Appendix F

Thermo-electrical Detailed Analysis

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(Astrium SAS, Toulouse, France)

Abstract

An important part of the power system engineering work is deeply linked to the thermal aspects of the various power components like batteries and solar panels. With the help of an internally developed coupled thermo-electrical solver, previously untried detailed analyses on various power systems were performed in Astrium, stemming interesting results.
The wide-spread Thermisol thermal solver in the Systema software suite was extended with a power add-on. The principle was to add an electrical layer through dedicated nodes complementary to the existing thermal nodes. It allowed the power users to code electrical systems and user components on the same environment as the existing Thermisol codes.
This new solver was applied for a full satellite power system analysis. The coupling with the thermal aspect allowed the re-use of thermal files and designs to prepare the analysis. An electrical layer composed of the user components of a classical power system (battery, solar array, power regulation and distribution) was added to perform fully coupled thermo-electrical analysis, adding higher accuracy to the battery, solar array and regulation modeling.
In the frame of an ESA study to investigate on solar array thermal / electrical imbalance in power systems equipped with MPPT, in-depth modeling of solar panels were also performed on both electrical and thermal aspects. This allowed cell level analysis for very fine phenomenon like the local cell gradients created by dissipation of back panel diodes and harness during orbit cycles, sensitivity studies to default or accurate local and global shadowing analyses.
The solver was also included in a software loop with coupled SAS/MPPT hardware for validation testing.

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Thermo-electrical detailed analysis

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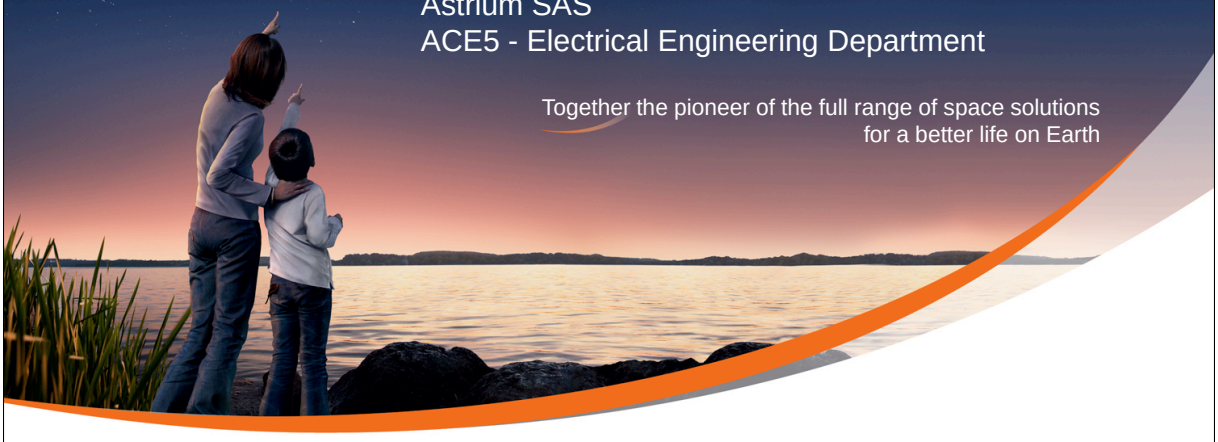

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General introduction

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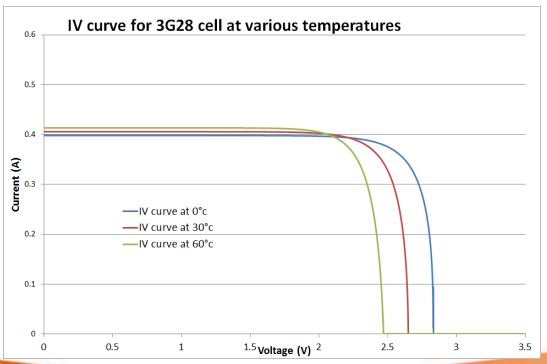
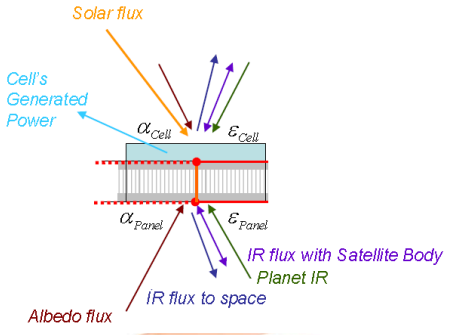
Why did we need a thermo-electrical dedicated solver ?

