Appendix F

MASCOT thermal design
how to deal with late and critical changes

Luca Celotti Małgorzata Sołyga
(Active Space Technologies GmbH, Germany)

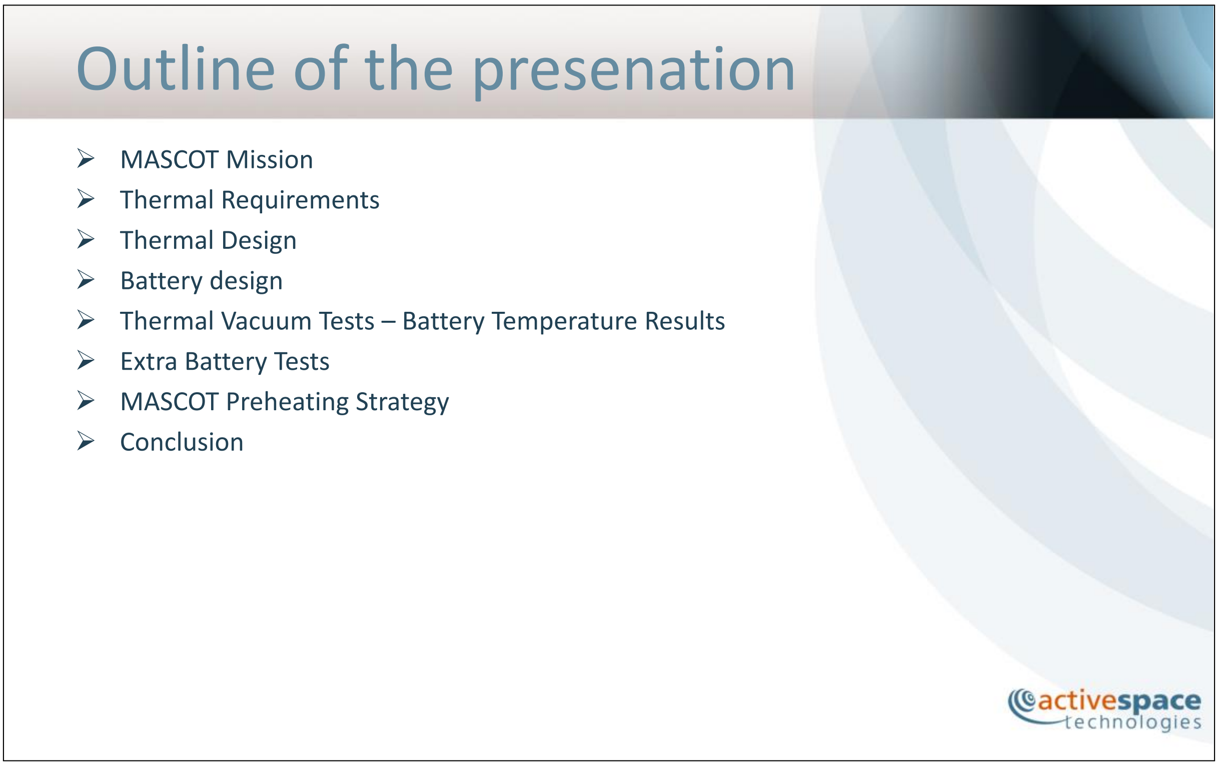
Volodymyr Baturkin Kaname Sasaki Christian Ziach
(DLR, Germany)

Abstract

MASCOT is a lander built by DLR, embarqued on JAXA's Hayabusa-2, a scientific mission to study the asteroid 162173 1999 JU3, launched on the 3rd of December 2014. As part of the project challenges, the short schedule for the whole development of the lander (2.5 years from PDR to launch), the strict and contrasting thermal requirements for different phases of the mission, mass&power/technology/volume limitations put the thermal design at the edge of the state of art technology solutions. As a result, the thermal system development has been on-going until the last phases of the project, on order to cope with late changes and technologies development.

This presentation focusses on the thermal control system evolution during the last months before launch and just after it and the tight schedule available to cope with late system changes. It shows the design modifications and updates, together with thermal modelling changes following intensive testing phases, in particular for the lander battery pack and the heating/pre-heating strategy for different mission phases. Many thermal vacuum campaigns, modelling re-iterations, better understanding of the main S/C thermal behaviour, together with the great team determination helped reaching a succesfull launch followed by an on-flight system verification.


MASCOT thermal design: how to deal with late and critical changes
activespace technologies
Luca Celotti
November, 3-4 2015
ESTEC, Nordwijk - The Netherlands
making space a global endeavour
activespace technologies
Luca Celotti, Małgorzata Sołyga
ActiveSpace Technologies GmbH
DLR
Volodymyr Baturkin, Kaname Sasaki, Christian Ziach
DLR Institut für Raumfahrsysteme
Explorationssysteme RY-ES

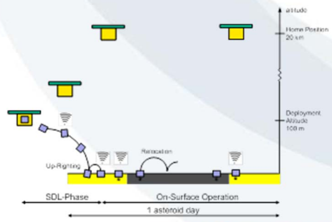

Outline of the presenation
MASCOT Mission
Thermal Requirements
Thermal Design
Battery design
Thermal Vacuum Tests – Battery Temperature Results
Extra Battery Tests
MASCOT Preheating Strategy
Conclusion
activespace technologies

