Supercapacitor for Launcher Applications

4TH SPACE PASSIVE COMPONENT DAYS - SPCD 2022
11 - 14 October 2022 | ESA\ESTEC

Supercapacitor for Launcher Applications

1. THE PROJECT
2. WHAT IS A SUPERCAPACITOR ?
3. SPECIFICATIONS / REQUIREMENTS
4. MANUFACTURING & TESTS
5. CONCLUSIONS & PERSPECTIVES

1

THE PROJECT

Partners / Project Tasks

almatech: the prime contractor in charge of the development of the **B**ank **O**f **S**uper**c**apacitor Cells (BOSC) and in particular of its packaging structure

arianeGROUP: the end-user in charge of the Requirements review,
Support to Technology Review, Design Trade-Off and Roadmap

NAWA TECHNOLOGIES: the electrical cells manufacturer in charge of the development of the BOSC and in particular of its electrochemical cells

esa: the supervisor and financial support

Supercapacitor for Launcher Applications

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THE PROJECT

Localisation / Key Competencies / Expertise

almatech

EPFL Innovation Park, Bâtiment D
CH-1015 Lausanne
SUISSE

- Project Management
- Quality assurance
- Design
- Analysis
- Assembly and Integration
- Testing

- High precision mechanisms
- Ultra-stable structures
- Integrated Systems
- Thermal Hardware

arianeGroup

51-61 Route de Verneuil
78133 Les Mureaux
FRANCE

Space enablers

- Communicating
- Positioning
- Improving
- Protecting
- Browsing
- Anticipating

- System Design
- Composite materials
- Energetic materials
- Liquid and solid propellants
- Integration

NAWA TECHNOLOGIES

190 avenue Célestin Coq
13106 Rousset
FRANCE

- Project Management
- Design
- Analysis
- Electrical Testing

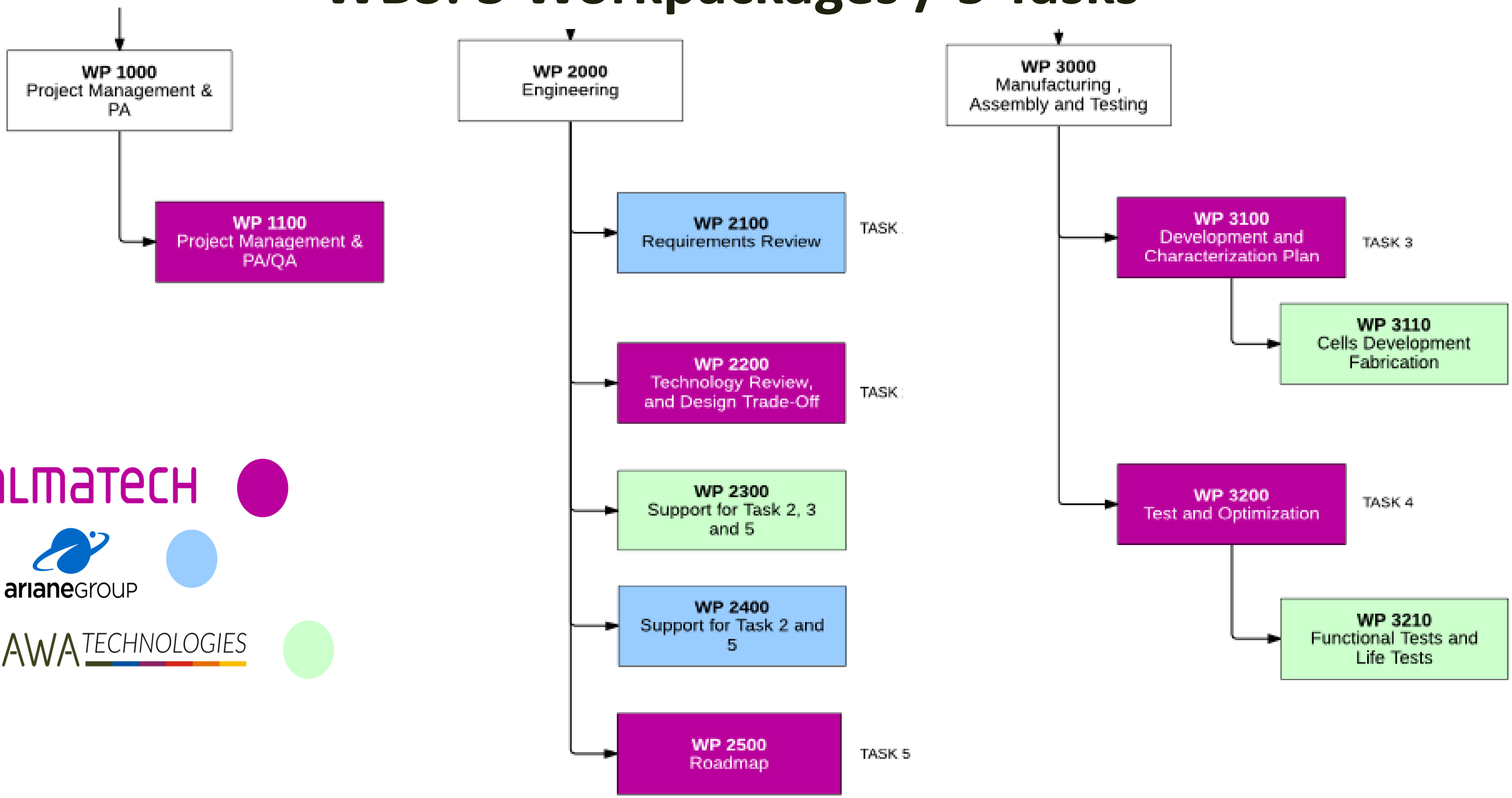
- Growth VACNT
- Carbon electrodes for EDLC
- Pouch-cell assembly
- Electrical characterizations
- Electrochemical deposition of conducting polymer

