Appendix K

MASCOT
Thermal subsystem design

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Abstract

MASCOT is a lander built by DLR, embarked on JAXA's Hayabusa-2, a scientific mission to study the asteroid 162173 1999 JU3. It is a small lander, less than 300x300x200mm?, with onboard payloads (camera, magnetometer, radiometer and IR spectrometer), developed in collaboration by DLR and CNES. MASCOT lands on the asteroid surface, after being released by Hayabusa-2 from a very close position above the asteroid surface, and investigates the asteroid surface. The thermal design of the lander represents one of the main challenges in the whole project because of multiple constraints, depending on the mission phase, mass, power and free space available.

MASCOT, notwithstanding its small size, is equipped with redundant heat-pipe system, MLI blanket, heaters. The thermal design of the lander has been chosen after a trade-off phase concerning the technology which could suit better the opposing requirements of the mission: low heat exchange between the lander and the exterior (including the main spacecraft) in cruise, possibility to transfer all the heat dissipated by the internal paylaods and electronic boards during operations on asteroid surface. After selecting the heat-pipe technology as baseline, a development phase was undertaken by the partners both in terms of manufacturing, testing, thermal characterization phase and analitical modelling in order to match the thermal requirements.

Heaters are used to assure the survival of the most delicated parts of the lander during cold cruise phases: the battery cells (only primary battery on-board), the electronic boards and the main payload. Strict requirements are given by the main spacecraft in terms of maximum power available to heat the lander during cruise. MLI blankets are used where the available space allows it, e.g. to extra insulate the Ebox from the rest of the lander creating a „hot compartment" and between the lander and the main spacecraft to reduce the heat exchange with it during cruise below the given limits. The whole thermal concept in all its parts undertook a detailed modelling phase in parallel to an experimental phase in vacuum chamber to improve the model and to qualify the system.

MASCOT thermal design is here presented through the following points:

- MASCOT as part of HY-2 mission: mission, constraints, challenges
- Challenging thermal requirements
- Main thermal strategy and trade-offs: available technologies, constant conductance heat-pipes
- Thermal design
- Vacuum chamber testing
- Thermal model results
- Conclusions and future steps

MASCOT
Thermal subsystem design

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making space a global endeavour

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Outline

MASCOT thermal design is here presented through the following points:

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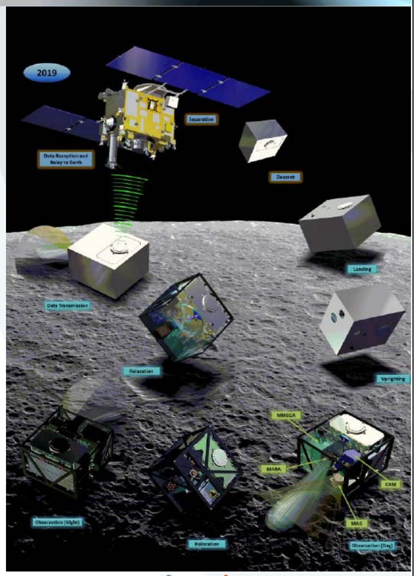
MASCOT as part of HY-2 mission

MASCOT (Mobile Asteroid Surface Scout) is a lander built by DLR, in collaboration with CNES and JAXA, embarked on JAXA's Hayabusa-2, a scientific mission to study the asteroid 162173 1999 JU3.

It is a small lander, less than 300x300x200mm³, with onboard payloads (camera, magnetometer, radiometer and IR spectrometer), developed by DLR, CNES and IAS.

During cruise phases MASCOT is cradled by the support structure MESS inside HY-2 spacecraft.

MASCOT lands on the asteroid surface, after being released by Hayabusa-2 from a very close position above the asteroid surface, and investigates the asteroid surface.



