# 2019 NASA Aerospace Battery Workshop

## Space Cells and Space Batteries by EAS: Custom Made Battery Design and New Cell Developments

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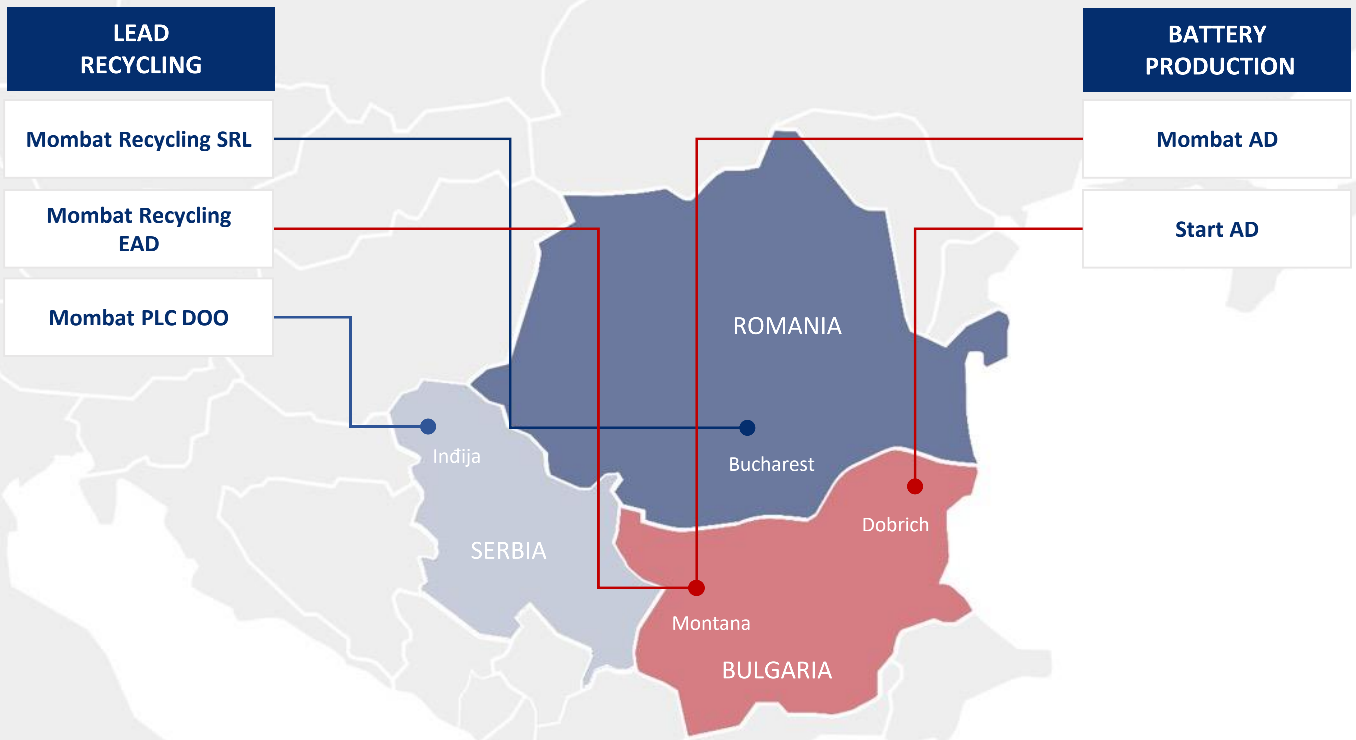
Huntsville, Alabama
November 20th 2019

# Monbat Group

Monbat is a leading manufacturer and distributor of lead-acid batteries used in transportation, telecommunications and industrial applications. The Company offers a broad range of starter, stationary and other special purpose batteries.

The lead-acid group is vertically integrated business model with operating production and recycling facilities in Bulgaria and an additional recycling plant in Romania and Serbia.

Monbat sells the majority of its products to the aftermarket in over 60 countries through an extensive network of distributors.




MONBAT GROUP

*(Public company on the BSE)*

| 178M Eur | 4.100.000 | 350.000 | 475 |
|---|---|---|---|
| Turnover 2018 | SLI Batteries Production Capacity | AGM Batteries Production Capacity | Employees |

# EAS Company History

**April 1996**

Foundation of GAIA Akkumulatorenwerke GmbH at Nordhausen/ Germany

Development of cell portfolio of large cylindric cells for hybrid electric applications based on a unique electrode production technology using NCA and LFP chemistries.

**September 2011**

Foundation of Joint Venture EAS Germany GmbH

focus aerospace and industrial applications and hybrid-electric power systems

**August 2012**

Successful introduction of new NCA aerospace cells for launchers serving various launching systems such as Proton M, Eurokot, Yushnoe

**January 2015**

Successful introduction of large sized ultra high power LFP cells for first VTOL aircrafts

**June 2017**

Merger of GAIA and EAS Germany via asset deal into EAS Batteries GmbH with MONBAT as new owner

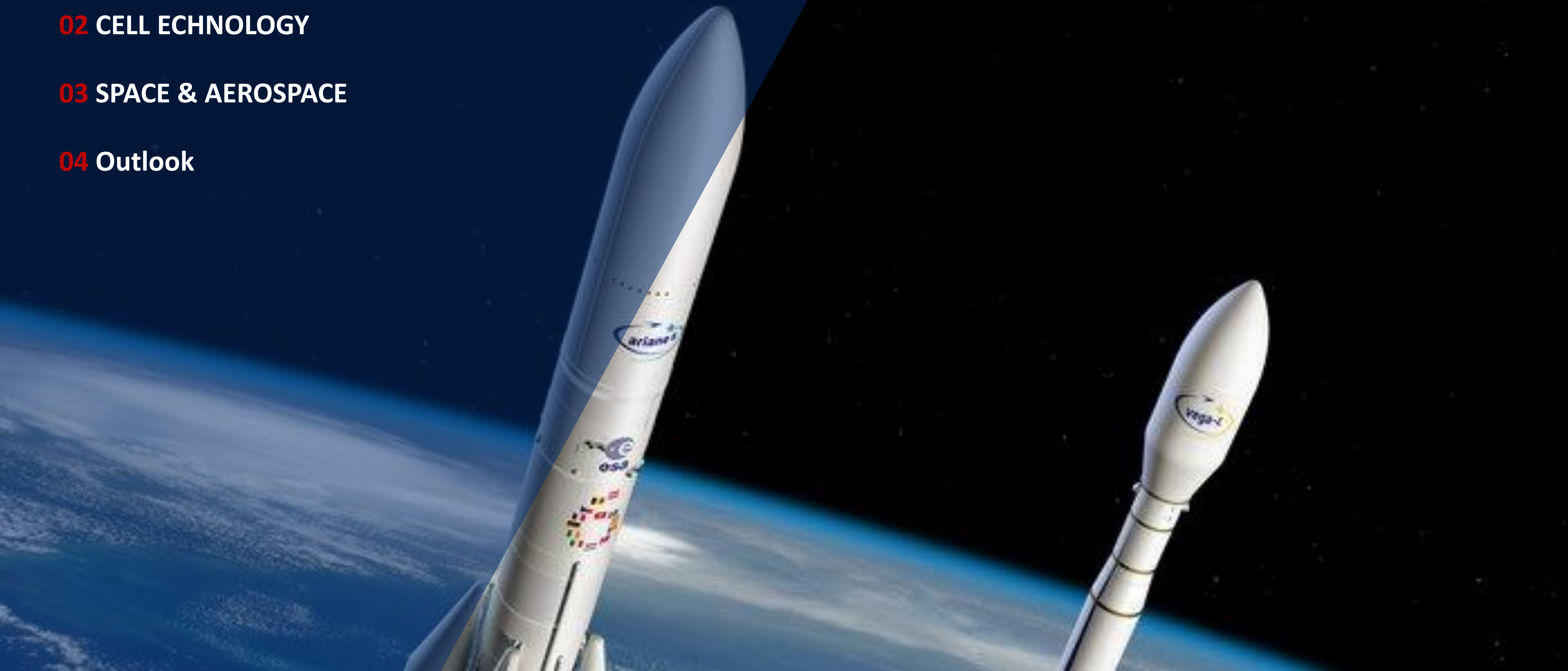
significant investments in and improvement of production technology, battery development and testing and new product line