- Important thermal dependency of power components
  - Solar array, batteries, power electronics…
  - Exemple on the solar array component



Electrical aspect
I = function (V, T)



Thermal aspect
T = function (I, V, …)

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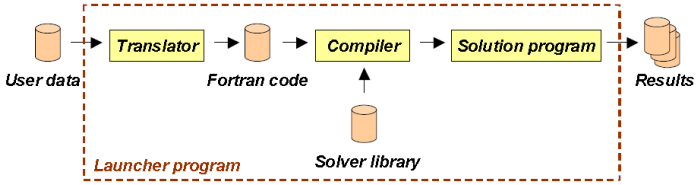
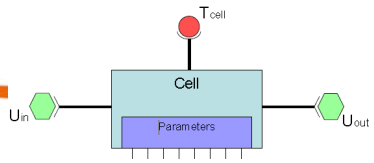
Solver architecture

- Based on THERMISOL, the Astrium thermal solver (from SYSTEMA)
  - Package includes translator (or pre-processor), computation library and dedicated solution program
  - Equivalent to using Thermisol as development environment



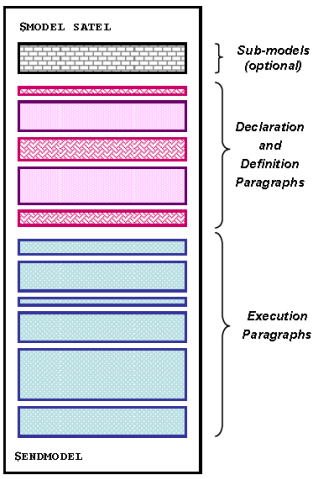
- A Power add-on layer was added, with new electrical nodes in addition to thermal nodes already in place



Example of a solar array cell component

Solver architecture

- Some architecture advantages :
  - User components (importation of dedicated power models)
  - High performance – number of nodes, algorithms for thermo-electrical coupled calculation
  - Direct link with Systema suite for flexibility
  - Re-use of existing thermal analyses
  - A lot of freedom (ex: parametrical analysis)
- Architecture disadvantages :
  - No solver graphical interface (but in development)
  - Fortran coding and some thermal solver background needed for complex analysis



Typical code structure

Application to power system analysis

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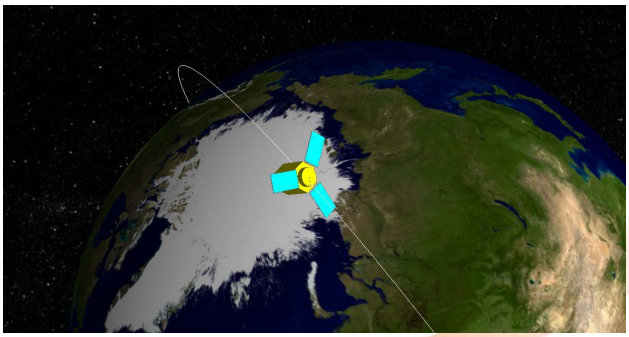
Application to power system analysis

- Aim : to perform an energy budget on a typical LEO satellite mission
  - Outputs : Solar array and battery behaviour over one day of mission



- Inputs :
  - Geometrical model
  - Orbit and kinematics
  - Thermal data on solar array and satellite external surfaces
  - Electrical data on satellite power system

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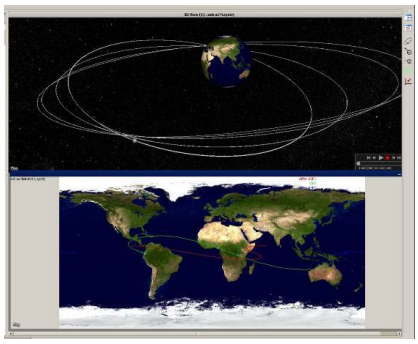
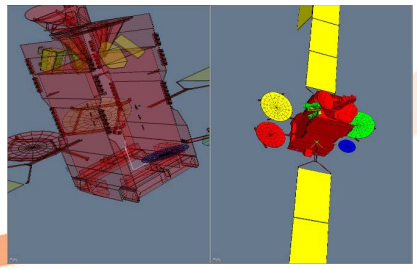
Simulation process – Systema / Thermica part

- Geometrical modeling in Systema software
- Kinematics and orbit input

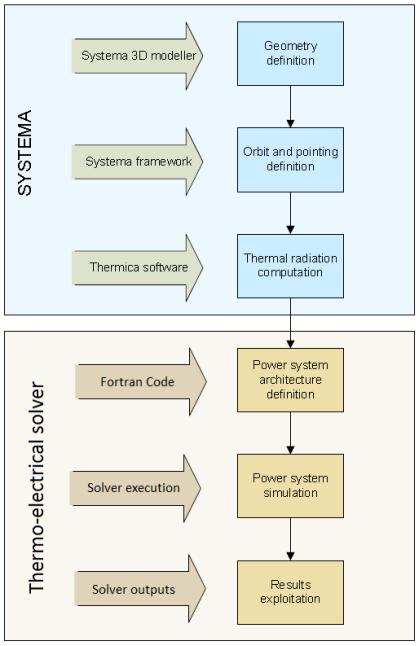


- Simulation to get required outputs
  - Albedo, IR and solar fluxes
  - Thermal fluxes
  - Radiative Couplings between surfaces

