High Specific Energy Pouch Cell Battery Modules for Space Applications

Erik J. Brandon, Eric Poliquin, John-Paul Jones, Randy Ballat, Keith Billings

Jet Propulsion Laboratory, California Institute of Technology

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NASA Jet Propulsion Laboratory
California Institute of Technology

Rover capabilities limited by available energy

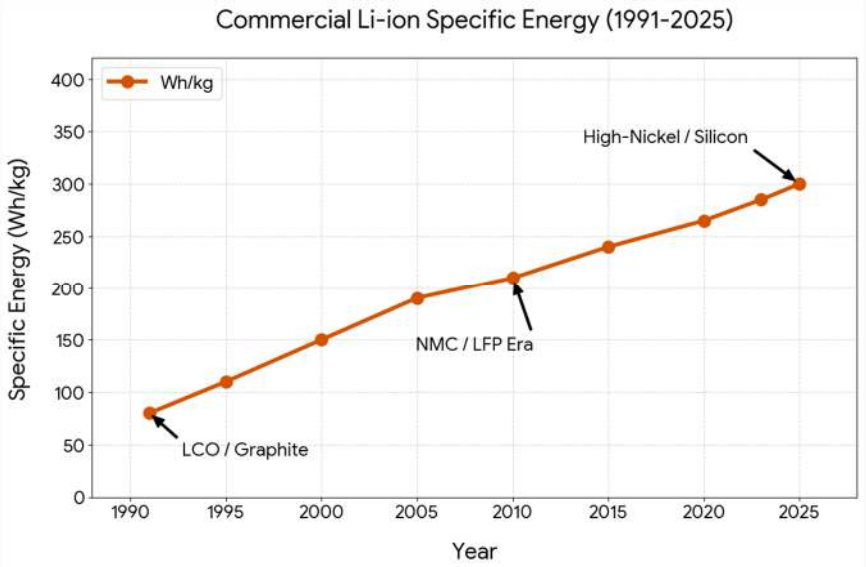
JPL Lunar Rover Testing

- Increasing lunar rover power needs
- Permanently shadowed region exploration
  - Need to increase operational times in dark from hours to days
- Lunar night survival
  - Achieve weeks (354 hours at equator)
- Power Options
  - Solar + conventional Li-ion (massive batteries)
  - Radioisotope heat/power are limited commodities
- *Need much higher specific energy storage*

Careful assessment of energy storage needs

Emerging energy storage needs

- **Mass constrained rovers that require significant energy**
- **Long discharge times:** days to weeks vs. hours
- **Low discharge rates:** C/100 or more vs. C/5
- **Moderate cycle life:** 100s vs. 1000s of cycles
- **Wider temperature operations:** <-20°C and >+30°C

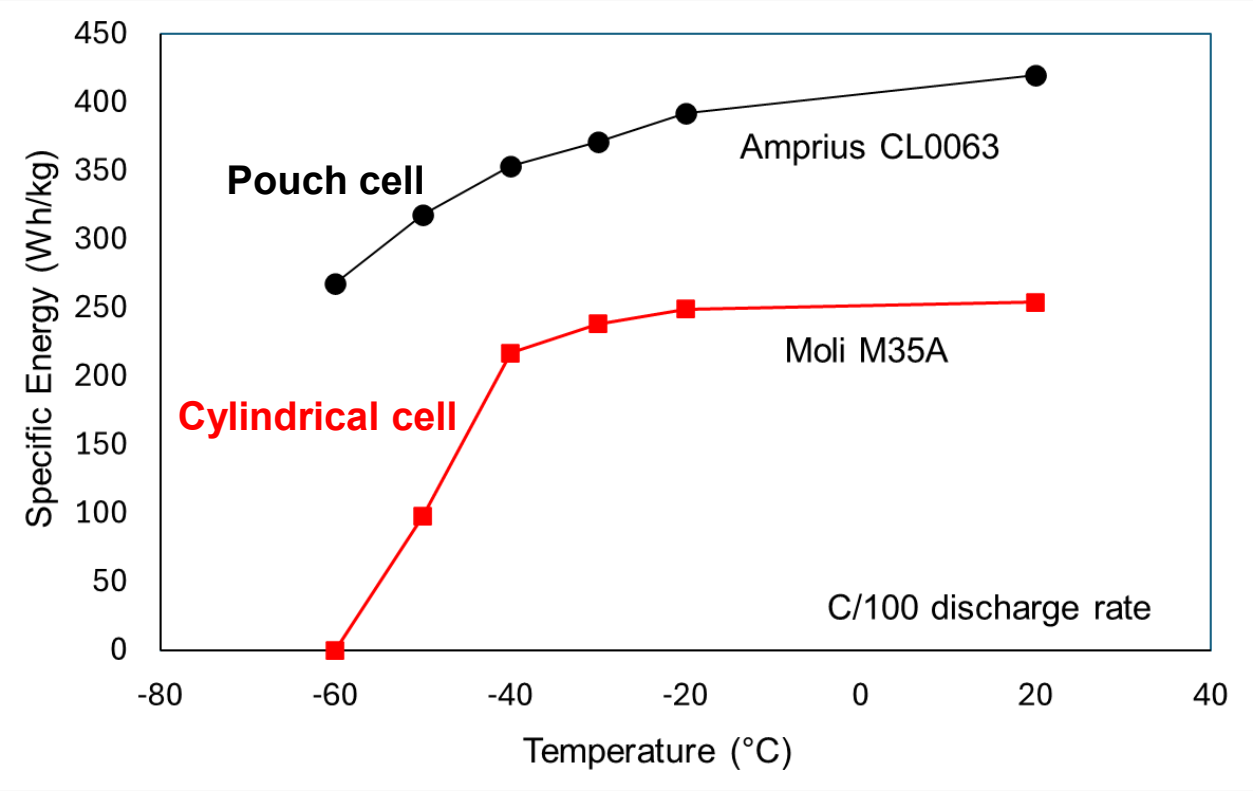


Commercial small cylindrical lithium-ion cell specific energy

Proposed new battery module design

Performance	Cell Level Specific Energy (Wh/kg)	Module Level Specific Energy (Wh/kg)
State of the Art Space Rated Battery	270	**125-150**
Targeted Performance	>400	**≥300**

A leap in capability: advanced pouch cells



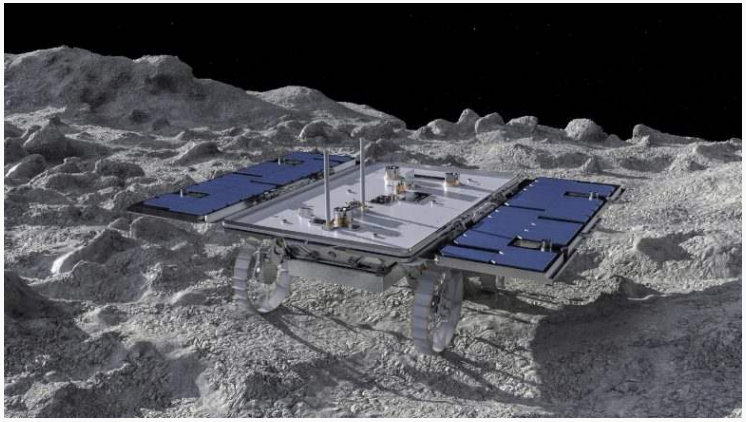
Specific energy exceeding 400 Wh/kg at higher temperatures; good low temperature performance