MASCOT Misison

MASCOT (Mobile Asteroid surface SCOuT)

- A lander built by DLR (in collaboration with CNES)
- On-board JAXA's Hayabusa-2 mission, a scientific mission to study the asteroid "Ryugu" (former 162173 1999 JU3)
- Smaller than 300x300x200mm³
- Carries 4 payloads for scientific investigation of the asteroid surface:
  - IR spectrometer (mOmega)
  - Camera
  - Magnetometer
  - Radiometer
- Will be released by the mothership and "fall" on the asteroid surface

Courtesy of DLR



Courtesy of DLR

activespace technologies

Thermal requirements

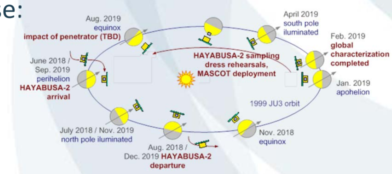
The thermal requirements MASCOT must satisfy and the environment in which it will operate vary significantly, depending on the mission phase:

- Cruise Phase: MASCOT is attached to HY-2 on its way to the asteroid

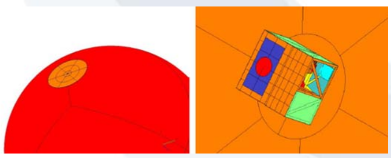
→ In this phase, the lander should limit as much as possible the heat exchange with the S/C and with the environment

- Near-Asteroid Phase: MASCOT is still attached to HY-2, which is hovering above the asteroid
- On-Asteroid Phase: In this Phase MASCOT is performing its operations on the asteroid surface (after free-fall phase)

→ In those two phases, the lander should reject as much heat as possible in order not to reach maximum operational temperature limits.



Courtesy of DLR



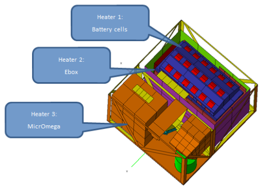
activespace technologies

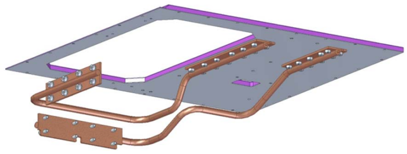
Thermal design

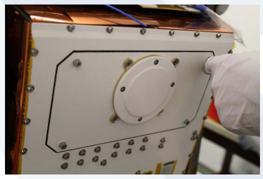
The design should fulfill the contrasting requirements during different mission phases and it should insulate MASCOT from HY-2 as much as possible and be passive (due to the limited power provided by HY-2).

Thus, it was decided to use variable conductance heat transfer technology from the electronic box (the most dissipative element) to the radiator.

Heating power available is going to be distributed to the most critical parts (mOmega, EBOX, battery).




Courtesy of DLR


Courtesy of DLR

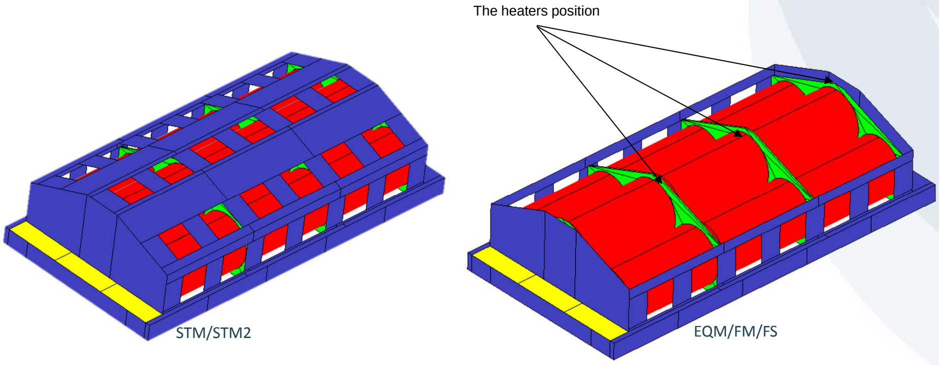
→ ***The heating strategy for the battery unit and its design has evolved during the whole project, making crucial parts of the thermal subsystem.***

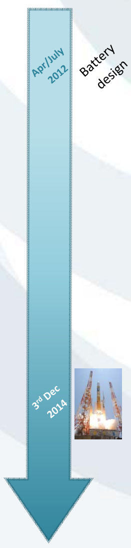
activespace technologies

Battery design

The battery of MASCOT includes 9 cells. In order to keep these cells warm enough to operate (above -40°C), each cell is wrapped with a flexible heater.

The design was then modified and the heaters have been placed in elements between the cells. Before the heaters were wrapping each cell.