Courtesy of DLR

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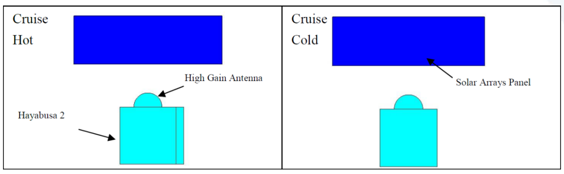
Challenging thermal requirements

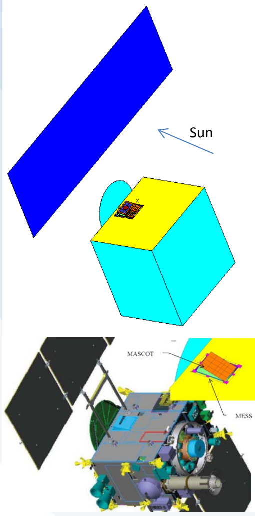
→ Different mission phases → Opposite thermal requirements:

4 years Cruise phase: **cold condition**

- MASCOT as much as possible insulated from the exterior
- Necessity to keep the internal components above minimum non-OP temperatures
- Reduced heat exchange (MASCOT+MESS, cruise and return cruise) with the main S/C (max +/-5W)
- Reduced power consumption (cruise) for heaters (max 5W always ON)



Cruise phase, as seen form the Sun



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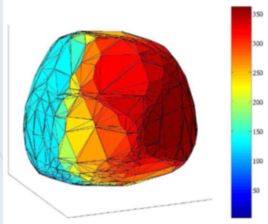
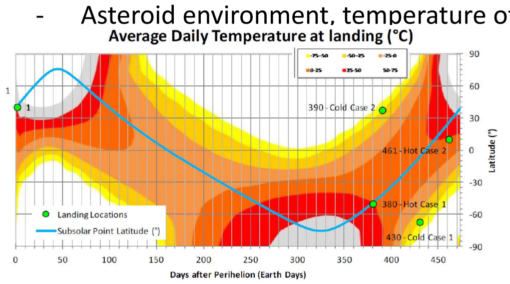
Challenging thermal requirements

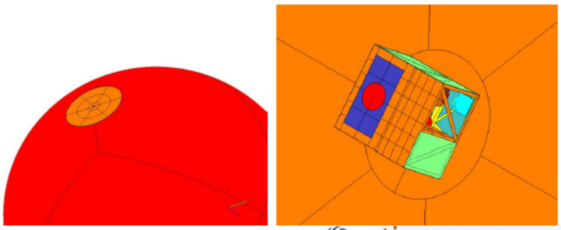


→ Different mission phases → Opposite thermal requirements:

On asteroid phase: **„hot“ condition**

- Landing site evaluation
- Dissipate as much as possible heat from the payloads and internal subsystems to the deep space via the lander radiator
- Asteroid environment, temperature of the ground, sun illumination





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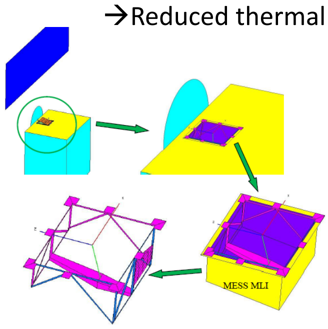
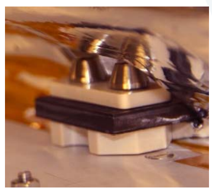
Main thermal strategy for MESS / S/C

Insulate as much as possible the lander and MESS from the main S/C in order to fulfill JAXA requirements for cruise „on board“ and „empty“ cases (for heat fluxes).

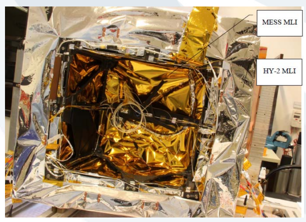
Strategy:

→MLI blanket to protect the S/C from external heat exchanges (+/-5W radiative)
→Reduced thermal coupling between MESS and S/C (+/-5W conductive)
→Reduced thermal coupling between MASCOT and MESS (+/-5W conductive)