SUPERCAPACITOR FOR LAUNCHER APPLICATIONS

1

THE PROJECT

WBS: 3 Workpackages / 5 Tasks



almatech
arianeGroup
NAWA TECHNOLOGIES

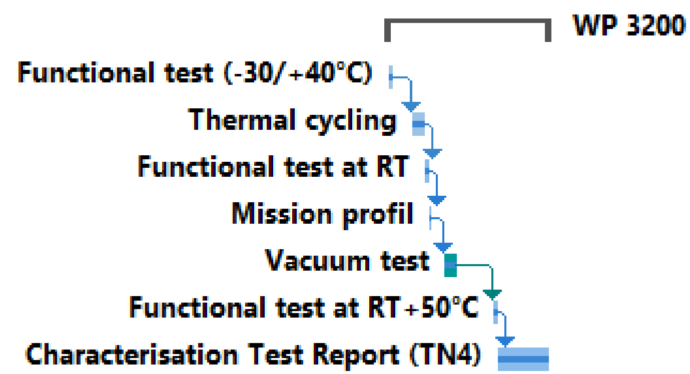
Supercapacitor for Launcher Applications

1

THE PROJECT PLANNING

Kick-Off Meeting	Feb. 2017	T0
PDR	June 2017	5
TRR	June 2019	29
CDR / TRB	sept.-19	32
Final Review	nov.-19	34

Functional and Life test	**Mon 01.07.19**	**Thu 05.09.19**
Functional test (-30/+40°C)	Mon 01.07.19	Tue 02.07.19
Thermal cycling	Thu 11.07.19	Mon 15.07.19
Functional test at RT	Tue 16.07.19	Wed 17.07.19
Mission profil	Thu 18.07.19	Thu 18.07.19
Vacuum test	Wed 24.07.19	Mon 29.07.19
Functional test at RT+50°C	Wed 14.08.19	Thu 15.08.19
Characterisation Test Report (TN4)	Fri 16.08.19	Thu 05.09.19



Supercapacitor for Launcher Applications

2

WHAT IS A SUPERCAPACITOR ?

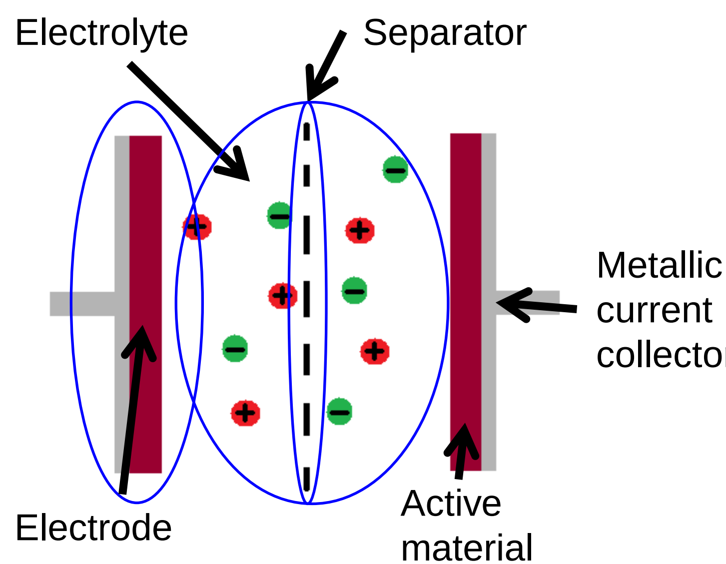
Device for electrical energy storage between battery and conventional capacitor

- **Supercapacitor is NOT a battery**
  - Capacitive operating and no faradic system

    Capacity quasi independent of voltage,

    No chemical reaction, just charge adsorption to form electrochemical double layer

Advantage	Inconvenient
Long life cycle	Low specific energy
High power density	Linear voltage decreasing during discharge
High current	High self-discharge
Large operating window in term of temperature	
Safer operating	



