

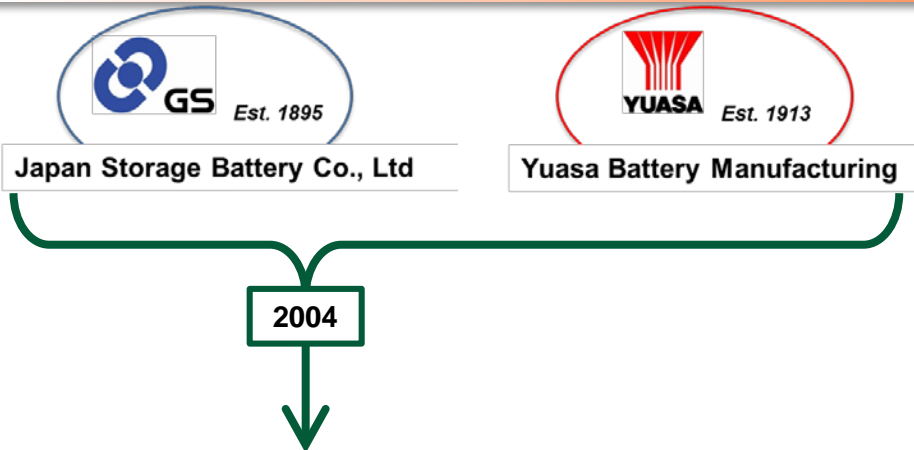
# GS Yuasa Modular Battery Qualification Update and Cell Performance Model Validation

2018 Space Power Workshop  
April 26, 2018

Thomas Pusateri, Curtis Aldrich, George Bergmark, Masazumi Segawa



- GS Yuasa corporate introduction
- Update of space Li-ion activity
- Introduction of the space-qualified MA190 modular space battery
- LSE cell Life and Performance model validation
- Debut of cell and battery Life and Performance model for GYLP customers



## GS Yuasa Corporation

Develops management plan and strategy for GS group and administrate the group companies to enhance the total value of the group.

## GS Yuasa International

Manufacturing and sales of automotive & industrial batteries, power supply systems, switch gear, lighting & ultra violet systems, specialty equipment and other electrical equipment

### GS Yuasa Battery Ltd.

Sales of aftermarket automotive batteries & automobile-related products.

### GS Yuasa Technology Ltd.

Manufacturing and sales of specialty batteries.

### Lithium Energy Japan (JV) (2007)

Development, manufacturing and sales of large lithium-ion batteries for electric vehicles.

### Blue Energy Co., Ltd (JV) (2009)

Development, manufacturing and sales of lithium-ion batteries for hybrid electric vehicles.

### Lithium Energy and Power (JV) (2013)

Development and sales of lithium-ion batteries for electric and hybrid electric vehicles.

### GYLP and Other Affiliates

- **Consolidated FY2016 Net Sales: \$3.2B**
- **Li-Ion sales \$350.9M in FY2016**
- **37 affiliates in 17 countries**
- **14,710 employees worldwide**
- **GS Yuasa Lithium Power, Inc.**
  - **established 2006 (USA)**

- Established: 2006
- Mandate: Sales channel for GS Yuasa's li-ion energy storage technologies and solutions in North America
- Mission: Deliver best-in-class solutions for North American clients within the Aerospace, Military, and Specialty industries
- Focus: Quality, Service, Value
- Functions: Sales, service, engineering, manufacturing program management, logistics and export compliance
- Size: 26 employees and contractors
  - 17 with B.S. or advanced engineering/technical degrees
  - NASA-certified Level B Trainers
- Certifications: ISO 9001 and EN/JISQ/AS9100



Incorporated in Georgia, US company, ITAR compliant, DDTC registered

## GS Yuasa is a world leader in Li-ion energy storage for orbital vehicles

- Number of satellites..... 174+
  - LEO/MEO..... 79+
  - GEO..... 95
- 1<sup>st</sup> satellite on-orbit..... Servis 1 (30 Oct. 2003)
- Longest satellite on-orbit (yrs)..... >12 (IPSTAR, 11 Aug. 2005) still operational
- Watt hours on-orbit..... >3.25 million
- Space cell qualification programs..... >21
- Cell sizes (Ah) flown..... 35; 50; 100; 175; 190; 200
- Performance to date..... No failures
- Backlog (Wh)..... >1MWh

## Launch vehicles & number of satellites

Ariane-5ECA	39	Atlas-5 (401)	5	Soyuz-2-1b Fregat	3	H-2A-2024	2	Atlas-5 (421)	1
Soyuz-2-1 Fregat	24	Falcon-9 v.1.1	5	Zenit-3SLB	3	H-2A-204	2	Dnepr	1
Proton-M Briz-M (Ph.3)	18	Proton-M Briz-M (Ph.4)	5	Antares 120	2	Rokot-KM	2	Epsilon CLPS	1
H-2A-202	14	Falcon-9 v.1.2	4	Antares 230	2	Zenit-3SL	2	Falcon-9 v.1.2 (refly)	1
H-2B-304	13	H-2A	4	Atlas-5 (431)	2	Antares 130	1	GSLV Mk.2	1
Soyuz-STB Fregat-MT	9	Proton-M Briz-M (Ph.2)	4	Epsilon	2	Ariane-5GS	1	Proton-M Briz-M (Ph.1 M1)	1



Updated FEB 2018

## JHU/APL

- LSE50, LSE55
- Critical space science missions
- Van Allen Probes (RBSP), Double Asteroid Redirection Test (DART)

## OrbitalATK

- LSE100, LSE110, LSE134, LSE145, LSE190
- Several platforms supported. Batteries built by EPT and GYLP
- CRS Cygnus Vehicle, >39 flight batteries manf. and delivered by GYLP
- GEOStar-2, GEOStar-3, LEOStar-3, MEV

## International Space Station

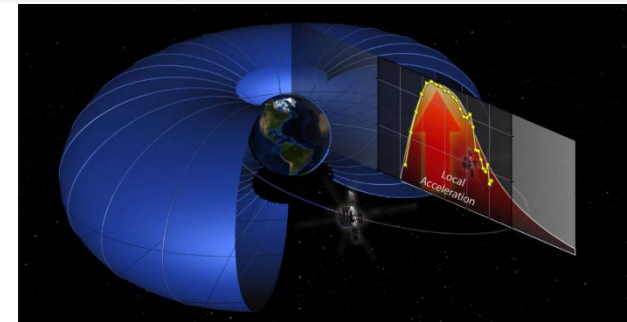
- Won highly competitive down-select process
- >5 year period of performance, >1000 LSE134 cells
- 6 of 24 ORU batteries have been installed (channels 3A and 1A)

## Boeing LTA

- LSE42, LSE102, LSE190
- >\$3.5 Million awarded
- ViaSat-3 Americas & EMEA, GiSat

## Other Govt. Programs

- LSE Gen. III cells selected for flight vehicles
- \$7 Million in contracts awarded



# GYLP In The News

http://www.gsyuasa-lp.com/



Powering the Next Generation

**LTA**

News Release  
April 20, 2016  
GS Yuasa Lithium Power

**GS Yuasa Lithium Power and The Boeing Company Enter into Long Term Supply Agreement**

Rowlett, GA – GS Yuasa Lithium Power (GYLP), the US subsidiary of GS Yuasa Corporation (GYC) (Tokyo Stock Exchange: 6574), announced today that they have entered into a Long Term Supply Agreement with The Boeing Company (Boeing) for the supply of GS Yuasa Technology's (GYT) Lithium-ion cells for use in satellite applications.

The agreement runs through 20 support Boeing classes.

"GYLP is pleased to award based on our 20+ years of experience and expertise in the aerospace and defense markets. The simplicity across satellite process efficiency."

GS Yuasa group experience dates since 1966. GY Lithium-ion cells

About GS Yuasa  
GS Yuasa Corp  
Battery, GS Yuasa applications. The environments, <http://www.gsyuasa.com>

**ViaSat-3**

News Release  
October 10, 2016  
GS Yuasa Lithium Power

**Boeing Awards GS Yuasa Lithium Power Order for Space Qualified Lithium-ion Cells**

Rowlett, GA, October 10, 2016 – GS Yuasa Lithium Power (GYLP), a US subsidiary of GS Yuasa Corporation (GYC) (Tokyo Stock Exchange: 6574), announced today that it has received an order from The Boeing Company for the supply of GS Yuasa Technology's (GYT) Lithium-ion cells for use in satellite applications.

This award follows the LSE190 qualification process for the ViaSat-3 communication satellite. The LSE190 is a high power, high performance Lithium-ion cell used in a variety of satellite applications. The LSE190 is a high power, high performance Lithium-ion cell used in a variety of satellite applications.

"GYLP is pleased to award based on our 20+ years of experience and expertise in the aerospace and defense markets. The simplicity across satellite process efficiency."

GS Yuasa group experience dates since 1966. GY Lithium-ion cells

About GS Yuasa  
GS Yuasa Corp  
Battery, GS Yuasa applications. The environments, <http://www.gsyuasa.com>

**>3MWh**

News Release  
September 29, 2017  
GS Yuasa Lithium Power

**GS Yuasa Lithium Ion Cells Surpass 3,000,000 Watt-Hours On Orbit**

Rowlett, GA – GS Yuasa Lithium Power announced today that GS Yuasa Technology's lithium ion (Li-ion) cells have surpassed 3.0 MWh of energy storage on orbit. GS Yuasa lithium ion cells have now been flown on more than 150 spacecraft supporting commercial communication, remote sensing, scientific, defense and multiple human-rated applications.

"The reliability and excellent performance of GS Yuasa's space Li-ion cells allow our customers to perform longer and more complex missions, especially with the increase in power demand for electric propulsion systems on new satellites. In GS Yuasa's 100th anniversary year we have been able to achieve this exceptional milestone through the dedication of our employees, the cooperation of our partners and the efforts of our customers," said Bill Maki, President of GS Yuasa Lithium Power. "Based on exceptional value, heritage and performance, GS Yuasa is the first company to achieve this milestone."

All GS Yuasa Li-ion cells for space share the same basic chemistry, design, materials, construction and manufacturing processes. With no cell failures on orbit, volume of life and performance data and a solid connection between the cells offered today and the reliability of its industry leading Li-ion spaceflight heritage, GS Yuasa's value proposition is stronger than ever.

Unlike commercial cells all GS Yuasa Li-ion space cell and chemistry performance attributes are optimized exclusively for the unique environments and duty cycles imposed by spaceflight. The ability to configure a battery system with cells of this pedigree allows GS Yuasa to deliver solutions in support of critical missions without having to exercise the battery to meet design life requirements exceeding 15 years. The resulting high specific-power batteries help customers to meet power system mass targets and reduce launch costs while minimizing program insurance costs.

To learn more about GS Yuasa's LSE family of Li-ion cells for space, please contact GS Yuasa Lithium Power, Inc.



**MEV**

News Release  
October 31, 2016  
GS Yuasa Corporation

**Orbital ATK Selects GS Yuasa Lithium-ion Cells For Innovative Mission Extension Vehicle Satellite**

Rowlett, GA (GYC) (Tokyo Stock Exchange: 6574) announced today that it has received an order from Orbital ATK for the supply of GS Yuasa Technology's (GYT) Lithium-ion cells for use in satellite applications.

The MEV is an on-orbit, autonomous satellite. The launch of the MEV will provide well as part of the MEV mission.

In addition to the MEV mission, GS Yuasa Lithium Power is also providing cells for the JPS-2 mission.

"GYLP is pleased to award based on our 20+ years of experience and expertise in the aerospace and defense markets. The simplicity across satellite process efficiency."

