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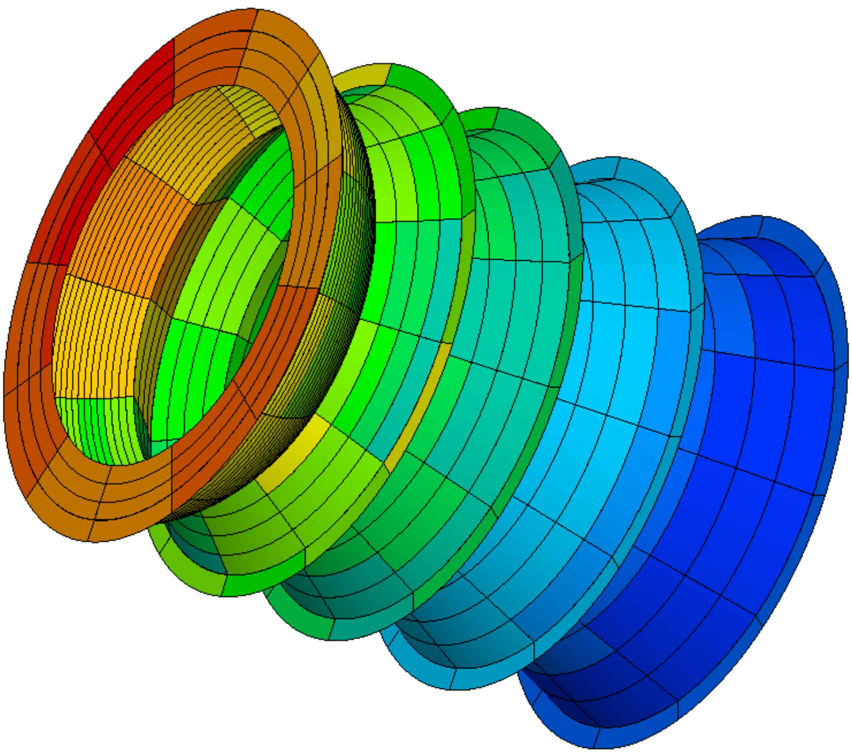

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Abstract

This document contains the minutes of the 23rd European Workshop on Thermal and ECLS Software held at ESA/ESTEC, Noordwijk, The Netherlands on 6–7 October 2009. It is intended to reflect all of the additional comments and questions of the participants. In this way, progress (past and future) can be monitored and the views of the user community represented. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.
Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under 'Workshops'.

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Programme Day 1

9:00 Registration

9:45 **Welcome and introduction**

Harrie Rooijackers (ESA/ESTEC, The Netherlands)

10:00 **Progress of the CIGAL2 distribution project**

Thierry Basset & Jean-Paul Dudon (Thales Alenia Space, France)
François Brunetti (DOREA, France)

10:30 **Heat shield thermal sensitivity analysis**

Matteo Gorlani (Blue Engineering, Italy)
Valter Perotto (Thales Alenia Space, Italy)

11:00 Coffee break in the Foyer

11:30 **TMRT** — A thermal model reduction tool

Mathieu Bernard (EADS Astrium, France)
Thierry Basset (Thales Alenia Space, France)
Sandrine Leroy & François Brunetti (DOREA, France)
James Etchells (ESA/ESTEC, The Netherlands)

12:00 **GENETIK** — Genetic algorithm for the sizing cases research

Hélène Pasquier & Stéphane Clouet (CNES, France)

12:30 **SYSTEMA**

Marc Baucher (EADS Astrium, France)

13:00 Lunch in the ESTEC Restaurant

14:00 **THERMICA – THERMISOL**

Timothée Soriano (EADS Astrium, France)

14:30 **ESATAN Thermal Modelling Suite** — Product developments

Henri Brouquet (ITP-UK, United Kingdom)

15:00 **ESATAN Thermal Modelling Suite** — Demonstration

Henri Brouquet (ITP-UK, United Kingdom)

15:30 Coffee break in the Foyer

16:00 **Methods for solving linearized networks in satellite thermal analysis**

Martin Altenburg & Johannes Burkhardt (EADS Astrium, Germany)

16:30 **Herschel experience on modelling and verification of active heater control**

Savino De Palo & Marco Compassi (ThalesAlenia Space, Italy)
Claudio Damasio (ESA/ESTEC, The Netherlands)

17:00 **Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit**

Simone Del Togno & Gabriele Messina (DLR, Germany)

17:30 Social Gathering in the Foyer

19:30 Dinner in *Het Zuiderbad*

Programme Day 2

9:00 **Thermal design for an asteroidal lander**
Riccardo Nadalini (Active Space Technologies, Germany)

9:30 **TCDT** — Distribution and maintenance
Andrea Tosetto & Matteo Gorlani (Blue Engineering, Italy)
Harrie Rooijackers (ESA/ESTEC, The Netherlands)

10:00 **A thermal/structural mapping tool for thermo-elastic distortion analysis**
Daniel Wild (EADS Astrium, United Kingdom)

10:30 **Updates to the SINAS tool for mapping of lumped parameter temperatures onto a structural FE models**
Simon Martin & James Etchells & Simon Appel (ESA/ESTEC, The Netherlands)

11:00 Coffee break in the Foyer

11:30 **ESATAP 2.0.0** — Status and evolution of developments dedicated to thermal end users
Alain Fagot & François Brunetti (DOREA, France)
Harrie Rooijackers & Hans Peter de Koning (ESA/ESTEC, The Netherlands)

12:00 **Final validation phases of the IITAS project for Industrial Implementation of STEP-TAS**
Eric Lebègue (CSTB, France)
Hans Peter de Koning (ESA/ESTEC, The Netherlands)

12:30 **Mathematical models for the Columbus engineering support team**
Savino De Palo & Gaetana Bufano & Albina Quaranta (ThalesAlenia Space, Italy)
Marco Bruno (Sofiter System Engineering, Italy)

13:00 Lunch in the ESTEC Restaurant

14:00 **On orbit performance of the EuTEF thermal control system** — 1 Year on board the ISS
Alberto Franzoso & Marco Molina & Paolo Ruzza & F. Tominetti & M. Grilli (Carlo Gavazzi Space, Italy)

14:30 Closure

Day 1

Tuesday 6th October 2009

1.1 Welcome and introduction

H. Rooijackers (ESA/ESTEC) welcomed everyone, outlined the main goals of the workshop, and reminded everyone about the 2010 ICES conference to be held in Barcelona. (See appendix A)

1.2 Progress of the CIGAL2 distribution project

JP. Dudon (Thales Alenia Space) described the developments that had been made to the `CIGAL2` package since it had been released to the community at the previous workshop. He outlined the changes already implemented in the Radiative and Conductive modules, and the future use of a third party meshing package. F. Brunetti (DOREA) then gave a video demonstration of the new pre- and post-processing features. (See appendix B)
T. Soriano (EADS Astrium) asked whether the Radiative module took specularity into account. JP. Dudon told him that specularity was handled.
S. Price (Astrium UK) had noticed that the presentation had featured geostationary spacecraft, and asked whether it was also possible to simulate non-Earth missions, such as to Mars or Mercury, or to have complex trajectories. JP. Dudon replied that the "orbitography" graphical tool could only show Earth orbiting satellites, but the rest of the software was able to handle more complex missions. Only Earth-based missions were implemented in the "orbitography" module.

1.3 Heat shield thermal sensitivity analysis

M. Gorlani (Blue Engineering) presented the basic requirements for the Solar Orbiter mission, and the challenges presented by the heat shield analysis, and how stochastic techniques had been applied to identify interesting cases. He showed that the results obtained by using percentile bounds were not the same as those obtained for $\mu \pm 3\sigma$ bounds on a Gaussian distribution, even though both cases covered a 99.7% confidence interval of probable outcomes. (See appendix C)
There were no questions.

1.4 TMRT — A thermal model reduction tool

M. Bernard (Astrium) presented the rationale behind the development of a common thermal model reduction tool. Thales Alenia Space and Astrium already had in-house tools but were not in a position to commercialise them. With support from the Agencies, both companies wanted to harmonise the tools that they already used internally and with their sub-contractors. He outlined the model reduction process, and described the method of designating nodes to be kept, to be grouped or to be suppressed and how this was expressed in the matrix equations. S. Leroy (DOREA) then gave a live demonstration of using the TMRT to reduce a simple 10-node model into a 3-node model. (See appendix D)

HP. de Koning (ESA/ESTEC) commented that from his own experience, it was very easy to make mistakes during model reduction, and asked whether there were any diagnostics in the software to check for correct configuration. S. Leroy confirmed that there were diagnostic checks in the software. M. Bernard said that there were many consistency checks made between the detailed and the reduced models, and that any diagnostic messages were output to file, with a summary.

HP. de Koning asked whether the system was able to handle sub-models. M. Bernard admitted that there were currently restrictions on the use of sub-models. The module importing the model only handled top-level models, and there were limits on the use of node variables. The model reduction used matrix inversion, based on numerical node numbers, and was not set up to handle symbolic node representation. To simplify the development, the matrix needed to contain simple node numbers only. The $CONDUCTORS blocks were also rewritten based on a purely numerical basis.

D. Battaglia (Thales Alenia Space) asked whether, in the frame of the checks made on the compatibility of the detailed and reduced models, there was any correlation of the heat loads. M. Bernard replied that the same format was used for the output produced by both the detailed and the reduced models, so the user could import both the detailed and the reduced results into post-processing tools for comparison. The experience with telecom satellites had been that the difference between the detailed and reduced models was less than 1°C for the nodes of interest.

S. Vey (ESA/ESTEC) had seen that the presentation showed a display of the reduced geometrical model, and asked whether there was a way to export the reduced GMM corresponding to more complex models. M. Bernard explained that for complex models in ESARAD or THERMICA it was necessary to create groups manually and to simplify the complexity of the geometry. This functionality was not implemented in the TMRT. The TMRT was intended to be used to produce a reduced list of couplings, and to transform node numbers from the detailed model into equivalent node numbers in the reduced model, and not to produce a simplified geometry.

1.5 GENETIK — Genetic algorithm for the sizing cases research

H. Pasquier (CNES) described the basic principles of genetic algorithms, and how they could be applied to thermal design, and how they had been integrated into the analysis pipeline that included CONDOR, GAETAN, and ESATAN. (See appendix E)

M. Gorlani (Blue Engineering) asked how many cases had been run for the analysis campaign shown in the presentation. H. Pasquier said that the thermal chain was run 1000 times, so a lot of calculations were needed during the simulations. They had set up a library in order to keep all of the results in memory, make sure that the same run was not done twice, and therefore optimise the number of calculations.

M. Gorlani asked whether the simulation was used only to find the worst cases, or whether it was used to help with design optimisation. H. Pasquier answered that it had only been used to find the worst cases for a satellite mission.

HP. de Koning (ESA/ESTEC) asked whether the method was parallelisable. H. Pasquier confirmed that it was, but had not started implementation.

HP. de Koning asked whether the algorithm could also be used for optimisation based on extreme cases, or on hot and cold gradients. H. Pasquier said that it was possible to do lots of things with GAETAN, so it depended on what criteria were defined. The parameter of interest was defined at the start of each run. There was a single objective per run.
JP. Dudon (Thales Alenia Space) asked whether the new version of the software would allow users to choose the number of mutations carried over into the next generation. H. Pasquier said that for mutations there would only be one choice, but for the crossover selection the user would be able to specify more. Even with GENETIK it was important to have a user who understood the system, and who could therefore choose the evolution parameters appropriately.
P. Zevenbergen (Dutch Space) asked whether it was possible to encounter convergence problems using genetic algorithms. H. Pasquier said that it was always possible, yes, but that was what they were trying to avoid by developing the protocol. The idea was to do a very big simulation, and to have a large amount of data, and then see whether changing certain parameters helped the system to converge faster. The user needed to keep a critical view on the protocol.
G. Jahn (Astrium GmbH) commented that it was possible for there to be a local optimum, and this could be avoided if the charts could show a complete spectrum between red and blue, rather than simply good child and bad child. Using the complete spectrum could save one step in the protocol. H. Pasquier admitted that they only had two colours in the GAETAN software and could therefore only show whether a case was good or bad.

1.6 SYSTEMA

M. Baucher (EADS Astrium) described the recent release history of SYSTEMA, and showed how the geometry, kinematics and trajectory aspects of a mission could be changed independently of each other to build up the overall analysis. This avoided most of the recalculation required in a more sequential system. SYSTEMA had recently implemented a means of introducing symbolic variables into the models, which could then be changed as required for different analysis cases. (See appendix F)
T. Tirolien (ESA/ESTEC) asked about the new variable feature, and how it could be used in parametric studies: was there a way to define a parameter with a range and step value? M. Baucher said that the user could now define a parameter in the SYSTEMA models, and then run THERMICA and THERMISOL using particular values. T. Tirolien supposed that it was therefore necessary to provide a script to set the parameter and run the script as part of the analysis chain. He asked whether this parametric capability applied to any parameter, such as specularity. M. Baucher said that it would be possible to vary the specularity. They were still learning how to make the best use of this new capability, and would be looking at how to provide this as a step in the analysis chain. Any value that could be edited in SYSTEMA could be replaced by such a parameter.
M. Gorlani (Blue Engineering) asked about the strategy for using these parameters. Were they simply a means of providing a difference in settings in related models, or did they provide something more? M. Baucher answered that today, in order to modify an element, the user needed to edit the input of configuration files. The parameter feature allowed the user to specify a symbolic value that could be changed without changing the models. T. Soriano (EADS Astrium) explained that the goal was to allow the user to be able to specify a set of values in a file, and run the model many times without needing to go back into the system or edit files. The idea was to have a parametric mission with a set of parametric values so there would be no need to re-edit the system every time. M. Gorlani understood that the user would be able to provide a file containing parameter values, but would not be able to specify range or step values. T. Soriano said that the

user could use external tools to generate these values, and then run the parameter cases without needing to change the modules. M. Gorlani said that he could just provide these values in the input files. T. Soriano explained that the problem with editing directly in the input files, or generating the input files, was that it required tools which knew about the syntax of the input files. By having a simple parameter file containing just a list of parameter names and values, there was no longer any dependency on a specific input format for a specific version of the tools. Therefore the user would not need to change any local tools when moving from SYSTEMA version 4.2.2 to version 4.2.3.
HP. de Koning (ESA/ESTEC) asked whether POSTHER was included as part of SYSTEMA. T. Soriano said that it was provided with THERMISOL.
HP. de Koning wanted to avoid any confusion in the user community, and emphasized that STEP-NRF was included within STEP-TAS, and was not a separate format, so the standard should only be referred to as "STEP-TAS".
T. Tirolien had noticed that the demonstration had shown the camera being locked onto both the satellite and the Earth, and wanted to know whether it was possible to set the camera to look from the Earth to the spacecraft, or from the Sun to the spacecraft. M. Baucher said that these camera modes were not available in the current version, but would be available in version 4.3.4.

1.7 THERMICA – THERMISOL

T. Soriano (EADS Astrium) presented some new features in the latest versions of THERMICA and THERMISOL. THERMICA now offered the possibility of reporting and setting threshold values for percentage line sum error to improve the accuracy of the ray tracing. Changes had also been made to the conductive coupling calculations. THERMISOL now provided more extensions to the MORTRAN language to make life easier for the user. To allow easier sharing of models, a new converter was included that could generate "classical" MORTRAN that would be acceptable by both ESATAN and THERMISOL. (See appendix G)
HP. de Koning (ESA/ESTEC) asked for some clarification of the ray tracing accuracy improvements. He asked whether they applied only to the REF calculations. He had understood that one method worked on the standard deviation, and the other worked on the line sum. T. Soriano explained that when you exported the radiative couplings, the sum of those couplings, a function of area and emissivity, should be equal to 1.0. In reality, you wouldn't find that because a "symmetrification" was applied to each pair of REFs to account for the limited number of rays used. The new method checked for this symmetry and fired more rays as required. HP. de Koning observed that it was possible to have a line sum of one, but still to have errors in the REFs. T. Soriano agreed, and said that was the reason why the standard deviation method step was always run as part of the accuracy control. HP. de Koning asked whether the new method also applied to fluxes. T. Soriano replied that there was no "symmetrification" available for the flux calculations, so the new method could not be used for fluxes.

1.8 ESATAN Thermal Modelling Suite — Product developments

H. Brouquet (ITP Engines UK) explained that this was the first presentation since the aerospace engineering group had been taken over by its new parent, and showed the company's "family tree" and where it fitted in the ITP worldwide presence. He then summarised the product changes that had been announced at the previous workshop, and what had been achieved in the two releases

since then. A lot of work had gone into transforming the old radiative analysis GUI into a more general Workbench that could be used with or without the space-based mission environment, and which therefore also replaced the old PcESATAN. (See appendix H)
M. Gorlani (Blue Engineering) commented that during the Solar Orbiter analysis campaign, they had tried to build a fully parameterized GMM, but had encountered problems when loading and saving from the GUI where the parameters had been replaced by numerical values. H. Brouquet explained that it wasn't currently possible to transfer parameter variables from the GMM into the ESATAN file, and that they were output as numeric values. M. Gorlani stressed that the problem was that numerical values, and not parameter variables, were stored when the ESARAD model was saved from the Workbench, rather than when generating the ESATAN file. H. Brouquet replied that in theory all of the parameter variables should be retained when saving the GMM from the Workbench, but not when using the export model function.
M. Gorlani said that they had also experienced problems due to differences in the Linux version they were using and asked how the developers intended to support Linux. H. Brouquet said that the current policy was to support SuSE version 10 in the development environment, including testing and validation. Where possible, they would try to install different versions of Linux as virtual machines to reflect users' installations. For example, they had recently done some testing on CentOS-5.3 on 64-bit systems because that was what was in use at ESA. They would be trying to support more if needed. M. Gorlani said that A. Tosetto (Blue Engineering) would mention emulations of different systems during his presentation the next day. H. Brouquet admitted that they would not be able to support all platforms, but would now be focussing on PC-Windows and current versions of Linux used by customers.

1.9 ESATAN Thermal Modelling Suite — Demonstration

H. Brouquet (ITP Engines UK) gave a live demonstration of ESATAN-TMS r2, highlighting the new features. He conducted a "classical" thermal analysis, without orbit and space environment. He created a model of a base plate, two units with internal dissipation, and the non-geometric environment boundary node. He showed the creation of time-dependent values via the property editor, and the grouping of nodes to simplify conductor creation. At the end of the analysis he used ThermNV to post-process the temperature data and to have limits comparisons between different cases. (See appendix I)
D. Battaglia (Thales Alenia Space) commented that the model shown had consisted of two units on a panel with conductors between them. He asked whether the value of the conductor had been temperature dependent, and whether it was output as a constant value or as a variable. H. Brouquet said that currently the conductor value would be exported to the GMM as a constant value, but would be exported to ESATAN as a local variable.

1.10 Methods for solving linearized networks in satellite thermal analysis

M. Altenburg (Astrium GmbH) presented the latest work on developing methods for converting thermal networks containing radiative (T^4) couplings into equivalent linear forms in an attempt to improve convergence and stability in the solutions. He described the use and results of both ordinary differential equation and quasi-analytical approaches. (See appendix J)

HP. de Koning (ESA/ESTEC) asked whether any attempt had been made to use other solvers than those provided by MATLAB, such as one of the open source solvers. M. Altenburg answered that he had only experimented with the different MATLAB solvers, and had found some problems with all of them. He had found that ODE15s was the "best" solver. He had been in contact with MATLAB to try to resolve the problems, but did not have a complete solution yet. H. Rooijackers (ESA/ESTEC) commented that some solvers were available from LAPACK. For research purposes, LAPACK had also been optimized for Intel processors, and some solvers would work in parallel on multi-core systems.
J. Etchells (ESA/ESTEC) asked for clarification about the slide that had shown the divergence of the two solutions. The slide showed a difference between the ODE and QA solver solutions. He was curious to know whether both solutions diverged, or whether it was only one. M. Altenburg replied that ODE15s was the solver that gave the problems.

1.11 Herschel experience on modelling and verification of active heater control

S. de Palo (Thales Alenia Space) presented a brief overview of the thermal control of some of the key systems on the Herschel service module. He went on to describe the challenges involved in verifying the correct functioning of the heater controllers especially in light of the low sample rates available during testing. (See appendix K)
J. Persson (ESA/ESTEC) said that the presentation had shown that they had verified the stability of the temperature control, but asked about the stability of the algorithm that had been developed to verify the test data. S. de Palo explained that when working with the transfer function, it was necessary to set up a control loop. In the MATLAB toolbox the user could set various parameters, such as the Nyquist frequency. In this case, the stability under discussion was not quite the same as that of control theory, and could be described more like a limitation of the temperature variation. From a strictly control theory standpoint, "stability" was not the correct word to describe it.
J. Etchells (ESA/ESTEC) was interested in the Pulse Width Modulation slide, and asked how they had decided on the PWM frequency. S. de Palo replied that all of the timings had already been fixed in the design before the verification stage had been reached. C. Damasio (ESA/ESTEC) confirmed that the time values were all due to limitations of the hardware, and that the control functions had been implemented too late for the findings to be fed back in to influence the design.
HP. de Koning (ESA/ESTEC) asked how the 64 second sample time had been discovered so late in the process. S. de Palo said that he did not know the history: he had simply worked with the thermal control team and had not been involved in providing the original requirements for the testing. He admitted that it had been a big surprise. For similar work on Columbus, the thermal model and the hardware had both had a time step of one second so that they could see what was going on. He believed that the problem in this case lay somewhere in the interface to the controller.

1.12 Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit

S. Del Togno (DLR) described the extreme thermal environment anticipated for BepiColombo in its orbit around Mercury, and how this influenced the design of the BepiColombo Laser Altimeter (BELA). He explained how to incorporate temperature dependent thermo-optical properties into the ESATAN-TMS models of the spacecraft, both the GMM and the TMM. (See appendix L)

P. Poinas (ESA/ESTEC) asked when or why they had decided to move to temperature dependent properties. Was it when the first analysis gave the wrong results? S. Del Togno explained that the decision to investigate using temperature dependent properties had been based on the spectrum expected at each orbit position. P. Poinas said that he understood the differences in the spectrum, and asked whether there had been any comparisons with the different optical properties. S. Del Togno said that they had made a comparison later, using fixed values for the optical properties of the baffle, but only for steady state. The transient analysis had given problems, with an error of 10K, which was clearly not desirable.

Day 2

Wednesday 7th October 2009

2.1 Thermal design for an asteroidal lander

R. Nadalini (Active Space Technologies) presented the challenges involved in modelling the thermal environment for a lander on a small asteroid using a generic method that had been inspired by a presentation on EXOMARS at the previous year's workshop. He described how to calculate the solar flux at different latitudes on the asteroid, and the infra-red fluxes based on the local soil temperature profile. (See appendix M)

H. Isik (Turkish Aerospace Industries) asked about the colours shown on the lander model. He had understood that the lower part had a gold coating, but what about the top? R. Nadalini said that the top surface was white because it needed to have a low solar absorptivity and high infra-red emissivity. H. Isik asked why they had not used MLI. R. Nadalini said it all came down to mass. The first approach was to try to use coatings because they were lighter and cheaper. There was a big push to reduce mass, and therefore cost. In the case that they could not achieve the required results using coatings, then they would look at using MLI.

M. Gorlani (Blue Engineering) asked about the next step: which method would be used to cope with differences in slopes, and the orientation of the lander on the surface? R. Nadalini said that the model allowed either to incline the whole surface, or the lander on the surface.

M. Gorlani was interested to know which method had been used to choose the design cases. Did they have some criteria to choose the five worst cases, or was a particular parameter important? R. Nadalini said that the first step was to try to see how important the orientation was. He wanted to have a symmetric design to avoid having to consider too much variation based on which side of the lander was facing the sun or in shadow. The scientists needed to provide information on which kinds of slopes were expected, so that the thermal engineers could do a test run. If the effect was important, they would then try to parameterize the model to take the slope into account. The problem was that any change to orientation or slope affected the radiative model, and so the changes had to be made in the geometry file, and then cascaded through the rest of the analysis. If the parameters affected only the thermal solution, they would be easier to handle. As a workaround, it had been necessary to pre-calculate arrays of fluxes and then select the appropriate array. R. Nadalini said that as far as he was aware, the customer was probably only interested in the worst case analysis and margins, and did not need all possible variations.

M. Gorlani commented that an asteroid had no atmosphere, so that limited any atmospheric effect that would be important for some planetary landers, and therefore calculating the effect of slopes was more important. He said that Blue had performed lots of parametric runs using `ESARAD` and therefore had experience managing large numbers of analysis cases like the ones shown.

J. Etchells (ESA/ESTEC) asked whether there had been any need to consider the effects of dust on the sky temperature. R. Nadalini replied that this was not necessary for the asteroid environment but would be for a planet such as Mars. He understood that the EXOMARS people had built up a database and extracted the effect on the incident flux, etc. They were then able to damp the solar flux by using a factor relating to the optical depth of the atmosphere. However, for the asteroid case, the effect of any dust was important at and in the surface, and not on the sky temperatures.

2.2 TCDT — Distribution and maintenance

A. Tosetto (Blue Engineering) presented a brief history of the Thermal Concept Design Tool project and its availability to the European space thermal community. He described various improvements that had been made since the previous workshop, based on feedback from users. He demonstrated several of these, such as the improved bounding box and axis display for shells, attitude visualisation, parameterized geometrical models, and improved synchronization of changes between geometrical and thermal models. (See appendix N)
D. Gabarain (ESA/ESTEC) asked whether it was possible to define a radiative case involving an elliptical planetary orbit. A. Tosetto said that the orbit was generally elliptical, so all the user needed to do was to define different major and minor axes.
A. Uygur (Turkish Aerospace Industries) commented on a slide that said that Excel 2007 would be supported in the future. He wanted to know what was supported at the moment. A. Tosetto said that there was already one user who worked with Excel 2007, and that they had not received any problem reports. However, they had not yet run any formal verification tests against Excel 2007.

2.3 A thermal/structural mapping tool for thermo-elastic distortion analysis

D. Wild (Astrium UK) presented details of a process based on simple text files for mapping temperature data from a thermal geometrical model onto a mechanical finite element model. The process used `TASverter` to convert from `ESARAD` to `THERMICA` in order to output the node centres using the UNF format, and a C++ program to perform some simple geometrical mathematics to map temperatures between the models. (See appendix O)
R. Nadalini (Active Space Technologies) said that the presentation had included some nice ideas, and wondered how the process dealt with edge effects, such as the edge of a panel, or junctions, or external edges. D. Wild answered that the software was able to recognise the node on the edge of a panel, and then looked backwards towards the centre. For junctions, the user needed to group nodes together in order to avoid "look-across". The software would then only map within the groups that had been defined. R. Nadalini supposed that the software calculated based on the 8 regions defined for each node, and beyond those regions the distance to the node would be taken into account. D. Wild confirmed this, but said that the software only looked at the other nodes defined within a group.
M. Bernard (Astrium) had understood that the mechanical nodes on the edge of the panel could look at other nodes in the 8 regions, and that if one panel node was next to a region that was not empty then the mechanical node would have the same temperature. D. Wild said that the user had to manually manage certain edge cases. It was usually a problem of the geometrical model, and it was hard to anticipate when such problems would occur, but it was relatively easy to go back to redefine the groups.

M. Bernard felt that it was an interesting approach to use the centres of the thermal meshes, but said that people were used to thinking in terms of an iso-thermal mesh where all points on a node had the same temperature. For some parts of the model this would have no effect on the end result, but for huge nodes with huge meshes, it could give a great difference between the meshes. T. Soriano (EADS Astrium) remarked that this would then give the node temperature at the point at the centre of the shape. D. Wild said that the coordinates in the universal neutral file represented the centres of the shells. It was the shells that they looked at, so they used the centroids of the shells. For each shell the file also contained some other numbers such as the temperature.
T. Soriano warned that the thermal node temperature was the average temperature of the surface, so there could be higher temperatures within the shape. There could therefore be significant differences in actual temperature gradients across big shapes and small shapes with the same average thermal node temperature. Using the node centres could therefore have a large effect on the results. D. Wild agreed, but said that this was really a problem with the thermal mesh, and that such effects were usually easy to see when visualising the results afterwards. The user needed to consider this possibility during the modelling. The developers were aware of the problem and would need to keep an eye on it in the future.

2.4 Updates to the SINAS tool for mapping of lumped parameter temperatures onto a structural FE models

J. Etchells (ESA/ESTEC) presented the work of Simon Martin, a stagiaire who had just returned to Cambridge University. The work during the stage had been to re-implement large parts of the `SINAS` tool, already presented at previous workshops, in order to simplify the work flow, to develop a replacement for the `NASTRAN` DMAP functionality for manipulating gradient areas, and to refactor many of the old array constructs that had been inherited from `FORTRAN` to use modern software idioms such as Python dictionaries. (See appendix P)
A. Tralli (BuNova Development) said that this was a very interesting presentation on an interesting subject. He asked whether the goal had been to redo `NASTRAN` for thermo-elastic analysis. J. Etchells said that was not the case. They were still using `NASTRAN` for the structural analysis, but what they had done was to replace `NASTRAN` for creating the conduction and constraint matrices. The difference between what they had done and most mapping approaches which use the grid positions, was to use the topology of the finite element model to get the mapping. He said he should have included a slide from Simon Appel's presentation on `SINAS` at the 2006 workshop[1], which showed the results on a non-contiguous mesh. He said that in that example where the two nodes were well insulated from each other, the traditional approach would give strange gradient effects in the finite element model over the insulated boundary. Taking the topology into account as well gave another set of temperature gradients. A. Tralli agreed, especially for the higher order elements.
A. Tralli asked about the use of the Lagrange multipliers, and whether there had been any strange effects. J. Etchells answered that the Lagrange multipliers were only used to apply constraints and to relate thermal node temperatures to finite element node temperatures because they were using a conjugate gradients solver. A. Tralli commented that the difficulty was to handle a matrix with zero on the main diagonal. J. Etchells agreed that the problem was non-positive definite.

[1] https://exchange.esa.int/thermal-workshop/attachments/workshop2006/appendix/SAppel.pdf

2.5 ESATAP 2.0.0 — Status and evolution of developments dedicated to thermal end users

H. Rooijackers (ESA/ESTEC) began by giving a brief summary of the goals of the ESATAP project and the history so far. F. Brunetti (DOREA) then continued by outlining the limitations of the early versions, both in performance and memory usage, and that the user interface had been geared towards expert software developers rather than thermal engineering users. He gave a video demonstration of the new task wizard that had been designed to simplify use by thermal engineers. A. Fagot (DOREA) described various improvements to the underlying architecture, mainly to do with user input validation and error checking. They had worked closely with Dutch Space to develop a limits reporting facility which could handle the comparison of results from multiple analysis runs. (See appendix Q)
There were no questions.

2.6 Final validation phases of the IITAS project for Industrial Implementation of STEP-TAS

HP. de Koning (ESA/ESTEC) described current work by the European thermal tool developers to integrate a STEP-TAS import/export facility in their tools using underlying software tools and libraries from ESA, CSTB and the University of Manchester. CSTB had implemented a framework for the automated validation of more than one hundred test cases drawn from the TASverter test suite involving import and export of geometrical models in STEP-TAS format into and out of CIGAL2, ESARAD and THERMICA. The validation used BagheraView to generate ten standard views of each model, with a pixel-by-pixel comparison of the resulting images. Similar import/export facilities were planned for TMG and Thermal Desktop in the future. (See appendix R)
S. de Palo (Thales Alenia Space) asked whether the TMG mentioned meant the classic version or the new NX. HP. de Koning answered that the interface was planned for both versions.
S. de Palo asked how boolean operations would be handled in the conversion of the geometry. HP. de Koning answered that cutting operations would be handled in a similar way to that used by TASverter. Cutting operations in ESARAD could be exported to boolean operations in STEP-TAS and imported back into ESARAD. The result of importing such a STEP-TAS model with boolean operations into another tool depended on how the model was interpreted and the capabilities of the tool. THERMICA v4 has some support for cutting operations, but not for all shapes. Some shapes could be handled directly, but more complicated operations would generate a warning and require some manual clean-up. Where possible, the boolean operations should convert automatically, leaving the rest for manual conversion. CIGAL2 did not handle cutting operations, so importing a model with boolean operations would generate a warning and the user would need to do something manually to adapt that part of the model.

2.7 Mathematical models for the Columbus engineering support team

S. de Palo (Thales Alenia Space) gave an overview of the various thermal mathematical models developed for the analysis of the Columbus air and water loops during the CDR and FAR phases, and their continued use to help monitor the Columbus thermal environment in flight. He

described the analysis of telemetry data showing unforeseen behaviour in the cabin air loop, and the investigation into the cause. (See appendix S)
HP. de Koning (ESA/ESTEC) noted that there had been some talk of extending the ISS mission to 2018 or even 2020, and asked whether there was a need to start planning for related analysis. S. de Palo said that he had presented the current analysis standpoint and that someone else [a non-analyst] must have been talking about future plans. He had seen presentations about the ATV, and has been curious to know whether similar CDR models had been used for brainstorming on-orbit situations.
HP. de Koning asked about the format of the received telemetry data. S. de Palo answered that the data was received in Excel and ASCII files.
J. Persson (ESA/ESTEC) commented that when the model had been correlated in phase C/D, they had used idealized conditions. He wondered whether there had been any adjustments for the flight configuration. S. de Palo said that he was mainly concerned with the ATCS. He had correlated the pump assembly results against the telemetry and had modified the model to fit the flight data, but this had not been done for the CDR. The CDR sizing had been performed for the entire system. The model now needed some parameterization to handle information available from the telemetry for configuring the pump package, etc. Fixed ICD values had been used for the heat exchanger limits in the CDR analysis, but these did not reflect the dynamic values encountered under real conditions on the space station. He thought that there was a need for more detailed modelling of the heat exchangers in order to understand some of the transients seen in the telemetry.

2.8 On orbit performance of the EuTEF thermal control system — 1 Year on board the ISS

A. Franzoso (Carlo Gavazzi Space) presented an overview of EuTEF, a platform mounted on the outside of the Columbus model that housed various instruments with passive thermal control systems. He described the investigation of unexpected temperatures observed in the telemetry data and how these were tracked back to certain mission events requiring particular orientations of the space station. He also described the use of `SINDA` and `TOPIC` to make a simple six-node model for rapid analysis in order to avoid the 12-hour analysis runs required for the complete model. (See appendix T)
M. Gorlani (Blue Engineering) had a remark about using `TOPIC`. He said that `TOPIC` was included with the Thermal Concept Design Tool, and that the `TCDT` could be used as a pre-processor to provide input for `TOPIC`. A. Franzoso stressed that the use of `TOPIC` was not a choice based on such factors such as the reliability of the model, but simply because they wanted to have the lowest level of complexity for a new engineer who would only be working on the project for a couple of weeks. `TOPIC` provided the simplest interface of all of the tools. They had nothing against using the `TCDT`. M. Gorlani said that the `TCDT` could launch `TOPIC` and then provide the results in Excel.
D. Battaglia (Thales Alenia Space) had noted that in the explanation about the reduction of the model they had tried to remove the CEPA. He wondered how they had then been able to use the temperature as a boundary condition. A. Franzoso explained that they had used the flight data as the base board for the correlation. The CEPA was the common adaptor for all of the EuTEF payloads. They had not used the CEPA as a free condition, but the results were good, even for those elements not coupled by the CEPA.
A. Franzoso commented that they would need lots of stagiaires to investigate all of the interesting flight data that had come from EuTEF.

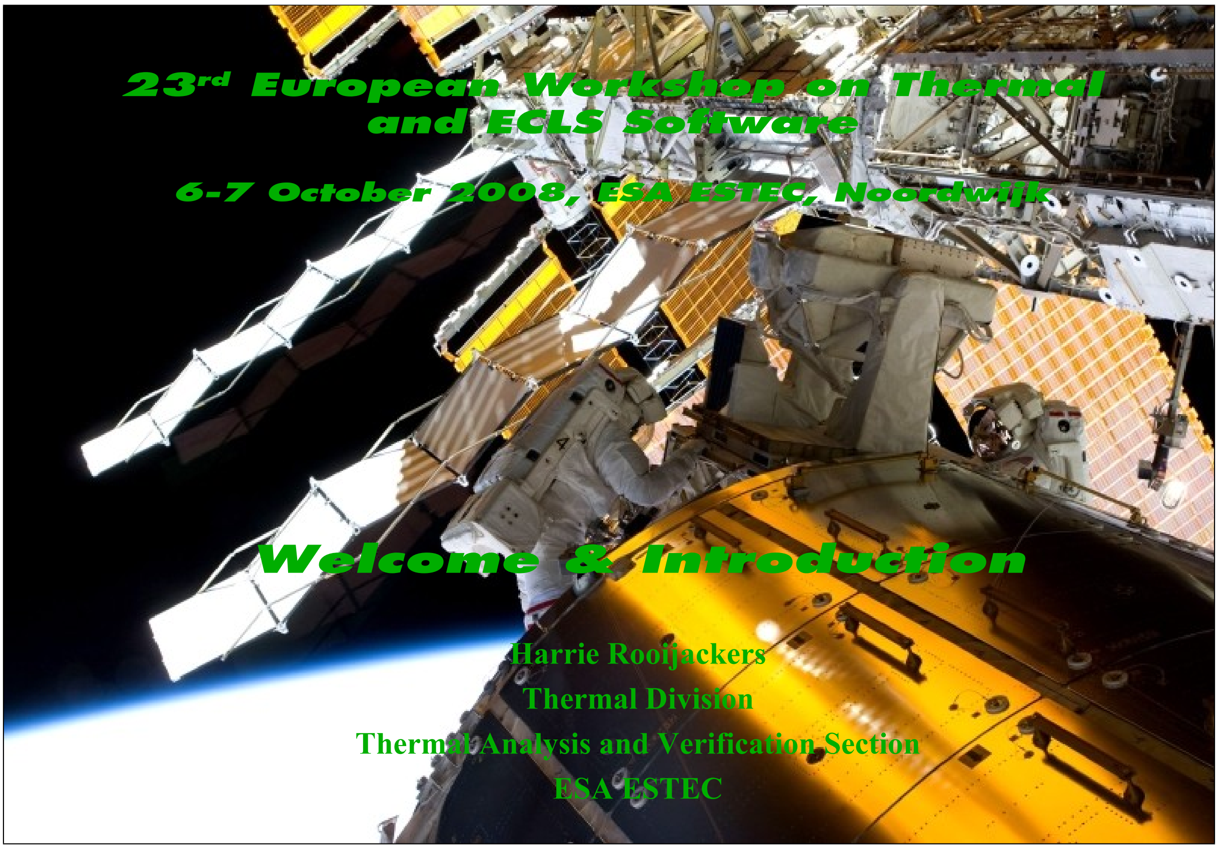
2.9 Workshop Close

H. Rooijackers (ESA/ESTEC) thanked all of the presenters and participants, reminded them of the deadline for the ICES submissions, and looked forward to seeing everyone again at the next workshop.

Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)



Workshop objectives

To promote the exchange of views and experiences amongst the users of European thermal/ECLS engineering analysis tools and related methodologies

To provide a forum for contact between end users and software developers

To present (new versions of) thermal/ECLS engineering analysis tools and to solicit feedback for development

To present new methodologies, standardisation activities, etc.

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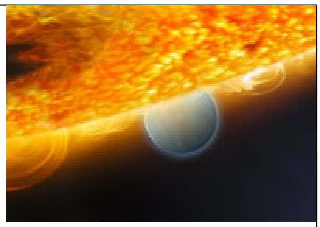
ESA Workshop Team



Harrie Rooijackers — Organiser
Duncan Gibson — Software Support & Workshop Secretary

with help from the ESA Conference Bureau

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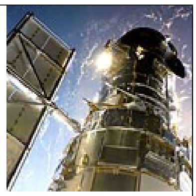
Programme



Two-day programme

Presentations of 30 min, including 5 minutes for questions and discussions

Cocktails today after the workshop in the Foyer

Dinner (optional) tonight in Noordwijk

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Practical information

Presenters: If not done already please leave your presentation (PowerPoint and PDF file) with Duncan or Harrie before the end of Workshop.

No copyrights, please!

Workshop Minutes will be supplied to participants afterwards, on CD-ROM and on the Web.

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Practical information

Lunch: 13:00 - 14:00

Cocktail today at 17:30 in the Foyer

Check your details on the list of participants and inform the Conference Bureau of any modifications.
Leave your email address!

Workshop dinner tonight!

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6-7 October 2009
sheet 8

Workshop diner

in “Het Zuiderbad", Koningin Astrid Boulevard 104,
2202 BD Noordwijk, tel +31(0)1736 20551

fixed menu with choice of main course (fish, meat or vegetarian) for €29,50 p.p.
Drinks are charged individually.

Restaurant booked today for 19:30

Please arrange your own transport

"Dutch" dinner == to be paid by yourself

If you would like to join, then contact the registration desk today **before 13:00**,
to let the restaurant know what to expect

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Restaurant “Het Zuiderbad”

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6-7 October 2009
sheet 10

Menu

(€ 29,50 p.p. excluding drinks)

Pomodorisoup with basilcream
or
Broth of veal with chervil

~~~~~~~~~~~

Grilled oilfish served with a choronsauce
or
With serranoham rolled chicken, stuffed with mozzarella, served with a herboil

~~~~~~~~~~~

Tiramisu with vanillasauce and whipped cream

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sheet 11

ICES 2010

The 40th International Conference on Environmental Systems (ICES) will be held July 11-15, 2010, Barcelona, Spain.

Deadline for submitting abstracts: Monday 2 November, 2009

Abstracts may be submitted online at www.aiaa.org/events/ices (preferred)

Abstracts must include paper title, author(s) name(s), mailing and e-mail addresses, phone and fax numbers

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Appendix B

Progress of the CIGAL2 distribution project

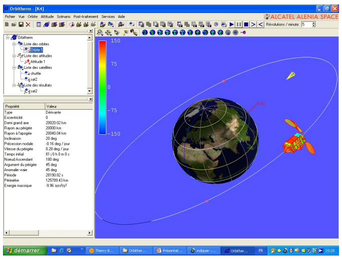
Thierry Basset Jean-Paul Dudon
(Thales Alenia Space, France)

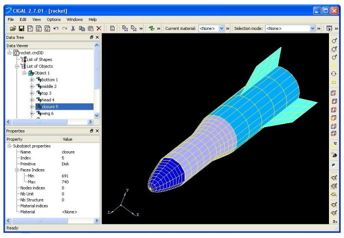
François Brunetti
(DOREA, France)

Abstract

To increase the reactivity and performance of thermal analysis, Thales Alenia Space Cannes has decided to integrate step by step its thermal software CORATHERM in the graphical pre and post-processing tool CIGAL2. As it was presented at 2008 ECLS workshop, the objective is to take profit of the powerful, complete and user friendly framework offered by CIGAL2 to extend it to end-to-end thermal analysys process including also computation management.
This year we intend to provide to European thermal users a new release of this integrated tool which will include a full integrated 3D conductive chain, a thermal model reduction tool (Thales Alenia Space Torino & Toulouse) and an orbitography module. Besides this the CIGAL2 new generation application combines a powerful modelling and meshing tool with the main CORATHERM modules to perform thermal analysis on a future satellite or payload.
This paper presents also the improvement brought to Coratherm architecture in order to make it more outstanding and to increase its performances and reactivity. Recently CIGAL2 has been chosen to be the CAD modelling tool for draft designing of satellite thermal control during invitation to tender phases in Thales Alenia Space Cannes.
Finally, this tool will be also available soon for other purpose than thermal such as ESD analysis, CIGAL2 integrating SPARCS simulation complete process and for electronics thermal control design.

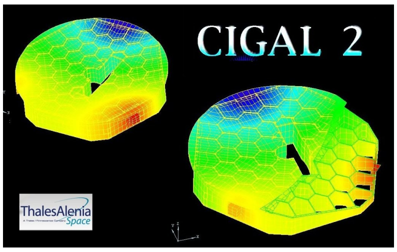
Progress in CIGAL2 distribution project

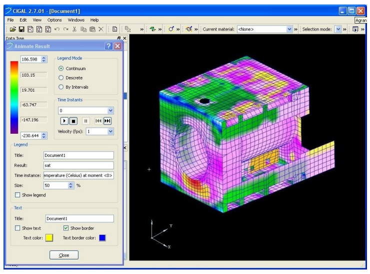




THALES ALENIA SPACE
CANNES

T. BASSET – J-P. DUDON
F. BRUNETTI (DOREA)





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Summary

- Policy an context around CIGAL2 distribution project
- Progress in CIGAL2 developments in 2009
  - Integration of a Radiative module
  - Integration of 2D & 3D Conductive modules
- CIGAL2 project in 2010
  - Integration of the CORATHERM solver (RPT)
  - Integration of the orbitography module
  - Improvement of the 3D meshing capabilities
- New applications for CIGAL2

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Summary

- **Policy an context around CIGAL2 distribution project**
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  - Improvement of the 3D meshing capabilities
- Other applications for CIGAL2

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Current and Future Policy

- TAS thermal s/w strategy is focused on :
  - Maintain & improve
    - → Performance, Reliability, Flexibility, Reactivity of used tools
  - Develop CORATHERM and data standard exchange (STEP-TAS)
  - Opening of CORATHERM
    - → **2008** : Distribution of our Pre and Post processing tool CIGAL2
      - Supply of CIGAL2 according to software licence agreement and secured patch
    - → **2009**: Distribution of CIGAL2 new release including radiative and conductive calculation
      - http://download.dorea.eu/user/cigal2/
  - This tool, fully funded by Thales Alenia Space, will not be commercialised but freely distributed with a maintenance funding :
    - → by TAS for corrective maintenance
    - → by customer for specific needs (evolution maintenance)
    - → by agencies for basic needs (evolution maintenance)

    Developments will be managed by Thales Alenia Space.
  - Contact : thierry.basset@thalesaleniaspace.com

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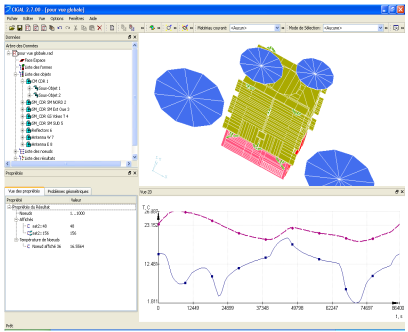
Pre and Post processing tool CIGAL2

- Context
  - Tool developed initially by Open Cascade and then by DOREA since 2007
  - Tool owned by Thales Alenia Space
- Brief functional overview
  - Pre-processing part
    - Import of CAD files
    - Building of radiative GMM with materials and nodal breakdown
    - Building of 2D & 3D conductive GMM with materials and nodal breakdown
    - Checking models
  - Post processing part
    - 2D curve plotting
    - 3D cartography of results with animation for transient
  - *And now* some integrated computation modules



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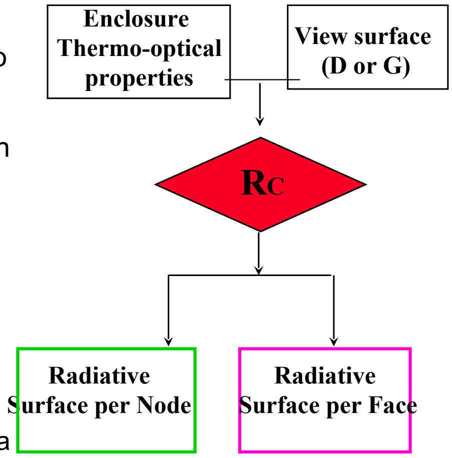
Integration in CIGAL2 of Radiative Exchange Calculation

- From view surfaces : calculation of radiative couplings taking into account diffuse multi-reflections and transmissions
  - Advantage : Change easily material characteristics for adjusting radiative exchanges
  - Method valid if uniform flux per node to take into account reflection with more accuracy



- Radiative Surfaces Calculation in a cavity based on matrix method

$$R_{ij}^{-1} = SV_{ij}^{-1} - \begin{vmatrix} \frac{1-\varepsilon}{\varepsilon S} & 0 & \dots \\ 0 & \dots & 0 \\ \dots & 0 & \frac{1-\varepsilon}{\varepsilon S} \end{vmatrix}$$

  - Method well adapted in the case of little models
    - ➔Small Matrix => low calculation time
  - Method well adapted in the case of surfaces with a high reflectivity (material with low emissivity)
    - ➔In this case iterative method is less efficient (needs a lot of iterations)

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Integration in CIGAL2 of Conductive Exchange Calculation

Presentation of RC conductive module (1/2)

- On the basis of the 2D or 3D conductive GMM (Pre-pro)
- Automated computation of elementary conductive couplings
  - FDM (2D) or FEM (3D) detailed conductive model
- Reduction of the detailed model and generation of the equivalent TLP model
  - Condensation of the detailed model to keep only couplings between **user defined "macroscopic" nodes**
  - **Take count of radiative aspects** in the reduction process
  - **Outputs :** ***Equivalent*** **conductive couplings compliant with other TLP solvers (ESATAN)**
- Possibility to recalculate temperature on original detailed model from the reduced thermal model
  - Very useful to transfer detailed temperature cartography to mechanical engineer for thermo-elastic analysis

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Integration in CIGAL2 of Conductive Exchange Calculation

Presentation of RC conductive module (2/2)

- Other capabilities
  - Easy connection between several conductive models in contact through interface nodes (no need of a concurrent mesh)
  - Definition of super-nodes by gathering various thermal nodes (for example when small gradients are firstly observed) : "averaged nodes"
  - Elimination of thermal nodes non required in the final model : "suppressed nodes"
  - Temperature or power zoom on some zone of the model : "partial or recalculated nodes"
  - Automated computation of nodal thermal capacitance on shell models
  - ***Automatic redistribution of nodal thermal capacitance on bulk type 3D models***

Soon

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Integration in CIGAL2 of the Conductive Module : Visualisation

Video Chaine conductive intégrée :
F. Brunetti

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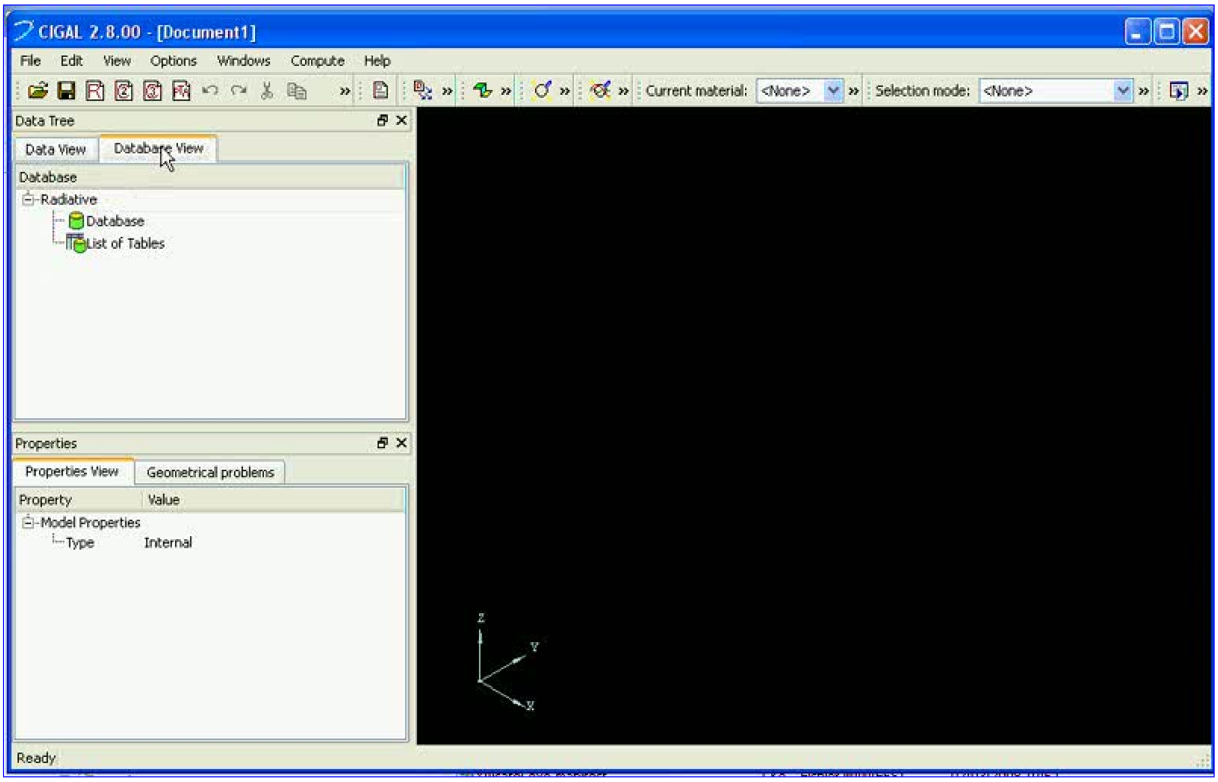
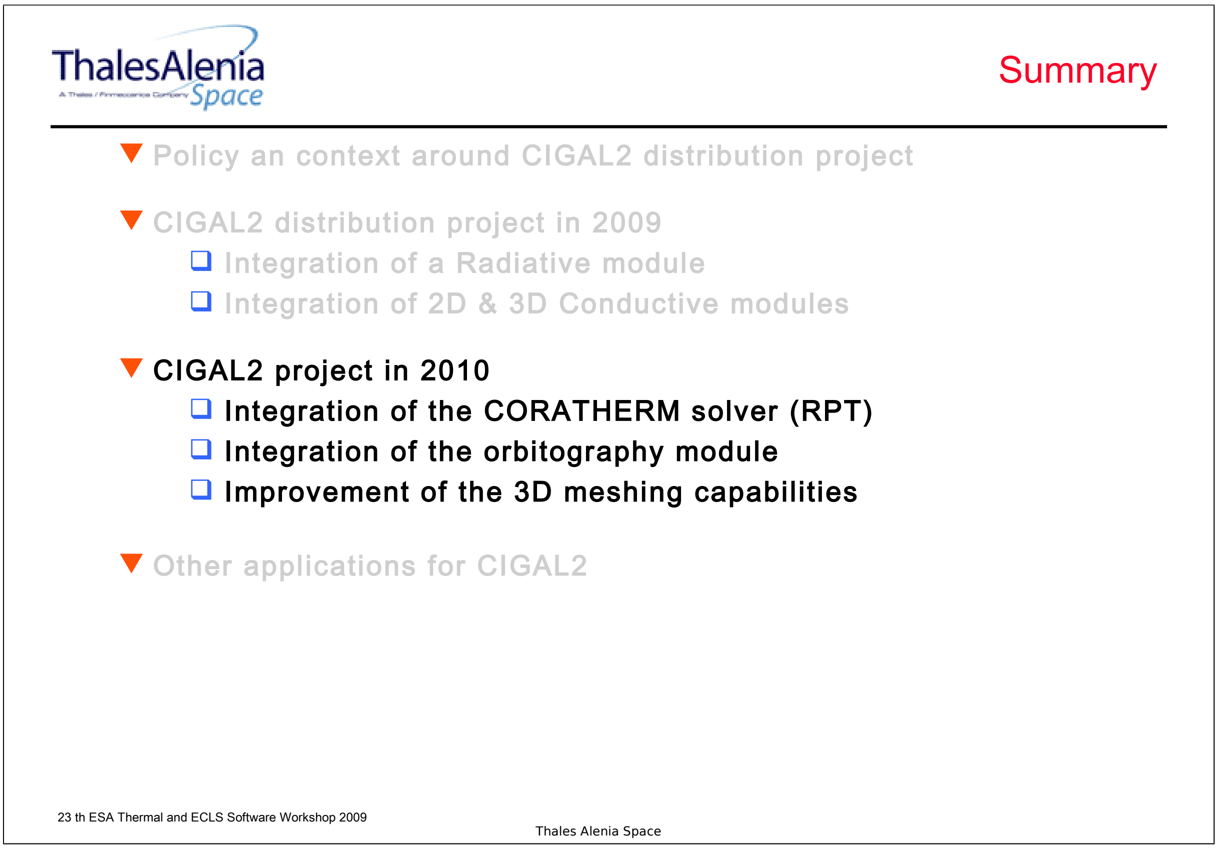
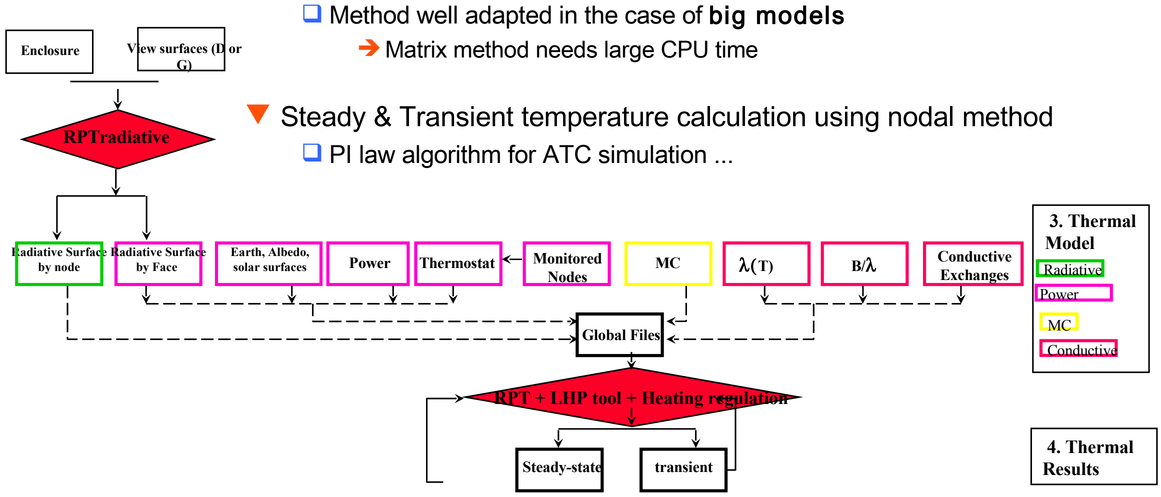


If clicking on the picture above does not run the movie then try opening the file ‘movies/Cigal2.html’ manually.



