

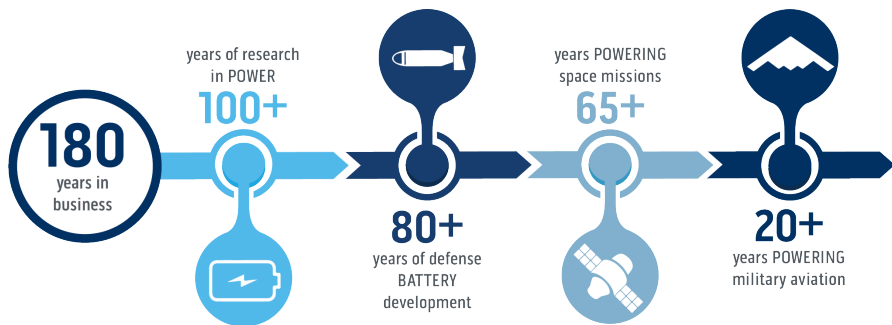
# Qualification of COTS Battery Modules Designed for Spacecraft Electrical Power Systems

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Michel Lannes

Space Power Workshop  
(April 25-27, 2023)



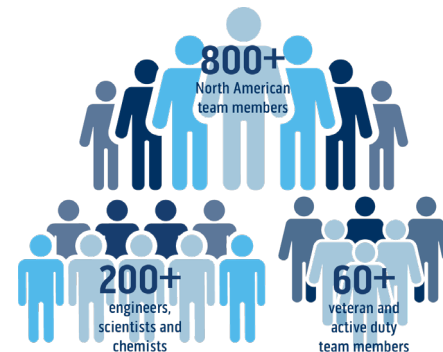
# EaglePicher at a Glance



Expertise in More than



Battery Chemistries



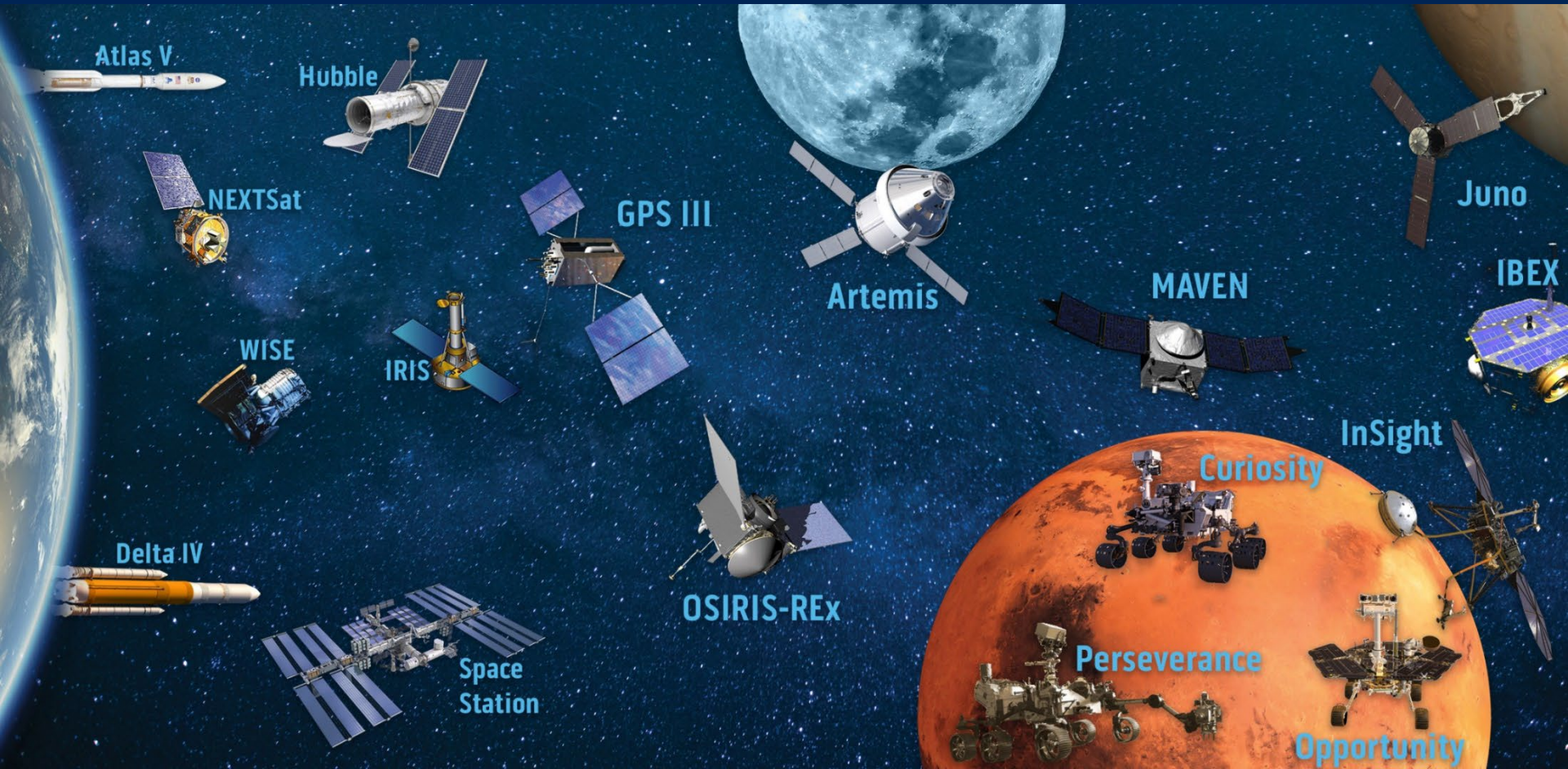
The background of the image is a dark blue space scene. On the left, a portion of the Earth is visible, showing white clouds and blue oceans. A satellite with two large solar panel arrays is positioned in the center-right, oriented towards the right. The satellite has a central body with a circular antenna or sensor. The overall image has a blue color cast.

