Appendix T

GENETIK+
Introducing genetic algorithm into thermal control development process

Guillaume Mas
(CNES, France)

Abstract

In 2014, GENETIK+, a tool that couples CNES genetic algorithm with SYSTEMA Software has been developed, showing great potential to help thermal engineers in their work.
In 2015, new functionnalities have been implemented to GENETIK+ to help analyzing physically the results of the optimization process such as visualization of the response surface and sensitivity analyses.
Thanks to these updates, GENETIK+ has been used on real application cases to show the interest of using optimization algorithm in each steps of thermal control development process.
From worst case analyses to in-flight model correlation, the results obtained with GENETIK+ open new possibilities for thermal engineers.
The objectives of the presentation are to:

- Present GENETIK+ functionalities
- Show the potential of introducing optimization algorithms into thermal control development process

GENETIK+

INTRODUCING GENETIC ALGORITHM INTO THERMAL CONTROL DEVELOPMENT PROCESS

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Marco SCARDINO (ISAE-SUPAERO Trainee)

03 – 04 November 2015

AGENDA

- CONTEXT OF THE STUDY
- GENETIK+ UPDATES OVERVIEW
- APPLICATION CASES
- PERSPECTIVES AND CONCLUSION

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CONTEXT OF THE STUDY

2014 creation of GENETIK+:

- GENETIK+ allows coupling between SYSTEMA and CNES algorithm GENETIK
- First tests on application cases show great possibilities
- 2014 work conclusions :
  - Full potential to investigate (model correlation, reduction, …)
  - Possibility to use GENETIK+ to explore the space of solution
  - Need post processing tool to understand optimisation process results

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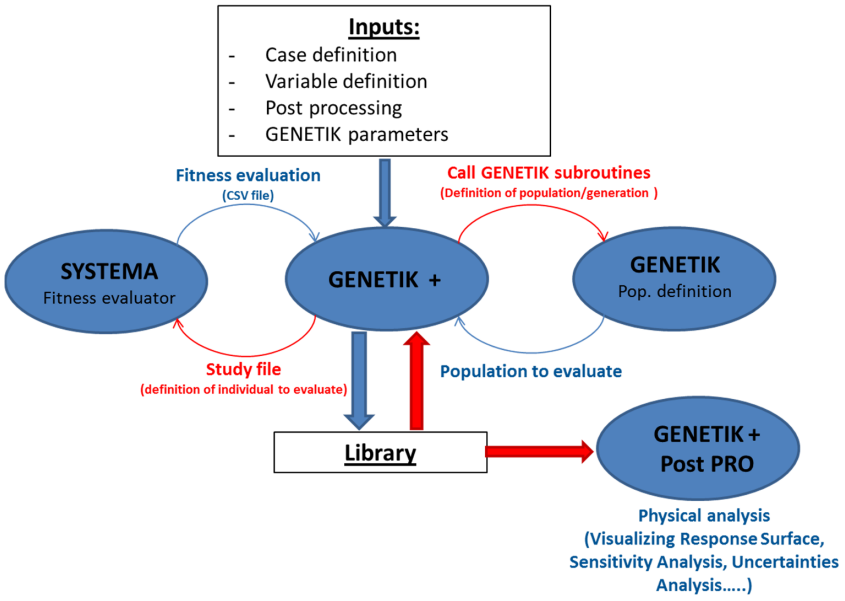
GENETIK+ UPDATES OVERVIEW

2015 – Improvement of GENETIK+:

- Increase of GENETIK+ possibilities:
  - Integration of Multi-cases optimization ➔ $Fitness_{TOT} = \sum_{i=1}^{N} \alpha_i Fitness_i$
    - model correlation on several cases (cold and hot configurations,…)
    - Research of optimum design for several orbital configurations
  - New user interface ➔ User friendly
    - GENETIK+ can be used by non experts in optimisation process
  - Increase of source code robustness and validation ➔ GENETIK+ able to be used in a real project context

