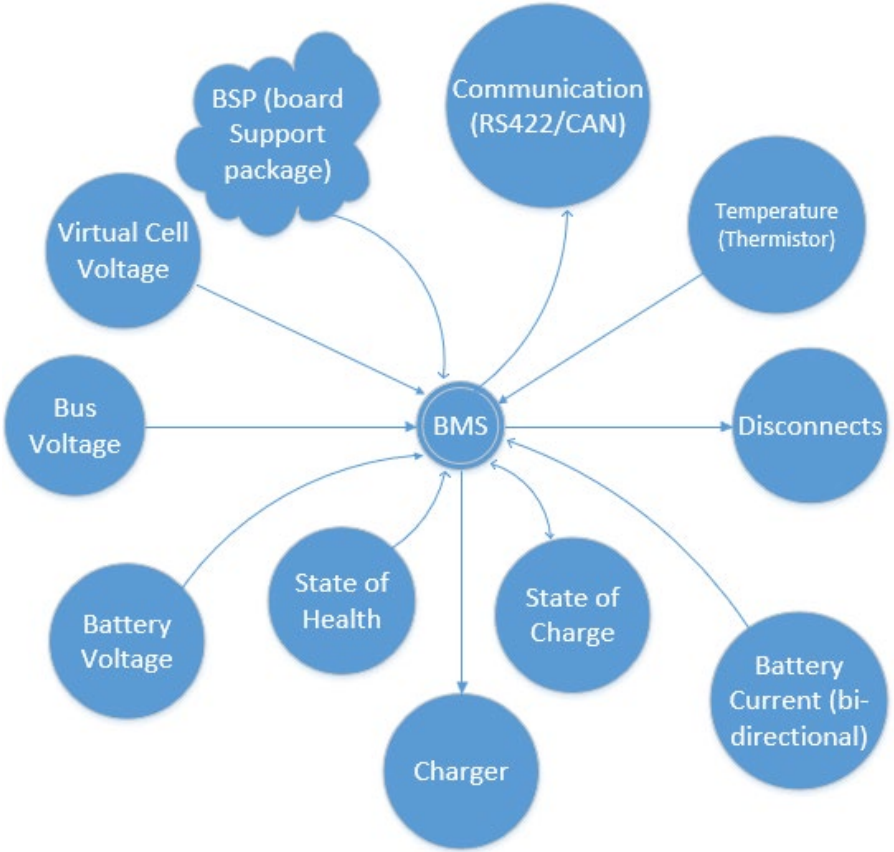
- Lead times
  - Small Cell – less than 6 months
    (EaglePicher procures selected cells in 20k to 30k lots for short lead times)
  - Prismatic – 6 to 12 months
  - Large Cell – 12 to 14 months

Cells

- Flight pedigree
- Cell performance data
- Cell retention risk
- Cell failure risk
  - Custom
  - Commercial
- Cell failure mitigation

BMS (Battery Management System)

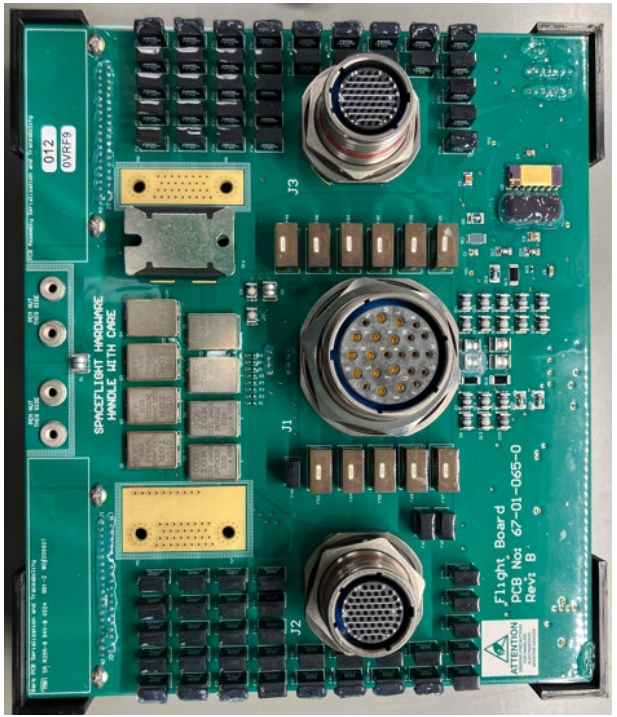
- What is a BMS ?
- Why do we need it?