Amprius CL0063 cell

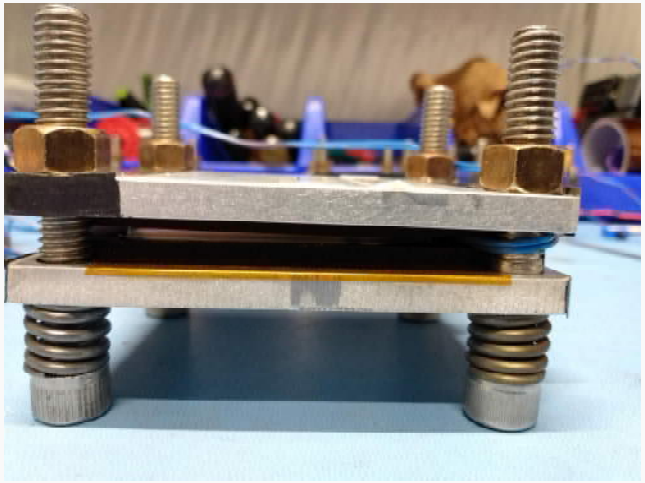
Parameter	Value
Chemistry	Si / NMC
Capacity (Ah)	5.0 (2C)
Energy (Wh)	16.5 (2C)
Voltage	2.5 - 4.25
Mass (g)	45

Making them work for space

- **Pouch cell choice** → 1) high specific energy, 2) adequate cycle life at relevant rates, 3) high production
- **Vacuum survival** → traditional concern: integrity of the pouch material
- **Low mass battery module** → avoid traditional heavy packaging used for applying pressure to cells
- **Flight qualification (TRL 6)** → ensure design can meet environmental qual campaign



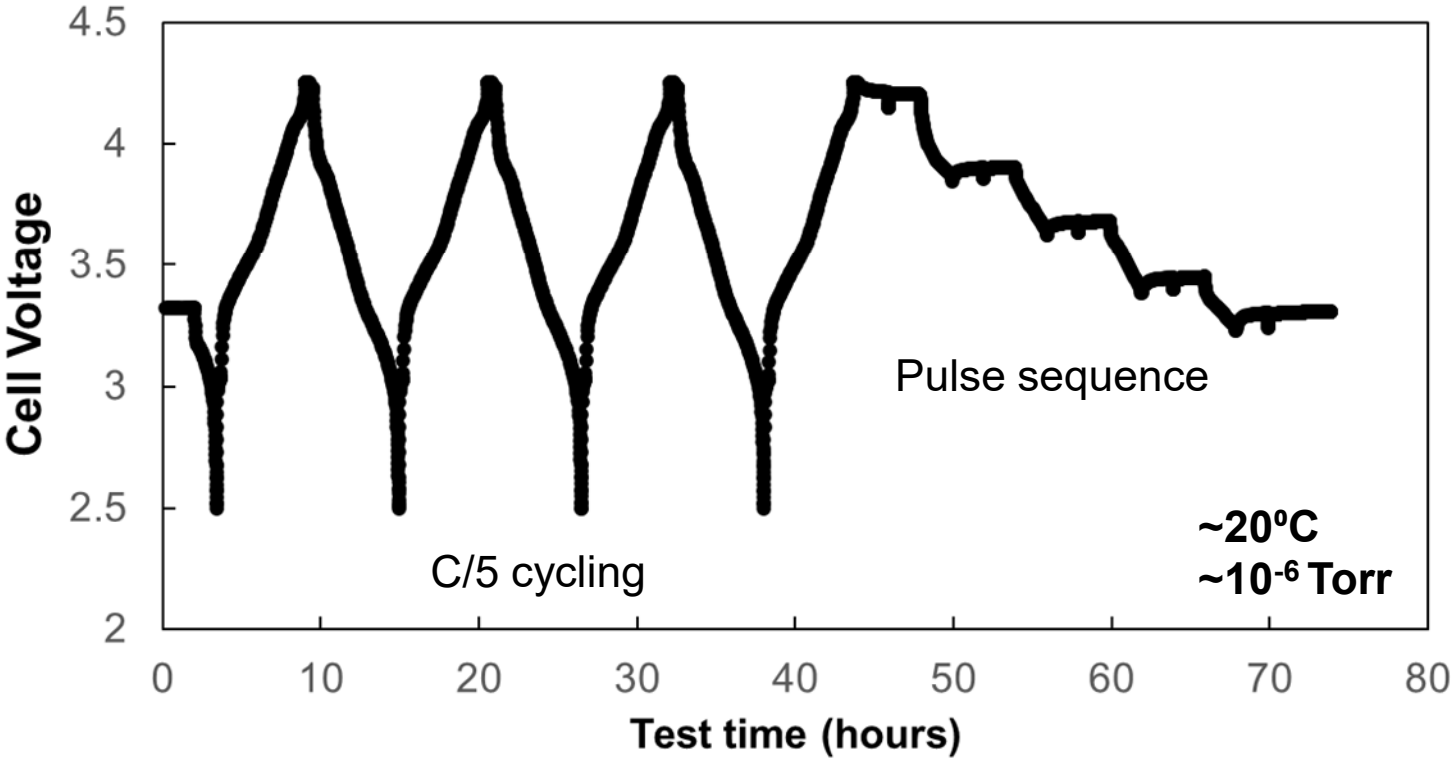
Vacuum screening of cells

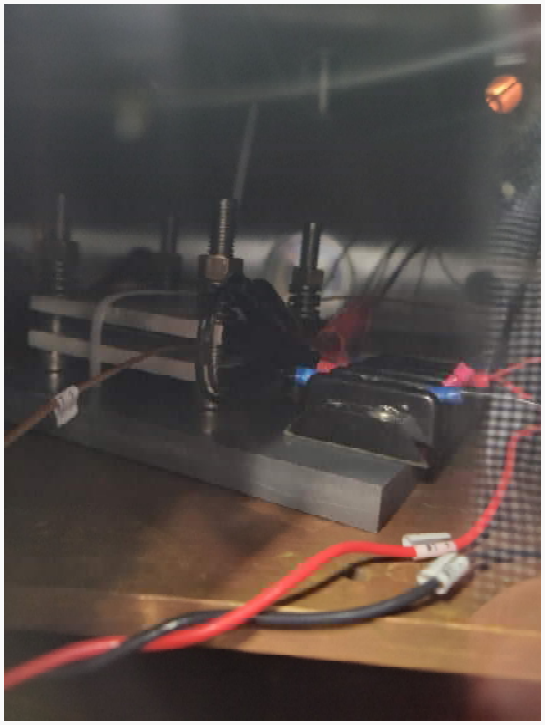


Pouch Cell Test Fixture

JPL Battery Test
Vacuum Chamber

Cycling cells under vacuum





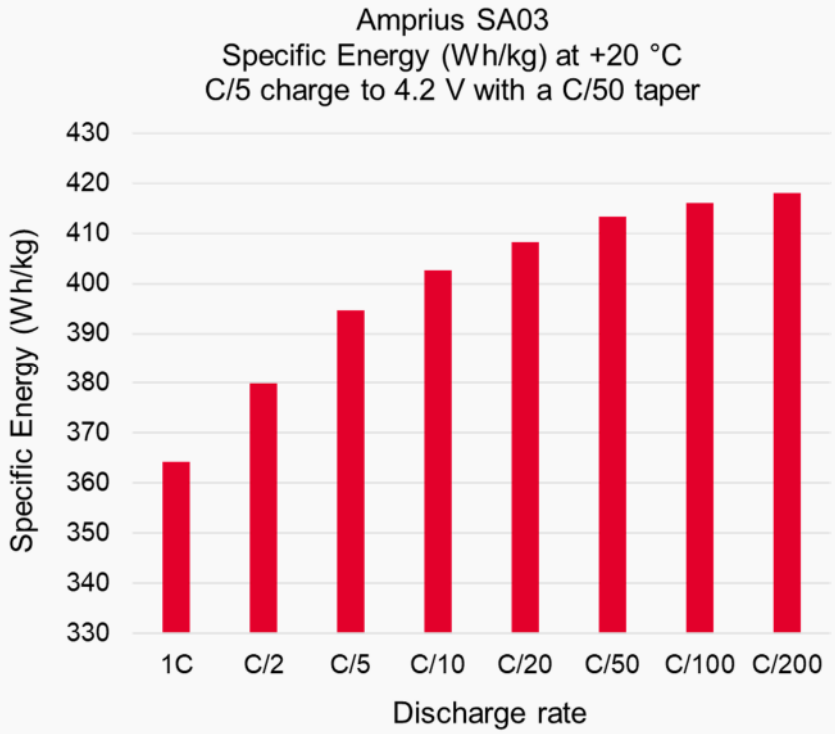
Initial screening of pouch cells under vacuum indicates no change from ambient pressure cycling