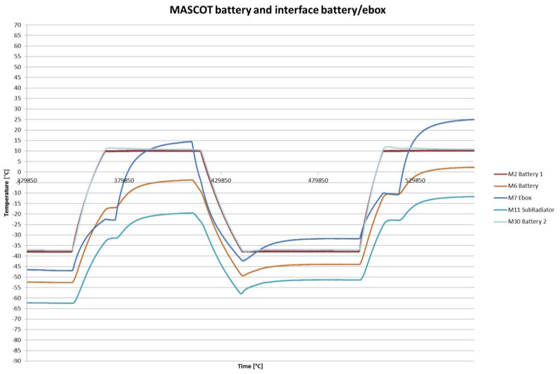


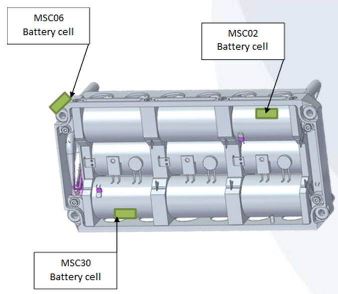


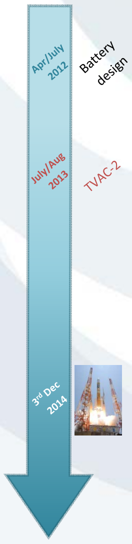
activespace technologies

Thermal Vacuum Test (TVAC-2)

The STM model of MASCOT has been tested, including the battery STM model.





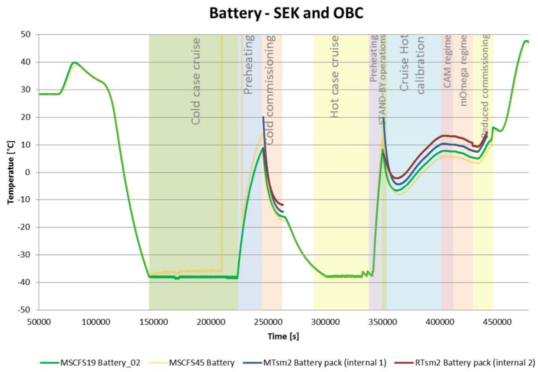


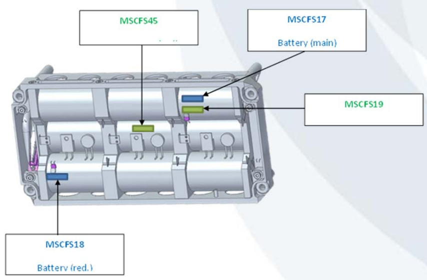
Different battery cells reach quite similar temperatures in all test phases.

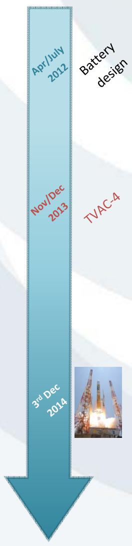
activespace technologies

Thermal Vacuum Test (TVAC-4)

In TVAC-4 test campaign, the temperatures on the battery STM2 were measured by the facility sensors as well as by the sensors read by on-board computer and HY-2 sensor (first time in which all these sensors were used).





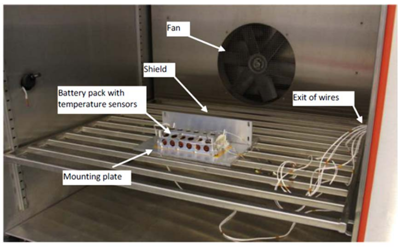


The test results showed that there is big difference between measured values from difference systems (in some cases almost 10°C).

activespace technologies

Sensors calibration

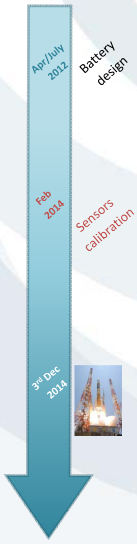
After the test campaign (TVAC-4) an extra test has been performed by DLR in order to verify the measurements coming from different sensors on the battery STM2.



Courtesy of DLR

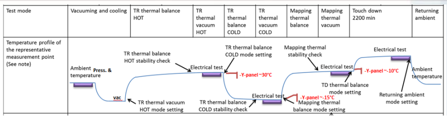
Temperature [°C]					
Climatic chamber Set up	Main HY PT2000	RET HY PT2000	Main OBC PT1000	RET OBC PT1000	SEK PT100 (average for 4 sensors)
-38.0	-38.50	-38.06	-35.46	-35.75	-38.19
0.0	-0.34	0.16	3.37	3.15	0.05
21.0	20.72	21.26	24.92	24.70	20.93
22.0	21.87	22.52	26.08	25.86	22.12
50.0	49.95	50.54	54.95	54.73	50.20

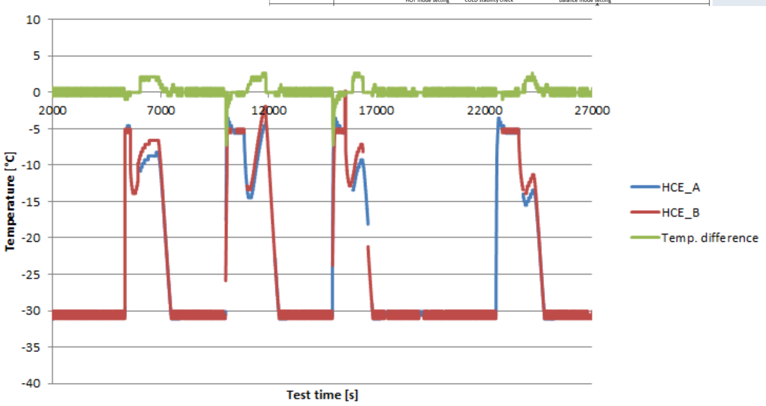
Temperature sensors (HY-2 and OBC) differences fixed via re-calibration and new temperature/resistance curves.