Courtesy of DLR



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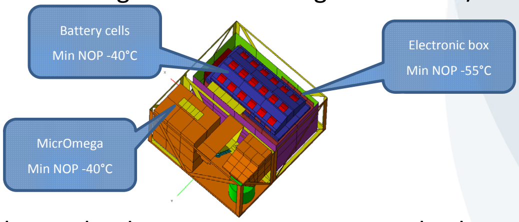
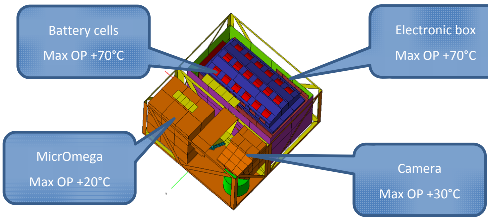
Main thermal strategy for MASCOT

Surviving temperatures must be guaranteed during hibernation/cruise mode.



On asteroid surface, the paylaods and subsystems must be kept within their minimal and maximum temperature limits to guarantee the success of the mission (2 asteroid „day-nights“, 15 hours).



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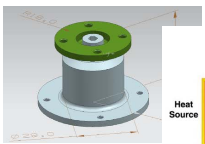
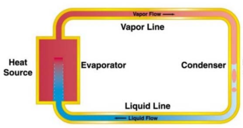
Main thermal strategy for MASCOT

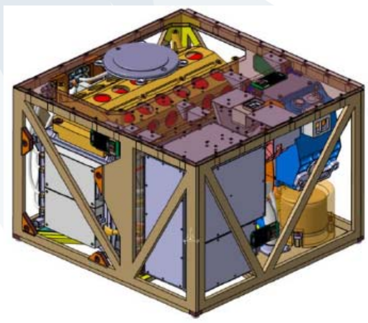
Two opposite requirements present for the two main mission phases, cruise and on-asteroid

→Technology for thermal control able to fulfill both the requirements

Possible solutions:







- Heat-switch
- Loop heat-pipes
- Variable conductance heat-pipes
- Evapoartive systems with storage of consumable liquib
- <u>„Constant“ conductance heat-pipes</u>

Trade-off in terms of mass, maturity of the technology, available space in the lander, simpler design, performances, eventual heating power by the main S/C, short lead time.

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Main thermal strategy for MASCOT

„Constant“ conductance heat-pipes (Heat Pipes Laboratory)

- No use of a reservoir
- No non condensable gas inside
- Independent from the value of the radiator face-sheet conductivity

→ Solution based on the selection of the work fluid in order to have a passive regualtion system and to fulfil:
  - Low heat transfer and small GL at temepratures below -20°C
  - Enough heat transfer and large GL above +20°C

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Main thermal strategy for MASCOT

„Constant“ conductance heat-pipes (Heat Pipes Laboratory)

→ Methanol used for MASCOT heat-pipes
→ Flight heirtage of combination copper+methanol/water/acetone
  → Fragment, 1980
  → Skala, 1983
  → Magion-4, 1995
  → Magion-5, 1996
→ Appearance of variable heat conductance properties, function of the operative temperature, for methanol and acetone
  → on-flight check on microsatellites Magion-4 and Magion-5

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Main thermal strategy for MASCOT

„Constant“ conductance heat-pipes (Heat Pipes Laboratory)

- Copper shell and capillary structure instead of aluminium:
  - Faster design and selection of wicks with different parameters
  - Flexibility for bending at small radii
- 8 different wick types manufactured and tested to fulfil the requirements, final result:
  - Porosity 85%
  - Sintered copper metal felt wick with artery effect
- Preparation of the materials and parts:
  - Methanol preliminary purified via degassing
  - Case and wick purification with solvents, vacuum, high T >950°C
  - Corrosion protection via nickel-plating