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# EaglePicher in Space



# Space Applications Heritage



# Custom Cells and Batteries





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# 10p8s Battery Design

# COTS Battery Overview

- + Orion crew module battery design heritage adapted for commercial applications
  - + Unmanned
- + Cell agnostic
  - + Right cell for the right application
  - + Power cells typically better suited for high cyclic environment
  - + Energy cell typically better suited for low cycle count with high energy requirement
- + Supports a range of space missions
  - + LEO, GEO, HIEO, MEO
- + Can be arranged in parallel or series in EPS to increase capacity or voltage
- + Flight units delivered to two customers
- + First launch expected Q2 2023

Part Number	Capacity (C)	Configuration	Cell Type
SAR-10241	18.8Ah	8P8S	Power
SAR-10235	23.5Ah	8P8S	Energy
SAR-10243	23.5Ah	10P8S	Power
SAR-10237	29.4Ah	10P8S	Energy
SAR-10245	28.2Ah	12P8S	Power
SAR-10239	35.2Ah	12P8S	Energy



# 10p8s Qualification Battery Performance specification

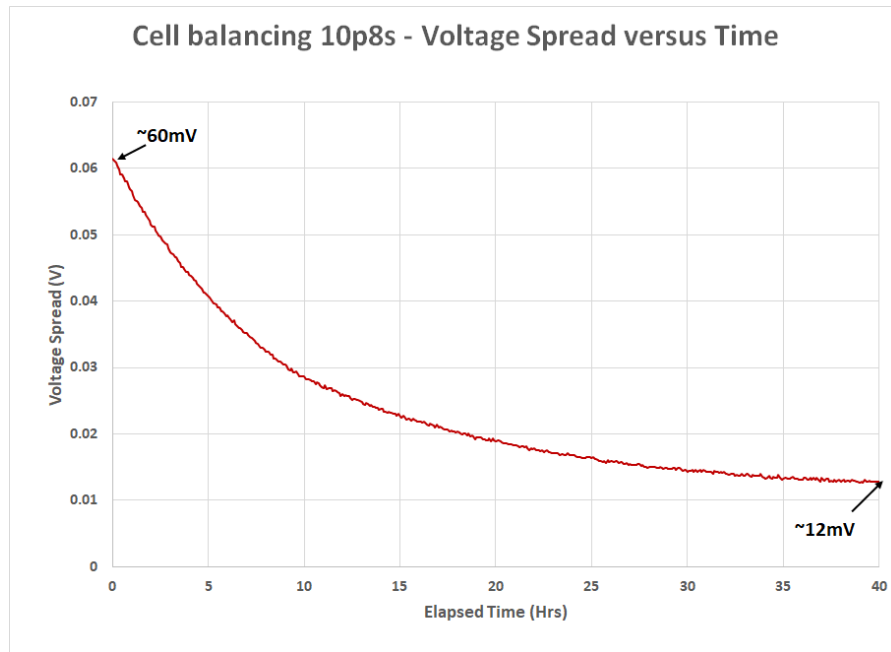
- + 10p8s battery baselined on several programs
- + Qualification testing performed on this configuration

Item	Requirement
Battery capacity @ 20°C	29.4 Ah
Battery energy @ 20°C	845 Wh
Battery nominal voltage @20°C	28V
Maximum continuous discharge current	60 A
Maximum pulse discharge current	80 A, 2s
Battery operating temperature (charging)	0°C to 45°C
Battery operating temperature (discharging)	-10°C to 45°C



# Cell Balancing

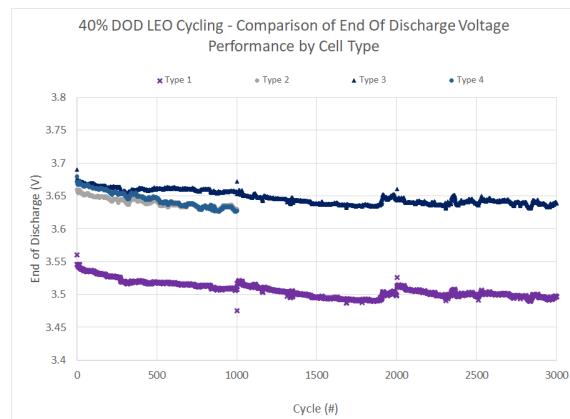
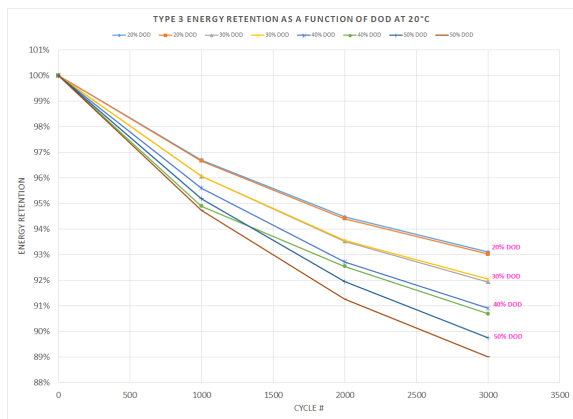
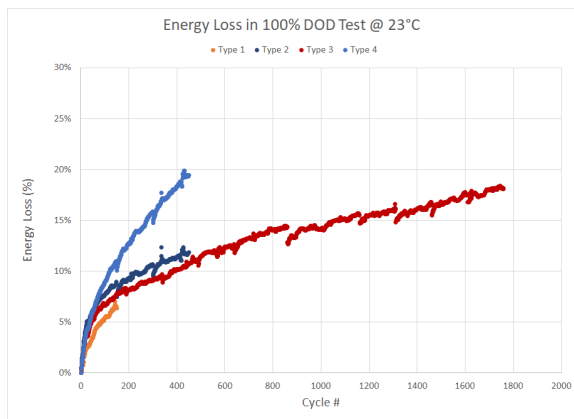
- Analog Balancing
- Proportional cell loading based on cell voltage
  - Balancing current up to 600mA
- Autonomous and or externally commanded balancing
- Balancing tested after battery full charge