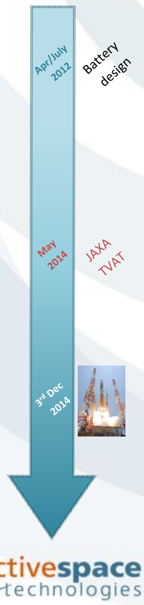
Flight simulation test in JAXA

First use of battery EQM



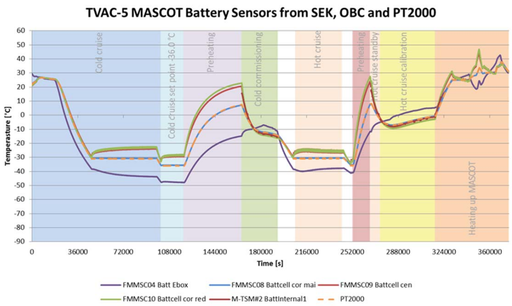


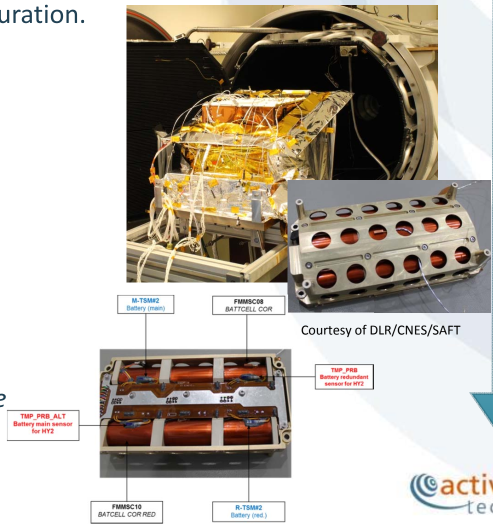
Regardless for the calibration fixed, temperature differences betwee the HY-2 sensors are present, moreover an anomalous long duration of pre-heating phases appeared.



Thermal Vacuum Test (TVAC-5)

In this test the FM of MASCOT has been tested with the FM model of the battery. During this test the big temperature difference between the cells have been noticed as well as a much longer preheating duration.





Courtesy of DLR/CNES/SAFT

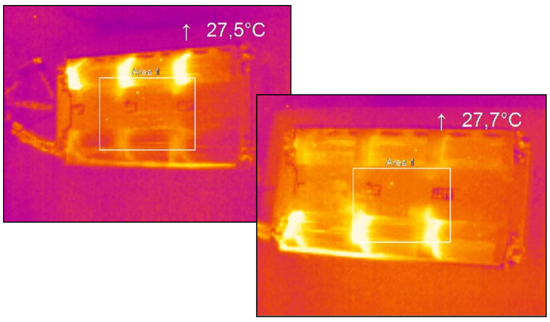
A clear HW issue is present, appearing in the EQM and FM, not present in the STMs.

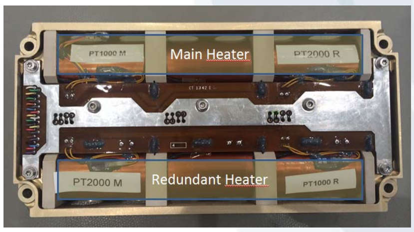
Further investigations were necessary!

activespace technologies

Extra battery tests – FM IR test

- Deep evaluation of the design changes implemented by the battery supplier
- IR test perfomed on the FM by DLR to evaluate the heaters efficiency





Courtesy of DLR/CNES/SAFT

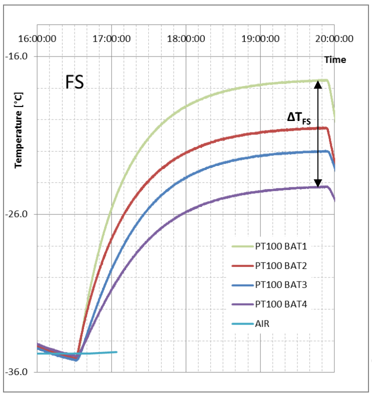
The heaters and spreaders do not provide enough heating uniformity to the battery pack generating a longitudinal temperature difference.

The position of the temperature sensors controlling the heating lines generates a temperature difference along the cells.

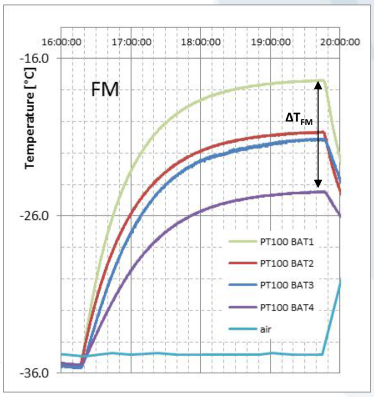
activespace technologies

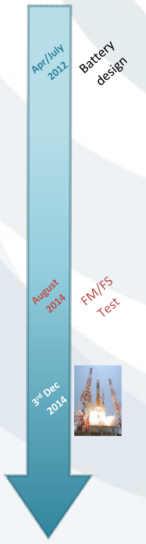
Extra battery tests – FM/FS test

Comparative heating test for FM and FS model has been performed. Test results showed that the thermal behaviour of both battery models is very similar.