GENETIK+ UPDATES OVERVIEW

2015 – Post processing Module – Library exploitation:

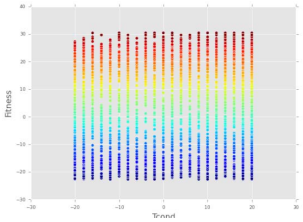


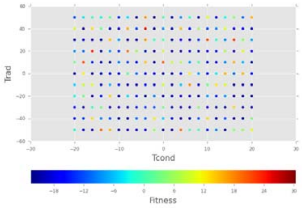
GENETIK+ UPDATES OVERVIEW

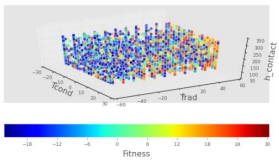
2015 – Post processing Module – Library exploitation:

Visualization for understanding optimization solutions ➔ Physical analysis

- Scatter plots – preliminary results analysis

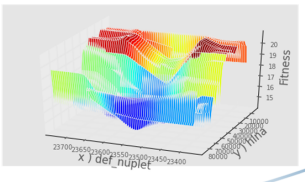






- Response surface Methodology – back to physics
  - ✦ 2 Interpolation Methods
    - » Kriging
    - » Radial Basis Function (RBF)
  - ✦ 2 Regression Methods
    - » Miltivariate Adaptative Regression Spline (MARS)
    - » Ordinary Least Squares (OLS)

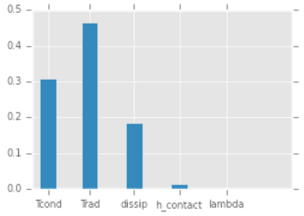
RBF



GENETIK+ UPDATES OVERVIEW

2015 – Post processing Module – Library exploitation:

- Sensitivity analyses on parameters
  - Integration of SOBOL Index method → Global sensitivity analysis on parameters
    - » First order impact of each parameters on thermal model behaviour
    - » Coupled impact of parameters on thermal model behaviour



- Parameters uncertainty analysis
  - Find the ΔT max. to cover all the parameters uncertainties
  - Link with parameters distribution law to determine ΔT for a given probability

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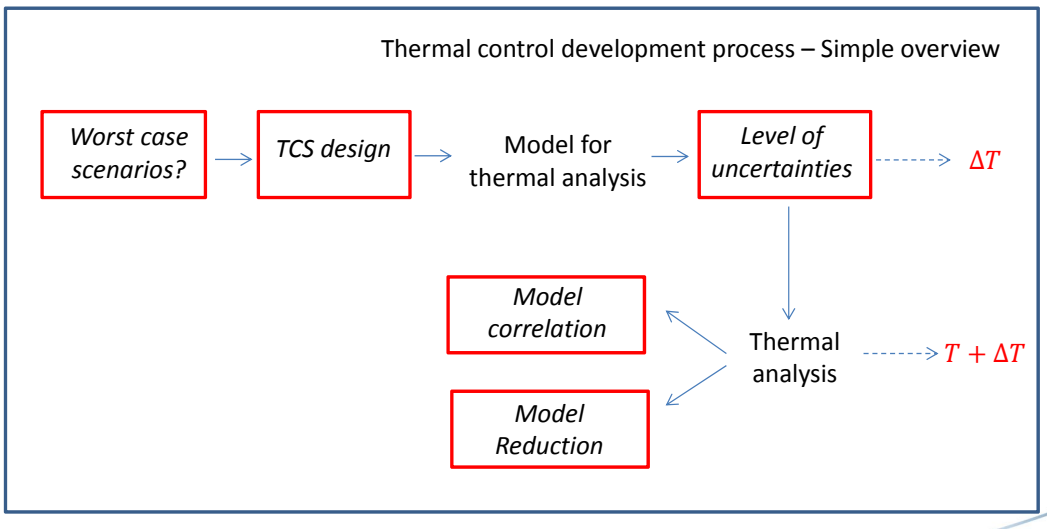
APPLICATION CASES

Optimisation algorithm - On which step of thermal control development?