Cell to cell voltage spread down to ~12mV in 40 hours

# Cell Selection

- + EPT has implemented a cell evaluation program
  - + Initial characterization to evaluate impact of rates and temperatures on performance
  - + Life tests consisting of accelerated and real time (LEO) cycling tests and storage life tests
  - + 10 cell types evaluated to date
  - + 4 currently in test, 3 more planned to start before YE 2023
- + Enables cell selection that best fit mission requirements
- + Insurance against eventuality of cell obsolescence



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# 10p8s Battery Qualification

# Qualification Test Suite

- + Initial inspection
  - + Physical examination
  - + Ground bonding
  - + Isolation
- + Capacity
- + QT Sine and Random Vibration
- + QT shock testing
- + TVAC cycles
- + Thermal cycles
- + EMI/EMC
- + Pulse discharge testing



# Initial inspection

- + Physical examination Visual inspection for workmanship, cleanliness, and FOD
  - + Battery measured and weighed

Battery length	10.2 in
Battery width	6.8 in
Battery Height	3.5 in
Battery weight	5.6 kgs

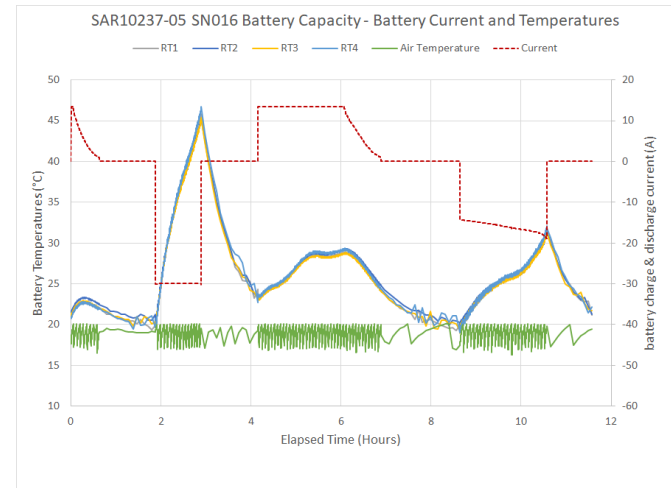
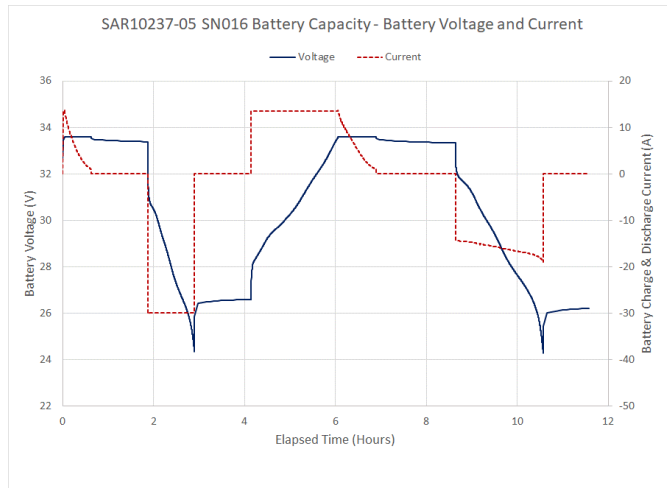
- + Battery ground bonding and electrical insulation meets specification



# Initial capacity

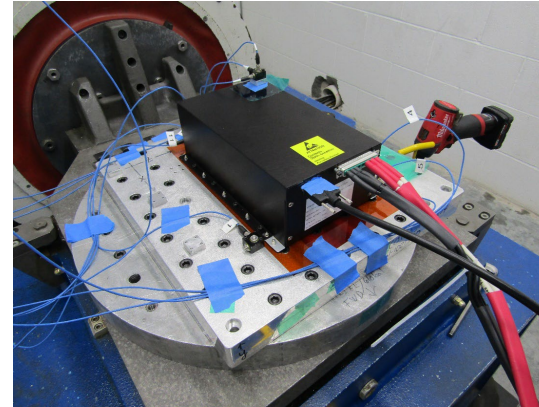
- + Battery capacity measured at 30A and 460W (~16A) at 20°C following CC/CV charge to 4.2V and until first cell hits 3V
- + Meets specification requirements for capacity (29.4Ah) and energy (845Wh)