Integration of Thermal solver (RPT) in CIGAL2

- Radiative surfaces Calculation in a cavity by **iterative method**. The aim is to calculate the absorbed power by nodes
  - Iterative algorithms well adapted in the case of surfaces with **high absorptivity/emissivity**
    - ➔ generate a low number of iterations
  - Method well adapted in the case of **big models**
    - ➔ Matrix method needs large CPU time
- Steady & Transient temperature calculation using nodal method
  - PI law algorithm for ATC simulation ...



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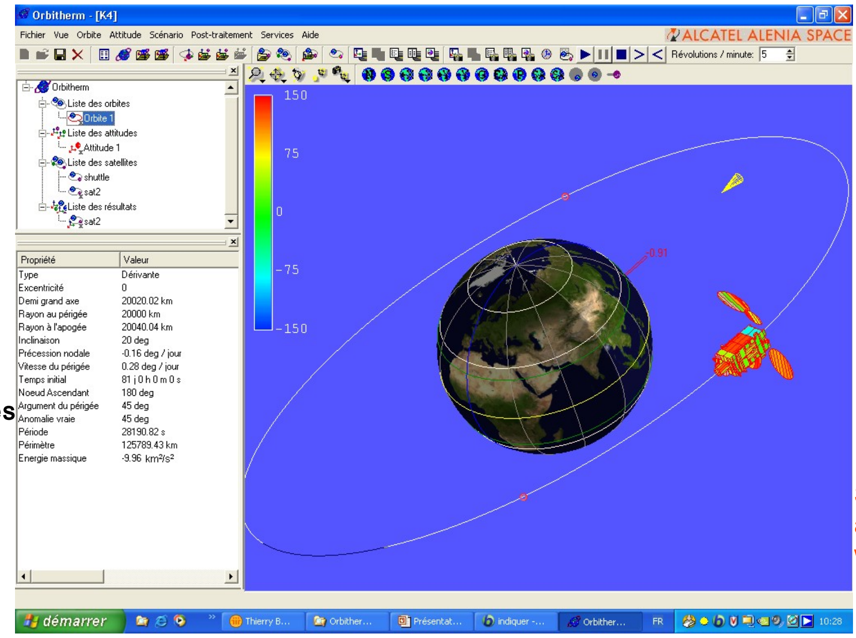
Integration of Orbitography module

Model Data Tree

Properties Editing



3D interactive window (build, check and display)

Soon fully available within CIGAL 2

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Integration of a new 3D meshing in CIGAL2

- Objective : Enhance reactivity and quality of 3D conductive modelling
- Main requirements
  - Improvement of the current module dedicated to 3D conductive modeling
    - More powerful CAD link
      - Direct shell mesh generation from CAD definition inputs
    - More powerful 3D shell and volumic mesher
      - New poly-line primitive
      - Replacement of NETGEN by GMSH
      - Mesh and prepare nodal breakdown
      - …
    - Automated assistance to user for matching mesh between neighbouring surfaces
    - …
  - Preparing opening of CIGAL2 to other domains (ESD analysis)
    - Enlarge CAD import capability
      - Import and manage solids for example

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  - Improvement of the 3D meshing capabilities
- **New applications for CIGAL2**

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Project : CIGAL2 for ESD analysis

Context

- SPARCS is Thales Alenia Space simulation tool for GEO satellite charging simulation based on plasma-spacecraft interaction modelling

Objective

- Today SPARCS is interfaced with COTS s/w for pre and post processing and this causes some industrial problems
  - ➔Reducing cost by using license free s/w
  - ➔Simplify handling and external distribution of SPARCS
  - ➔Add some new pre-post capabilities (e.g more assisted retouch of CAD geometry, 3D transient animation of results, …)
- Need for an integrated end-to-end s/w chain for ESD analysis

2009/2010 Project

- Development of an integrated S/C charging simulation chain in CIGAL2
- Collaboration TAS-DOREA
- A first step toward a multidisciplinary tool (Thermal / Space Environment)

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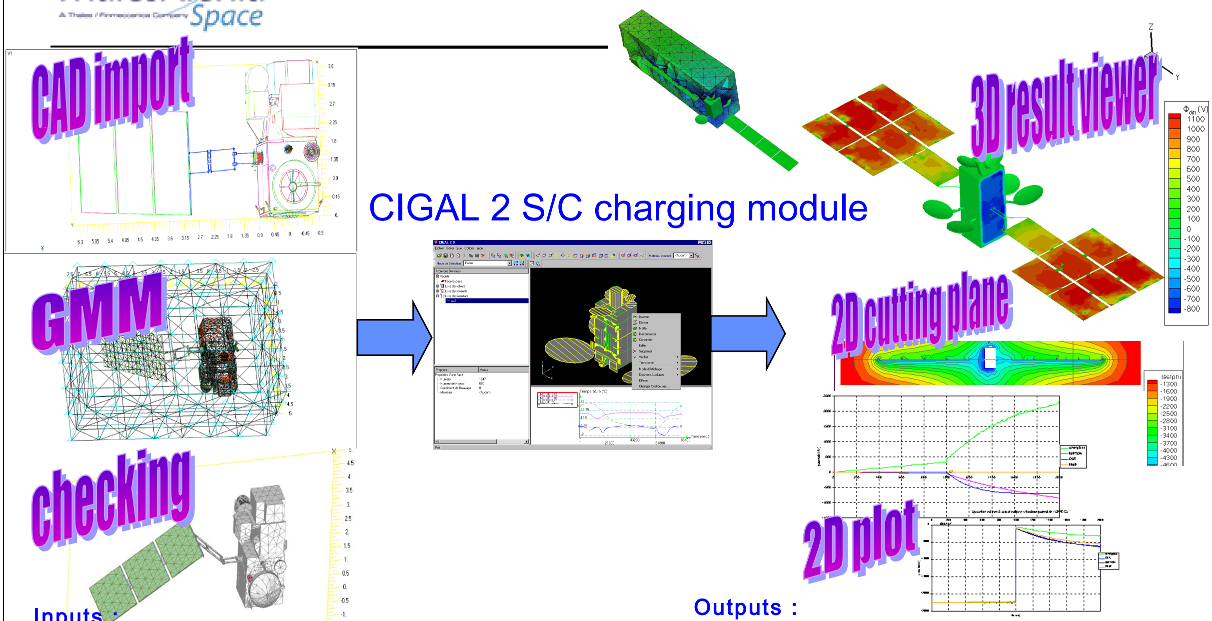
Project : CIGAL2 for ESD analysis



Inputs :
- Geometry/FEM mesh
- Boundary conditions (electron/ion distribution, …)
- Materials
- Run definition data

Outputs :
- Absolute and differential electric potential on SC surfaces (3D & 2D plot)
- Primary and secondary currents
- Iso-potential lines around S/C

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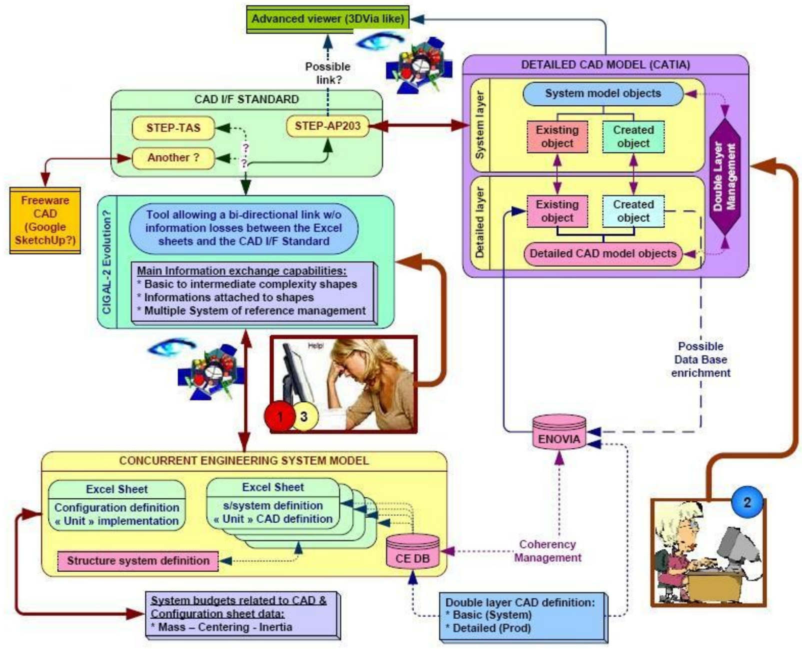
Project : CIGAL2 like interfaces between CDE and CAD application



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Other applications in view

- Outside TAS Cannes scope …
  - Several presentations of the project in THALES group aroused interest for various thermal activities
    - ➔TAS-Toulouse for antenna studies
    - ➔TAS-Torino for infrastructure & instrument
    - ➔Thales Group for electronic cards & units
    - ➔Thales Group for electron emitter device
  - Presentation and proposal to test CIGAL 2 to the european thermal s/w community
    - ➔Second distribution at 23th ECLS Workshop
    - ➔***Some feedback from test of 2008 release ?***

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Appendix C

Heat shield thermal sensitivity analysis

Matteo Gorlani
(Blue Engineering, Italy)

Valter Perotto
(Thales Alenia Space, Italy)

Abstract

The presentation will provide the results of the sensitivity analysis performed for the thermal model of Solar Orbiter Thermal Heat Shield. The sensitivity analysis applied to the geometrical mathematical model and the thermal mathematical model of the Solar Orbiter Thermal Heat Shield, has been performed with the stochastic approach based on the Monte Carlo Simulation method. The whole procedure will be described.

HEAT SHIELD THERMAL ANALYSIS SENSITIVITY

Matteo Gorlani
Blue Engineering, Torino, Italy
Valter Perotto
Thales Alenia Space, Torino

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Sheet 1

Topics

- Introduction
- Stochastic Sensitivity
- Sensitivity Analysis
- Analysis Validation
- Results
- Conclusions

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Sheet 2

INTRODUCTION (1/3)

SENSITIVITY - STANDARD METHOD

- Number of analysis = number of parameters
- Sensitivity vs. one parameter at time

- Single Temperature Sensitivity [°C] ΔTi
- Total Temperature Sensitivity [°C], RSS $\Delta T = \sqrt{\Sigma i(\Delta Ti)^2}$
- Uncertainty = RSS + Modelling error (typ. 3°C)
- Min/Max Predicted Temperature [°C] Tmin/max = Tnom -/+ UFP

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INTRODUCTION (2/3)

STOCHASTIC APPROACH

BACKGROUND APPLICATIONS

- General Application: "Feasibility of using a Stochastic Approach for Space Thermal Analysis"
- Model Optimisation/Reduction: "Thermal Model Reduction with Stochastic Optimisation"
- Design: "A tool for flexible and rapid thermal analysis and design in feasibility and preliminary phases of space projects
- Model Optimisation/Correlation: "Thermal Test Correlation With Stochastic Technique"

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INTRODUCTION (3/3)

SENSITIVITY - STOCHASTIC METHOD

- Number of analysis = sample dimension
- Sensitivity vs. parameters (accounting for PDF)

  - the random variables are the input parameters
  - the input sample has dimension m=500
  - analyses performed with ESARAD and ESATAN
  - output responses: sample with dimension m=500
  - stochastic process managed by means of PANAMA

STOCHASTIC SENSITIVITY (1/3)

DEFINITION OF CORRELATION

- influence of the different input parameters
- rate of change of correlated input/output parameters

Pearson's Coefficient

$$r_{xy} = \frac{\sum_{k=1}^{N}(X_k - \bar{X})(Y_k - \bar{Y})}{\sqrt{\sum_{k=1}^{N}(X_k - \bar{X})^2}\sqrt{\sum_{k=1}^{N}(Y_k - \bar{Y})^2}}$$

Design robustness

Areas for design optimisation.

STOCHASTIC SENSITIVITY (2/3)

DEFINITION OF UNCERTAINTY

Output considered as normally distributed

- mean value calculated: $\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$
- standard deviation calculated: $\sigma = \sqrt{\frac{1}{N-1}\sum(x_i - \bar{x})^2}$

uncertainty obtained for the output parameter X:

$(\mu - 3^* \sigma) < X < (\mu + 3^* \sigma)$ with the 99.7% of probability

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STOCHASTIC SENSITIVITY (3/3)

DEFINITION OF UNCERTAINTY

Output generally distributed

- percentile 0.15% calculated: P0.15
- percentile 50% calculated: P50
- percentile 99.85% calculated: P99.85

$$P[a] = \int_{-\infty}^{a} P_X(x)dx$$

$$P[a < X < b] = \int_{a}^{b} P_X(x)dx$$

uncertainty obtained for the output parameter X:

- P0.15 < X < P99.85 with the 99.7% of probability

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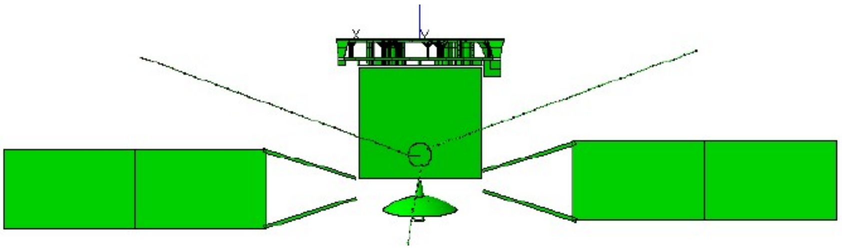
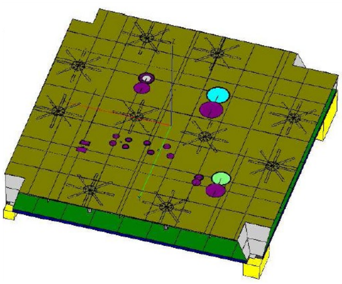
SENSITIVITY ANALYSIS (1/6)

HEAT SHIELD THERMAL MODEL

Solar Orbiter:
Min. distance from sun
0.22 AU →
solar flux 28250 W/m2



Phase B study:
•Prime EADS-Astrium UK
•Heat shield: TAS-I



Thermal analysis:
•Prime EADS-Astrium UK → Overall models and feed-through/baffle models
•TAS-I → Heat Shield model, using reduced S/C model and feed-through models from Astrium

Heat Shield models
•GMM: Esarad 6.2 (fully parameterized, great feature !)
•TMM: Esatan 10.2 (about 3000 nodes, complex heat balances calculations, easy with library routines)

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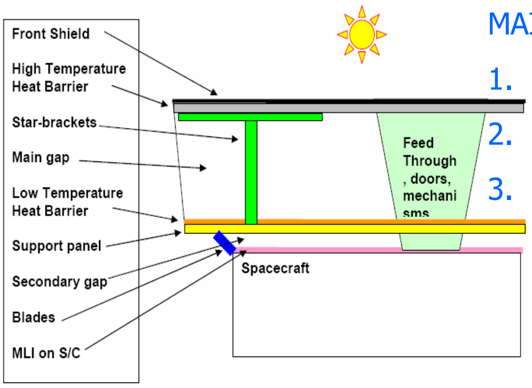
SENSITIVITY ANALYSIS (2/6)



MAIN REQUIREMENTS:

1. Radiative heat transfer to S/C within ± 30W
2. Conductive heat transfer to S/C within ± 30W
3. IR heat transfer to instruments within ± 90W

SPECIFIC DESIGN SOLUTIONS:

1. Geometry
2. High Temperature MLI (T_{front} about 600C)
3. Low conductivity blades and star-brackets

UNCERTAINTY ASSESSMENT

The severe environment and the new solutions require an accurate identification of the driving design parameters (i.e. geometry, opt. properties) and of the uncertainty → STOCHASTIC METHOD WAS SELECTED

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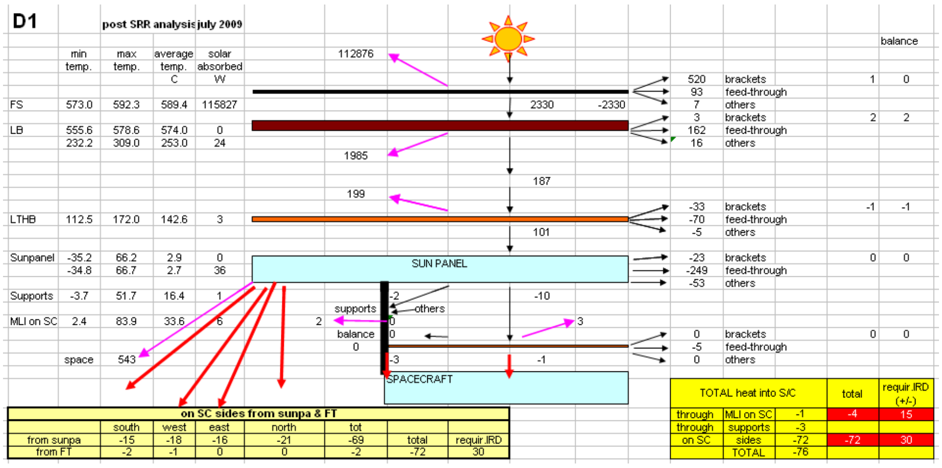
SENSITIVITY ANALYSIS (3/6)



UNCERTAINTY ASSESSMENT

The severe environment and the new solutions require an accurate identification of the driving design parameters (i.e. geometry, opt. properties) and of the uncertainty → STOCHASTIC METHOD WAS SELECTED

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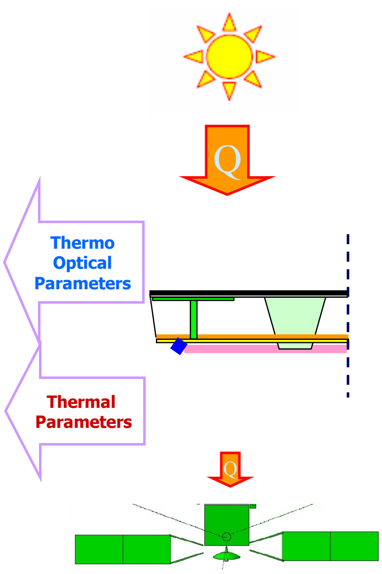
SENSITIVITY ANALYSIS (4/6)

INPUT PARAMETERS

	Average	Inaccuracy (2σ)
Alpha Front Shield – Space Side	0.8	0.04
Epsilon Front Shield – Space Side	0.61	0.04
Epsilon Front Shield – S/C Side	0.71	0.04
Epsilon HTHB – S/C Side	0.161	0.04
IR Specular Reflection HTHB [a]	0.739	20%
Epsilon FT – Inner Side	0.8	0.02
Epsilon Aluminium LTHB and MLI on SC	0.05	0.02
Epsilon support panel side SC	0.78	0.02
Alpha EOL support panel side SC	0.23	0.02
Epsilon Star Brackets (Titanium 649C)	0.2	0.04
Epsilon Star Brackets (Titanium 399C)	0.15	0.04
GL FT-Support Panel [W/K]	0.023	50%
GL FT (SWA-SENS)-Support Panel [W/K]	0.05	50%
GL FT (BOX)-Support Panel [W/K]	0.03	50%
Conductance Support Panel (Kz)	4	20%
Conductance Support Panel (Kxy)	8.7	20%
GL HTMLI [W/K]	0.019	30%
GR HTMLI	0.014	30%



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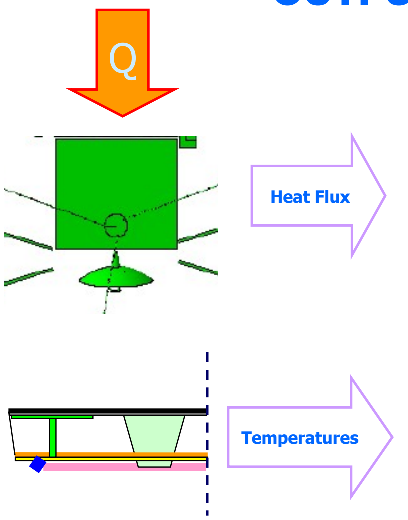
SENSITIVITY ANALYSIS (5/6)

OUTPUT PARAMETERS



Heat Fluxes

QL MLI on SC - Internal SC	[W]
QL Supports - Internal SC	[W]
Total Heat into SC - Radiators	[W]
Total Heat into SC	[W]
Total QR into SWA/SENS	[W]
Total QR into Instruments	[W]

FS - Average Temperature	[°C]
LB - Average Temperature (FS Side)	[°C]
LB - Average Temperature (SC Side)	[°C]
LTHB - Average Temperature	[°C]
SP - Maximum Temperature	[°C]
SP - Minimum Temperature	[°C]
SP - Average Temperature	[°C]
Supports - Maximum Temperature	[°C]
Supports - Minimum Temperature	[°C]
Supports - Average Temperature	[°C]
MLI on SC - Average Temperature	[°C]

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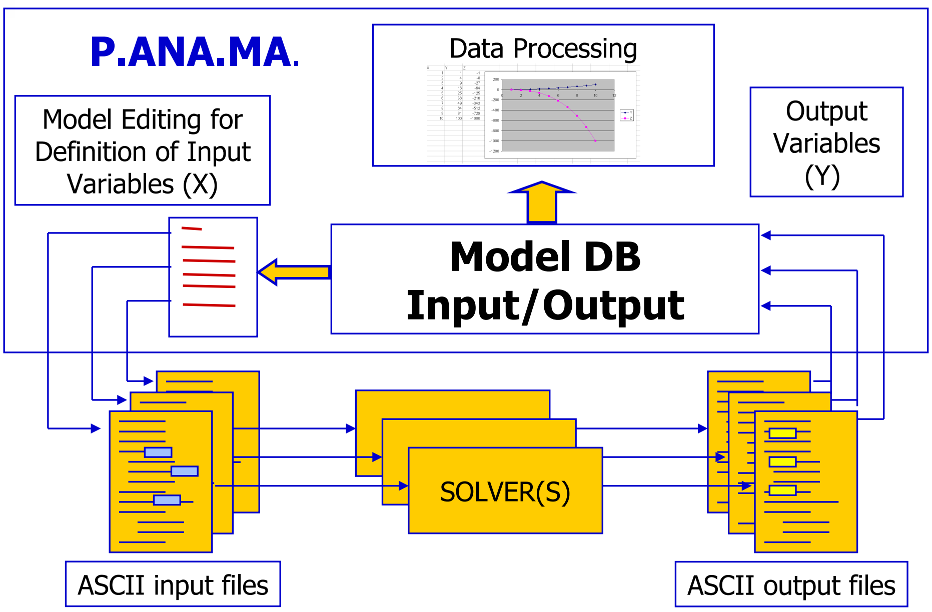
SENSITIVITY ANALYSIS (6/6)



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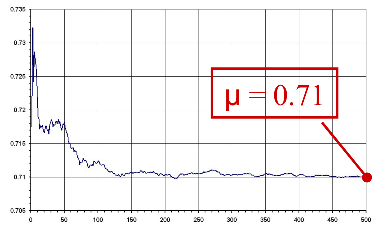
ANALYSIS VALIDATION

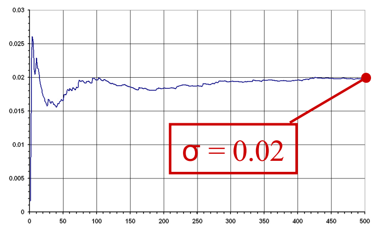
VERIFICATION OF INPUT SAMPLE

Defined Sample = Obtained Sample

Reasons for differences:

- dimension of the sample
- wide area of probability neglected due to superimposed limits





Epsilon Front Shield – S/C Side

RESULTS (1/2)

UNCERTAINTY TABLE

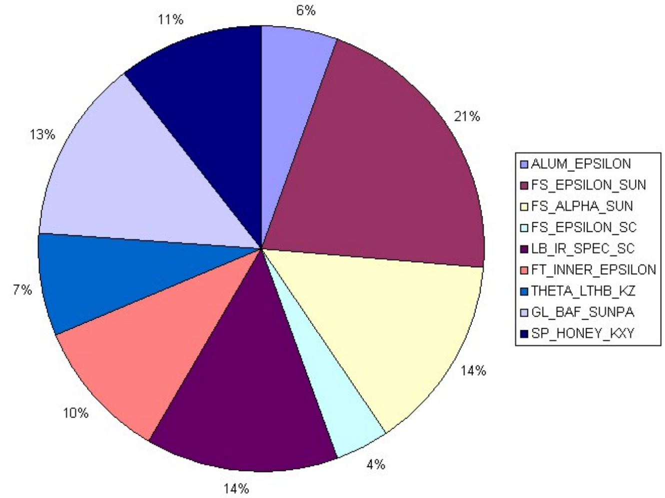
Output Parameters			Gaussian Interpretation				General Interpretation		
Id	Name	Unit	μ	σ	μ - 3σ	μ + 3σ	P50	P0.15	P99.85
1	FS - Average Temperature	[°C]	588.9	8.4	563.8	614.0	588.8	563.8	615.1
2	LB - Average Temperature (FS Side)	[°C]	573.3	8.3	548.5	598.1	573.2	548.4	599.1
3	LB - Average Temperature (SC Side)	[°C]	254.1	9.4	225.9	282.3	253.6	230.4	287.4
4	LTHB - Average Temperature	[°C]	141.7	4.8	127.4	156.1	142.0	125.4	154.3
5	SP - Maximum Temperature	[°C]	94.8	5.8	77.4	112.1	94.7	80.5	133.9
6	SP - Minimum Temperature	[°C]	-22.9	2.1	-29.3	-16.5	-22.8	-35.3	-18.3
7	SP - Average Temperature	[°C]	23.4	1.9	17.8	29.0	23.3	18.8	30.0
8	Supports - Maximum Temperature	[°C]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	Supports - Minimum Temperature	[°C]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	Supports - Average Temperature	[°C]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	MLI on SC - Average Temperature	[°C]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
12	QL MLI on SC - Internal SC	[W]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
13	QL Supports - Internal SC	[W]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	Total Heat into SC - Radiators	[W]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
15	Total Heat into SC	[W]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	Total QR into SWA/SENS	[W]	30.6	0.8	28.1	33.2	30.6	28.4	33.2
17	Total QR into Instruments	[W]	45.4	1.0	42.3	48.5	45.3	42.7	48.9

NOTE differences in Tmin/max with Interpretation. Classical sensitivity had given narrower range.

→ adv. of STOCH. METHOD

RESULTS (2/2)

DRIVING PARAMETERS: RADIATIVE HEAT INTO INSTRUMENTS



NO CRITICAL PARAMETER, MANY WITH VERY SIMILAR IMPORTANCE

→ DESIGN IS ROBUST (do not put all your eggs in one *design parameter*...)

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CONCLUSIONS

STOCHASTIC METHOD IS USEFUL:

- Accurate determination of driving parameters, assessment of design robustness, of areas of design improvement
- Accurate determination of uncertainty
- Nominal case margin assessment

BUT

- Uncertainty band of parameters must be carefully assessed (expertise needed)
- A specific tool is necessary, able to interface with thermal S/W (e.g. PANAMA)
- Significant computing resources are necessary

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Appendix D

TMRT
A thermal model reduction tool

Mathieu Bernard
(EADS Astrium, France)

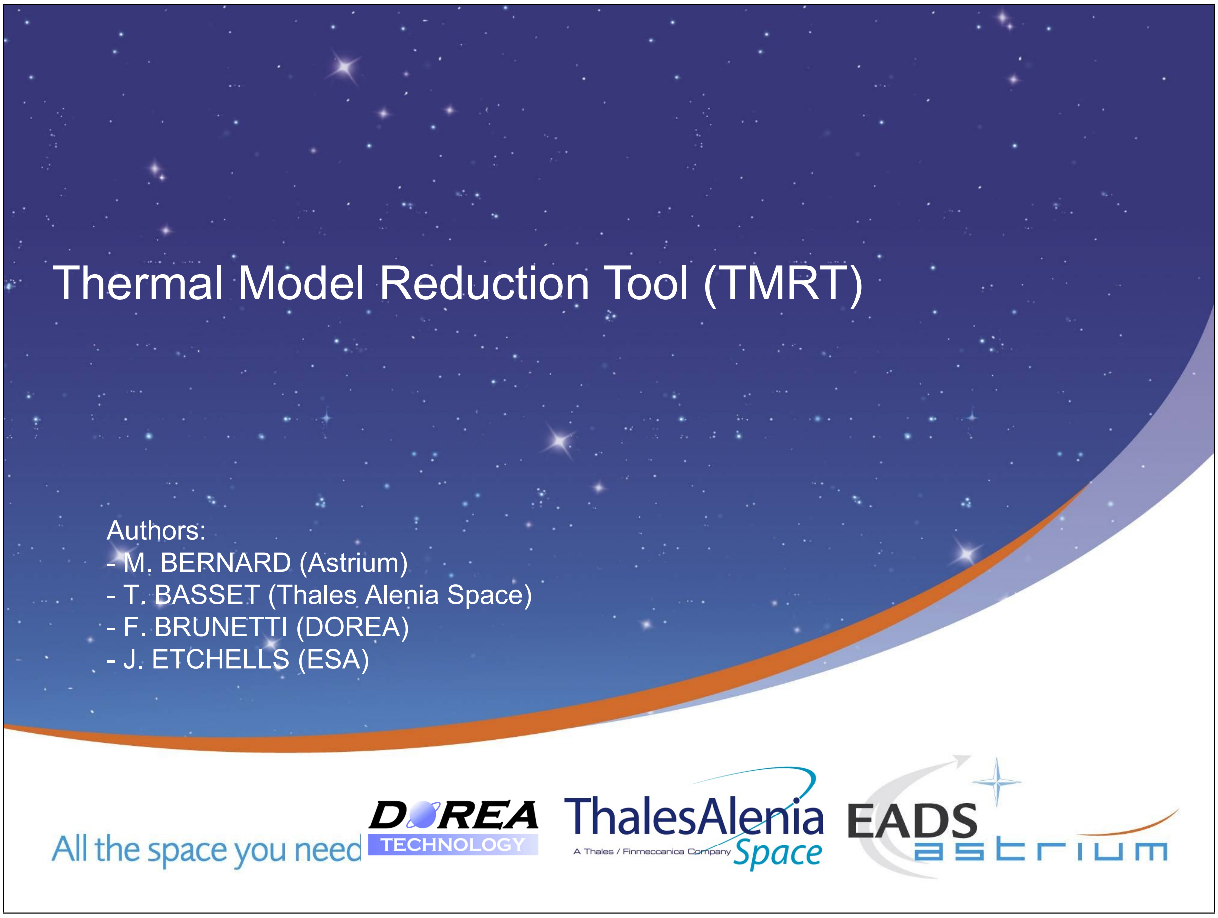
Thierry Basset
(Thales Alenia Space, France)

Sandrine Leroy François Brunetti
(DOREA, France)

James Etchells
(ESA/ESTEC, The Netherlands)

Abstract

TMRT is a software performing thermal model reductions, based on equivalent conductance matrices. It gathers the experience and knowhow of both THALES ALENIA SPACE and ASTRIUM in this domain. The presentation will first introduce the theory of the reduction method. Then, a demonstration will be made and used to show the advantages of the TMRT reduction method.


Thermal Model Reduction Tool (TMRT)
Authors:
- M. BERNARD (Astrium)
- T. BASSET (Thales Alenia Space)
- F. BRUNETTI (DOREA)
- J. ETCHELLS (ESA)
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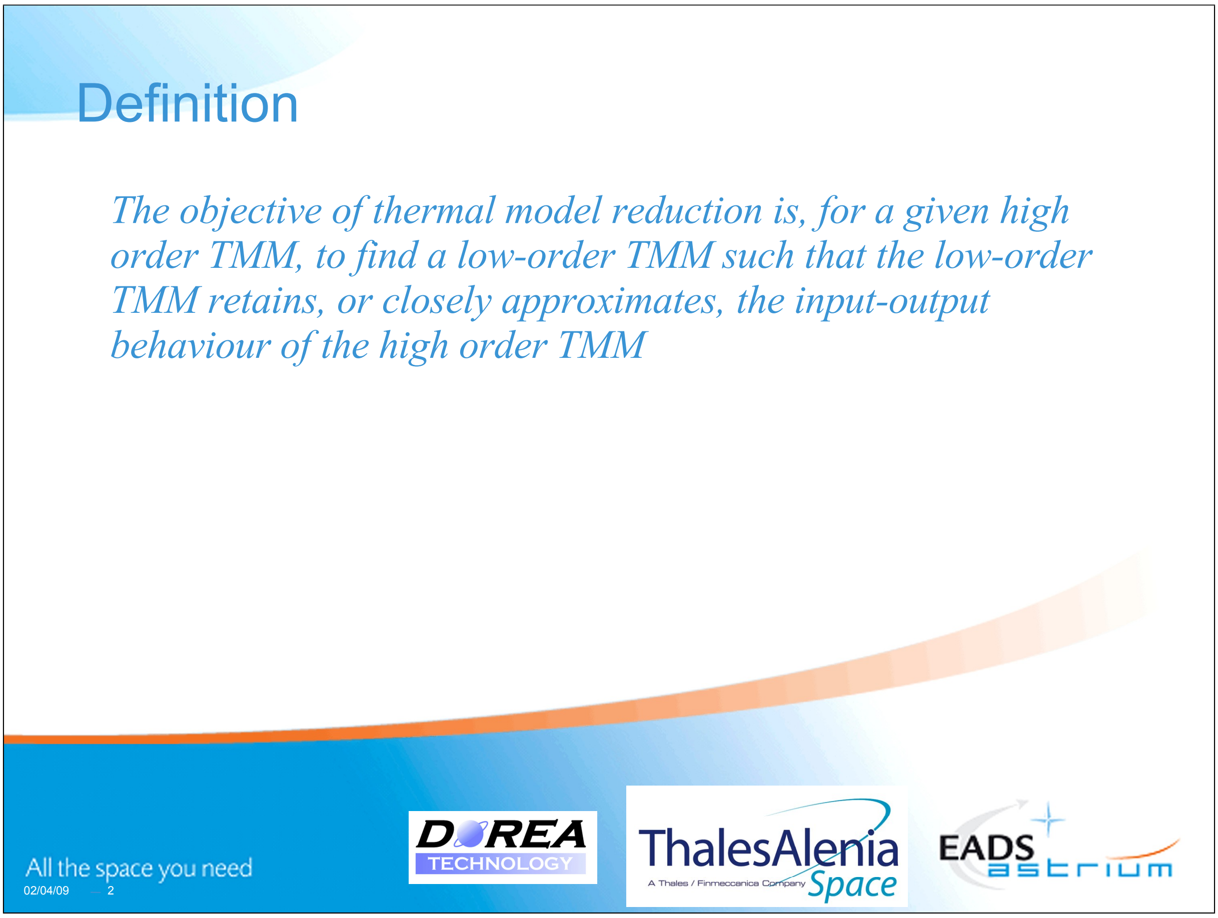
EADS astrium