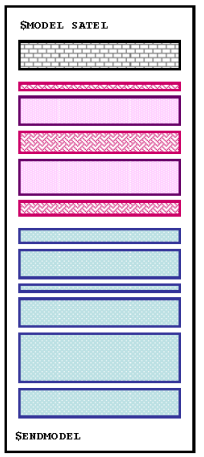


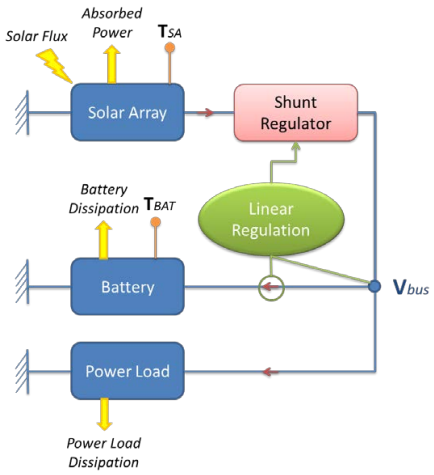
Electrical analysis

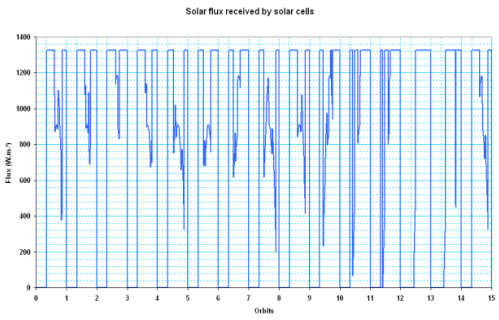
- The thermal data and fluxes are injected into the electrical modeling
  - User components of different electrical blocks
  - Links with fluxes from Systema simulation
- The thermo-electrical solver is applied on a chosen timeframe
  - Dedicated $CONTROLS and $EXECUTION routines



Thermo-electrical analysis







Fluxes and inputs from SYSTEMA

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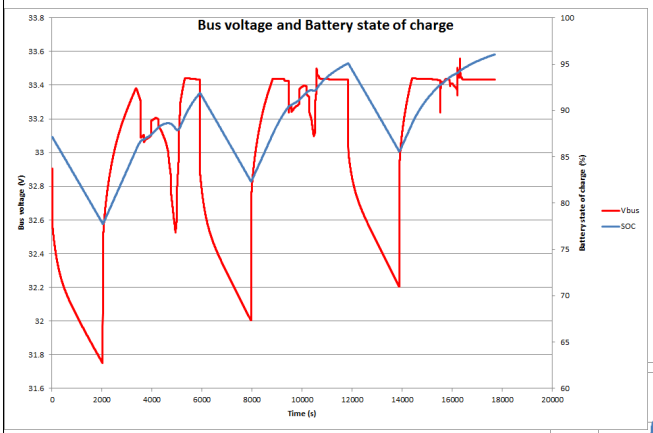
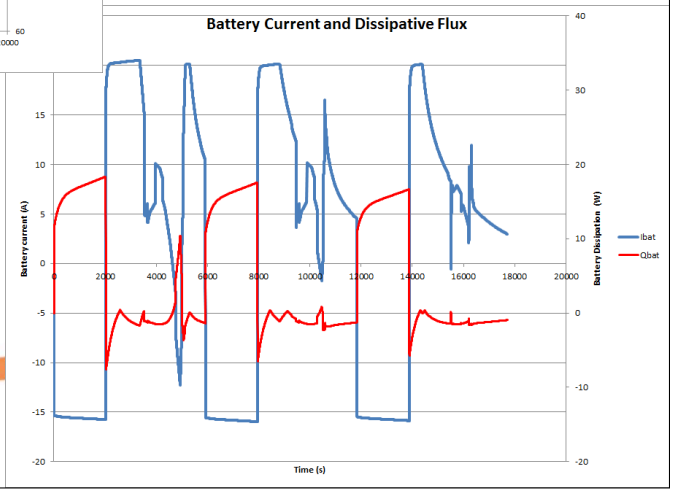
Power System Analysis Results



Battery state of charge (in blue), Battery bus voltage (in red).



Battery current (in blue), Battery dissipation(in red).