GS Yuasa group experience dates since 1966. GY Lithium-ion cells

About GS Yuasa  
GS Yuasa Corp  
Battery, GS Yuasa applications. The environments, <http://www.gsyuasa.com>

**JPS-2**

News Release  
October 31, 2016  
GS Yuasa Lithium Power

**Orbital ATK Selects GS Yuasa Lithium-ion Cells to Power Joint Polar Satellite System (JPSS)-2**

Rowlett, GA (GYC) (Tokyo Stock Exchange: 6574) announced today that it has received an order from Orbital ATK for the supply of GS Yuasa Technology's (GYT) Lithium-ion cells for use in satellite applications.

The JPSS-2 is a high power, high performance Lithium-ion cell used in a variety of satellite applications. The JPSS-2 is a high power, high performance Lithium-ion cell used in a variety of satellite applications.

"GYLP is pleased to award based on our 20+ years of experience and expertise in the aerospace and defense markets. The simplicity across satellite process efficiency."

GS Yuasa group experience dates since 1966. GY Lithium-ion cells

About GS Yuasa  
GS Yuasa Corp  
Battery, GS Yuasa applications. The environments, <http://www.gsyuasa.com>

**MA190**

News Release  
January 10, 2018  
GS Yuasa Corporation

**GS Yuasa Lithium Power Completes Qualification of a New Modular, Scalable Lithium Ion Battery for Spacecraft**

Rowlett, GA – GS Yuasa Lithium Power (GYLP), the US subsidiary of GS Yuasa Corporation (GYC) (Tokyo Stock Exchange: 6574) announced today the availability of a new, space-qualified Lithium ion (Li-ion) battery based on the multi-cell LSE190 cell manufactured by GS Yuasa Technology (GYT) in Kyoto, Japan.

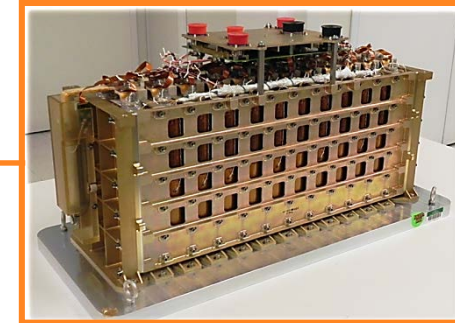
A 12-cell configuration of the MA190 battery module successfully completed qualification testing including shock, sine and random vibration, and thermal vacuum testing. The MA190 can be assembled to contain 6 to 12 LSE190 cells per module with flexibility to connect cells in parallel. For qualification, a 12-cell module was tested because its thermal behavior and environmental tolerance envelopes those of smaller module configurations.

The LSE190 is part of GYT's generation III Li-ion family of cells. It has been qualified to NASA JSC 20190 "Crewed Space Vehicle Battery Safety Requirements" and has accrued significant spaceflight heritage in LEO and GEO regimes including multiple human-rated missions. The LSE190 is the largest of the space-qualified wound prismatic cell sizes offered by GS Yuasa and represents the portfolio's lowest cost in terms of dollars per watt-hour.

"Maximizing the accessibility of GYT's industry leading space Li-ion technology in North America through high TRL and complete battery offerings continues to be GYLP's focus," said Bill Maki, GYLP President. "Developed to complement GYT's Li-ion based batteries available from our partner (Explicor) Technologies (Explicor, MO), the MA190 reflects our effort to bring the best possible value to our customers."

# **GS Yuasa Modular Space Battery Overview and Qualification Test Summary**





EPT part no.: SAR-10199  
electrical config.: 1P9S  
spaceflight heritage: 7 yrs



EPT part no.: SAR-10197  
electrical config.: 2P9S  
spaceflight heritage: 8 years



EPT part no.: SAR-10213  
electrical config.: 2P9S  
2018 launch



EPT part no.: SAR-10209  
electrical config.: 1P8S  
2017 launch

# EPT Spaceflight Heritage with GS Yuasa cells: 26 batteries

Designs may be modified to meet customer specific requirements without invalidating qualification history.

- The MA190 module is a scalable and configurable cell pack based on GS Yuasa's LSE190 Li-ion cell
- Modules may each contain between 6 and 12 LSE190 cells
- Cells may be electrically connected in series (1P), 2P or 3P yielding 190, 380 and 570Ah respectively
- A 12 cell, 1P battery module completed qualification testing in 2017



The MA190-112 Qualification Unit

## MA190 Module Configuration Numbering

Modular Aerospace Battery

Available Configurations

MA 190 - 1 12

LSE190 Li-ion cell

1 6

2 7

Cells in parallel

3 8

Cells per module

9

10

11

12

-106

-107

-108

-109

-110

-111

-112

-206

-208

-210

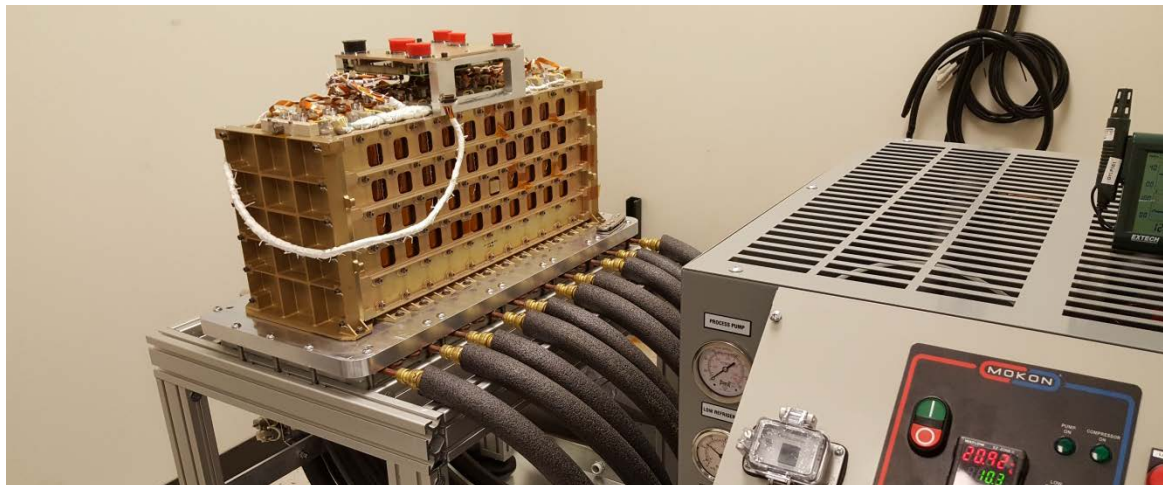
-212

-306

-309

-312

- Qualification Unit
  - 1P12S Configuration
    - Largest modular configuration
    - Most complex wiring
    - Largest connector interface
      - Connector Plate placed in worst case location for dynamic testing
  - 12 cells selected from multiple production lots
    - All flight qualified production units
  - Successfully completed environmental qualification
  - Plan to start long-term cycling test on cold plate Q2 2018

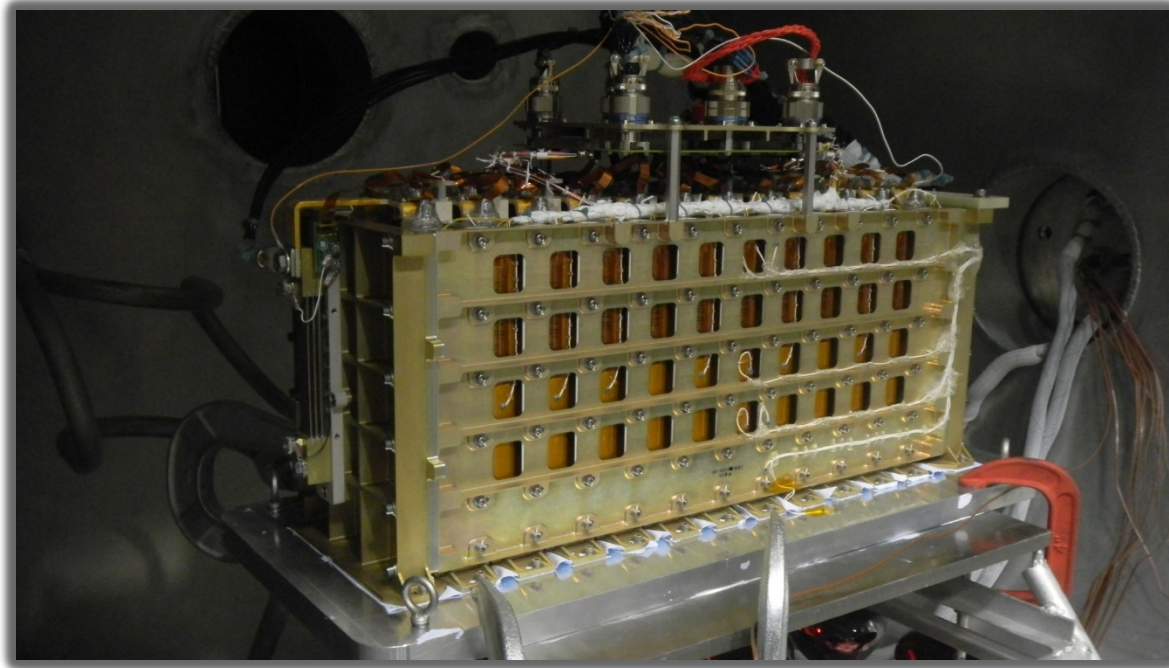


The qualification model built from spare flight cells.

- 4 different lots
- activation dates ranging from 07/2012 to 10/2015

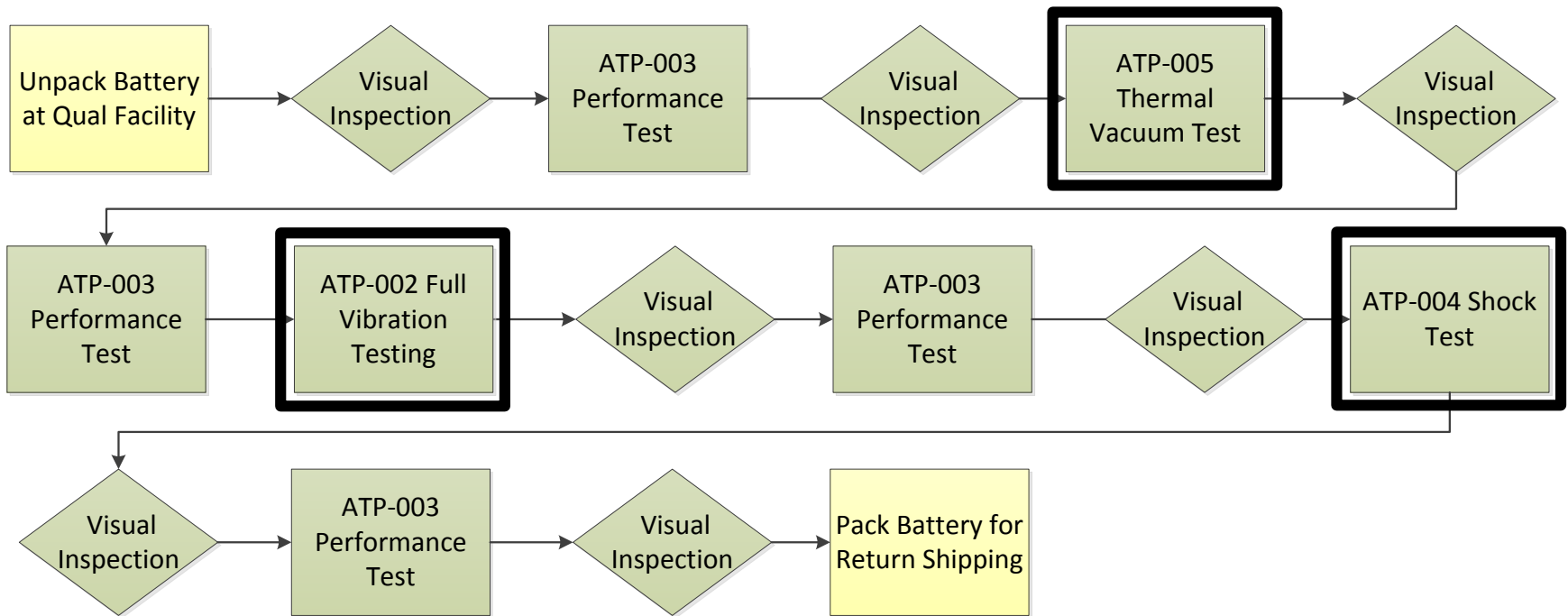
Cell Position #	Cell SN	Lot#	Cell Activation Date
1	323	Lot009	10.2015
2	317	Lot009	10.2015
3	318	Lot009	10.2015
4	308	Lot008	05.2013
5	249	Lot006	09.2012
6	218	Lot005	07.2012
7	245	Lot006	09.2012
8	286	Lot008	05.2013
9	319	Lot009	10.2015
10	316	Lot009	10.2015
11	320	Lot009	10.2015
12	321	Lot009	10.2015