High Specific Energy Cell: Amprius SA03

- High production cell
- Achieved 395 Wh/kg at the cell level at C/5
- Over 400 Wh/kg is achievable at C/10 and lower
- **Discharging over days means >C/24 rates**

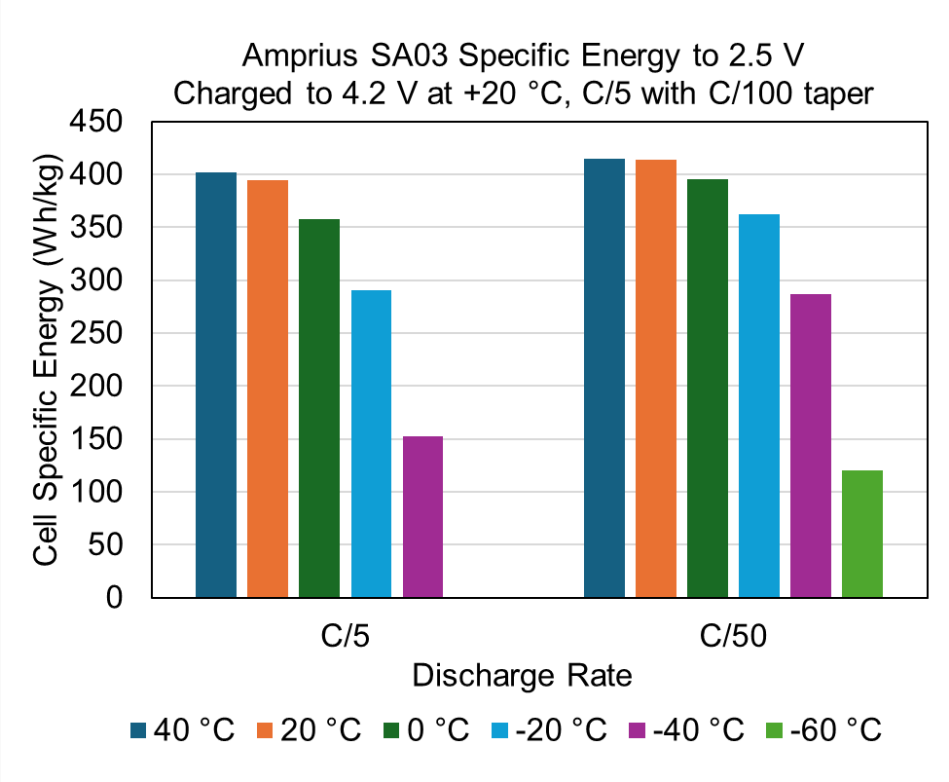
Amprius SA03 Cell

Parameter	Value
Chemistry	Si / NMC
Capacity (Ah)	11.8 (C/5)
Energy (Wh)	40.26 (C/5)
Voltage	2.5 - 4.20
Mass (g)	102



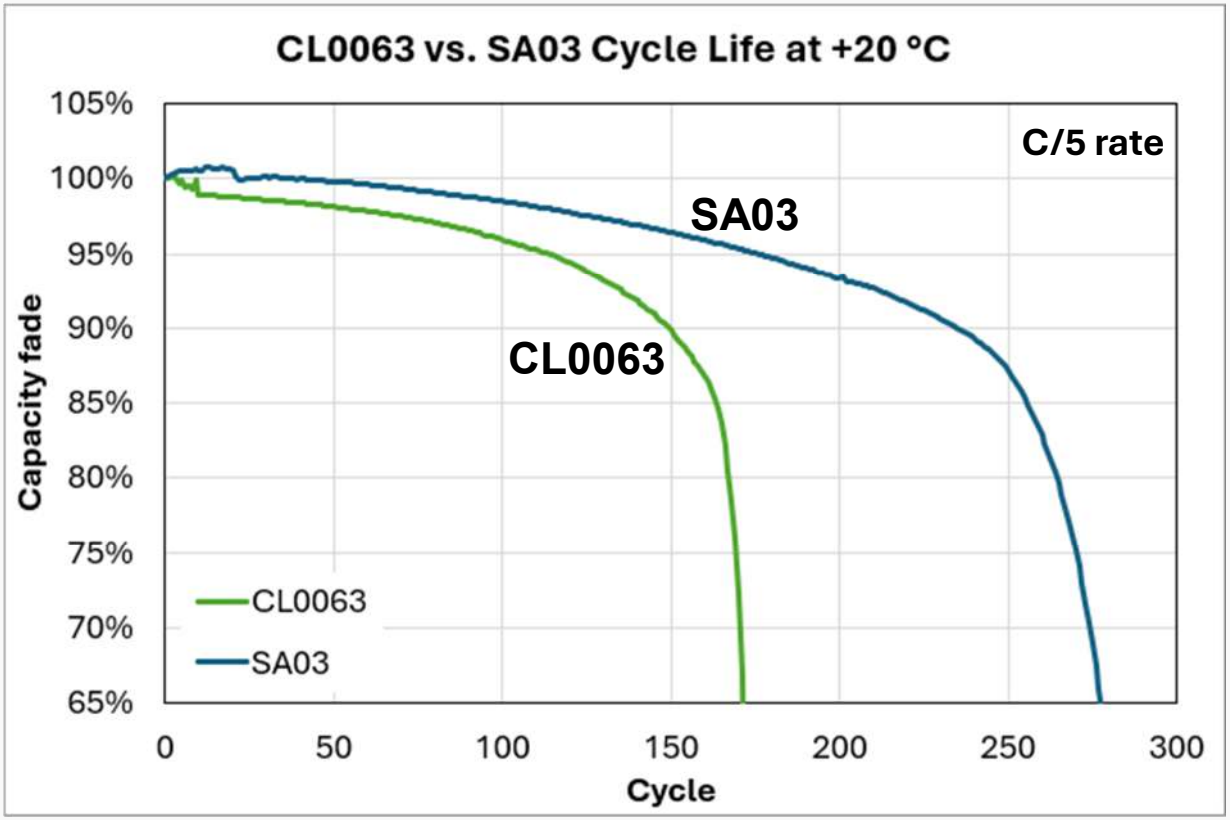
This cell chosen for module design

Performance at Lower Temperatures for SA03 Cell



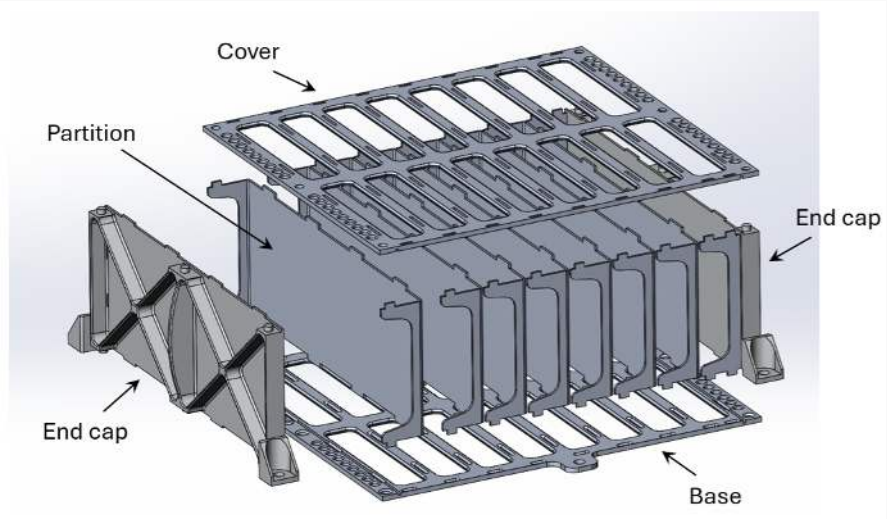
Even at -40°C, higher specific energy than most commercial cells