Initial Capacity	Discharge Capacity	Discharge Energy	Average Discharge Voltage	Average Discharge Current
30A discharge	30.5 Ah	856.2 Ah	28.06 V	30 A
460W discharge	30.8 Ah	887.4 Ah	28.82 V	16 A



# Sine and Random Vibration

- + Low level modal sine surveys (5-2000 Hz) performed before and after every run
- + Random levels same as NASA GEVS (Random)
- + Battery discharged at 5A during vibration
  - + No fluctuations in battery voltage, cell voltage, or battery current observed during tests
- + Resonant frequencies well above 300Hz
- + Frequency shifts <10% for all axes
- + No impact on battery capacity and energy



## Sine

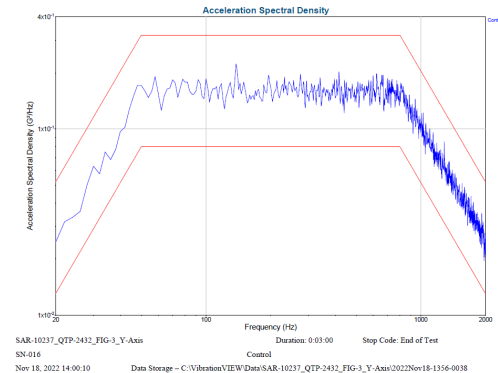
Frequency (Hz)	Qualification (g)
5.00	1.00
22.00	20.00
100.00	20.00

## Random

Frequency (Hz)	PSD (g <sup>2</sup> /Hz)
	Qualification
20	0.026
50	0.16
800	0.16
2000	0.026
<b>Overall</b>	<b>14.1Grms, 180 seconds</b>

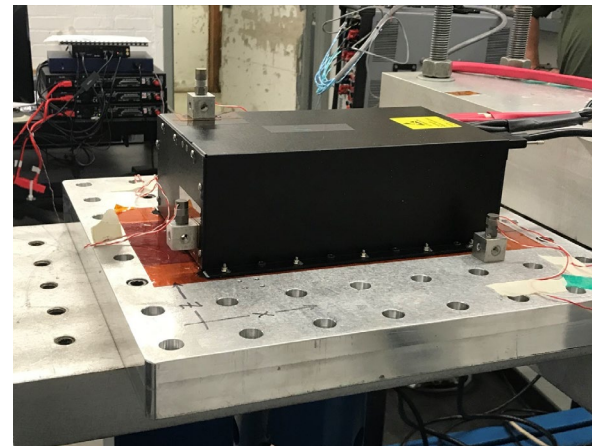
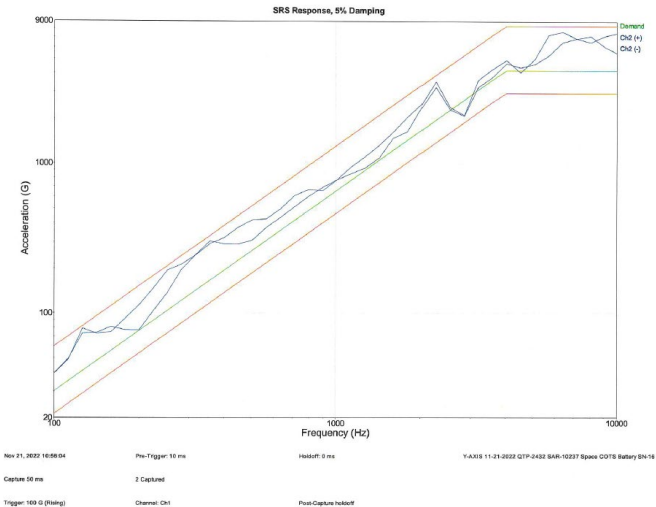
## Resonant Frequencies