## MA190-112 1P12S Environmental Test Summary



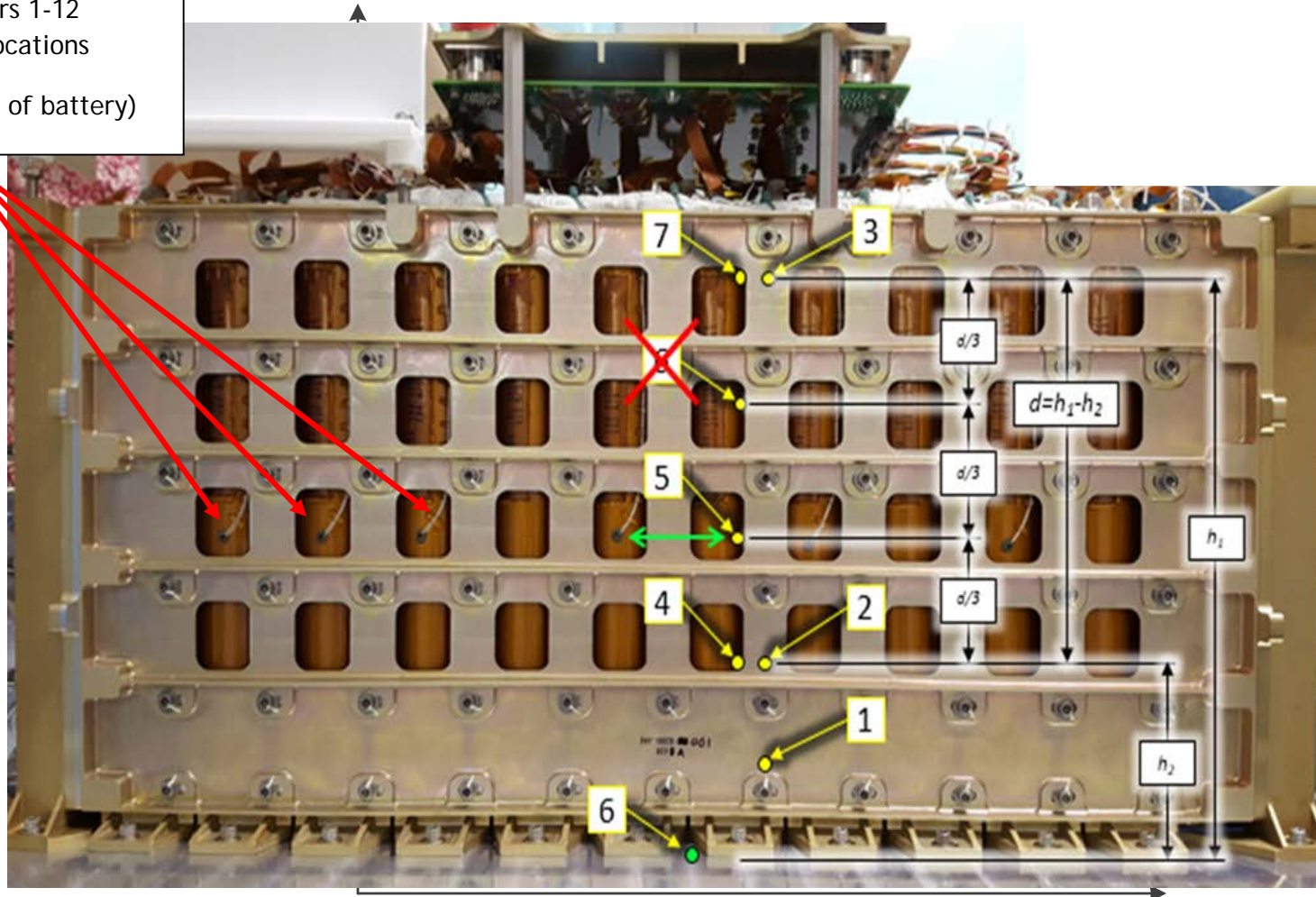
MA190-112 QUALIFICATION UNIT

# Battery Environmental Qualification Test Flow



Full Hot Performance Test: 30°C environment, 126A (2/3C) discharge, 100%DOD

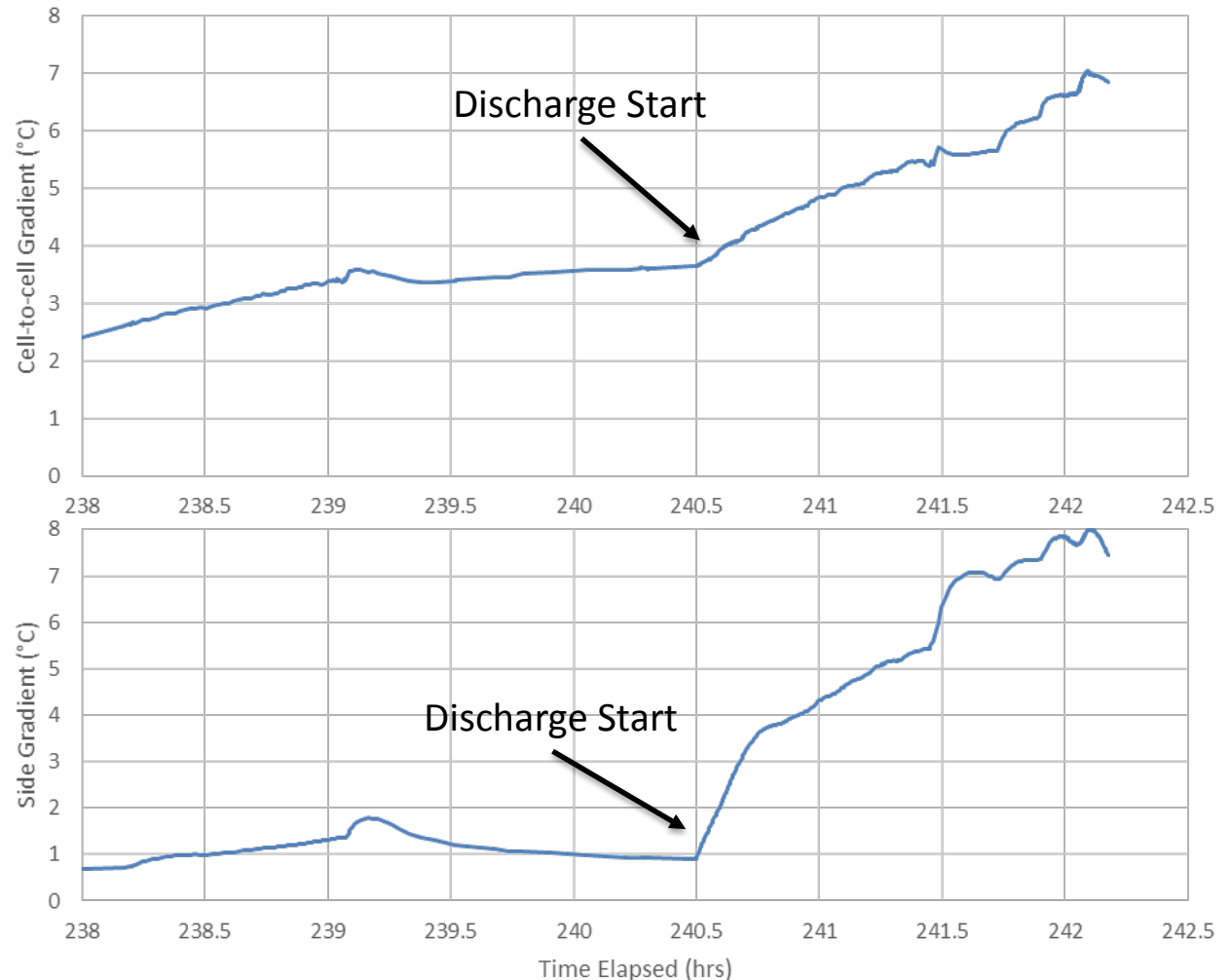
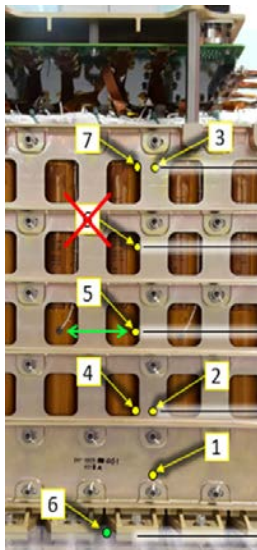
Cell Thermistors 1-12  
approximate locations  
(on both sides of battery)



Full Hot Performance Test: 30°C environment, 126A discharge 100%DOD

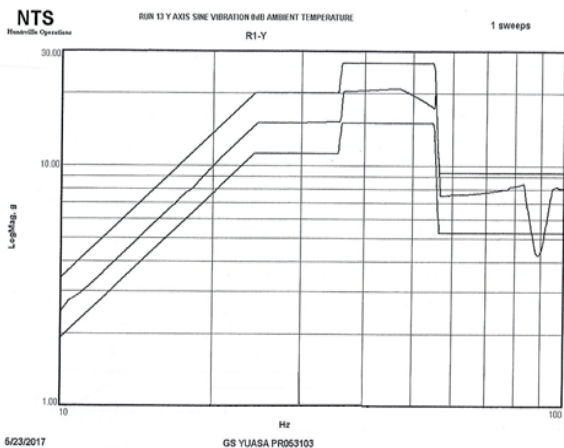
**Requirement:**  
cell temperature  
gradients may  
not exceed 10 °C