Definition
The objective of thermal model reduction is, for a given high order TMM, to find a low-order TMM such that the low-order TMM retains, or closely approximates, the input-output behaviour of the high order TMM
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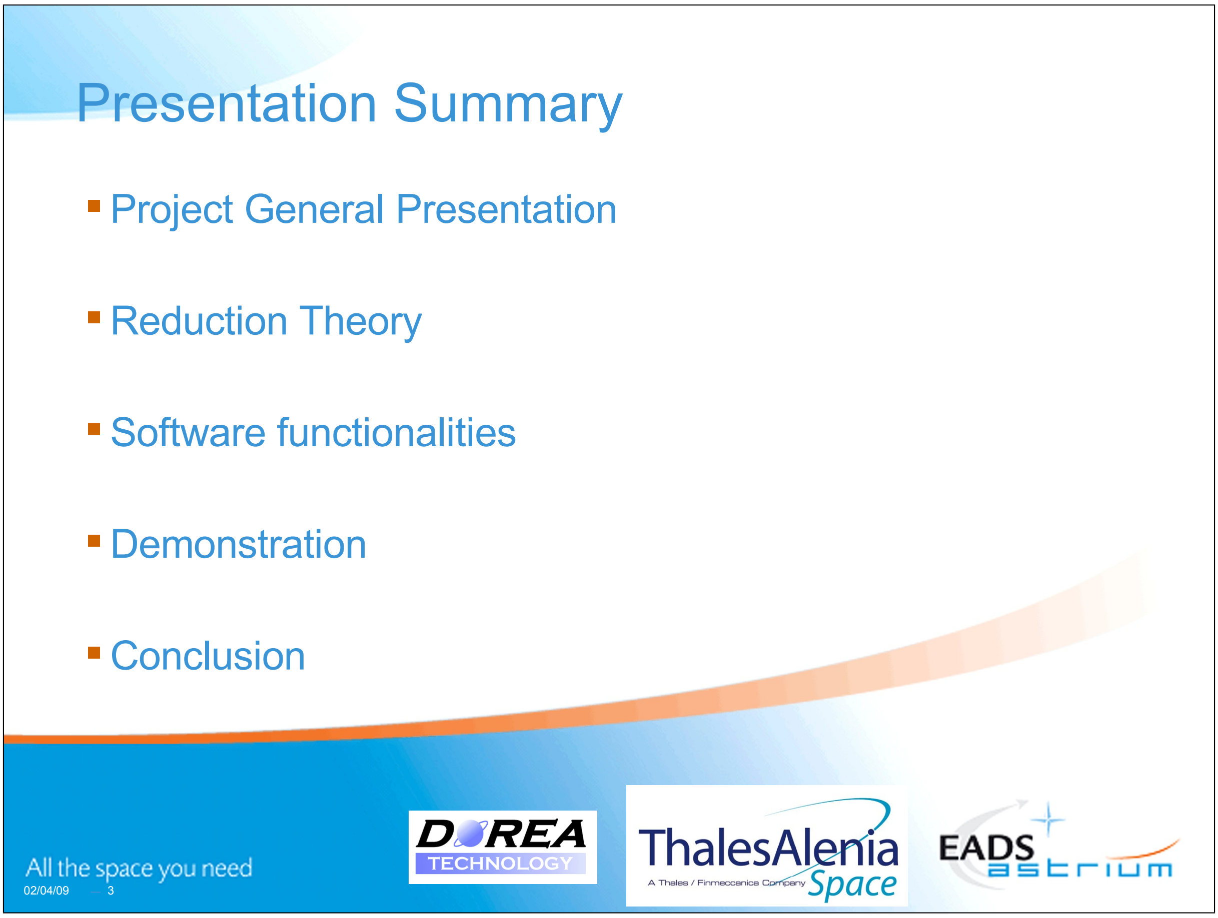
Presentation Summary
Project General Presentation
Reduction Theory
Software functionalities
Demonstration
Conclusion
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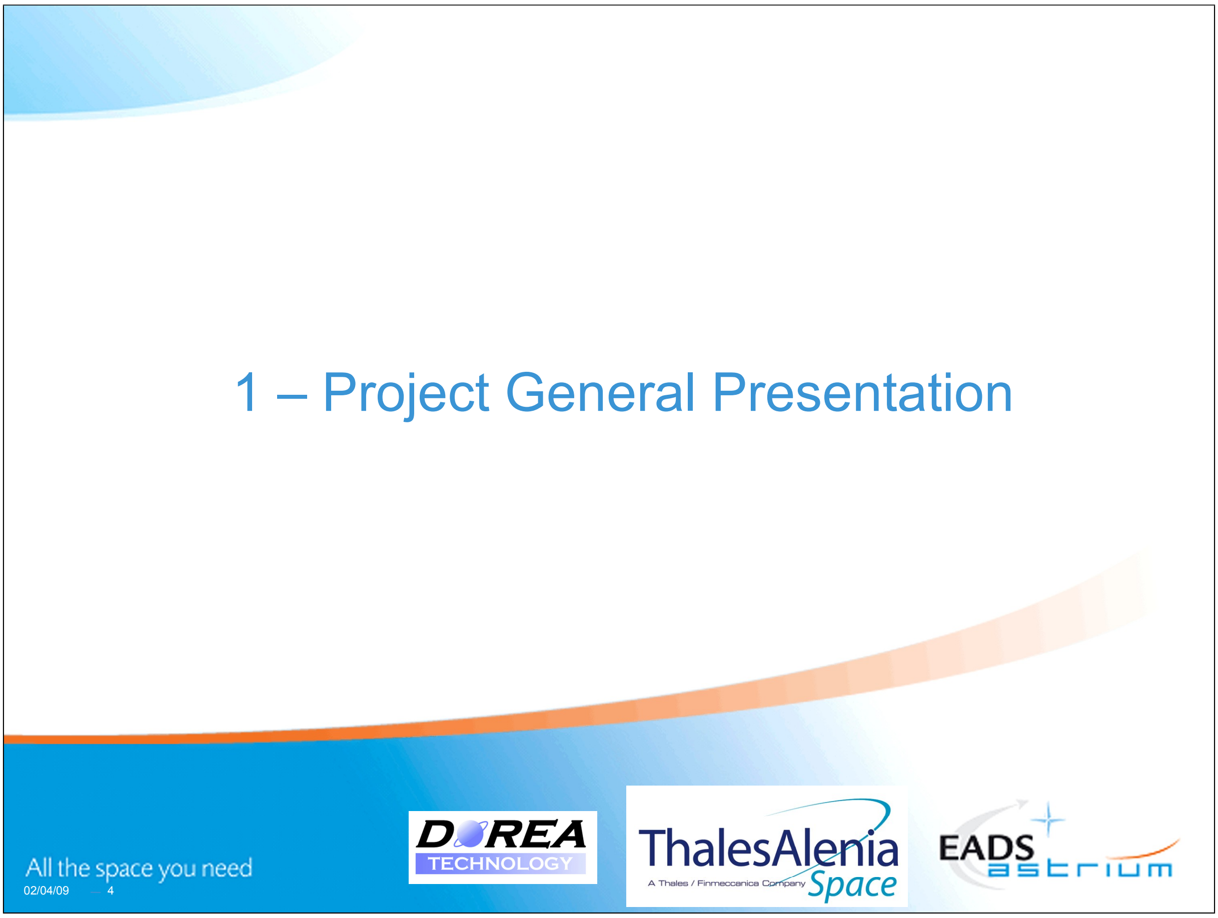
1 – Project General Presentation
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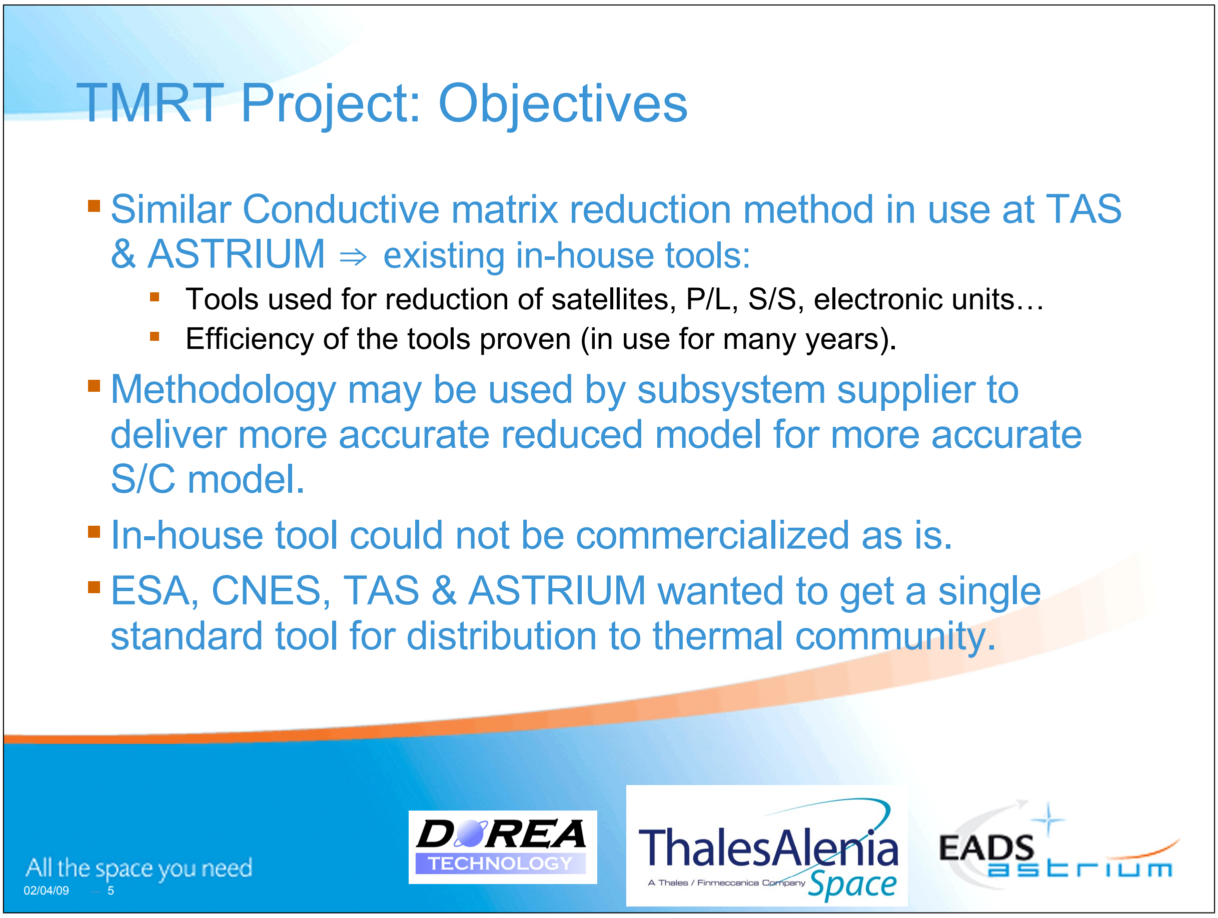
TMRT Project: Objectives
Similar Conductive matrix reduction method in use at TAS & ASTRIUM ⇒ existing in-house tools:
Tools used for reduction of satellites, P/L, S/S, electronic units…
Efficiency of the tools proven (in use for many years).
Methodology may be used by subsystem supplier to deliver more accurate reduced model for more accurate S/C model.
In-house tool could not be commercialized as is.
ESA, CNES, TAS & ASTRIUM wanted to get a single standard tool for distribution to thermal community.
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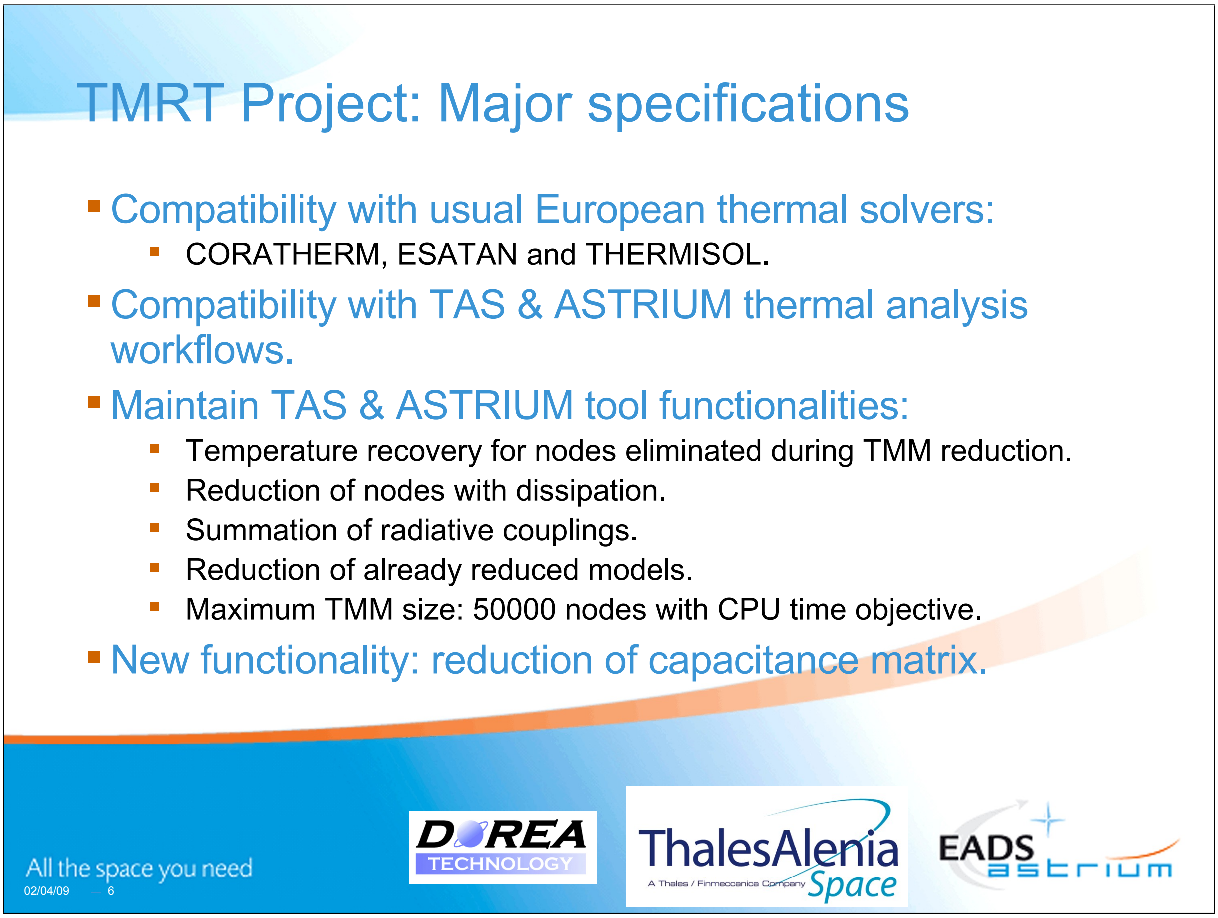
TMRT Project: Major specifications
Compatibility with usual European thermal solvers:
CORATHERM, ESATAN and THERMISOL.
Compatibility with TAS & ASTRIUM thermal analysis workflows.
Maintain TAS & ASTRIUM tool functionalities:
Temperature recovery for nodes eliminated during TMM reduction.
Reduction of nodes with dissipation.
Summation of radiative couplings.
Reduction of already reduced models.
Maximum TMM size: 50000 nodes with CPU time objective.
New functionality: reduction of capacitance matrix.
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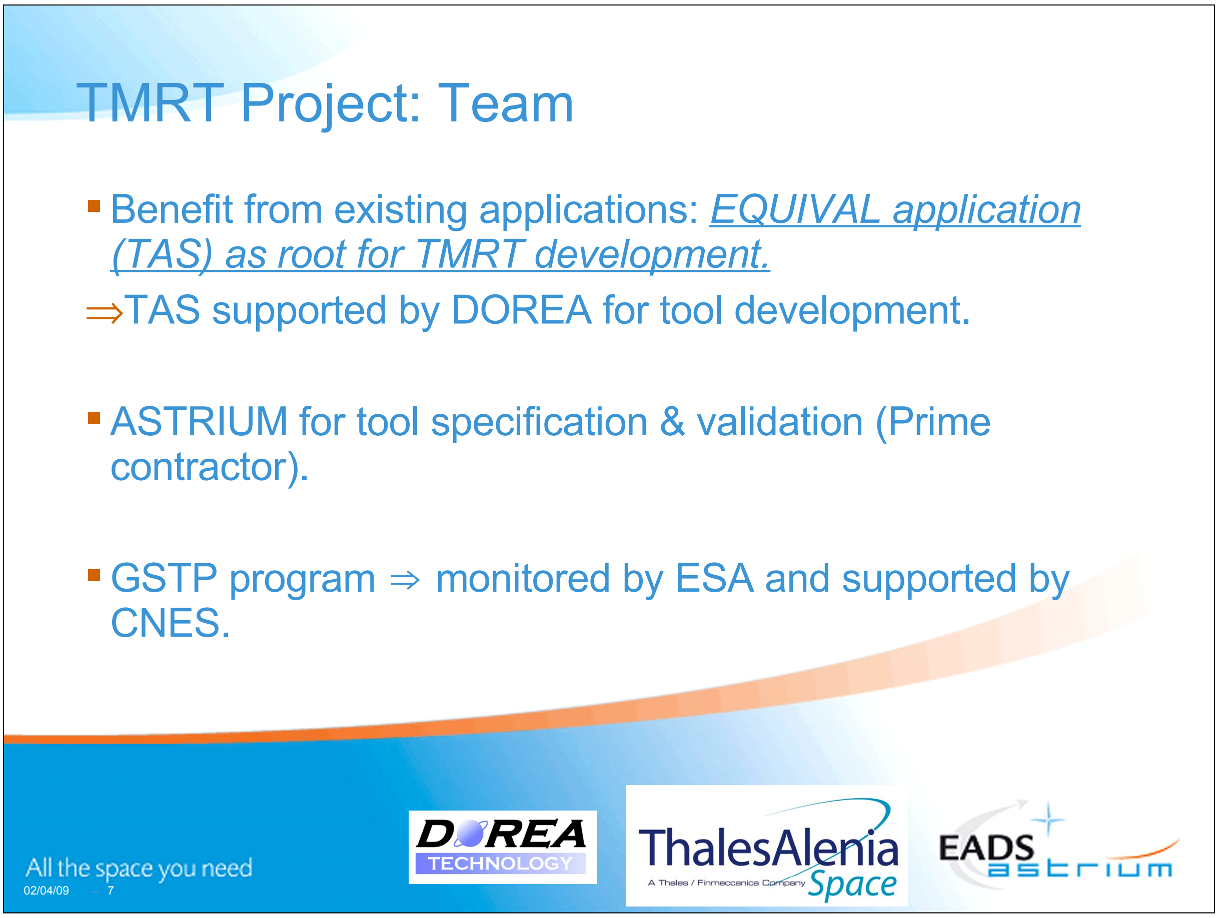
TMRT Project: Team
Benefit from existing applications: EQUIVAL application (TAS) as root for TMRT development.
⇒TAS supported by DOREA for tool development.
ASTRIUM for tool specification & validation (Prime contractor).
GSTP program ⇒ monitored by ESA and supported by CNES.
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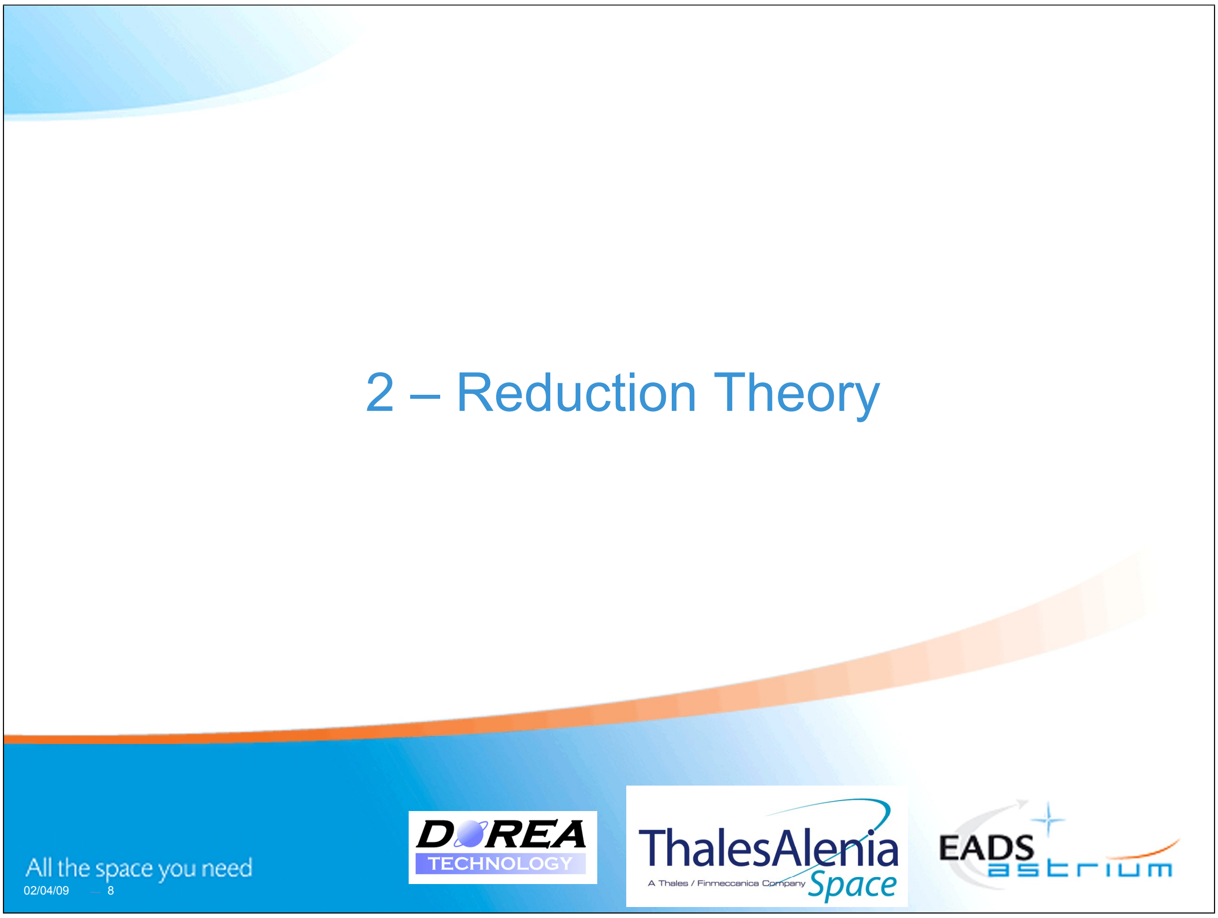
2 – Reduction Theory
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TMRT Theory: Matrix Equations

- Thermal System Heat Equation:

$$[C_{DD}]\{T_D\}+\{Q_D\}+\{P_D\}-[M_{DD}]\left\{\frac{\partial T_D}{\partial t}\right\}=\{0\}$$

- 3 kinds of nodes in detailed model:
  - K = kept nodes.
  - S = suppressed nodes (only if not radiative).
  - G = grouped nodes G defining average nodes A.

$$\begin{bmatrix} C_{KK} & C_{KS} & C_{KG} \\ C_{SK} & C_{SS} & C_{SG} \\ C_{GK} & C_{GS} & C_{GG} \end{bmatrix}\begin{Bmatrix} T_K \\ T_S \\ T_G \end{Bmatrix}+\begin{Bmatrix} Q_K \\ Q_S \\ Q_G \end{Bmatrix}+\begin{Bmatrix} P_K \\ 0 \\ P_G \end{Bmatrix}-\begin{bmatrix} M_{KK} & 0 & 0 \\ 0 & M_{SS} & 0 \\ 0 & 0 & M_{GG} \end{bmatrix}\begin{Bmatrix} \frac{\partial T_K}{\partial t} \\ \frac{\partial T_S}{\partial t} \\ \frac{\partial T_G}{\partial t} \end{Bmatrix}=\begin{Bmatrix} 0 \\ 0 \\ 0 \end{Bmatrix}$$

TMRT Theory: Matrix Equations

- Average Node Definition TA:
  - $T_A=\sum_G a_{AG}T_G$
  - a_{AG} = area/capacitance ratio of node G vs node A.

- Physical hypothesis: *Fluxes, radiative exchanges or convective exchanges proportional to node area.*
  - $P_G=a_{GA}P_A$

TMRT Theory: Matrix Equations

- Equivalent equations:
  - Reduced system heat equation:

$$[C'_{RR}]\begin{Bmatrix}T_K\\T_A\end{Bmatrix}+[PwD_{RD}]\begin{Bmatrix}Q_K\\Q_S\\Q_R\end{Bmatrix}+\begin{Bmatrix}P_K\\P_A\end{Bmatrix}-[M'_{RR}]\begin{Bmatrix}\frac{\partial T_K}{\partial t}\\ \frac{\partial T_A}{\partial t}\end{Bmatrix}=\{0\}$$

  - Temperature recovery equation:

$$\begin{Bmatrix}T_S\\T_G\end{Bmatrix}\approx[TRt_{MR}]\begin{Bmatrix}T_K\\T_A\end{Bmatrix}+[TRq_{MM}]\begin{Bmatrix}Q_S\\Q_G\end{Bmatrix}$$

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TMRT Theory: Radiative Approximation

- Error for radiative exchanges is a second order:

$$\sum_G a_{AG}T_G^4=\sum_j a_{AG}(T_A+\Delta T_G)^4$$

$$\sum_G a_{AG}T_G^4=T_A^4\underbrace{\sum_G a_{AG}}_{=1}+4T_A^3\underbrace{\sum_G a_{AG}\Delta T_G}_{=0}+6T_A^2\sum_G a_{AG}\Delta T_G^2+..$$

$$\sum_G a_{AG}T_G^4\approx T_A^4+6T_A^2\sum_G a_{AG}\Delta T_G^2$$

Proportional to radiative fluxes for detailed model

Proportional to radiative fluxes for Reduced model

Relative error is a second order

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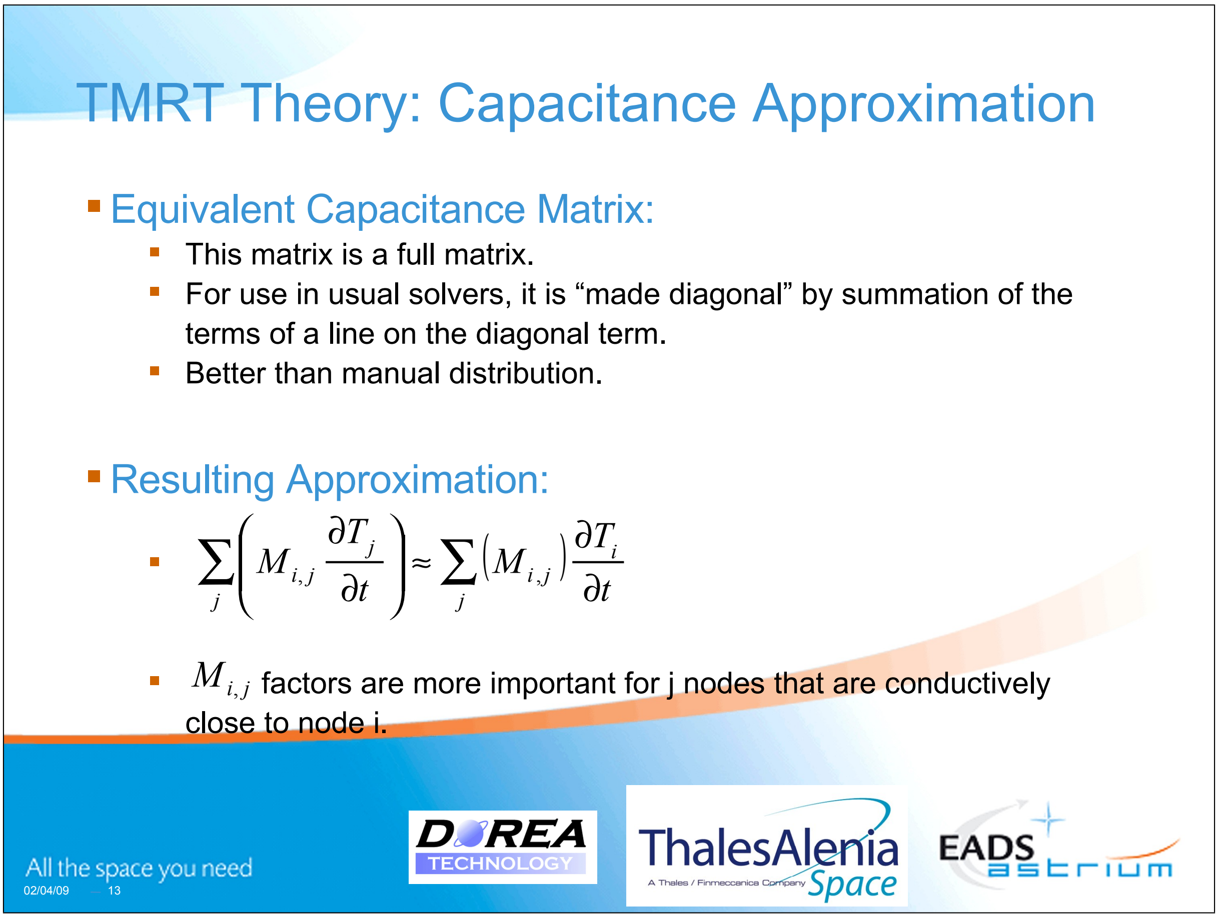
TMRT Theory: Capacitance Approximation
Equivalent Capacitance Matrix:
This matrix is a full matrix.
For use in usual solvers, it is “made diagonal” by summation of the terms of a line on the diagonal term.
Better than manual distribution.
Resulting Approximation:
$\sum_j \left(M_{i,j} \frac{\partial T_j}{\partial t} \right) \approx \sum_j \left(M_{i,j} \right) \frac{\partial T_i}{\partial t}$
$M_{i,j}$ factors are more important for j nodes that are conductively close to node i.
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3 – Software Functionalities
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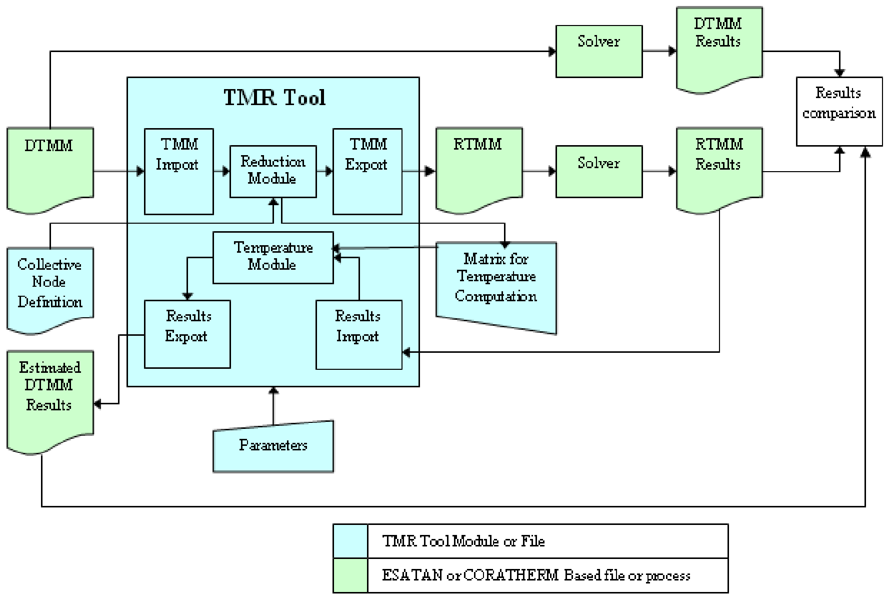
TMRT Functionalities: Logic Diagram



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TMRT Functionalities: Reduction

- Reduced model conductive coupling list computed by:
  - Building the original system conductance matrix from its conductive coupling list.
  - Importing the reduction definition.
  - Computing the equivalent conductance matrix.
  - Building the reduced model conductive coupling list from the equivalent conductance matrix.
- Reduced model radiative coupling list computed by summation of detailed model radiative couplings.

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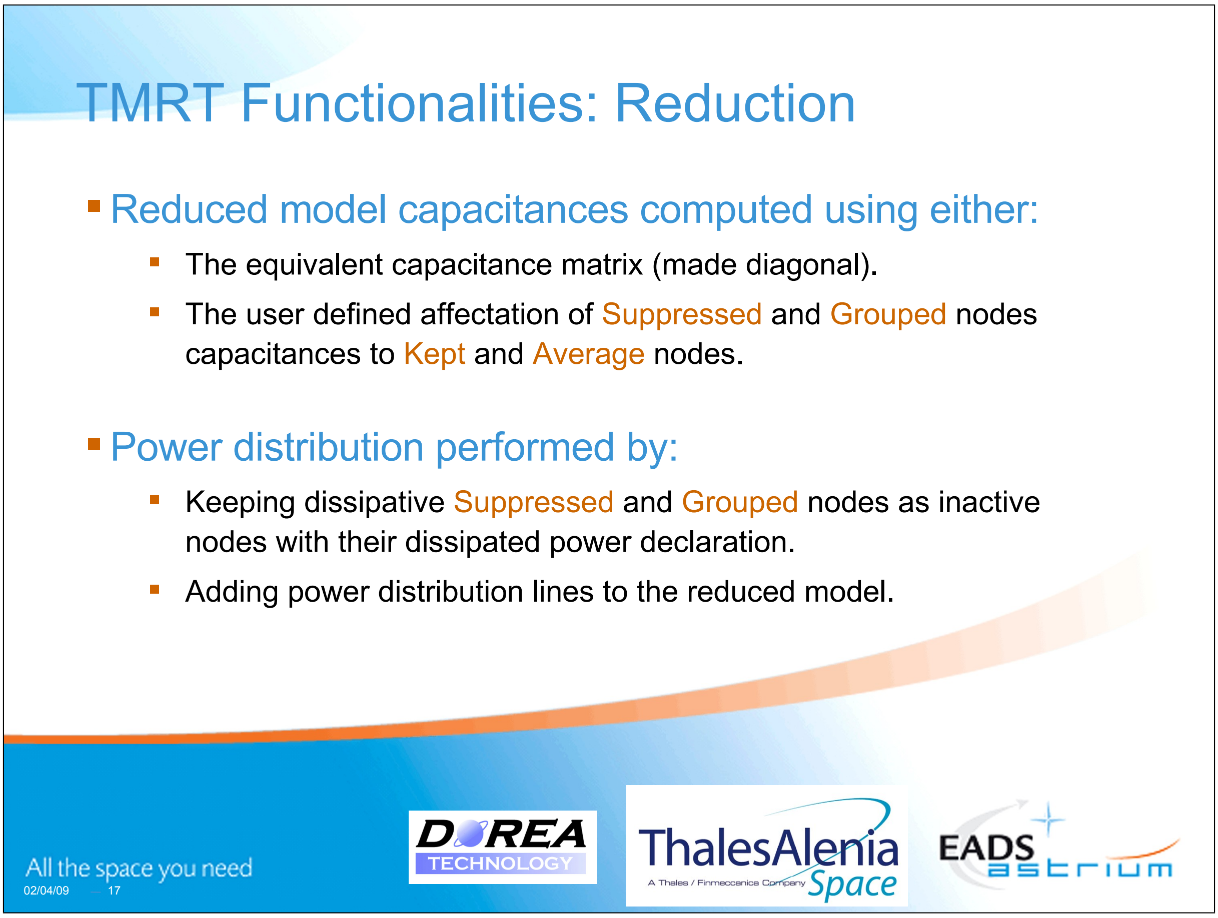
TMRT Functionalities: Reduction
Reduced model capacitances computed using either:
The equivalent capacitance matrix (made diagonal).
The user defined affectation of Suppressed and Grouped nodes capacitances to Kept and Average nodes.
Power distribution performed by:
Keeping dissipative Suppressed and Grouped nodes as inactive nodes with their dissipated power declaration.
Adding power distribution lines to the reduced model.
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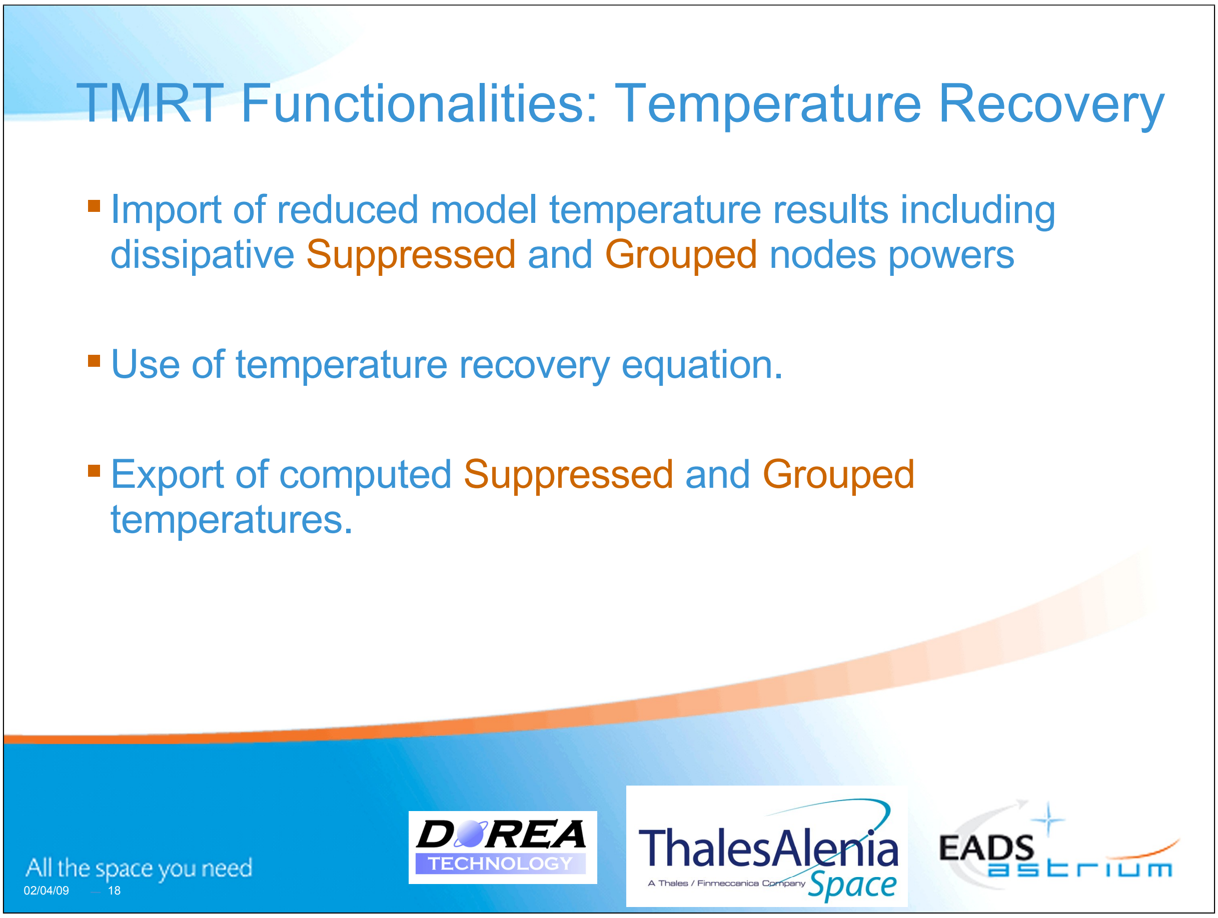
TMRT Functionalities: Temperature Recovery
Import of reduced model temperature results including dissipative Suppressed and Grouped nodes powers
Use of temperature recovery equation.
Export of computed Suppressed and Grouped temperatures.
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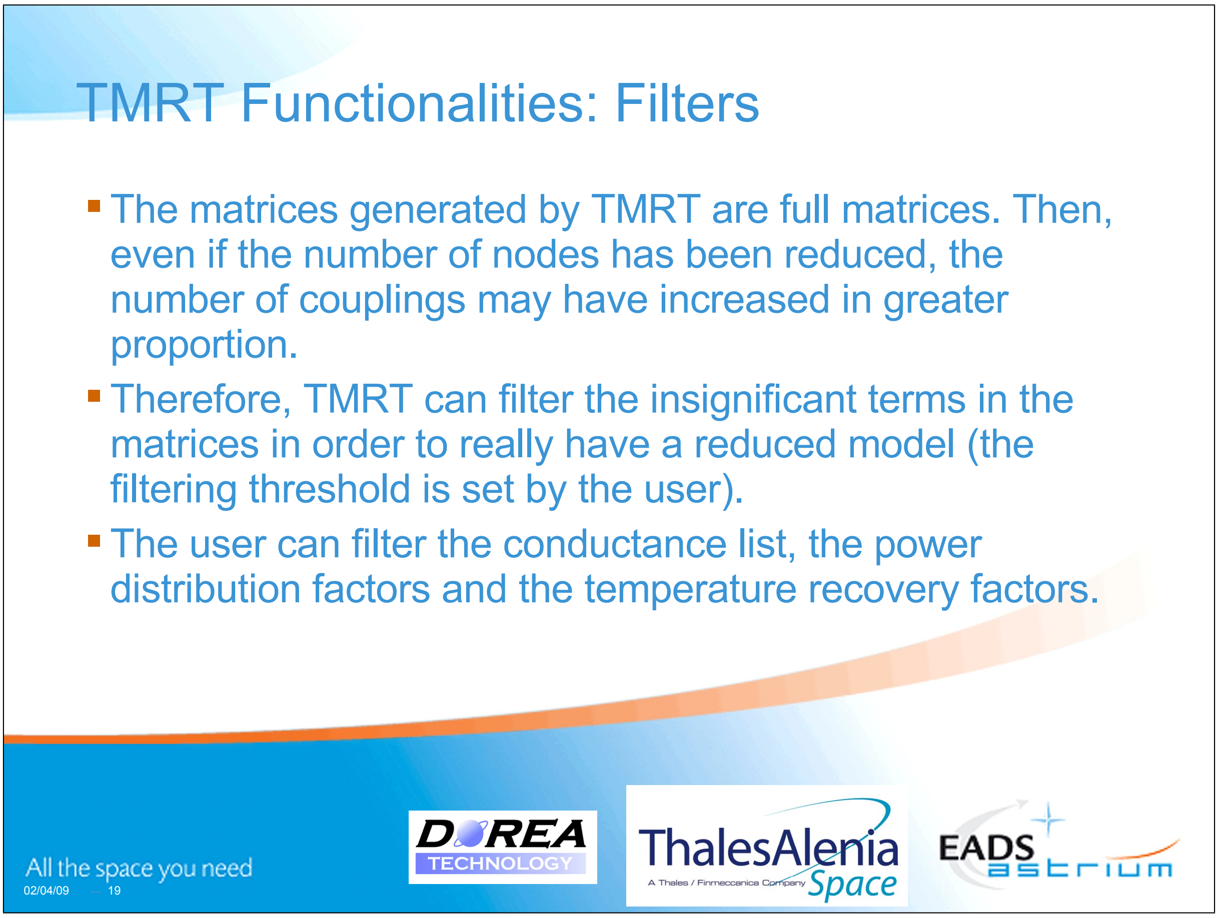
TMRT Functionalities: Filters
The matrices generated by TMRT are full matrices. Then, even if the number of nodes has been reduced, the number of couplings may have increased in greater proportion.
Therefore, TMRT can filter the insignificant terms in the matrices in order to really have a reduced model (the filtering threshold is set by the user).
The user can filter the conductance list, the power distribution factors and the temperature recovery factors.
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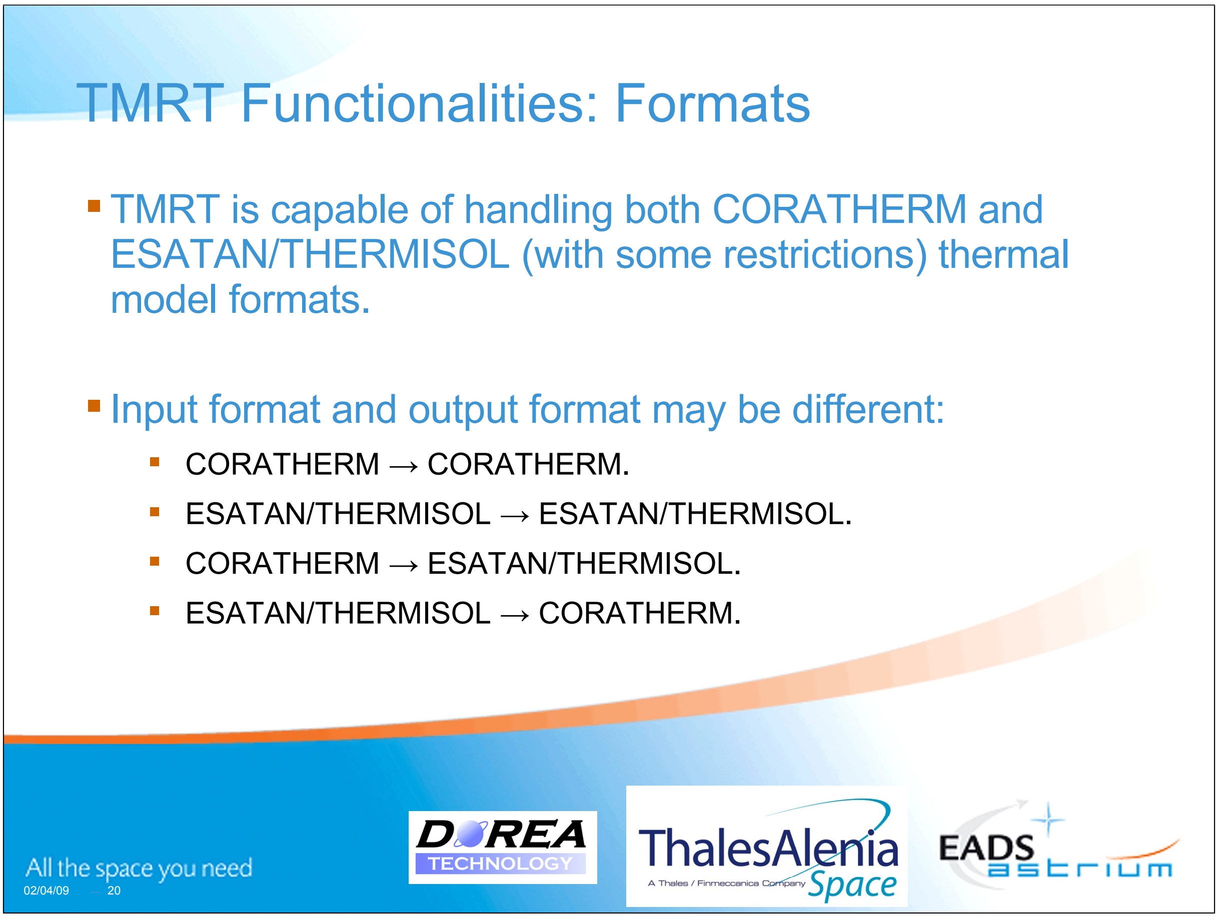
TMRT Functionalities: Formats
TMRT is capable of handling both CORATHERM and ESATAN/THERMISOL (with some restrictions) thermal model formats.
Input format and output format may be different:
CORATHERM → CORATHERM.
ESATAN/THERMISOL → ESATAN/THERMISOL.
CORATHERM → ESATAN/THERMISOL.
ESATAN/THERMISOL → CORATHERM.
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TMRT Functionalities: Post-process Nodes

- Recomputed Average (RA): Computing the average temperature for a group of nodes of the original thermal model.
- Conductive Exchange (CE): Computing the power conductively exchanged between 2 groups of nodes of the original thermal model.
- Computation performed during temperature recovery.

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4 – Demonstration

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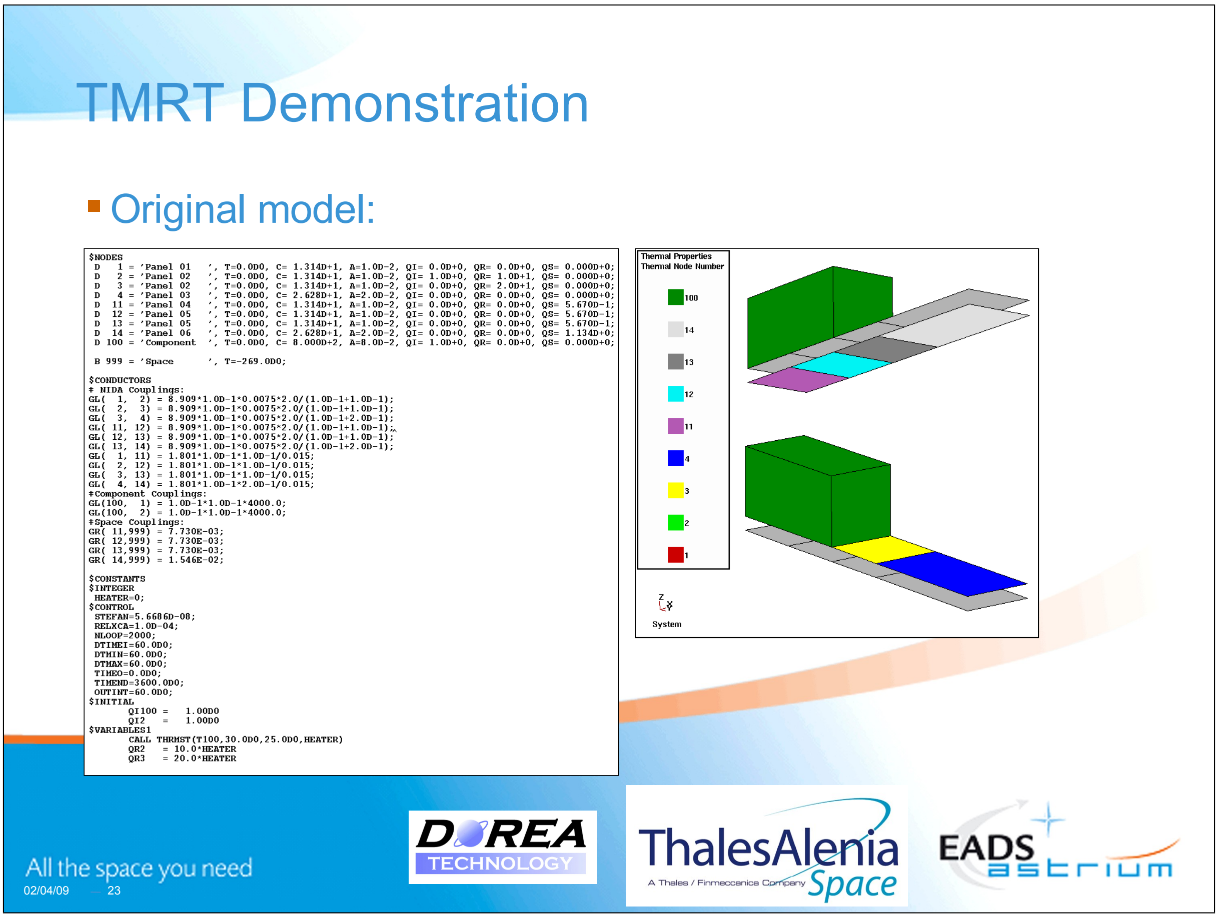
TMRT Demonstration
Original model:
$NODES
 D   1 = 'Panel 01   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 0.000D+0;
 D   2 = 'Panel 02   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 1.0D+0, QR= 1.0D+1, QS= 0.000D+0;
 D   3 = 'Panel 02   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 0.0D+0, QR= 2.0D+1, QS= 0.000D+0;
 D   4 = 'Panel 03   ', T=0.0D0, C= 2.628D+1, A=2.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 0.000D+0;
 D   11 = 'Panel 04   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 5.670D-1;
 D   12 = 'Panel 05   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 5.670D-1;
 D   13 = 'Panel 05   ', T=0.0D0, C= 1.314D+1, A=1.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 5.670D-1;
 D   14 = 'Panel 06   ', T=0.0D0, C= 2.628D+1, A=2.0D-2, QI= 0.0D+0, QR= 0.0D+0, QS= 1.134D+0;
 D 100 = 'Component   ', T=0.0D0, C= 8.000D+2, A=8.0D-2, QI= 1.0D+0, QR= 0.0D+0, QS= 0.000D+0;
 B 999 = 'Space   ', T=-269.0D0;
$CONDUCTORS
# NIDA Couplings:
GL(1, 2) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+1.0D-1);
GL(2, 3) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+1.0D-1);
GL(3, 4) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+2.0D-1);
GL(11, 12) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+1.0D-1);
GL(12, 13) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+1.0D-1);
GL(13, 14) = 8.909*1.0D-1*0.0075*2.0/(1.0D-1+2.0D-1);
GL(1, 11) = 1.801*1.0D-1*1.0D-1/0.015;
GL(2, 12) = 1.801*1.0D-1*1.0D-1/0.015;
GL(3, 13) = 1.801*1.0D-1*1.0D-1/0.015;
GL(4, 14) = 1.801*1.0D-1*2.0D-1/0.015;
#Component Couplings:
GL(100, 1) = 1.0D-1*1.0D-1*4000.0;
GL(100, 2) = 1.0D-1*1.0D-1*4000.0;
#Space Couplings:
GR(11,999) = 7.730E-03;
GR(12,999) = 7.730E-03;
GR(13,999) = 7.730E-03;
GR(14,999) = 1.546E-02;
$CONSTANTS
$INTEGER
 HEATER=0;
$CONTROL
 STEFAN=5.6686D-08;
 RELXCA=1.0D-04;
 NLOOP=2000;
 DTIMEI=60.0D0;
 DTMIN=60.0D0;
 DTMAX=60.0D0;
 TIMEO=0.0D0;
 TIMEND=3600.0D0;
 OUTINT=60.0D0;
$INITIAL
       QI100 =   1.00D0
       QI2   =   1.00D0
$VARIABLES1
       CALL THRMST(T100,30.0D0,25.0D0,HEATER)
       QR2   = 10.0*HEATER
       QR3   = 20.0*HEATER
Thermal Properties
Thermal Node Number
100
14
13
12
11
4
3
2
1
System
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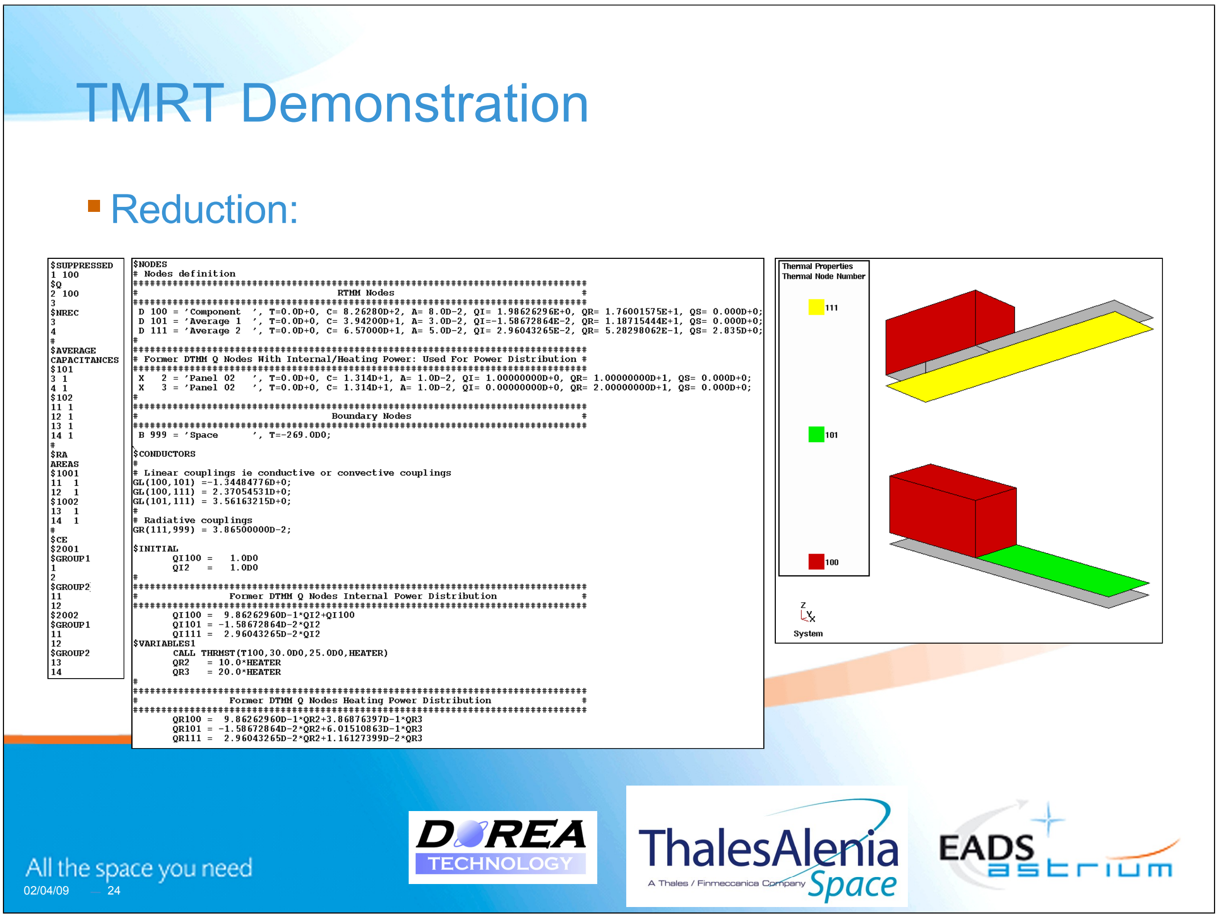
TMRT Demonstration
Reduction:
$SUPPRESSED
1 100
$Q
2 100
3
$NREC
3
4
#
$AVERAGE
CAPACITANCES
$101
3 1
4 1
$102
11 1
12 1
13 1
14 1
#
$RA
AREAS
$1001
11 1
12 1
$1002
13 1
14 1
#
$CE
$2001
$GROUP1
1
2
$GROUP2
11
12
$2002
$GROUP1
11
12
$GROUP2
13
14
$NODES
Nodes definition
###
RTMM Nodes
###
 D 100 = 'Component ', T=0.0D+0, C= 8.26280D+2, A= 8.0D-2, QI= 1.98626296E+0, QR= 1.76001575E+1, QS= 0.000D+0;
 D 101 = 'Average 1 ', T=0.0D+0, C= 3.94200D+1, A= 3.0D-2, QI=-1.58672864E-2, QR= 1.18715444E+1, QS= 0.000D+0;
 D 111 = 'Average 2 ', T=0.0D+0, C= 6.57000D+1, A= 5.0D-2, QI= 2.96043265E-2, QR= 5.28298062E-1, QS= 2.835D+0;
#
###
Former DTMM Q Nodes With Internal/Heating Power: Used For Power Distribution
###
 X   2 = 'Panel 02   ', T=0.0D+0, C= 1.314D+1, A= 1.0D-2, QI= 1.00000000D+0, QR= 1.00000000D+1, QS= 0.000D+0;
 X   3 = 'Panel 02   ', T=0.0D+0, C= 1.314D+1, A= 1.0D-2, QI= 0.00000000D+0, QR= 2.00000000D+1, QS= 0.000D+0;
#
###
Boundary Nodes
###
 B 999 = 'Space   ', T=-269.0D0;
$CONDUCTORS
#
Linear couplings ie conductive or convective couplings
GL(100,101) =-1.34484776D+0;
GL(100,111) = 2.37054531D+0;
GL(101,111) = 3.56163215D+0;
#
Radiative couplings
GR(111,999) = 3.86500000D-2;
$INITIAL
       QI100 =   1.0D0
       QI2   =   1.0D0
#
###
Former DTMM Q Nodes Internal Power Distribution
###
       QI100 = 9.86262960D-1*QI2+QI100
       QI101 = -1.58672864D-2*QI2
       QI111 = 2.96043265D-2*QI2
$VARIABLES1
       CALL THRMST(T100,30.0D0,25.0D0,HEATER)
       QR2   = 10.0*HEATER
       QR3   = 20.0*HEATER
#
###
Former DTMM Q Nodes Heating Power Distribution
###
       QR100 = 9.86262960D-1*QR2+3.86876397D-1*QR3
       QR101 = -1.58672864D-2*QR2+6.01510863D-1*QR3
       QR111 = 2.96043265D-2*QR2+1.16127399D-2*QR3
Thermal Properties
Thermal Node Number
111
101
100
System
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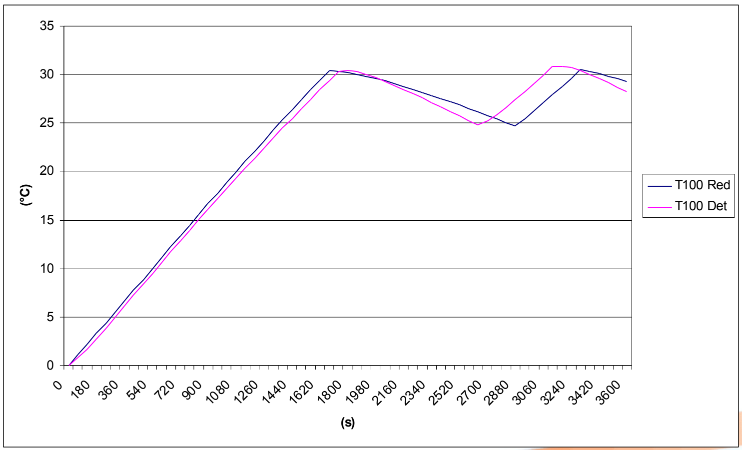
TMRT Demonstration

- Unit Temperature Response Comparison:



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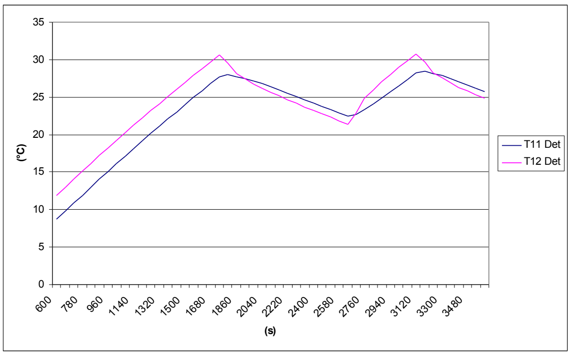
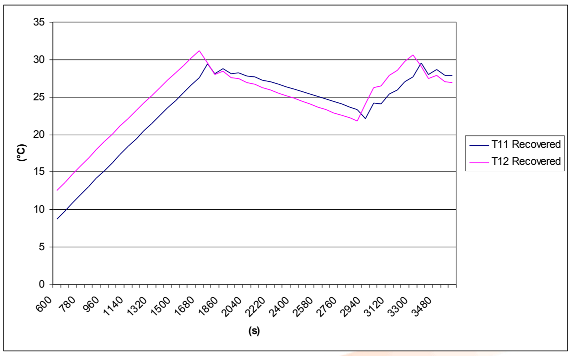
TMRT Demonstration

- Temperature Recovery:





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5 – Conclusion

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Conclusion

- Present Situation: End of software validation
- For huge models, special attention is needed for reasonable CPU time duration (software optimised for LINUX 64bits)
- Commercialization: Q4 2009 with dedicated documentation :
  - Theoretical manual explaining theory based on rigorous mathematical demonstration.
  - User’s manual.