BMS (Battery Management System)

- Digital
  - Serial communication
  - Virtual Cell and Battery Voltages
  - Battery Current
  - SOC (State of Charge)
  - SOH (State of Health)
  - Faults and Errors
  - Potential bi-directional control
  - Balance

- Analog
  - Virtual Cell and Battery scaled analog voltage
  - Battery current (as a scaled voltage)
  - Faults as an OC error
  - Balance

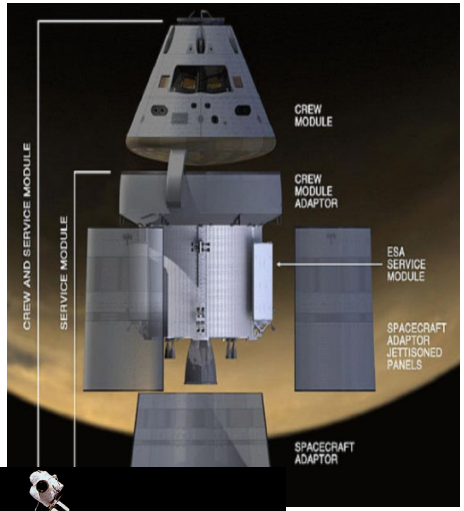


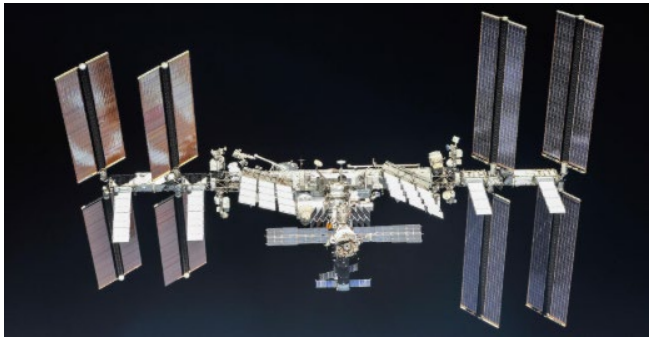
NASA Crew Rated Batteries

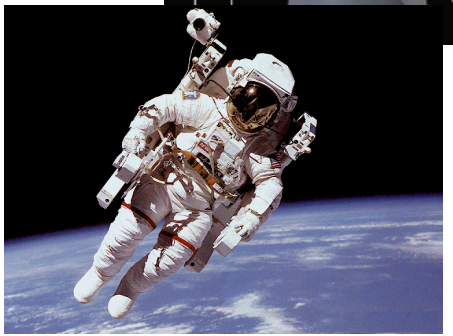
- EaglePicher Technologies has been designing and building Space batteries for over 40 years.
- NASA qualified JSC-20793 designs and crewed missions since 2016.
- Our recent designs have passed vibration, shock, and thermal tests on first attempt
- Our NASA rated crew designs have passed propagation testing for the first time.

NASA Crew

- EaglePicher provided the cells for the original ISS batteries
- We provide the batteries for the first Orion proof of flight tests
- EaglePicher has supplied the first in a series of high reliable safe batteries for the crew-rated Orion flights
- We are supplying batteries for the latest missions from the legacy primes and the latest new Space companies
  - Landers
  - EVA Suits
  - Space Planes
  - Boosters



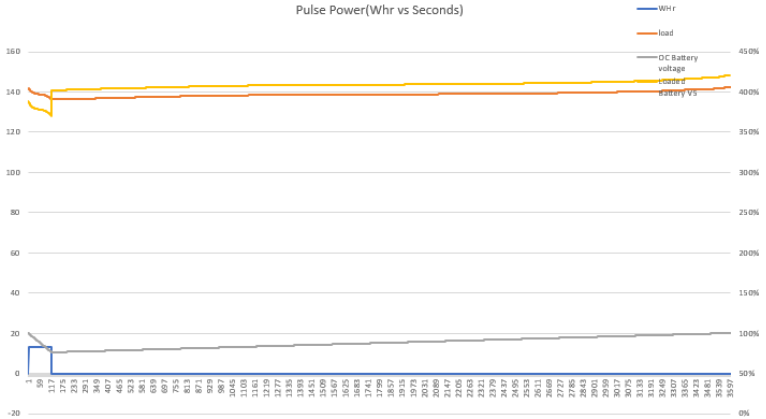


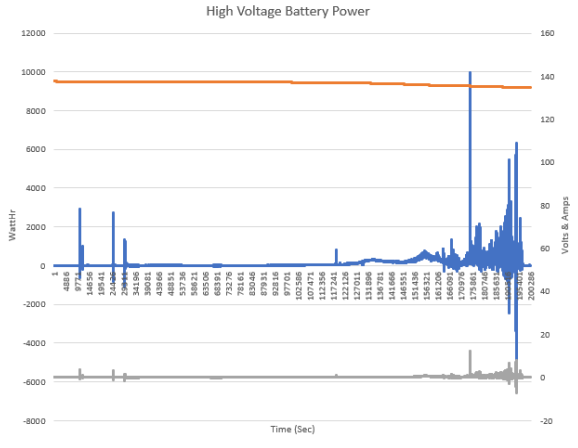


EAGLEPICHER TECHNOLOGIES

Pulse power

- Tends to be higher voltage
  - 100VDC to 300VDC Nominal
- Short pulse duration
  - Less than 2 minutes
- High Current
  - 100A to 1000A pulse
- Recharges from the craft bus
  - 28VDC to 70VDC
- Recharge can be 58 minutes to hours





Short duration -

- De-orbit of existing end of life satellites
- Service of existing on-station satellites
- Fact finding mission for new technology
- Battery Type
  - Primary

    CFx - EaglePicher Cell chemistry that does not require customer activation, or recharge maintenance

  - Secondary Li-Ion

EAGLEPICHER
TECHNOLOGIES

EaglePicher has been in Space before NASA was NASA EaglePicher continues to lead with Space technology