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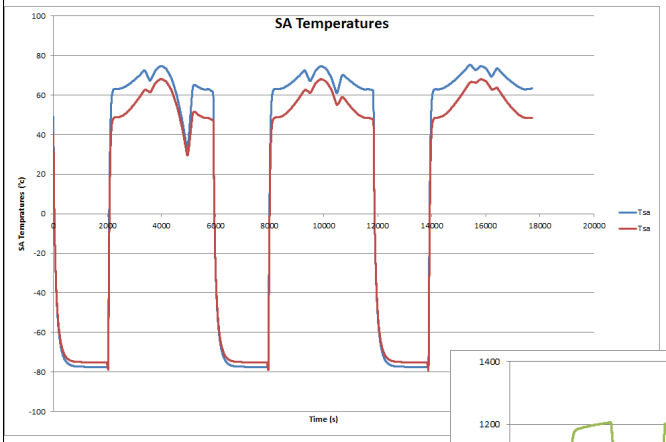
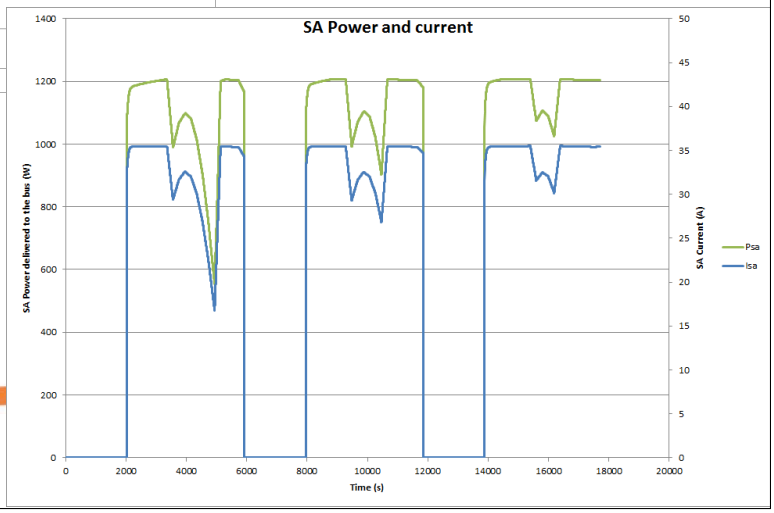
Power System Analysis Results



Solar Array temperatures (front SA in blue, Back SA in red).



Solar Array Power (in blue), Solar array current (in red).

Conclusion for Power analysis

- Possibility to simulate whole power systems with thermo-electrical components
- High flexibility at every level
  - Mission and thermal inputs modifications
  - User components
  - Execution, controls and outputs

Application to Solar Array thermo-electrical analysis

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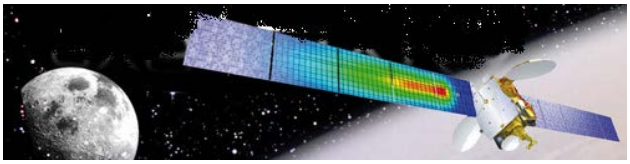
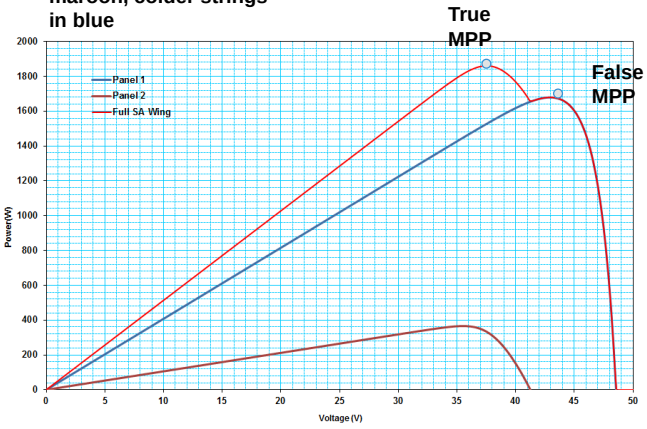
ESA study context

- ESA contract « Investigations on Solar Array thermal / electrical imbalance in power systems equipped with Maximum Power Point Tracker »
- Objective : to study the electrical / thermal imbalance phenomenon on the solar arrays



Hotter strings in maroon, colder strings in blue



- Loss of power
- Possible lock of the power system on a stable false operating voltage

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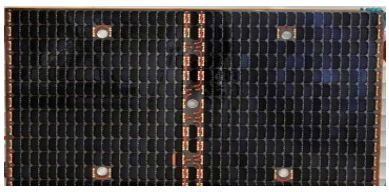
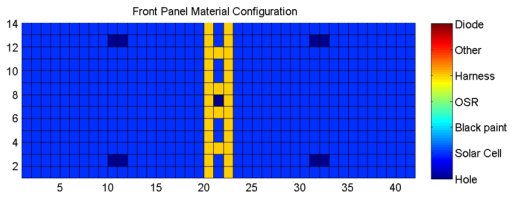
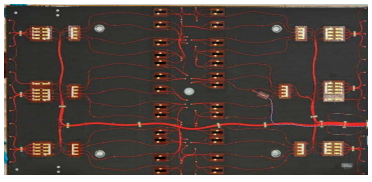
Development of a new solver