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Appendix E

GENETIK
Genetic algorithm for the sizing cases research

Hélène Pasquier Stéphane Clouet
(CNES, France)

Abstract

GENETIK is a CNES internal tool which use genetic algorithm for sizing cases research. A first development phase has been started in 2005, with a validation on simple cases.
In 2009, a second development and validation phase has led to an optimized tool in term of results and methodology.
The objectives of the presentation are the following:

- Describe the principles of genetic algorithms,
- Focus on optimization in GENETIK in term of algorithm operators and methodology,
- Present validation cases and results.

GENETIK :

Genetic algorithms for the sizing cases research

PASQUIER Hélène, *Thermal Engineer, CNES*

CLOUET Stéphane, *CNES trainee*

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Agenda

- Context of the study
- Genetic Algorithms
  - Presentation
  - Operator optimization
- Example
- Conclusion

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Agenda

- Context of the study
- Genetic Algorithms
  - Presentation
  - Operator optimization
- Example
- Conclusion

Context of the study

- New project → complex orbit and many possible attitude (random attitude for example)
  - → **More complicated to determine the dimensioning case for thermal analysis**
- Use of genetic algorithms for sizing cases research → training period in 2005 has led to a first internal tool GENETIK
- 2009 : new training period to
  - Improve knowledge on genetic algorithms
  - Optimize GENETIK
  - Validate the internal tool on simple cases

Agenda

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Genetic Algorithms - *Presentation*

- Search technique used to find solutions to optimization problems
- Technique inspired by evolutionary biology such as inheritance, mutation, selection, and crossover.
- Vocabulary :
  - Gene : parameter of the problem (ex. : altitude of the satellite)
  - Individual : combination of genes
  - Population : set of individual
  - Fitness : evaluation function to optimize (most of the time temperature)

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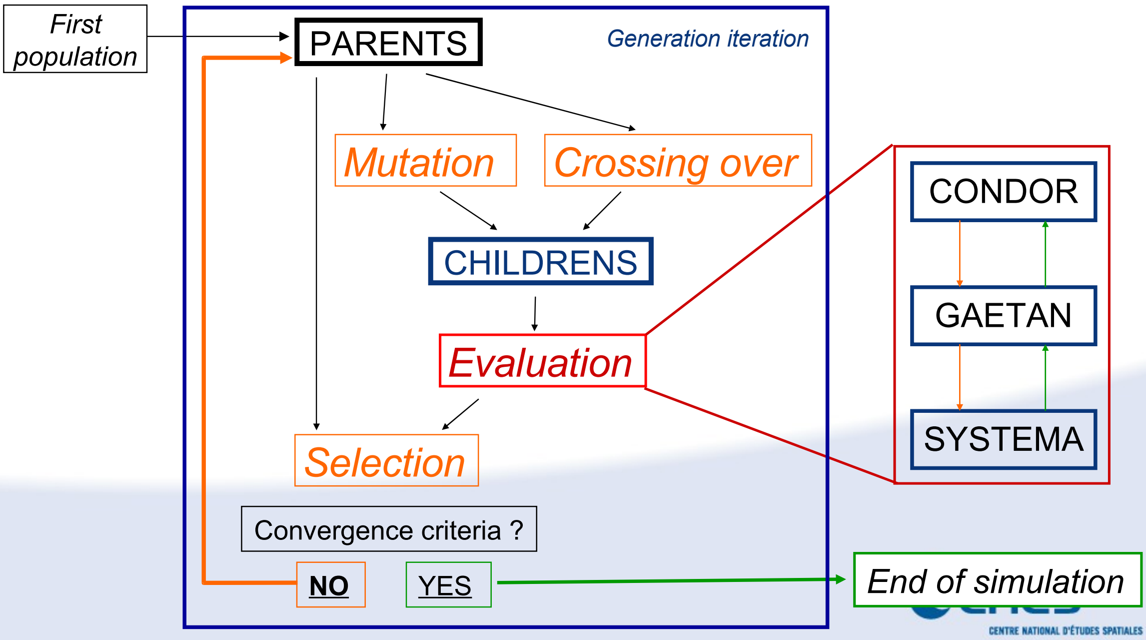
Genetic Algorithms - *Presentation*

- General architecture of the algorithm :



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Agenda

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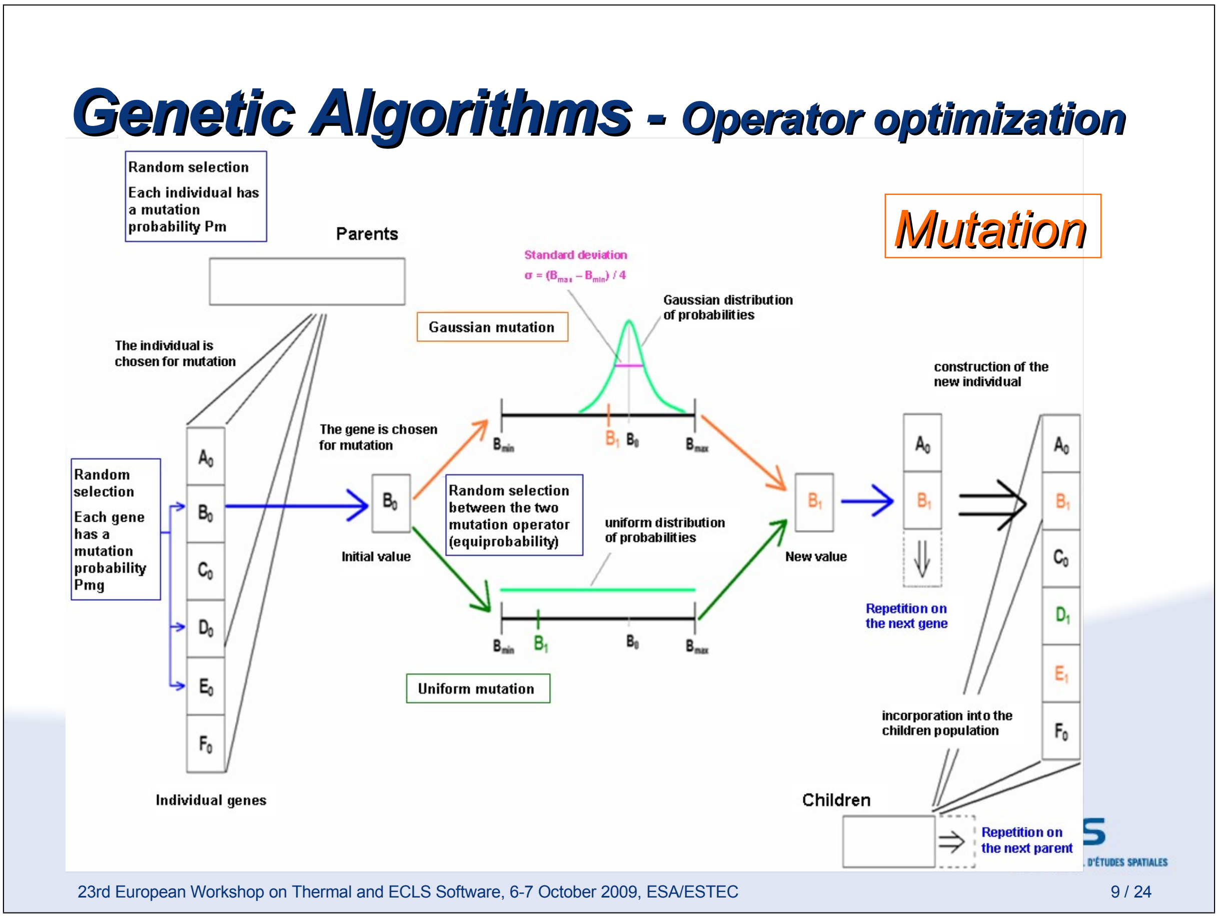
Genetic Algorithms - Operator optimization
Mutation
Random selection
Each individual has a mutation probability Pm
Parents
The individual is chosen for mutation
Random selection
Each gene has a mutation probability Pmg
Individual genes
The gene is chosen for mutation
Initial value
Gaussian mutation
Standard deviation
σ = (Bmax – Bmin) / 4
Gaussian distribution of probabilities
Random selection between the two mutation operator (equiprobability)
uniform distribution of probabilities
Uniform mutation
New value
construction of the new individual
Repetition on the next gene
incorporation into the children population
Children
Repetition on the next parent
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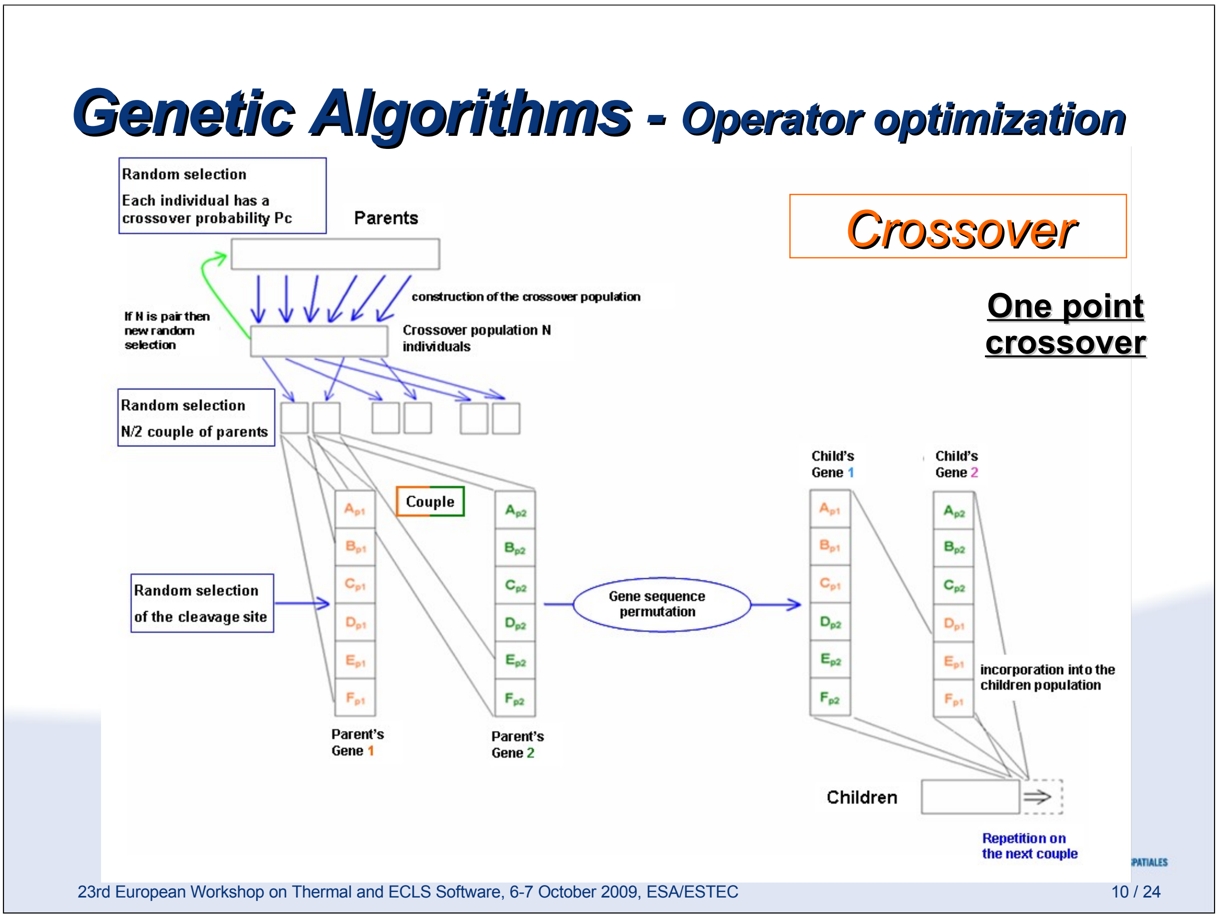
Genetic Algorithms - Operator optimization
Crossover
One point crossover
Random selection
Each individual has a crossover probability Pc
Parents
construction of the crossover population
If N is pair then new random selection
Crossover population N individuals
Random selection
N/2 couple of parents
Couple
Random selection of the cleavage site
Parent's Gene 1
Parent's Gene 2
Gene sequence permutation
Child's Gene 1
Child's Gene 2
incorporation into the children population
Children
Repetition on the next couple
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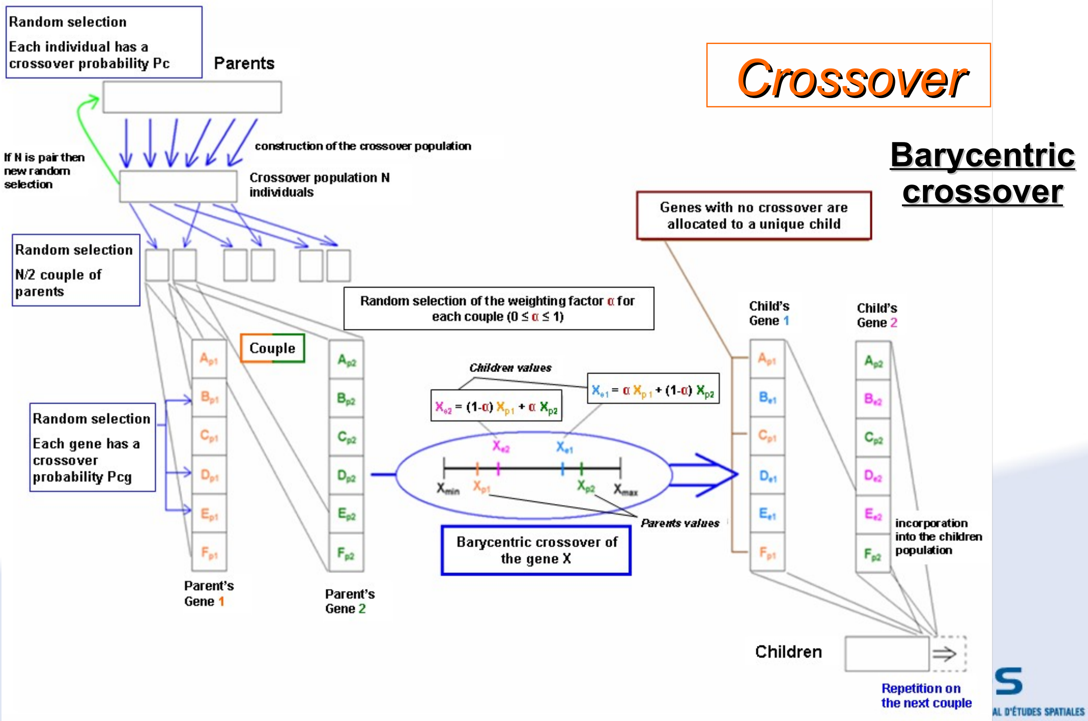
Genetic Algorithms - *Operator optimization*



Genetic Algorithms - *Operator optimization*

Selection

SELECTION :

Keep the **best** individuals to converge but keep **diversity** to avoid convergence to a local optimum

➡ Two different ways :

- **elitism**
- **roulette wheel**

WHAT IS A INTERESTING INDIVIDUAL FOR SELECTION :

- An individual with a good fitness
- An individual which is "far" from the other good individuals
- An individual which dominate a "zone" in the search space

➡ Elitism threshold on fitness

➡ Threshold on each gene of the individual

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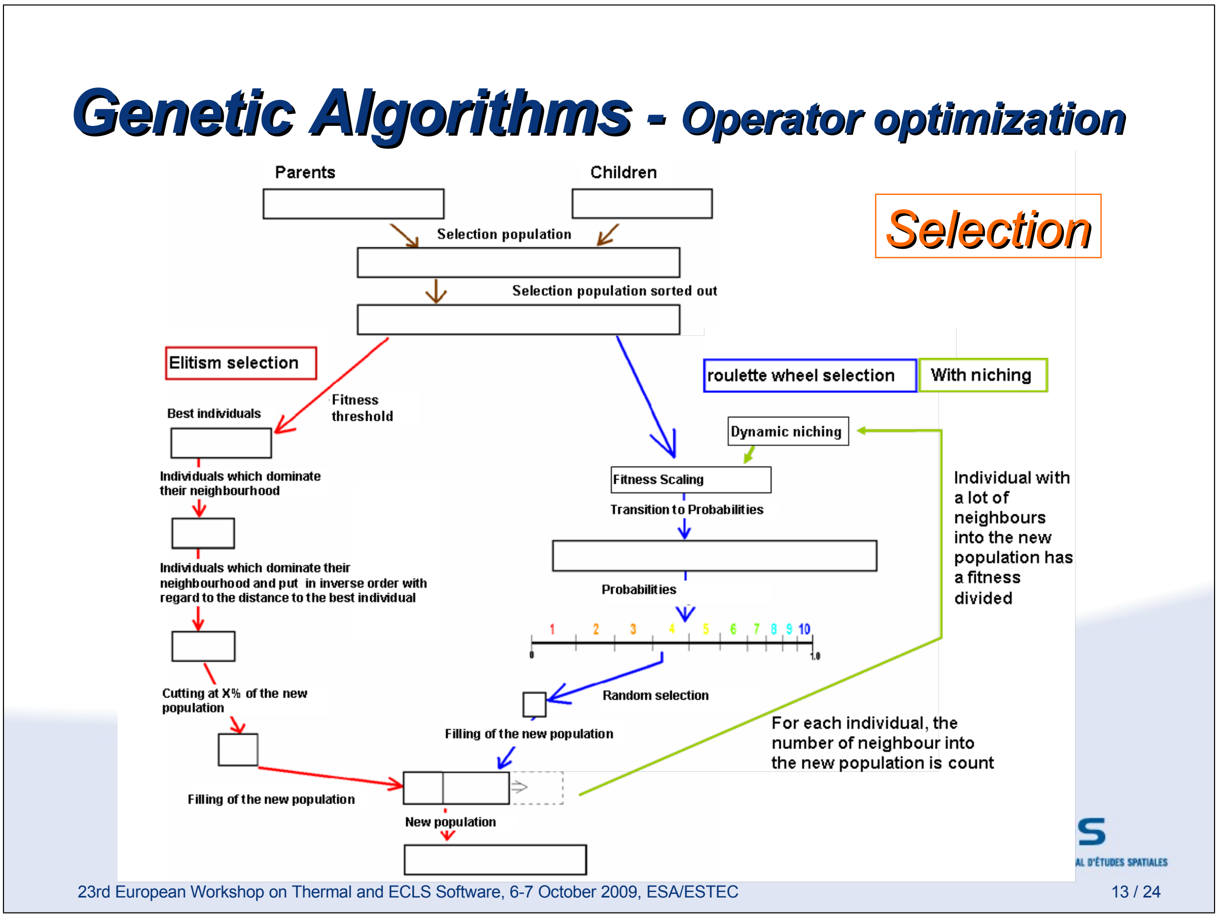
Genetic Algorithms - Operator optimization
Selection
Parents
Children
Selection population
Selection population sorted out
Elitism selection
Best individuals
Fitness threshold
Individuals which dominate their neighbourhood
Individuals which dominate their neighbourhood and put in inverse order with regard to the distance to the best individual
Cutting at X% of the new population
Filling of the new population
New population
roulette wheel selection
With niching
Dynamic niching
Fitness Scaling
Transition to Probabilities
Probabilities
1 2 3 4 5 6 7 8 9 10
Random selection
Filling of the new population
Individual with a lot of neighbours into the new population has a fitness divided
For each individual, the number of neighbour into the new population is count
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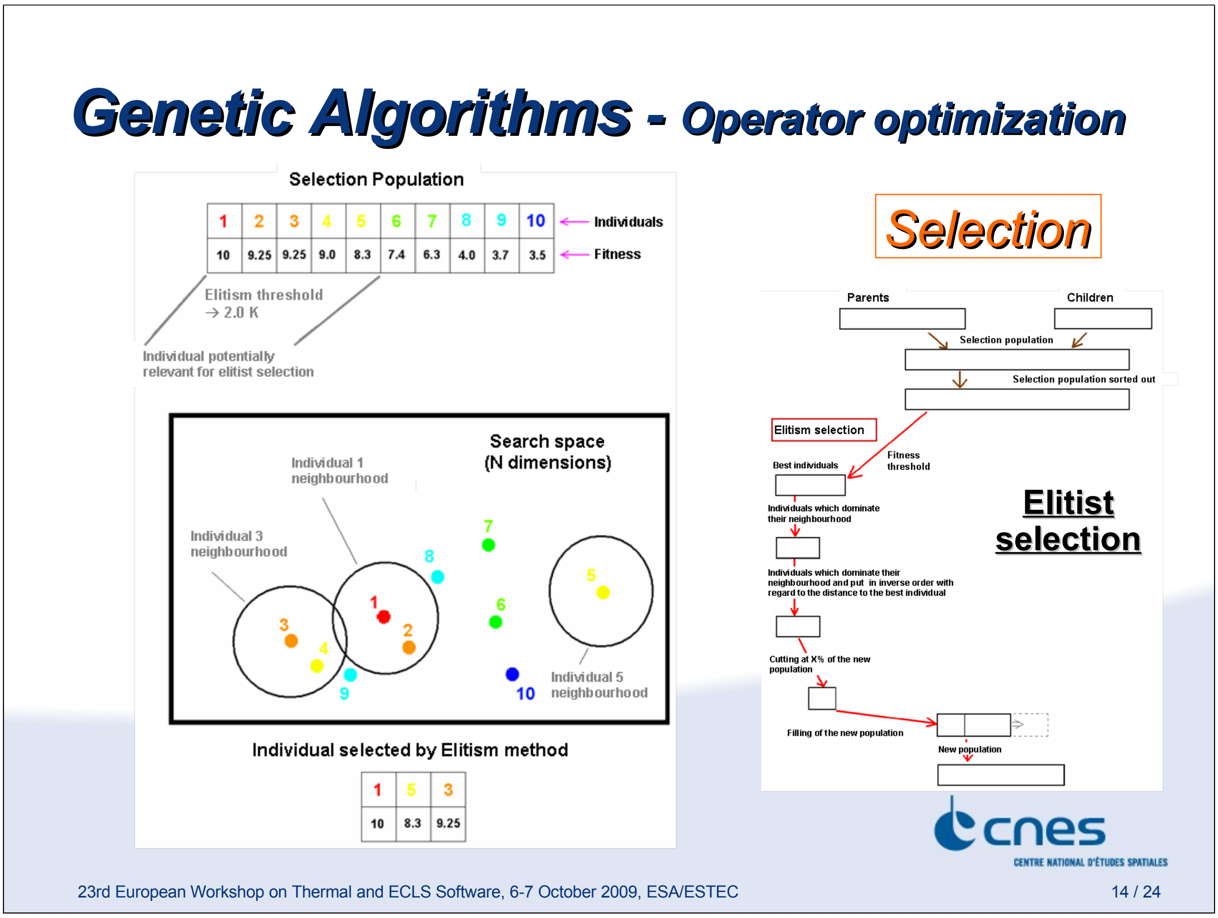
Genetic Algorithms - Operator optimization
Selection
Selection Population
1 2 3 4 5 6 7 8 9 10 Individuals
10 9.25 9.25 9.0 8.3 7.4 6.3 4.0 3.7 3.5 Fitness
Elitism threshold → 2.0 K
Individual potentially relevant for elitist selection
Search space (N dimensions)
Individual 1 neighbourhood
Individual 3 neighbourhood
Individual 5 neighbourhood
Individual selected by Elitism method
1 5 3
10 8.3 9.25
Elitist selection
Parents
Children
Selection population
Selection population sorted out
Elitism selection
Best individuals
Fitness threshold
Individuals which dominate their neighbourhood
Individuals which dominate their neighbourhood and put in inverse order with regard to the distance to the best individual
Cutting at X% of the new population
Filling of the new population
New population
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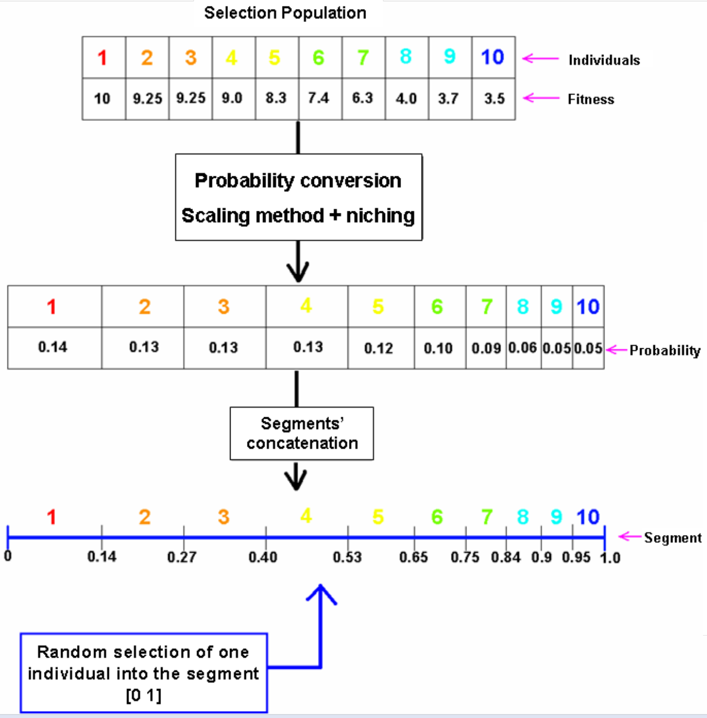
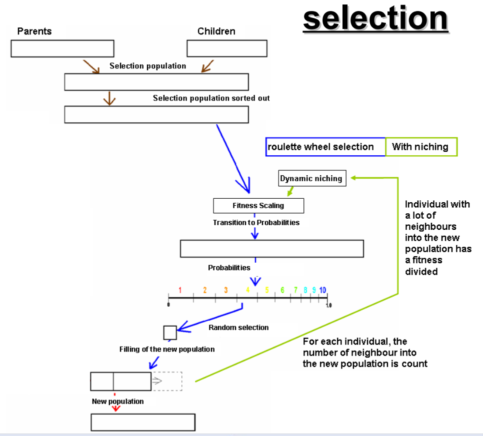
Genetic Algorithms - Operator optimization



Selection

Roulette wheel selection



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Agenda

- Context of the study
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  - Operator optimization
- Example
- Conclusion

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Example

- On a simple geometry (cube with anisotropic conductivity)
- Sun synchronous orbit
- Tested parameters :
  - Altitude : [700 ; 900] km
  - Solar hour at ascending node : [06h00 ; 12h30]
  - Albedo : [0.35 ; 0.50]
  - Attitude vector 1 : { z, -z }
  - Attitude vector 2 : {x, -x, y, -y}
  - Day of the year : [1 ; 365]

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Example

- Protocol
  - First simulation :

    IDENTIFICATION of the important gene – optimization of the selection parameter
  - Second simulation

    CONFIRMATION of all the local optima
  - Third and last simulation

    LOCAL EXPLORATION around the local optima to determine the global one

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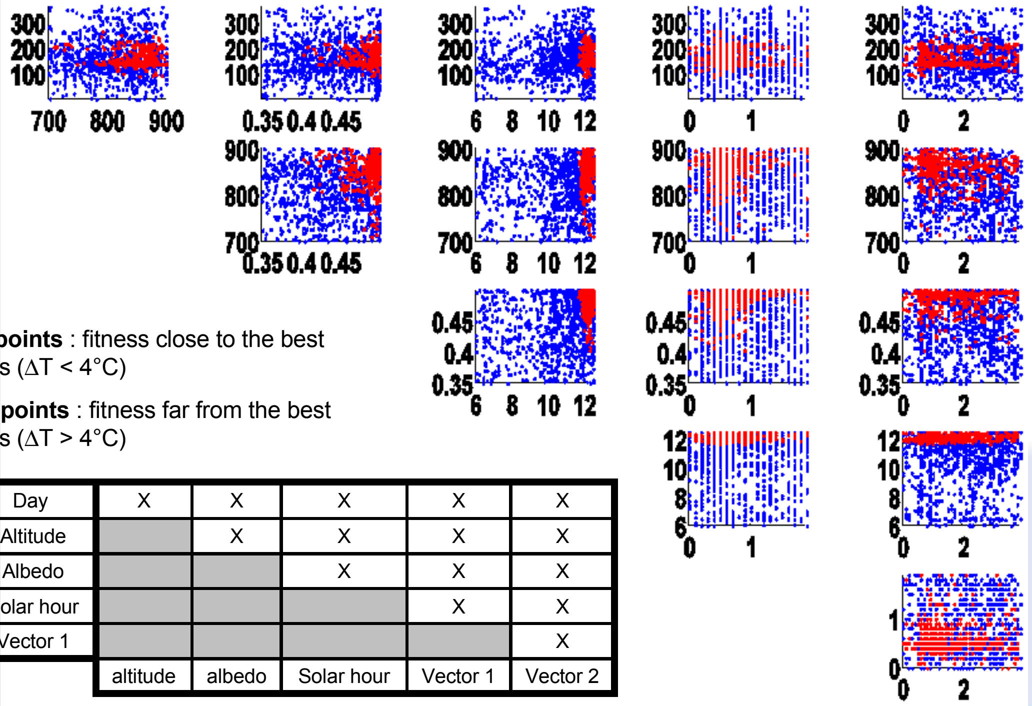
Example – first simulation



Red points : fitness close to the best fitness (ΔT < 4°C)

Blue points : fitness far from the best fitness (ΔT > 4°C)

	altitude	albedo	Solar hour	Vector 1	Vector 2
Day	X	X	X	X	X
Altitude		X	X	X	X
Albedo			X	X	X
Solar hour				X	X
Vector 1					X

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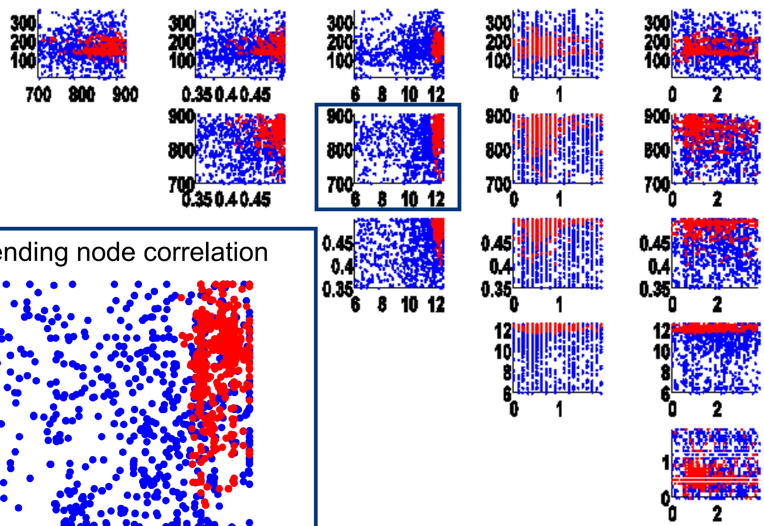
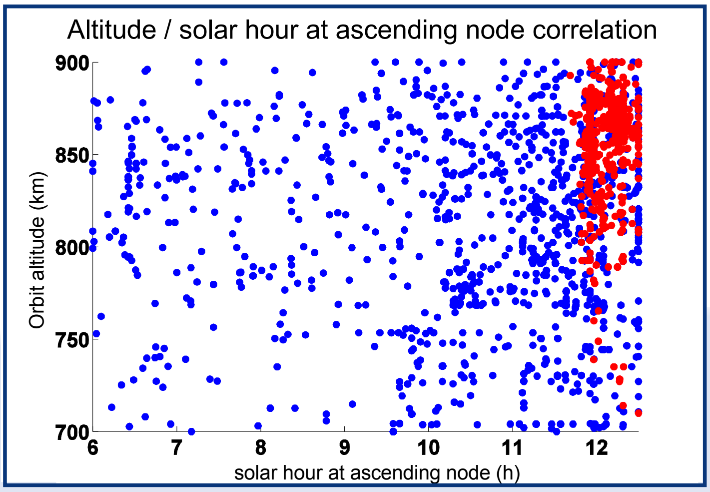
Example – first simulation





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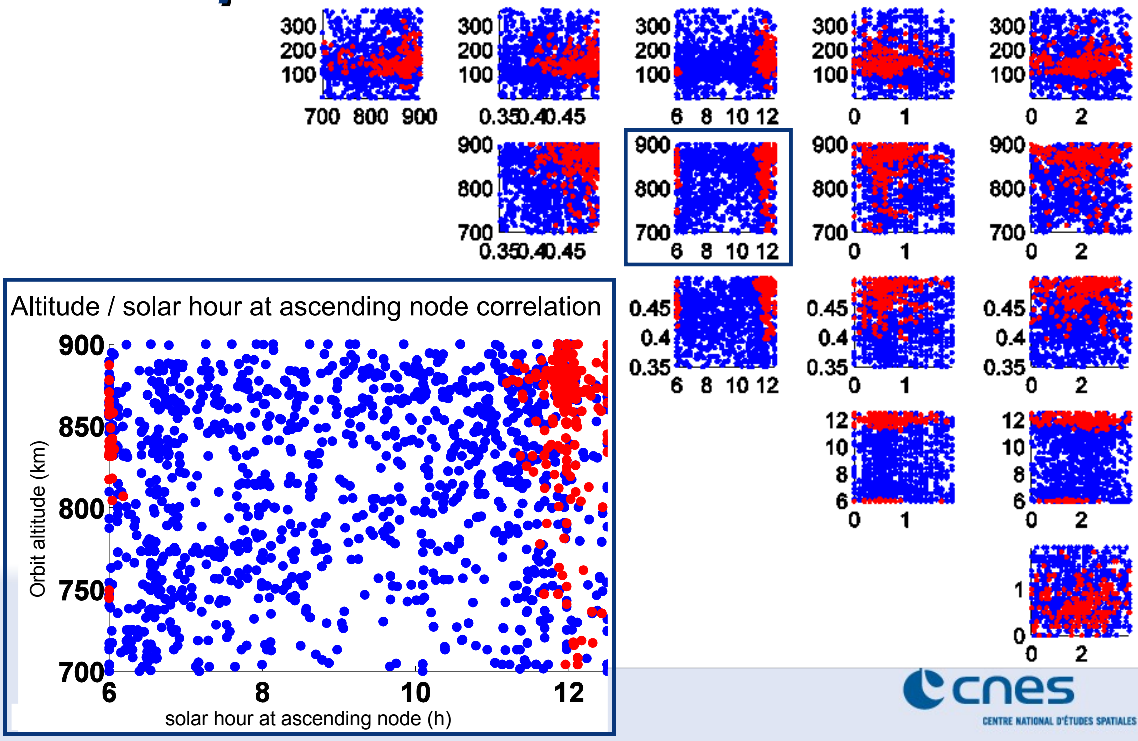
23rd European Workshop on Thermal and ECLS Software, 6-7 October 2009, ESA/ESTEC 20 / 24

Example – *second simulation*



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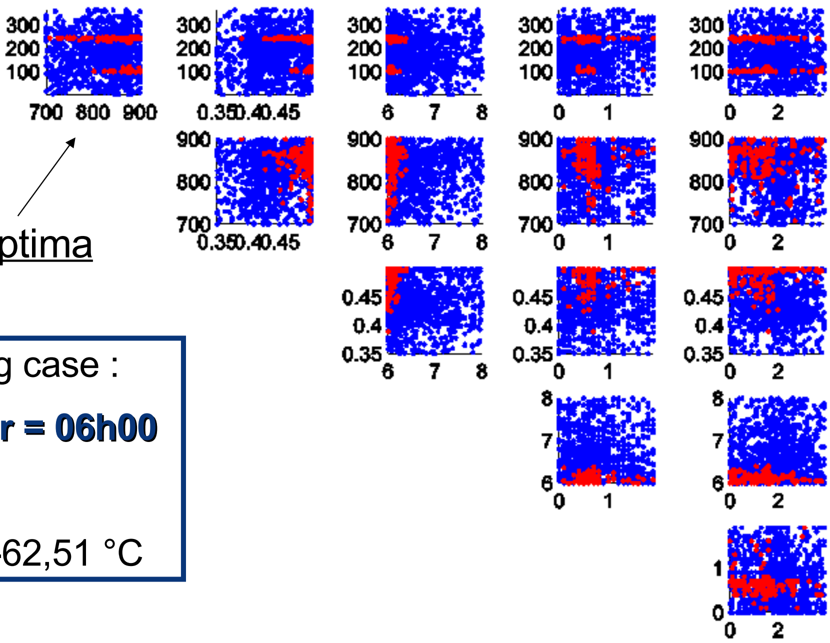
Example – *third simulation*

Local simulation on the two optima :



New local optima

Final sizing case :

Solar hour = 06h00

Day = 242

Fitness = -62,51 °C

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Agenda

- Context of the study
- Genetic Algorithms
  - Presentation
  - Operator optimization
- Example
- Conclusion

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Conclusion

- GENETIK is today optimized
- Validation on a simple case → definition of a user protocol
- Simulation duration → ~50 to 70h on one processor
- New development to allow a continuous exploration for attitude
- After a complete validation, integration in GAETAN V5

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Appendix F

SYSTEMA

Marc Baucher
(EADS Astrium, France)

Abstract

V4 modularity

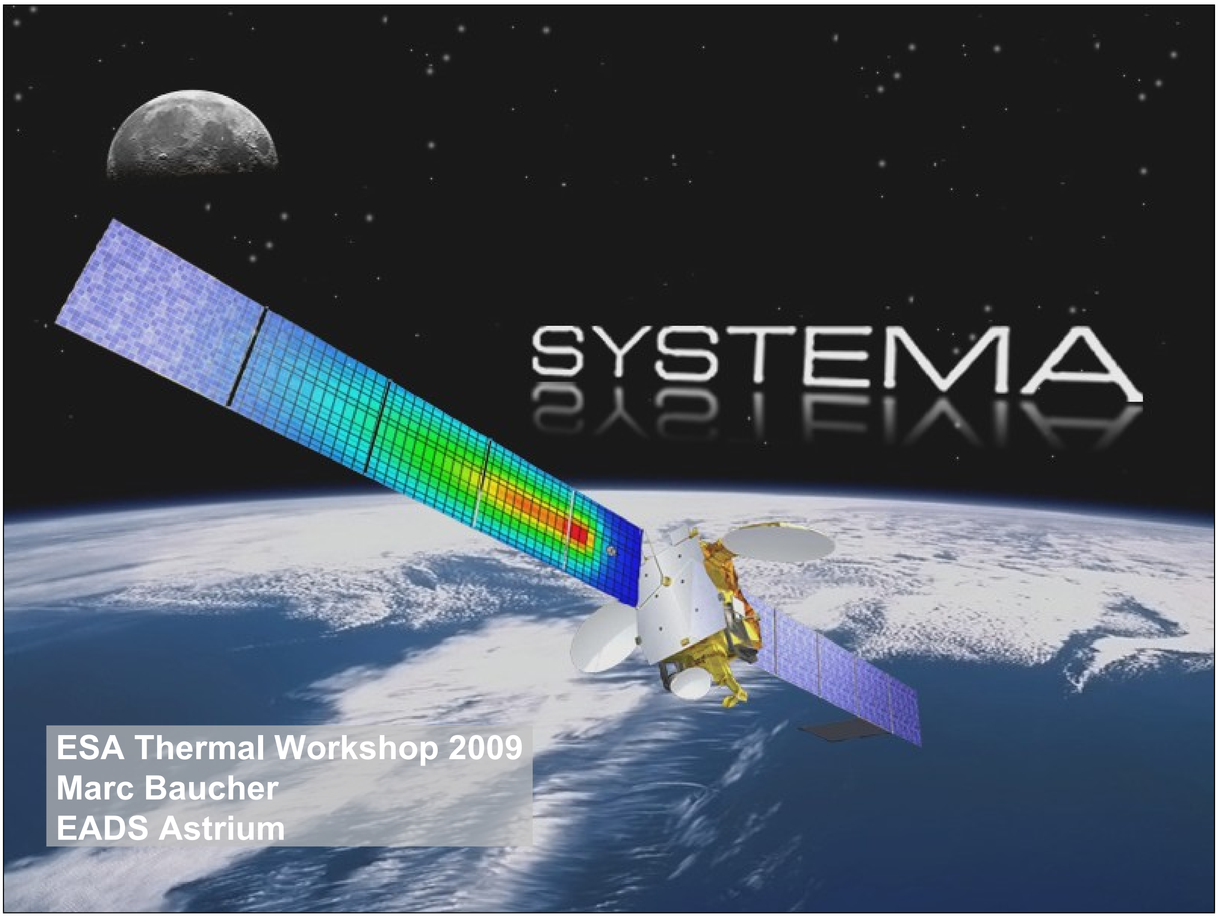
Previously, on v3 releases, creating the input data of a simulation was a based on a sequential process. Now the v4, in addition to extended modeling capabilities, brings a new way of building models and missions. The modeling process in v4 is completely based on a modular and dynamic framework that makes switch possible from all input data. Moreover, any modification is dynamically applied to all other related elements.
This first part reminds the v4 concepts and compares v3 and v4 processes.

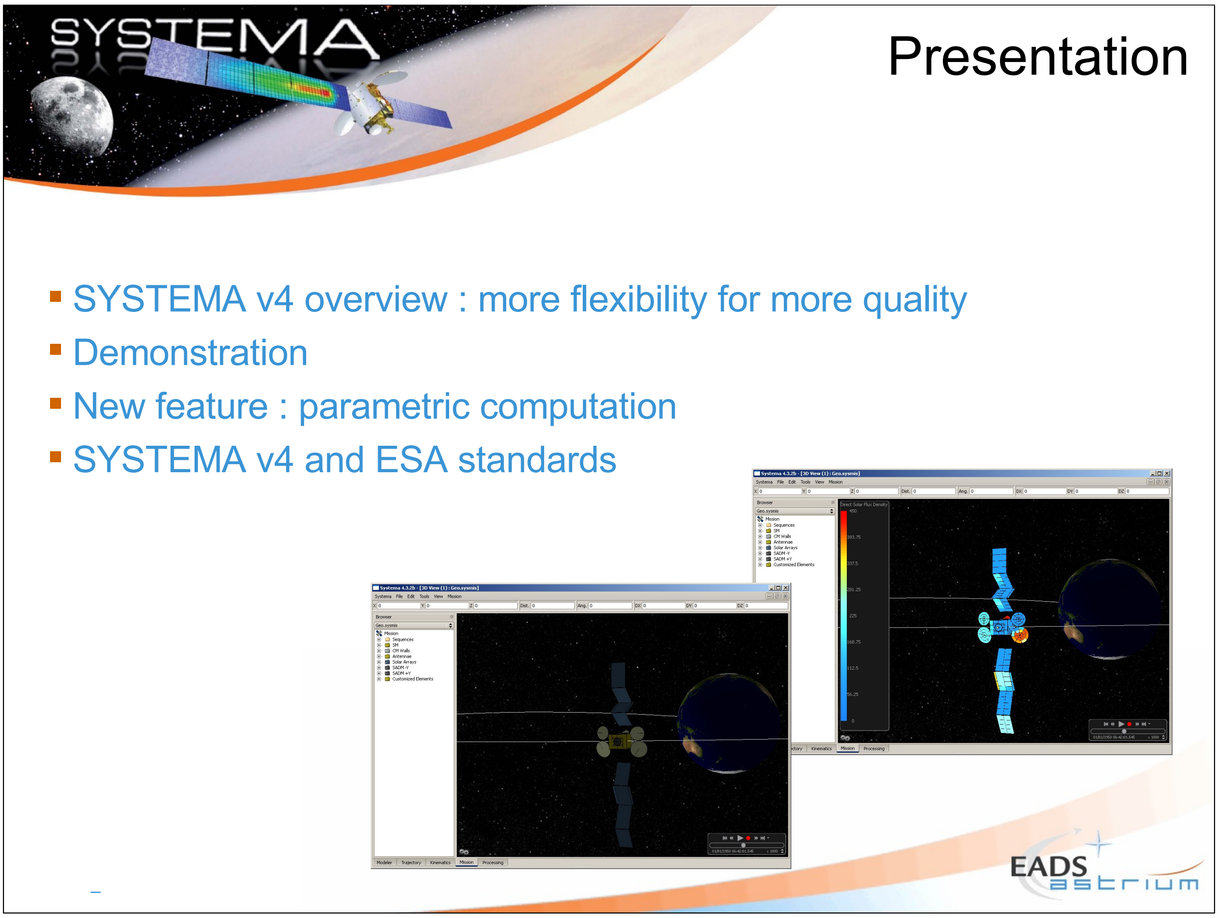
Parametric analysis & Batch process

In version 4.3.3, the concept of parameters allows to define parametric models and missions. It is also now possible to perform complete batch process using parametric inputs.

Interfaces

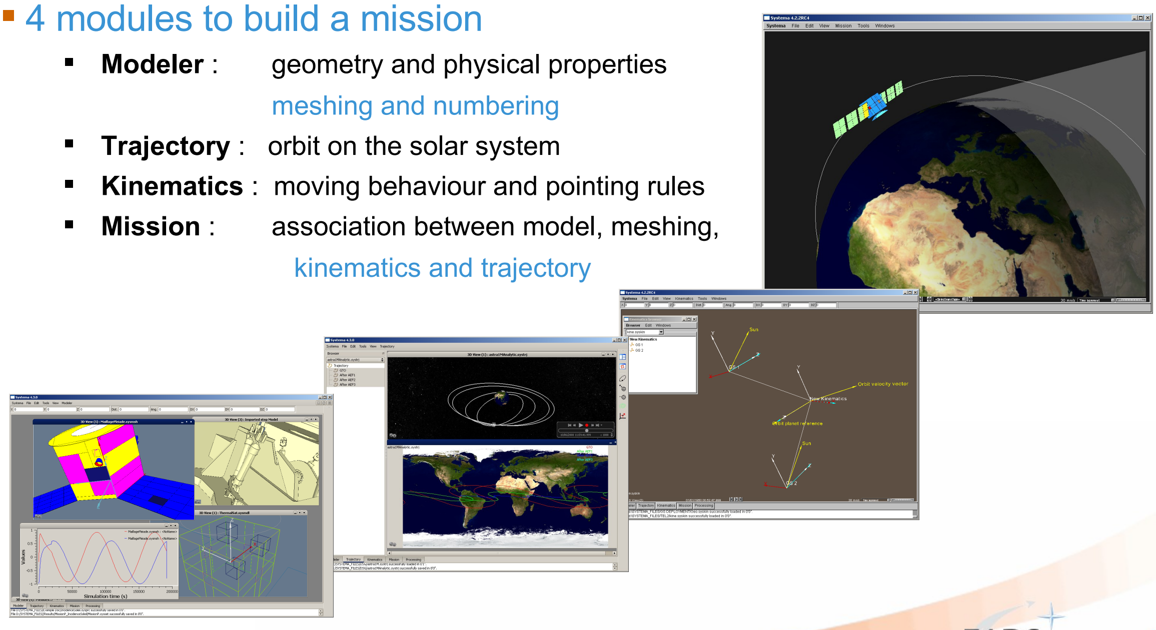
SYSTEMA / THERMICA has now a new import/export integrated option with the STEP-TAS format. Moreover, a new converter translates the SYSTEMA native output format (HDF5/SDS) to STEP-NRF. This will also allow the integration of ESATAP in post-processing.