01 PRODUCTION TECHNOLOGY

02 CELL ECHNOLOGY

03 SPACE & AEROSPACE

04 Outlook



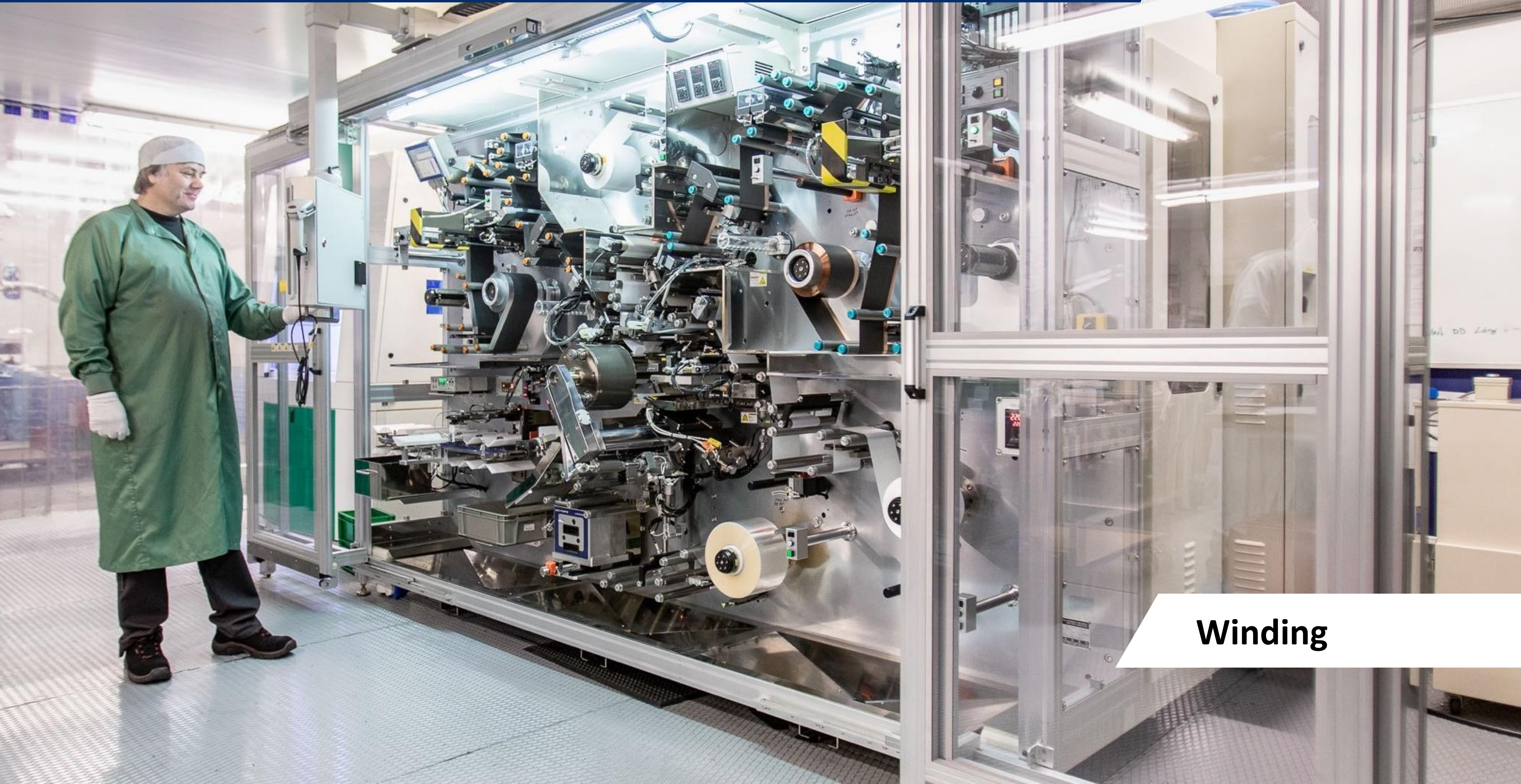
# Mixing

# Extrusion


# Slitting

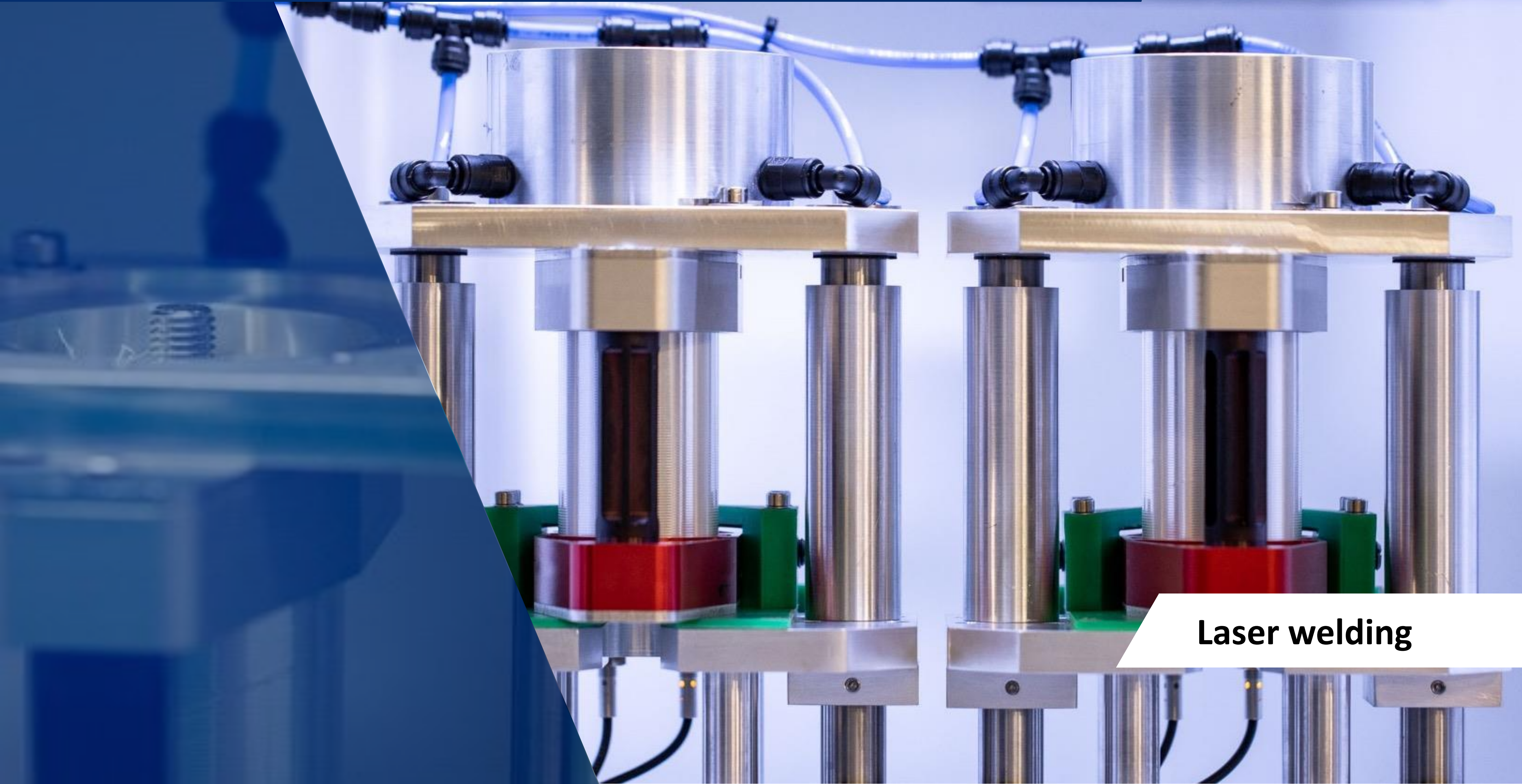
# Lamination

# Calandering



# Winding

## Contacting



# Laser welding

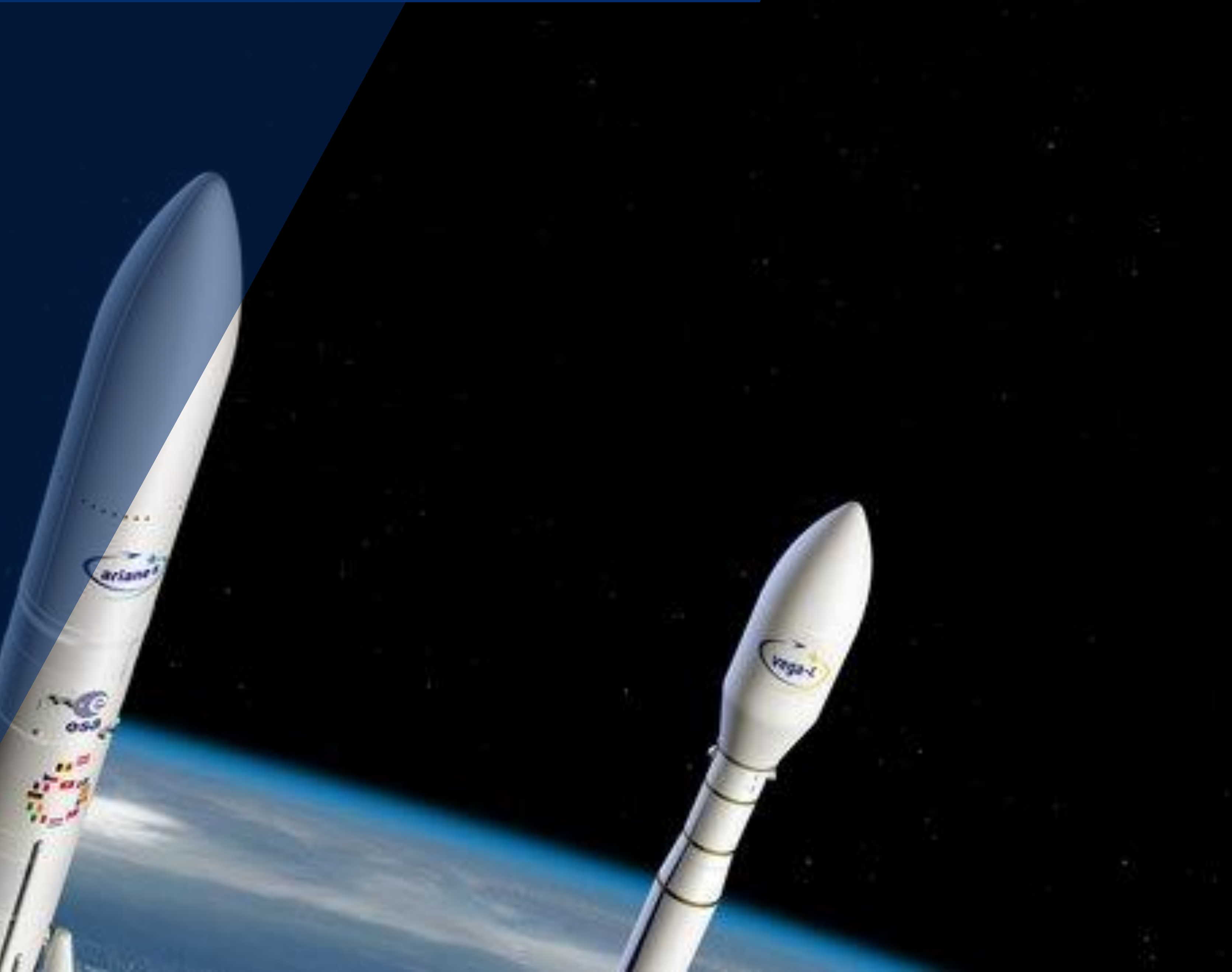
# Filling

01 PRODUCTION TECHNOLOGY

**02 CELL TECHNOLOGY**

03 SPACE & AEROSPACE

04 Outlook



# EAS Cell Portfolio

**7.5Ah NCA / 3.6V UHP**
Ultra High Power

**10Ah NCA / 3.6V HE**
High Energy

**22Ah LFP / 3.2V HP**
High Power

**40Ah LFP / 3.2V HP**
High Power

Stainless steel construction avoids corrosion and provides shock resistance

Simple connections ease operational use and provide low resistance interface

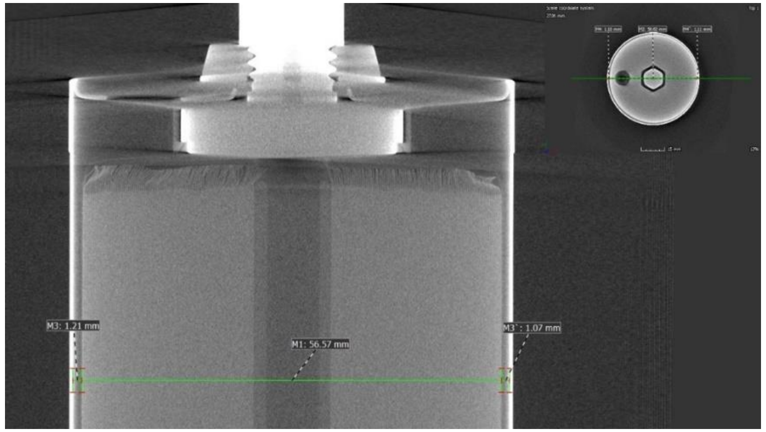
High maximum pulse discharge to meet exceptional peak demands

Large cell size reduces the number of interconnections and the demand on management system