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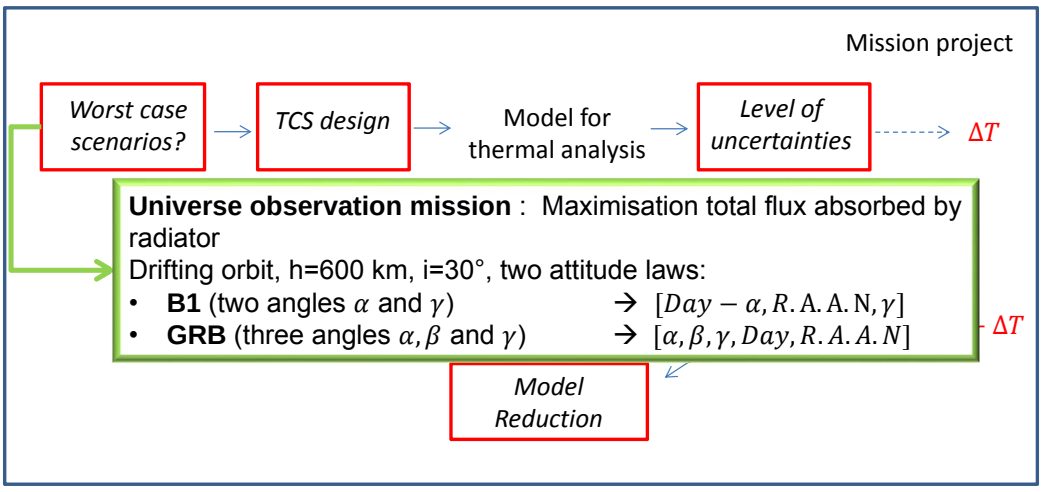
APPLICATION CASES

Optimisation algorithm – Worst cases definition of complex missions:



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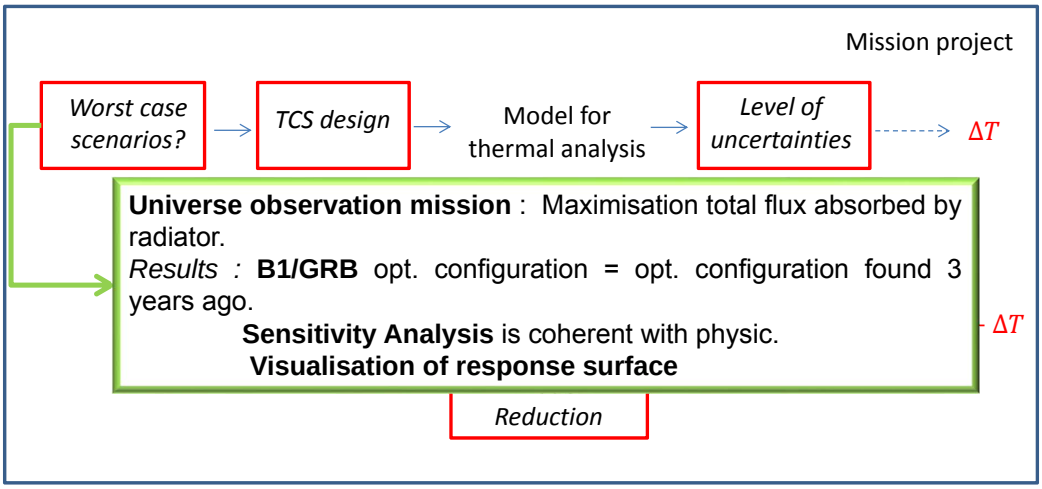
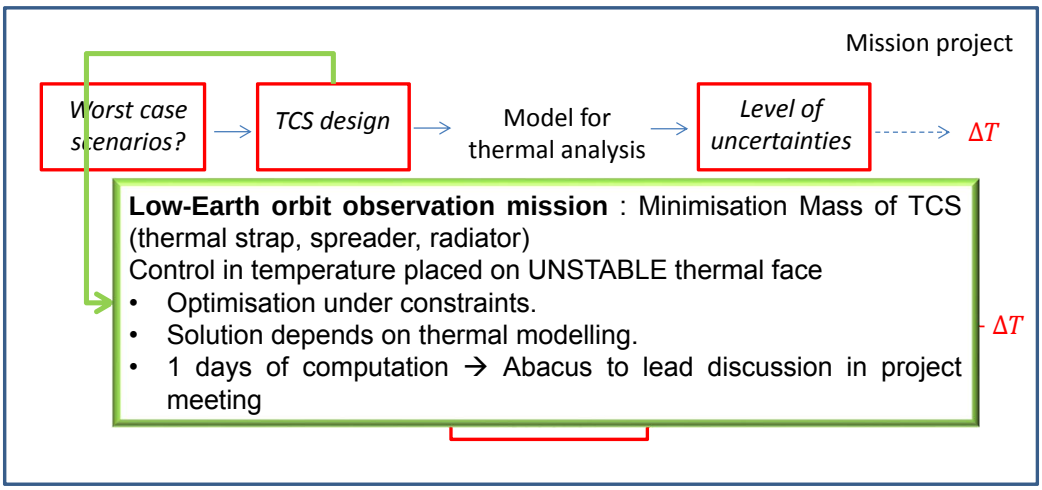
APPLICATION CASES