	X-axis (Longitudinal)			Y-axis (Normal)			Z-axis (Lateral)		
	Pre-sine	Post-sine	Post-random	Pre-sine	Post-sine	Post-random	Pre-sine	Post-sine	Post-random
	Pre-random	Post-random	Pre-sine	Post-sine	Post-random	Pre-sine	Post-sine	Post-random	
<b>Accelerometer 3</b>	361.2 Hz	364.5 Hz	385.8 Hz	766.5 Hz	785.1 Hz	755.1 Hz	379.0 Hz	380.1 Hz	380.1 Hz
<b>Accelerometer 4</b>	363.4 Hz	365.6 Hz	363.4 Hz	917.5 Hz	925.8 Hz	887.7 Hz	353.7 Hz	351.6 Hz	332.1 Hz
<b>Accelerometer 5</b>	599.5 Hz	594.1 Hz	580.0 Hz	614.0 Hz	614.0 Hz	606.7 Hz	349.0 Hz	347.4 Hz	327.2 Hz



# Shock testing

- + Battery tested to 2000g
- + Battery discharged at 5A during vibration
  - + No fluctuations in battery voltage, cell voltage, or battery current observed during tests



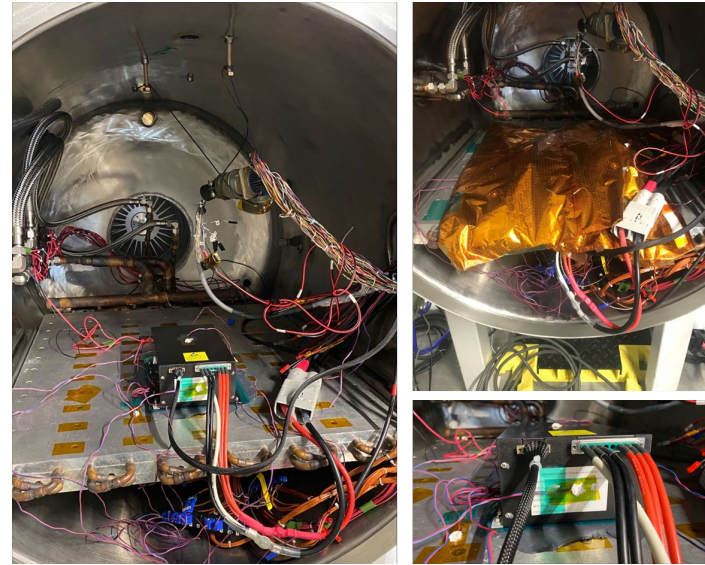
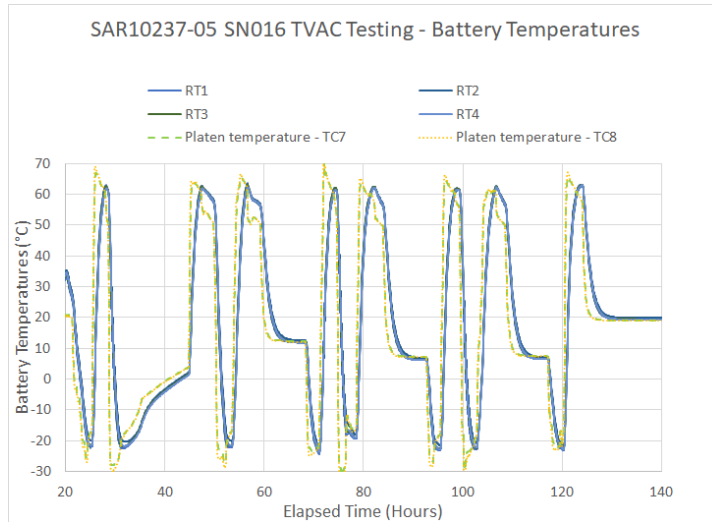
## Shock levels