Cell-to-Cell Gradient	7.0 °C
Top-to-bottom Cell Gradient	8.0 °C





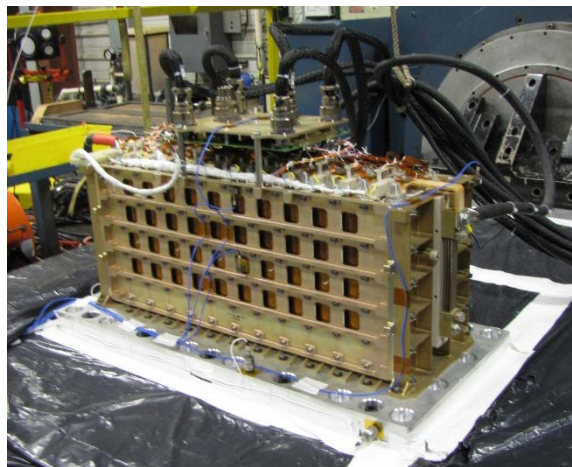
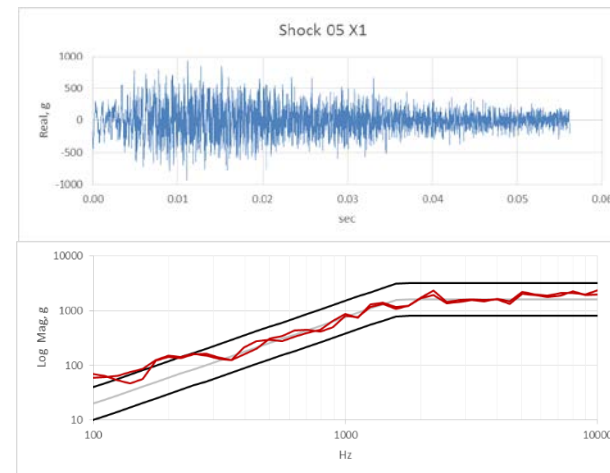
## Sine Vibe



## Random Vibe

- Primary modal response of the battery:  
X: 550 Hz  
Y: 242 Hz  
Z: 212 Hz

## Shock



Date	Step	Capacity (Ah)	AC Impedance (mOhm)	Temperature
01/31/2017	Battery pre-ship to NTS	<b>200.83</b>	10.920	+15 °C
02/23/2017	Battery as received at NTS	201.39	11.216	Ambient
03/08/2017	full performance, cold	189.395	n/a	-5 °C
03/09/2017	full performance, model validation	197.663	n/a	+10 °C
03/09/2017	full performance, hot	201.093	n/a	+30 °C
03/09/2017	post t-vac	200.69	11.356	Ambient
03/31/2017	post vibe	200.07	12.805	Ambient
04/26/2017	post shock	199.89	12.153	Ambient
05/24/2017	final (post sine retest)	<b>198.12</b>	13.896	Ambient

# **Cell Life Cycle Testing and Performance Modeling**

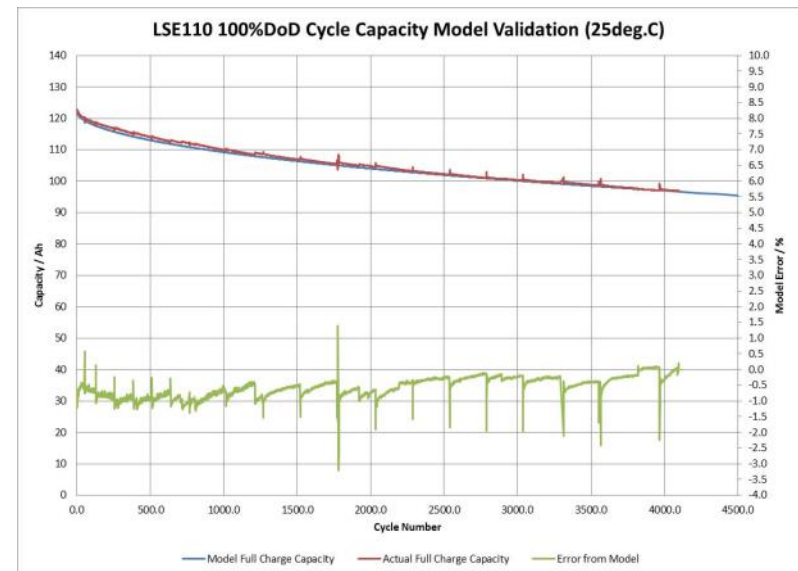
The GS Yuasa Capacity and Voltage Retention Model is an internally developed tool for predicting cell performance in a variety of ground and dynamic on-orbit usage profiles.

The model is based on the empirical life testing data accumulated by GS Yuasa over the past 15 years.

Model will accurately predict 3 key metrics for determining a cell's useful life:

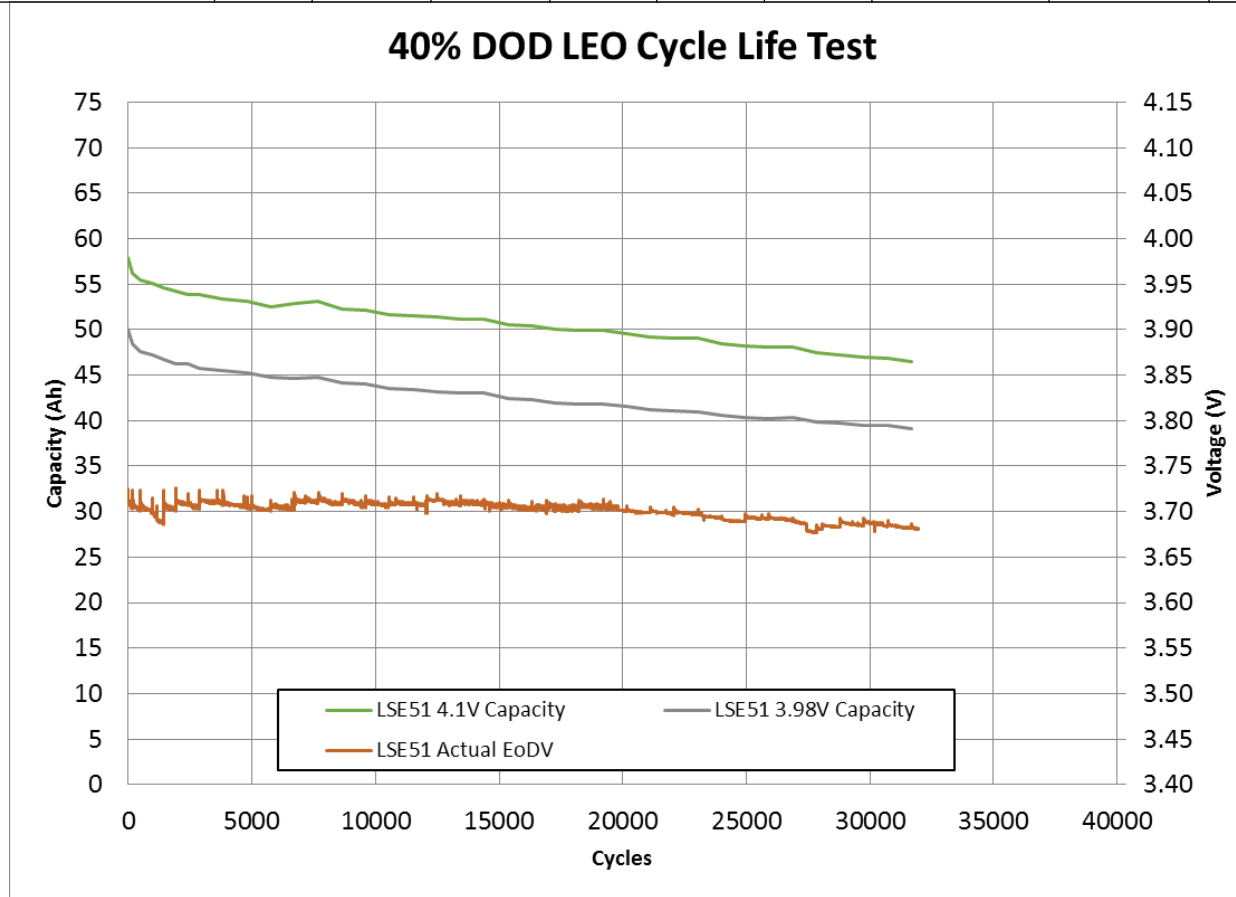
- Full Charge Capacity
- On-Orbit Capacity
- End of Discharge Voltage

**See Reference:  
2014 Space Power Workshop**



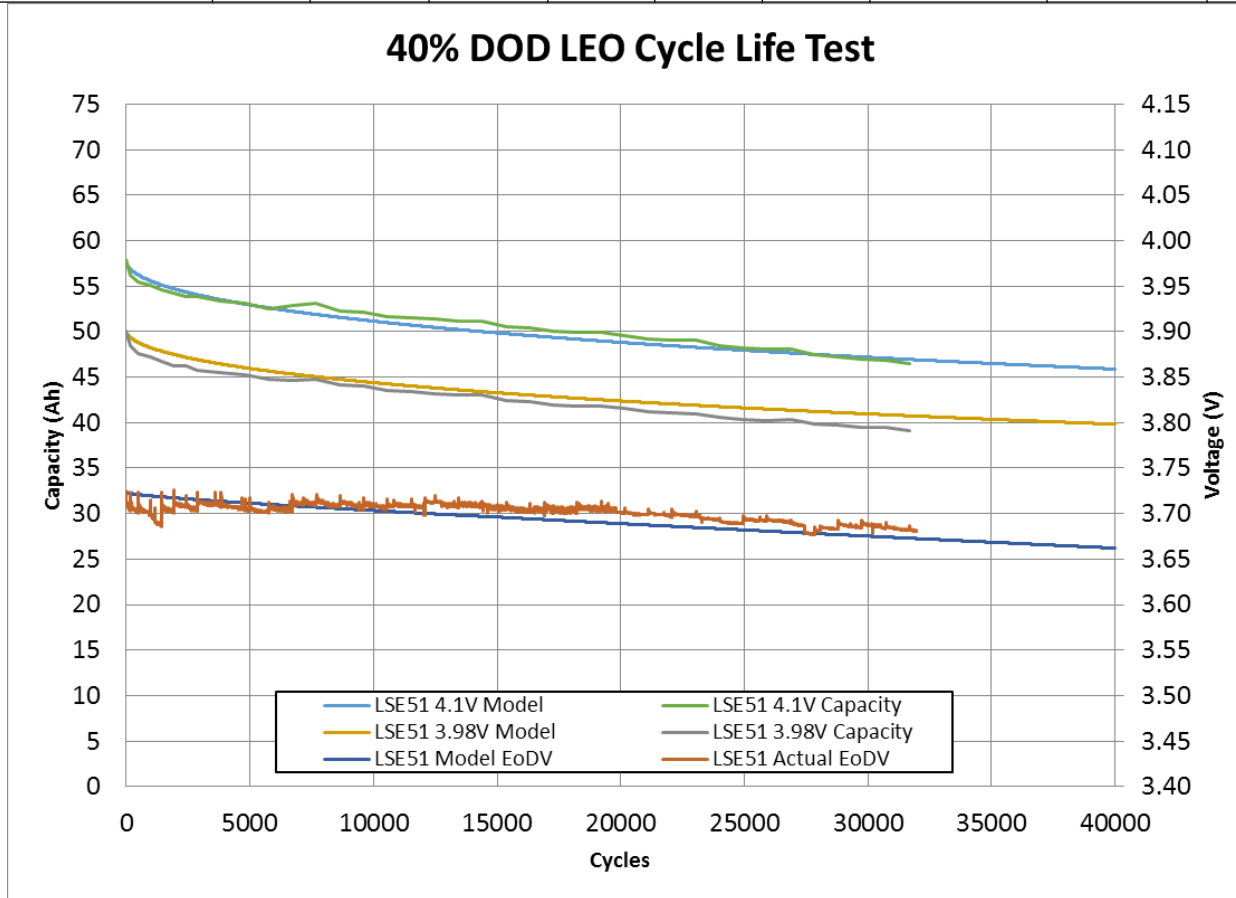
# 40% DOD LEO Cycle

Test Name	Cell Type	Test Conditions						Ambient Test Temp	Start Date	Remark
		Charge Condition (CCCV unless noted)			Discharge Condition					
		EoCV	Rate	Time	EoDV	Rate	Time			
40%DoD Cycling	LSE51	3.98V	25.5A	1hr	(3.40V)	40.8	0.5hr	20°C	9/28/2009	Deep DoD LEO Cycle