Optimisation algorithm - Worst cases definition of complex missions:



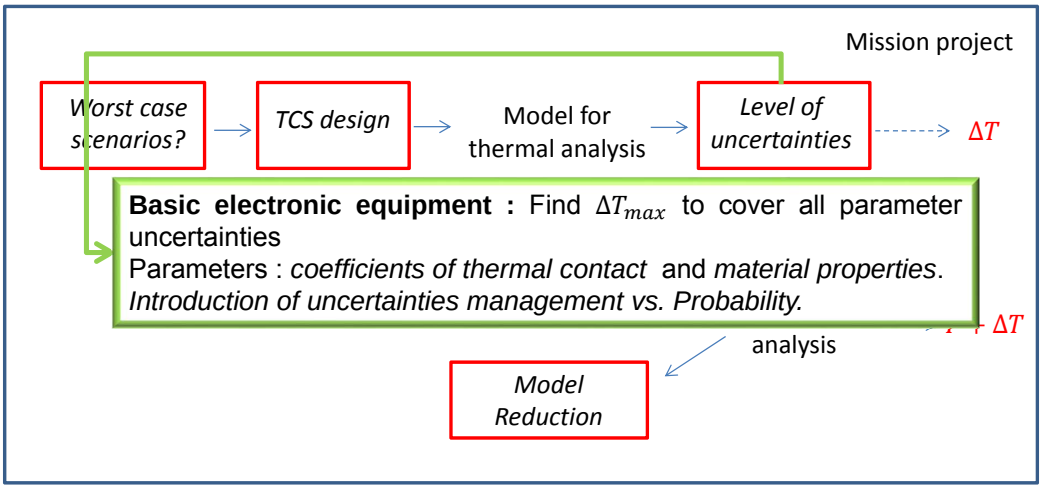
APPLICATION CASES

Optimisation algorithm – Thermal control design definition:



APPLICATION CASES

Optimisation algorithm – Uncertainties calculation:



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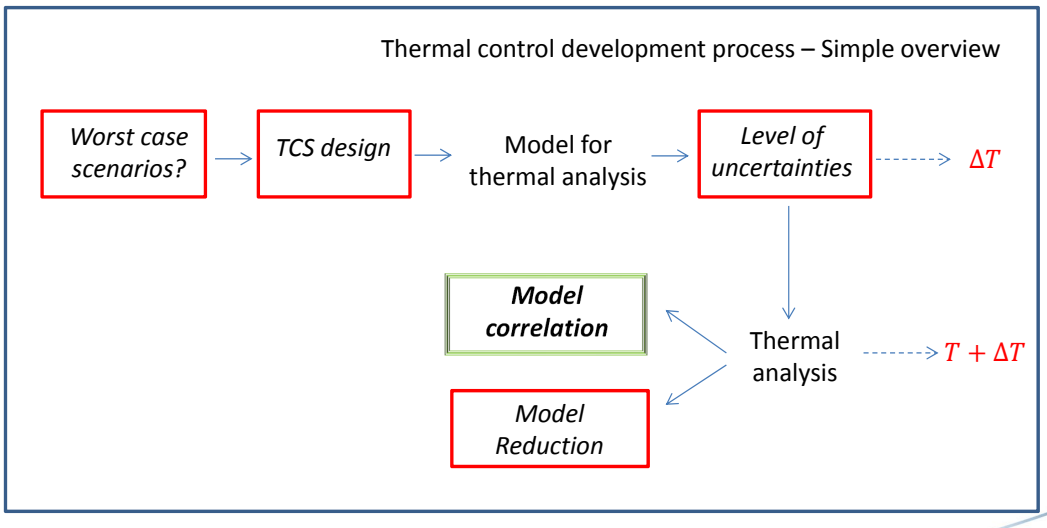
APPLICATION CASES

Focus on thermal model correlation process:



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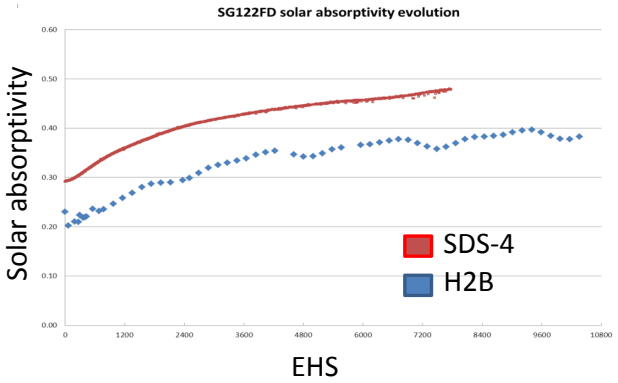
APPLICATION CASES

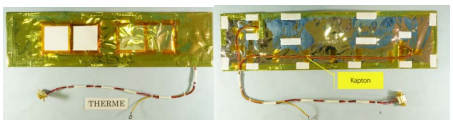
THERME Experiment - Thermal Model Correlation on flight data:

- Characterise ageing of spatial coating
  - From maximal temperature reached in orbit, find α of coating → radiative equilibrium:

$$\phi_{sol}(\alpha, C_s, \beta) + \phi_{alb}(\alpha, C_s, C_a) + \phi_{Earth}(\varepsilon, C_t) - \phi_{IR}(\varepsilon, T) = 0$$

  - On SDS-4, offset compared to previous in-flight data → Samples not isolated from spacecraft



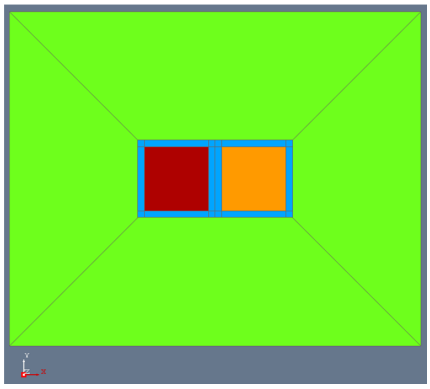


	On ground	In Orbit (first value)
PSBN	0,16	0,3
SG122FD	0,21	0,29

APPLICATION CASES

THERME Experiment - Thermal Model Correlation on flight data:

- "Realistic" samples modelling
  - Thermal leaks: harness-samples (via simple contact and via adhesive tape), MLI-samples (adhesive tape), samples-temperature sensor and harness-SC panel.
    → **5 contact coefficients as parameters**.