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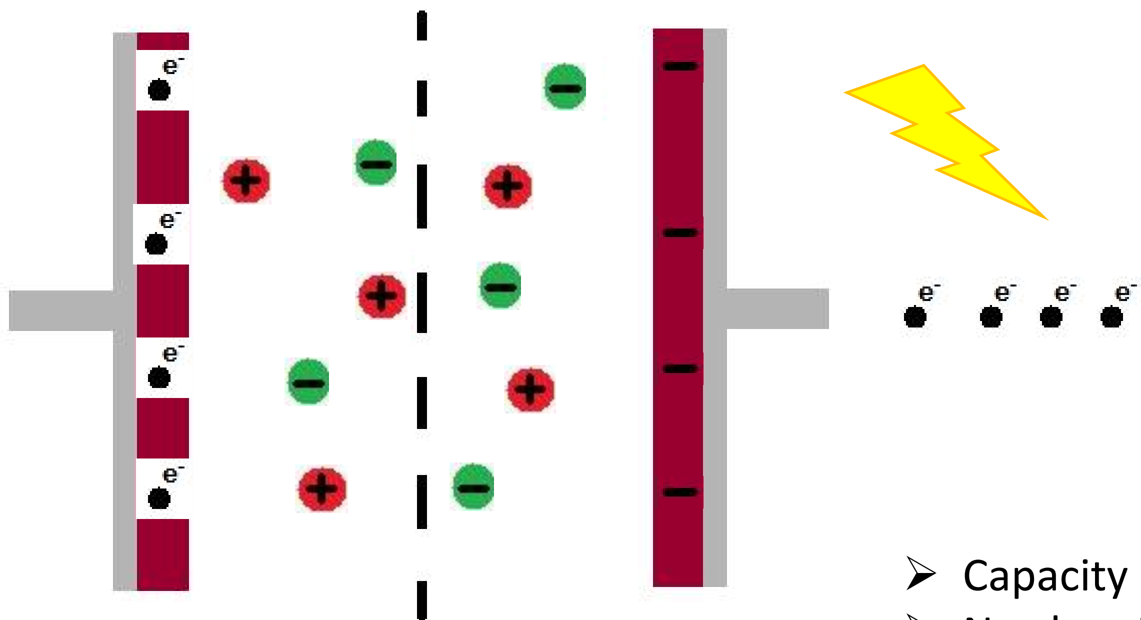
WHAT IS A SUPERCAPACITOR ?

Electrochemical Capacitive Mechanism

Charge Loading Process



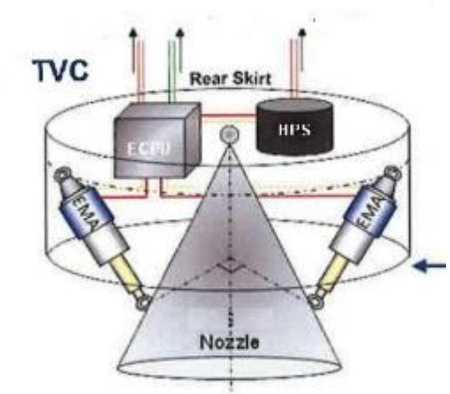
- Capacity quasi independent of voltage,
- No chemical reaction,
- Just charge adsorption to form electrochemical double layer

Supercapacitor for Launcher Applications

3

SPECIFICATIONS / REQUIREMENTS

Launcher Applications



✓ 3 identified needs for Launcher applications:
  - ❑ **Electromechanical Thrust Vector Actuation System (EMTVAS)**
  - ❑ **Pyrotechnics Power Supply**
  - ❑ **Safeguard**

➢ Determination of Specifications and Requirements for **each** application

Supercapacitor for Launcher Applications

3

SPECIFICATIONS / REQUIREMENTS

Launcher Applications

- ✓ 3 identified needs for Launcher applications:
  - ❑ Electromechanical Thrust Vector Actuation System (EMTVAS)
  - ❑ **Pyrotechnics Power Supply**
  - ❑ Safeguard

- ➢ But in term of technical specifications (power density, energy density), only **Pyrotechnic Power Supply** could be reasonably realise with **only supercapacitor cells**
- ➢ EMTVAS and Safeguard applications would need **hybrid systems** (Supercapacitors + Batteries)
- ➢ Moreover, the quantity of cells needed for one BOSC is reasonable and compatible with the project (development time, number of cells, production time, cost…)

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SPECIFICATIONS / REQUIREMENTS

BOSC for Pyrotechnic Power Supply

- Numerous Specifications and Requirements for application

Overview BOSC:

- Available energy 1Wh, 32V
- Operational under 7,5g constant acceleration all axis during 3min
- Functional temperature between -30°C and +70°C
- Dimension max L/H/W : 15/15/10cm for maximum 1kg

