SpaceCap Stack Development to Market & Qualification Activity

Executive Summary

ESA Contract No 4000119350/16/NL/CBi

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1. TERMS AND ABBREVIATIONS

- SpaceCap – single supercapacitor
- SCM or Module – SpaceCap Module consisting of 8 supercapacitors, current bridges, overvoltage protection and balancing system.
- SCS – SpaceCap Stack – one or more SpaceCap Modules in application, as required per system.
- ESR – Equivalent Series Resistance
- EDM – Engineering Demonstrator Model

2. PROJECT OVERVIEW

Skeleton's SpaceCap component is an experimental supercapacitor (Electric Double Layer Capacitor, EDLC) offering high power density (P_{MAX} = 87 kW/L) combined with high energy density (E_{MAX} = 7.6 Wh/L) for its comparatively small capacitance of 110 F.

Image 1: SpaceCap component

Early development of the SpaceCap component, as the first activity in cooperation with ESA and Thales Alenia Space France, focused on the electrochemical development of the active carbon material, Carbide Derived Carbon (CDC), showing the technology can deliver a combination of power and energy density well beyond the state of the art.

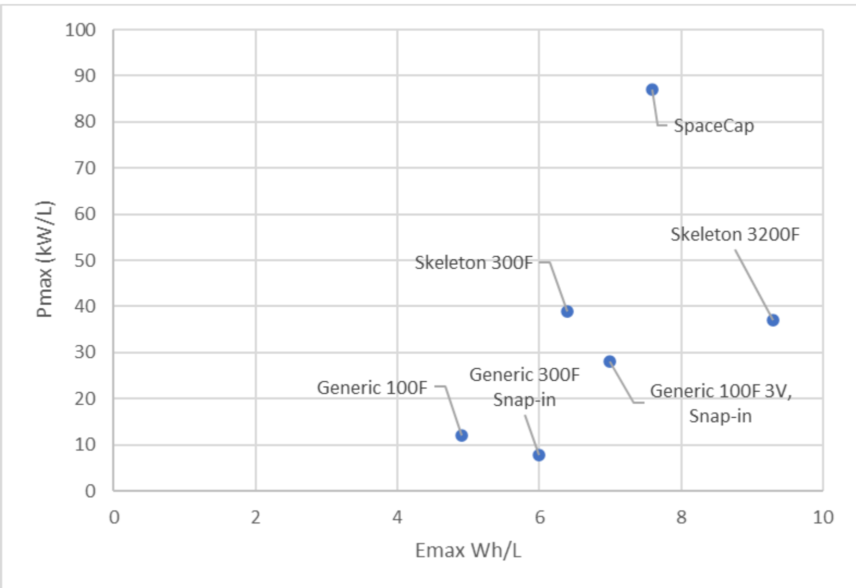

Figure 1: Volumetric performance comparison of small supercapacitors available in the market (100-300F) and a larger 3200 F commercial unit from Skeleton.

The current activity performed preliminary verification of the SpaceCap component and first iteration of an engineering demonstrator model of a Module consisting of 8 SpaceCap cells connected in series. Both developments carry the task of informing a delta design in future developments.