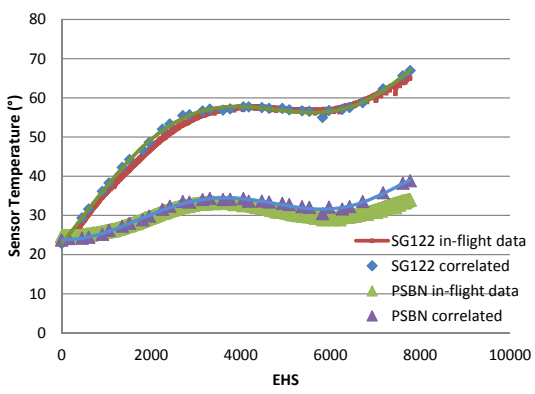
- Correlation process:
  - First approach: Begin of Life (BOL) and End of Life (EOL).
    - BOL properties known / EOL properties unknown
  - Second approach: Begin of Life (BOL).

First approach	Second approach
$BOL\ \Delta T_{max} \approx 1.76°C$	$BOL\ \Delta T_{max} \approx 0.0095°C$
$EOL\ \Delta T_{max} \approx 4.96°C$ ($\Delta\alpha_{max} \approx 0.02$)	–

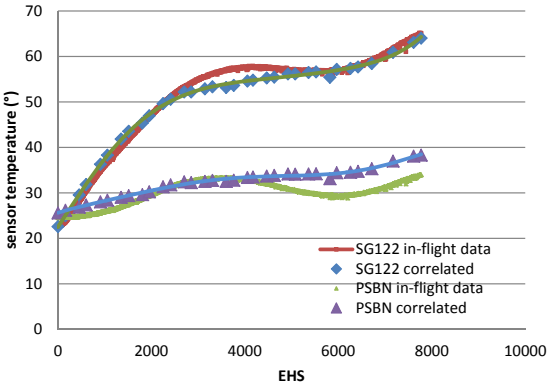
APPLICATION CASES

THERME Experiment - Thermal Model Correlation on flight data:

- Sensor temperature evolution – comparison of the 2 approaches
  - BOL/EOL approach able to represent whole thermal model behaviour
  - BOL approach perfect representation in early mission phase



BOL - EOL



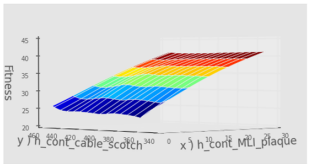
BOL

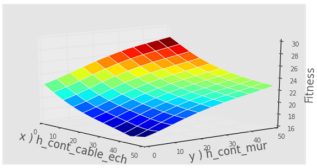
APPLICATION CASES

THERME Experiment - Thermal Model Correlation on flight data:

- Sensitivity Analysis – Improve THERME design ?
  - Parameters play different roles on two samples, due to their **different thermal conductivity**.
    - » PSBN (conductive substrate) most influential parameters: *MLI-sample* and *sample-harness via tape*
    - » SG122 (Kapton substrate) most influential parameters: *harness-wall* and *sample-harness*