SAFETY FIRST

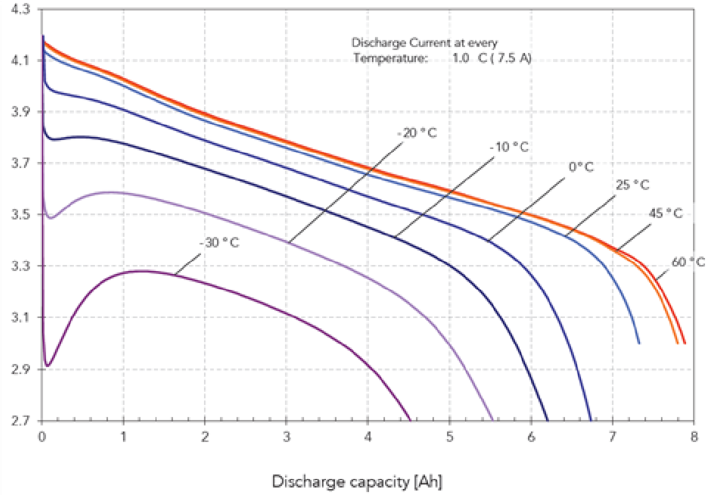
Made in Germany

# EAS NCA space cell with 7.5 and 10 Ah

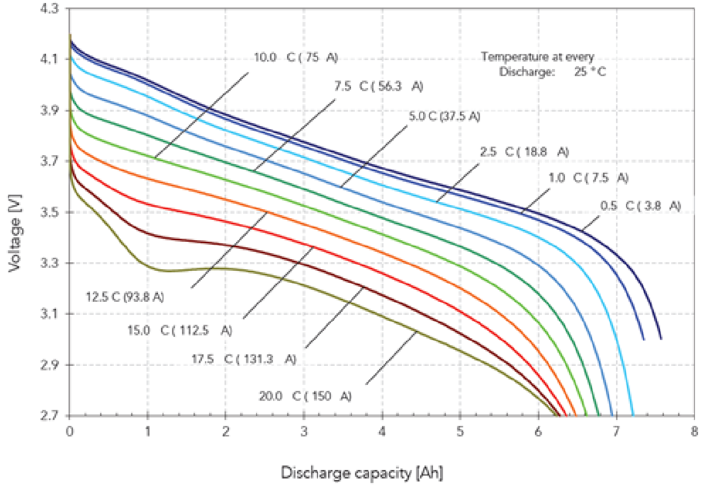



## 7.5 Ah

Voltage vs discharge capacity for various temperatures

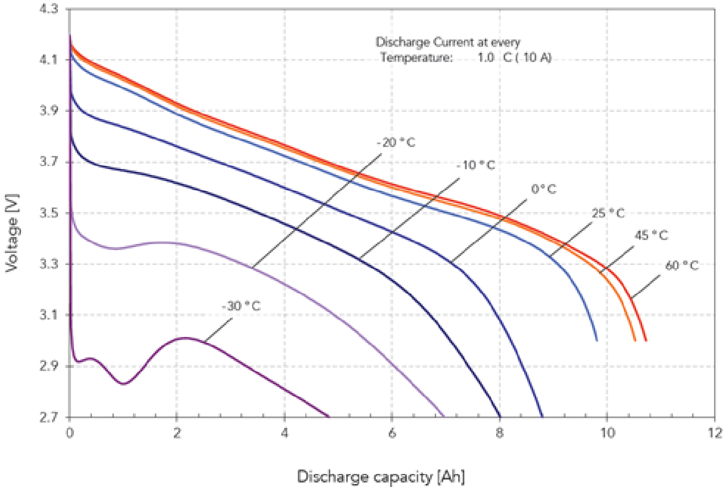



Voltage vs discharge capacity for various discharge currents

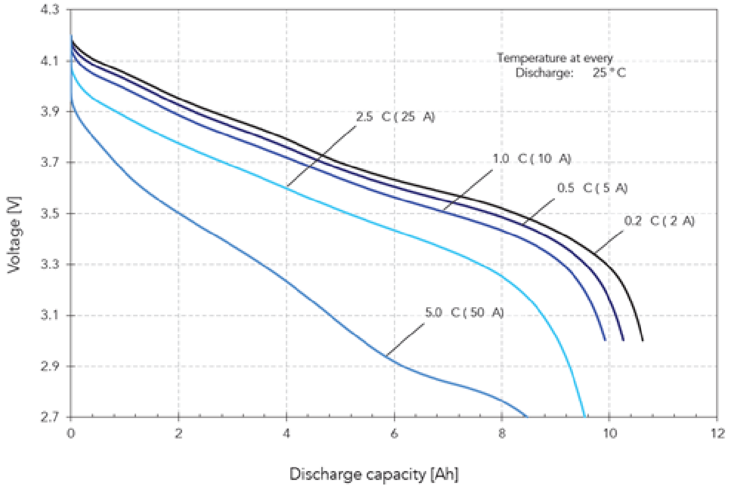



## 10 Ah

Voltage vs discharge capacity for various temperatures




Voltage vs discharge capacity for various discharge currents

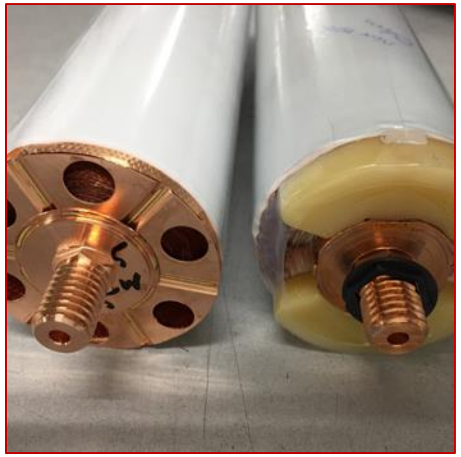


# New Cell Generation II

More active material

Basis for Following cell generation III

Own patent Pending



Lower Resistance

Significant Increase in Cycle life

Faster and automated production

# VEGA TDRS battery – project

Development of an ultra robust and shock proof high capacity space battery for providing power to the NASA TDRS communication system for VEGA and VEGA C.

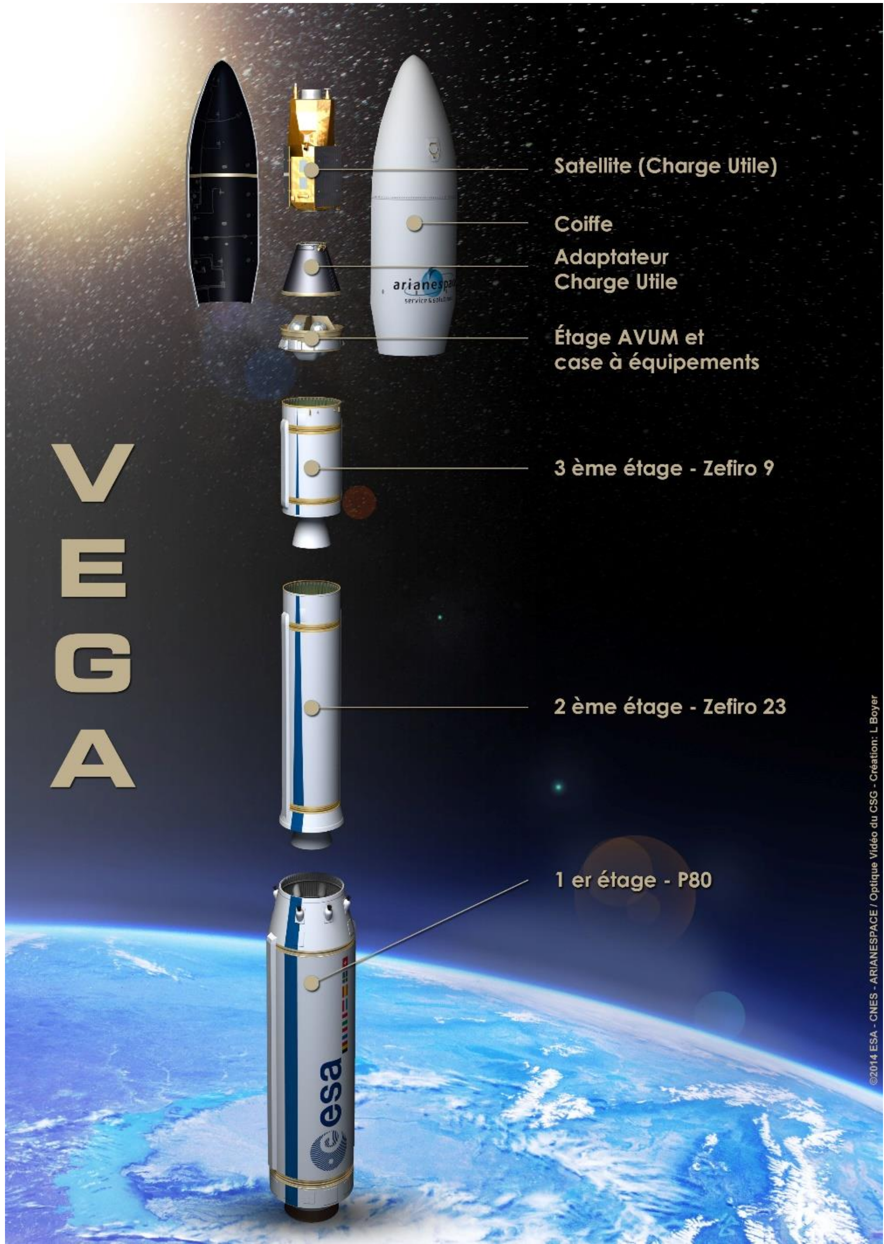
Battery located on the payload adapter (PLA)

Battery optimized in terms of weight and volume.
Only discharge function during mission.

Battery Interface Adapter (BIA) including BMS, switches, fuses, etc. separated from space battery.

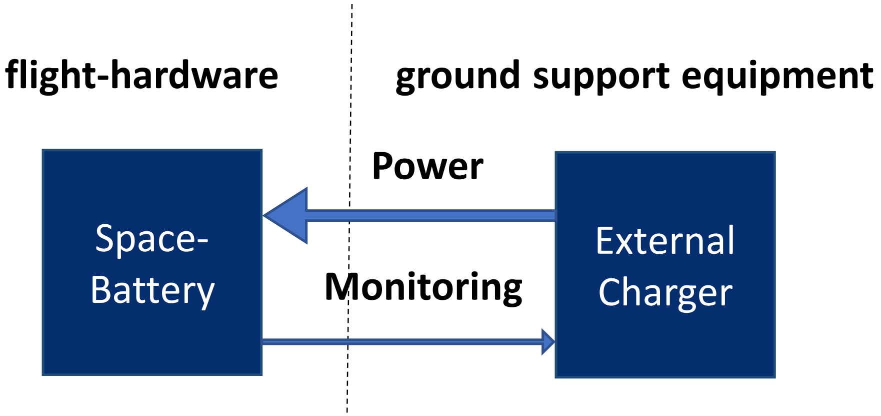
Battery charger separated from space battery and BIA.