3

SPECIFICATIONS / REQUIREMENTS

Cells for Pyrotechnic Power Supply

- Numerous Specifications and Requirements for application

Overview Cell:

- 11 Cells connected in series
- No electronic balancing
- Capacitance 200 F, Specific energy 15 Wh/kg, Specific Power 20.8 kW/kg, Maximum voltage 3.3 V
- Functional temperature between -30°C and +70°C
- Mass Cell 15g

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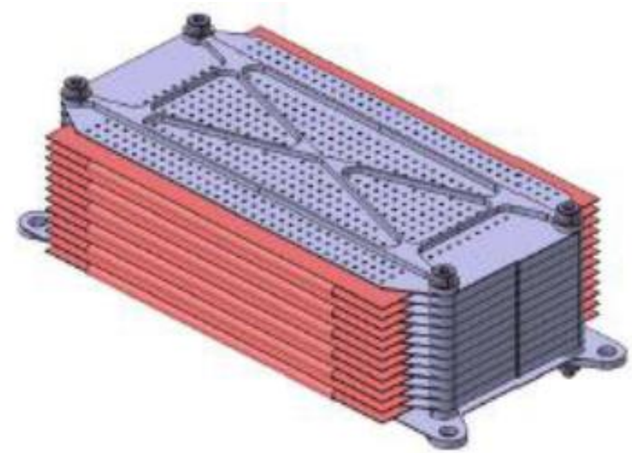
MANUFACTURING & TESTS

BOSC & Cells design

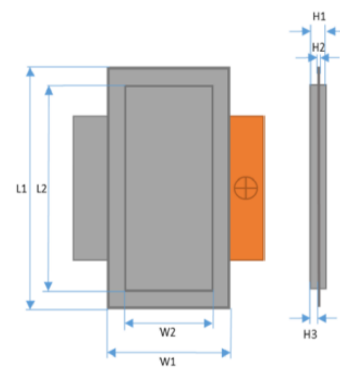
Global design BOSC:

- Hard support system with a possibility to easy adapt the number of integrated cells with less design modification and without degradation of mechanical performances



Global design Cell: (mass and size cell imposed)

- Large Tab for high current
- Pouch-cell configuration cell for maximize ratio active / inactive mass for complete system (BOSC)



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MANUFACTURING & TESTS

Cells Technologies

No technology commercially available to match the desired performances

➢ Numerous investigated electrode technologies: (measured data except requirement)

Technology	Maximum Voltage (V)	Mass (g)	Capacitance / F	Specific energy (Wh/kg)	Specific Power(kW/kg)	Voltage (V)
Requirements	**3,3**	**15,0**	**200**	**15,0**	**20,8**	**2,85**
Cell VACNT-Power (1st gen)	3,3	17,5	9	0,7	9,3	3,3
Hybride cell	2,7	10,0	35	3,0	2,5	2,5
Energy Cell (1st generation)	2,5	10,0	84	7,3	1,0	2,5
Energy Cell (final project)	**2,5**	**10,3**	**56**	**4,7**	**4,9**	**2,5**

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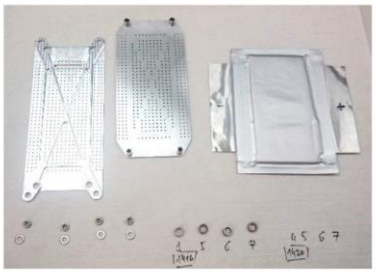
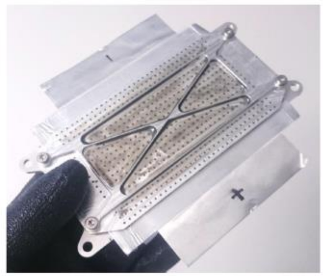
MANUFACTURING & TESTS

Cell support for BOSC

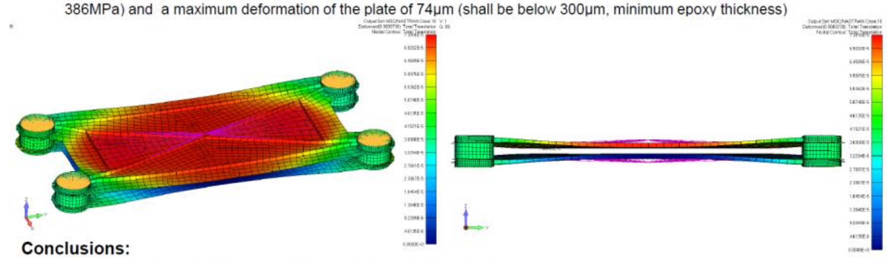




Total mass of 1 stack = 72g

List of potential issues:

- Structural analysis results show (Spread plate modelled): a stress max of 88 MPa (shall be below σyield_7075T73 = 386MPa) and a maximum deformation of the plate of 74µm (shall be below 300µm, minimum epoxy thickness)