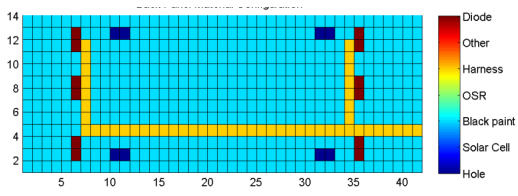
- A lot of factors come into play for this phenomenon
- Need for very extensive modelling :
  - High number of thermal / electrical nodes
  - High level of details on thermal effects (panel layout, effect of view factors)
  - Flexible environmental modelling : both LEO missions and scientific extraplanetary missions
  - High level of coding flexibility : various cell models to be studied, multiple thermal effects to simulate like misalignment, radiations, shadowing…

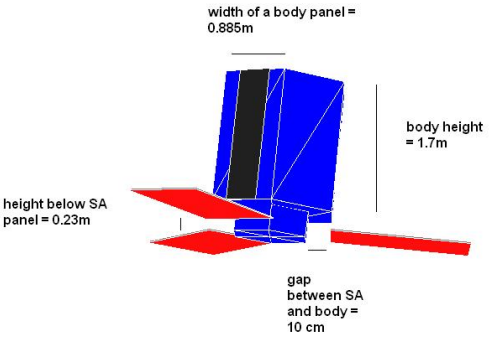
Detailed modelling on solar panel



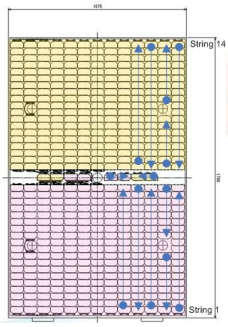






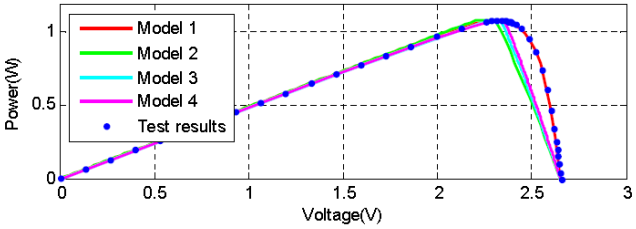


- Geometrical modelling of the body for view factor effects
- Very accurate modelling of panels layout (front and back) – including harness, diodes, and realistic stringing



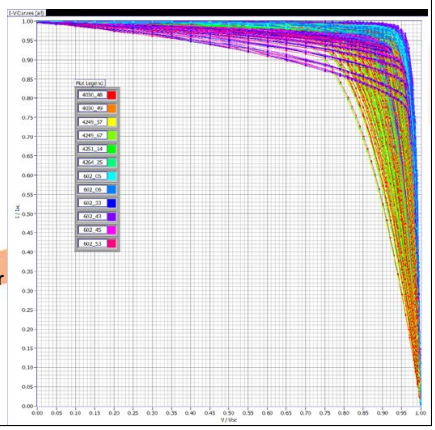
Cell models inputs

- Various classic cell models identified



PV curves of modelled solar cells (3G28 type) compared to test data

- Need to implement innovative cell model through data interpolation
  - Based on extensive test data from another part of the study



IV curves for various temperatures, solar fluxes and radiation levels for tested cells

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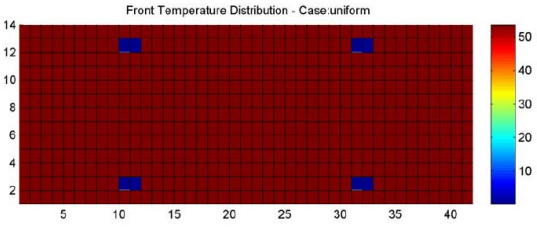
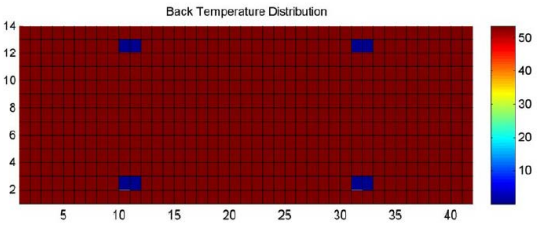
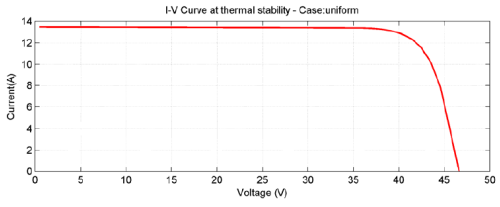
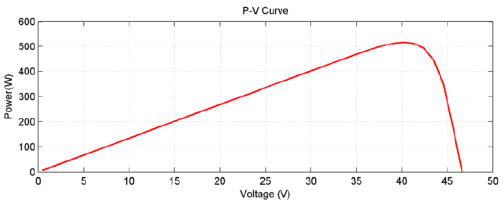
Examples on various detailed analyses LEO case in sunlight – uniform temperature