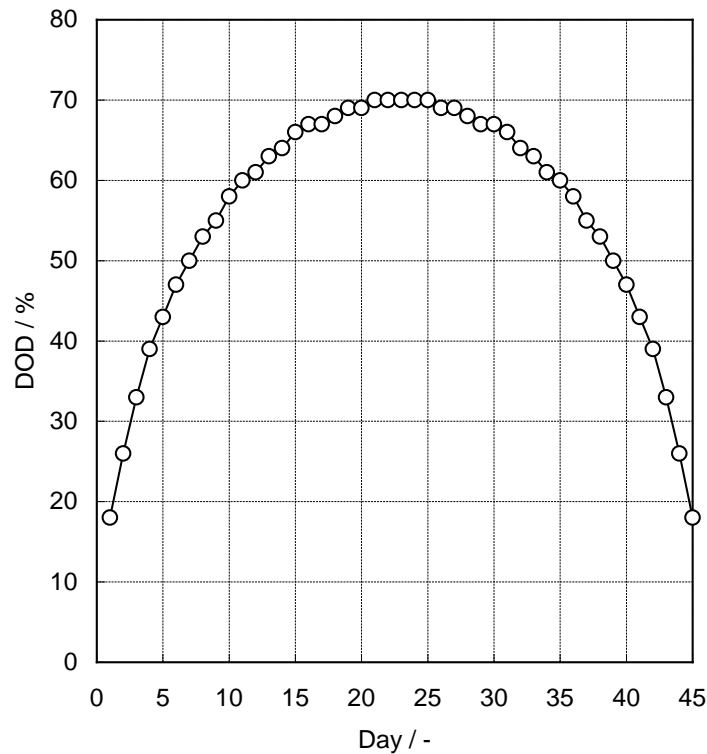
# 40% DOD LEO Cycle

Test Name	Cell Type	Test Conditions						Ambient Test Temp	Start Date	Remark
		Charge Condition (CCCV unless noted)			Discharge Condition					
		EoCV	Rate	Time	EoDV	Rate	Time			
40%DoD Cycling	LSE51	3.98V	25.5A	1hr	(3.40V)	40.8	0.5hr	20°C	9/28/2009	Deep DoD LEO Cycle



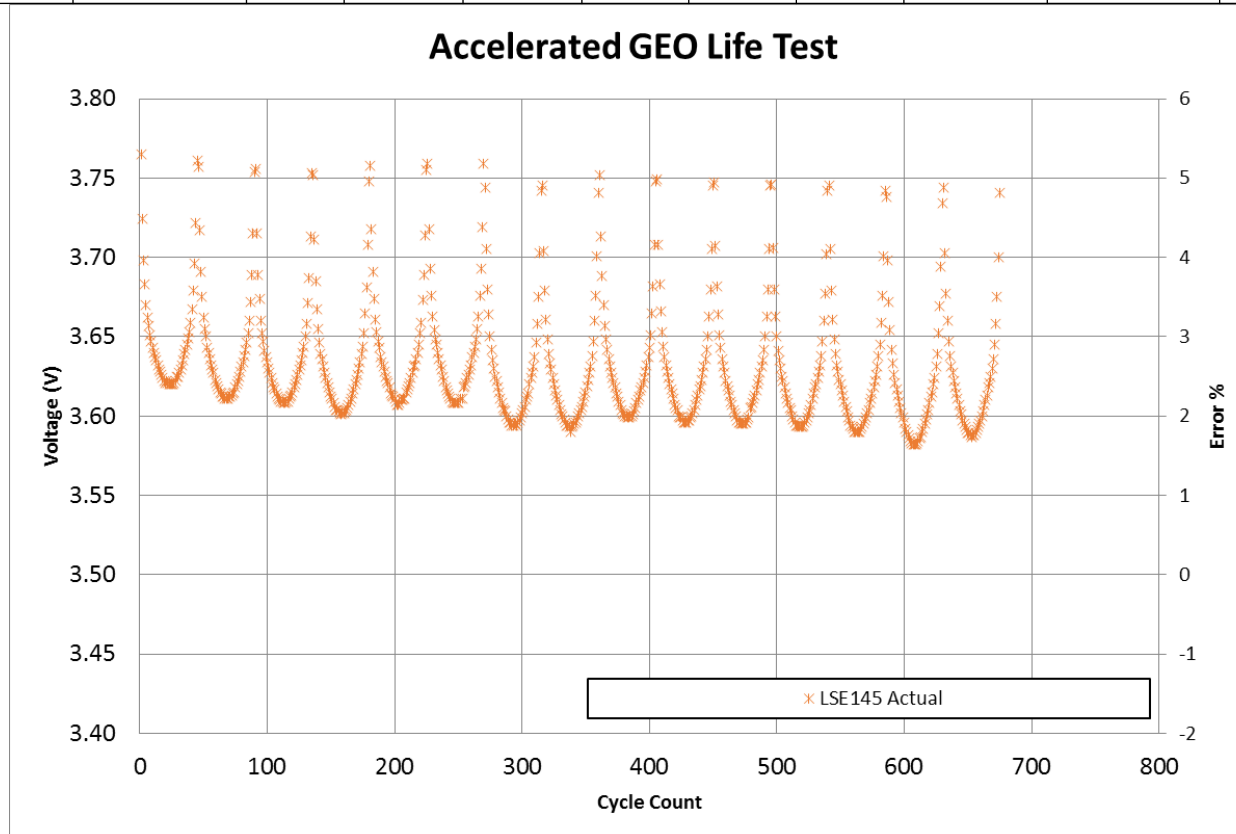
# Semi-accelerated GEO Life Cycle Test

Cell	Solstice Season	Eclipse Season
<b>LSE145</b> <b>Energy Type</b> <b>Gen. 3 cell</b>	<b>SOC: ~90% (4.0VEOCV)</b> <b>Temperature: 25°C</b> <b>Duration 69days</b>	<b>1 cycle per day for 45 days</b> <b>Charge: 0.1C(14.5A),</b> <b>Duration: 24h-discharge time</b> <b>Discharge: 0.595C (86.3A)</b> <b>Min duration: 18.15min, Max Duration: 70.5m (see chart)</b> <b>Temperature: 10°C</b>



# Semi-accelerated GEO Life Cycle Test

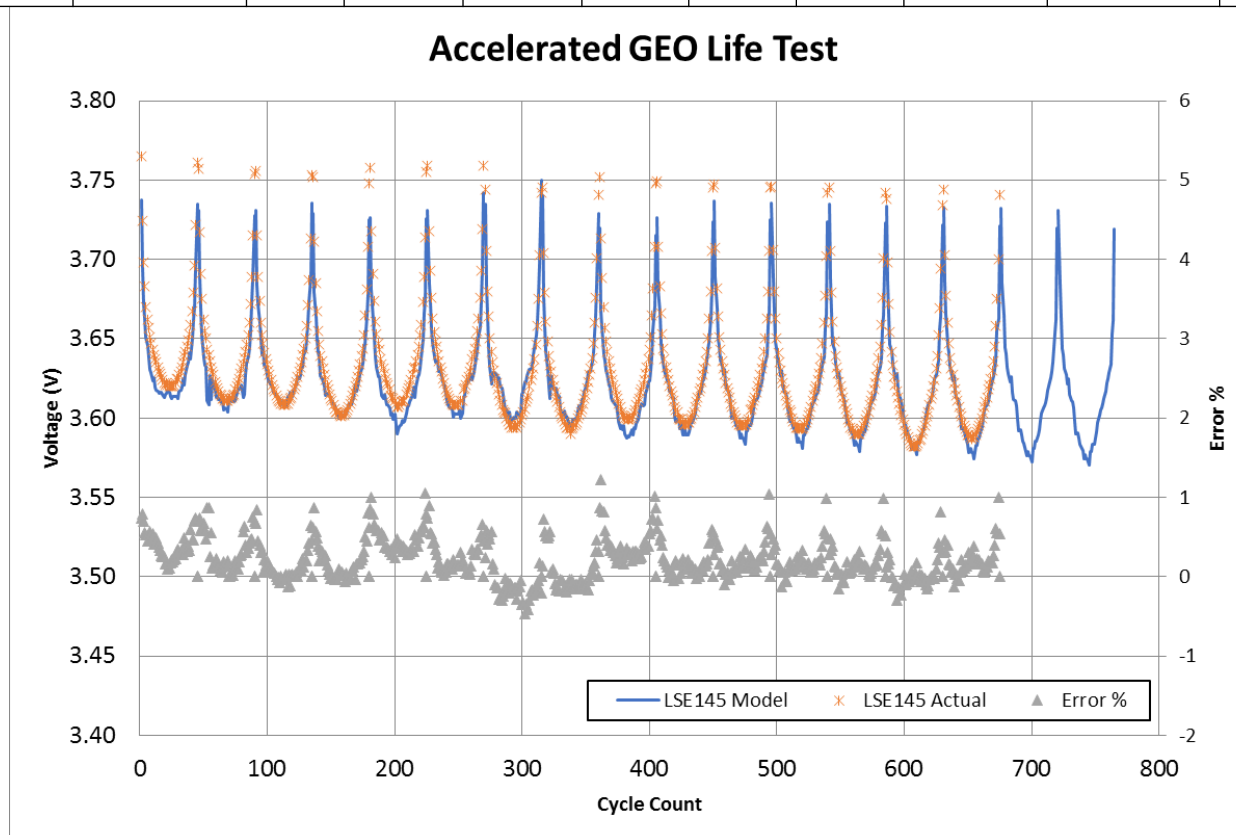
Test Name	Cell Type	Test Conditions						Ambient Test Temp	Start Date	Remark
		Charge Condition (CCCV unless noted)			Discharge Condition					
		EoCV	Rate	Time	EoDV	Rate	Time			
Semi-Accelerated GEO Cycle	LSE145	4.00V	14.5A	22.83hr	(3.40V)	86.3A	Varies	10°C	10/2009	60 day solstice season 25°C 45day eclipse season





# Semi-accelerated GEO Life Cycle Test

Test Name	Cell Type	Test Conditions						Ambient Test Temp	Start Date	Remark
		Charge Condition (CCCV unless noted)			Discharge Condition					
		EoCV	Rate	Time	EoDV	Rate	Time			
Semi-Accelerated GEO Cycle	LSE145	4.00V	14.5A	22.83hr	(3.40V)	86.3A	Varies	10°C	10/2009	60 day solstice season 25°C 45day eclipse season



Positive error % represents conservative estimate with respect to actual data

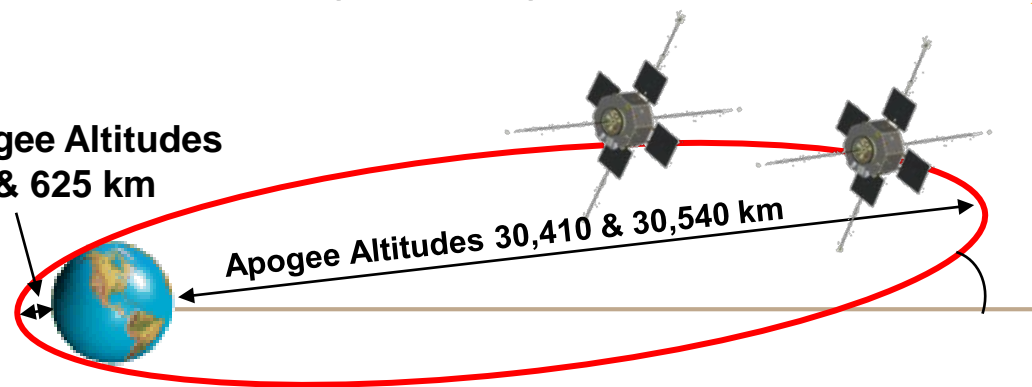
John Hopkins University Applied Physics Laboratory (JHU/APL) has shared on-orbit battery performance data collected from their twin Van Allen Probe spacecraft.