SYSTEMA
ESA Thermal Workshop 2009
Marc Baucher
EADS Astrium


SYSTEMA
Presentation
SYSTEMA v4 overview : more flexibility for more quality
Demonstration
New feature : parametric computation
SYSTEMA v4 and ESA standards
EADS
astrium

Overview

- 4 modules to build a mission
  - **Modeler** : geometry and physical properties
    meshing and numbering
  - **Trajectory** : orbit on the solar system
  - **Kinematics** : moving behaviour and pointing rules
  - **Mission** : association between model, meshing,
    kinematics and trajectory



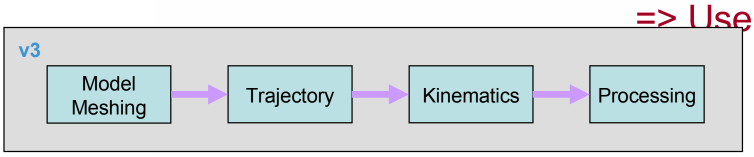
EADS astrium

Overview

- Back to v3 : an iterative process
  - Step-by-step mission building :
    - Model needed by trajectory
    - Trajectory needed by kinematics

    => Parallel edition not easy
  - "Thinking about everything" problematic :
    - Model shall be adapted to the kinematics frames
    - Trajectory orbits shall be split to define kinematics phases

    => Useless building

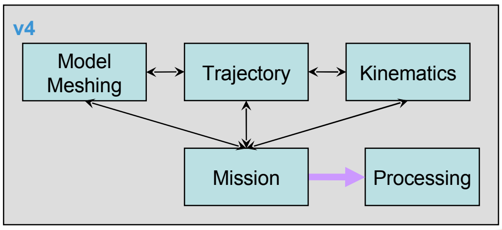


EADS astrium

SYSTEMA

Overview

- v4 : more flexibility for more quality
  - Step-by-step mission building => Parallel edition
    - Parallels modifications are allowed, everything is modified in 'real time'
    - You can exchange information between modules
  - "Thinking about everything" problematic => Independent structures
    - No need to think about kinematics during model and trajectory building
    - Modularity and reuse stimulated by independent conception

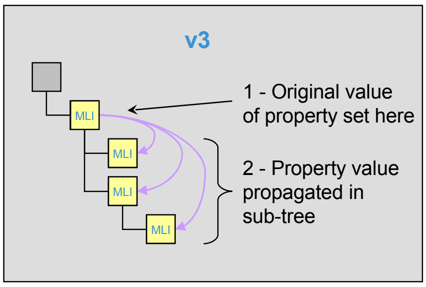


EADS astrium

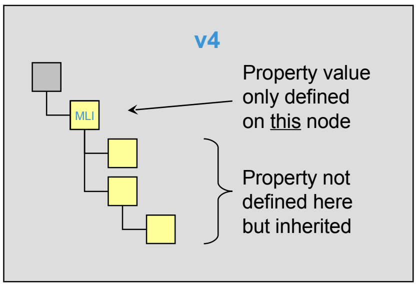
SYSTEMA

Overview

- Easier material assignment



Values are defined everywhere



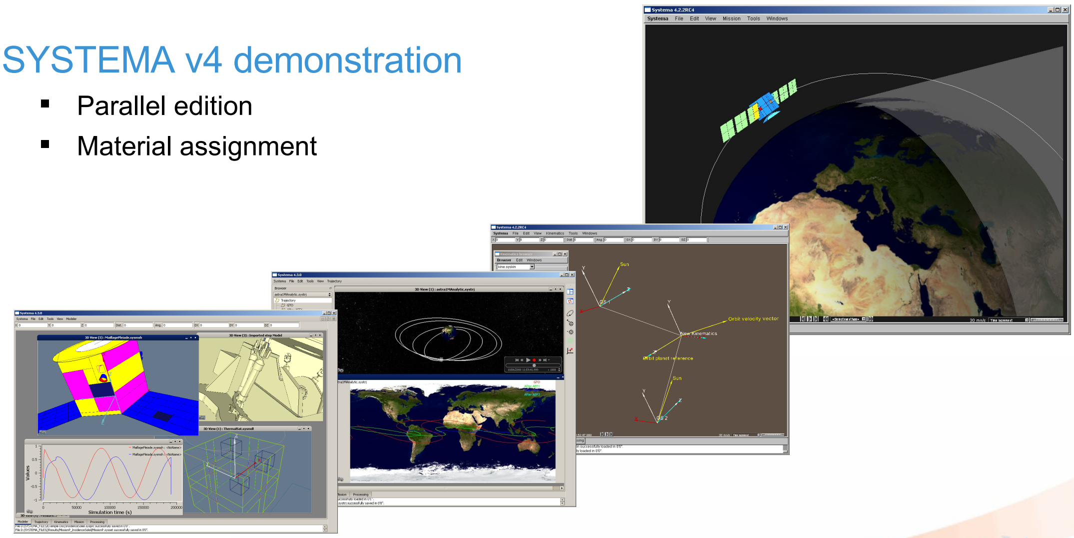
Values are defined only where it makes sense for user

EADS astrium

SYSTEMA

Overview

- SYSTEMA v4 demonstration
  - Parallel edition
  - Material assignment



EADS astrium

SYSTEMA

Versions

- V 4.3.1
  - November 2008

  Presented at the 2008 ECLS Workshop, ESTEC
- V 4.3.2
  - May 2009

  Presented at the 2009 THERMICA Workshop, Toulouse
- V 4.3.3
  - December 2009

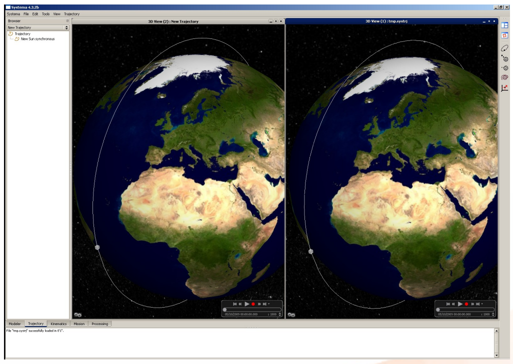
  Next release

Model & Mission Parameterization
Non-Geometrical Model Completion

EADS astrium

Parametric computation

- New feature : parametric computation
  - Defining a mission dependent on parameters
  - Running thermal casework with chosen values for parameters
  - Chaining parametric computation to find worst thermal cases

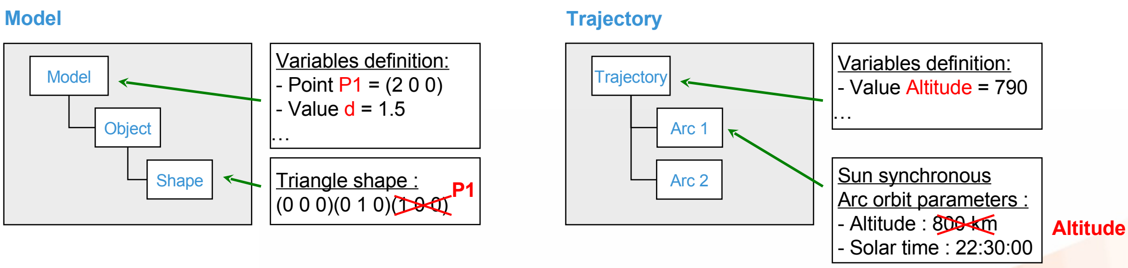


EADS astrium

Parametric computation

- First step : defining parameters
  1. For each entity, defining which parameter you want to use
  2. Then using these parameters instead of classic values

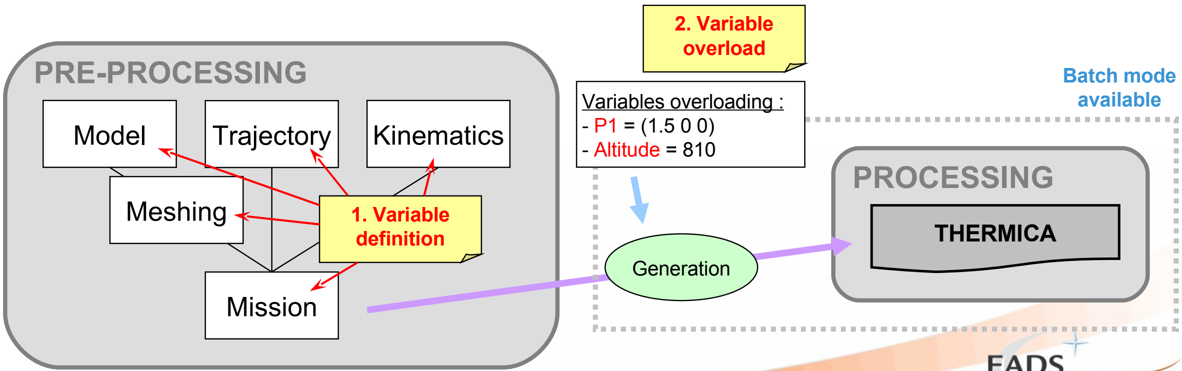
Example :



EADS astrium

Parametric computation

- Second step : overloading parameters
  - Now, for each thermal run, you can use different values by overloading of the variable values
  - Using batch mode, you can build your own worst case analysis



ESA standards

- **STEP-TAS**

  Validation in progress
  Make the exchange of model and meshing easier

- **STEP-NRF**

  SYSTEMA contains integrated solutions for post-processing :
  - Curves and 3D motion interactive display
  - POSTHER for thermal automatic report generation

  SYSTEMA is also able to convert results to STEP-NRF format


SYSTEMA
SYSTEMA
THERMICA
THERMISOL
Visit our Web site :
www.systema.astrium.eads.net
Contact :
timothee.soriano@astrium.eads.net
marc.baucher@astrium.eads.net
EADS astrium
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Thermica Suite
Thermica
Thermisol
Overview
Technical details
Applications
Smart2
Quartz
Support
About us
Community
Distributors
Contact
You are here : Home > Products > Thermica Suite > Thermisol > Applications
THERMISOL - Applications
THERMISOL has been used, validated and optimized on many projects. Thanks to 5 years of intense use in Astrium, convergence optimizations were finely tunes. Here are examples of the THERMISOL special features.
Automatic time-step adjustment
SCRANKAUTO provides an automatic time-step based on minimum and maximum error specifications.
During the computation, the error is estimated by the Taylor development and the time-step is
plotted hereafter shows the evolution of temperature for 3 nodes : 1000 (central body), 2000 (antenna), and 3000 (solar panel).
The oscillations can be drastically reduced by the use of an automatic time stepping. In the previous input file, the call to SLFWBK has been replaced by a call to the subroutine SCRANKAUTO, and two control variables have been added in the paragraph $CONTROLS :
ERRMIN = 0.01; ERRMAX = 0.01;
The new solution is plotted in the following graph :
Automatic time-step adjustment

Appendix G

THERMICA – THERMISOL

Timothée Soriano
(EADS Astrium, France)

Abstract

Process Control

Presentation of the new functionalities & outputs dedicated to control the convergence of the simulations.

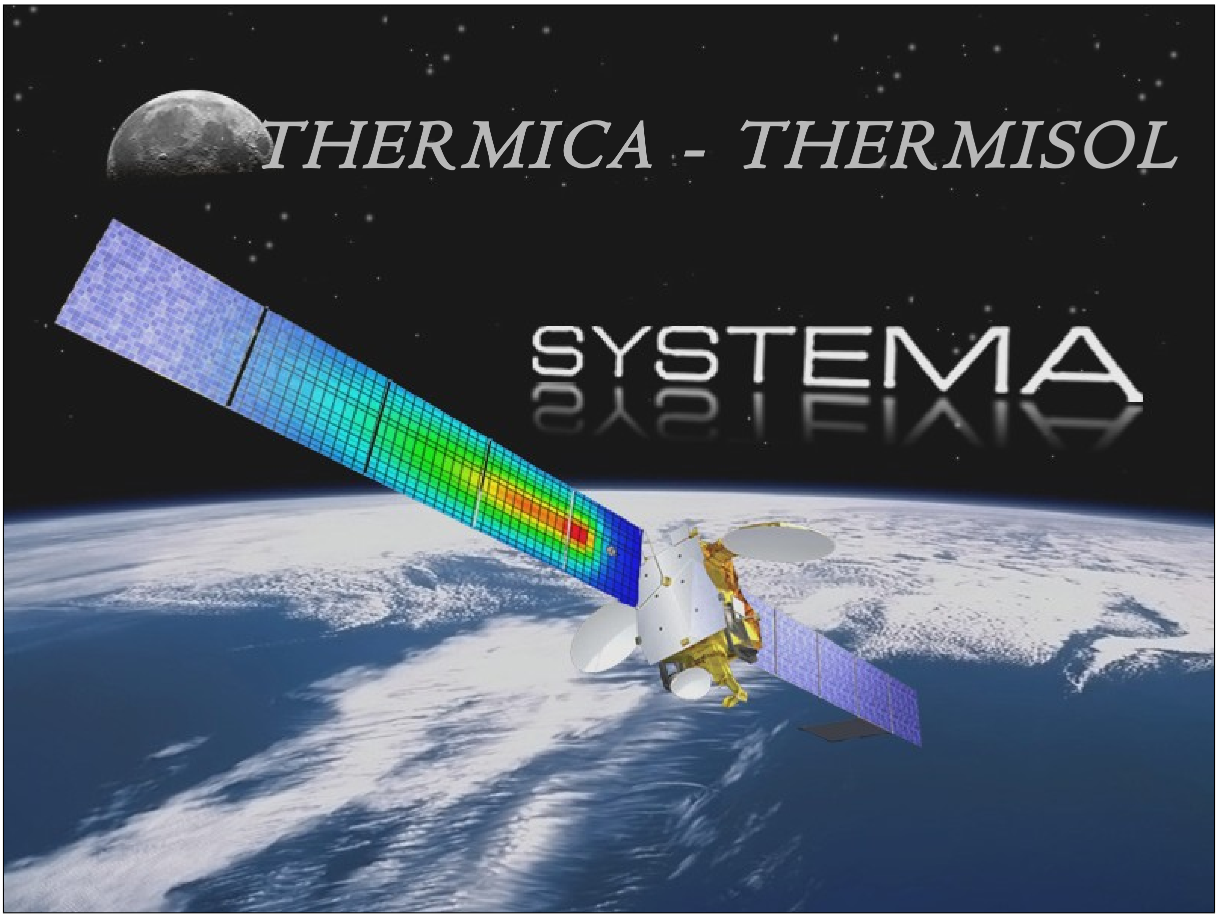
- New summary tables in log files for Ray-Tracing algorithms
- New accuracy loops in the Radiation & Solar Flux modules
- Extended data in the THERMISOL process control file
- New error definitions in THERMISOL

THERMISOL to ESATAN converter

THERMISOL is based on the ESATAN language and more than 95% of the commonly used syntax is supported by both software. THERMISOL now offers additional advanced functionalities and also more users friendly syntax (free format, real format automatic adaptation, easy Mortran data access . . .). To ensure the compatibility, a converter translates a THERMISOL input file and re-formats it in order to be 100% compliant with both software.

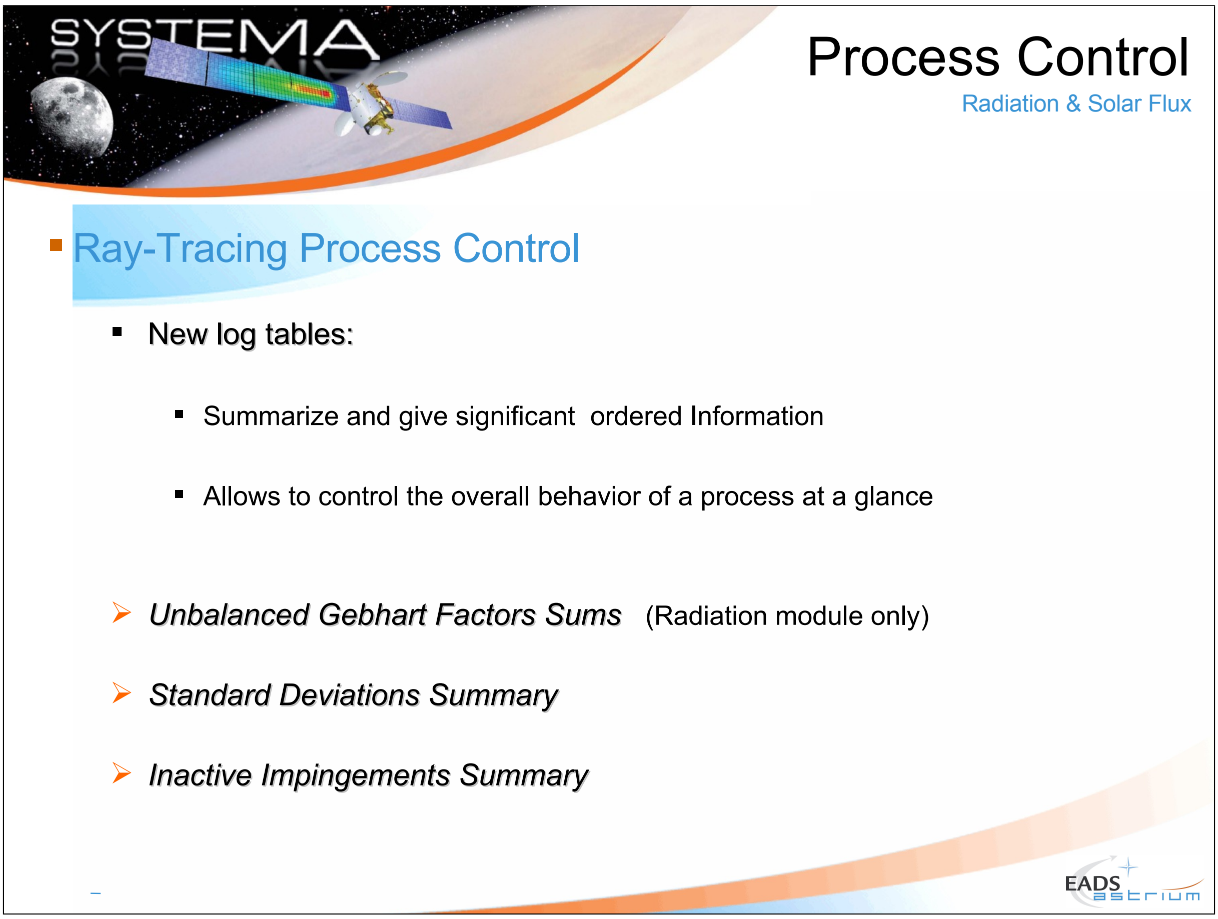
Latest Validations & Performances Tests

The v4 is now completely mature to be integrated into production processes.
This is a short presentation of process integrations and results based on industrial cases.


THERMICA - THERMISOL
SYSTEMA


SYSTEMA
Versions
V 4.3.1
November 2008
Presented at the 2008 ECLS Workshop, ESTEC
V 4.3.2
May 2009
Presented at the 2009 THERMICA Workshop, Toulouse
V 4.3.3
December 2009
Next release
Model & Mission Parameterization
Non-Geometrical Model Completion
Advanced Process Control
Automatic Ray-Tracing Accuracy Control
Advanced Mortran Syntax
THERMISOL – ESATAN converter
EADS astrium


SYSTEMA
Content
Process Control
More information to control convergence parameters in THERMICA and THERMISOL
New Ray-Tracing Accuracy Loops
THERMISOL: New Mortran Easy Syntax
Mortran Implicit Calls: Parametric Mortran Access
Mortran Macros: Allows multi-affectation and multi-modification
THERMISOL to ESATAN converter
Reformat the input file in order to be 100% compatible with both solver
EADS astrium


SYSTEMA
Process Control
Radiation & Solar Flux
Ray-Tracing Process Control
New log tables:
Summarize and give significant ordered Information
Allows to control the overall behavior of a process at a glance
Unbalanced Gebhart Factors Sums (Radiation module only)
Standard Deviations Summary
Inactive Impingements Summary
EADS astrium

SYSTEMA

Process Control

Radiation & Solar Flux

REF Sums

Initially the REF sums are equal to 1.0

But when computing the GR, the REF are modified

in order to get the symmetrization:

$$GR_{ij} = \varepsilon_i .\ S_i .\ REF_{ij} = \varepsilon_j .\ S_j .\ REF_{ji}$$

This table summarizes the symmetrizations that lead

to REF sums different than 1.0

IR Gebhart Factor Budget :

REF (IR) sum : error above 10 % :

Emission Node	Rays Emitted	VF sum	Error
99	10000	0.8383	16.2 %
247	20000	1.147	14.7 %

REF (IR) sum : error between 5 % and 10 %:

Emission Node	Rays Emitted	VF sum	Error
279	20000	1.099	9.87 %
280	20000	1.074	7.36 %
138	10000	0.9274	7.26 %
13	10000	1.057	5.73 %

REF (IR) sum : error between 1 % and 5 %:

Emission Node	Rays Emitted	VF sum	Error
133	10000	1.038	3.84 %
58	10000	1.038	3.79 %
3	10000	1.034	3.35 %
53	10000	1.028	2.83 %
275	20000	1.028	2.75 %
35	10000	1.022	2.23 %
90	10000	1.02	2 %
248	20000	1.019	1.9 %
97	20000	1.019	1.89 %
55	10000	1.015	1.5 %
230	10000	1.012	1.25 %
96	20000	1.011	1.06 %
252	20000	1.01	1.03 %

Number of REF (IR) bellow 1 % of error: 377 (91.7 %)

Customized levels of unbalanced REF sums

Unbalanced nodes

Percentage of error

Accurate Nodes

–

astrium

SYSTEMA

Process Control

Radiation & Solar Flux

New Accuracy Loops

- A new accuracy control has been developed in the 4.3.3

It allows the user to specify a target accuracy to be reached

The application then automatically loops and adjusts the number of ray

- This version is based on the 2 aspects:

- Maximum Standard Deviation (theoretical ray-tracing error)
- Maximum REF unbalance (empirical ray-tracing error)

–

EADS astrium

Process Control
THERMISOL

THERMISOL: Convergence Control File

- Dynamically written file
- More information than before
- Frequency of update controlled by new parameter: CSV_FREQ

Steady-state run : SOLVIT

LOOPCT	RELXCC	NRLXCC	ENBALA	ENBALR	ENBALT	DAMPT	VTEMPERATURE
10	1.25E+01	421001 (E30000S)	7.79E+03	3.87E-01	5.51E+04	1.8759	10
50	9.96E-01	345102 (E30000S)	2.58E+01	1.28E-03	2.03E+02	1.7104	10
100	4.76E-01	1640031 (E30000S)	1.23E+01	6.13E-04	2.54E+02	1.948	10
150	5.89E-03	1640021 (E30000S)	3.09E-01	1.53E-05	4.96E+00	1.8614	2
200	1.79E-04	1640011 (E30000S)	7.84E-03	3.90E-07	5.69E-02	1.7643	1
216	9.52E-05	1640035 (E30000S)	4.01E-03	1.99E-07	7.42E-02	1.9243	1

Evolution of convergence evolution

Damping Factors

$VTEMPERATURE optimization

Evolution of energetic balances

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Process Control
THERMISOL

- Transient run

% TIME	TIMEN	DTIMEU	LOOPCT	RELXCC	NRLXCC	ENBALT	MAX ERROR	NERRMAX	% BELOW 1.000e-01
1.62%	180	30	165	9.57E-07	22077 (ATLID_IF)	2.03E-03	3.02E+00	21160 (ATLID_IF)	88.39%
3.24%	360	30	153	9.58E-07	22077 (ATLID_IF)	-5.36E-04	2.63E+00	21160 (ATLID_IF)	88.66%
4.86%	540	30	150	9.99E-07	22077 (ATLID_IF)	-4.39E-04	2.29E+00	21160 (ATLID_IF)	88.86%
6.36%	706.018	16.018	97	9.73E-07	22077 (ATLID_IF)	-1.45E-04	5.62E-01	21160 (ATLID_IF)	93.49%
7.85%	872.036	30	190	-9.96E-07	21211 (ATLID_IF)	-4.50E-03	1.66E+00	21160 (ATLID_IF)	89.73%
9.47%	1052.036	30	145	-9.75E-07	21211 (ATLID_IF)	-1.62E-03	1.45E+00	21160 (ATLID_IF)	89.87%
11.36%	1262.036	30	145	9.79E-07	21211 (ATLID_IF)	2.71E-03	1.23E+00	21160 (ATLID_IF)	90.34%
12.94%	1437.525	30	139	-9.50E-07	22077 (ATLID_IF)	3.97E-04	1.16E+00	21160 (ATLID_IF)	90.74%
14.62%	1623.891	18.183	100	9.51E-07	22077 (ATLID_IF)	-4.75E-04	5.43E-01	22079 (ATLID_IF)	93.76%
16.51%	1833.891	30	129	-9.95E-07	22077 (ATLID_IF)	7.75E-04	7.57E-01	22079 (ATLID_IF)	92.68%
18.15%	2016.168	30	125	-9.87E-07	22041 (ATLID_IF)	-1.09E-03	6.25E-01	22079 (ATLID_IF)	93.56%
19.93%	2213.479	30	128	9.59E-07	21211 (ATLID_IF)	1.96E-03	5.29E-01	22079 (ATLID_IF)	93.96%
21.61%	2399.913	30	142	9.75E-07	22077 (ATLID_IF)	1.32E-03	4.39E-01	22079 (ATLID_IF)	94.70%
23.32%	2590.436	30	137	-9.98E-07	22077 (ATLID_IF)	-7.32E-04	5.49E-01	22079 (ATLID_IF)	93.96%
25.44%	2825.925	30	117	-9.90E-07	22077 (ATLID_IF)	6.98E-06	3.33E-01	22079 (ATLID_IF)	95.64%

Transient Total Heat Balance

Time Data

Implicit Convergence Parameters

Error (in K) related to Time Discretisation

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SYSTEMA

Process Control

THERMISOL

THERMISOL Error Definitions: Static Errors

- Relaxation Coefficient (RELXCA)

Not a physical criteria but is a pertinent criteria on numerical convergence

- Absolute / Relative Energy Balance (ENBALA / ENBALR)

Physical criteria suitable for steady-state analysis that sums flux contributions to boundary conditions

- Total Energy Balance (ENBALT)

Physical criteria suitable for both steady-state and transient analysis that sums the total flux of each node (including capacitive flux for transient analysis)

This new criteria introduces for the first time a physical criteria on the implicit resolution of transient analysis

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SYSTEMA

Process Control

THERMISOL

THERMISOL Error Definitions: Dynamic Error

- Time Discretization Error (ERRT)

In earlier versions**, the error related to the time discretization was given by **CSGFAC

*However, for a Crank-Nicholson scheme, it is possible to **estimate directly** the **error in Kelvin** made **due to the time-step used**.*

This error tends to zero when the time-step used gives locally a quadratic temperature profile

Related to this error, the convergence controller file gives:

- the maximum error reached on each time-step and for which node

- the percentage of nodes bellow the ERRMAX user's specified coefficient

- the optimal time-step that should lead to a 100% of nodes bellow ERRMAX

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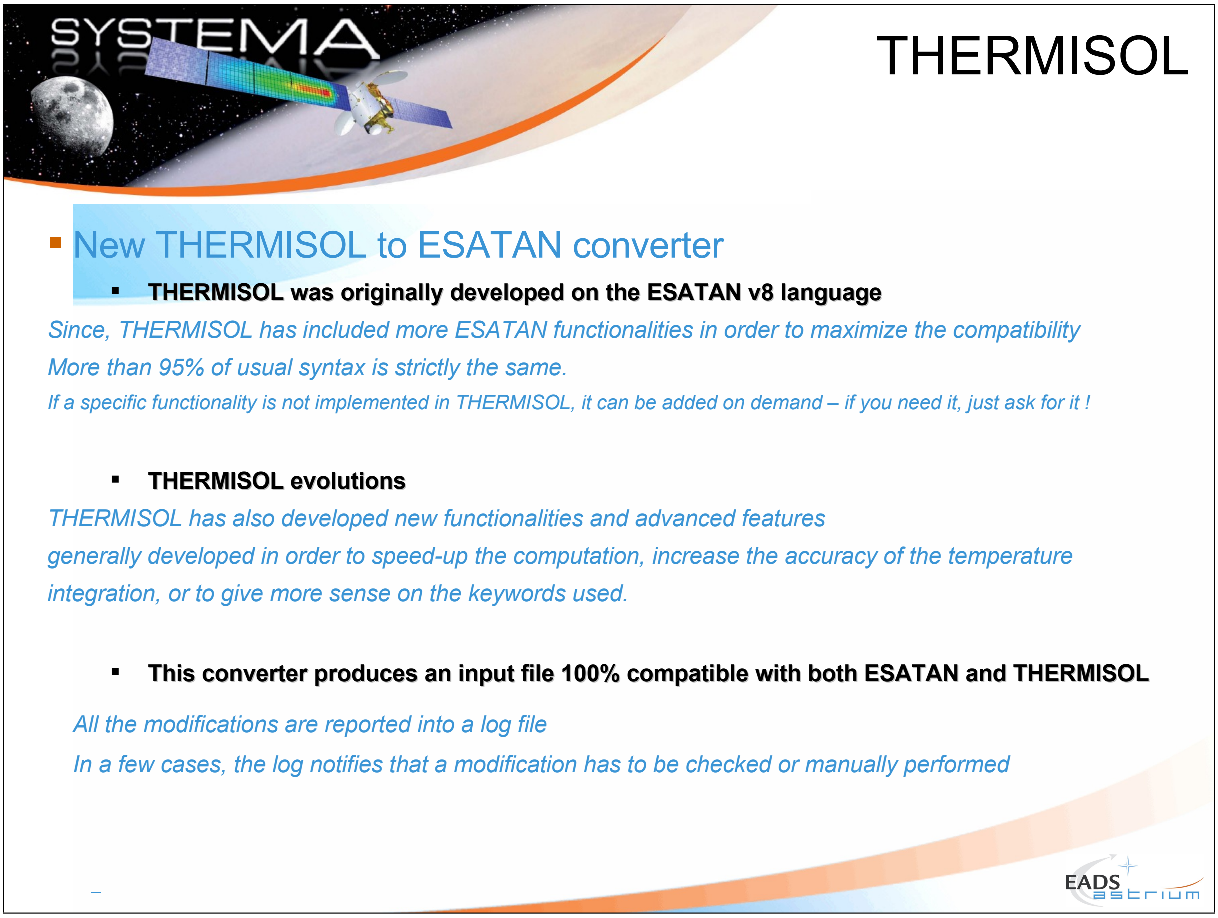
SYSTEMA
THERMISOL
New THERMISOL to ESATAN converter
THERMISOL was originally developed on the ESATAN v8 language
Since, THERMISOL has included more ESATAN functionalities in order to maximize the compatibility
More than 95% of usual syntax is strictly the same.
If a specific functionality is not implemented in THERMISOL, it can be added on demand – if you need it, just ask for it !
THERMISOL evolutions
THERMISOL has also developed new functionalities and advanced features
generally developed in order to speed-up the computation, increase the accuracy of the temperature integration, or to give more sense on the keywords used.
This converter produces an input file 100% compatible with both ESATAN and THERMISOL
All the modifications are reported into a log file
In a few cases, the log notifies that a modification has to be checked or manually performed
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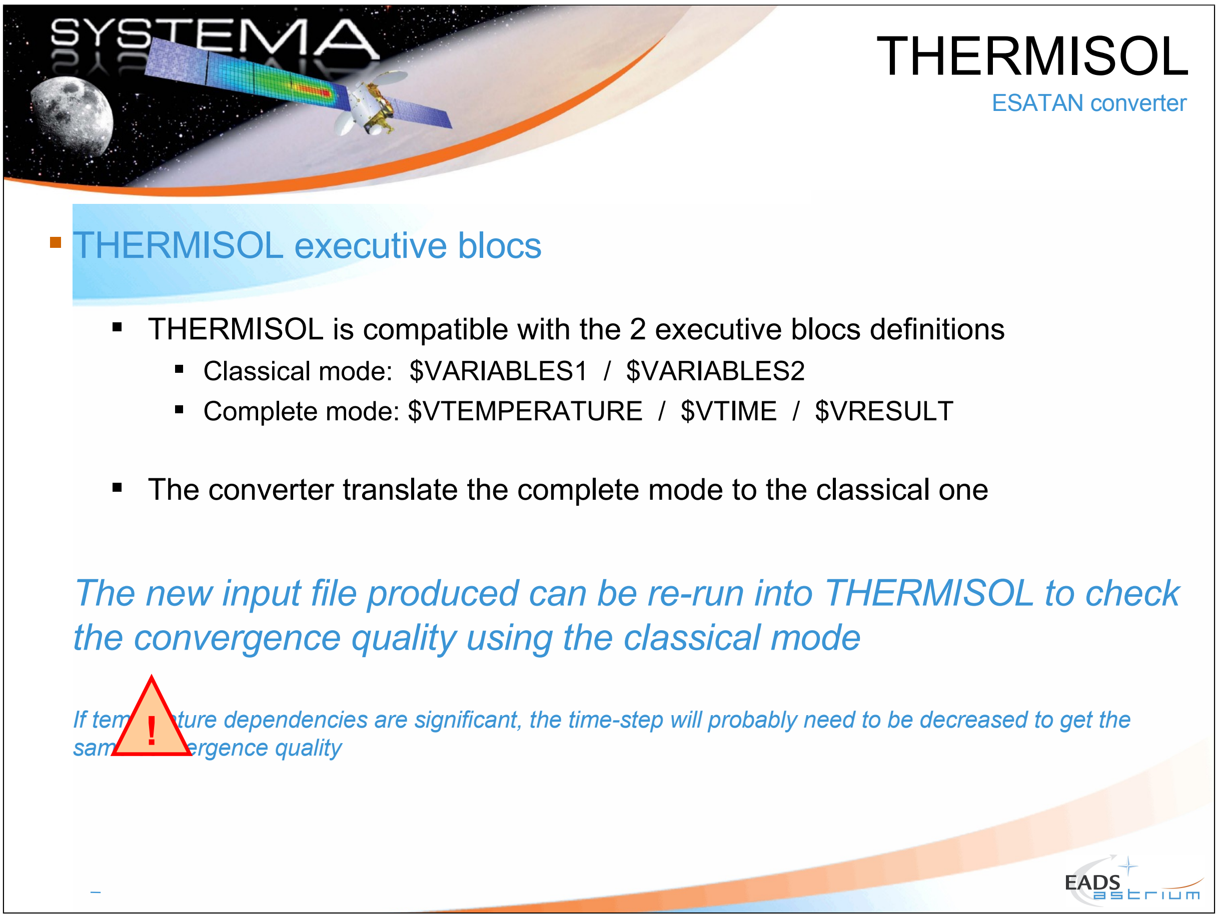
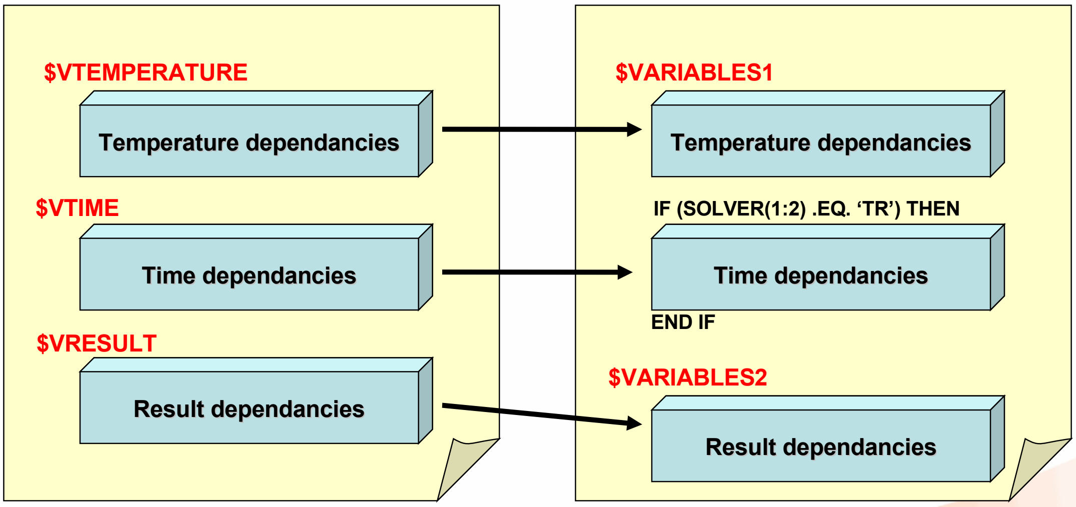

SYSTEMA
THERMISOL
ESATAN converter
THERMISOL executive blocs
THERMISOL is compatible with the 2 executive blocs definitions
Classical mode: $VARIABLES1 / $VARIABLES2
Complete mode: $VTEMPERATURE / $VTIME / $VRESULT
The converter translate the complete mode to the classical one
The new input file produced can be re-run into THERMISOL to check the convergence quality using the classical mode
!
If tem ture dependencies are significant, the time-step will probably need to be decreased to get the
sam ergence quality
EADS astrium

THERMISOL

ESATAN converter

Complete mode *Classical mode*



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THERMISOL

ESATAN converter

- Syntax corrections
  - Free format

The THERMISOL preprocessor can read free format (even if the Fortran created is written in a pure Fortran77 using fixed format)

The converter positions every Mortran line at the 6th column

  - Real formats

The THERMISOL preprocessor automatically detects real's formats and write a correct Fortran to prevent from random behaviors at subroutine calls

The converter re-write all reals in double precision format to avoid inconsistencies

  - Implicit declaration loops

THERMISOL accepts both the ESATAN syntax and the FORTRAN syntax

The converter translate FORTRAN loops to the ESATAN syntax

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SYSTEMA

THERMISOL

ESATAN converter

Syntax translations

- Specific THERMISOL keywords

Specific options, like the H5 output controls or advanced accuracy management, are commented

- THERMISOL Mortran Data Access

Quick data access are converted as follow

N xxxx	*INTNOD(CURRENT, xxxx)*
N:model:xxxx	*INTNOD(model, xxxx)*
N variable	*INTNOD(CURRENT, variable)*
NS xxxx = 'B'	*CALL STATST('Nxxxx','B')*

Warning: some THERMISOL NS statements (using variable) cannot be automatically converted

The log file gives explicitly the eventual manual modifications to be performed

–

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SYSTEMA

THERMISOL

ESATAN converter

Syntax advanced translations (1/2)

- THERMISOL Implicit Mortran Data Access

In THERMISOL, it is possible to implicitly reference a node or a coupling using variables and/or formulas

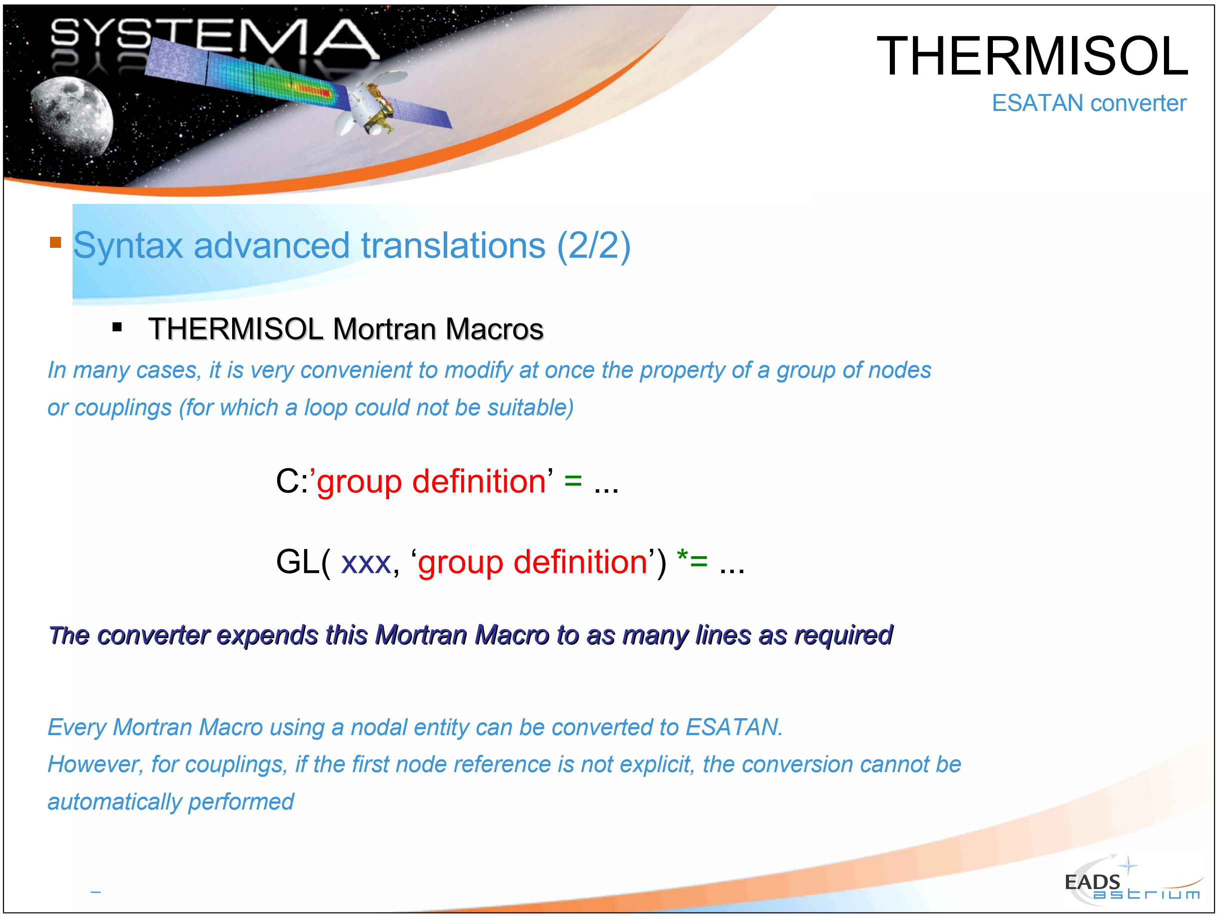
```
$INITIAL
  DO INODE = 1, 6
    C:INODE = 8.43e-01* A:INODE
    C:(INODE + 760) = 9.52e-01* A:(INODE+760)
    C:SUBMOD1:INODE = 8.43e-01* A:SUBMOD1:INODE
    GL(INODE, INODE+760) = 0.25
  END DO
```

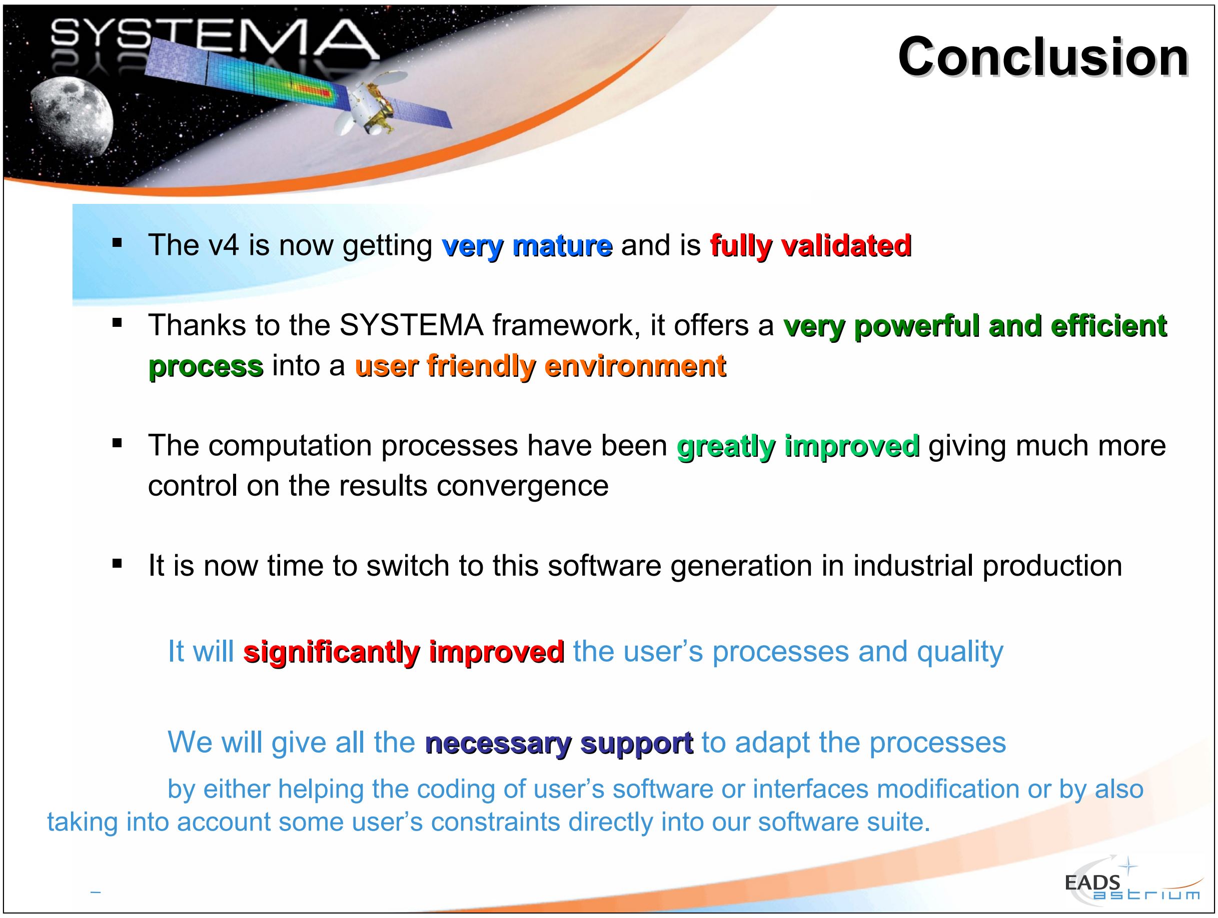
Nodal implicit references are converted in pure ESATAN format using the INTNOD function

Coupling implicit references cannot be automatically translated

–

EADS astrium


SYSTEMA
THERMISOL
ESATAN converter
Syntax advanced translations (2/2)
THERMISOL Mortran Macros
In many cases, it is very convenient to modify at once the property of a group of nodes
or couplings (for which a loop could not be suitable)
C:'group definition' = ...
GL(xxx, 'group definition') *= ...
The converter expends this Mortran Macro to as many lines as required
Every Mortran Macro using a nodal entity can be converted to ESATAN.
However, for couplings, if the first node reference is not explicit, the conversion cannot be
automatically performed
EADS astrium


SYSTEMA
Conclusion
The v4 is now getting very mature and is fully validated
Thanks to the SYSTEMA framework, it offers a very powerful and efficient process into a user friendly environment
The computation processes have been greatly improved giving much more control on the results convergence
It is now time to switch to this software generation in industrial production
It will significantly improved the user's processes and quality
We will give all the necessary support to adapt the processes
by either helping the coding of user's software or interfaces modification or by also taking into account some user's constraints directly into our software suite.
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THERMICA
THERMISOL
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www.systema.astrium.eads.net
Contact :
timothee.soriano@astrium.eads.net
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You are here : Home > Products > Thermica Suite > Thermisol > Applications
THERMISOL - Applications
THERMISOL has been used, validated and optimized on many projects. Thanks to 5 years of intense use in Astrium, convergence optimizations were finely tunes. Here are examples of the THERMISOL special features.
Automatic time-step adjustment
SCRANKAUTO provides an automatic time-step based on minimum and maximum error specifications.
During the computation, the error is estimated by the Taylor development and the time-step is
plotted hereafter shows the evolution of temperature for 3 nodes : 1000 (central body), 2000 (antenna), and 3000 (solar panel).
The oscillations can be drastically reduced by the use of an automatic time stepping. In the previous input file, the call to SLFWBK has been replaced by a call to the subroutine SCRANKAUTO, and two control variables have been added in the paragraph $CONTROLS :
ERRMIN = 0.01; ERRMAX = 0.01;
The new solution is plotted in the following graph :
Automatic time-step adjustment

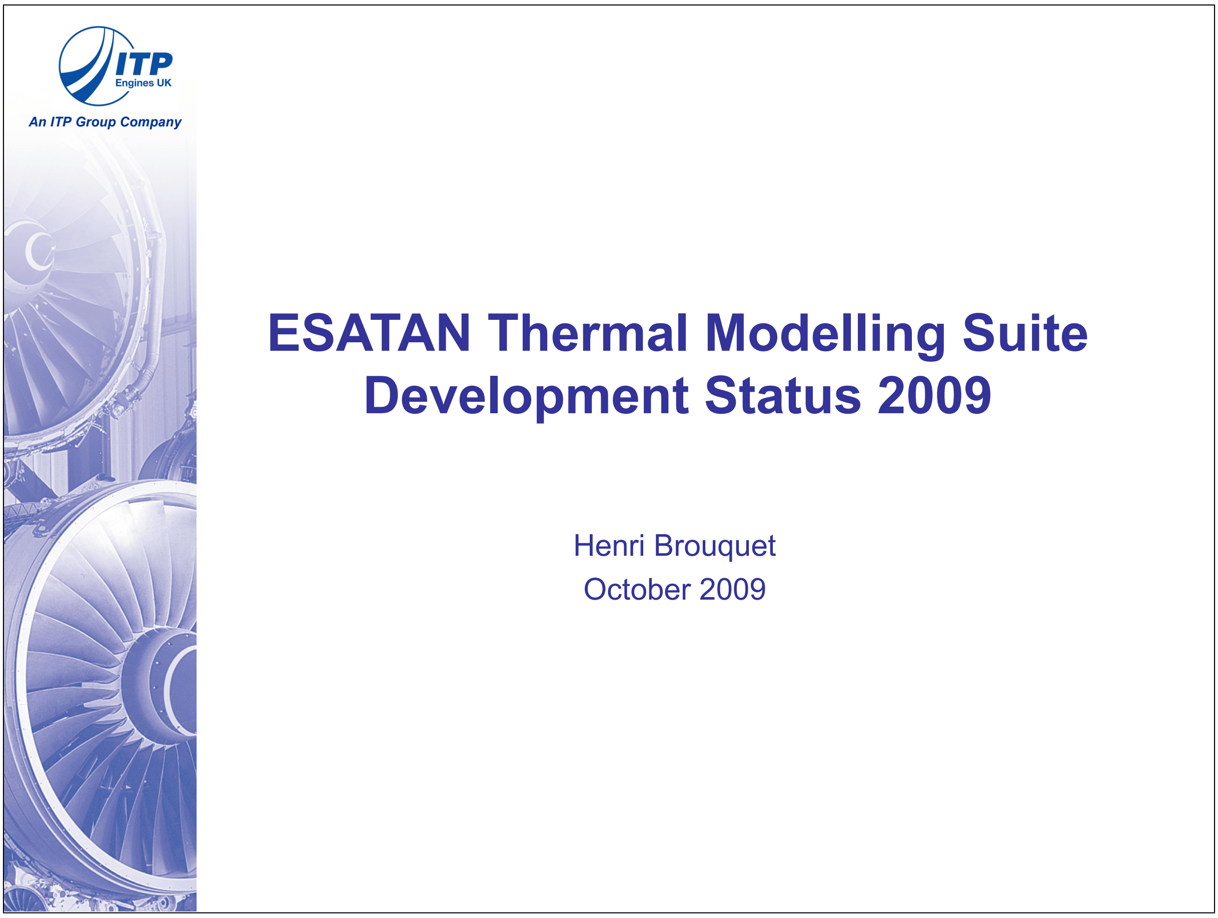
Appendix H

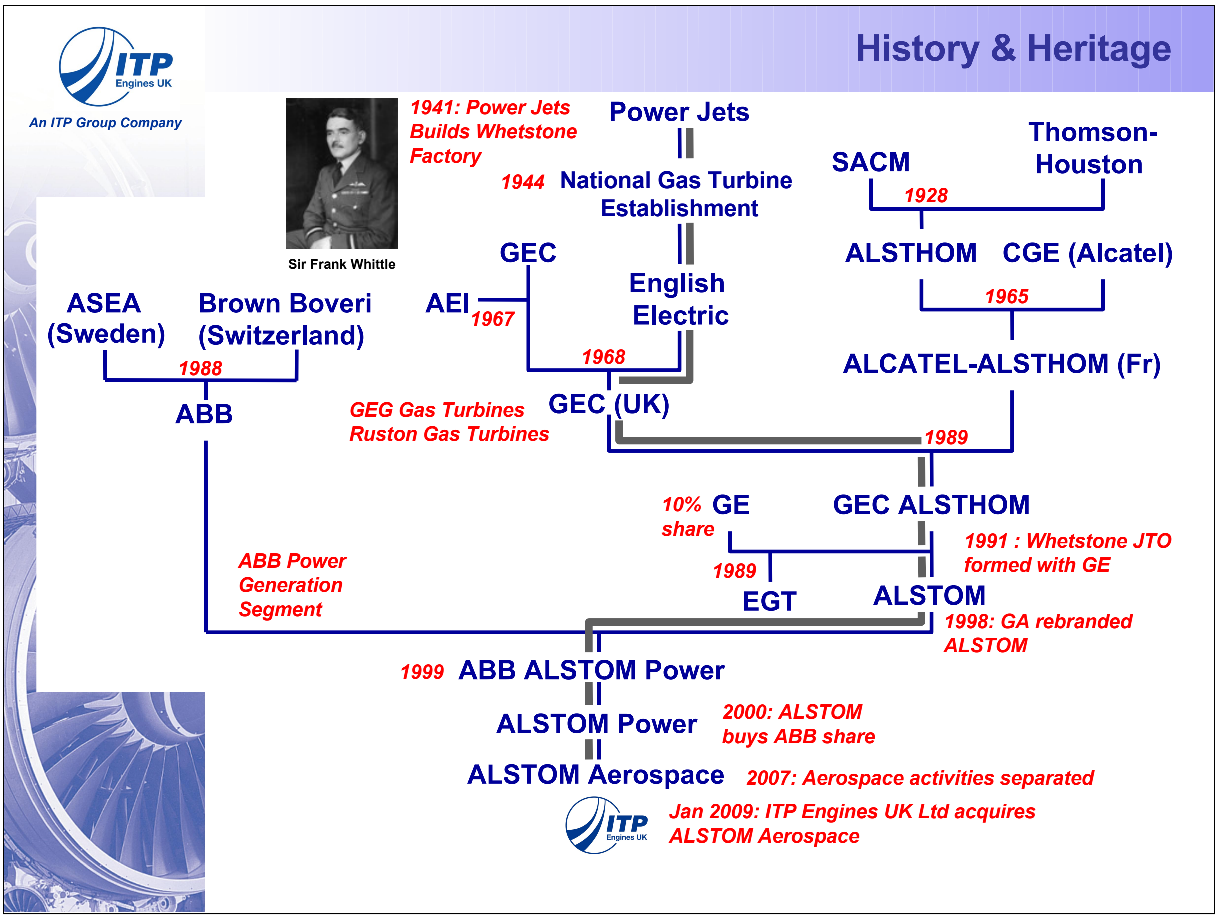
ESATAN Thermal Modelling Suite
Product developments

Henri Brouquet
(ITP-UK, United Kingdom)

Abstract

Overview of new features introduced in the latest versions of ESATAN-TMS.