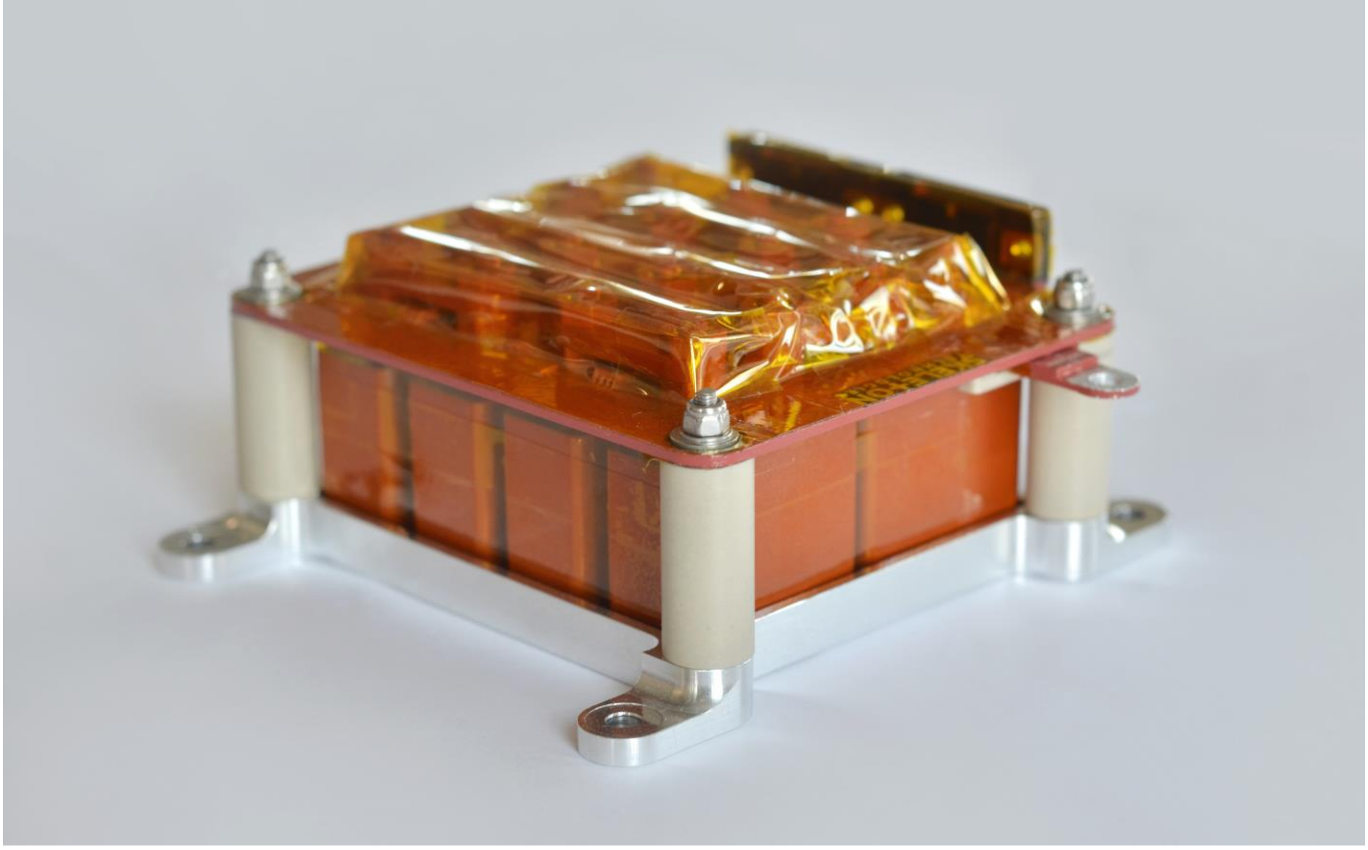

Image 2: SpaceCap module.

The project was executed by a consortium of three partners with Skeleton Technologies OÜ (EE) as the prime contractor and Thales Alenia Space – France (TAS-F) and Tartu Observatory (EE) as the subcontractors.

The responsibilities of the consortium lead included the development work and electrical testing of both the SpaceCap component and the supercapacitor Module EDM. TAS-F activities related to the evaluation of feasibility of using supercapacitors in specific applications/ payloads and Tartu Observatory had the responsibility of carrying out mechanical testing.