Frequency (Hz)	Qualification (g)
100.00	60.00
1000.00	2000.00
10000.00	2000.00



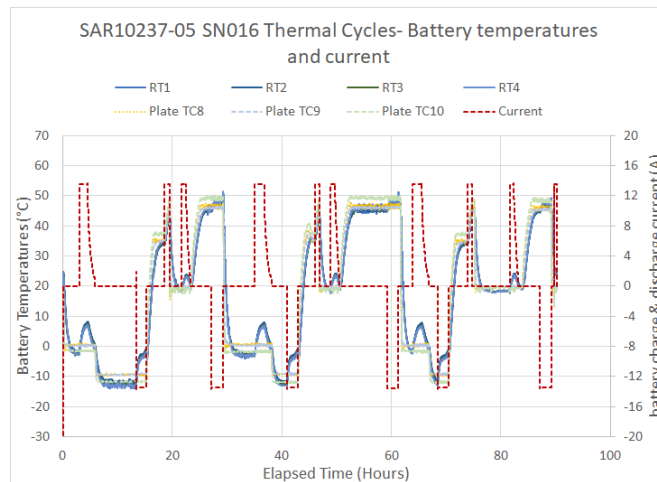
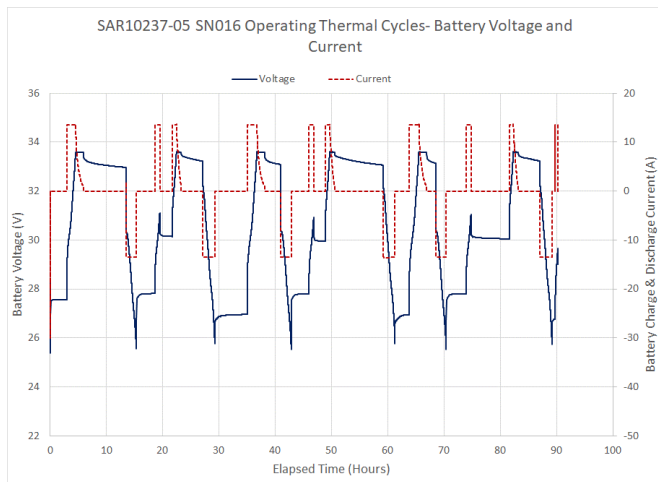
# TVAC testing

- + 8 cycles between  $-20^{\circ}\text{C}$  and  $60^{\circ}\text{C}$  with minimum 1- hour soaks at plateaus
- + Battery capacity measured at  $20^{\circ}\text{C}$  in vacuum before and after cycling
- + No impact of operating in vacuum at temperature extremes



# Operating Thermal Cycles (Air)

- + 3 cycles performed between  $-10^{\circ}\text{C}$  and  $45^{\circ}\text{C}$  with minimum 1-hour soaks prior to discharge
  - + 3 full discharges at  $-10^{\circ}\text{C}$
  - + 3 full discharges at  $45^{\circ}\text{C}$
- + Battery charging allowed during temperature transition steps
- + Demonstrates ability of battery to operate at temperature extremes



# EMI/EMC

- + The battery was tested per MIL-STD 461G
- + RE102, Radiated Emissions
  - + No emissions over limit
- + CE102, Conducted Emissions
  - + No emissions over limit
- + CS118 Electro-Static Discharge
  - + No susceptibility observed
- + The battery was charged and discharged after testing with no observed issue