ITP Engines UK
An ITP Group Company
ESATAN Thermal Modelling Suite
Development Status 2009
Henri Brouquet
October 2009


ITP Engines UK
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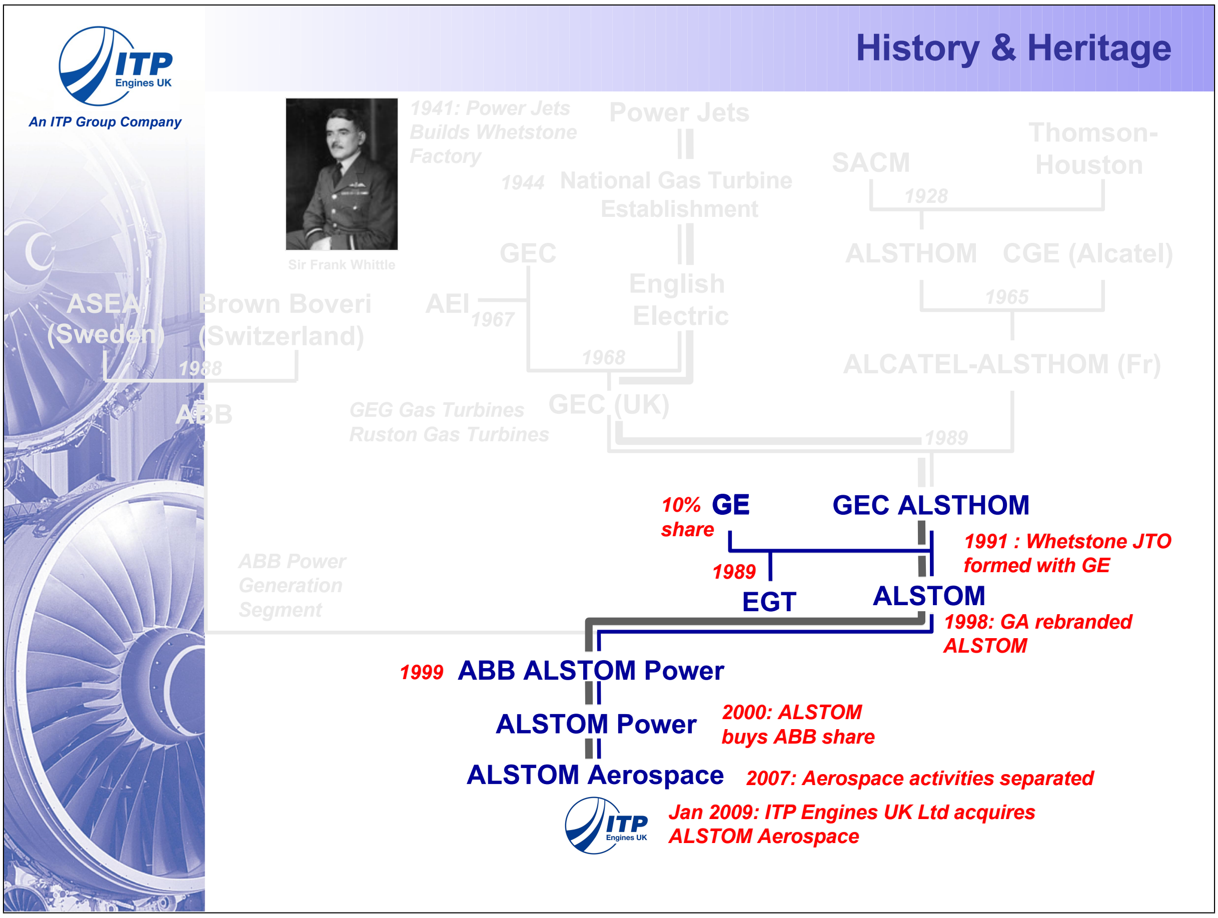
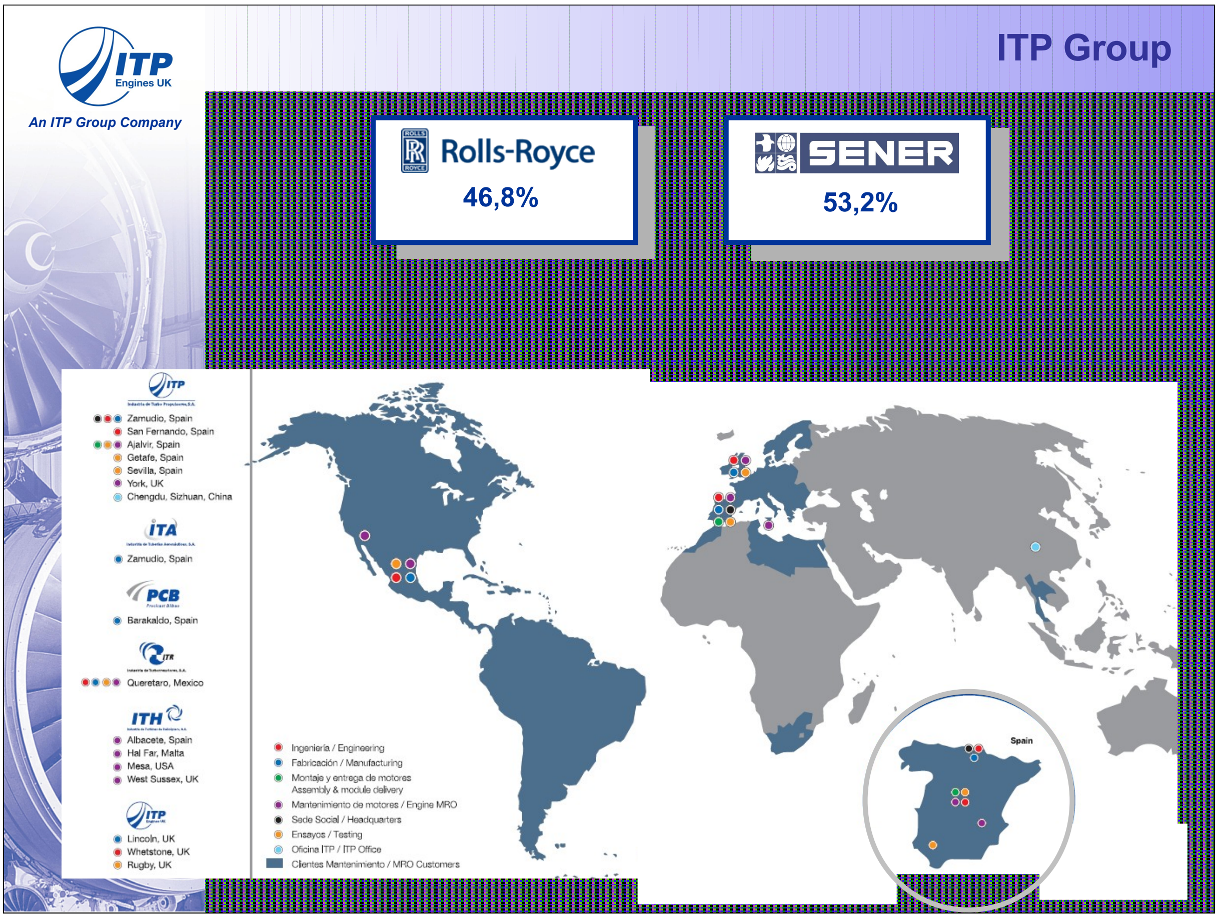
History & Heritage
Sir Frank Whittle
1941: Power Jets Builds Whetstone Factory
Power Jets
1944 National Gas Turbine Establishment
GEC
English Electric
AEI
1967
1968
GEC (UK)
GEG Gas Turbines
Ruston Gas Turbines
ASEA (Sweden)
Brown Boveri (Switzerland)
1988
ABB
SACM
Thomson-Houston
1928
ALSTHOM
CGE (Alcatel)
1965
ALCATEL-ALSTHOM (Fr)
1989
GEC ALSTHOM
10% share
GE
1991 : Whetstone JTO formed with GE
1989
EGT
ALSTOM
1998: GA rebranded ALSTOM
ABB Power Generation Segment
1999 ABB ALSTOM Power
ALSTOM Power
2000: ALSTOM buys ABB share
ALSTOM Aerospace
2007: Aerospace activities separated
Jan 2009: ITP Engines UK Ltd acquires ALSTOM Aerospace



History & Heritage
ITP Engines UK
An ITP Group Company
1941: Power Jets Builds Whetstone Factory
Power Jets
Sir Frank Whittle
1944 National Gas Turbine Establishment
SACM
Thomson-Houston
1928
ALSTHOM
CGE (Alcatel)
GEC
English Electric
1965
ASEA (Sweden)
Brown Boveri (Switzerland)
AEI
1967
1968
ALCATEL-ALSTHOM (Fr)
1988
ABB
GEG Gas Turbines
Ruston Gas Turbines
GEC (UK)
1989
10% share
GE
GEC ALSTHOM
1991 : Whetstone JTO formed with GE
ABB Power Generation Segment
1989
EGT
ALSTOM
1998: GA rebranded ALSTOM
1999 ABB ALSTOM Power
ALSTOM Power
2000: ALSTOM buys ABB share
ALSTOM Aerospace
2007: Aerospace activities separated
ITP Engines UK
Jan 2009: ITP Engines UK Ltd acquires ALSTOM Aerospace



ITP Group
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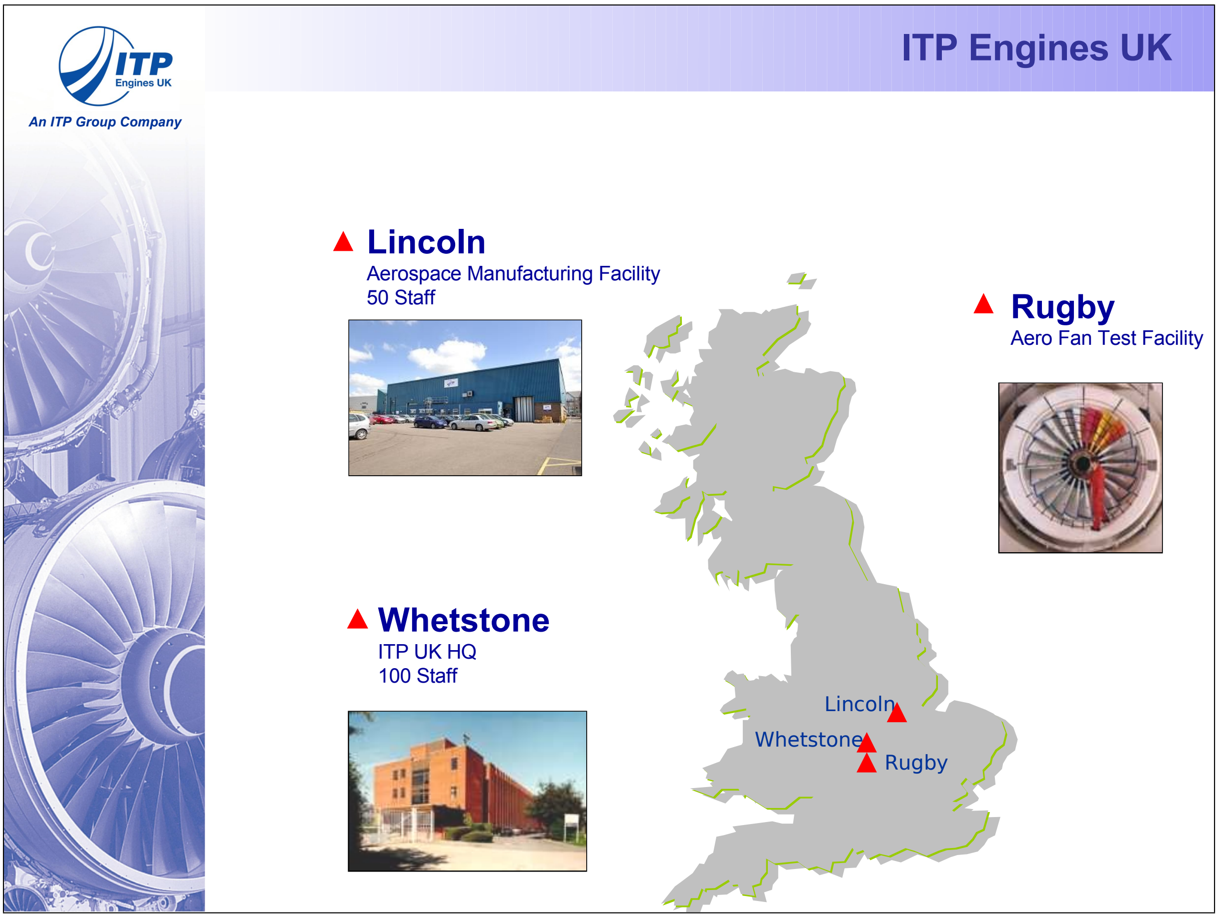
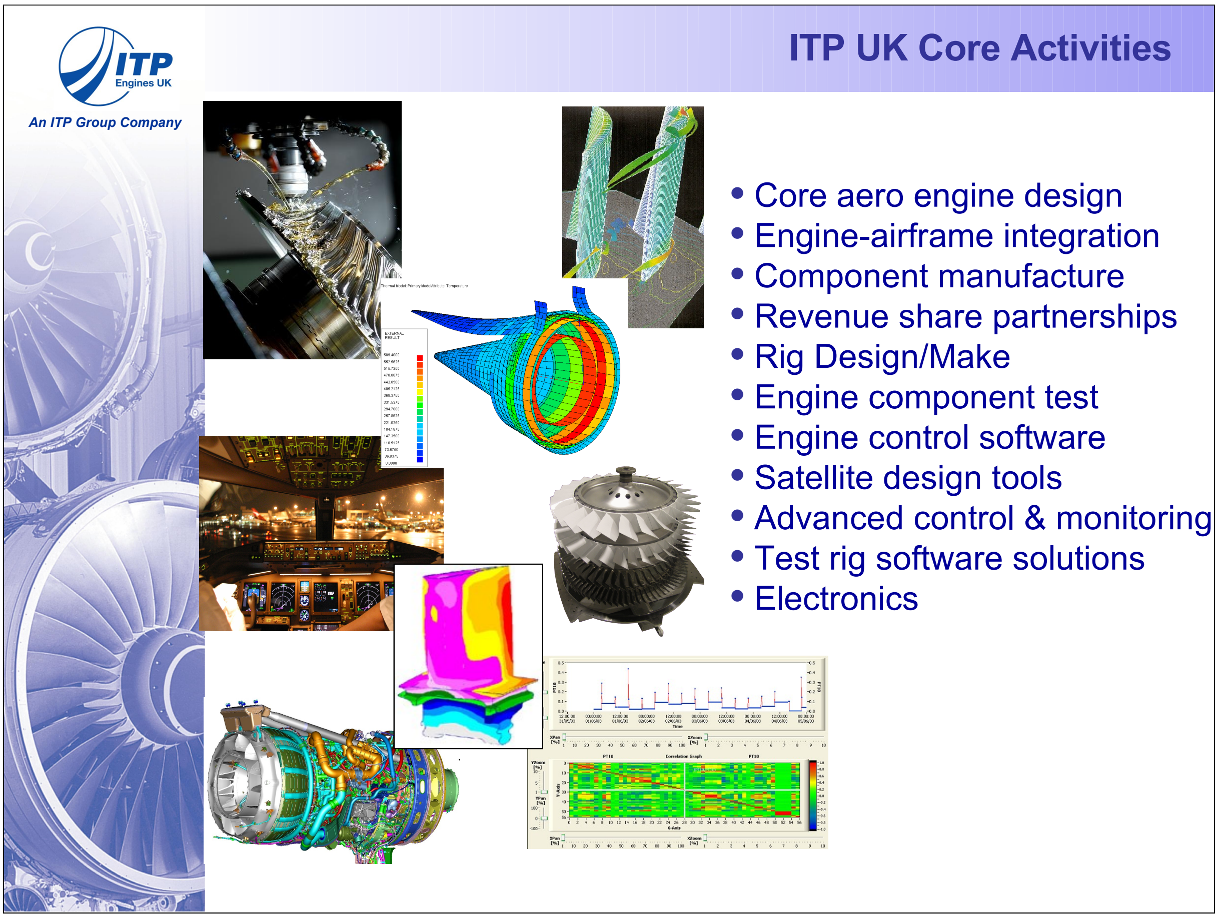
Rolls-Royce
46,8%
SENER
53,2%
ITP
Zamudio, Spain
San Fernando, Spain
Ajalvir, Spain
Getafe, Spain
Sevilla, Spain
York, UK
Chengdu, Sizhuan, China
ITA
Zamudio, Spain
PCB
Barakaldo, Spain
ITR
Queretaro, Mexico
ITH
Albacete, Spain
Hal Far, Malta
Mesa, USA
West Sussex, UK
ITP
Lincoln, UK
Whetstone, UK
Rugby, UK
Ingeniería / Engineering
Fabricación / Manufacturing
Montaje y entrega de motores Assembly & module delivery
Mantenimiento de motores / Engine MRO
Sede Social / Headquarters
Ensayos / Testing
Oficina ITP / ITP Office
Clientes Mantenimiento / MRO Customers
Spain


ITP
Engines UK
An ITP Group Company
ITP Engines UK
Lincoln
Aerospace Manufacturing Facility
50 Staff
Rugby
Aero Fan Test Facility
Whetstone
ITP UK HQ
100 Staff
Lincoln
Whetstone
Rugby


ITP
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ITP UK Core Activities
• Core aero engine design
• Engine-airframe integration
• Component manufacture
• Revenue share partnerships
• Rig Design/Make
• Engine component test
• Engine control software
• Satellite design tools
• Advanced control & monitoring
• Test rig software solutions
• Electronics

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ESATAN-TMS r1
January 2009

Features

ITP Engines UK
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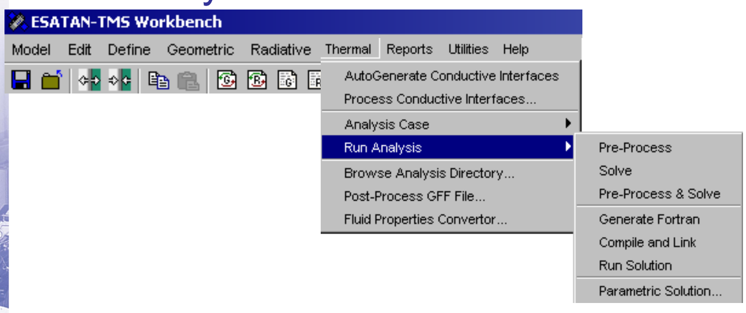
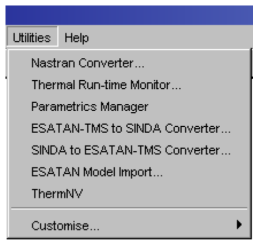
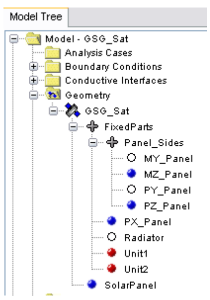
ESATAN-TMS r1 Features

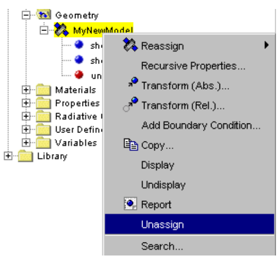
- New layout for Workbench

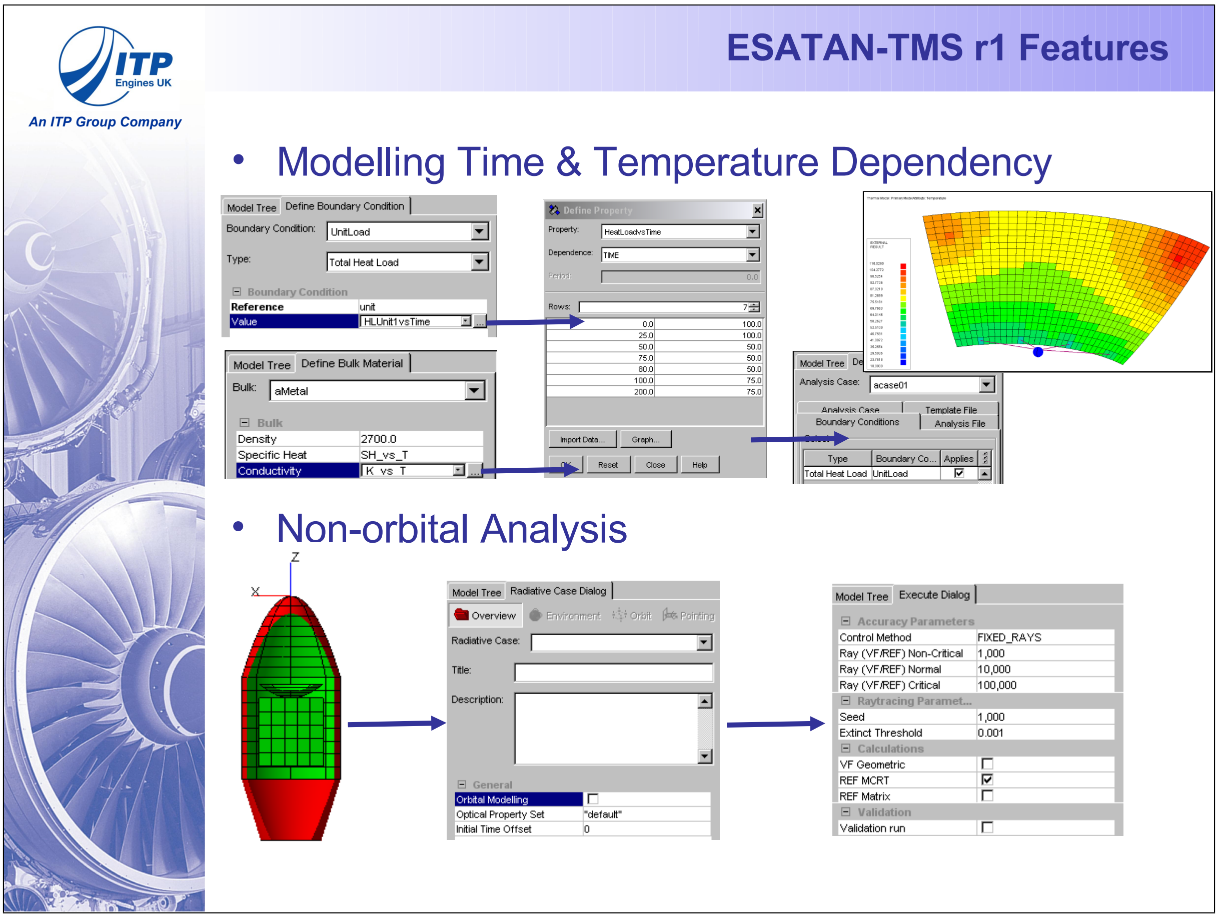


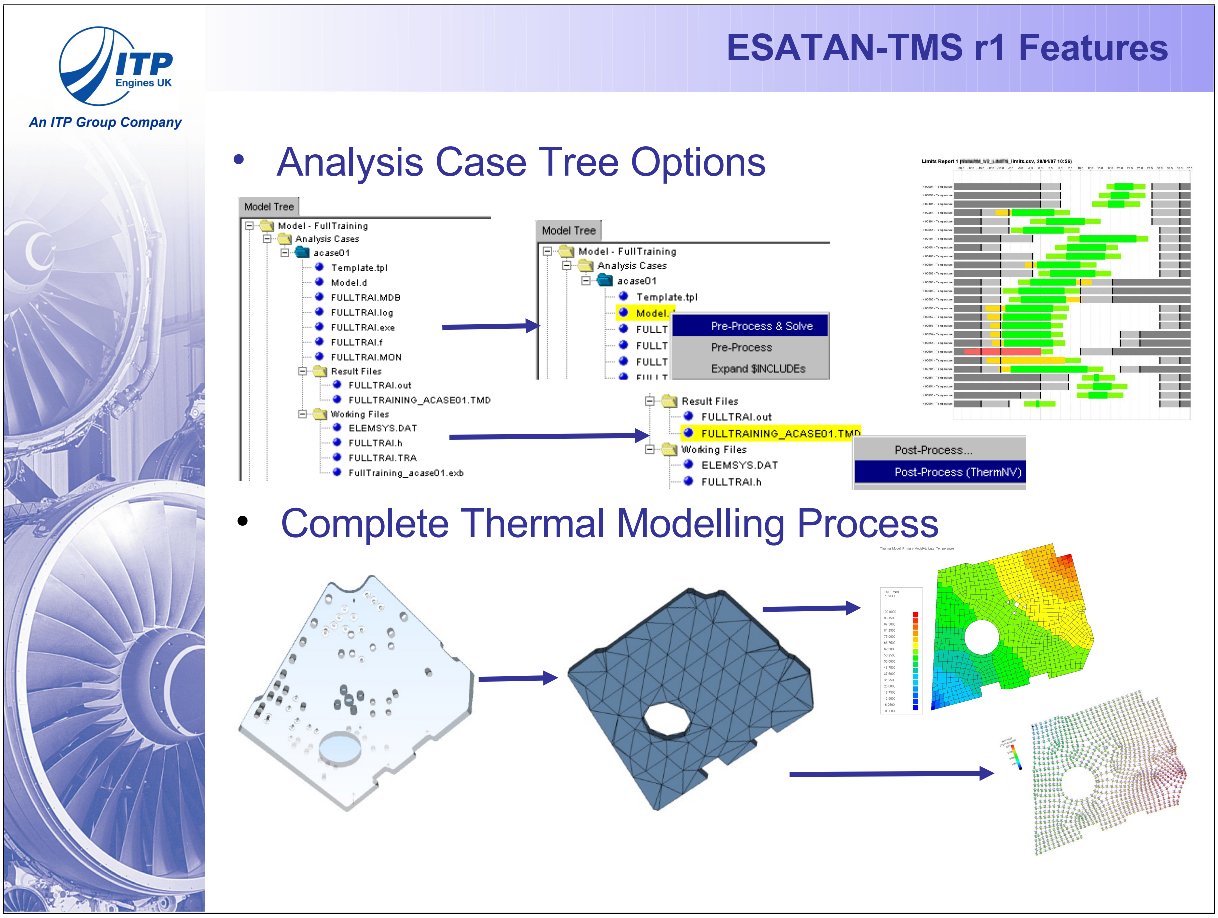


- Shell assignment






ITP
Engines UK
An ITP Group Company
ESATAN-TMS r1 Features
• Modelling Time & Temperature Dependency
Model Tree
Define Boundary Condition
Boundary Condition:
UnitLoad
Type:
Total Heat Load
Boundary Condition
Reference
unit
Value
HLUnit1vsTime
Define Bulk Material
Bulk:
aMetal
Bulk
Density
2700.0
Specific Heat
SH_vs_T
Conductivity
K vs T
Define Property
Import Data...
Graph...
Reset
Close
Help
Analysis Case:
acase01
Analysis Case
Template File
Boundary Conditions
Analysis File
Type
Applies
Total Heat Load
UnitLoad
• Non-orbital Analysis
Z
X
Radiative Case Dialog
Overview
Environment
Orbit
Pointing
Radiative Case:
Title:
Description:
General
Orbital Modelling
Optical Property Set
"default"
Initial Time Offset
0
Execute Dialog
Accuracy Parameters
Control Method
FIXED_RAYS
Ray (VF/REF) Non-Critical
1,000
Ray (VF/REF) Normal
10,000
Ray (VF/REF) Critical
100,000
Seed
1,000
Extinct Threshold
0.001
Calculations
VF Geometric
REF MCRT
REF Matrix
Validation
Validation run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Engines UK
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ESATAN-TMS r1 Features
• Analysis Case Tree Options
Model Tree
Model - FullTraining
Analysis Cases
acase01
Template.tpl
Model.d
FULLTRAI.MDB
FULLTRAI.log
FULLTRAI.exe
FULLTRAI.f
FULLTRAI.MON
Result Files
FULLTRAI.out
FULLTRAINING_ACASE01.TMD
Working Files
ELEMSYS.DAT
FULLTRAI.h
FULLTRAI.TRA
FullTraining_acase01.exb
Pre-Process & Solve
Pre-Process
Expand $INCLUDEs
Post-Process...
Post-Process (ThermNV)
• Complete Thermal Modelling Process

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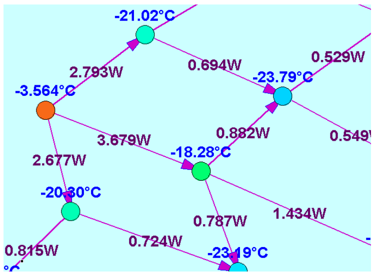
Maintenance Activity

- ESATAN-TMS Thermal if now fully double precision
- Support for HDF results data file
  - New DMPTMD routine

```
C To generate a TMD dump file (Binary HDF format file)
       CALL DMPTMD(' ',
      &      'NODES(L,T,C,QI,QE,QA,QS,QR), CONDUCTORS(GL,GR,GF)',
      &      CURRENT, ' ')
C
```

- ThermNV new display unit label
- Improvement for SLCRNC



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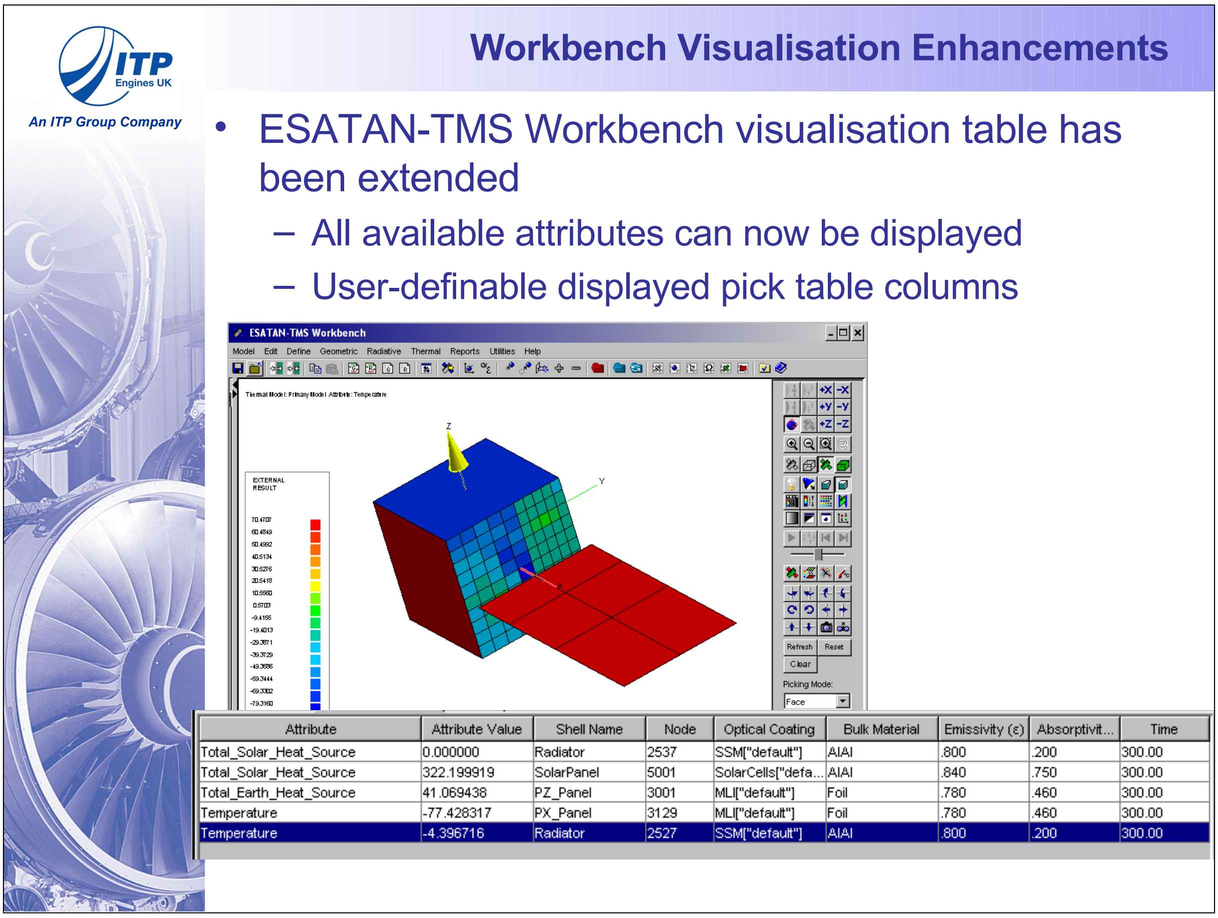
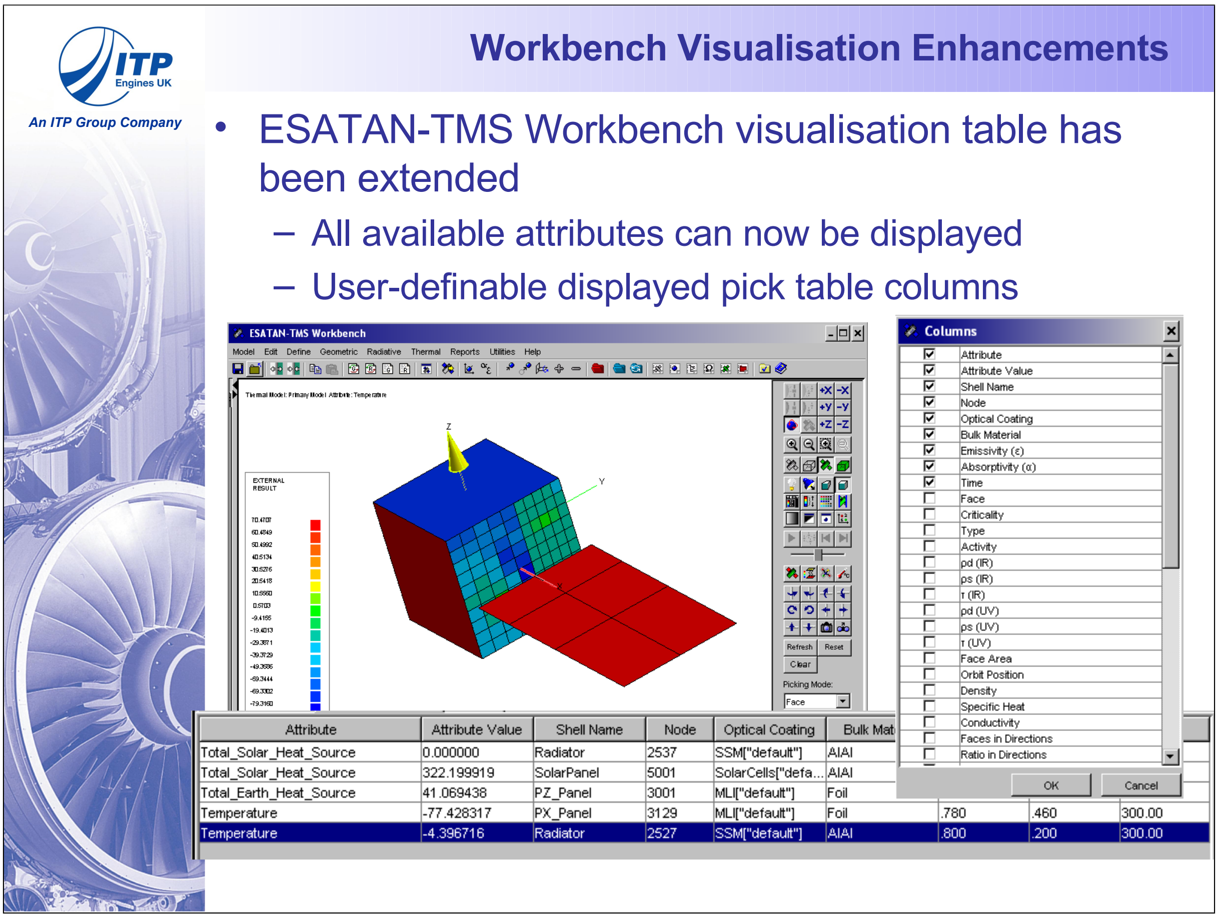
Additional Work after 2008 workshop (user request)


ITP Engines UK
An ITP Group Company
Workbench Visualisation Enhancements
• ESATAN-TMS Workbench visualisation table has been extended
– All available attributes can now be displayed
– User-definable displayed pick table columns
ESATAN-TMS Workbench
Attribute | Attribute Value | Shell Name | Node | Optical Coating | Bulk Material | Emissivity (ε) | Absorptivit... | Time
Total_Solar_Heat_Source | 0.000000 | Radiator | 2537 | SSM["default"] | AlAl | .800 | .200 | 300.00
Total_Solar_Heat_Source | 322.199919 | SolarPanel | 5001 | SolarCells["defa... | AlAl | .840 | .750 | 300.00
Total_Earth_Heat_Source | 41.069438 | PZ_Panel | 3001 | MLI["default"] | Foil | .780 | .460 | 300.00
Temperature | -77.428317 | PX_Panel | 3129 | MLI["default"] | Foil | .780 | .460 | 300.00
Temperature | -4.396716 | Radiator | 2527 | SSM["default"] | AlAl | .800 | .200 | 300.00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An ITP Group Company
Workbench Visualisation Enhancements
• ESATAN-TMS Workbench visualisation table has been extended
– All available attributes can now be displayed
– User-definable displayed pick table columns
ESATAN-TMS Workbench
Columns
Attribute
Attribute Value
Shell Name
Node
Optical Coating
Bulk Material
Emissivity (ε)
Absorptivity (α)
Time
Face
Criticality
Type
Activity
ρd (IR)
ρs (IR)
τ (IR)
ρd (UV)
ρs (UV)
τ (UV)
Face Area
Orbit Position
Density
Specific Heat
Conductivity
Faces in Directions
Ratio in Directions
OK
Cancel
Attribute | Attribute Value | Shell Name | Node | Optical Coating | Bulk Mat
Total_Solar_Heat_Source | 0.000000 | Radiator | 2537 | SSM["default"] | AlAl
Total_Solar_Heat_Source | 322.199919 | SolarPanel | 5001 | SolarCells["defa... | AlAl
Total_Earth_Heat_Source | 41.069438 | PZ_Panel | 3001 | MLI["default"] | Foil
Temperature | -77.428317 | PX_Panel | 3129 | MLI["default"] | Foil | .780 | .460 | 300.00
Temperature | -4.396716 | Radiator | 2527 | SSM["default"] | AlAl | .800 | .200 | 300.00

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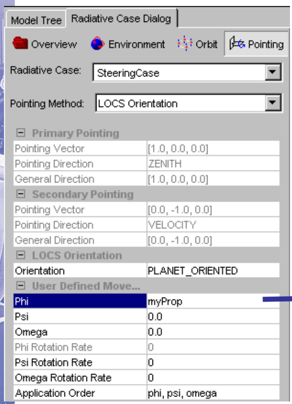
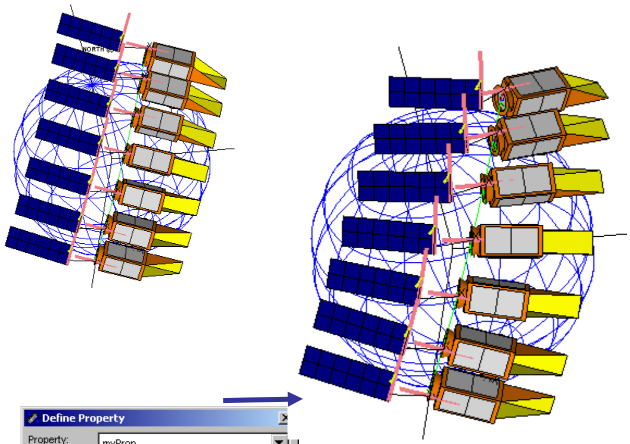
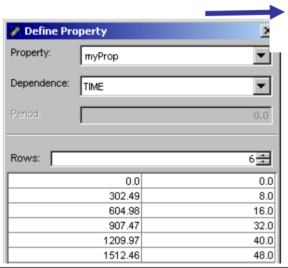
Time Dependent Steering

- ESATAN TMS Workbench offers support for User-defined pointing of Spacecraft
  - Allow definition of time dependent User-defined Movement







Property definition of Angle vs Time

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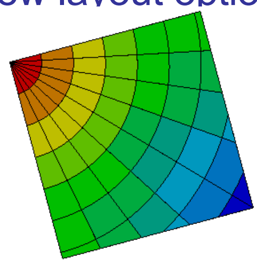
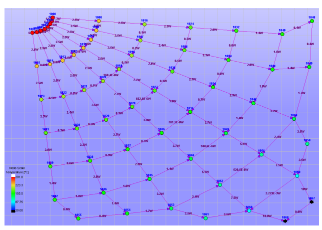
Coordinate Output

- ESATAN-TMS Workbench extended to output thermal node coordinates
- ESATAN-TMS Thermal extended to add the nodal entities FX, FY and FZ to thermal nodes
- ThermNV extended to include new layout option

```
$NODES
  D2  , T = 0.0,
   C  = 0.000000 * Cp_19 * Dens_19,
   A  = 1.000000, ALP = 0.160000, EPS = 0.780000,
   FX = 0.500000, FY = 0.500000, FZ = 1.00000;
  D3  , T = 0.0,
   C  = 0.000000 * Cp_7 * Dens_7,
   A  = 1.000000, ALP = 0.160000, EPS = 0.780000,
   FX = 0.500000, FY = 0.000000, FZ = 0.500000;
  D4  , T = 0.0,
   C  = 0.000000 * Cp_13 * Dens_13,
   A  = 1.000000, ALP = 0.160000, EPS = 0.780000,
   FX = 1.00000, FY = 0.500000, FZ = 0.500000;
```





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ESATAN-TMS r2

September 2009

Features

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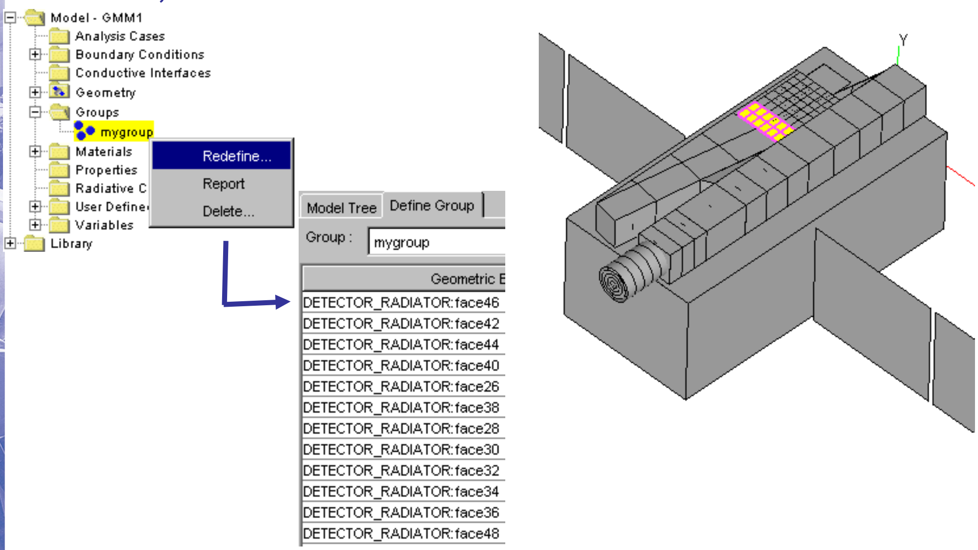
Support for Group Definition

- Allow a named collection of geometric entities to be defined as a group
- A Group can be any combination of shells, shell sides, faces or thermal nodes



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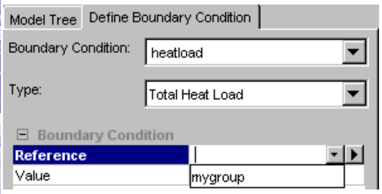
Support for Group Definition

- Fully available for boundary condition and user-defined conductors
- Information on defined group automatically output in thermal input file
  - Max/Min, total heat capacity, heat flux




```
$CONSTANTS
#
$CHARACTER
   # user-defined groups
   grp_mygroup = '#1000-1080, 2800, 2810, 5000';
#
C
$OUTPUTS
C
C Group characteristic data
      CALL PRTGRP(grp_mygroup, CURRENT)
C
```

```
ESATAN-TMS Thermal  10.4.2
03 October 2009    05:14:53

Characteristic data for node group defined by
  ZLABEL   = '#1000-1080, 2800, 2810, 5000'
  Submodel = PLATE2_ACASE01

Minimum Temperature :                      293.00
Maximum Temperature :                      293.00
Total Capacitance :                       6042.34

Total Albedo Heat Flux (QA) :                0.00
Total Earth Heat Flux (QE) :                 0.00
Total Internal Heat Flux (QI) :             30.00
Total Remainder Heat Flux (QR) :             0.00
Total Solar Heat Flux (QS) :                 0.00
Total Linear Heat Flux (GL) :               12.45
Total Radiative Heat Flux (GR) :            35.96
Total One-Way Heat Flux (GF) :               0.00
```

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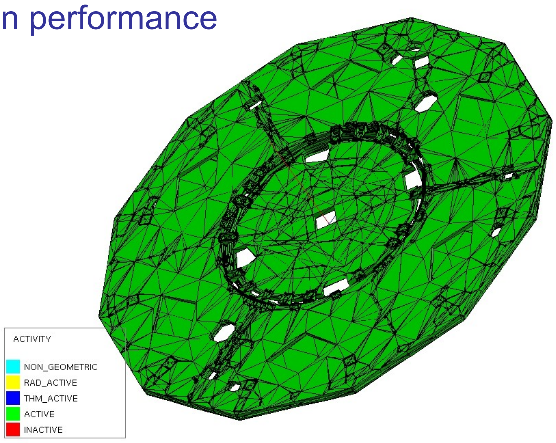
Performance and Scalability Improvement

- Performance and Scalability for radiative calculation and the analysis file output
- Excellent results achieved (Acceptance model on Linux)
  - >40% Reduction in associated file size
  - >70% reduction in peak memory usage
  - >70% improvement in performance



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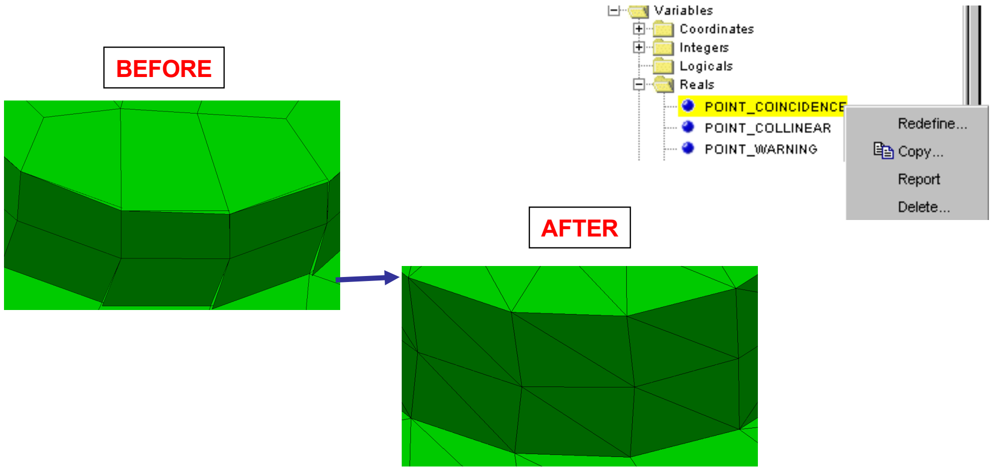
Nastran Import

- Automatic split into triangular shell for non co-planar quadrilateral
  - Avoid any gaps in geometry due to point shifts
- Introduction of new user tolerance parameters
  - Point_coincidence & Point_collinear



ITP Engines UK
An ITP Group Company

www.esatan-tms.com

support@esatan-tms.com

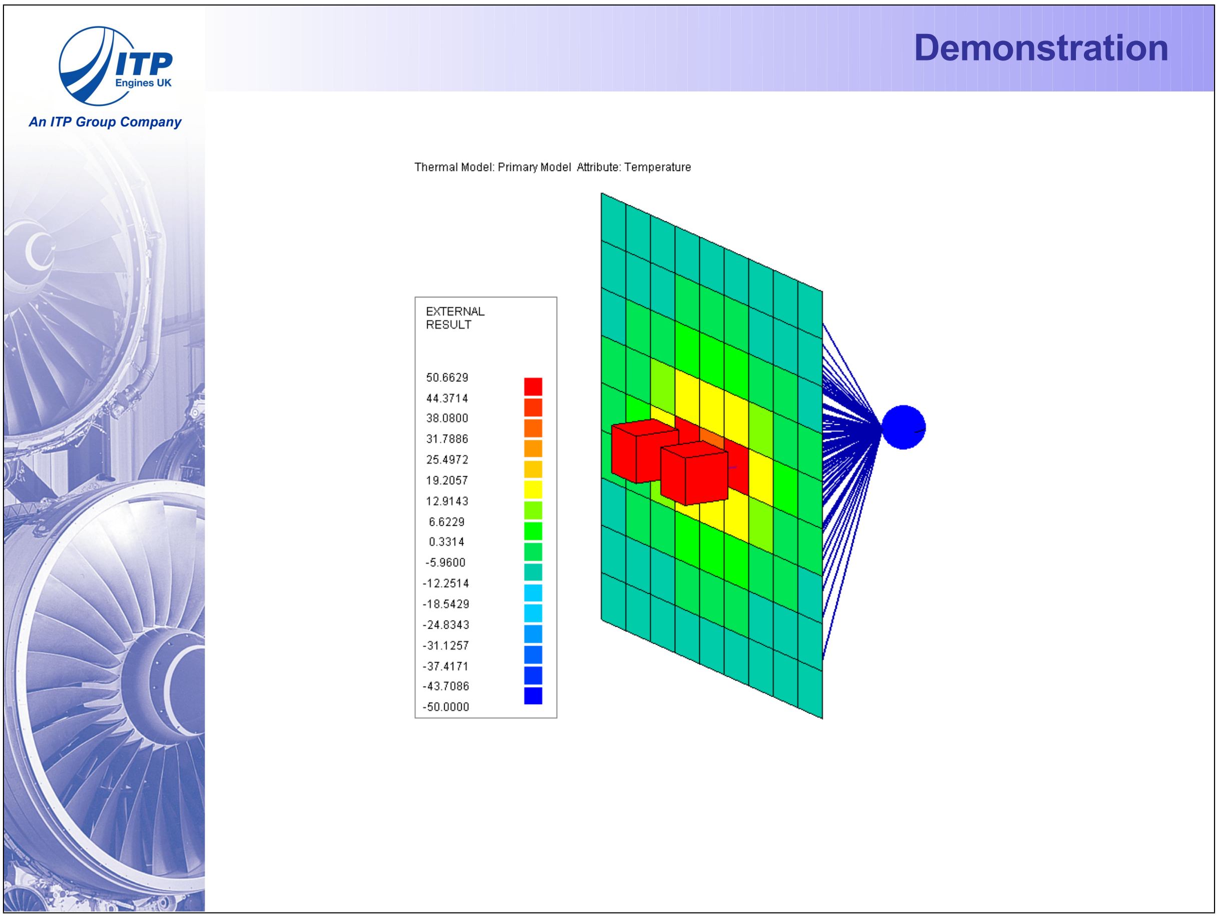
Appendix I

ESATAN Thermal Modelling Suite
Demonstration

Henri Brouquet
(ITP-UK, United Kingdom)

Abstract

Demonstration of the latest version of ESATAN-TMS.