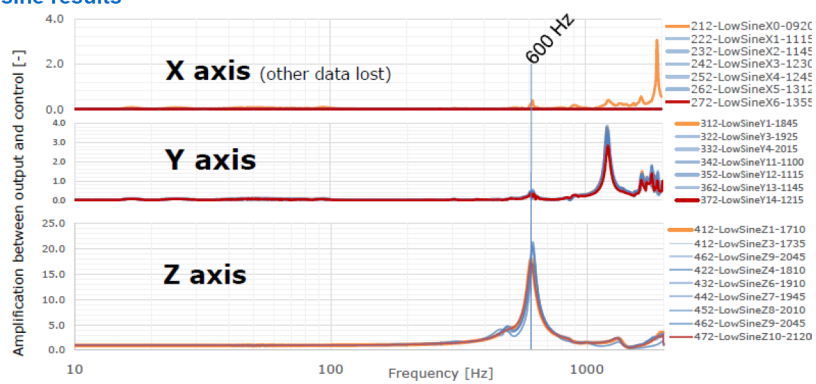


Conclusions:

- Stresses are significantly below the allowable structural limit
- Deformation is less than epoxy thickness. No contact between aluminum support plate and pouch cell occurred
- Spring clamped cannot have caused an overpressure inside the pouch cell

Vibration test

Low sine results



Z-axis damping

Test No	Control acceleration	Measured acceleration	Ratio of G_{RMS} accel	Amplification	Damping	Equivalent Q factor
472 (final Lowsine)	0.496 [g]	8.69 [g]	-	17.5	3.77%	13.3
441 (-12dB)	8.11 [g_{RMS}]	33.75 [g_{RMS}]	4.2	467	3.13%	16.0
451 (-6dB)	16.02 [g_{RMS}]	60.37 [g_{RMS}]	3.8	288	4.77%	10.5
461 (-3dB)	22.31 [g_{RMS}]	49.49 [g_{RMS}]	2.2	70.1	4.34%	11.5
471 (0dB)	31.77 [g_{RMS}]	105.78 [g_{RMS}]	3.3	170	5.96%	8.4

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MANUFACTURING & TESTS

Cells & BOSC Manufacturing

Problems encountered:

- ❑ No technology commercially available : actual technologies performances under desired performances (volumetric energy ; ratio capacitance/mass…)
  - ➢ Numerous studied optimisations or approaches
    - active material (synthesis process) ↗ Capacitance, ↗ Voltage
    - electrolyte (formulation) ↗ Temperature range, ↗ Voltage, ↘ Resistance
    - inactive material (pouch-cell film) ↘ Mass
- ❑ Active Material development in progress (synthesis, electrodes)
- ❑ Young Cell assembly line: lot of rebut (electrolyte microleak)
- ❑ Specific integration Cells in BOSC (sizing Cells ; sticking Cell and support, heat curing compatibility ; electrical linked TAB of cells in BOSC…)

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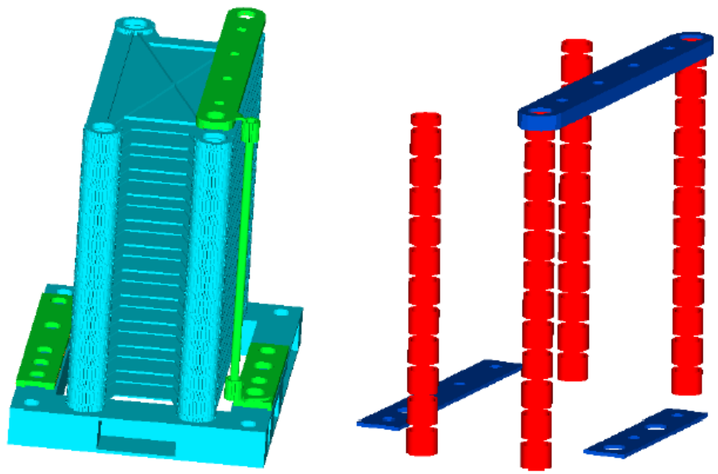
MANUFACTURING & TESTS