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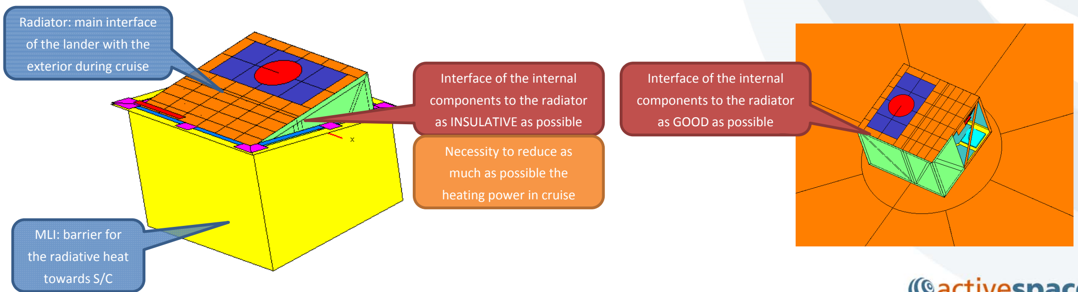
Thermal design

The whole thermal design is based on a very delicate equilibrium:

- surviving temperatures must be guaranteed during hibernation/cruise mode
  → thermal design with minimal heat exchange with the exterior
- distribution of the available heating power and temperature sensor in cruise
- on asteroid condition, the heat produced by the internal components must be rejected as efficiently as possible



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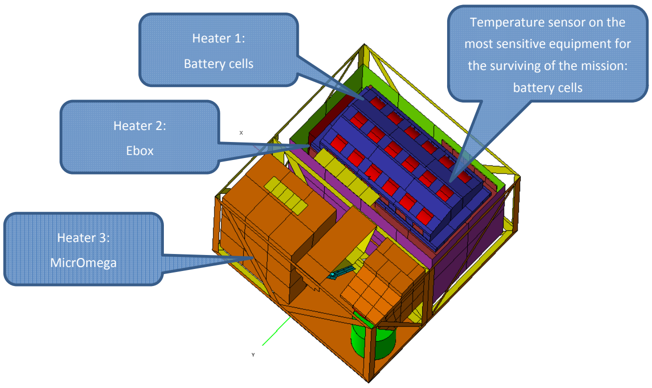
Thermal design

The thermal design of MASCOT is mainly **passive** (heaters only during cruise).

Heater line available from the S/C, but only **one temperature sensor usable**.



- Temperature of the other sensitive equipments is estimated by thermal model.
- Total heater power available: 10W with duty cycle < 50%.

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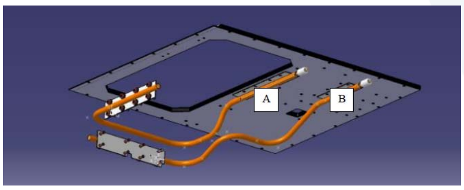
Thermal design

Heat-pipes model created in accordance with heat-pipes manufacturer and DLR expert; then tuned with the data obtained from thermal characterization of the prototypes.

Another requirements for cruise phases: commissioning/check-out: the system must be able to switch ON during cruise and operate a system check-out:
→ the heat-pipes must be able to change their behaviour **also** in cruise.



Courtesy of DLR

Two different designs of the heat-pipes (configuration constraints): MSCHPA and MSCHPB.

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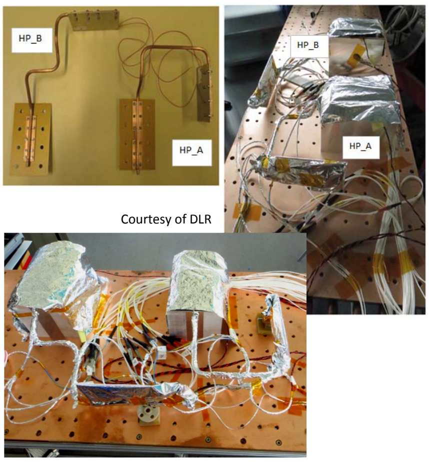
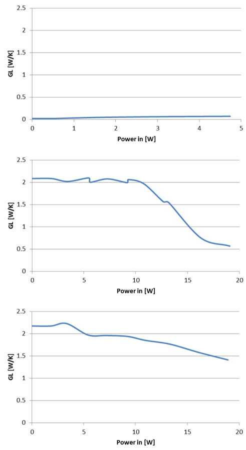
Thermal design