ITP
Engines UK
An ITP Group Company
Demonstration
Thermal Model: Primary Model Attribute: Temperature
EXTERNAL
RESULT
50.6629
44.3714
38.0800
31.7886
25.4972
19.2057
12.9143
6.6229
0.3314
-5.9600
-12.2514
-18.5429
-24.8343
-31.1257
-37.4171
-43.7086
-50.0000

Appendix J

Methods for solving linearized networks in satellite thermal analysis

Martin Altenburg   Johannes Burkhardt
(EADS Astrium, Germany)

Abstract

The presentation discusses a further development step of the Astrium in-house S/W tool TransFAST. This tool was originally developed in order to establish methods for calculation of transfer functions in the frequency domain, as was required for thermal analysis of the LISA missions. The mandatory first step of such type of analysis is the transformation of the classical thermal network to a standard linear control system by linearization of the radiative terms at a certain steady-state. As an extension of the existing tool, this linear control system shall be solved in the standard time domain.

Application of this type of analysis becomes important for all missions, where extremely demanding requirements on geometrical and thus thermo-elastic stability are involved. In such cases the deviations from a certain steady-state are small enough for performing thermal analysis on linearized systems. The major aim of such methods is to perform analyses with significantly less effort compared to the classical approach, but promising to deliver reasonable and even more accurate results.

Two different approaches for solving the linearized thermal network in the time domain are presented, the well-known ordinary differential equation (ODE) methods, and a quasi-analytical method, which splits the differential equations in a homogenous and an in-homogenous part. The major advantage of analytic solutions would be that no transient calculation for the whole time period is necessary. This is particularly suitable for problems where only a small number of specified time points are of interest. Also these time points can be selected w/o any limitation w.r.t. exactness of the solution, because the calculation requires only the analysis of a function, instead of solving an algorithm which gradually time step by time step creates the solution. This implies that a (final) steady-state solution caused by a certain disturbance can be directly calculated without having potential numerical problems as for a transient calculation. Results obtained by these two approaches are compared vice versa and with results calculated by the standard thermal analysis S/W.

Methods for Solving Linearized Networks in Satellite Thermal Analysis

Martin Altenburg // 6.10.2009
martin.altenburg@astrium.eads.net

All the space you need

EADS astrium

Overview

Methods for Solving Linearized Networks in Satellite Thermal Analysis

- Motivation & Methodology
- ODE Approach
- Quasi-analytical Approach
- Exemplary Results
- Summary & Outlook

All the space you need
— Page 2
06.10.2009
23rd European Workshop on Thermal and ECLS Software:
Methods for Solving Linearized Networks in Satellite Thermal Analysis

EADS astrium

Motivation & Methodology

- Current & future science missions require ultra-stable S/C structures, with extremely demanding thermo-elastic stability requirements
- Thermal analysis accuracy has to be significantly improved
- Application examples:
  - → LISA aims to detect gravitational waves
  - → GAIA aims to create a precision 3-d star map of the galaxy
  - → Others …
- Perform thermal disturbance analysis for small deviations from the nominal state (i.e. standard thermal analysis steady-state solution)
- Linearization of the radiative terms of the heat balance equation, subsequent solution of the equation (linear control system now)
- Use standard programming environment (MATLAB)

All the space you need
— Page 3
06.10.2009
23rd European Workshop on Thermal and ECLS Software:
Methods for Solving Linearized Networks in Satellite Thermal Analysis
EADS astrium

Linear Control Methods

- Methods for application of linear control methods well established
  - → linearization of the heat balance equation
  - → frequency domain application (LISA, LISA Pathfinder)
    - → **d**irect **i**nversion of the **t**ransformed system matrix (DIT)
    - → **c**onditioned **e**valuation of the **f**requency response (CEF)

  see:
  Altenburg & Burkhardt: "A Software Tool Applying Linear Control Methods to Satellite Thermal Analysis" (last year workshop presentation)
- Significant advantages compared to standard methods:
  - → reduced computational & memory effort
  - → promises higher accuracy
- Extension of methods to (standard) time domain applications, e.g. Gaia
  - → ODE solvers, others …

All the space you need
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ODE (Ordinary Differential Equation) Approach

- Idea: apply standard methods for solving the linear control system, e.g. ODE solvers
- Thermal system characteristics:

→ stiff by nature
→ only real and negative Eigenvalues (heat flow in one direction only)
→ large difference between biggest and smallest Eigenvalue (orders of magnitude)

- Stiff problems are often solved better by applying implicit numerical methods
- Extensive comparison of MATLAB built-in solvers and others (literature search) w.r.t. computational effort and accuracy done

↓

- MATLAB built-on solver ODE15s showed best performance

→ implicit numerical ordinary differential equation solver
→ works with backward differentiation formulas and numerical differentiation formulas, based on the differentiation of a Lagrange polynomial

$$\sum_{m=1}^{k} \frac{1}{m}\nabla^{m} y_{i+1} - h\cdot F(x_{i+1}, y_{i+1}) = 0 \qquad \sum_{m=1}^{k} \frac{1}{m}\nabla^{m} y_{i+1} - h\cdot F(x_{i+1}, y_{i+1}) - \kappa\gamma_k\left(y_{i+1} - y_{i+1}^{(0)}\right) = 0$$

- ODE15s selected as baseline solver for time domain analysis

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Quasi-analytical Approach (1)

- Extended search for numerical solvers led to the idea to check also analytical methods
- Advantage of an analytical solution:
  → requires only the analysis of a function, instead of solving the complete algorithm
  → specific times of interest can be selected w/o any limitation w.r.t. exactness of the solution
  → steady-state solution can be directly calculated (particular part of the equation)
- Mathematical approach to solve a linear differential equation system

$$[\dot{x}] = [A_{DD}]\cdot[x] + [bu]$$

disturbance vector ($[bu]$)

- Split problem into a homogenous and a particular part ($x = x_h + x_p$)
  Solve the homogenous part with the standard approach for linear differential equation systems

$$[x_h] = c\cdot[v]\cdot e^{\lambda t} \xrightarrow{\text{Differentiation}} [\dot{x}_h] = \lambda\cdot c\cdot[v]\cdot e^{\lambda t}$$

- Apply standard approach and differential to homogenous part

$$\lambda\cdot c\cdot[v]\cdot e^{\lambda t} = [A_{DD}]\cdot c\cdot[v]\cdot e^{\lambda t} \xrightarrow{\text{Transformation}} \det([E]\cdot\lambda - [A_{DD}]) = 0$$

- Calculate Eigenvalues and Eigenvectors → homogenous solution

$$[x_h] = c_1\cdot[v_1]\cdot e^{\lambda_1\cdot t} + c_2\cdot[v_2]\cdot e^{\lambda_2\cdot t} + \ldots\ldots + c_n\cdot[v_n]\cdot e^{\lambda_n\cdot t}$$

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Quasi-analytical Approach (2)

- Particular solution depends on type of disturbance vector
- Example: constant disturbance vector *bu*
  → polynomial approach of first order (x_p = const, dx_p/dt = zero)
- Insert into differential equation and transform

$$[A_{DD}] \cdot [x_p] = -[bu]$$

- Combine homogenous and particular solution, solve the initial value problem by defining a logic initial value equal zero

$$[0] = [x_h(0)] + [x_p(0)]$$

$$[x_h(0)] = c_1 \cdot [v_1] + c_2 \cdot [v_2] + \ldots\ldots + c_n \cdot [v_n] = [V] \cdot [c]$$

- The system is transformed and the constants can be defined

$$[c] = -[V^{-1}] \cdot [x_p(0)]$$

- Extension to general disturbance vector (sine, Fourier series) under investigation

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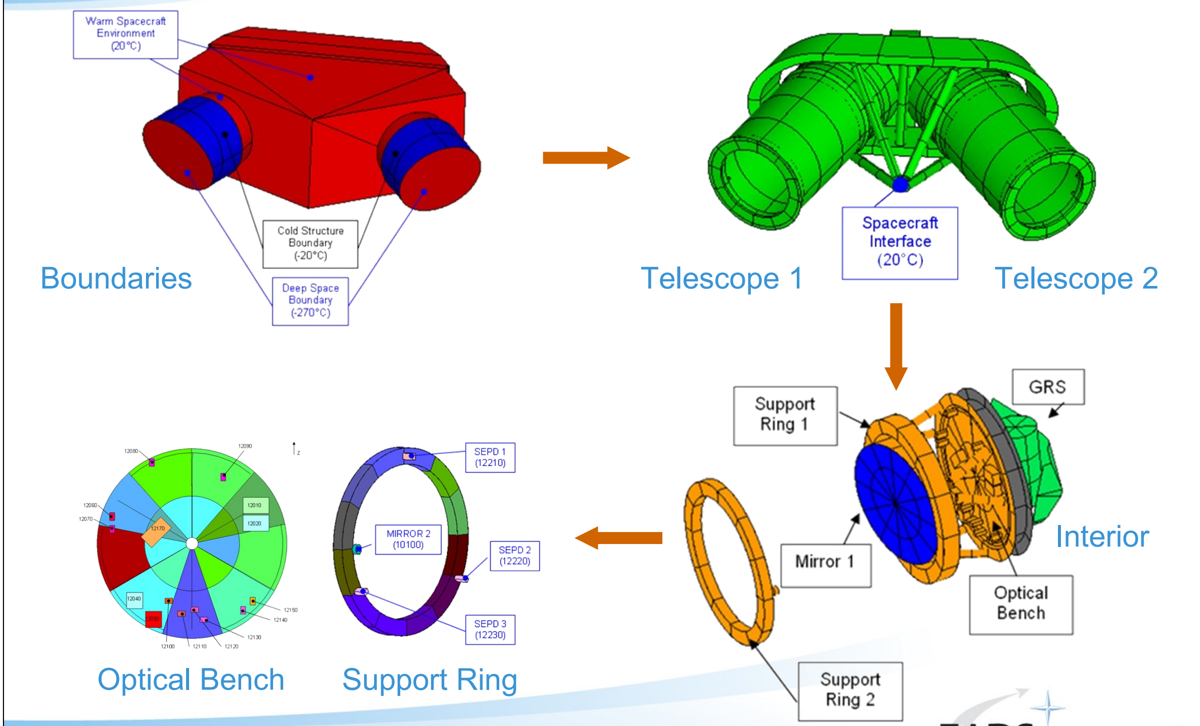
LISA Payload



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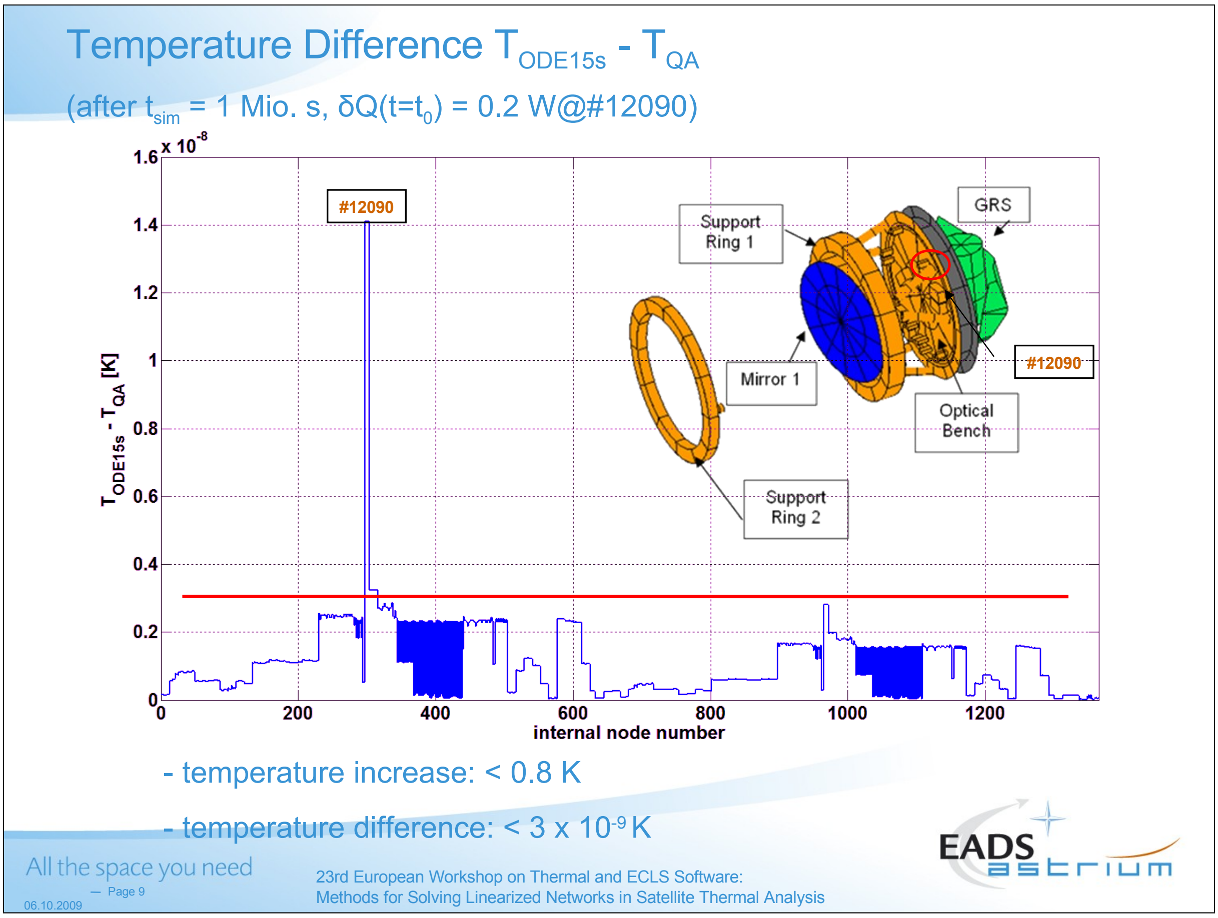
Temperature Difference T_ODE15s - T_QA
(after t_sim = 1 Mio. s, δQ(t=t_0) = 0.2 W@#12090)
x 10^-8
T_ODE15s - T_QA [K]
internal node number
#12090
Support Ring 1
GRS
Mirror 1
Optical Bench
Support Ring 2
- temperature increase: < 0.8 K
- temperature difference: < 3 x 10^-9 K
All the space you need
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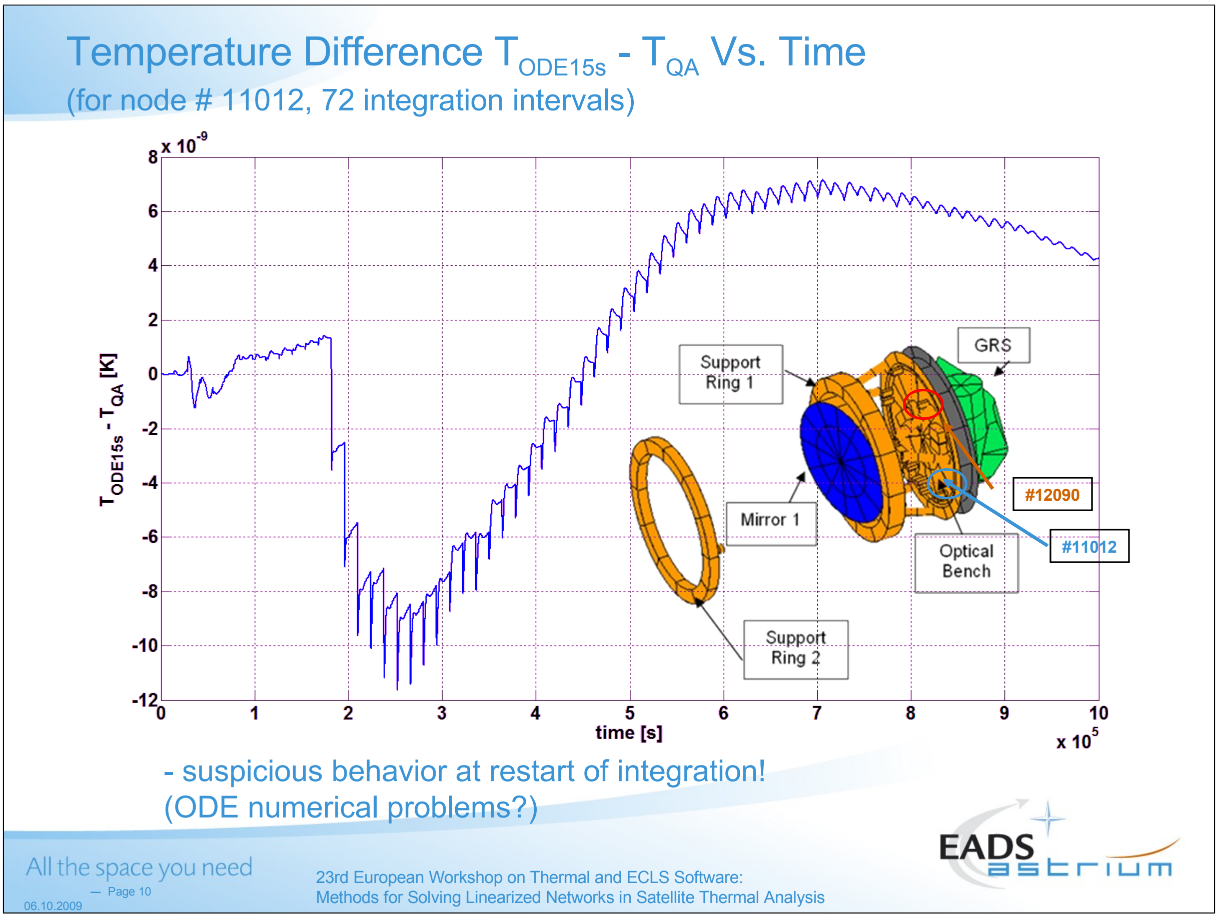
Temperature Difference T_ODE15s - T_QA Vs. Time
(for node # 11012, 72 integration intervals)
x 10^-9
T_ODE15s - T_QA [K]
time [s]
x 10^5
Support Ring 1
GRS
Mirror 1
#12090
#11012
Optical Bench
Support Ring 2
- suspicious behavior at restart of integration!
(ODE numerical problems?)
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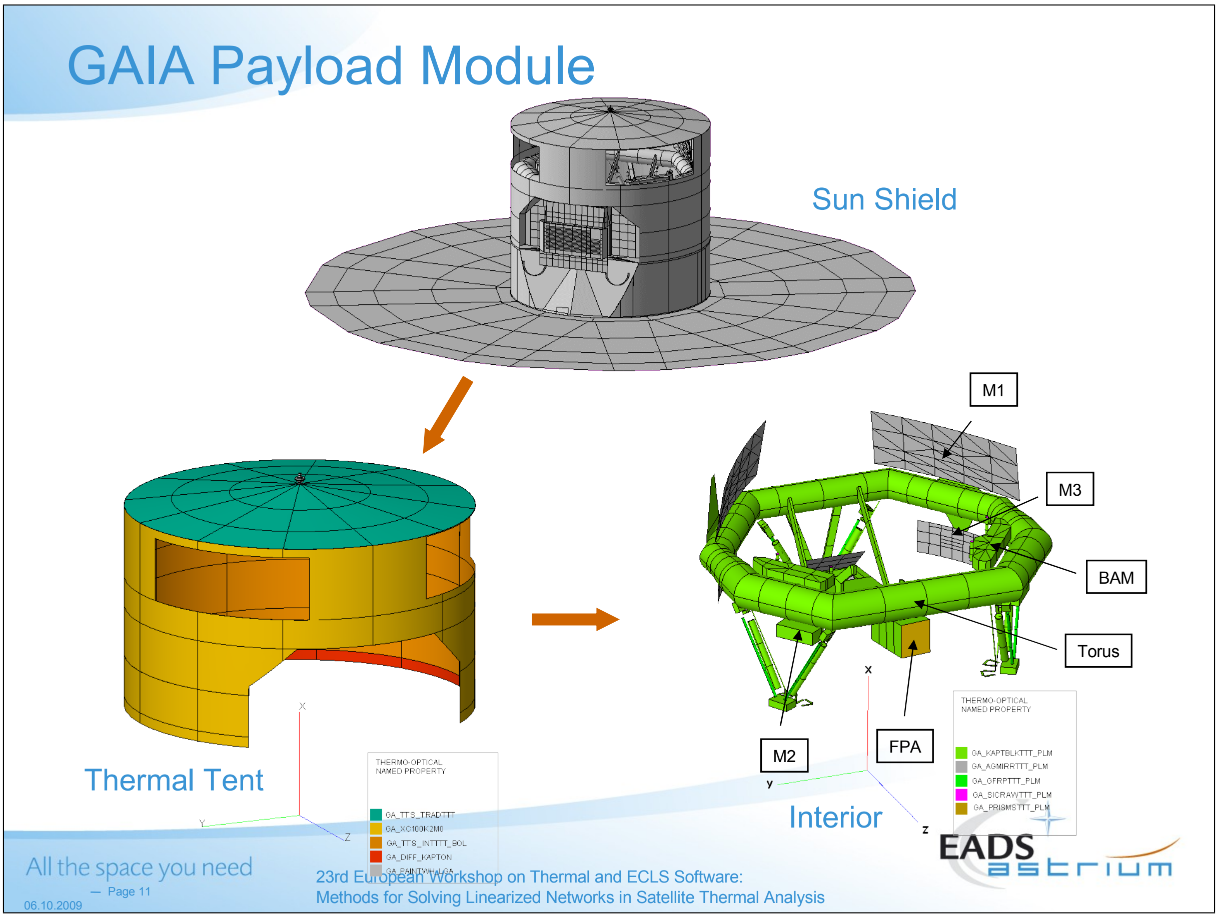
GAIA Payload Module
Sun Shield
Thermal Tent
Interior
M1
M3
BAM
Torus
M2
FPA
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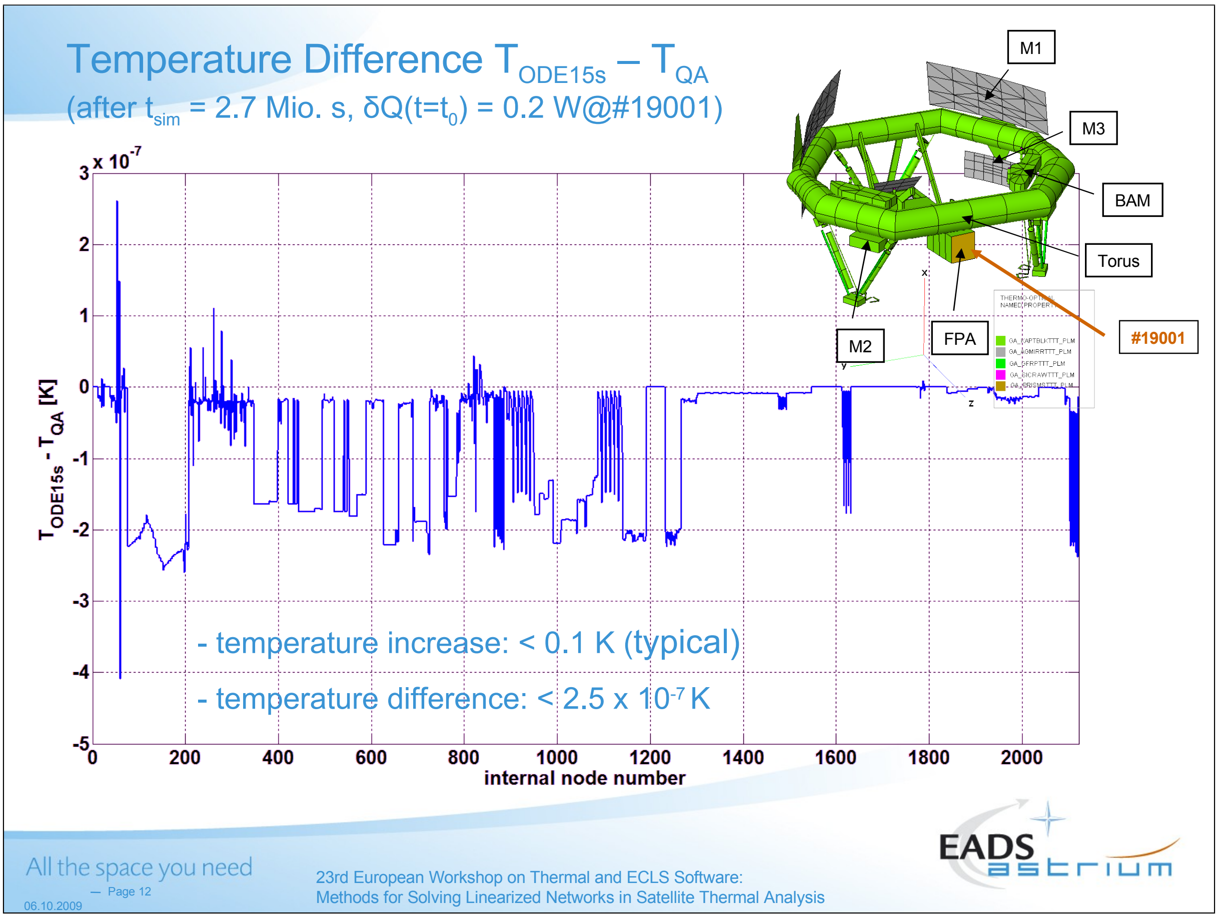
Temperature Difference $T_{ODE15s} - T_{QA}$
(after t_{sim} = 2.7 Mio. s, $\delta Q(t=t_0)$ = 0.2 W@#19001)
$x\ 10^{-7}$
$T_{ODE15s} - T_{QA}$ [K]
internal node number
- temperature increase: < 0.1 K (typical)
- temperature difference: < 2.5 x 10^{-7} K
M1
M3
BAM
Torus
M2
FPA
#19001
All the space you need
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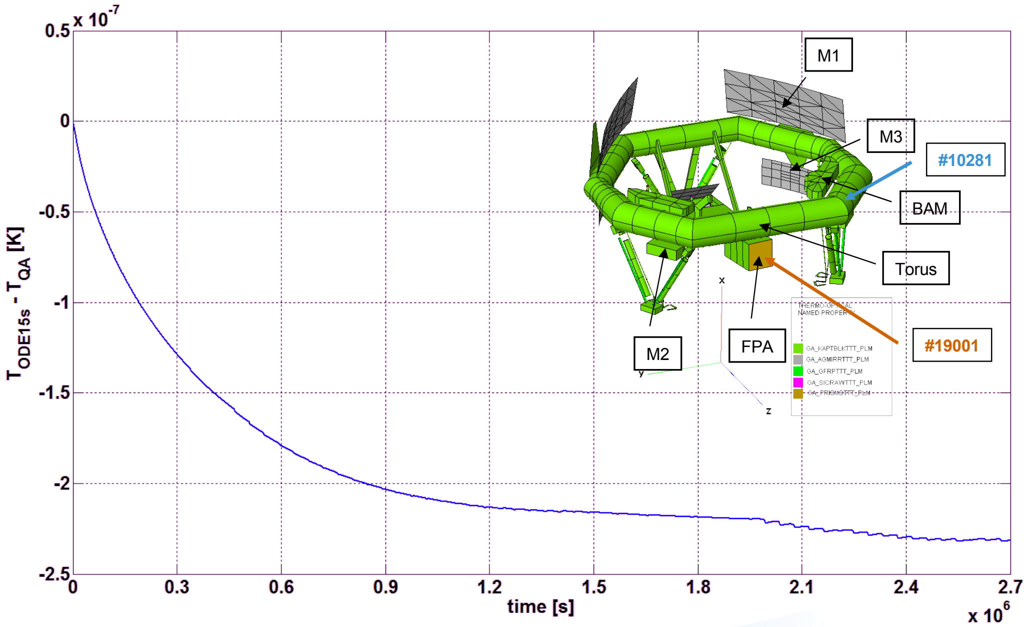
Temperature Difference T_{ODE15s} - T_{QA} Vs. Time

(for node # 10281)



- temperature difference drift → solutions diverge

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ODE vs. Quasi-analytical Approach (Summary)

- **LISA payload model**
  → very small temperature differences, ODE has some problems to resolve initial (step) input
  → temperature difference vs. time plots: no numerical drift
- **Gaia PLM model**
  → differences larger compared to LISA model, close to required absolute accuracy (μK range)
  → temperature difference vs. time plots: solutions diverge
- **Ordinary Differential Equation**
  → Pro: - capability to calculate any time-dependent perturbation function
  → Con: - needs to be run in small time interval steps (accuracy!)
  - difficult to identify the calculation error
- **Quasi-analytical approach**
  → Pro: - quasi steady-state calculation at any certain time of interest
  - in general faster
  → Con: - no guarantee to obtain a reasonable result for any type of perturbation
  - unknown accuracy for new particular solutions

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Comparison of Results – Standard Model vs. Linear Model

- Difference between linearized and non-linearized system

$$T^4 = (T_e + \delta T)^4 \cong 1 \cdot T_e^{\,4} + 4 \cdot T_e^{\,3} \cdot \delta T$$

- Approach for error estimation
  → calculation of a a steady-state solution in ESATAN
  → constant disturbance: new linear and nonlinear steady state calculation

$$\delta T_{nl} = T_{enl} - T_e \qquad \delta T_l = T_{el} - T_e$$

  → calculation of absolute and relative (scaled) differences

$$\delta T_{absdiff} = \delta T_{nl} - \delta T_l \qquad \delta T_{reldiff} = \frac{\delta T_{nl} - \delta T_l}{\delta T_{nl}}$$

- Expectations:
  → smaller relative error for smaller perturbations
  → smaller relative error at parts with less radiative heat exchange
  → non-linear solution should provide a cooler system (lower system energy)

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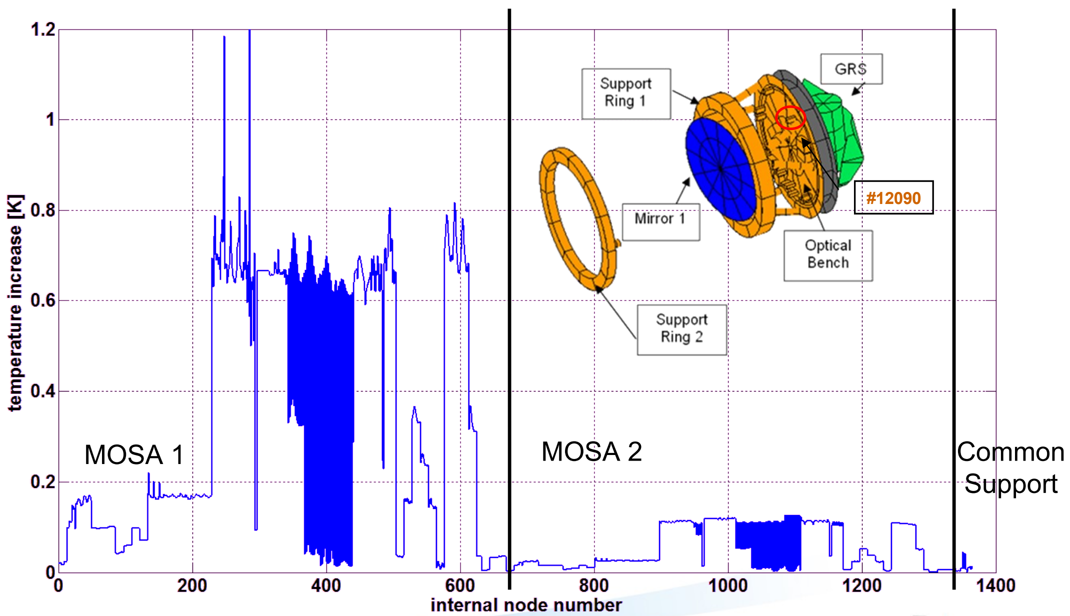
Temperature Increase for δQ =0.2 W @ # 12090 (Non-linear Solver)



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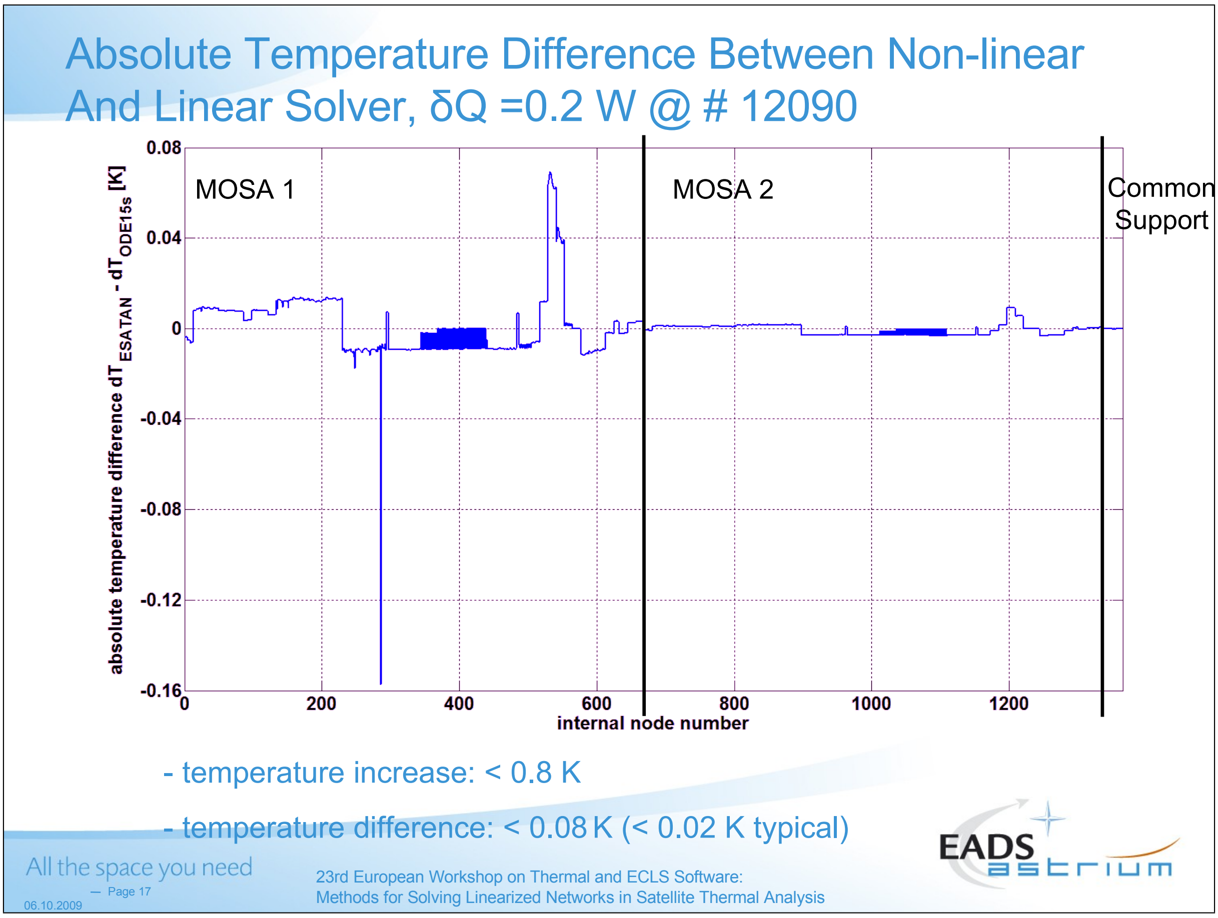
Absolute Temperature Difference Between Non-linear And Linear Solver, δQ =0.2 W @ # 12090
absolute temperature difference dT ESATAN - dT ODE15s [K]
MOSA 1
MOSA 2
Common Support
internal node number
- temperature increase: < 0.8 K
- temperature difference: < 0.08 K (< 0.02 K typical)
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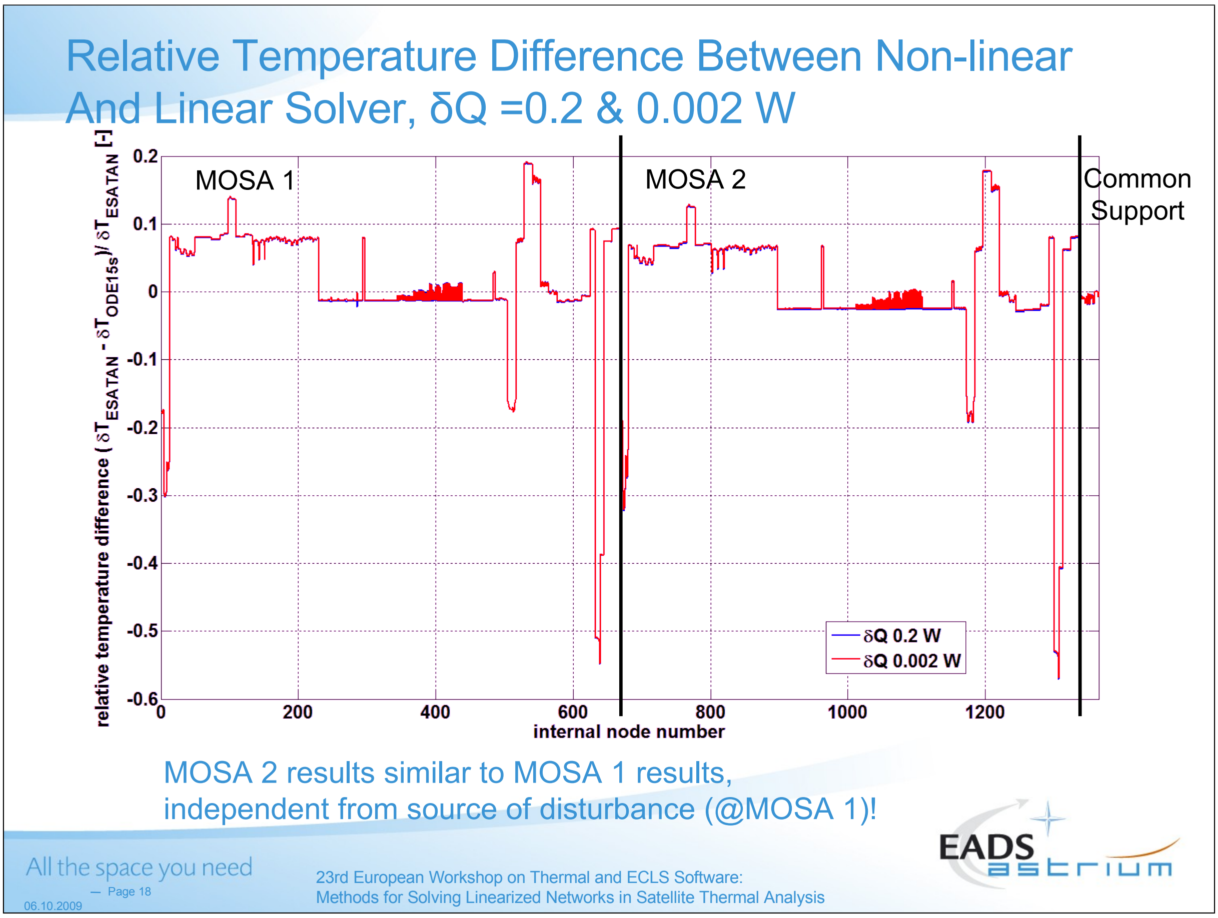
Relative Temperature Difference Between Non-linear And Linear Solver, δQ =0.2 & 0.002 W
relative temperature difference (δT ESATAN - δT ODE15s)/ δT ESATAN [-]
MOSA 1
MOSA 2
Common Support
δQ 0.2 W
δQ 0.002 W
internal node number
MOSA 2 results similar to MOSA 1 results, independent from source of disturbance (@MOSA 1)!
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Comparison of Results – Standard model vs. Linear Model (Summary)

- Link between level of disturbance and relative temperature differences confirmed only at nodes close to source of disturbance
- At some locations: unacceptable large deviations (>50%)
- Deviations are nearly independent from the level of disturbance (two telescopes!)

- Explanation:
  → ESATAN model and linear (MATLAB) model parameters are not exactly identical
  → potential linearization errors much smaller than effects induced by small differences of system parameters
  It has to be ensured that the system description of both models (Cp, GL, GR, etc.) is exactly identical!
  (Small differences were acceptable for frequency domain application)

- Assess/resolve this problem by
  → avoiding zero-capacities (MLI, arithmetic nodes) in the ESATAN model
  → applying only double precision accuracy, (.000000000000 - .000000368961)

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Summary & Outlook

- Methods for solving linearized thermal networks established
  → frequency domain (DIT & CEF)
  → time domain (ODE & QA)

- Non-linear vs. linear: discrepancies, but not linked to linearization

- Linear systems
  goal:
  establish verified and reliable methods for time domain analysis in order to solve high-accuracy problems
  further activities:
  → re-asses MATLAB internal memory problem (ODE, large models)
  → further work on quasi-analytical methods
  (general disturbance vector (sine, Fourier series))
  → implementation of (finally selected) methods in Astrium in-house tool TransFAST

- Solve standard non-linear thermal system in MATLAB
- Broader Literature research (solvers used by other disciplines)

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Contact

Dipl.-Ing. Martin Altenburg

EADS Astrium GmbH
88039 Friedrichshafen
Germany

Phone: +49-7545-8-2494
Fax: +49-7545-818-2494

E-Mail: Martin.Altenburg@astrium.eads.net

Dr.-Ing. Johannes Burkhardt

EADS Astrium GmbH
88039 Friedrichshafen
Germany

Phone: +49-7545-8-4989
Fax: +49-7545-818-4989

E-Mail: Johannes.Burkhardt@astrium.eads.net

Appendix - Linearization Approach

1) Re-arrangement of the thermal network matrices

$$CP_i \cdot \frac{dT_i}{dt} = \sum_{i,j=1}^{n} \left(\frac{\lambda_{i,j} \cdot A_{i,j}}{l_{i,j}} \cdot \left(T_j - T_i\right) \right) + \sum_{i,j=1}^{n} \left(\sigma \cdot \varepsilon_i \cdot A_i \left(T_j^4 - T_i^4\right) \right) + Q_i$$

$$diag[C] \cdot \left[\frac{dT}{dt}\right] = [K] \cdot [T] + [F] \cdot \left[T^4\right] + [Q]$$

1) Linearization of radiative terms around the equilibrium state

$$T^4 = \left(T_e + \delta T\right)^4 \cong 1 \cdot T_e^4 + 4 \cdot T_e^3 \cdot \delta T$$

1) Linear Control System
→ Distinguish node types

$$\left[\dot{x}\right] = [A] \cdot [x] + [B] \cdot [u]$$

$$[y] = [C] \cdot [x] + [D] \cdot [u]$$

Node Properties:
- Node number (N)
- External & internal heat sources (Q)
- Steady-State temperature (T)
- Heat capacity (CP)

Node Links:
- Heat conductance coefficient (GL)
- Heat radiation coefficient (GR)

Node Property:
- Heat capacity (CP)

[A]: Steady-State temperature (T), Heat capacity (CP), Heat conductance coefficient (GL), Heat radiation coefficient (GR)

[B]: Heat capacity (CP)

Appendix K

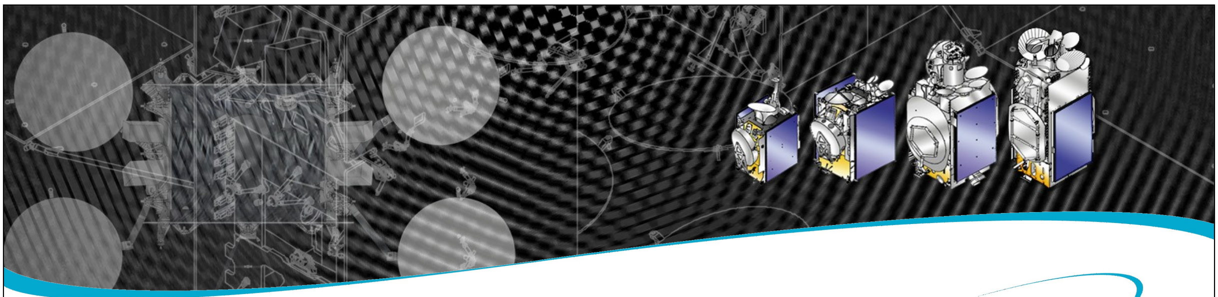
Herschel experience on modelling and verification of active heater control

Savino De Palo Marco Compassi
(ThalesAlenia Space, Italy)

Claudio Damasio
(ESA/ESTEC, The Netherlands)

Abstract

Herschel satellite was launched on May 14th, 2009 and is currently orbiting 1.5 million kilometres away from the earth on the second Lagrange point (L2) of the Sun-Earth system.
Main objective of the active thermal control system is the thermal stability of two HIFI instrument units ($3 \cdot 10^{-4}$ °C/s) and of the Star Tracker mounting plate ($2.5 \cdot 10^{-4}$ °C/s). After a brief introduction of the satellite, the presentation provides a general view on the lesson learnt from the thermal vacuum and thermal balance (TVTB) test performed in the ESA-ESTEC Large Space Simulator (LSS), control system design, thermal modelling and the current status of the ESA telescope.