BOSC final design

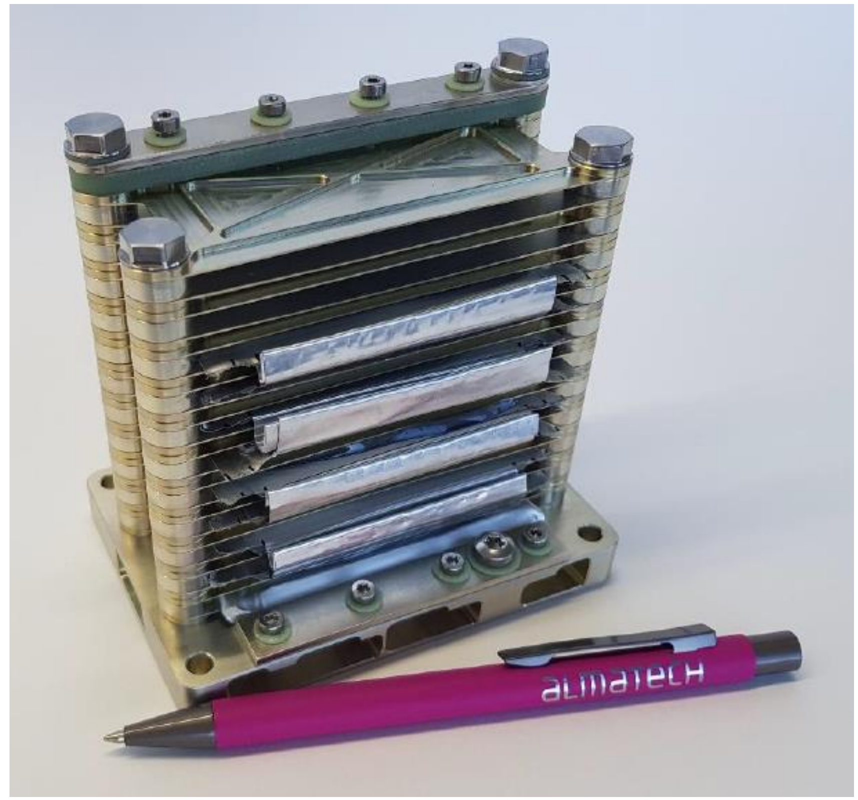
BOSC: FINAL DESIGN

The Bank Of SuperCapacitors is composed of:

- 2 VACNTs supercapacitor functional cells
- 9 VACNTs supercapacitor dummy cells



Cyan	EN AW 7075 T7351	Blue	Glass Fiber FR4
Green	Copper ETP	Red	Stainless Steel 301 (1.4305)



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MANUFACTURING & TESTS

Cells and BOSC tests

- 1 sequence of different electrical tests for Cell
- 1 sequence of different electrical and physical test for BOSC

Different tests : variation of parameters

- **Electrochemical characterization method** (Cyclic Voltametry, Potentio Electrochemical Impedance Spectroscopy, Specific Galvanometry, cycling)
- **Current** applied (1A / 3,5A)
- **Voltage** applied (2,7V / 3V)
- **Temperature** (-30°C / Room Temperature / 40°C / 50°C)
- **Pression** atmospheric / Vacuum (low 60mbar / several 10^{-5} Torr)

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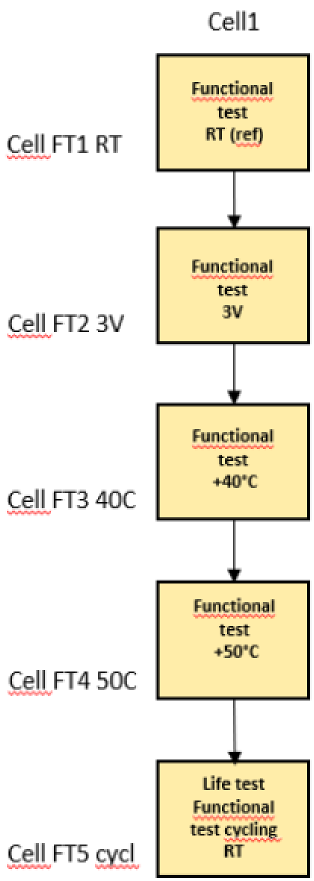
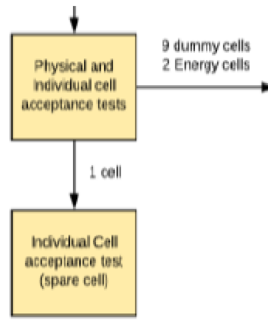
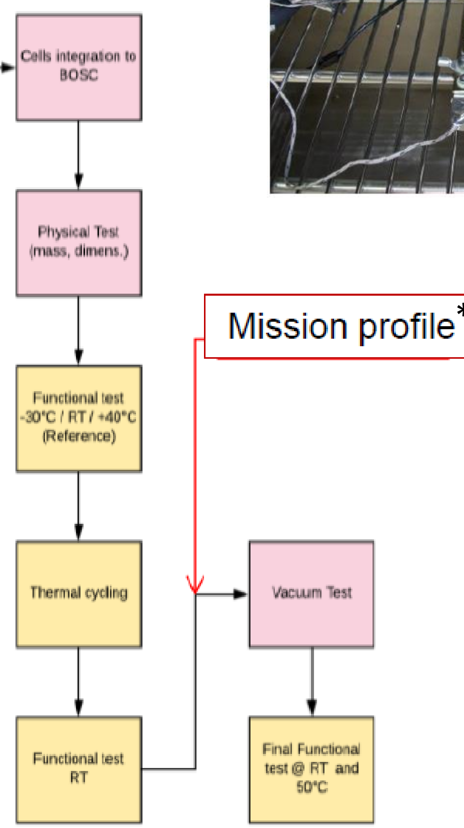
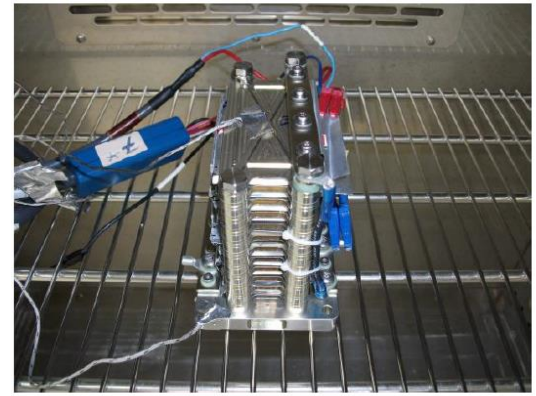
MANUFACTURING & TESTS