- Powered by GS Yuasa Generation 2 LSE50 (50Ah, 3.7V) cells
- Satellites launched August 30, 2012

Using the ground experience and orbit profile GYLP will model the mission and verify the End of Discharge Voltage results to those collected on-orbit.



**Perigee Altitudes**  
605 & 625 km

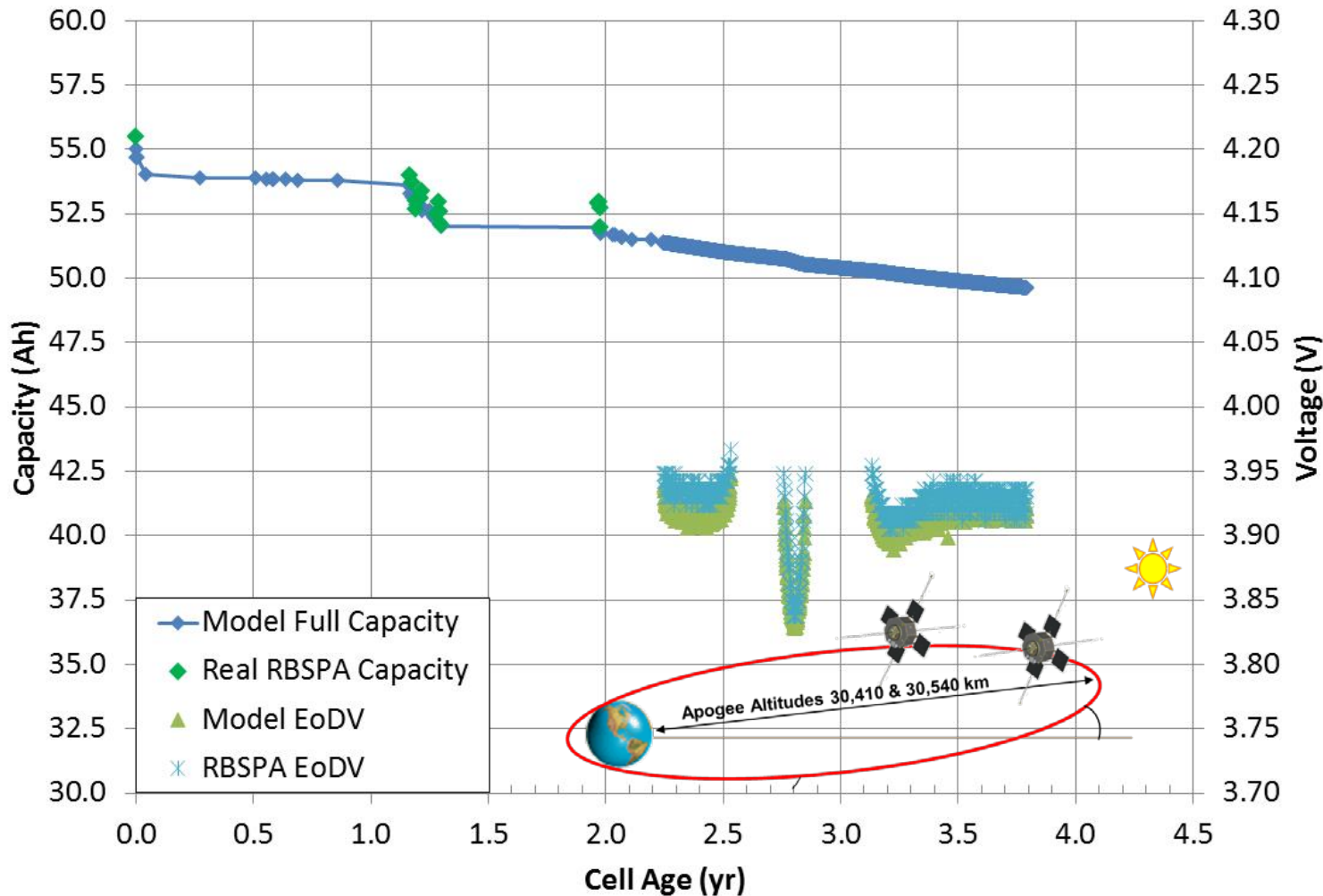


**Apogee Altitudes** 30,410 & 30,540 km



**Inclination**  
10°

## Van Allen Probe Mission Profile



Very high confidence in the ability to predict cell (and battery) performance when provided the relevant use case inputs.

- For a given set of mission parameters, what is the maximum continuous power an LSE cell can provide for an entire mission?

Mission Duration	4.1V/cell Power (W)
15year	???
18year	???
20year	???

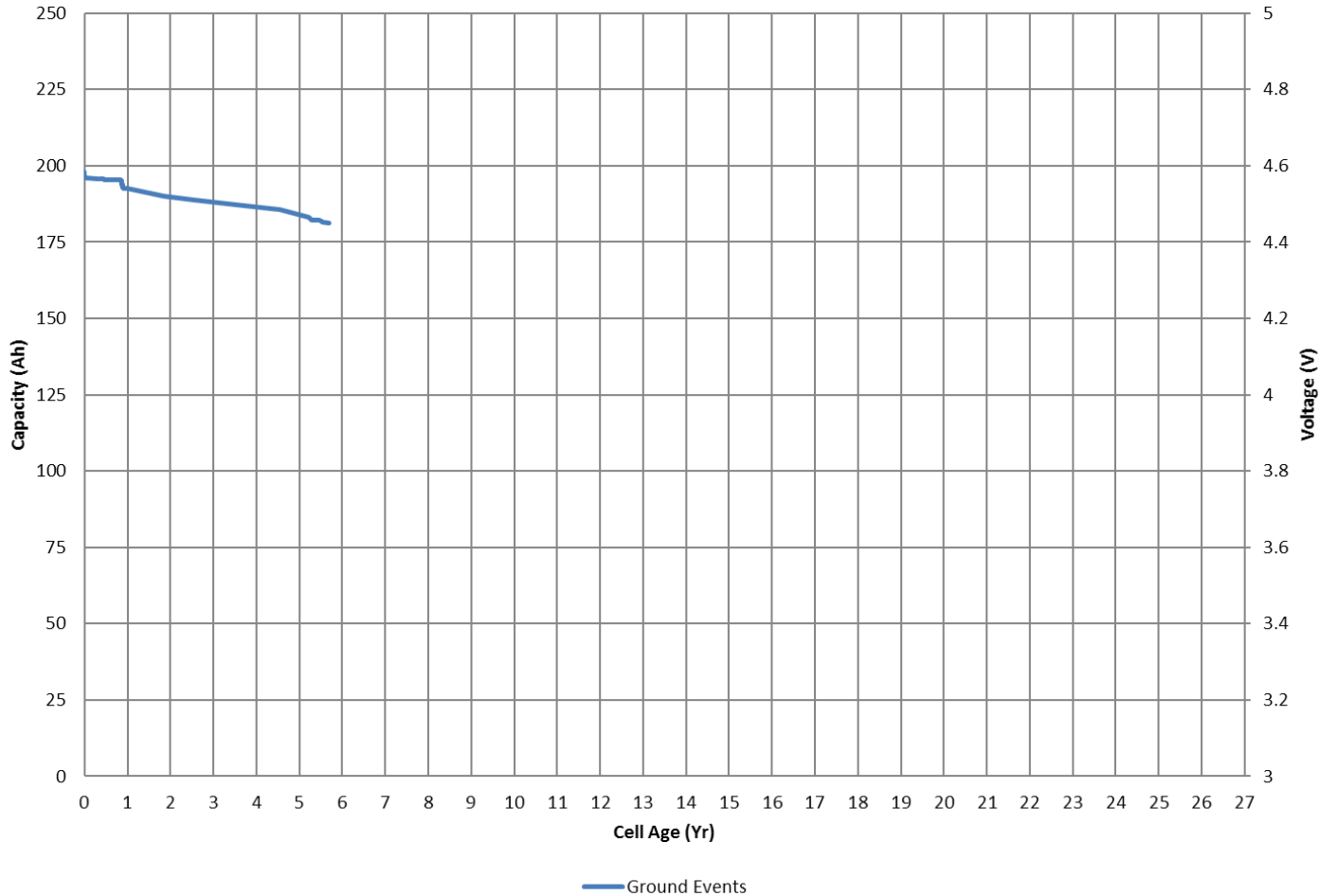
- Using the GS Yuasa Life and Performance model in an iterative fashion, this can be estimated!
- Additional mission assumptions:
    - BOL capacity 198Ah (minimum guaranteed activated capacity, 205Ah nominal)
    - Maximum EOCV 4.1V/cell
    - EoDV >3.6V/cell
    - Eclipse cycle discharge Ah cannot exceed 80% of cell's actual remaining capacity
  - All that's needed is a set of mission parameters

*What is the maximum power an LSE190 can provide in a GEO application for 18 years:*

- Battery manf. & ground activity
  - ~5.6yr duration
    - Duration and usage assumptions leading to higher capacity losses
- LSE190 Energy Type Cell
  - 18 year on-orbit (36 seasons)
  - Eclipse conditions:
    - 45 day period with max duration of 70min.
    - Temperature: 10°C
  - Solstice conditions: 60%SOC @10°C
  - NSSK cycles: 60 min discharge at TBD spacecraft power level 5 times per week.