Maximum safety – electrically configured for maximum safety, all monitoring and power lines of battery are short-circuit protected

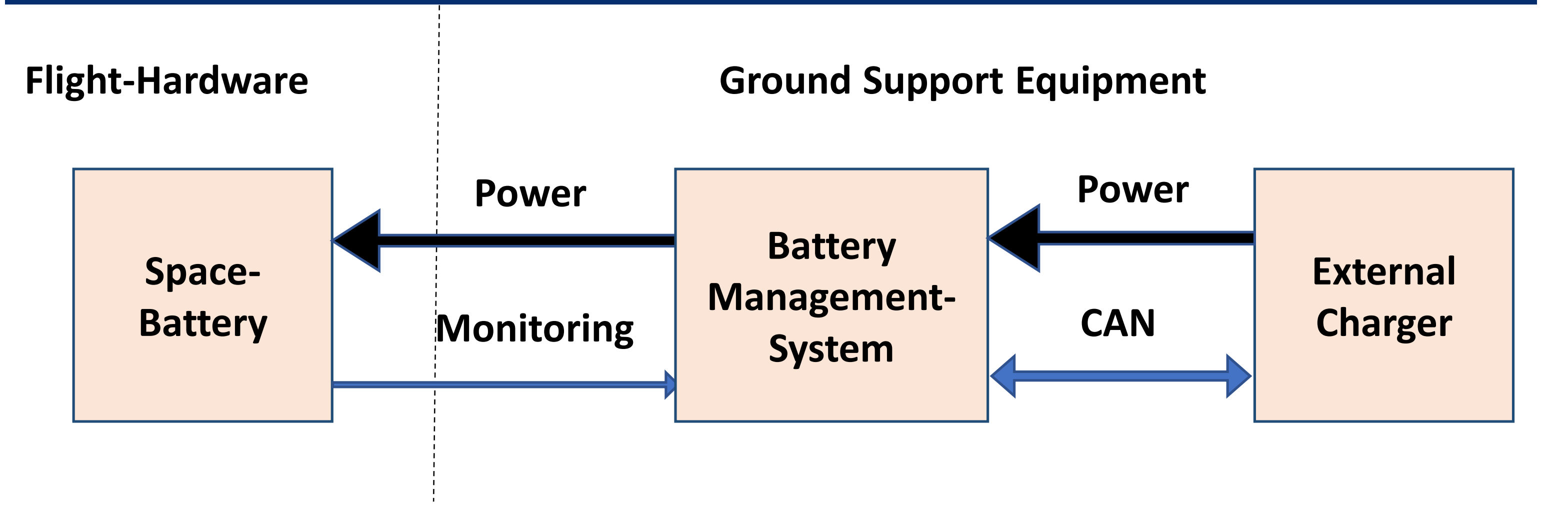


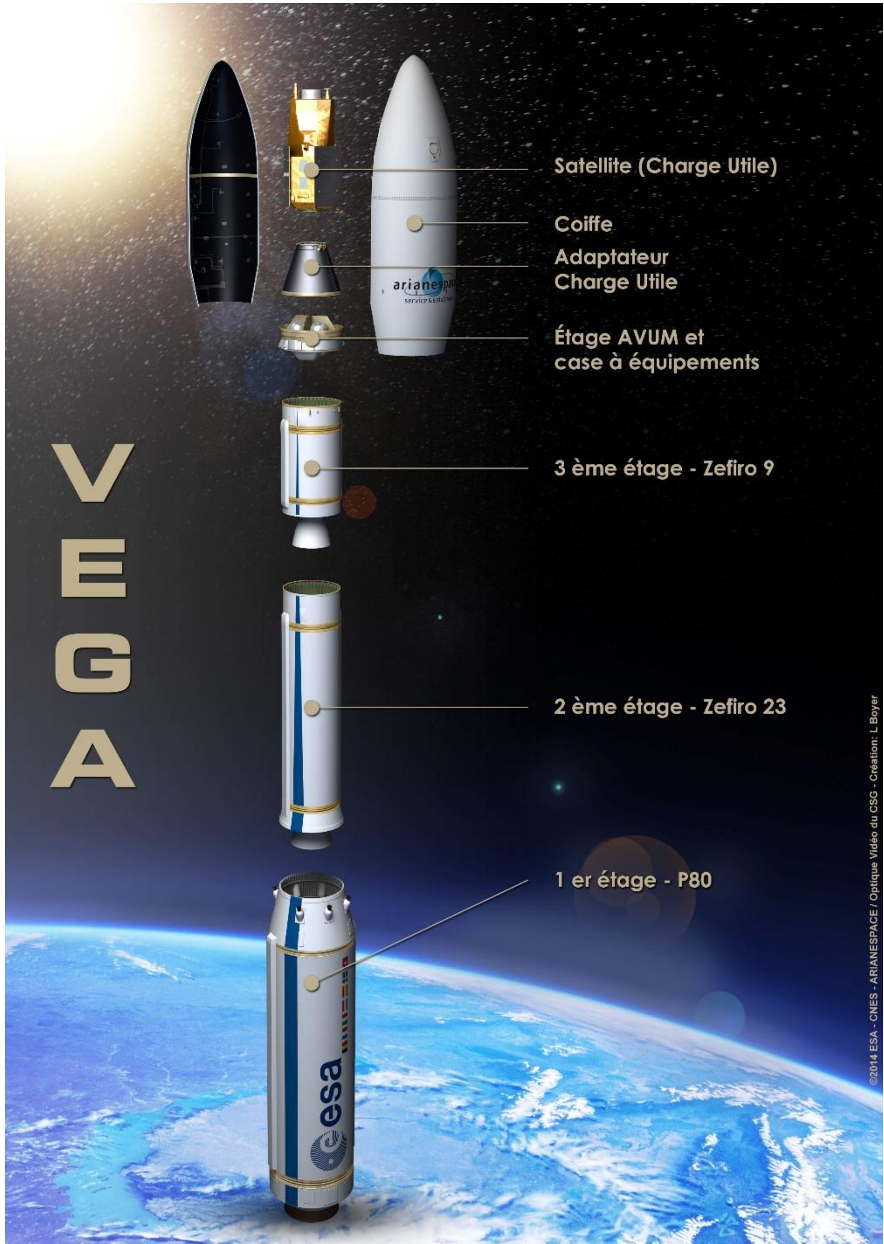
# VEGA TDRS battery – concept

## Functional Architecture

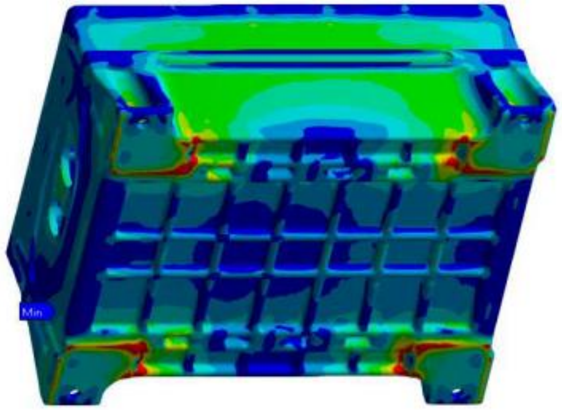


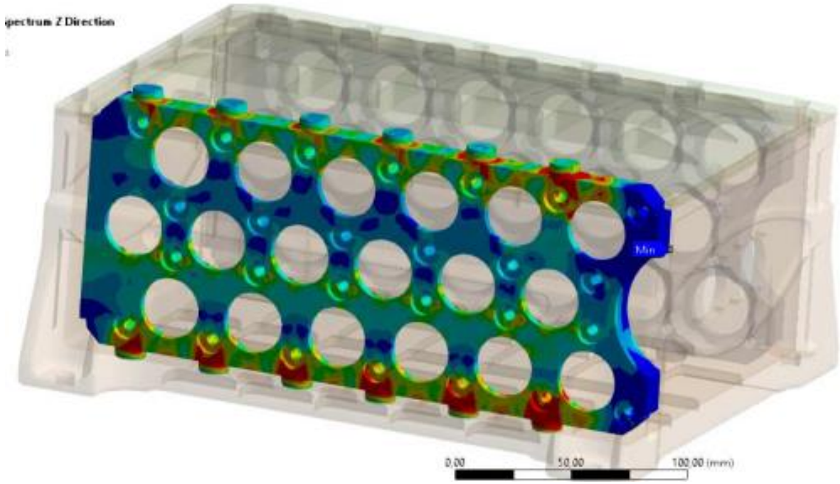

## Physical Architecture



## VEGA TDRS battery – design and FEM simulation




## DM Battery Test

**PHYSICAL MEASUREMENTS** ⇨ **LAUNCH ENVIRONMENT**

Physical measurements:

- Visual Inspection ⇩
- Dimension Check ⇩
- Mass Measurement

Launch environment:

- Low-Level Sine ⇩
- High-Level Sine ⇩
- Low-Level Sine ⇩
- High-Level Random ⇩
- Low-Level Sine ⇩

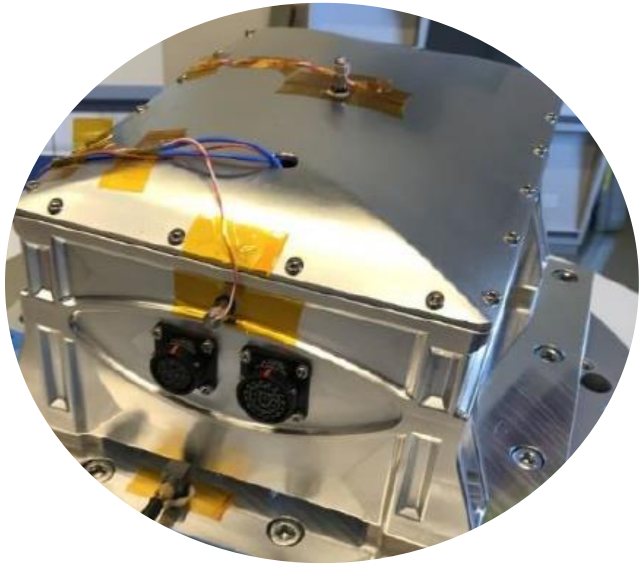
(Repeated for each orthogonal battery axis)

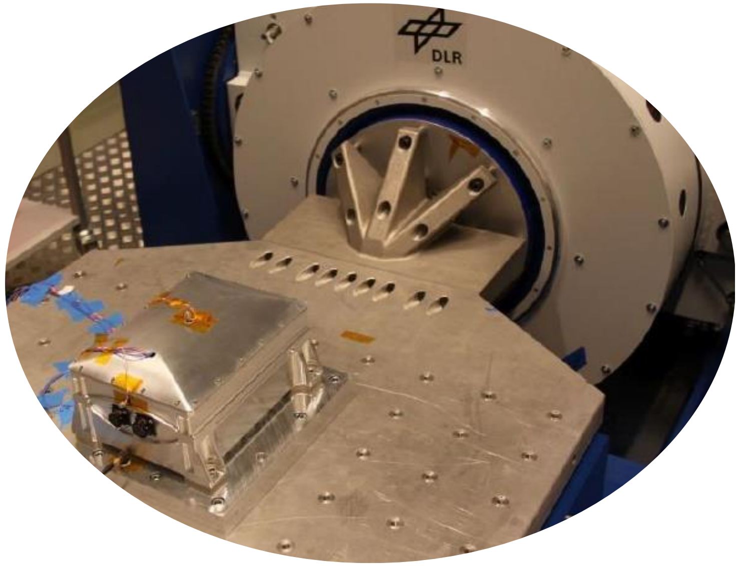
- Visual Inspection ⇩
- Pyroshock ⇩

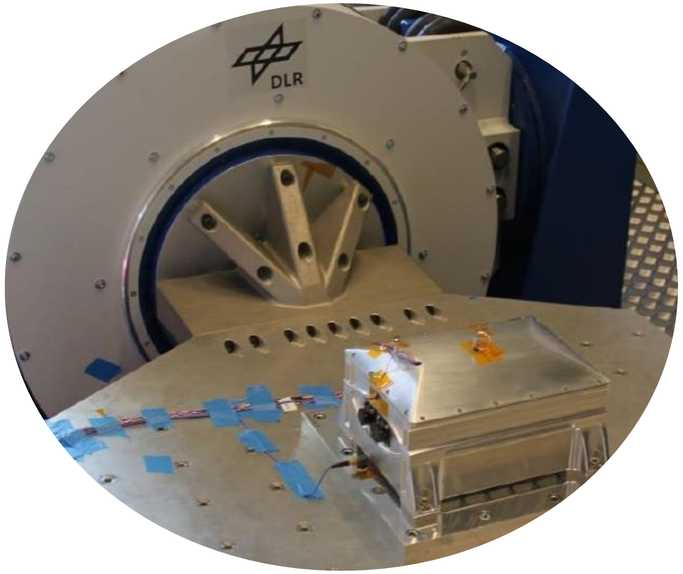
(Repeated for each orthogonal battery axis)