Cells and BOSC tests

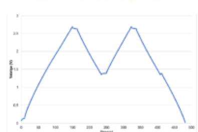




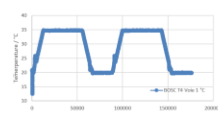




POTENSIOSTAT



CLIMATIC CHAMBER



*Mission profile = Multiple discharge peaks of high current (short time less 1 second) no possibility to charge between peaks

SUPERCAPACITOR FOR LAUNCHER APPLICATIONS

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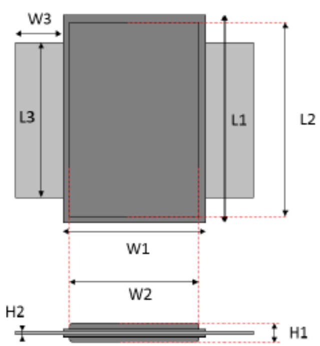
MANUFACTURING & TESTS

Cells tests

Characteristic	Cell
Size L1/W1/H1 (mm)	80/46/3
Mass (g)	10,3
Energy density (Wh/kg) at RT / 2,5V	4,7
Power density (kW/kg) at RT / 2,5V	4,9



Compliance matrix

Functional test at 23°C (RT) between 0V and 2.70V

Cell n°1	Capacitance (F)	ESR @ 1kHz (mΩ)	Time of charge (s)
$I_{discharge}$ = 1A	56.58	14.03	137
$I_{discharge}$ = 3.5A	60.83	14.03	37

Functional test at 23°C (RT) between 0V and 3.00V

Cell n°1	Capacitance (F)	ESR @ 1kHz (mΩ)	Time of charge (s)
$I_{discharge}$ = 1A	55.56	14.30	N/A
$I_{discharge}$ = 3.5A	59.81	14.30	42

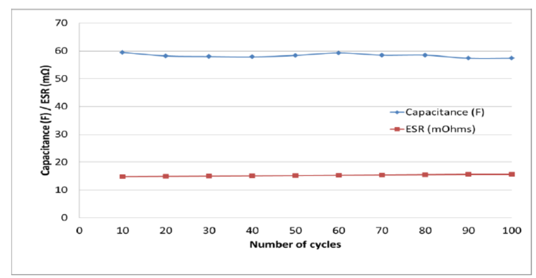
Functional test at 40°C between 0V and 2.70V

Cell n°1	Capacitance (F)	ESR @ 1kHz (mΩ)	Time of charge (s)
$I_{discharge}$ = 1A	55.48	13.30	N/A
$I_{discharge}$ = 3.5A	60.10	13.30	37

Functional test à 50°C between 0V and 2.70V

Cell n°1	Capacitance (F)	ESR @ 1kHz (mΩ)	Time of charge (s)
$I_{discharge}$ = 1A	55.19	13.46	N/A
$I_{discharge}$ = 3.5A	59.35	13.46	37

Cycling test à 23°C (RT) between 0V and 2.70V



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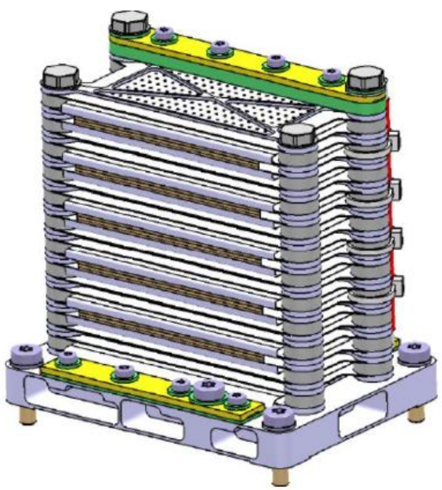
MANUFACTURING & TESTS