Temperature distribution – uniform temperature at 53.6°c





SA power characteristics

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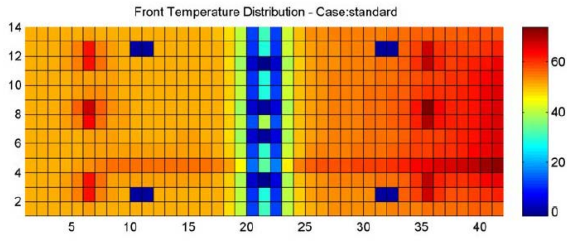
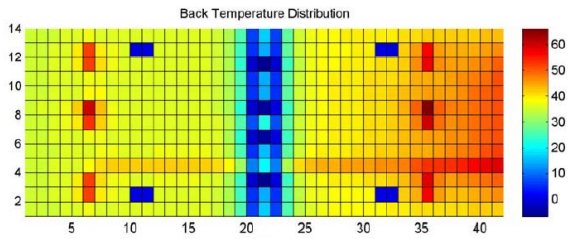
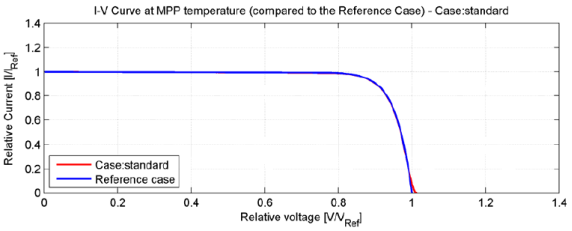
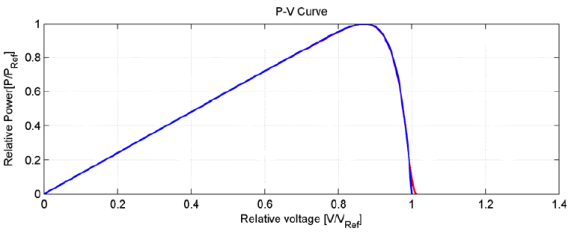
Examples on various detailed analyses
LEO case in sunlight - standard simulation





Temperature distribution



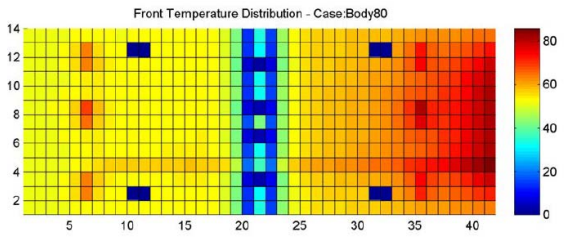


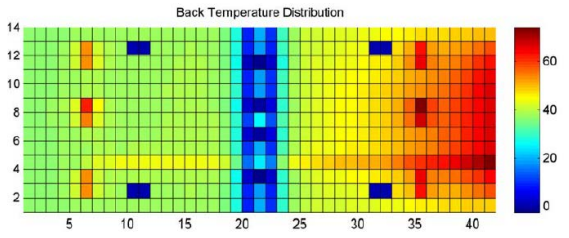
SA power characteristics compared to uniform case

	Cell Temperature (°c)	Vmp (mV)	Voc (mV)	Icc (mA)	Imp (mA)
Min value	28.12	2047.51	2368.65	508.81	486.54
Max value	73.79	2335.05	2646.19	539.80	516.25
Avg value	53.53	2175.06	2491.77	532.37	509.13

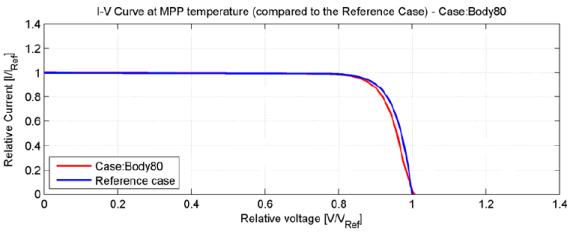
Summary of major Cell parameters

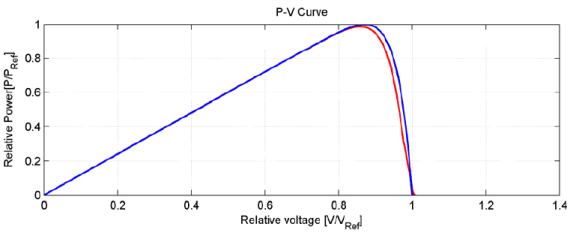
Examples on various detailed analyses
LEO case in sunlight - very hot body case