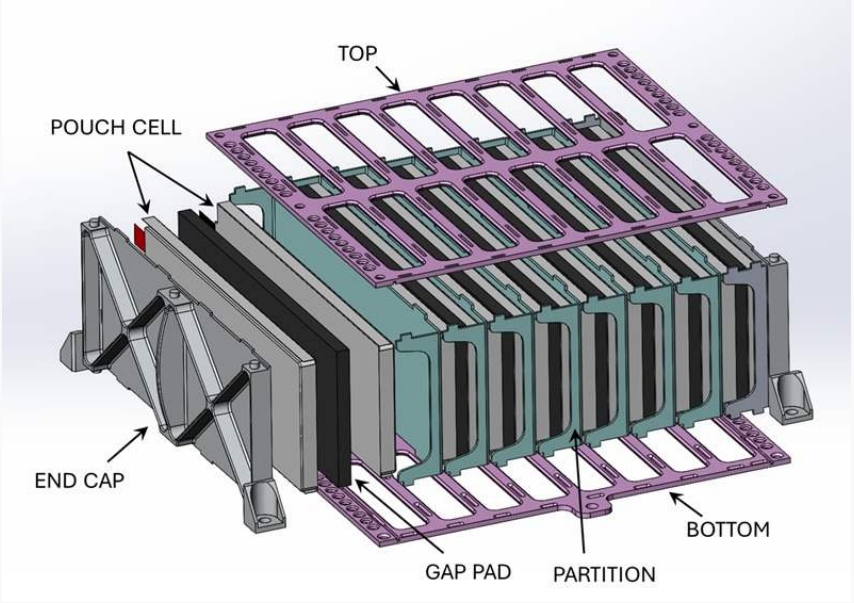
Full DOD Cycling for Two Cell Types



Improved cycle life with SA03 cell design vs. earlier design

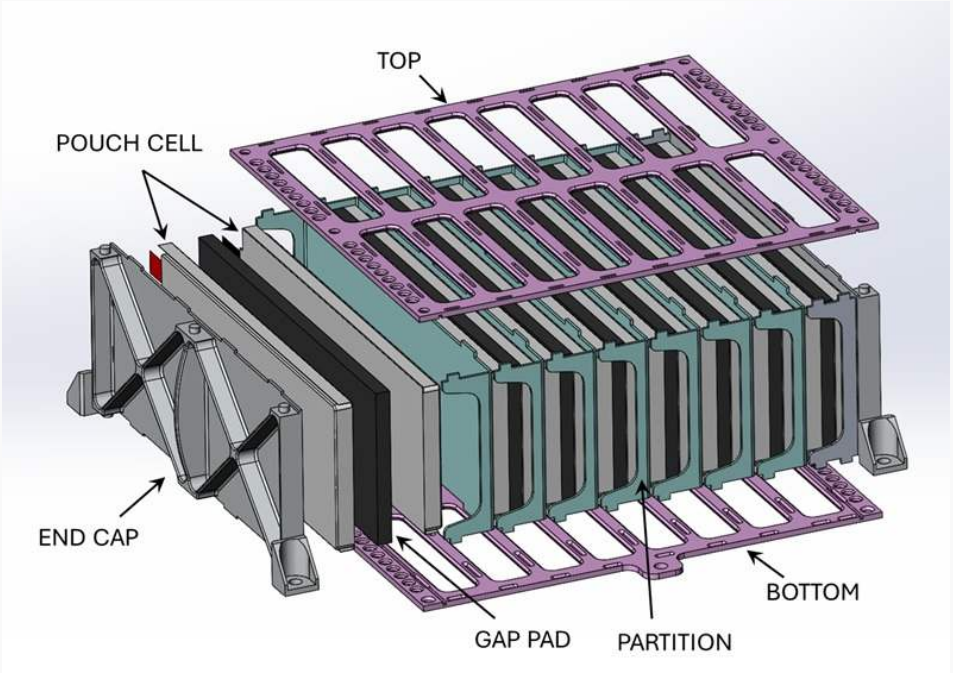
Low Mass Module Design

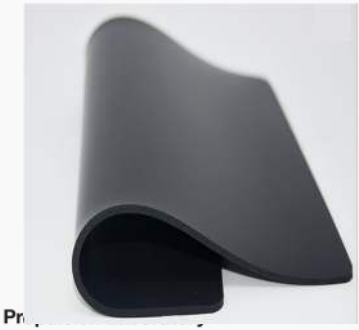




- Low mass structure (5052 aluminum)
- Modular construction
- Laser welded elements replacing rods and bolts
- Gap pads for compliance