# 18year GEO mission, maximum power

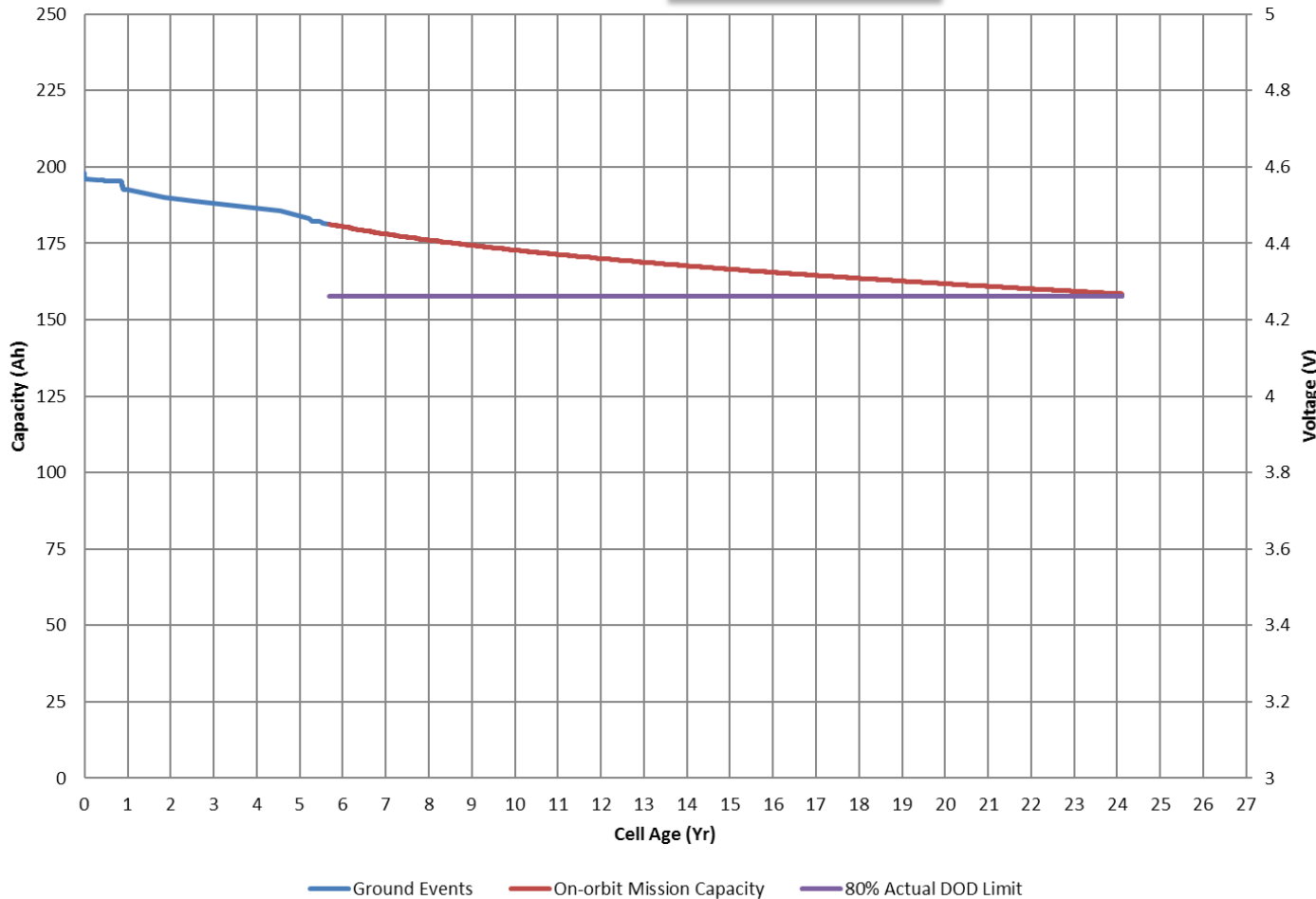
**LSE190 18yr GEO**



Event	Capacity (Ah)
Activation	198
Ground Events (5.6yr)	181.3
End of mission	TBD Ah

# 18year GEO mission, maximum power

**LSE190 18yr GEO- 400W Discharge**



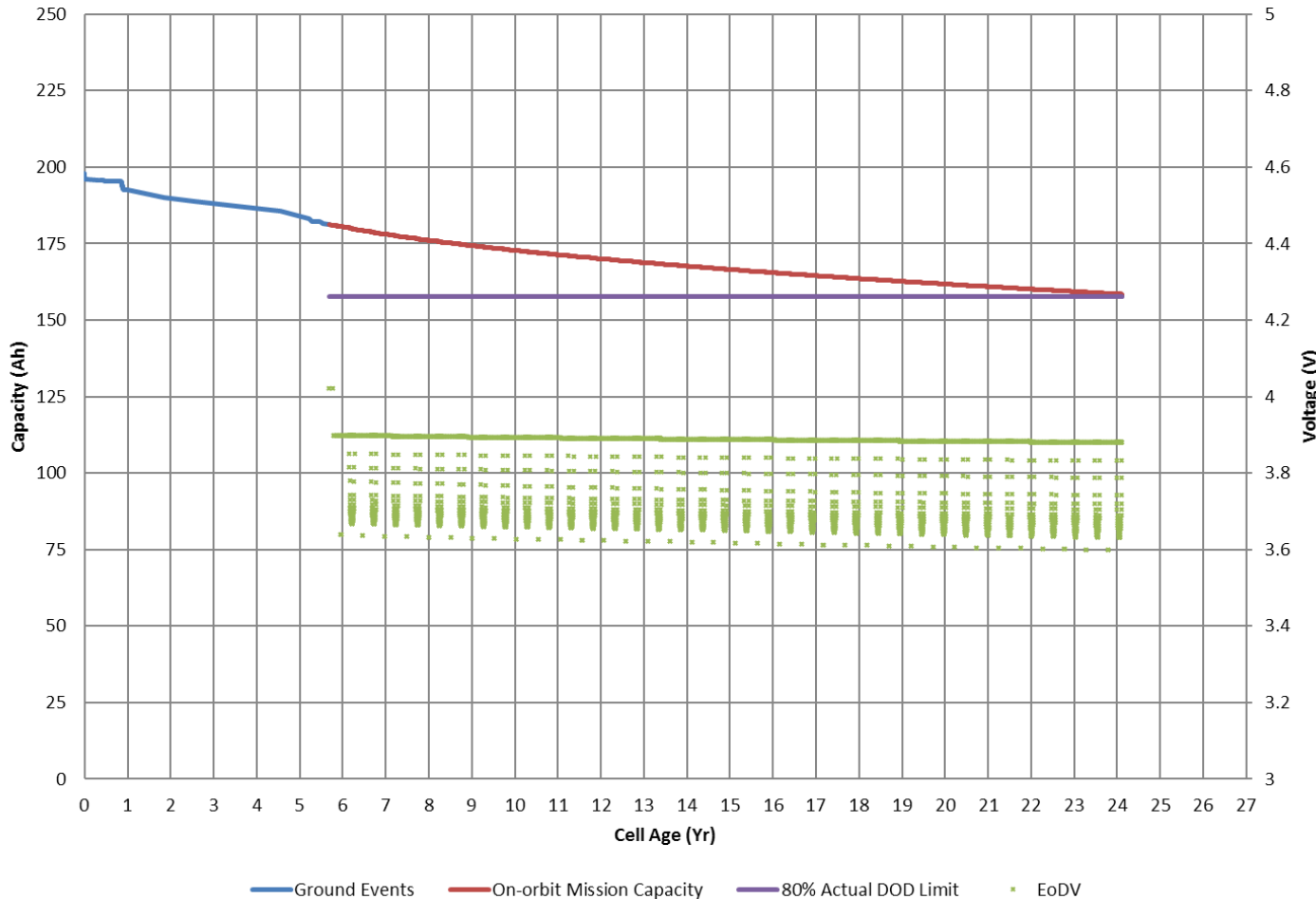
Event	Capacity (Ah)
Activation	198
Ground Events (5.6yr)	181.3
End of mission	158.5 Ah

At 400W/cell (~108A) spacecraft power, Capacity retention approaches the 80% max DOD after 18years on orbit

$108A * 70 / 60 = 126Ah$   
 $126 / 158.5 = 79.4\% DOD$

# 18year GEO mission, maximum power

### LSE190 18yr GEO-- 400W Discharge



Event	Capacity (Ah)
Activation	198
Ground Events (5.6yr)	181.3
End of mission	158.5 Ah

EoDV does not violate the 3.6V/cell minimum for the life of the mission  
 3.63V @season 36

NSSK DOD=20.5% of nameplate @400W.



The powers below represent the GEO eclipse power that yields a maximum real DoD of 80% at the final season max eclipse day

Mission Duration	4.1V/cell EoCV Power/cell (W)	4.2V/cell EoCV** Power/cell (W)
15year	407	435
18year	400	429
20year	395	425

\*\*Cell begins mission at 4.10V and rises to 4.15V and 4.20V when capacity or voltage limit is exceeded

The EoDV below represents the EoDV of the maximum eclipse day in season 30, season 36, and season 40.

Max EoCV	Power (W)	EoDV		
		Season 30	Season 36	Season 40
4.1	395	3.64	3.63	3.63
4.1	400	3.64	3.63	N/A
4.1	407	3.63	N/A	N/A
4.2	425	3.63*	3.64	3.63
4.2	429	3.63*	3.63	N/A
4.2	435	3.64	N/A	N/A

\*EoCV of 4.15V

### MA190 Modular Lithium Ion Battery For Satellites

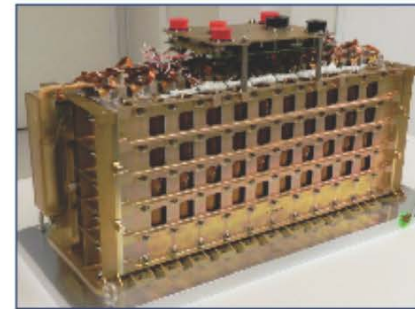
The MA190 module is a scalable and configurable cell pack based on GS Yuasa's LSE190 Generation III lithium ion cell.

With a nameplate capacity of 190Ah, the LSE190 cell has significant spaceflight heritage supporting both human rated LEO missions as well as commercial GEO satellites.

MA190 modules may each contain between 6 and 12 LSE190 cells. The cells in a module may be electrically connected in a simple series arrangement, yielding a module rated for 190Ah. Alternatively, two or three cells may be connected first in parallel and then in series yielding 380Ah or 570Ah modules.



The GS Yuasa LSE190 Li-ion Cell



MA190-112 Qualification Model

#### LSE190 Cell Safety Tests (JSC 20793)

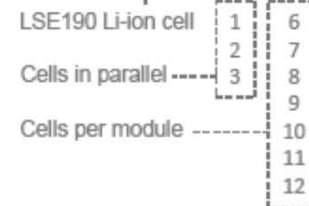
- Over-charge
- Over-discharge (forced reversal)
- External short circuit (2 & 5 milliohm)
- Crush (fresh & seasoned cells)
- Heat to vent
- Three orientation drop
- Vent and burst pressure

#### MA190 Module Qualification Tests

- Sine vibration
- Random Vibration
- Shock
- Thermal vacuum

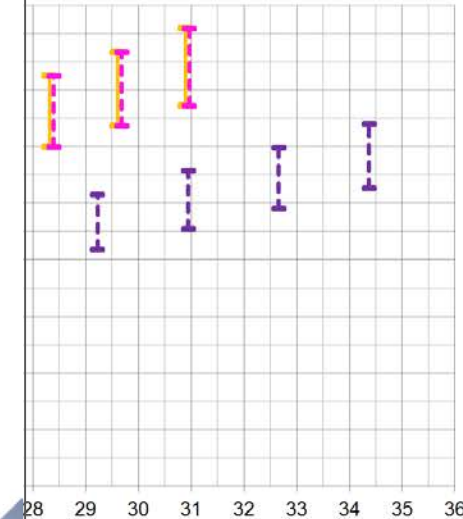
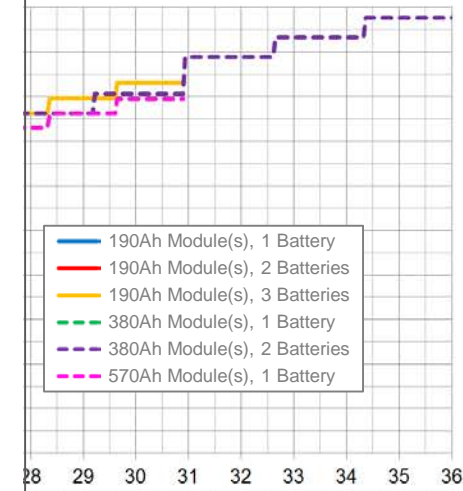
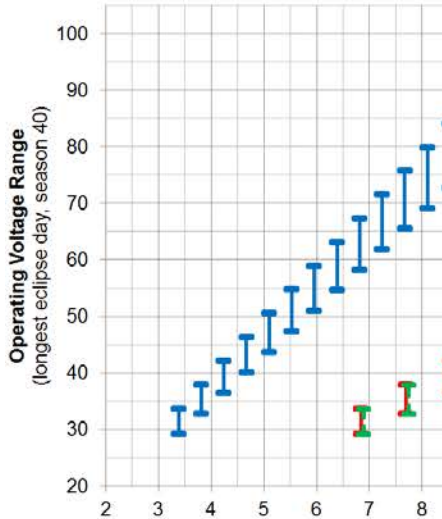
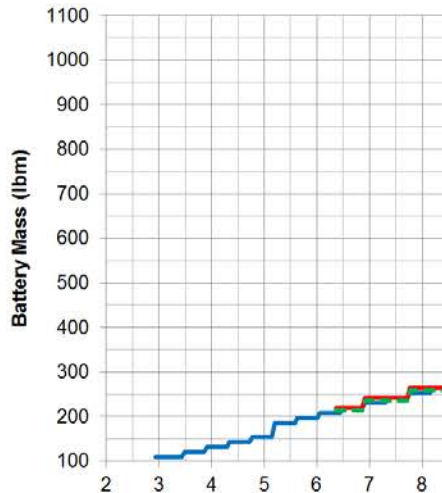
#### MA190 Module Configuration Numbering

Modular Aerospace Battery

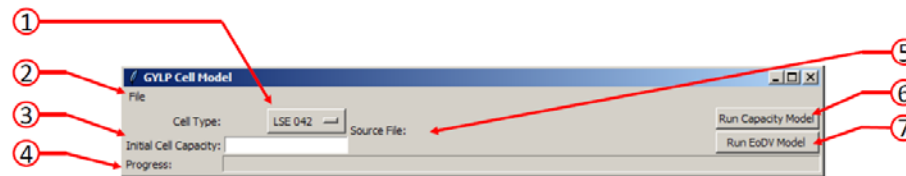


Available Configurations

- 106
- 107
- 108
- 109
- 110
- 111
- 112
- 206
- 208
- 210
- 212
- 306
- 309
- 312



- GYLP has emulated the GYT model and it can now be provided to users of the LSE Generation 3 Cells.
- Model has been simplified to improve the user experience and consists of the following parts:
  - Cell Model Input Sheet – An external spreadsheet for describing the steps of the mission. Contains several useful tools to help determine the proper inputs based on your mission criteria.
  - Cell Capacity and EoDV Retention model.exe – Executable containing the model presented to the user as a GUI.
    - Executable works on Windows OS machines.