Temperature distribution



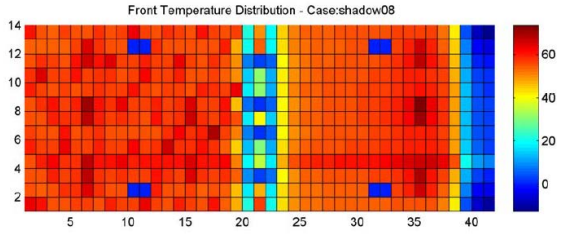


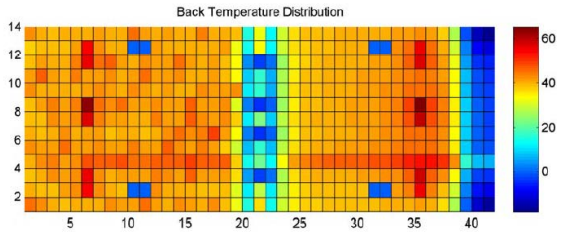
SA power characteristics compared to uniform case

	Cell Temperature (°c)	Vmp (mV)	Voc (mV)	Icc (mA)	Imp (mA)
Min value	31.53	1972.13	2295.90	509.48	487.18
Max value	85.75	2313.57	2625.46	541.03	517.43
Avg value	57.44	2150.48	2468.04	533.30	510.02

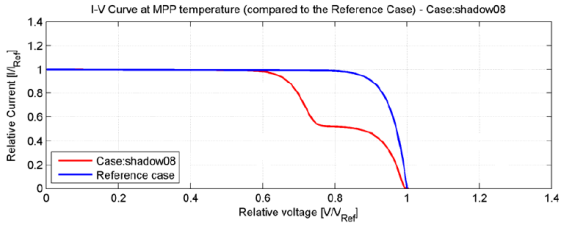
Summary of major Cell parameters

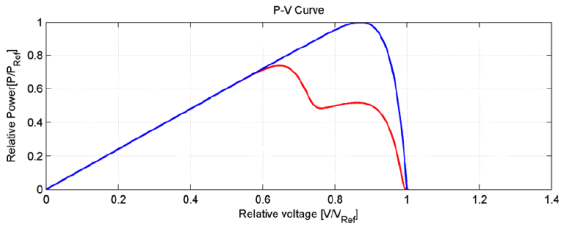
Examples on various detailed analyses
LEO case in sunlight - shadowing of 8% of SA





Temperature distribution



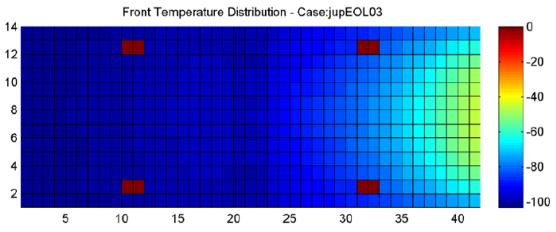


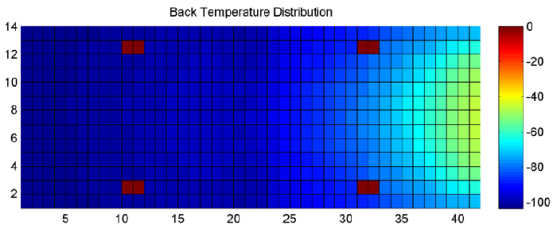
SA power characteristics compared to uniform case

	Cell Temperature (°c)	Vmp (mV)	Voc (mV)	Icc (mA)	Imp (mA)
Min value	-12.70	2048.96	2370.06	494.64	472.95
Max value	73.56	2592.39	2894.58	540.63	517.04
Avg value	52.15	2183.75	2500.15	532.06	508.83

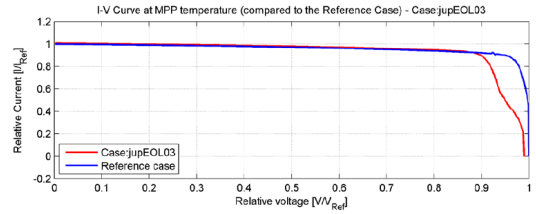
Table 7.1.26-2 - Summary of major Cell parameters