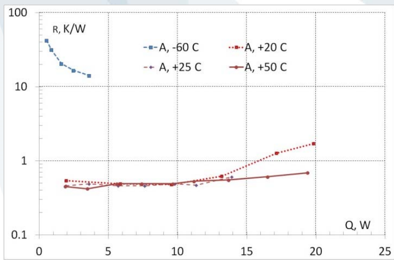
Heat-pipe thermal characterization



Courtesy of DLR



Different temperature levels (-60°C, +20°C, +50°C)



Partial results obtained for MSCHPA

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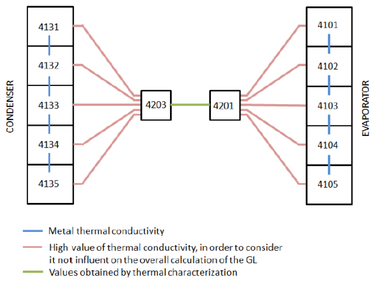
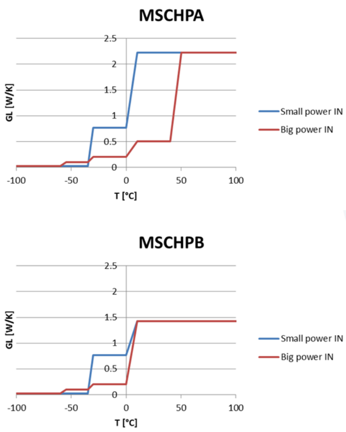
Thermal design

Heat-pipe modelling





P_HPA	[W]	<0.5	>0.5	<5.5	>5.5	<10	>10	independent
TCHPA [°C]	GLHPA [W/K]							
-100	0.022323							
-60	0.022323							
-55		0.022323	0.1					
-35		0.022323	0.1					
-30				0.769231	0.2			
0				0.769231	0.2			
10						2.222222	0.5	
40						2.222222	0.5	
50								2.222222
100								2.222222

P_HPB	[W]	<0.5	>0.5	<5.5	>5.5	<10	>10	independent
TCHPB [°C]	GLHPB [W/K]							
-100	0.02809							
-60	0.02809							
-55		0.02809	0.1					
-35		0.02809	0.1					
-30				0.769231	0.2			
0				0.769231	0.2			
10						1.428571	1.428571	
40						1.428571	1.428571	
50								1.428571
100								1.428571

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Vacuum chamber testing

Apart from the thermal characterization tests perfomed specifically on the heat-pipes, dedicated tests have been performed for the lander in cruise condition (on asteroid testing phase at the end of November 2013).

The S/C is represented by proper imitators for the same boundary conditions as in cruise phase.

Courtesy of DLR

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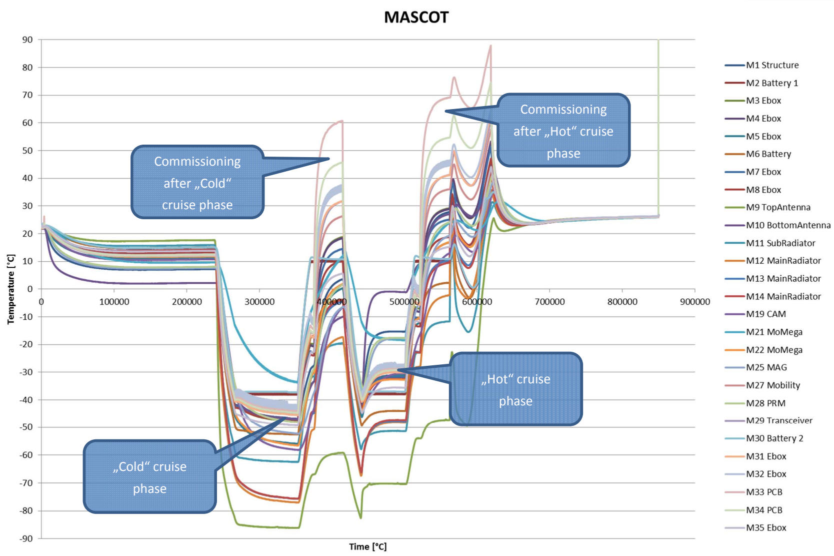
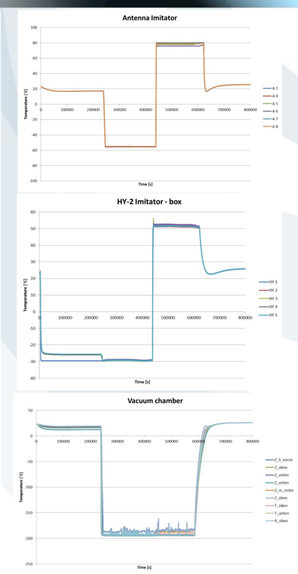
Vacuum chamber testing