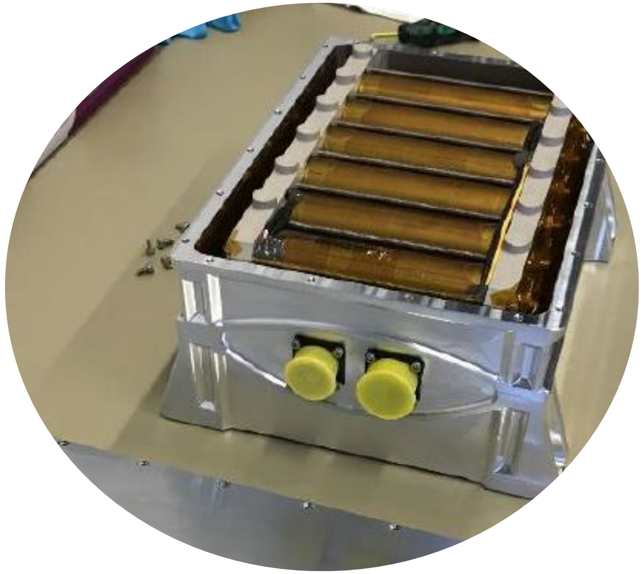
- Low-Level Sine ⇩
- Visual Inspection

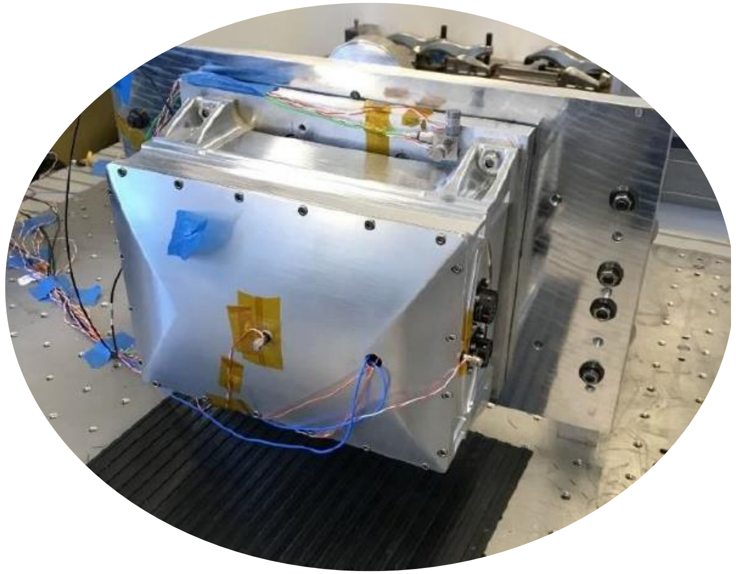
# VEGA TDRS battery – DLR test

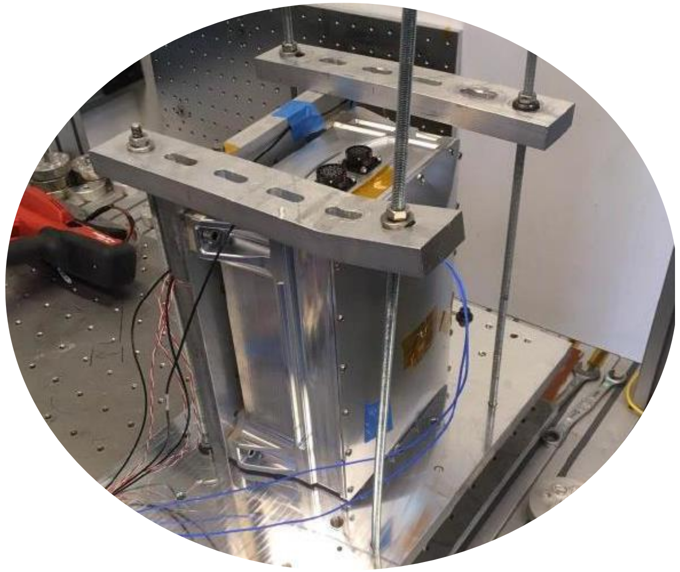




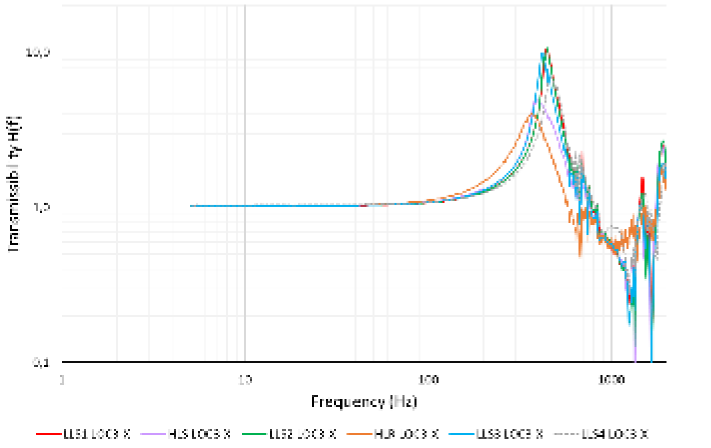





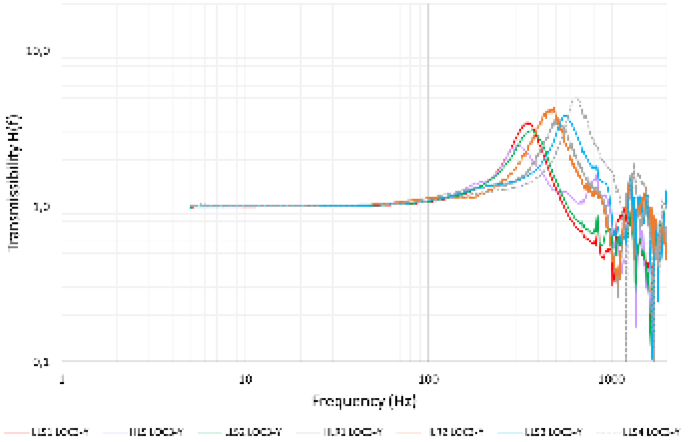


# VEGA TDRS battery – mechanical test results

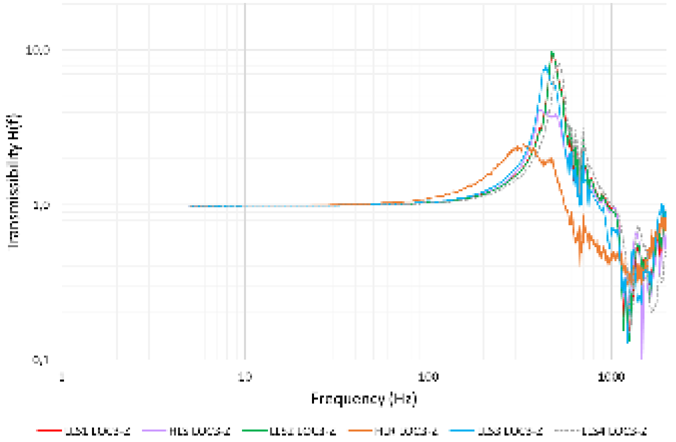
## LLS: BAT Lateral X, Cell Lateral



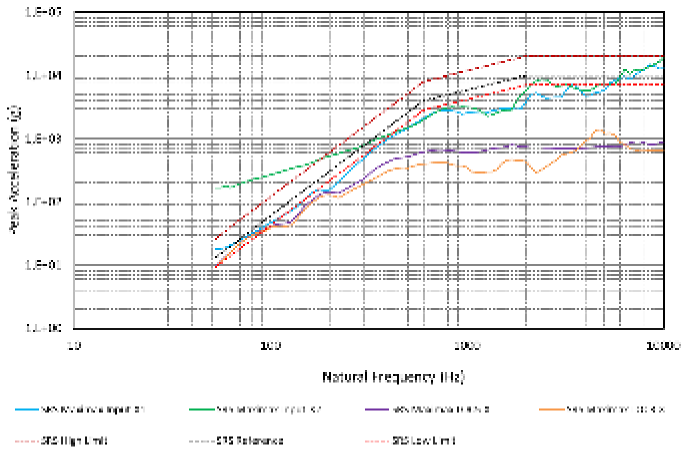

## LLS: BAT Lateral Y, Cell Axial



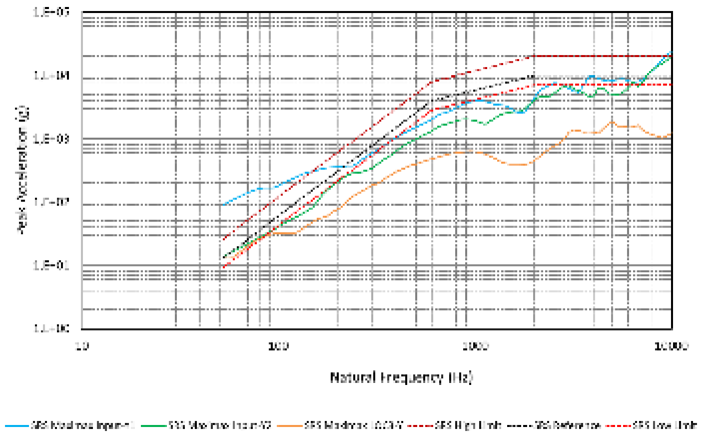

## LLS: BAT Vertical Z, Cell Lateral



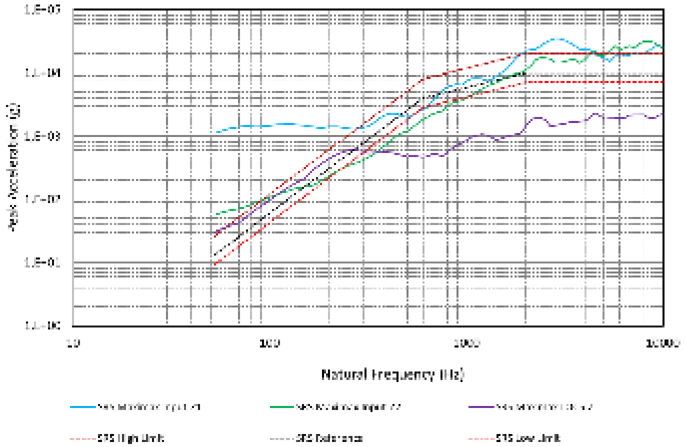

## Shock: BAT Lateral X, Cell Lateral




## Shock: BAT Lateral Y, Cell Axial




## Shock: BAT Vertical Z, Cell Lateral

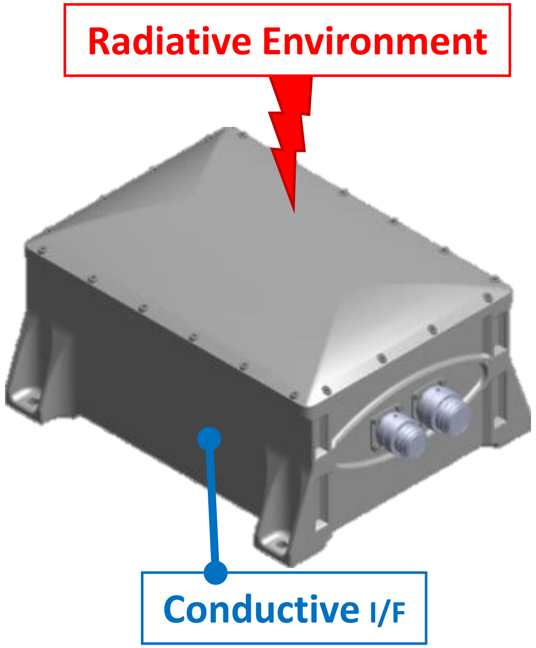


# VEGA TDRS battery – design philosophy

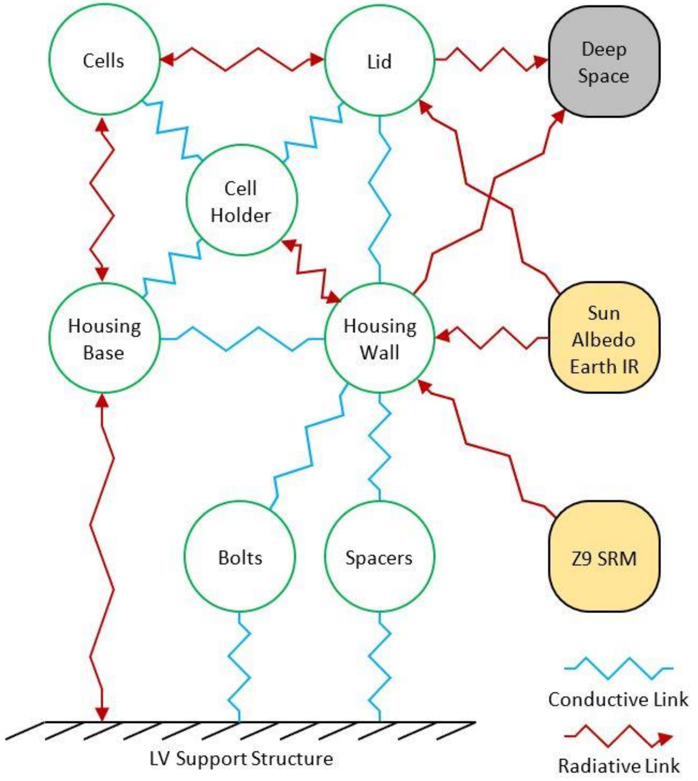
- Limited number of parts in battery assembly
- Two-part housing with self-contained cell block
  - minimises volume and parasitic mass
  - provides simple assembly process
- Cell holders transfer inertial forces from cells to housing
  - PEEK/G11 cell holders provide electrical and thermal isolation. Cell cans not load carrying
- Battery inertial forces transferred to support structure through integral feet
  - chassis consists of thin-wall closed box. Loads carried mainly by shear in the walls
  - walls act as shear panels with reinforcing ribs carrying bending loads