Courtesy of DLR





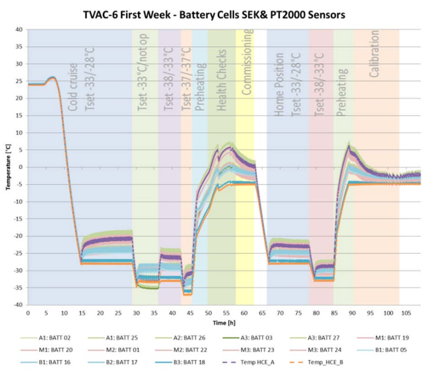
Battery FS is chosen for flight, while the FM unit will be used for testing in order to investigate the thermal behaviour of the current battery design.

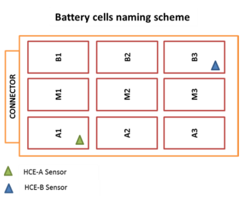
EQM heaters positioning is confirmed equal to FM/FS and different from STMs by the supplier.

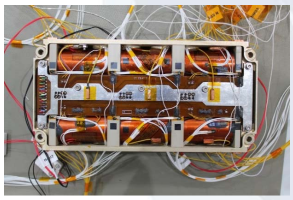
activespace technologies

Thermal Vacuum Test (TVAC-6)

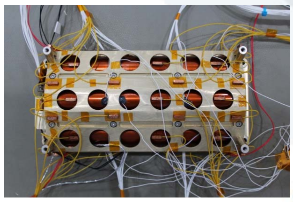
In TVAC-6 test campaign the FS of MASCOT has been tested with the battery FM. The main objective of this test was better thermal characterisation of the battery (as the idea of a stnad-alone test of the battery was discarded due to difficulties in replicating similar boundary conditions) – due to this fact on the battery almost 30 temperature sensors have been mounted.

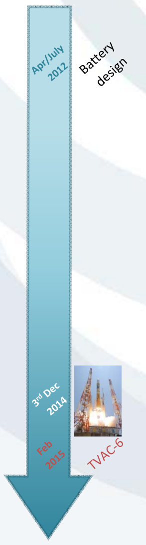






Courtesy of DLR/CNES/SAFT

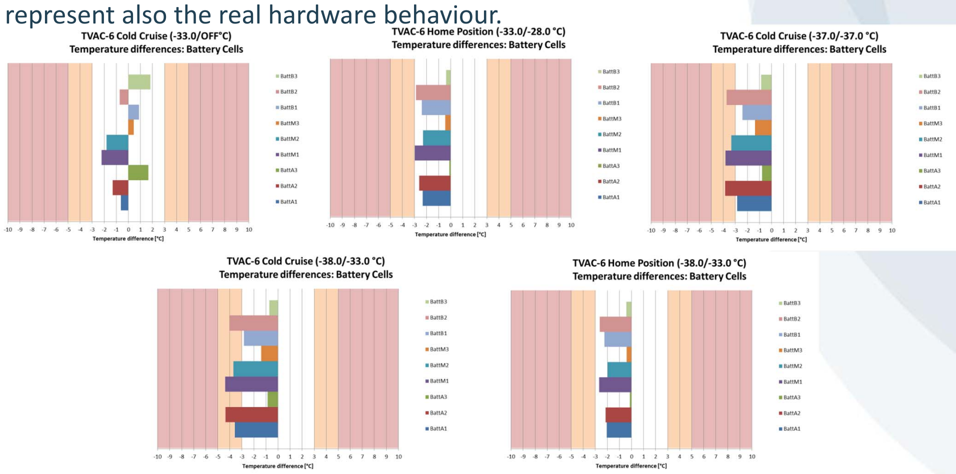


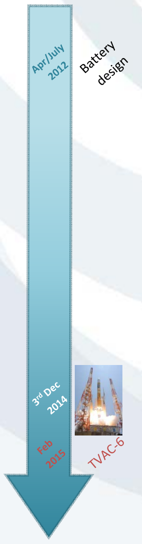


activespace technologies

Thermal Vacuum Test (TVAC-6)

After the test, correlation performed and battery thermal model updated to represent also the real hardware behaviour.





As this vacuum campaign happned after launch, a strategy for the launch and the first health-chack had to be evaluated, together with the pre-heating strategy.