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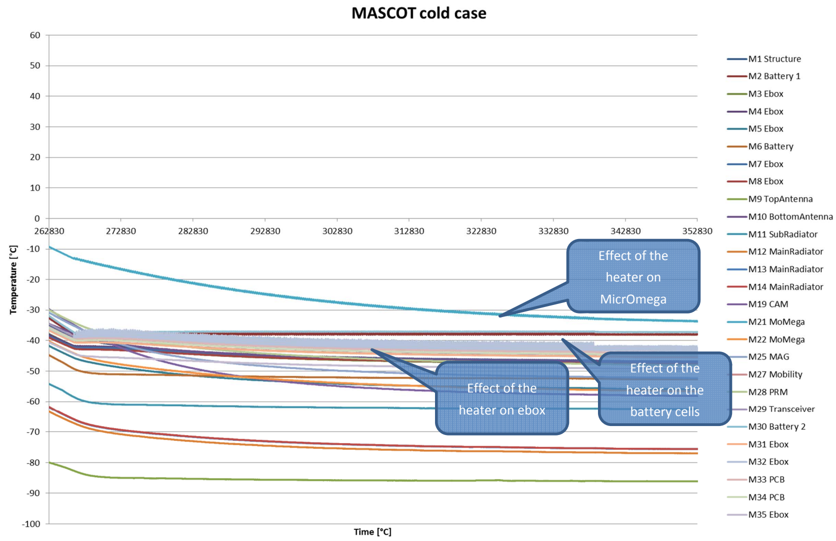
Vacuum chamber testing



All the components within their nonOP temperature requirements, as predicted by the thermal model

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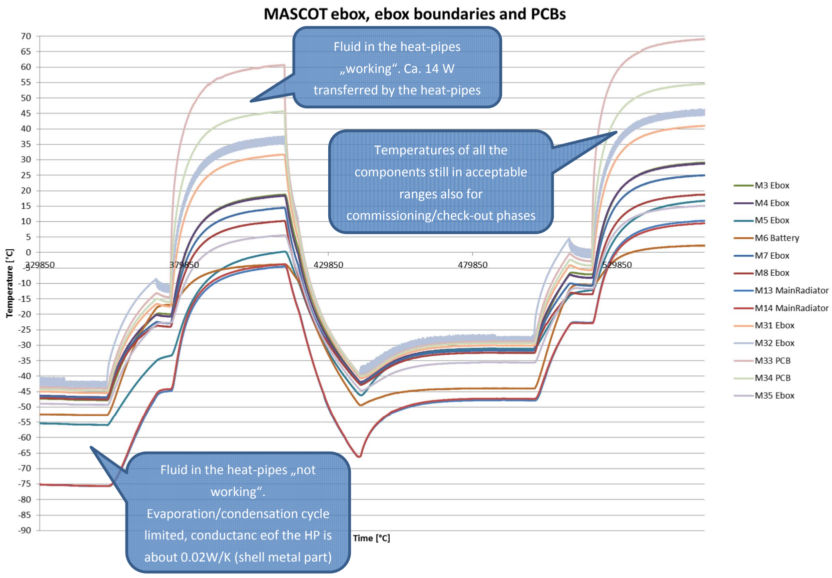
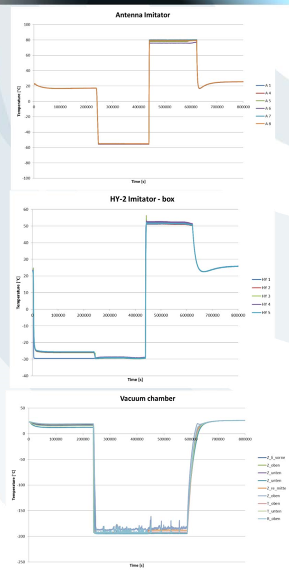
Vacuum chamber testing