- Principle of 'limited mechanical fixation' results in highly damped design
  - intelligent use of friction and material hysteresis limits amplification of random vibration and reduces shock transmission
- Stiff ($f_1$ > 300 Hz) and strong design

# VEGA TDRS battery – thermal analysis

- Conductive environment
  - Hot Case : Adapter Interface at 120°C
  - Cold Case : Adapter Interface at -30°C
- Radiative environment
  - Hot Case :
    - Deep space, Z9 solid rocket motor (SRM) radiation, solar radiation, solar albedo radiation , earth radiation
  - Cold Case :
    - Deep space
- Battery discharge profile
  - Pre-Launch :
    - 1045s at 36W
  - Launch :
    - 357s at 36W
  - Flight :
    - 12460s at 165W

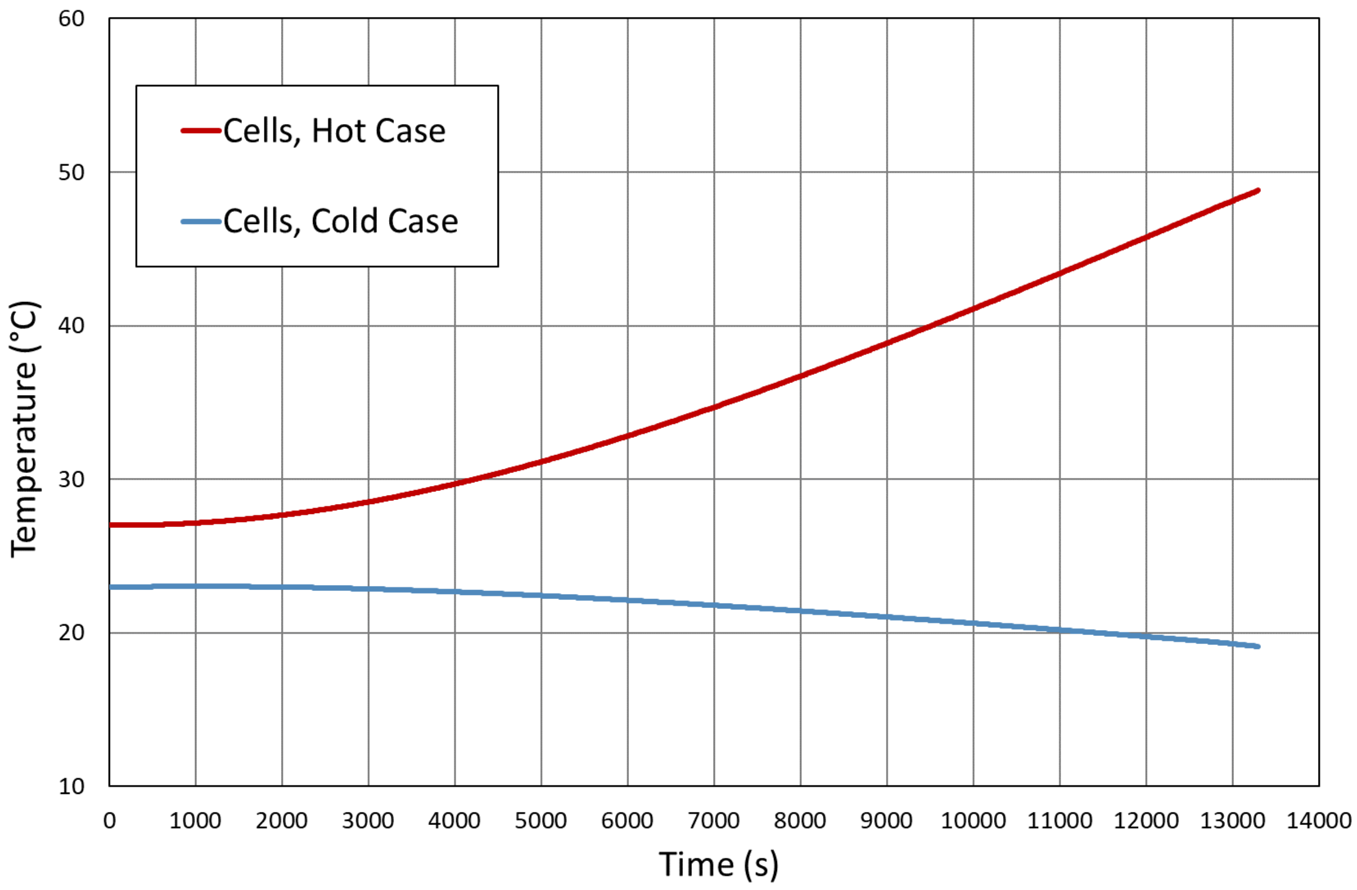



- TDRS battery thermal design
  - BAT operating (Fight Limit) temp. range ≈ 0°C +40°C
  - QL environmental temp. range ≈ -10°C +50°C
- Thermal design study using thermal network



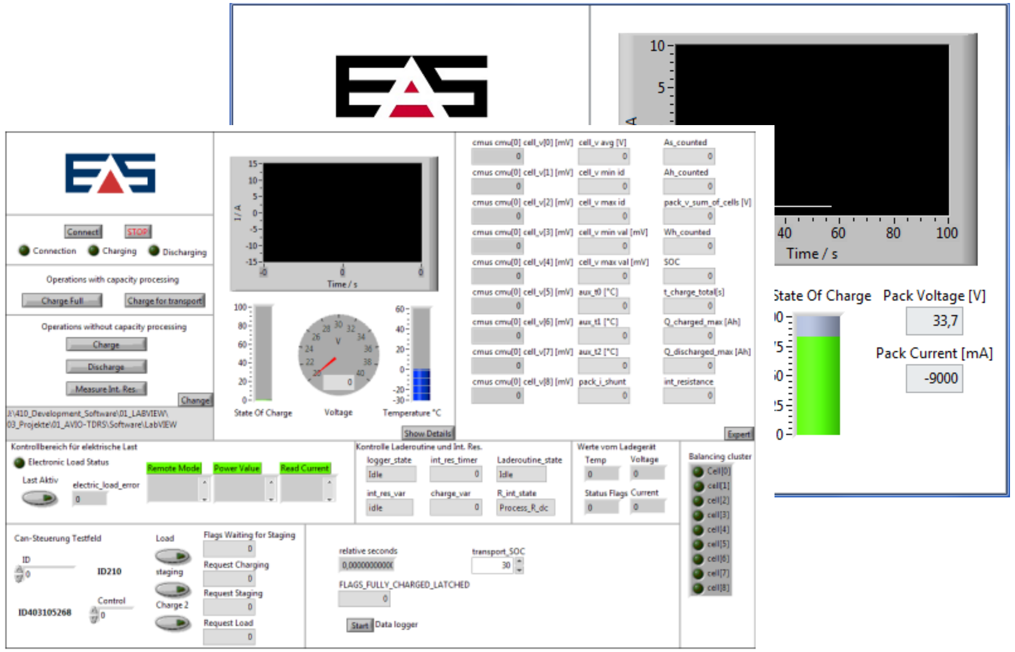
# VEGA TDRS battery – thermal analysis

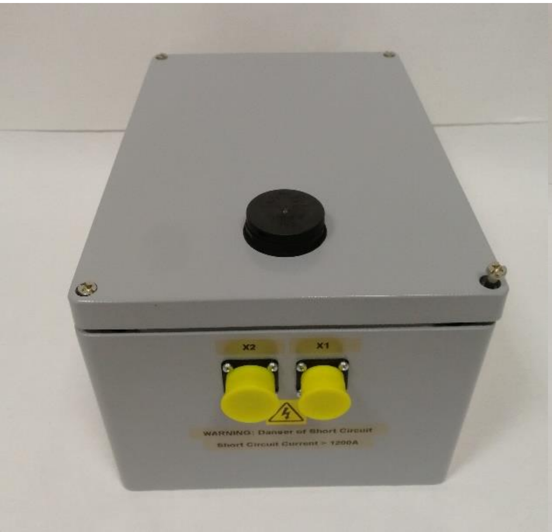
- TMM design study
  - Initial conditions 23°C cold-case, 27°C hot case
  - Passive thermal control (white paint)
  - BAT mounted on 8mm PEEK thermal spacers
- TMM results suggests
  - Cells thermally isolated despite harsh thermal environment. Remain well within qualified operating temperature range of -30°C to +60°C
  - To be correlated against thermal vacuum results