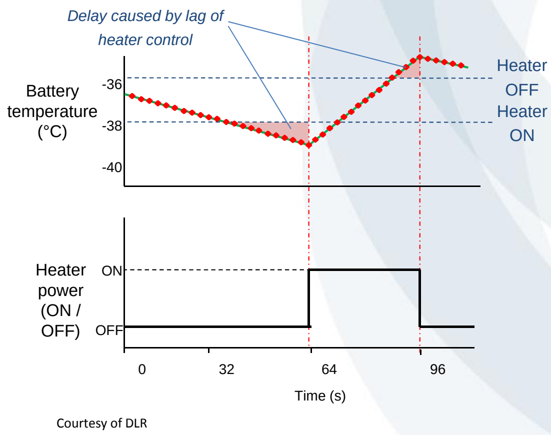
activespace technologies

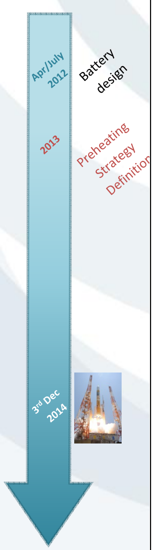
MASCOT preheating strategy

In order to keep MASCOT within the temperature limits, a heating and pre-heating strategy has been prepared (together with HY-2).

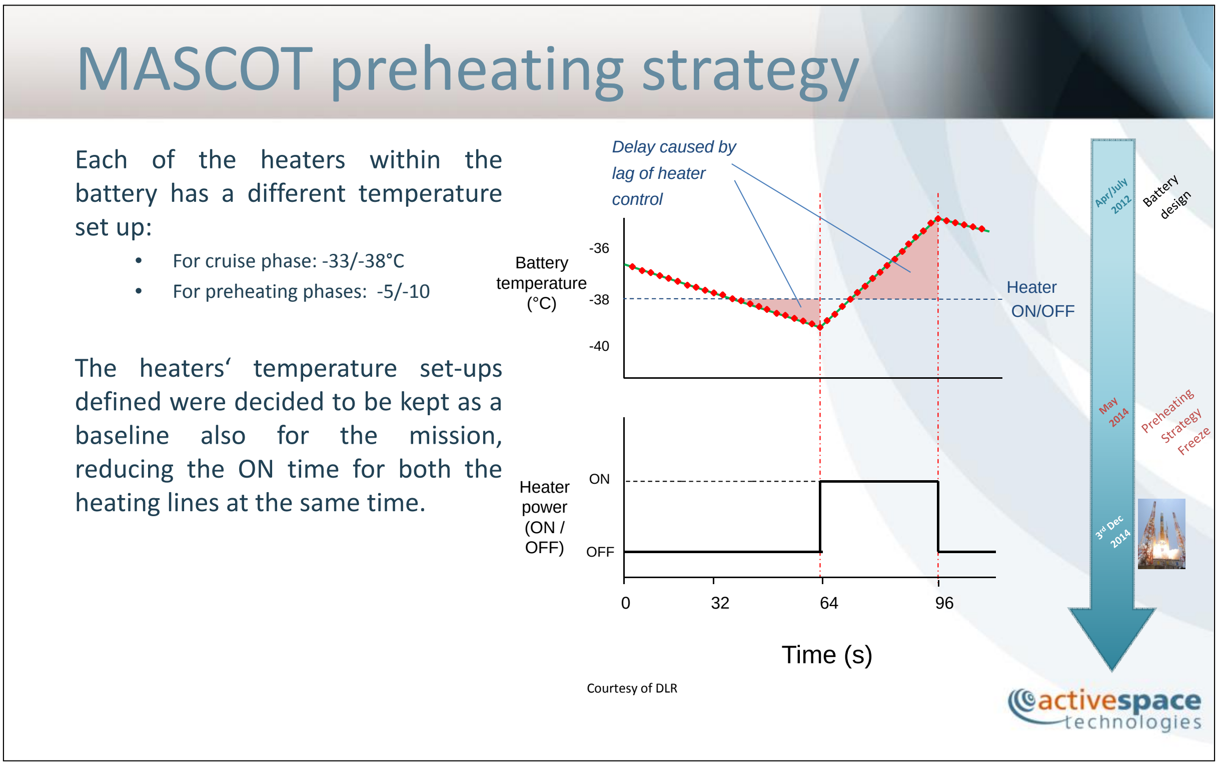
The MASCOT global thermal beahviour is kept within the ranges controlling the temperature of the battery pack (2 sensors) via two <u>independent</u> heating lines (A, B).