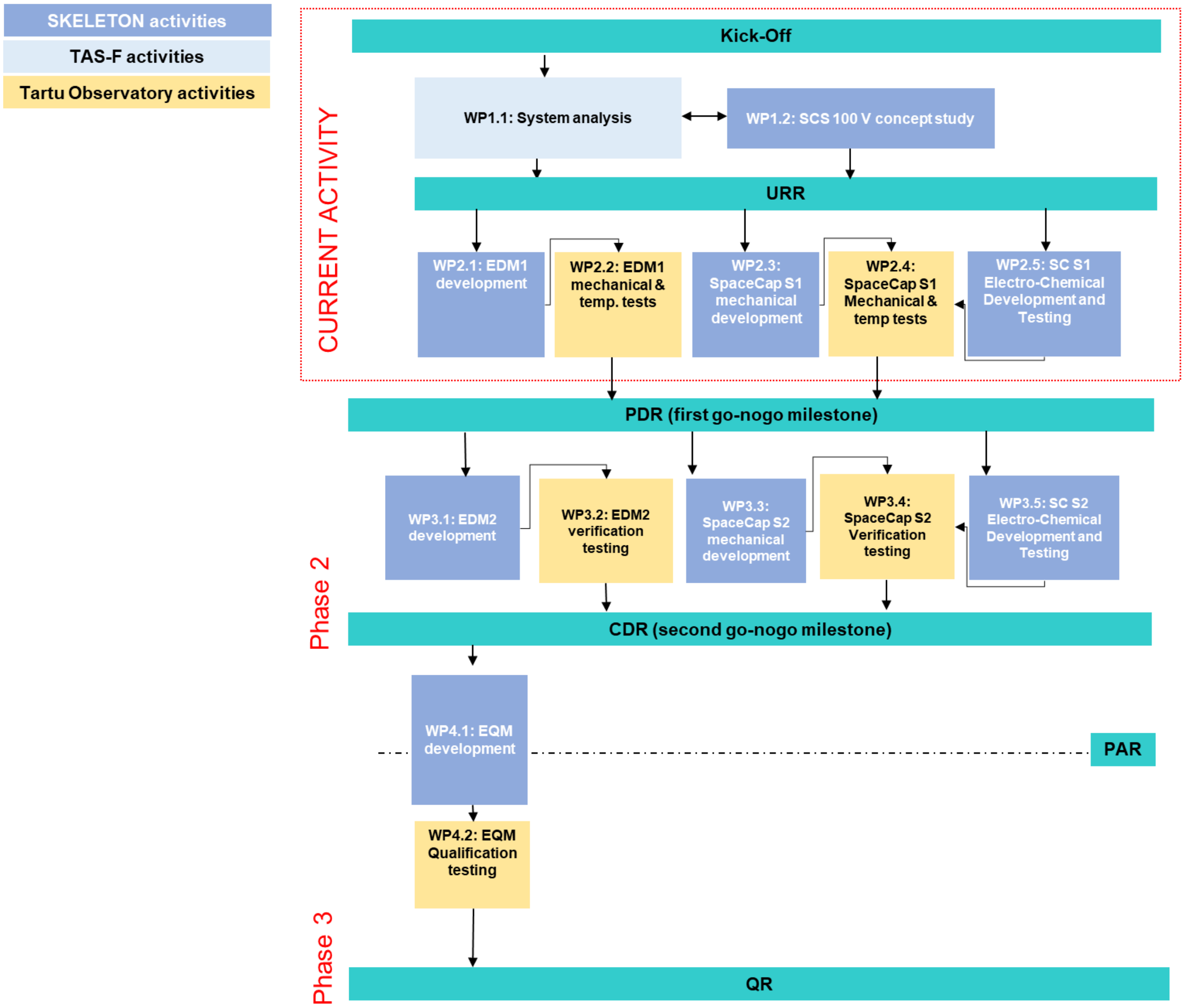

Figure 2: Work Program

Table 1: List and designation of activity deliverables

No	Deliverable	Responsibility	Description
TN1	System Evaluation of Supercapacitor Stack usage	TAS-F	Evaluation of the feasibility of using supercapacitors in different applications
TN2	User Requirements Document	TAS-F	Generic set of user requirements put forward by TAS-F
TN3	Verification and Qualification Plan	TAS-F	Test plan for future qualification activity
TN4	Technical Report (design justification document)	SKL	Review of the design choices and results for the first EDM.
TN5	User Manual	SKL	User manual for the 20 V EDM developed and tested.
TN6	Statement of Applicability	SKL	Set of matrices towards the URD and applicable standards.
TN7	EDM1 Test Report	SKL	Review of test progress and results pertaining to temperature performance, humidity, shock and vibration tests for the supercapacitor Module EDM.
TN8	SpaceCap Test Report	SKL	Review of test progress and results pertaining to, vacuum, shock, vibration and electrical tests for the SpaceCap component.
TN9	SpaceCap development report	SKL	Report on the manufacture and development of the SpaceCap component.
HDW	5 SpaceCap cells delivered	SKL	Cells delivered to ESA as examples

3. OUTCOME

A combination of electrochemical and mechanical improvements allowed Skeleton to release a next generation SpaceCap iteration with both improved capacitance and lower ESR.

Table 2: Improvements in SpaceCap electrical performance (pre burn-in values shown)

	First batch	Last batch	Improvement
Capacitance (pre burn-in)	113 F	124 F	10%
ESR_{10MS}	1.4 mOhm	1.27 mOhm	9%
ESR_{1S}	2.67 mOhm	2.30 mOhm	14%
ESR_{5S}	3.47 mOhm	3.0 mOhm	10%

High power density and low level of impedance: Compared to tantalum or electrolytic capacitors, supercapacitors have high energy content, but depending on application can fall short on power and may prove to have high level of impedance. At maximum power levels over 80 kW/L the SpaceCap component shows very high power performance can support loads at frequencies of up to 200 Hz.

High shock resilience: One of the main issues with COTS supercapacitors is lacklustre shock performance. At minimum, the shock performance should surpass 100g at 166 Hz. Both at Module and component level mechanical shock performance surpassed 200g at the same reference frequency of 166 Hz. The electrical tests before and after shock tests showed no decline in performance for the SpaceCap component and only a 10% degradation for the module.

Excellent potential for lifetime performance: Voltage hold lifetime tests at nominal voltage and temperature showed as low as only 16% degradation in capacitance and 66% increase in ESR in the nominal 1500-hour test, showing potential to last over 2000 hours were the test extended.

Delta design: The major weakness of the current design is performance variability, an unavoidable consequence of the hand-made processes involved in this development phase. For future developments Skeleton Technologies aims to move towards fully industrial scale processes in electrode processing as well as cell assembly reducing the variance in capacitance, ESR and lifetime to the same level as shown by Skeleton's COTS products.

No loss of mass detected in vacuum: One of the major concerns with the development of supercapacitors incorporating a low viscosity electrolyte was potential outgassing of electrolyte in hard vacuum. The components were tested at 10^{-5} hPa and $-30^{o}C$ for 48 hours with no detectable loss of mass.

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