BOSC tests

Characteristic	BOSC
Size L1/W1/H1 (mm)	108.30 / 75.00 / 108.00
Mass (g)	550



Only 2 functional cells linked in series without any electronic management card

Compliance matrix

Functional test at 23°C (RT) between 0V and 5.40V

BOSC	Capacitance (F)	ESR @ 1kHz (mΩ)
$I_{discharge}$ = 1A	22.83	90.50
$I_{discharge}$ = 3.5 A	25.25	90.50

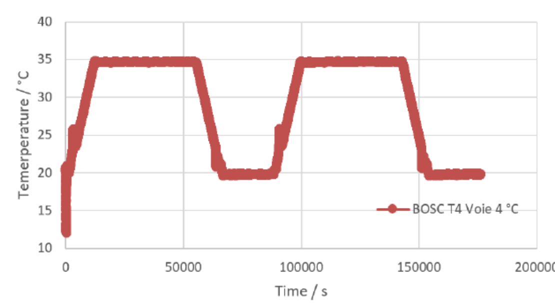
Functional test at -30°C between 0V and 5.40V

BOSC	Capacitance (F)	ESR @ 1kHz (mΩ)
$I_{discharge}$ = 1A	12.92	293
$I_{discharge}$ = 3.5A	0.42	293

Functional test at 40°C between 0V and 5.40V

BOSC	Capacitance (F)	ESR @ 1kHz (mΩ)
$I_{discharge}$ = 1A	22.72	62.53
$I_{discharge}$ = 3.5A	25.20	62.53

Thermal Cycling
Passed OK



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MANUFACTURING & TESTS

BOSC tests

Characteristic	BOSC
Size L1/W1/H1 (mm)	108.30 / 75.00 / 108.00
Mass (g)	550

Only 2 functional cells linked in series without any electronic management card

Compliance matrix

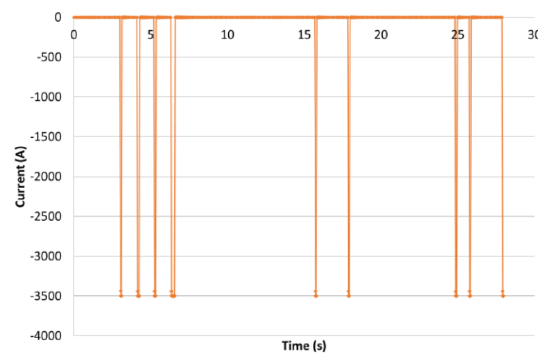
Functional test at 23°C between 0V and 5.40V

BOSC	Capacitance (F)	ESR @ 1kHz (mΩ)
$I_{discharge}$ = 1A	21.37	94.25
$I_{discharge}$ = 3.5A	21.78	94.25

Profile Mission

Realised Partially

limited applied current by available test equipment



Vacuum test

Failed

No visible degradation but microleak on cell (high increase of resistance, linked solvent of electrolyte evaporation

5

CONCLUSIONS & PERSPECTIVES

Conclusions

Project has been completed by end of 2019

- ✓ Functional and technical specifications have been defined after selecting the most promising application to integrate Supercapacitors in Launcher
- ✓ Multiple technologies of supercapacitor cells have been investigated
- ✓ Several productions of different prototypes have been realised, tested and sometimes integrated, not without numerous difficulties
- ✓ A Bank Of Supercapacitor Cells was designed, manufactured and partially tested
- ✓ 2 tests campaigns (for Cells and BOSC) were conducted to completion
- ☒ Some performances of the BOSC don't sufficiently meet the targeted requirement
- ✓ But some ways for improvement have already been defined

5

CONCLUSIONS & PERSPECTIVES

Limitation and Outlooks

During the project, NAWA supercapacitors presented some limitation in term of electrical performances (Capacitances of the cells (60F versus 200F expected), Specific Energy (4,7Wh expected versus 15Wh/kg expected), behaviour at negative temperature (-30° C)) and cell structural resistances (behaviour under vacuum)

Some improvement and outlooks:

- Electrical performances of cells: (materials, electrolyte)
- Mechanical design (under vacuum)
- Repeatability BOSC representativity wrt the application (number of functional cells),
- BOSC characterization under vibrations.

5

CONCLUSIONS & PERSPECTIVES

Perspectives

2022: New assembly line installed at NAWA: **New Machines** to get a **more Robust Process**

New Stacking machines, Pouch-cell Cavity maker, new Ultrasonic Welder, Plastic Sealing machine specific for TAB, new High Current (100A) Test Bench coupled with Ovens…

Acknowledgments

arianeGroup

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BOULANGER Pascal

esa

FARHAT Léo
LACOMBE Denis

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FARHAT Léo / leo.farhat@esa.int / +31 71 56 58 557

PALISSAT Géraldine / geraldine.palissat@esa.int / +31 71 56 58 917

LICHTENBERGER Marc / marc.Lichtenberger@almatech.ch / +41 78 974 46 92

BOISSET Aurélien / aurelien.boisset@nawatechnologies.com / +33 7 70 47 14 42