1. Cell Type Dropdown (nameplate capacity)
2. File Selection Dialog
3. Cell Capacity at activation
4. Cell model progress bar
5. Name and location of selected file
6. Capacity retention start button
7. EoDV model start button

After either model is complete, a file explorer window opens allowing the user to save the results in a folder of their choosing.

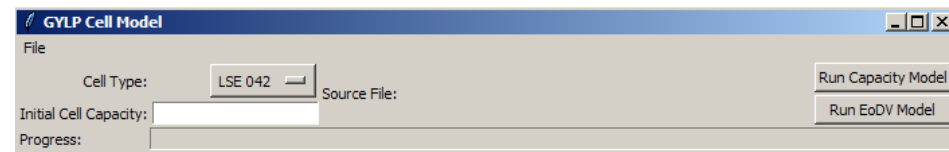
The model is split into two parts: an excel spreadsheet input sheet and a user interface for running the model.

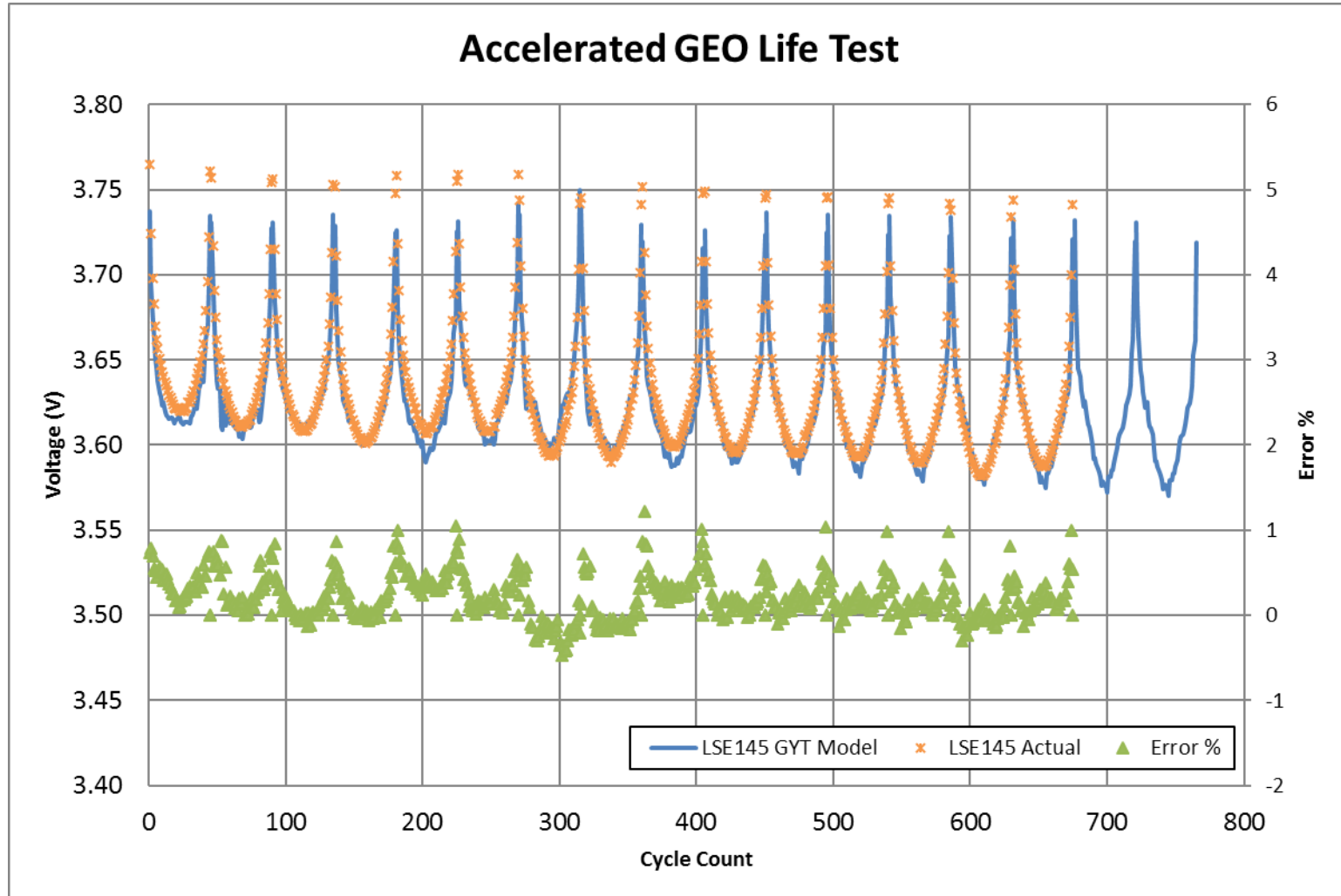
- Mission profile information is entered into the input sheet
- The model interface reads the input sheet and outputs the capacity retention and EoDV information
- The capacity retention model and the end of discharge voltage model are separated to allow workflow flexibility

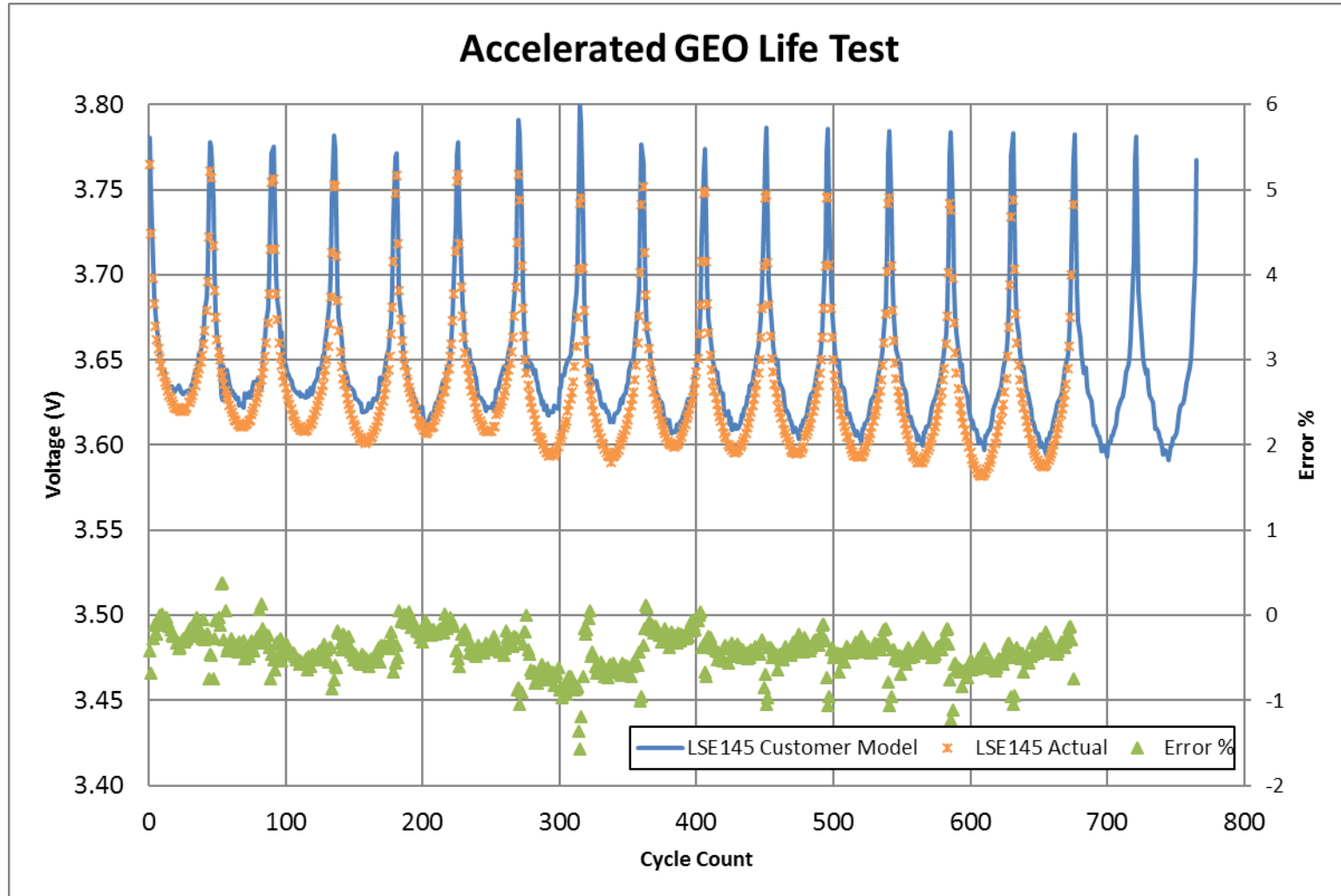
Modeling Conditions		Spacecraft Conditions		User defined input		Reference BOL Capacities for Cell Models			
Cell Model	LSE	Spacecraft Power Load (W)		Calculation		LSE Cell	Nameplate	Nominal	Guaranteed
Min BOL Capacity (Ah)	150	Number of Batteries supporting Load	3	Effective Battery Load (W)	0	51	51	57	53
Typical BOL Capacity (Ah)	160	Number of Batteries Bypassed	0	Effective Cells per battery	10	55	55	61	58
Nameplate Capacity (Ah)	165			Load per Cell (W)	0.00	102	102	114	107
				Nominal current (amps)	0.00	110	110	123	115
						134	134	148	139
						145	145	160	150
						190	190	205	198

Capacity Retention Model Inputs							End of Discharge Voltage Model Inputs						
Step Reserve (%)	Step Temp (deg C)	Cell SOC (%)	Step Duration (Days)	Cycle DOD (%)	Cycle Number (N)	Initial EODV (V)	Charge Rate (Amp)	Charge Duration (hrs)	Discharge Rate (Amp)	Discharge Duration (hrs)	BuDT (deg C)	EoDT (deg C)	Time to EoDV (hrs)









Industry leading spaceflight heritage  
Qualified, high value MA190 battery  
Validated and reliable performance modelling  
Will support launch vehicle applications