PBSN



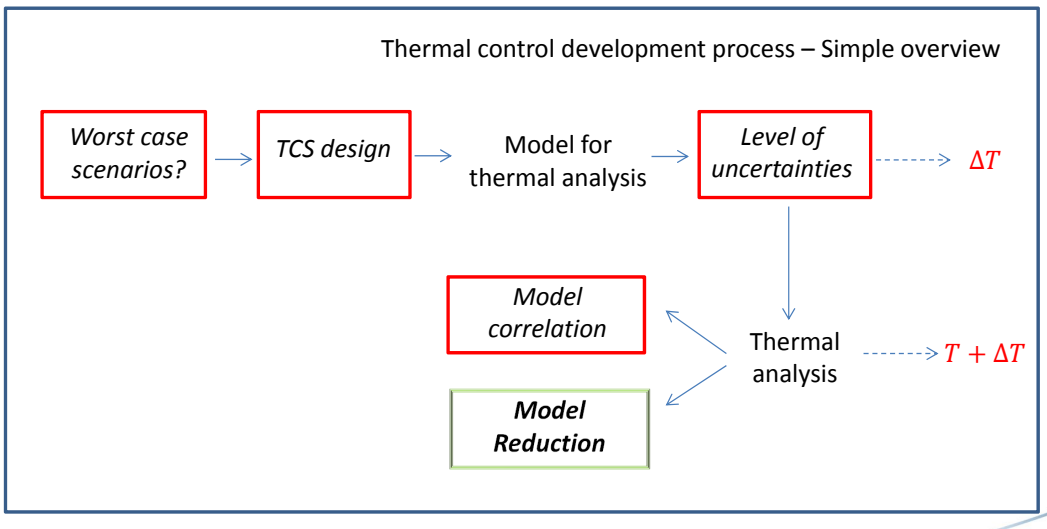


SG122

- New analytic formula for telemetry exploitation
  - Use of GENETIK+ to explore space of solution $\alpha=f(T_{wall},\phi_{sol},\phi_{Earth})$
  - Use of Post processing module to extract Response surface and its equation

APPLICATION CASES

Focus on thermal model reduction processes



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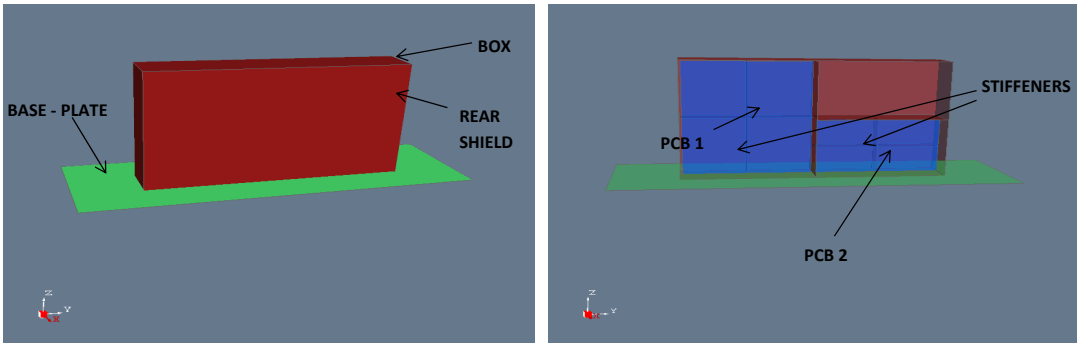
APPLICATION CASES

Thermal model reduction – Electronic equipment example:

- Classical electronic unit :
  - Composed by: *Printed Circuit Board, internal structure, external structure and harnesses*
  - Two sinks : 2 conductive sink (panel and *external harness*) and radiative sink



≈ 500 Thermal nodes

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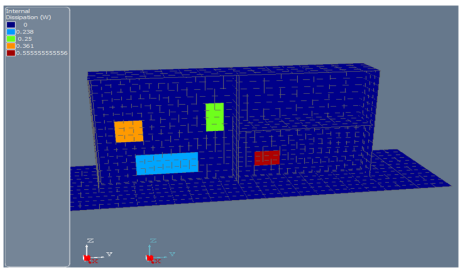
APPLICATION CASES

Thermal model reduction – Electronic equipment example:

- 3 working modes: *ON*, *OFF* and *Stand-by.*



Mode	PCB1 (W)	PCB2 (W)
ON	10,25	5
OFF	0	0
Stand-by	0	5

- 2 configurations: both conductive sinks have the same temperature

Case	T conductive (°)	T radiative (°)	Mode
Hot	50	50	ON
Cold	-10	0	OFF

APPLICATION CASES

Thermal model reduction – Electronic equipment example:

- Two reduction methods:
  1. **"Classical" method : 9 thermal nodes (against ≈ 500 of detailed model)**
  - ✦ Objective of GENETIK+: find *conductive couplings* among thermal nodes for the *two configurations* ➔ **22 parameters** (= 22 conductive couplings)

ΔT ⟶ Hot case : $\Delta T_{max} = 3{,}63°$ Cold case: $\Delta T_{max} = 0{,}59°$ $\Delta T < 5°$ ✓

Interface heat flows ⟶

Case	Heat flow	Reduced (W)	Detailed (W)	Δ (W)
Hot	Rad.	-2,829	1,994	-0,834
	Cond.	-12,421	-13,225	0,834
Cold	Rad.	3,212	3,243	0,031
	Cond.	-3,212	-3,243	-0,031

$\Delta\Phi < 1W$ ✓

- ✦ Conclusions:
  - » Optimisation with high number of variables
  - » GENETIK+ allows to reduce thermal model (calculation time 24h)

APPLICATION CASES

Thermal model reduction – Electronic equipment example:

- Two reduction methods:
  2. **Analytical reduction: Find an analytical formula of thermal model Temperature**

- Steps of the analytical reduction method:
  - Select *TRPs* (nodal description of reduced model)
  - Build *Response Surface* with OLS in *Steady-State*, using GENETIK+ data points
    → $T_{TRP} = f(External\ cond, mode)$
  - Find *transient response*

- Application case – Electronic equipment:
  - Steady-State Results: 3 TRPs, OLS second degree
  - Transient Response:
    Hyp: Evolution on time as linear first-order system, *system MISO (Multi Inputs – Single Output)*

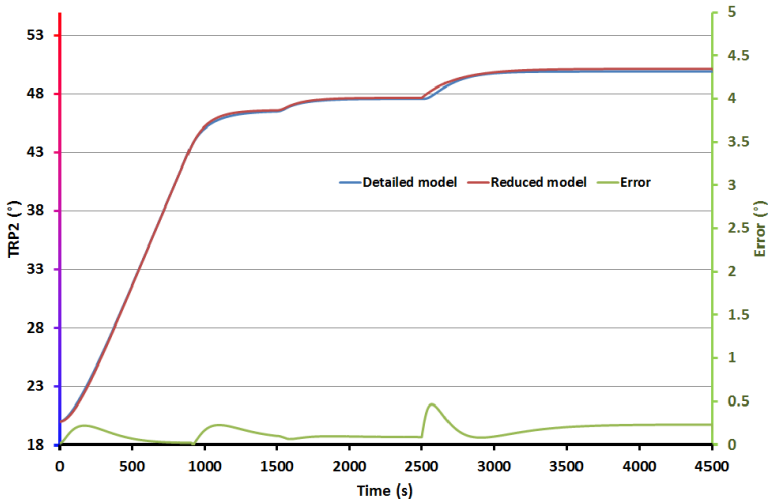
$$TRP(t) = \sum_i TRP(t-1)_i + (TRP(\infty)_i - TRP(t-1)_i) \cdot (1 - e^{-t/\tau_i})$$

with $i \in [T\_cond, T\_rad, mode]$

APPLICATION CASES

Thermal model reduction – Electronic equipment example:

- Results analysis:
  - Transient Response: **$2°/min$ T_cond , $10°/min$ T_rad** and **ON after convergence**



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PERSPECTIVES AND CONCLUSION

Conclusions:

- The new GENETIK+ version:
  - Optimisation on all steps of TCS definition process.
  - High performance with high number of parameters.
- GENETIK+ Post PRO.
  - *Response Surface* allows visualization of results and introduction of a new reduction method.
  - *Sensitivity Analysis* is physical coherent → Most influential and non influential parameters.
- Principal actor is still Thermal engineer.
- Time reduction for model correlation, model reduction,…….

Future works:

- Parallel coding → reduce calculation time
- Near Real Time model correlation → Extend analytical reduction approach
- Optimisation MultiCriteria