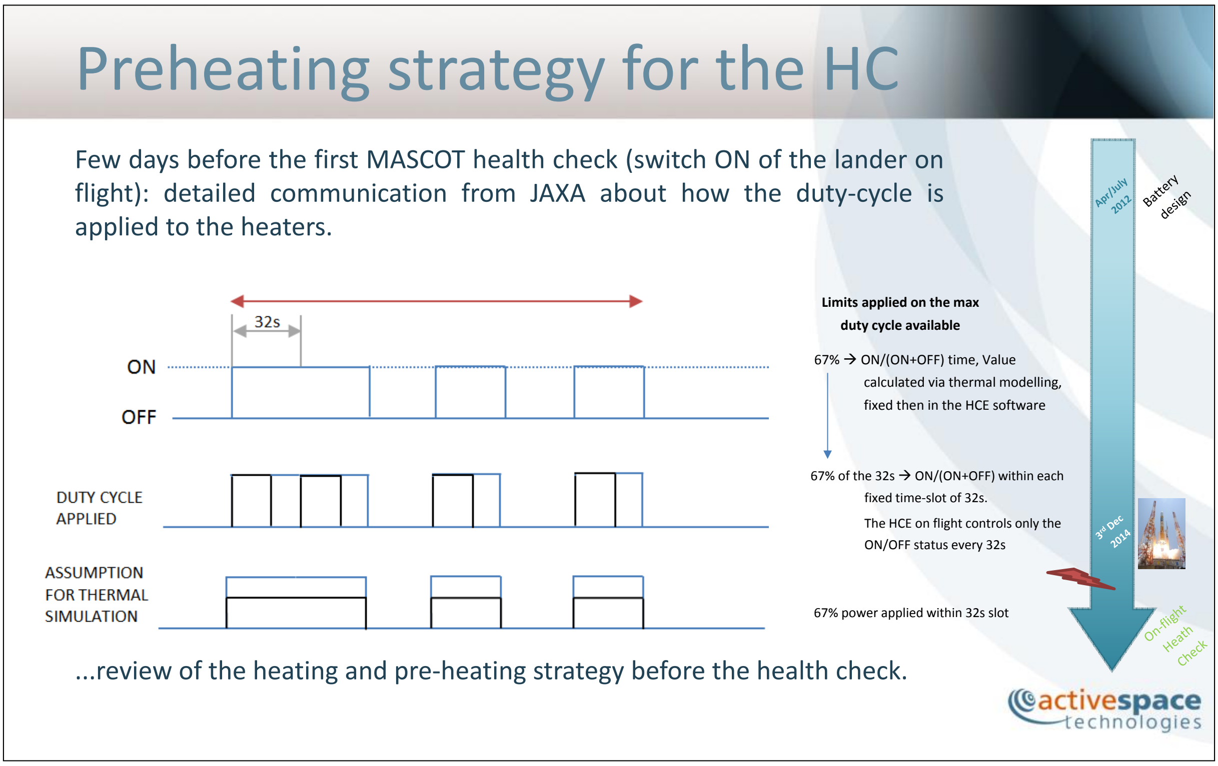
For health-checks the temperature of the whole lander has to be raised via raising the temperature set controlling he battery.





activespace technologies

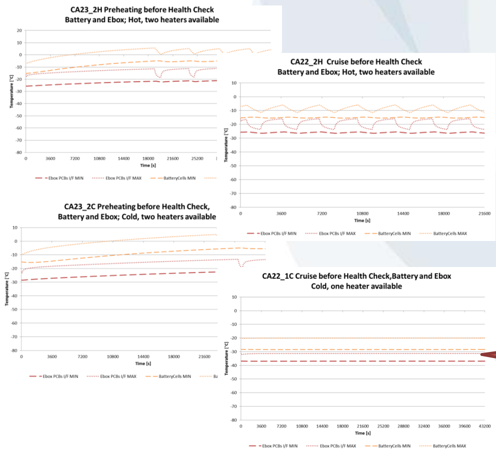

MASCOT preheating strategy
Each of the heaters within the battery has a different temperature set up:
• For cruise phase: -33/-38°C
• For preheating phases: -5/-10
The heaters' temperature set-ups defined were decided to be kept as a baseline also for the mission, reducing the ON time for both the heating lines at the same time.
Delay caused by lag of heater control
Battery temperature (°C)
-36
-38
-40
Heater ON/OFF
Heater power (ON / OFF)
ON
OFF
0
32
64
96
Time (s)
Courtesy of DLR
Apr/July 2012
Battery design
May 2014
Preheating Strategy Freeze
3rd Dec 2014
activespace technologies

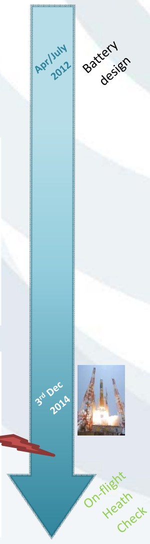

Preheating strategy for the HC
Few days before the first MASCOT health check (switch ON of the lander on flight): detailed communication from JAXA about how the duty-cycle is applied to the heaters.
32s
ON
OFF
DUTY CYCLE APPLIED
ASSUMPTION FOR THERMAL SIMULATION
Limits applied on the max duty cycle available
67% → ON/(ON+OFF) time, Value calculated via thermal modelling, fixed then in the HCE software
67% of the 32s → ON/(ON+OFF) within each fixed time-slot of 32s.
The HCE on flight controls only the ON/OFF status every 32s
67% power applied within 32s slot
...review of the heating and pre-heating strategy before the health check.
Apr/July 2012
Battery design
3rd Dec 2014
On-flight Heath Check
activespace technologies

Preheating strategy for the HC

After the understanding how the HY-2 operates the heaters, different options for health check temperature set-ups have been analysed.