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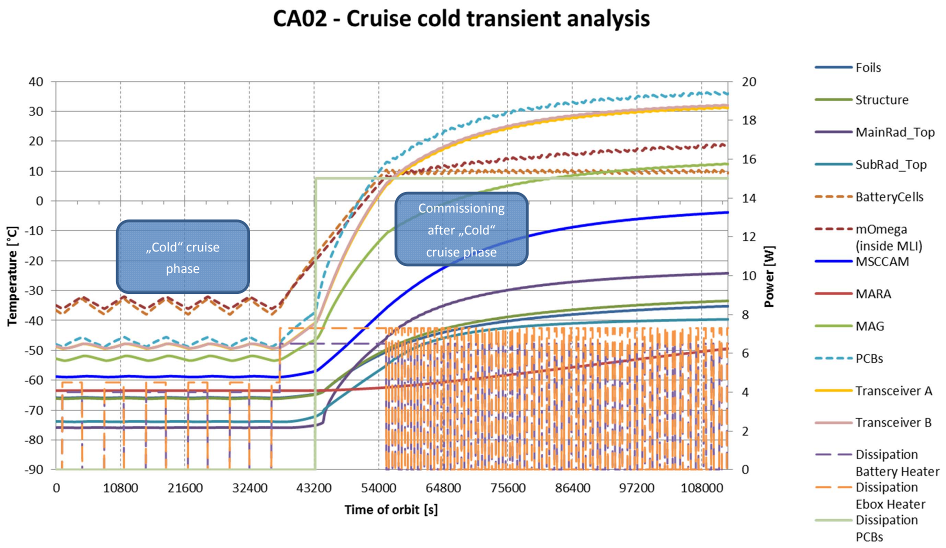
Thermal model results



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Thermal model results

Case	Heater power battery [W]	Heater power Ebox [W]	Heater power mOmega [W]	Total heaters power [W]	Duty cycle
Nominal cold cruise (52V HY-2)	8.3	9.3	3.0	20.6	21.6-23.4%
Safe cold cruise (36V HY-2)	4.0	4.5	1.5	10.0	45.1-48.7%
Nominal hot cruise (52V HY-2)	8.3	9.3	3.0	20.6	8.8-10.4%
Safe hot cruise (36V HY-2)	4.0	4.5	1.5	10.0	18.0-19.3%

Test results

Simulated case	Heater power battery [W]	Heater power Ebox [W]	Heater power mOmega [W]	Total heaters power [W]	Duty cycle
Continuous power COLD	1.95	2.14	0.68	4.77	-
Nominal cold cruise (52V HY-2)	-	-	-	-	23.2%
Safe cold cruise (36V HY-2)	-	-	-	-	47.7%
Continuous power HOT	0.8	0.25	0.85	1.9	-
Nominal hot cruise (52V HY-2)	-	-	-	-	9.2%
Safe hot cruise (36V HY-2)	-	-	-	-	19%

Model results

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Conclusions and future work

- The tests perfromed as cruise phase were succesful
- All the components are within the acceptable temperatures, as predicted by the model
- Heat exchange between S/C and lander as predicted by the model
- Duty cycles of the heaters within the limits and as predicted by the model
- „ON/OFF“ heat-pipes behaviour verified during cruise and commissioning/check-out simulated phases

- Heat-pipes are still to be verified for on asteroid conditions, with higher heat to be transferred and a last tuning phase about the performances may be necessary
- Improvements in the heat-pipes modelling foreseen taking into account new tests performed on QM HPs

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Thank you for the attention!

For further information, please visit our website

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