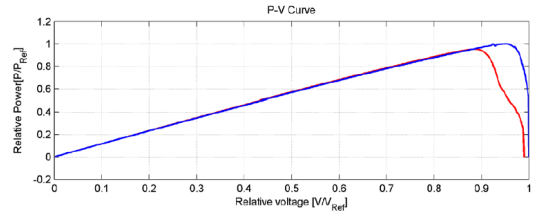
Examples on various detailed analyses
Jupiter case – Europa flyby





Temperature distribution





SA power characteristics compared to uniform case

	Cell Temperature (°c)
Min value	-103.38
Max value	-46.49
Avg value	-89.42

Table 6.2.3-2 - Summary of major Cell parameters

Conclusion

- A new tool for thermo-electrical analyses
  - Validated and used in Astrium Toulouse
  - Two licenses available at ESA (see G. Beaufils)
- Interesting perks
  - Full link with Systema suite, high number of nodes, user components, re-use of existing thermal analyses, parametric analyses…
- Opening a new range of detailed analyses
  - For Solar Array / Battery / Power electronics / RFCS components
  - Multiple applications for current science missions (JUICE, BEPI, Rovers…)

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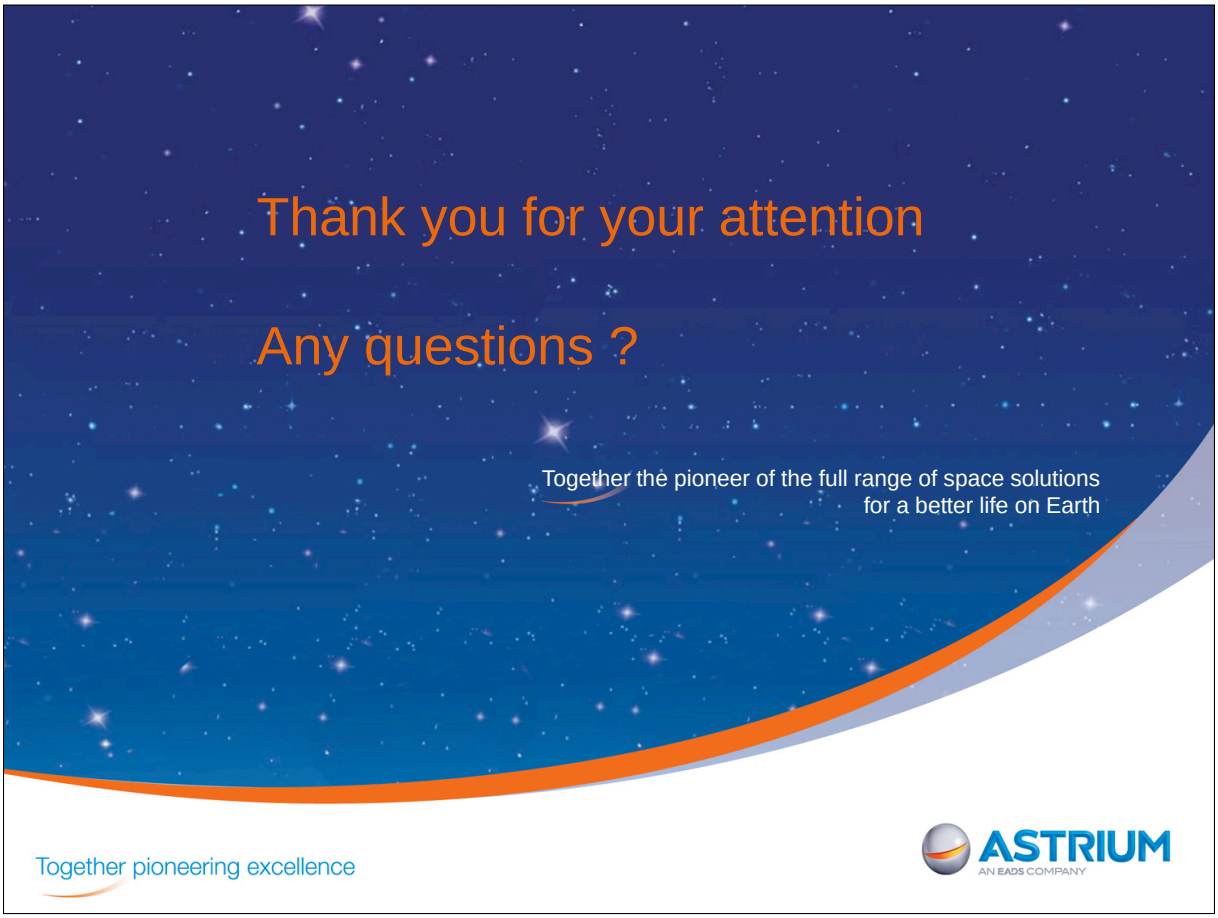
Thank you for your attention
Any questions ?
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