Gap Pads Provide Compliant Load Path for Cells



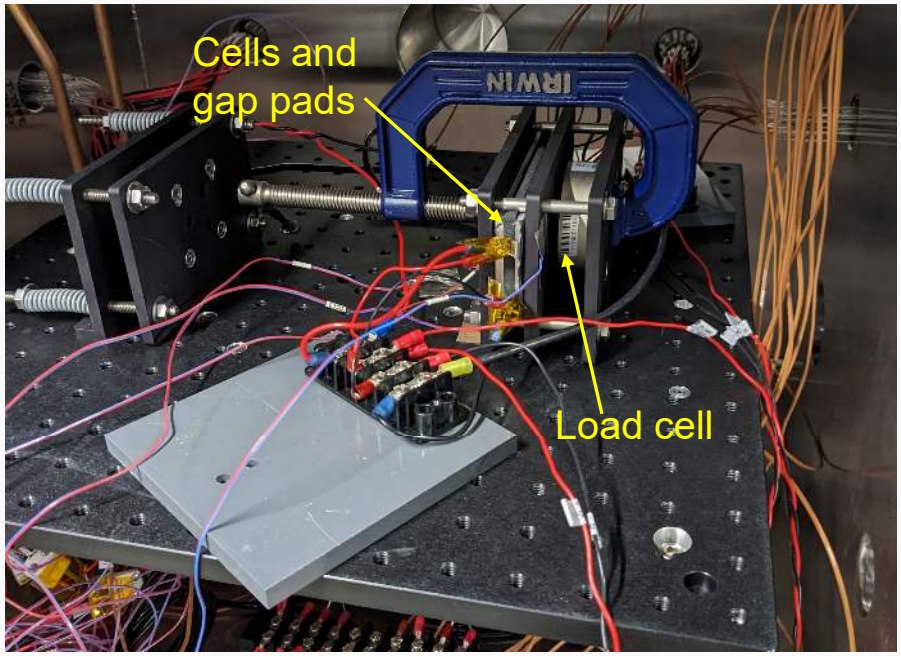


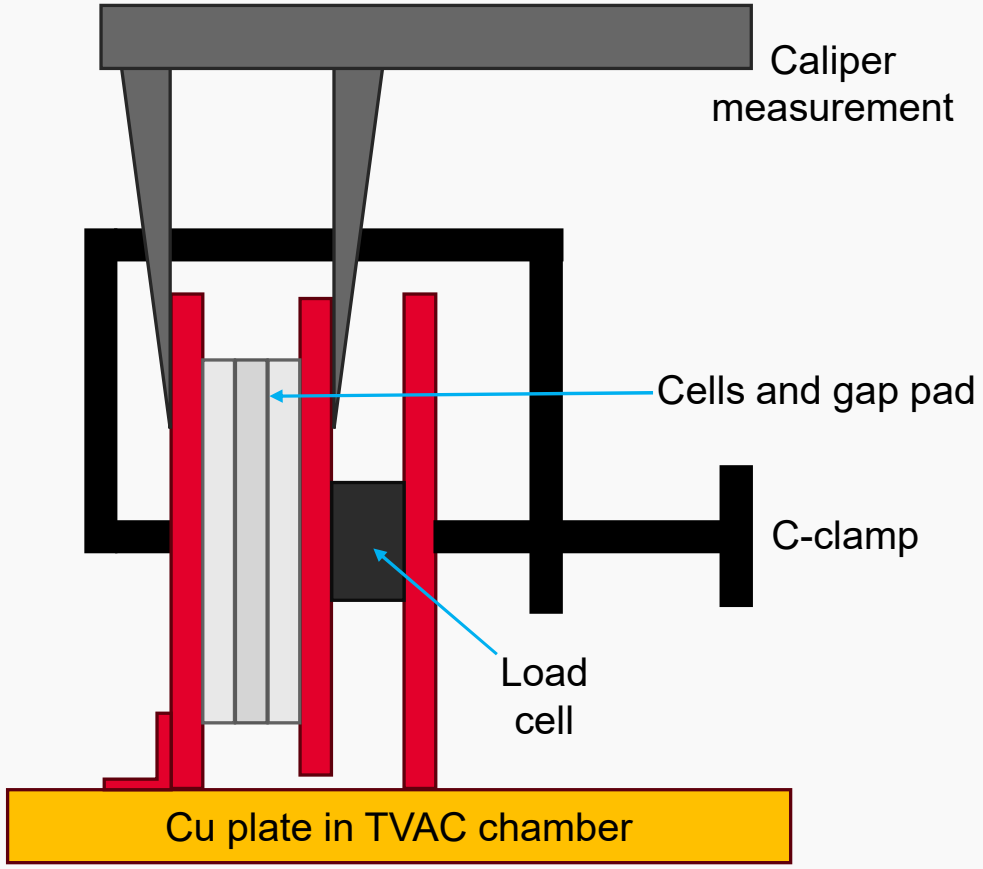
- **Silicone based gap pads:** mix of open/closed cell structure
- **Also testing polyurethane gap pads:** all open cell structure

Testing Gap Pad Response for Ideal Spacing

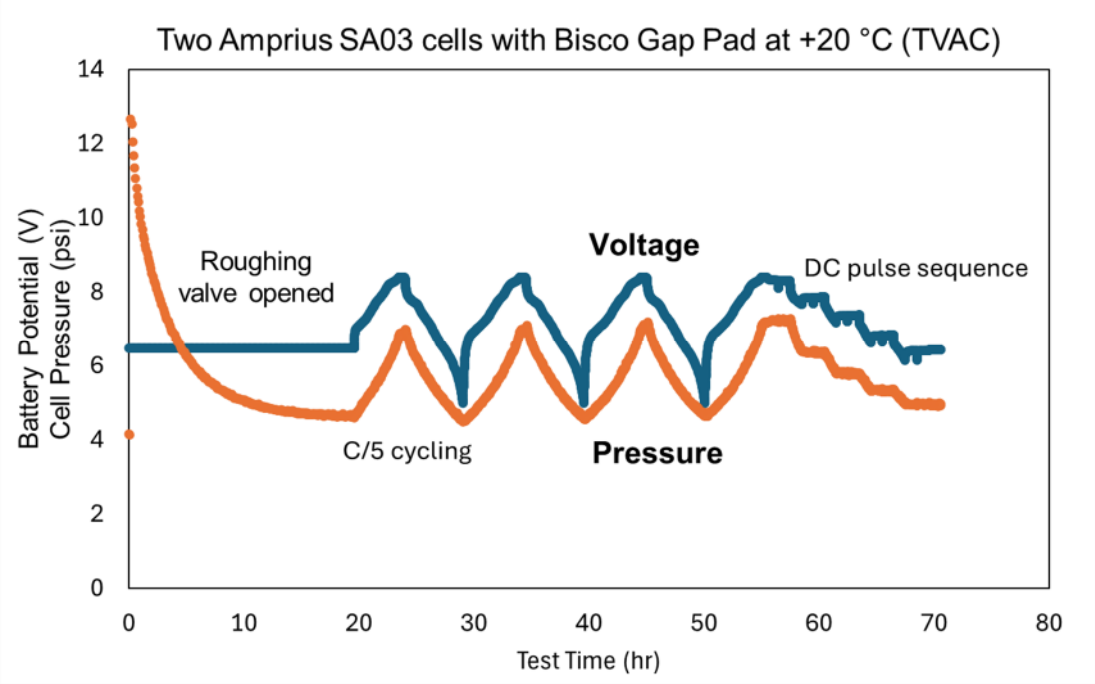
Test objectives:

- Determine initial gap pad set points to achieve proper loading over time
- Evaluate ability of gap pads to maintain adequate loading and compliance during cycling under vacuum



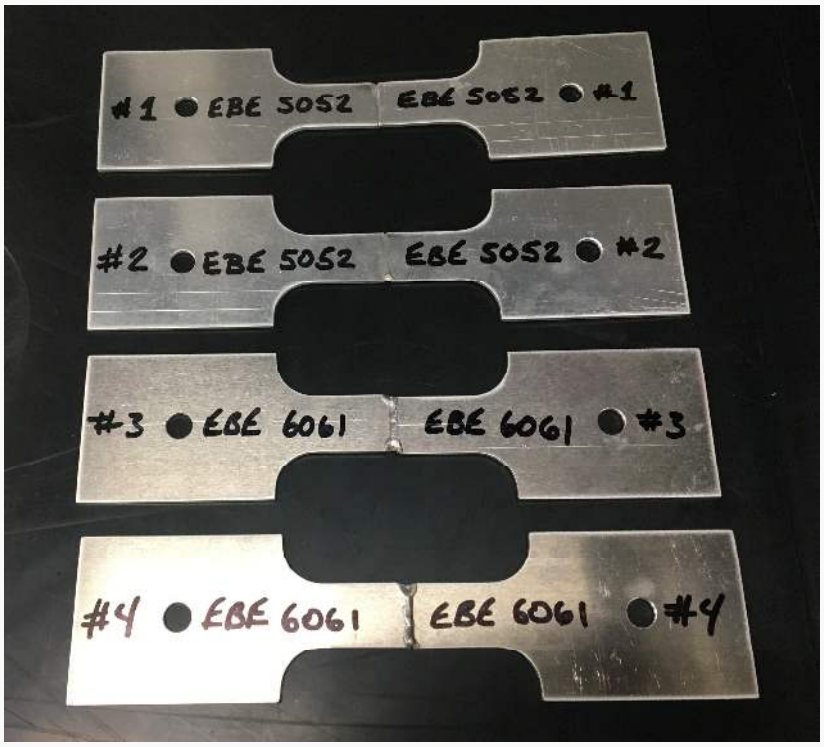


Gap Pad Testing

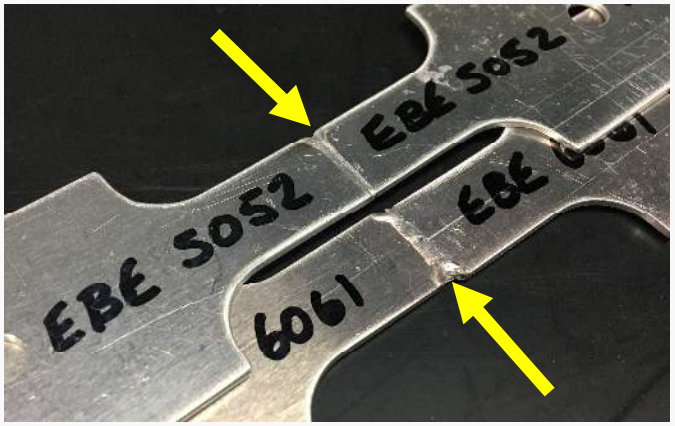


- Two cells are connected in series, using Bisco silicon gap pad (Rogers)
- C/5 cycling from 4.2 to 2.5 V, followed by DC pulse sequence
- Pressure increases as expected when cycling between 0-100% SOC