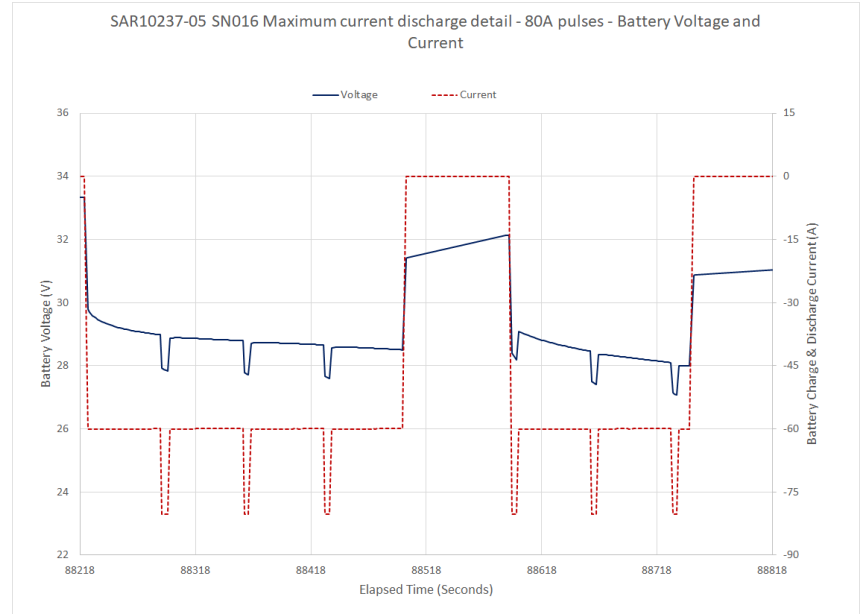
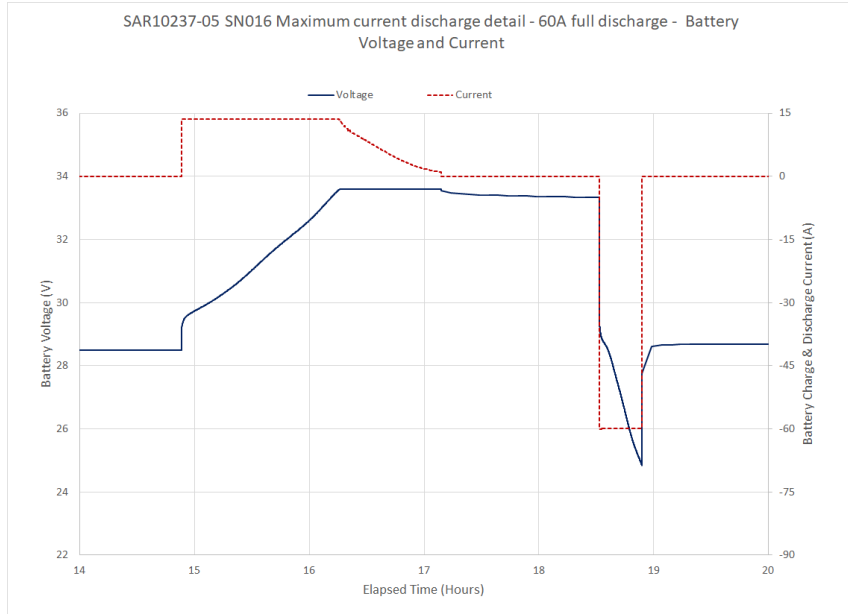
National Institute for Aviation Research  
Wichita State University  
1845 N. Fairmount  
Wichita, Kansas 67260-0093

23-2152-TR073  
Eagle Picher  
MIL-STD-461G EMC Test Report for the SAR-10237-05 Battery



# Maximum Continuous and Pulse Discharge Capability

- + The battery can be discharged continuously at 60A
- + 2s 80A pulse on top of 60A continuous capability demonstrated





# Conclusion/Summary

- + EaglePicher has an extensive heritage in space applications
  - + Over 3 Billion Cell-hours operating in space, Over 14 years operational on Mars
  - + Deep knowledge base on how to design for long endurance, high reliability missions
- + EPT developed COTS battery using commercial 18650 format cells has been qualified
  - + Low-cost solution
  - + Can be stocked for quick delivery
  - + Baselined on several flight programs
- + Engineering and Flight units delivered to two different customers
- + First launch Q3 2023
- + UN/DOT 38.3 completion Q3 2023

# + Thank You!

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