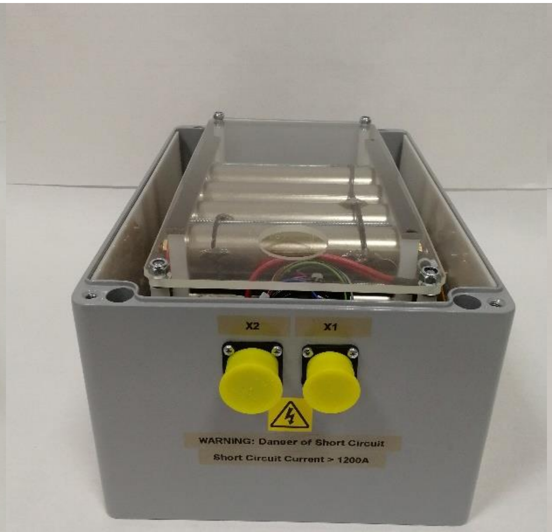


# VEGA TDRS battery - charger

- additional hardware (electric load) for discharge-functionality
- graphical user interface developed (GUI)
- CAN communication between GUI and BMS and discharge-unit
- monitoring of cell voltage and temperatures
- measurement of Battery capacity
- balancing of battery voltages
- battery can be charged to defined SOC (transportation / storage)






## Space References

EUROKOT

Russia

PROTON M

Khrunichev/Russia

RCI

India

YUSHNOE

Ukraine

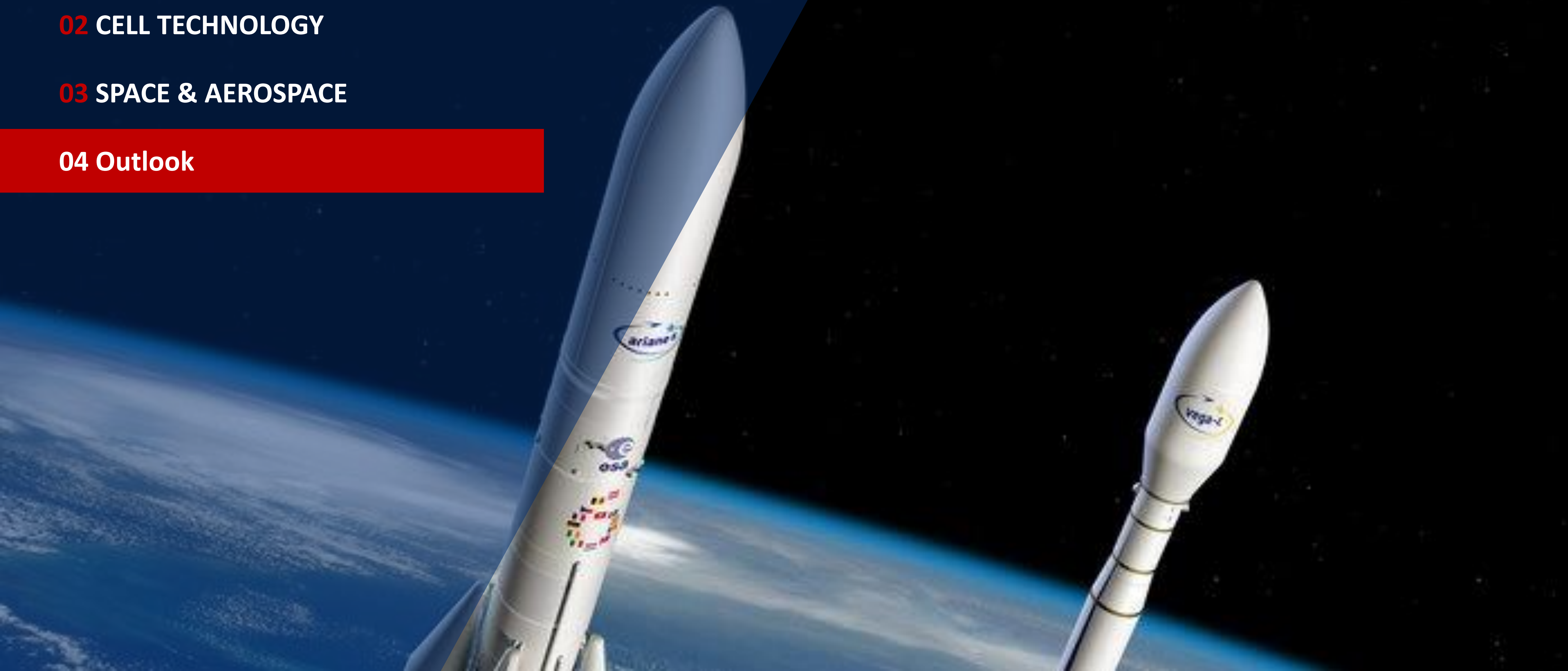
VEGA

ESA

Europe

# VTOL Batteries for High Power

| | | |
|---|---|---|
| Completely designed and engineered inhouse at EAS | 180s1p 576V 38Ah 22kWh 328kWp \| 15 x 12 cell-blocks in series | Demanding power electronics |
| Special BMS programming for flying application | Optimal cell sorting | Close cooperation with client engineers |
| Service at site if needed | Successful commissioning | Already airborne for many hours |

# EAS novel bipolar cell concept for aerospace applications

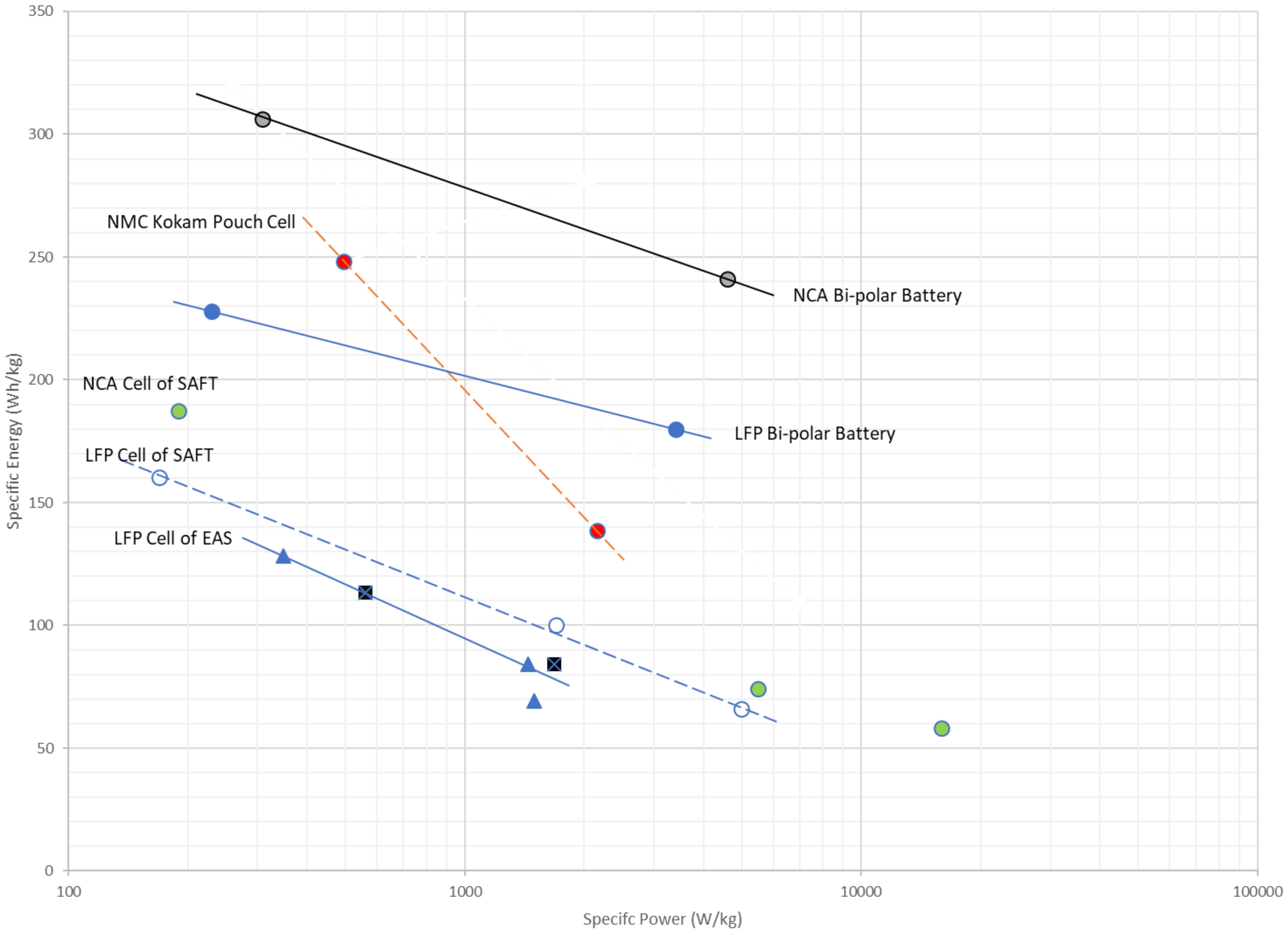
EAS launched a new and revolutionary cell concept based on its unique electrode production technology. This concept will lead to a significant increase in energy and power density