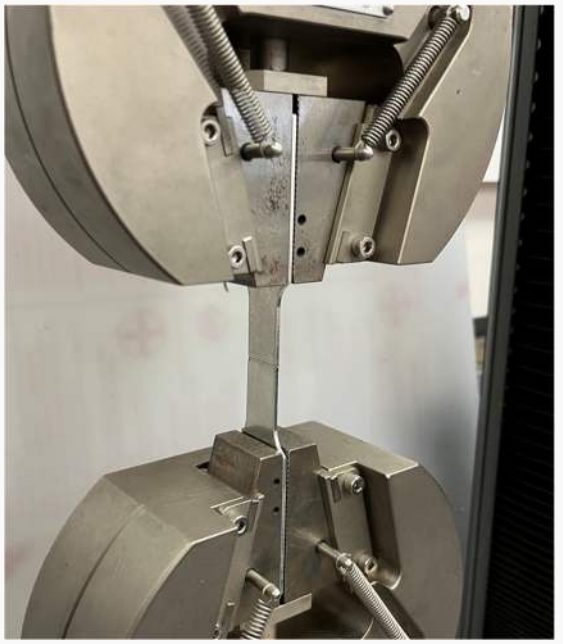
Laser Weld Test Coupons and Pull Testing



Laser welded test coupons
(5052 and 6061 alloys)