Case	HY-2 voltage	Heater	Status	Tset	Max duty cycle	Power applied [W]
Hot Cruise (Two heaters work)	50 V	HCE-A	Works	-20°C	35.0%	2.70
		HCE-B	Works	-15°C	60.0%	4.63
Hot Preheating (Two heaters work)	50 V	HCE-A	Works	-10°C	35.0%	2.70
		HCE-B	Works	-5°C	60.0%	4.63
Hot Health Check (Two heaters work)	50 V	HCE-A	Works	-10°C	35.0%	2.70
		HCE-B	Works	-5°C	60.0%	4.63
Hot Cruise (One heater works)	50 V	HCE-A	OFF	-	-	-
		HCE-B	Works	-15°C	60.0%	4.63
Hot Preheating (One heater works)	50 V	HCE-A	OFF	-	-	-
		HCE-B	Works	-5°C	60.0%	4.63
Hot Health Check (One heater works)	50 V	HCE-A	OFF	-	-	-
		HCE-B	Works	-5°C	60.0%	4.63
Cold Cruise Two (Two heaters work)	50 V	HCE-A	Works	-20°C	35.0%	2.70
		HCE-B	Works	-15°C	60.0%	4.63
Cold Preheating (Two heaters work)	50 V	HCE-A	Works	-10°C	35.0%	2.70
		HCE-B	Works	-5°C	60.0%	4.63
Cold Health Check (Two heaters work)	50 V	HCE-A	Works	-10°C	35.0%	2.70
		HCE-B	Works	-5°C	60.0%	4.63
Cold Preheating (Two heaters work, **different temp set**)	50 V	HCE-A	Works	-15°C	35.0%	2.70
		HCE-B	Works	-10°C	60.0%	4.63
Health check (Two heaters work, **different temp set**)	50 V	HCE-A	Works	-15°C	35.0%	2.70
		HCE-B	Works	-10°C	60.0%	4.63
Cold Cruise One (One heater works)	50 V	HCE-A	Works	-20°C	35.0%	2.70
		HCE-B	OFF	-	-	-

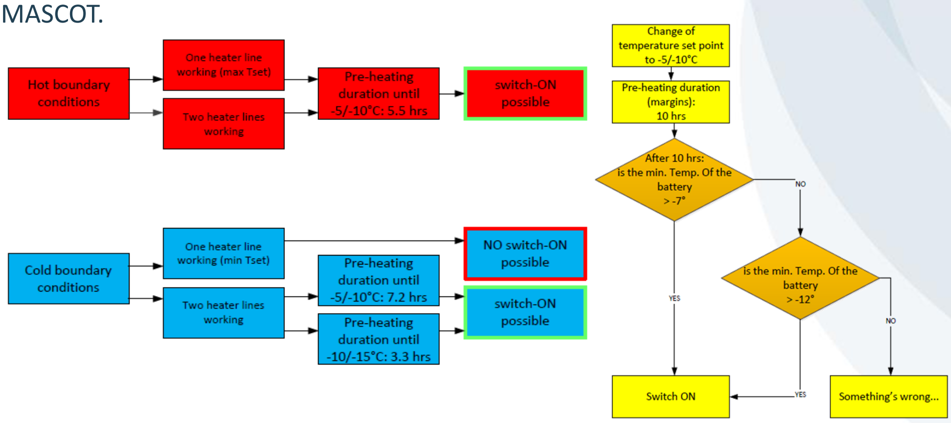


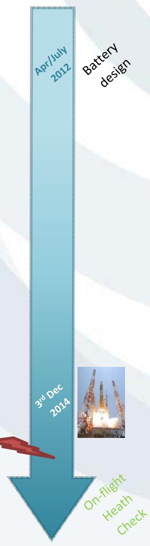


activespace technologies

Preheating strategy for the HC

Thermal simulations (includign hte temperature gradient on the battery cells) allowed to prepare the procedures to follow during the first health check of MASCOT.



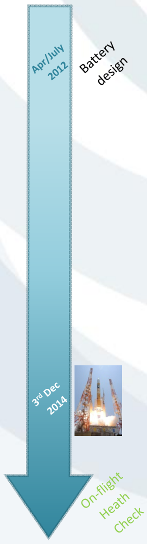


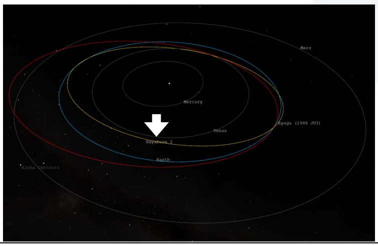
activespace technologies

Conclusion

MASCOT is a lander built by DLR, embarqued on JAXA's Hayabusa-2, a scientific mission to study the asteroid "Ryugu" (former 162173 1999 JU3), launched on the 3rd of December 2014. As part of the project challenges, the short schedule for the whole development of the lander (2.5 years from PDR to launch), the strict and contrasting thermal requirements for different phases of the mission, mass&power/technology/volume limitations put the thermal design at the edge of the state of art technology solutions. As a result, the thermal system development has been on-going until the last phases of the project, on order to cope with late changes and technologies development.

This presentation focusses on the thermal control system evolution during the last months before launch and even just after it. Thermal vacuum campaigns, modelling re-iterations, better understanding of the main S/C thermal behaviour, together with the great team determination helped reaching a succesfull launch followed by an on-flight system verification.





http://www.lizard-tail.com/isana/hayabusa2/ (Update from 10/2015)

activespace technologies

Contacts

Thank you for the attention!

For further information

Luca Celotti
luca.celotti@activespacetech.eu

Tel: +49 (0) 30 6392 6090
Fax: +49 (0) 30 201 632 829

Carl-Scheele Str. 14
12489 Berlin
Germany

activespace technologies