300 – 240 Wh/kg

500 – 8,000 W/kg

on pack level

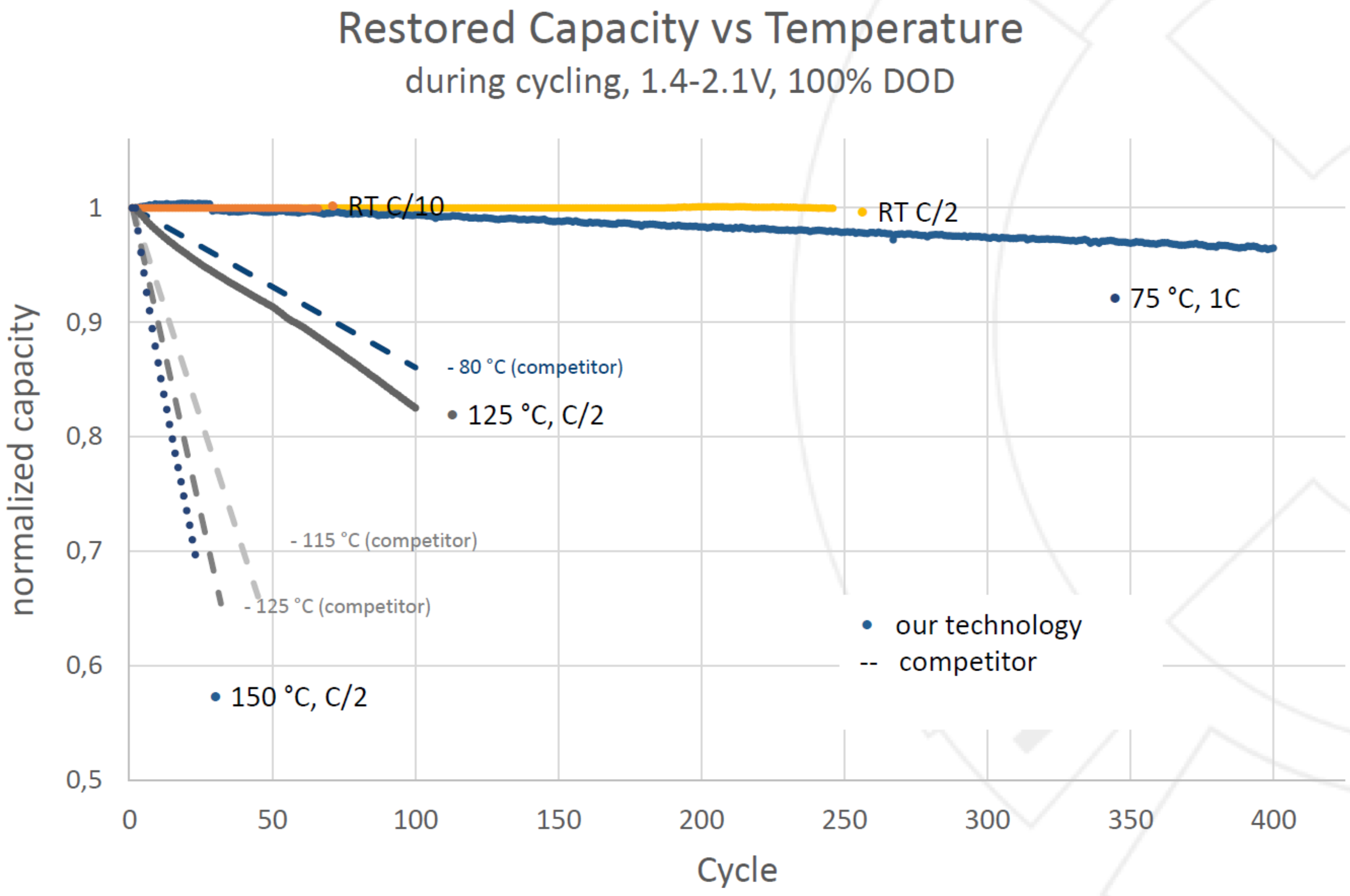
Patent Pending



# EAS high temperature cells

## LITHIUM-ION CELLS FOR ELEVATED TEMPERATURE USAGE

- Developed in 2019
- High temperature stable
- Field of application: Oil&Gas / Pipeline Inspection / Medical / Military
- Fulfillment of highest safety standards
- Manufactured in EU,
- LFP-titanate cell



## Take Home Points

- EAS has the knowhow and resources to design, manufacture and deliver space grade lithium cells and batteries
- EAS has the heritage in delivering mechanically robust and safe cells to the Space industry
- EAS has the passion and commitment to become a leading cell and battery supplier to the space industry through developing further our in-house engineering capabilities with project partners
- EAS looking to deliver excellent customer service and products to space battery customers

POWER YOU CAN TRUST

# Thank you for your attention

www.eas-batteries.com

# EAS space cell 7.5 Ah NCA cathode – full specifications

## UHP341440 NCA

**Lithium Ion Cell - High Power**

3.6 V / 7.5 Ah / 27 Wh

### Physical and Mechanical Characteristics

| | |
|---|---|
| Diameter | 34 mm |
| Length | 174 mm (144 mm without terminals) |
| Weight | 0.32 kg |
| Volume | 0.13 l |
| Material | Stainless steel housing<br>Positive terminal: Al M8 length: 10 mm<br>Negative terminal: Cu M8 length: 10 mm |

### Chemical Characteristics

| | |
|---|---|
| Cathode | Lithium Nickel Cobalt Aluminium Oxide (NCA) |
| Anode | Graphite |

### Electrical Characteristics

Reference Temperature 23°C +/- 3°C

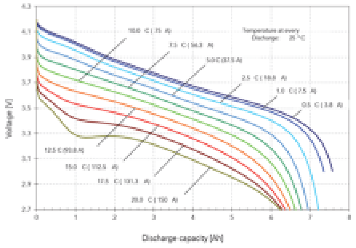
| | |
|---|---|
| Nominal operating voltage | 3.6 V |
| Nominal capacity at 0.2 C | 7.5 Ah |
| AC Impedance (1 kHz) | ≤ 1.2 mOhm |
| DC Resistance (ESR)<br>2s pulse discharge @ 20°C / 50% SOC | ≤ 6.5 mOhm |
| Specific energy at 0.2 C | 84 Wh/kg |
| Energy density at 0.2 C | 207 Wh/l |
| Specific power<br>2s pulse discharge @ 50% SOC, 60C | 2,340 W/kg |
| Power density<br>2s pulse discharge @ 50% SOC, 60C | 5,730 W/l |



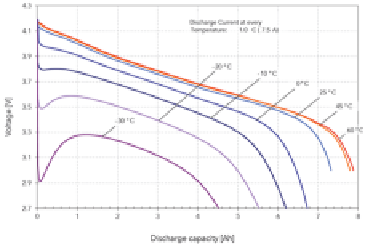
### Operating Conditions

| Operating Conditions | Reference Temperature 23°C +/- 3°C |
|---|---|
| Recommended charge method | Constant current / Constant voltage |
| End of charge | I ≤ C/100 |
| Maximum charge voltage | 4.2 V |
| Recommended charge current | Up to 7.5 A (1 C) |
| Maximum continuous charge current | Up to 30 A (4 C) |
| Maximum pulse charge current (15 s)<br>(Max SOC 70%, average current <88 A) | 120 A (16 C) |
| Recommended voltage limit for discharge | 3.0 V |
| Lower voltage limit for discharge | 2.7 V (at high current or low temperature) |
| Recommended discharge current | Up to 15 A (2 C) |
| Maximum continuous discharge current | Up to 150 A (20 C) |
| Maximum pulse discharge current (2 s) | Up to 300 A (40 C) |
| Operating temperature | -30°C to +60°C |
| Recommended charge temperature | 0°C to +40°C |
| Storage and transport temperature | -40°C to +60°C |
| Recommended storage | +10°C to +25°C, 30-50% SOC |
| Cycle life at 20°C and 100% DoD, 0.5 C | > 1,000 cycles to 80% of nominal capacity |
| Cycle life at 20°C and 80% DoD, 0.5 C | > 2,000 cycles to 80% of nominal capacity |

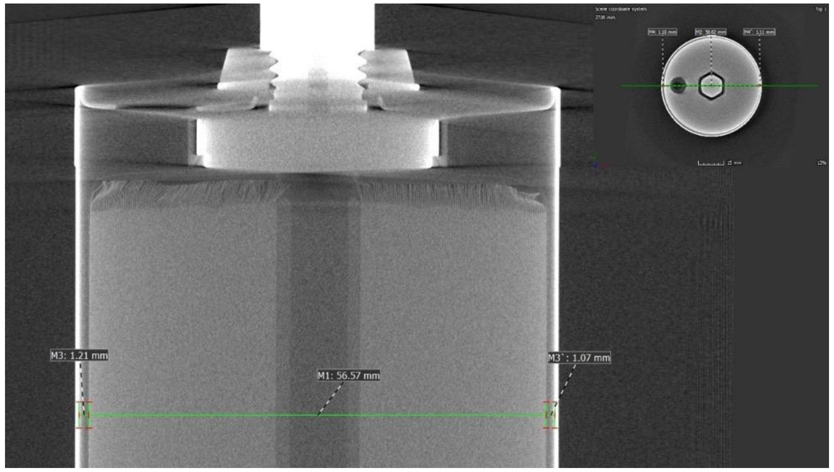
Voltage vs discharge capacity
for various discharge currents




Voltage vs discharge capacity
for various temperatures

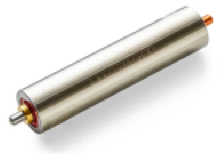




# EAS space cell 10 Ah NCA cathode – full specifications

## HE341440 NCA



**Lithium Ion Cell - High Energy**

3.6 V / 10 Ah / 36 Wh

### Physical and Mechanical Characteristics

| | |
|---|---|
| Diameter | 34 mm |
| Length | 174 mm (144 mm without terminals) |
| Weight | 0.32 kg |
| Volume | 0.13 l |
| Material | Stainless steel housing<br>Positive terminal: Al M8 length: 10 mm<br>Negative terminal: Cu M8 length: 10 mm |

### Chemical Characteristics

| | |
|---|---|
| Cathode | Lithium Nickel Cobalt Aluminium Oxide (NCA) |
| Anode | Graphite |

### Electrical Characteristics

Reference Temperature 23°C +/- 3°C

| | |
|---|---|
| Nominal operating voltage | 3.6 V |
| Nominal capacity at 0.2 C | 10 Ah |
| AC Impedance (1 kHz) | ≤ 2 mOhm |
| DC Resistance (ESR)<br>2s pulse discharge @ 20°C / 50% SOC | ≤ 6.5 mOhm |
| Specific energy at 0.2 C | 113 Wh/kg |
| Energy density at 0.2 C | 275 Wh/l |
| Specific power<br>2s pulse discharge @ 50% SOC, 60C | 2,000 W/kg |
| Power density<br>2s pulse discharge @ 50% SOC, 60C | 4,910 W/l |

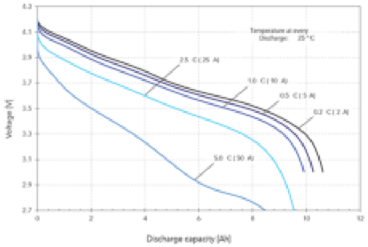


### Operating Conditions

Reference Temperature 23°C +/- 3°C

| | |
|---|---|
| Recommended charge method | Constant current / Constant voltage |
| End of charge | I ≤ C/100 |
| Maximum charge voltage | 4.2 V |
| Recommended charge current | Up to 5 A (0.5 C) |
| Maximum continuous charge current | Up to 20 A (2 C) |
| Maximum pulse charge current (15 s)<br>(Max SOC 70%, average current <88 A) | 50 A (5 C) |
| Recommended voltage limit for discharge | 3.0 V |
| Lower voltage limit for discharge | 2.7 V (at high current or low temperature) |
| Lower voltage limit for pulse discharge | 2.0 V |
| Recommended discharge current | Up to 10 A (1 C) |
| Maximum continuous discharge current | Up to 50 A (5 C) |
| Maximum pulse discharge current (2 s) | Up to 300 A (30 C) |
| Operating temperature | -30°C to +60°C |
| Recommended charge temperature | 0°C to +40°C |
| Storage and transport temperature | -40°C to +60°C |
| Recommended storage | +10°C to +25°C, 30-50% SOC |
| Cycle life at 20°C and 100% DoD, 0.5 C | > 1,000 cycles to 80% of nominal capacity |
| Cycle life at 20°C and 80% DoD, 0.5 C | > 2,000 cycles to 80% of nominal capacity |

Voltage vs discharge capacity for various discharge currents




Voltage vs discharge capacity for various temperatures