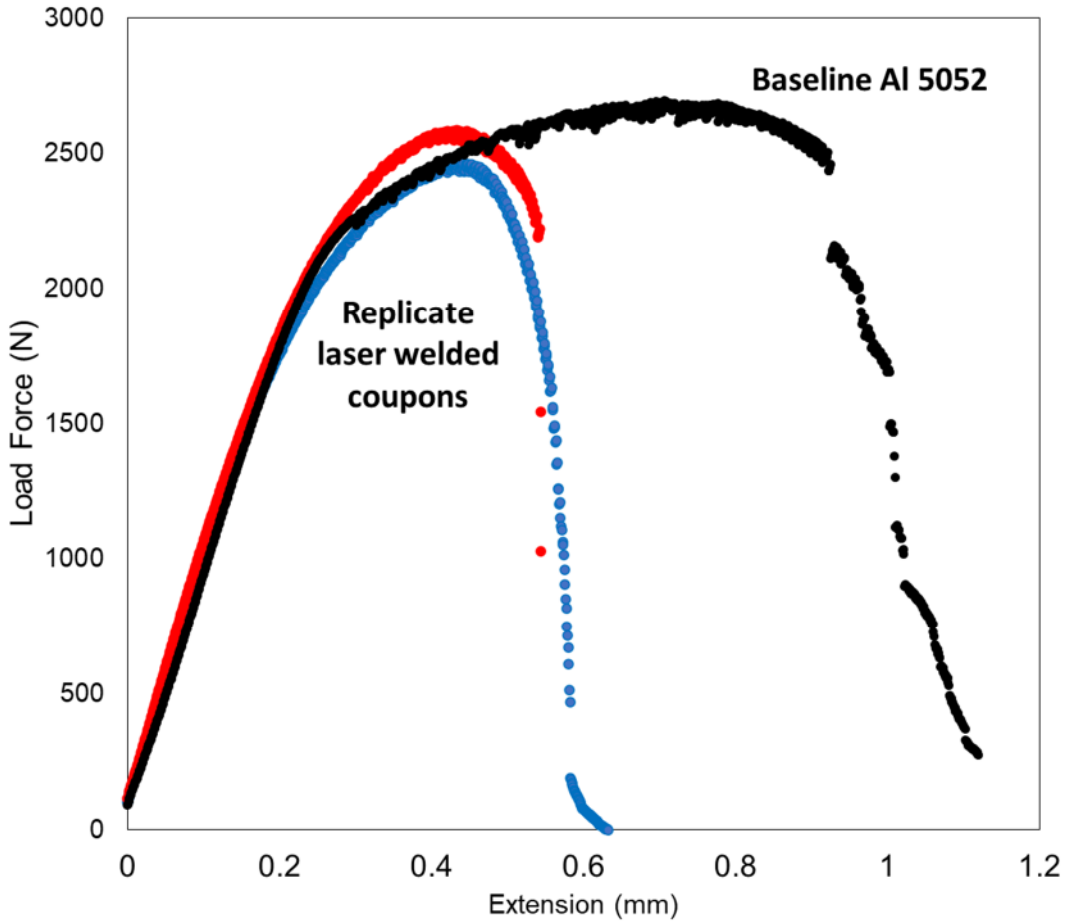


Close-up view of welds

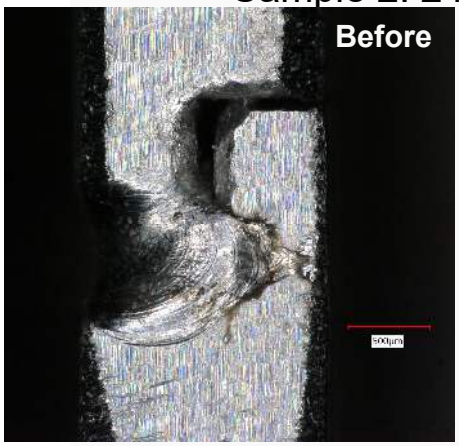


Instron pull testing

Laser Weld Process Development

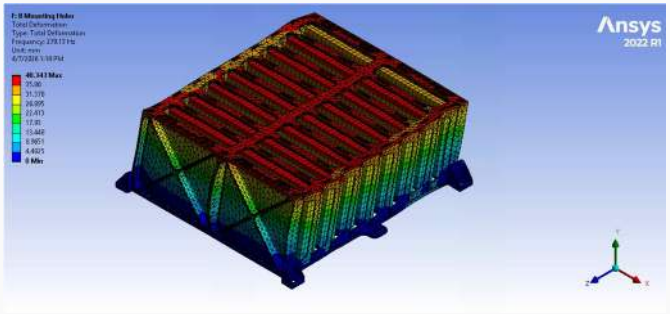


Ultimate load forces:
Baseline: 2694 N
Sample 1: 2587 N
Sample 2: 2466 N

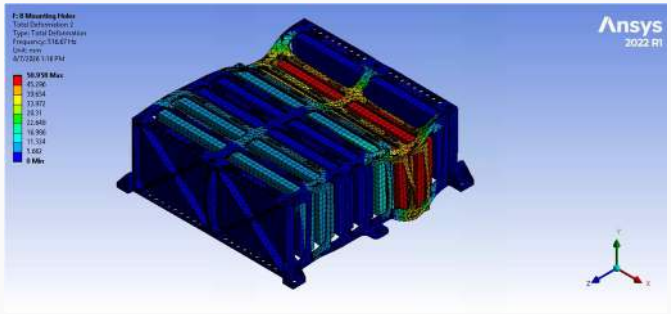


100X magnification

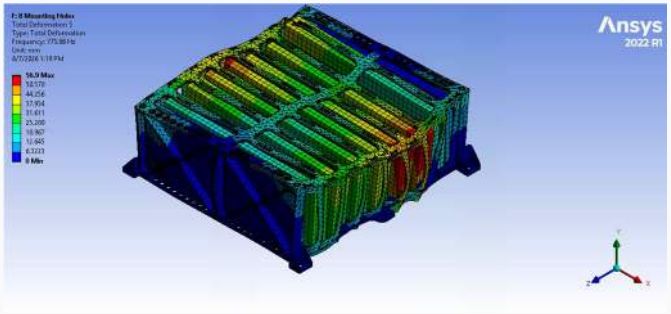
Modal Analysis Results



Mode 1: 279.13 Hz
Chassis Rocking Mode
Z-Axis Mass participation: 69.88%

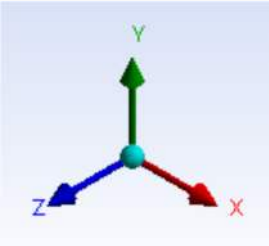


Mode 2: 516.67 Hz
Resonant Mode
Y-Axis Mass participation: 20.05%



Mode 4: 773.86Hz
Assembly twisting mode
X-Axis Mass participation: 22.76%

- Spring elements used to represent the stiffness and preload expected of the gap pad
- Using the General Environmental Verification Standards profile

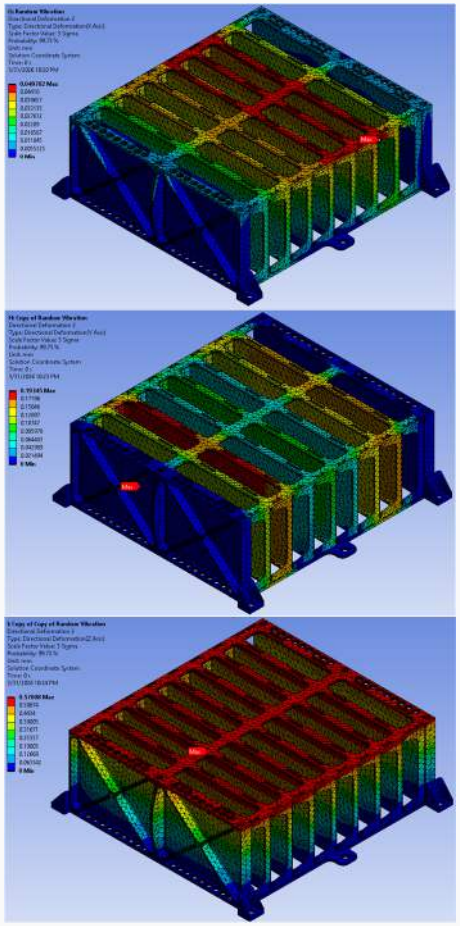


Random Vibration Maximum Deflections

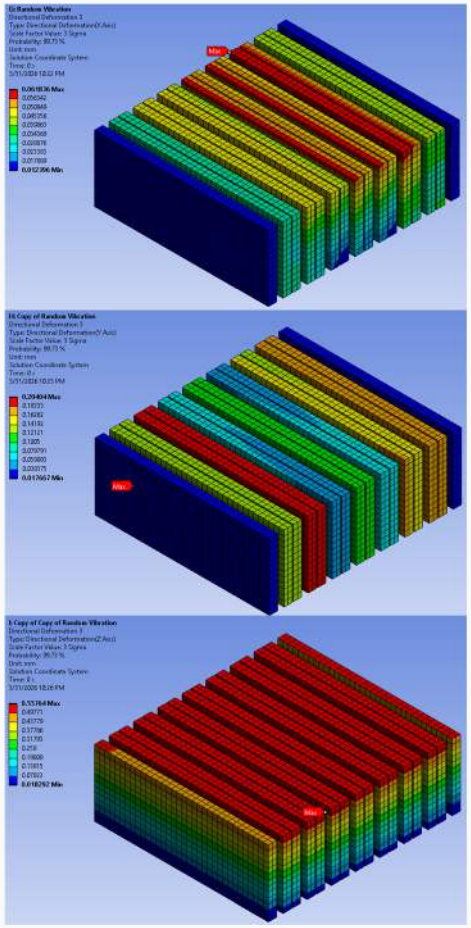
X-AXIS

Y-AXIS

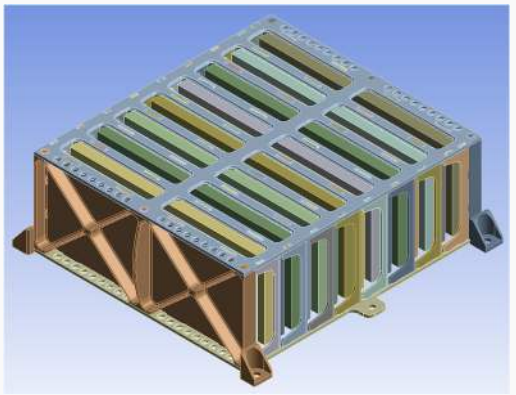
Z-AXIS

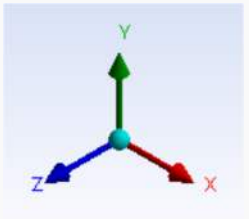


Structure deflections

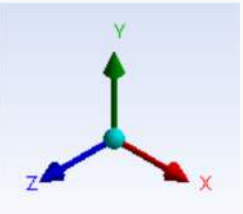


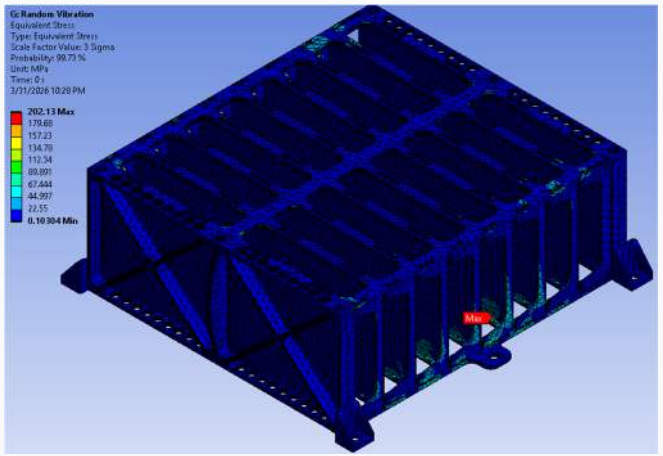
Battery cell deflections



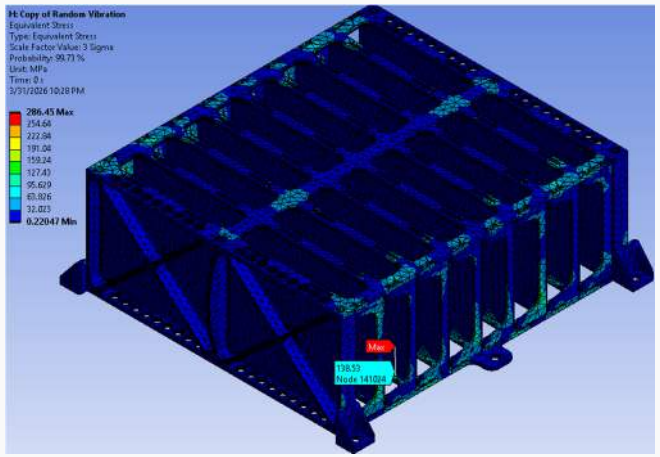


Random Vibe Stresses (Von-Mises Stresses)

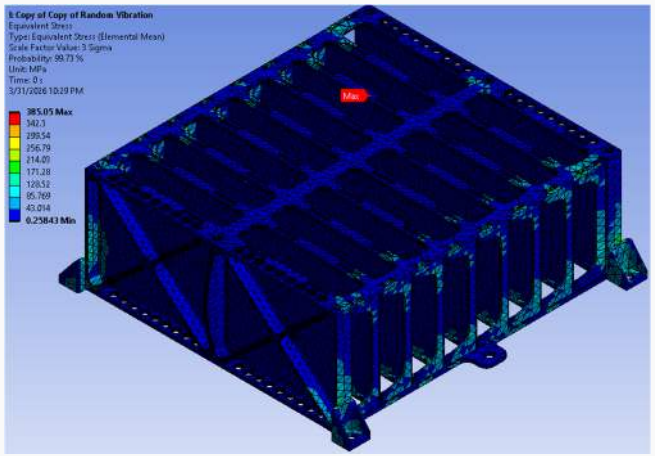




Structure Stresses (X-Axis)



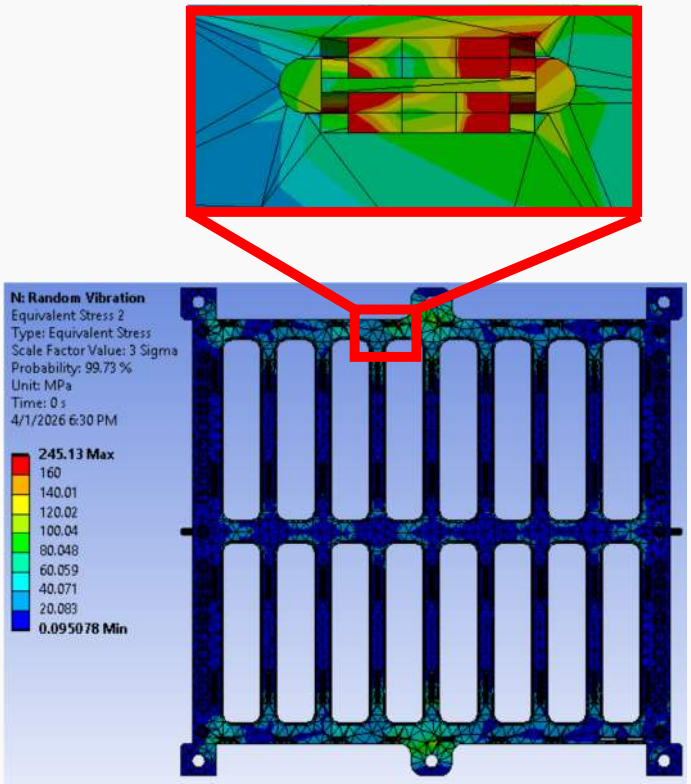
Structure Stresses (Y-Axis)



Structure Stresses (Z-Axis)

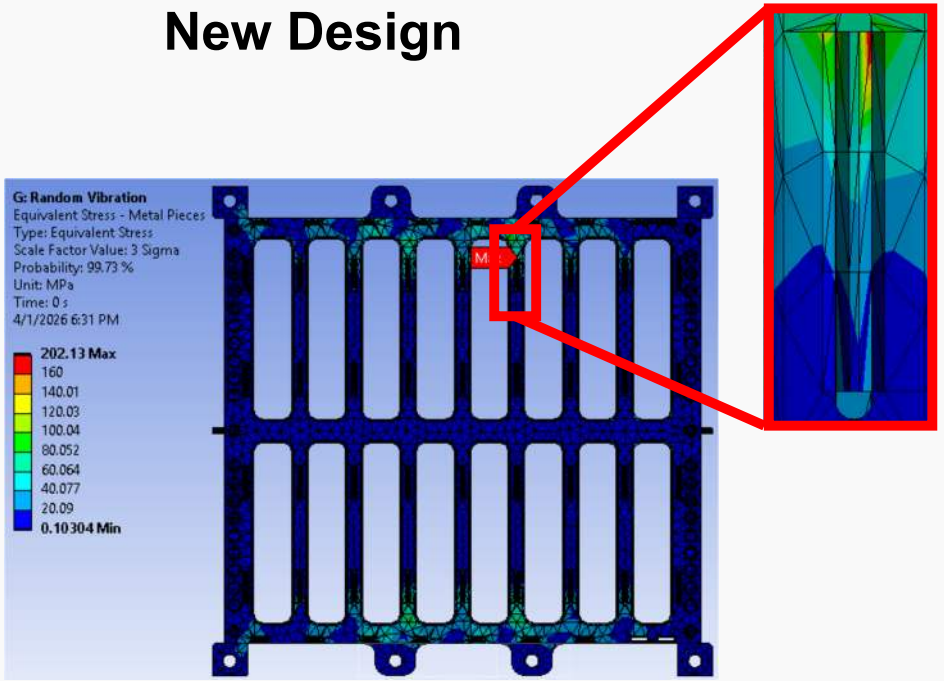
Maximizing weld strength

Original Design



- Original design showed high stress concentrations on the weld joints near the middle mounting holes
- Surpassed the material yield strength

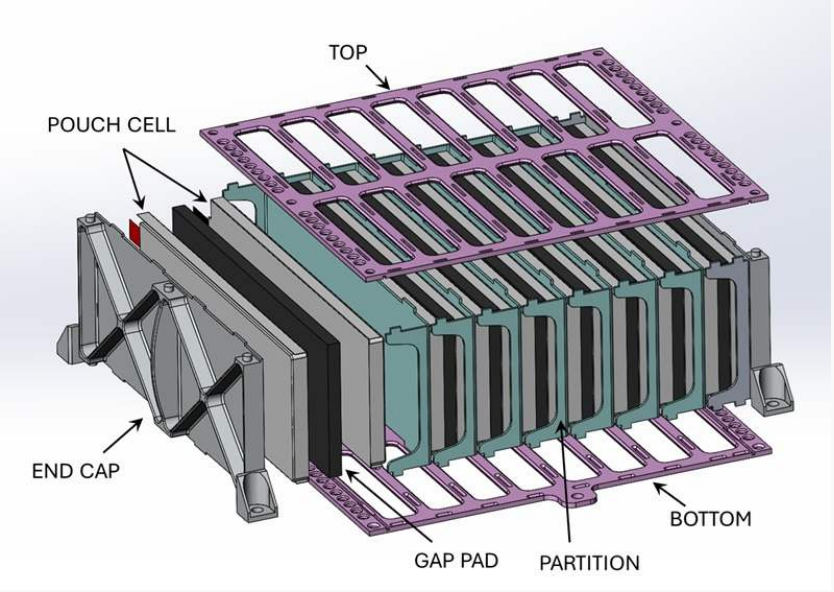
New Design



- New design modification distributes the load path more evenly among the weld joints
- Reduces stresses throughout the weld joints to accommodate positive margin to yield

Mass and module specific energy estimates

8S2P Configuration				
Component	**P/N**	**mass (g)**	**qty**	**Total (g)**
Cell	SA03	104.4	16	1670.4
End cover	20192512-1	42.2	2	84.4
Partition	25192513-1	24.0	7	167.8
Top	25192515-1	53.8	1	53.8
Bottom	25192516-1	55.3	1	55.3
Gusset	25192514-1	1.2	2	2.4
Gap pad	Poron 4701-50-15250-04	11.1	8	88.8
Double face 3M adhesive	Adhesive Transfer Tape 966	1.2	16	19.2
Total				2142.1



41.3 Wh at C/10 and 20°C

661 Wh / 2.142 kg = 308 Wh/kg (100% DOD)

Next Steps

- Initiate fabrication of module parts
- Screen / select cells
- Assemble and populate module
- Performance testing of the module (various rates, temperatures)
- Environmental qualification: TVAC, random vibe testing
- Achieve TRL 6 for lunar night survival mission
- Infusion as a lunar payload for tech demo by 2027
- Consider other types of pouch cells for future designs

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