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HERSCHEL EXPERIENCE ON MODELING AND VERIFICATION OF ACTIVE HEATER CONTROL

Savino DE PALO, Marco COMPASSI - ThalesAlenia Space

Claudio DAMASIO - ESA

Template reference : 100182079N-EN

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- INTRODUCTION
- SVM
- FINE CONTROL LAW
- PLANT TRANSFER FUNCTION
- CONTROL TUNING
- TVTB TEST
- STABILITY VERIFICATION
- FLIGHT
- CONCLUSIONS

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INTRODUCTION

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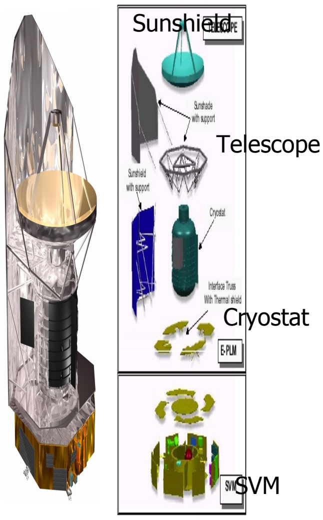
Herschel ESA Satellite was launched on 14th May 2009

Working in L2 orbit, investigating over the sub-millimeters and far-infrared range

Main instruments on board:

- 3.5 m Telescope
- Heterodyne Instrument for the Far Infrared (HIFI)
- Spectral Photometer Imaging REceiver (SPIRE)
- Photoconductor Array Camera & Spectrometer (PACS)



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SVM

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SVM Thermal Control Design objectives:

- Avionics and warm units → [-20;+40°C]
- Hydrazine units → [10;+50°C]
- Star tracker (STR) thermal stability
  - 250 mK over 100 s
  - feet gradients smaller than 0.4 K
  - variation amplitude +/-0.5 K
- HIFI and warm units thermal stability → 30 mK/100 s
- Radiative flux to the PLM limit → 10 W
- Conductive flux to the PLM limit → 150 mW

STM test performed on May 2005 in ESTEC

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FINE CONTROL LAW

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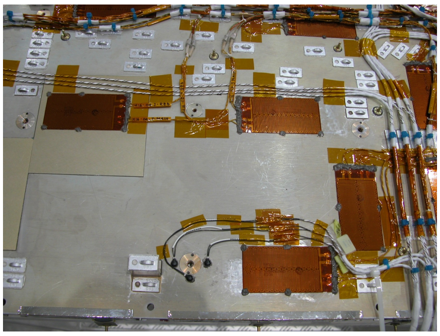
Temperature stability required for:

- FHWOV (HIFI unit)
- FHWOH (HIFI unit)
- STR



Control the mean temperature of 3 thermistors placed close to units

Heater circuits commanded by PI control

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FINE CONTROL LAW

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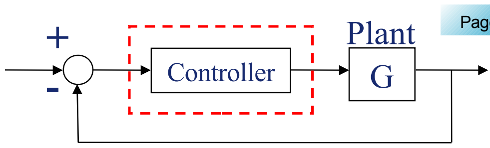

Control Algorithm

$$P_k = -\lambda P_{k-1} - \delta P_{k-2} + \alpha(T_{ref} - T_k) + \beta(T_{ref} - T_{k-1}) + \gamma(T_{ref} - T_{k-2})$$

P_k = heating power at current time *k*

P_{k-1} = heating power at the previous time *k-1*

P_{k-2} = heating power at the most previous time *k-2*

T_{ref} = reference temperature (set-point)

T_k = measured temperature at the current time *k*

T_{k-1} = measured temperature at time *k-1*

T_{k-2} = measured temperature at time *k-2*

α, β, γ, λ, δ = coefficients of the discretized regulator

Sampling frequency / command = 10s

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FINE CONTROL LAW

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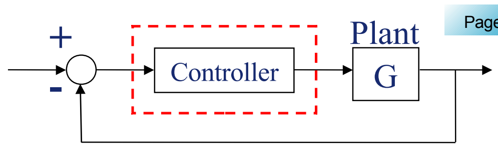
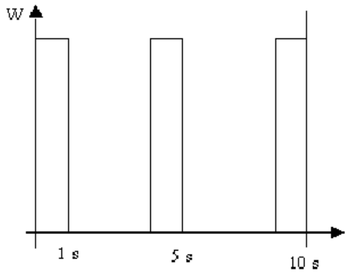
Pulse Width Modulation (PWM)



- P_k commanded every second as pulse train
- Pulse train uniformly distributed to reduce discretization disturbances
- Residual logic implemented after STM test

P_k computed – P actually injected

Cumulated residuals for additional pulses



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PLANT TRANSFER FUNCTION

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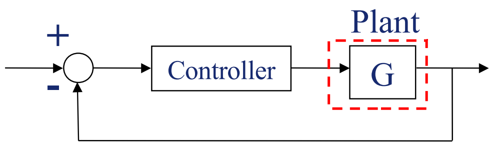
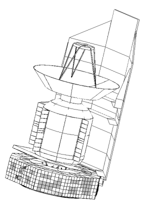
- Plant Model required to tune PI (α, β, γ, λ, δ)



- STM test → Space State model from Reduced TMM



ESATAN → *GL, GR, T, C...* → $\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$ → $G(s) = C(sI - A)^{-1} B + D$

- FM huge TMM (~ 4000 nodes) → System Identification (MATLAB)

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PLANT TRANSFER FUNCTION

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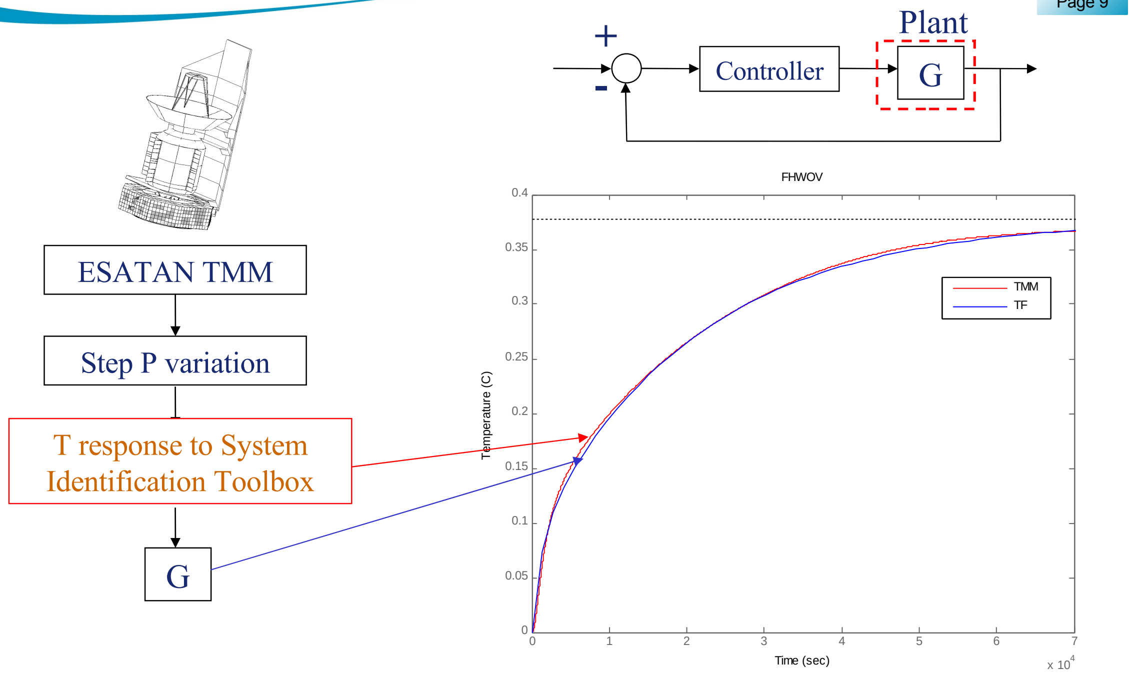

CONTROL TUNING

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- Control law coefficients designed in the continuous time domain (open loop transfer function)
- Tustin method (sampling =10 s)

Disturbance	Period	Amplitude vs Period	Amplitude
Quantization (=LSB)	10 s	acquisition refresh time	0.05 °C
Telemetry analog error	random	N/A	± 0.05 °C
S/C attitude change	514 s (single event)	Ramp	60 ° (a)
Unit dissipation power fluctuation	200 s	Square wave	0.015 W
Heater BUS voltage fluctuation	200 s	Square wave	0.125 V

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TVTB TEST

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FM TVTB was performed on Nov./Dec. 2008 in ESTEC

- Control law performance on HIFI and STR units → stability requirement verification

- Step changes of 1°C in the control set-points were given producing the required transient response

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TVTB TEST

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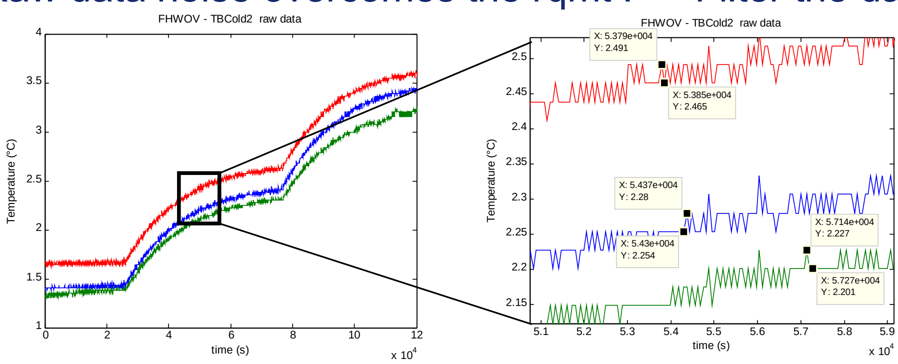
Sampling Rate = 64s ; ΔT min = 0.026°C

Minimum ΔT gradient between two samples
$0.026°C / 64s = 4.026 \cdot 10^{-4}$ °C/s > 0.03°C/100s

Raw data noise overcomes the rqmt ! → Filter the data



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TVTB TEST

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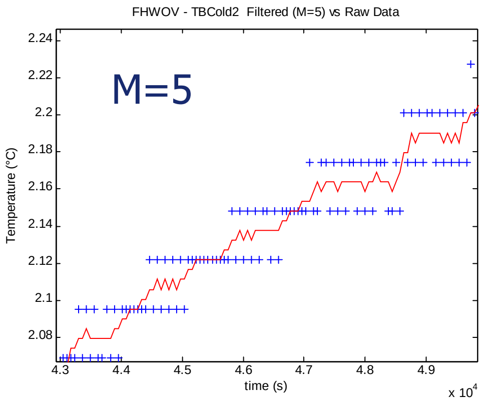
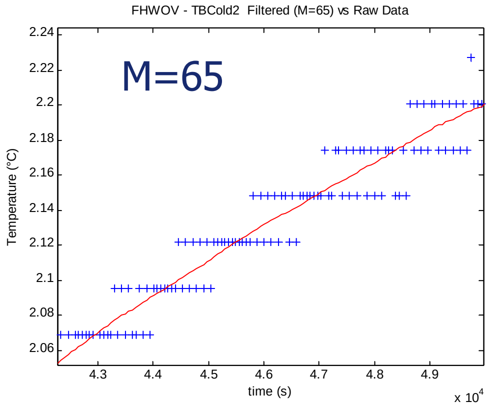
Moving Average Filter (MAF) as suggested by DSP theory

$$tfilt(i) = \frac{1}{M} \sum_{j=-(M-1)/2}^{(M-1)/2} traw(i+j)$$





Lowest span (M=5) selected to reduce to the minimum MAF weight on requirement verification

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TVTB TEST

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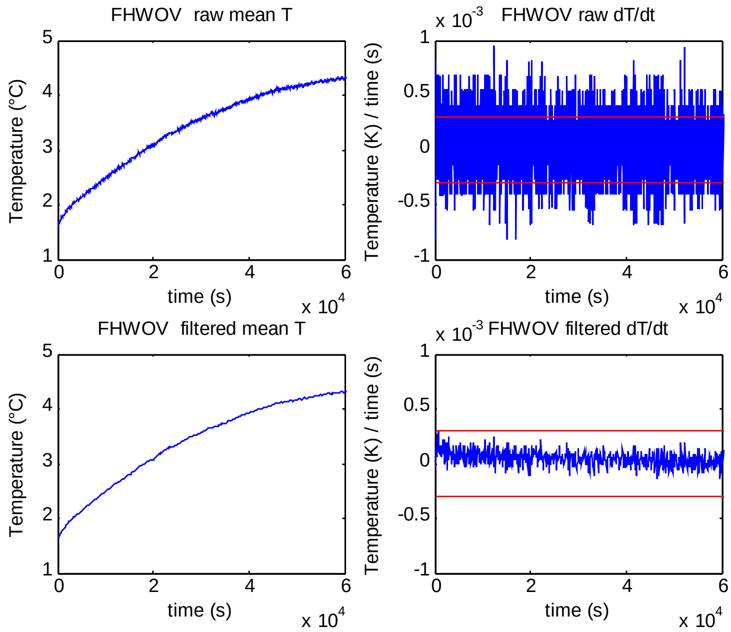

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STABILITY VERIFICATION

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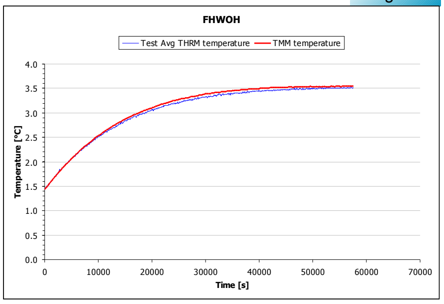
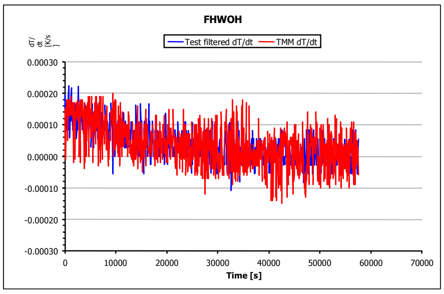
- TMM correlated for TVTB Predictions compared with test results
- TMM was able to reproduce with good fidelity the transient response providing even conservative values for stability verification
- TMM was used to verify stability requirements in Flight conditions





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FLIGHT

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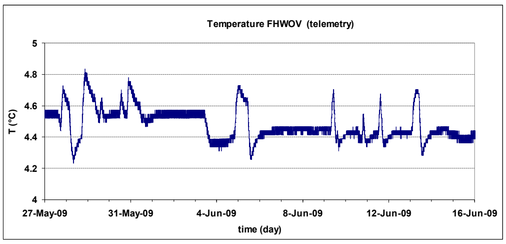

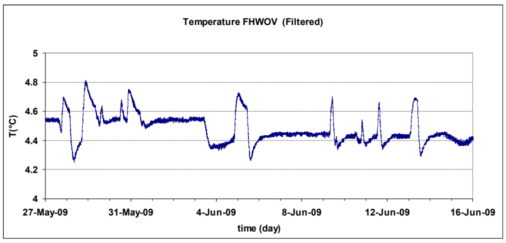

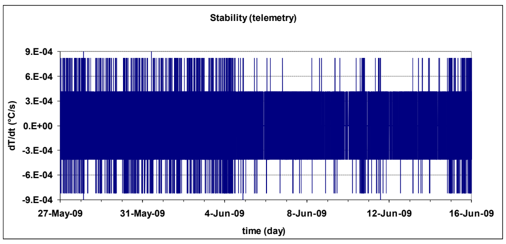

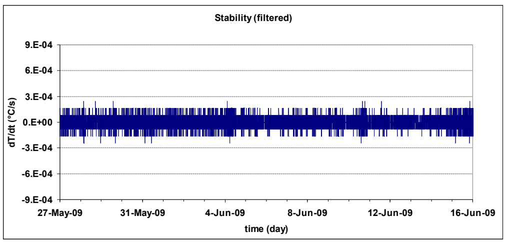

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CONCLUSIONS

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◇ Herschel active control loop performance vs thermal stability requirements verified at test/flight level

◇ TMM (ESATAN) was used for validation before flight

◇ System Identification played a key role for fast plant modeling (LTI) from huge TMM

◇ Test/flight data filtering (MAF) for correct verification of the requirement

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Appendix L

Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit

Simone Del Togno Gabriele Messina
(DLR, Germany)

Abstract

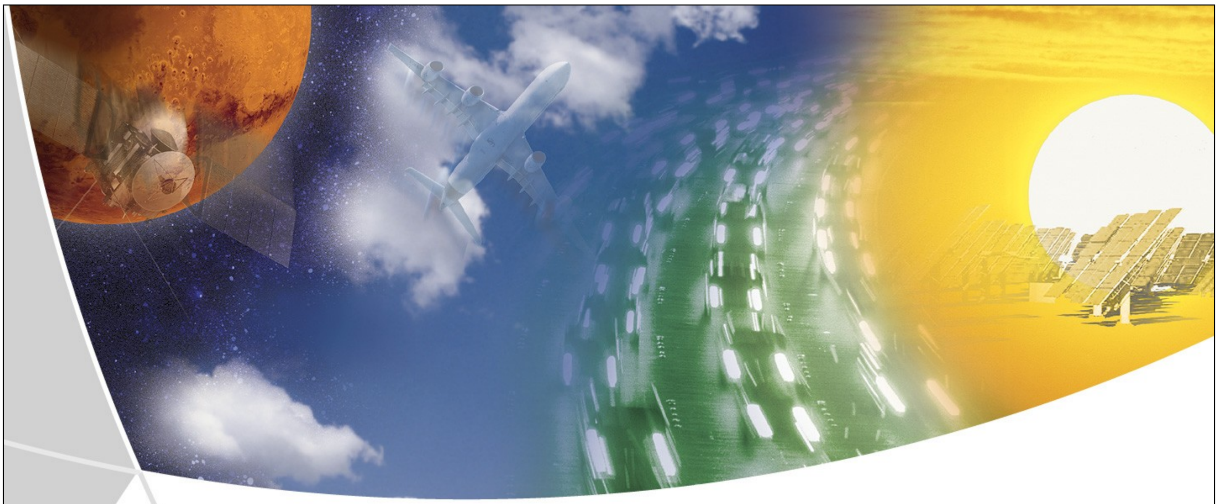
In the frame of the ESA BepiColombo mission to the planet Mercury the German Aerospace Center (DLR), in cooperation with the University of Bern, is designing the first European laser altimeter for planetary exploration (BELA).

While orbiting Mercury the solar flux reaches 14 kW and strikes on the instrument at angles of ≥ 38 deg from the instrument line of sight. The planet surface reaches 700 K while the view factor with the instrument aperture is high due to the low orbit altitude.

Under these conditions a major challenge is the design of the instrument baffles, which shall avoid direct sunlight to reach the optics, minimize the heat load to the instrument and the S/C cavity and reduce stray light.

We describe the thermal model of the transmitter baffle, focusing on advanced features like the approximation of ellipsoids and hyperboloids in the geometrical mathematical model, its optimization with respect to computational time and baffle efficiency, the dynamic implementation of wavelength dependant thermo- optical properties for the calculation of both absorbed planetary fluxes – as function of Mercury surface temperature – and radiative conductances (GR).

The worst cases selection in the scenario of the whole Mercury orbit about the sun is also presented followed by a detailed overview of the analysis results.



Thermal model and analysis of the BELA transmitter Stavroudis baffle in Mercury orbit

Simone Del Togno

DLR, German Aerospace Center, Berlin, Germany

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

The BepiColombo mission

BepiColombo is the first European mission to explore the planet Mercury, carried out jointly by ESA and JAXA

Launch is scheduled for August 2013; orbit insertion in late summer 2019

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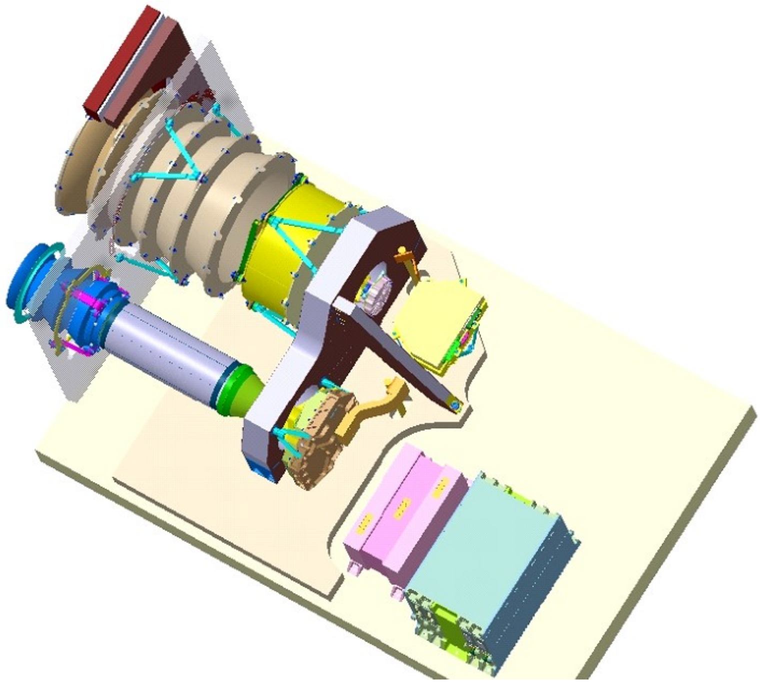
BELA Stavroudis Baffle in Mercury orbit

The BepiColombo Laser Altimeter (BELA)



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BELA Stavroudis Baffle in Mercury orbit

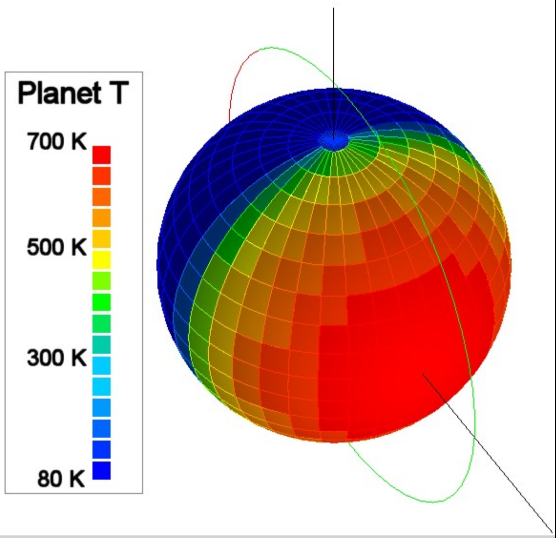
The Mercury environment

0.38 AU → thermal harsh environment:

- Solar flux up to 14 kW
- Planet surface 80 K < T < 700 K
  - → very high IR planetary fluxes
  - → substantial ΔT along the orbit

Charged particles, solar wind and high VUV radiation:

- ε, α ageing



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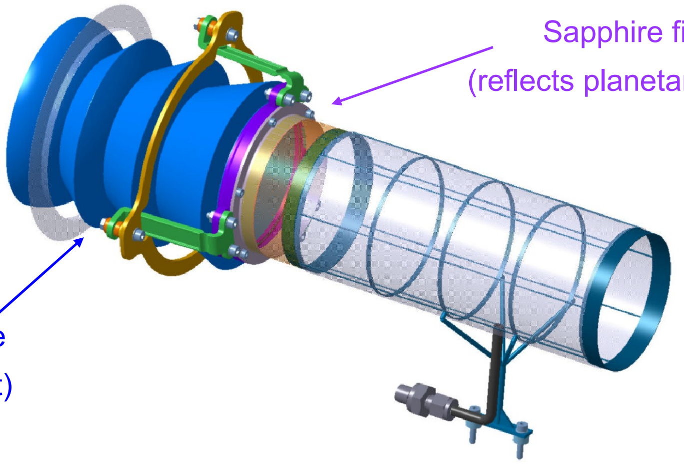
BELA Stavroudis Baffle in Mercury orbit

Transmitter baffle

Requirements:

- Avoid direct sun light on the optics
- Minimize the environmental heat load to both instrument and s/c
- Reduce the stray light



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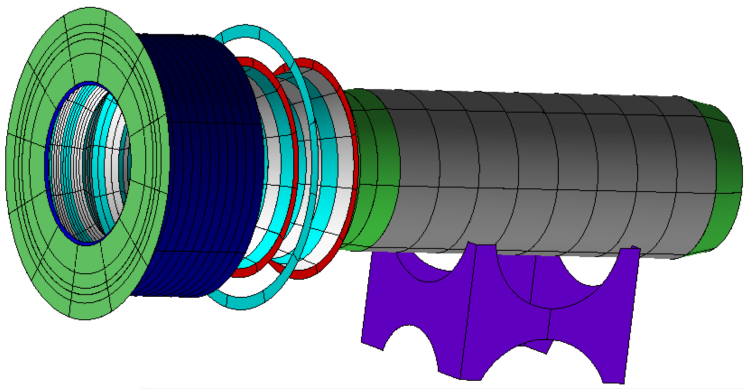
BELA Stavroudis Baffle in Mercury orbit

Thermal model

- 924 thermal nodes (360 for the baffle)
- 7329 radiative active faces (4512 for the baffle)

- Complex 3D optical surfaces in the GMM
- Temperature dependant thermo-optical properties



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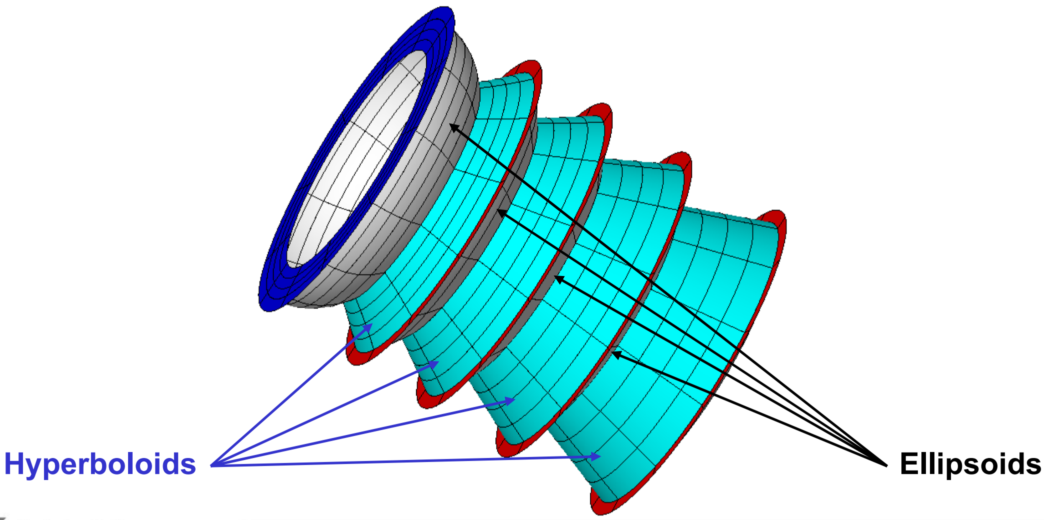
BELA Stavroudis Baffle in Mercury orbit

Geometrical Mathematical Model

Ellipsoid & Hyperboloids not in ESATAN-TMS

→ Geometry approximation required

cones, spheroids and paraboloids



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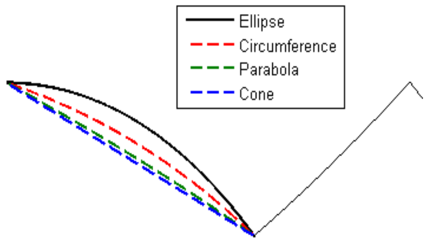
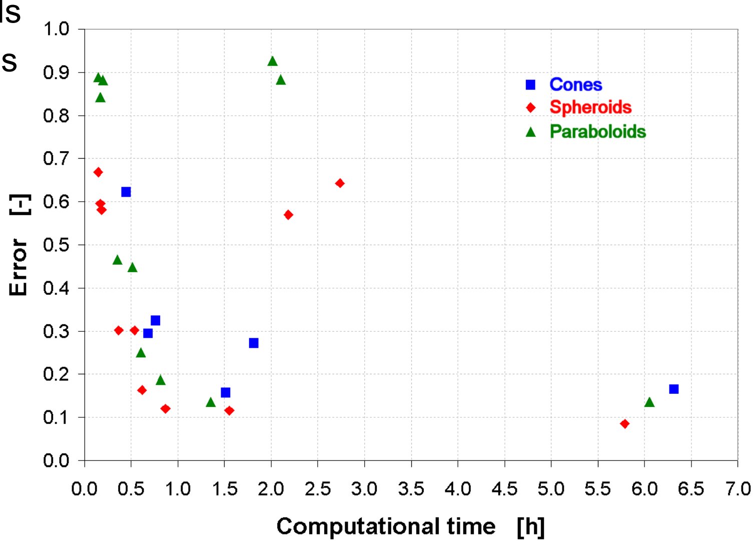
BELA Stavroudis Baffle in Mercury orbit

Geometrical Mathematical Model

Optimal discretization:

- non homogeneous mesh
- ellipsoids into spheroids
- hyperboloids into cones





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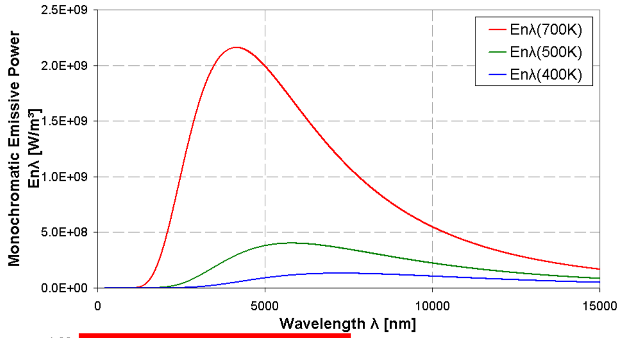
BELA Stavroudis Baffle in Mercury orbit

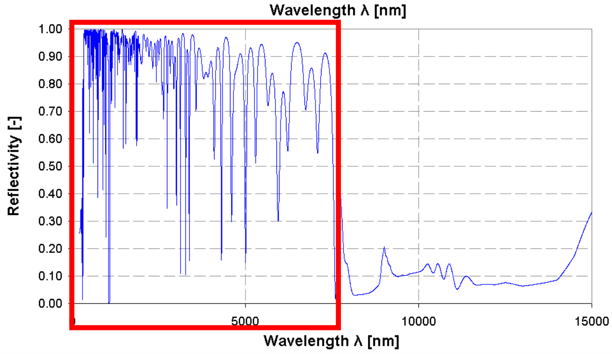
Temperature dependant thermo-optical properties

Mercury T = [80-700] K
→ different emission spectra



Filter properties strongly λ-dependant

→ Th-opt properties to be updated as function of planet temperature



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BELA Stavroudis Baffle in Mercury orbit

Temperature dependant thermo-optical properties

On each orbit position the filter spectrum is weighted on the planet spectrum

Grey-body assumption → the emission spectrum is function of the temperature

Flux through aperture:

$$QE = \varepsilon \cdot \sigma \cdot F \cdot T_{EQ}^4$$

Unknowns

F can be calculated analytically or numerically

QE is calculated by ESATAN-TMS

$T_{EQ}(t)$ → $\rho(t)$, $\varepsilon(t)$, $\tau(t)$

Implementation of T-dependant GRs requires high computational resources!

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BELA Stavroudis Baffle in Mercury orbit

How to do that in ESATAN-TMS?

Geometry file:

```
STRING PropEnv[42] = {"avrg", "AA", "AB", "AC", "AD", "AE", ...

OPTICAL TBU_Filter_int;

TBU_Filter_int[avrg] =  [0.65932778, 0.00000000, 0.01580000, ...
TBU_Filter_int[AA] =    [0.65193690, 0.00000000, 0.00120647, ...
TBU_Filter_int[AB] =    [0.65172261, 0.00000000, 0.00116262, ...
TBU_Filter_int[AC] =    [0.65140617, 0.00000000, 0.00109788, ...
TBU_Filter_int[AD] =    [0.65095839, 0.00000000, 0.00100626, ...
```

Kernel file:

```
PROP_ENV = Hot1.PROP_ENV;

FOR (orbit_index = 1;
     orbit_index < Hot1.NUM_ORBIT_POSITIONS;
     orbit_index = orbit_index + 1)

Hot1.PROP_ENV = PropEnv[orbit_index + 1];
PROP_ENV = Hot1.PROP_ENV;
```

Update PROP_ENV

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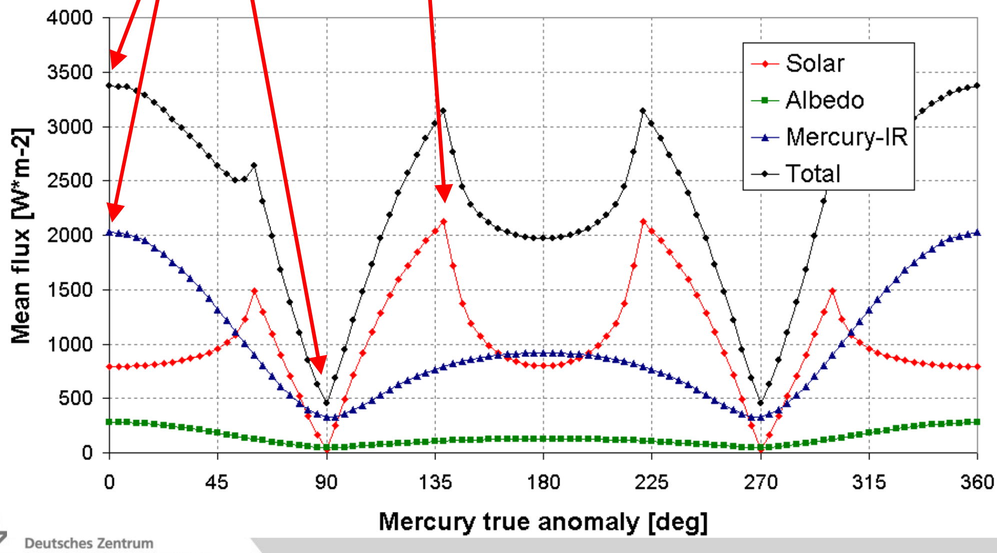
BELA Stavroudis Baffle in Mercury orbit

Worst cases

Max IR and total average fluxes: perihelion

Max average solar flux: ν = 140° (no eclipse)

Min fluxes: ν = 90°



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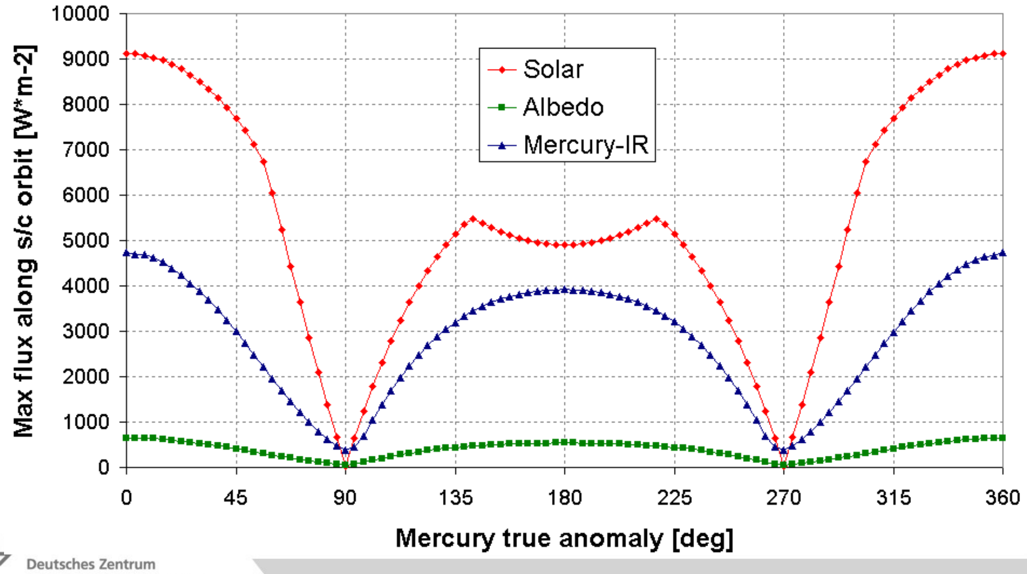
BELA Stavroudis Baffle in Mercury orbit

Worst cases

Peak of solar and IR fluxes: perihelion



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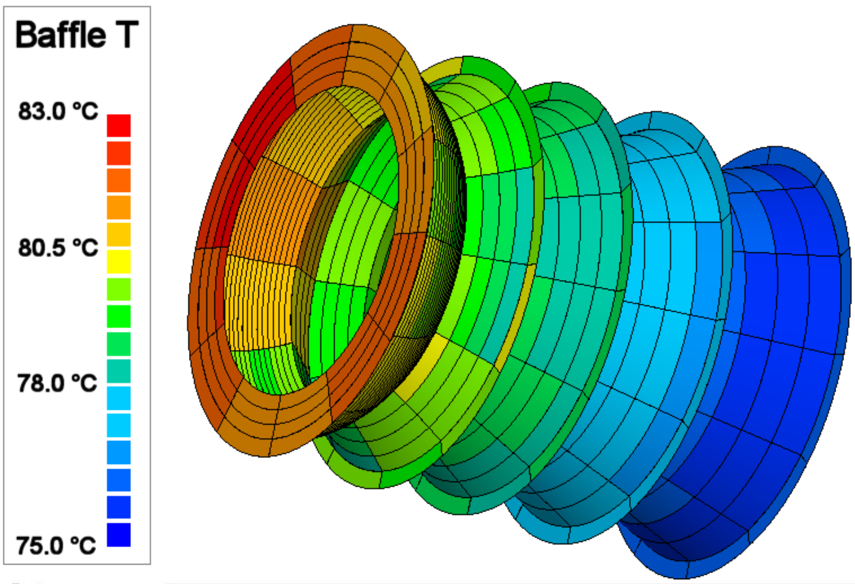
BELA Stavroudis Baffle in Mercury orbit

Analysis results: Steady state

Mercury at perihelion, BOL



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BELA Stavroudis Baffle in Mercury orbit

Analysis results: Steady state

Absorbed and rejected fluxes

At the aperture	85.2 W	
Instrument (sink)	0.06 W	0.07 %
S/C (sink)	5.22 W	6.12 %
Rejected	79.9 W	93.81 %
TOT	85.2 W	100.00 %

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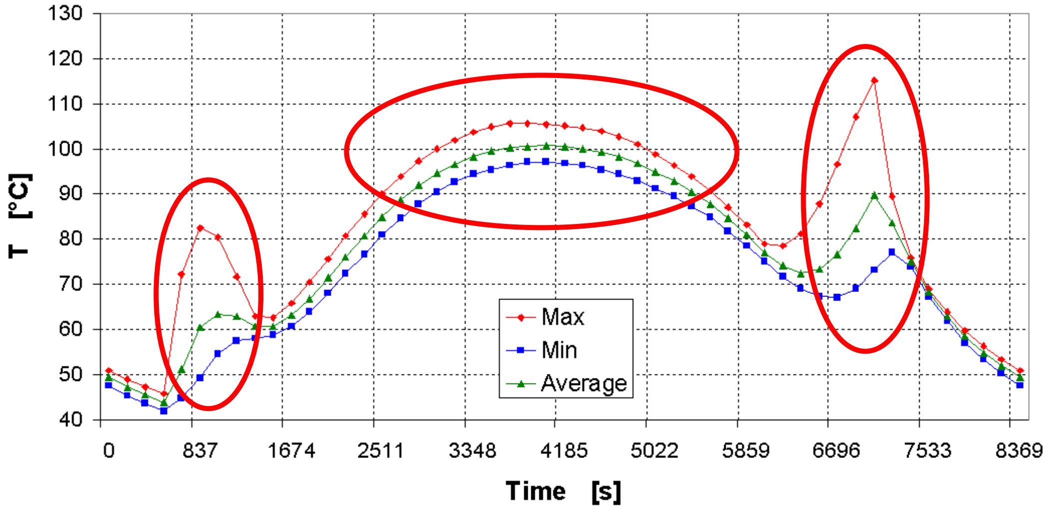
BELA Stavroudis Baffle in Mercury orbit

Analysis results: Transient



TMax = 115 °C

TMin = 42 °C

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BELA Stavroudis Baffle in Mercury orbit

Appendix M

Thermal design for an asteroidal lander

Riccardo Nadalini
(Active Space Technologies, Germany)

Abstract

After JAXA Hayabusa and NASA NEAR missions, several missions toward Near Earth Objects (NEO) are currently under study. One of the ongoing studies, part of the ESA cosmic vision 2015-2025 program, regards the ESA-JAXA cooperative Marco Polo mission, which aims at sampling a primitive NEO (D- or C-type).

Different landers are simultaneously under study by different teams. One of them is an Extra Small (XS), 10-kg class lander, studied by DLR in its concurrent engineering facility, study in which Active Space Technologies provided the thermal analysis and design that is presented here. Due to the limited resources available, the thermal control system must be entirely passive (no heaters).

Thermal requirements of the various systems are not extreme but they have to be maintained by insulating against a very harsh thermal environment (with a surface thermal excursion of 170°C in 2 hours) while, at the same time, dumping the dissipated heat (ca.12W) to the outside.

The analysis process of this Marco Polo lander follows a pattern that is exemplary for any object (lander or instrument) placed on the surface of an airless body in the solar system. First, the thermal characteristics of the body surface need to be established for different times in the available landing windows, then the worst cases are selected and the illumination of the object surfaces for them is calculated.

Once the environment (fluxes, soil, and surface temperature) is calculated, the thermal model of the lander can be combined with the model of the soil connected to the lander (immediately below) as well as with the appropriate boundaries (the surface of the asteroid in the surroundings) and the thermal design of the lander, in terms of connection and coatings can be performed.

In the case of the XS lander, the preliminary design is based on a good conductive and radiative insulation from the soil and in a mostly radiative dumping of the internal heat to the deep space.

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Thermal Design for an Asteroidal Lander

Riccardo Nadalini
Active Space Technologies GmbH

23rd European Workshop on Thermal and ECLS Software
Noordwijk, 6-7th October 2009

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- The mission and the lander
- Modelling approach
- Boundary conditions
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The mission

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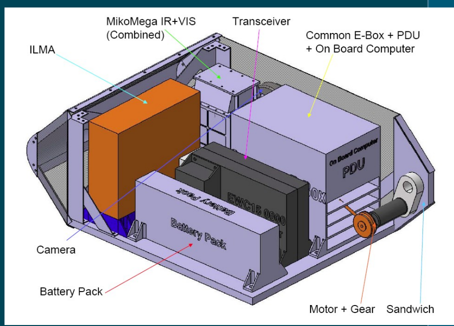
The Marco Polo Mission

- Mission being studied as part of ESA Cosmic Vision, selection end of 2009, lander studied in DLR CEF study
- Target is a Near Earth Object (NEO)
- Includes landing and Sample return from the surface
  - 10 Kg class lander,
  - ~3.5 Kg Payload
  - 12W Dissipation
  - Short life (10-20 hrs)
- Thermal aspects are critical
  - Normal requirements
  - Harsh Environment
  - S/C Environment



The target: 1999 JU3

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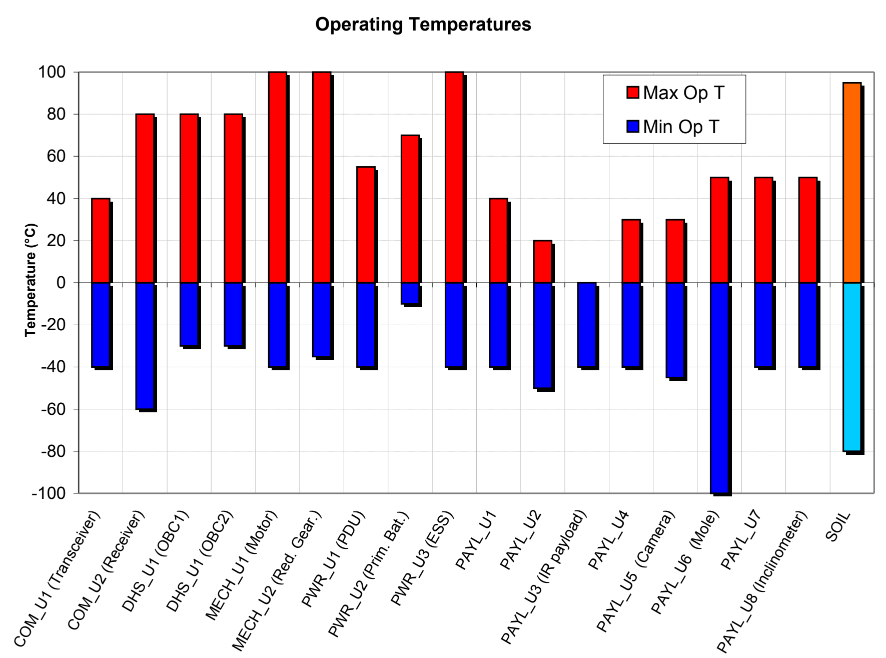
Target Asteroid

- Orbit Parameters
  - Rotation period: 27000s
  - Revolution period (adj): 473.75 days (1516 rotation periods)
  - Semimajor Axis (adj): 1.779258642127E+11 m
  - Eccentricity: 0.190028336
  - Latitude Spin Axis: 20°
  - Longitude Spin Axis: 330°
- Landing site latitude: 0° (longitude irrelevant)
- t_0 is midday (maximum solar flux)
- Albedo 0.06 (C-type Asteroid)
- Emissivity 0.95

Requirements



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Modelling Approach

1. Simulate undisturbed landing site
   - Model asteroid surface & Subsurface
1. “Land”
   - Model the interaction Lander/Environment
   - Calculate boundaries
1. Design
   - Run analyses with established boundaries
   - Change lander thermal design (materials, coatings, connections)
   - Recalculate boundaries

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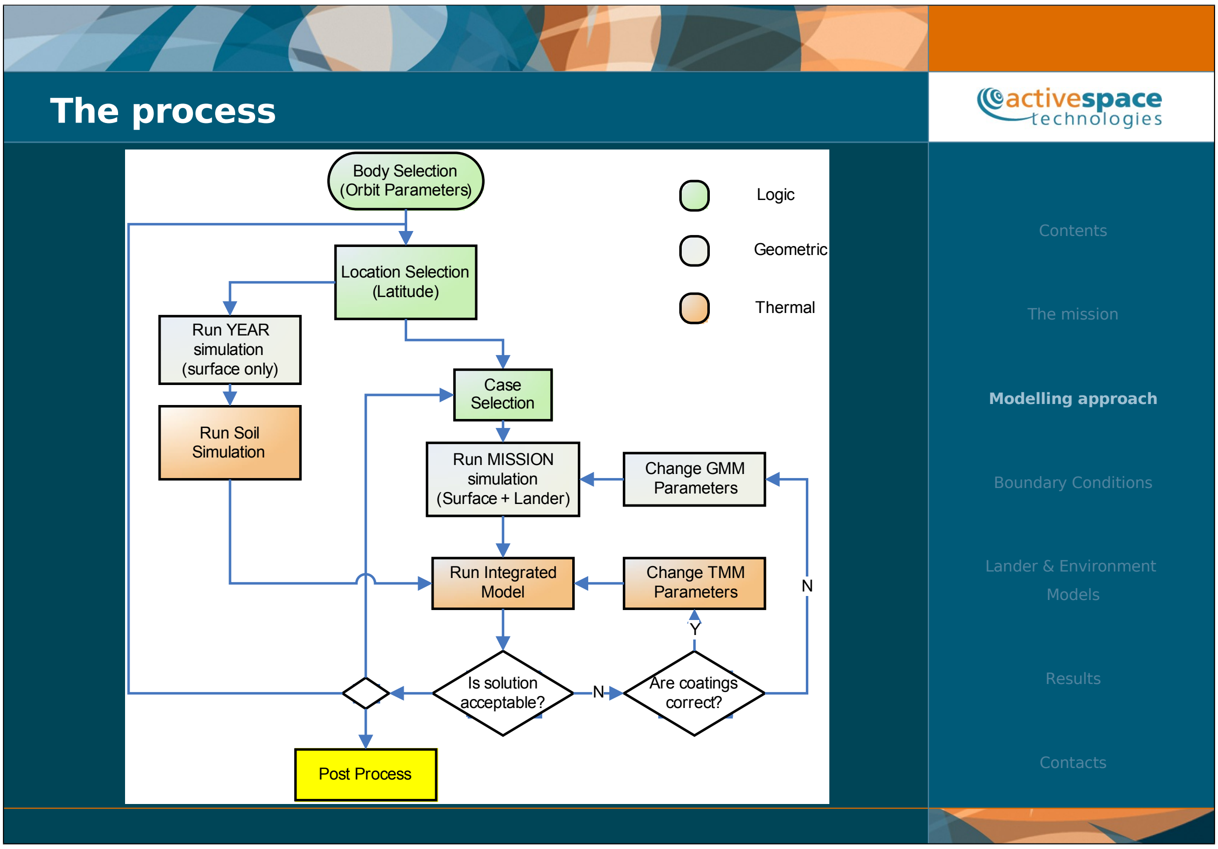
The process
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Body Selection (Orbit Parameters)
Location Selection (Latitude)
Run YEAR simulation (surface only)
Run Soil Simulation
Case Selection
Run MISSION simulation (Surface + Lander)
Change GMM Parameters
Run Integrated Model
Change TMM Parameters
Is solution acceptable?
Are coatings correct?
N
Y
N
Post Process
Logic
Geometric
Thermal
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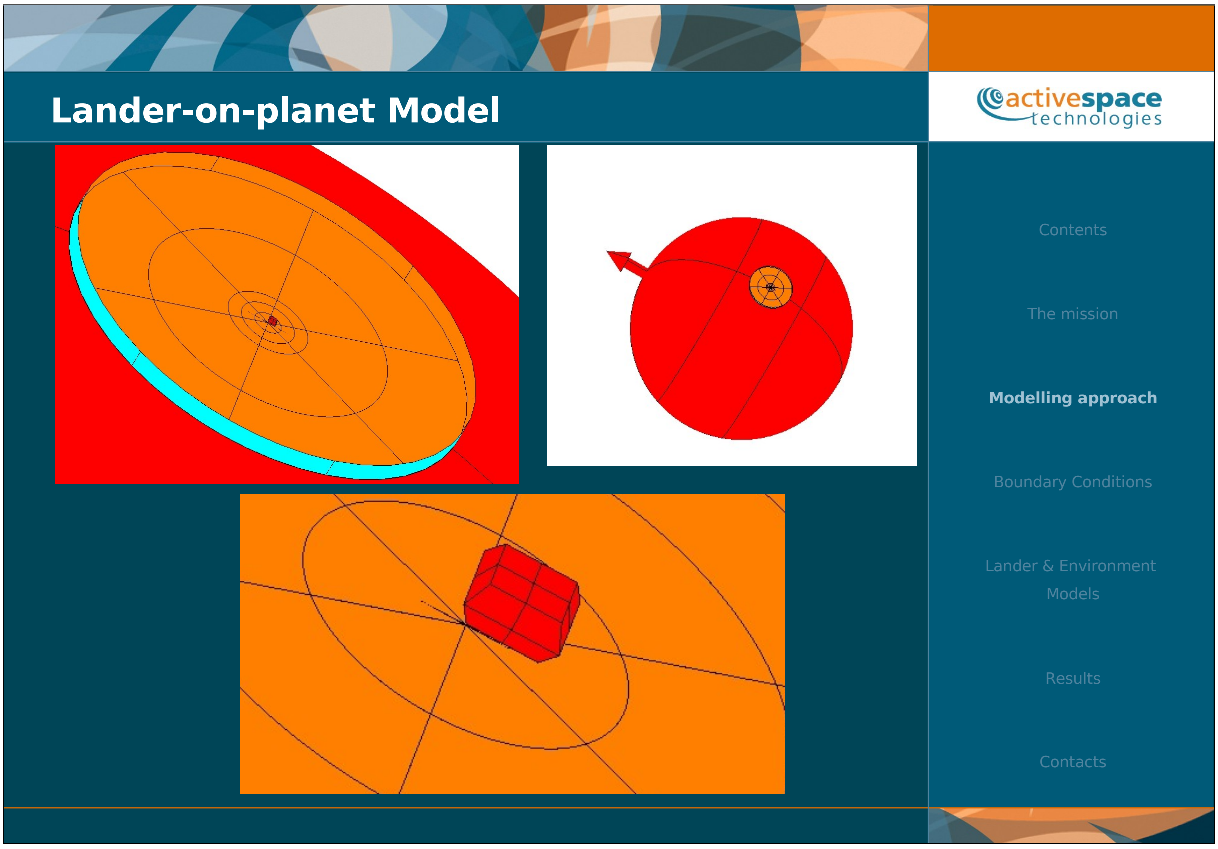
Lander-on-planet Model
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Boundary conditions

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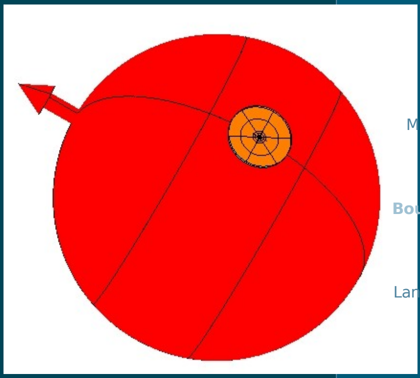
Boundaries that need to be calculated

- Surface and subsurface temperature
- reflected fluxes, shadows

Planet-and-surface model

- Planet just to orient the surface
- Creates QS array to soil model
  - Full orbit in Radiative case(s)
    - 360° Anomaly
    - 18000+ steps



Lander-on-Planet Model

- Exomars derivation
- Shadow on soil BELOW lander
- Shadows and reflections on lander
- Only mission (12 steps/day, 2-3 days)

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The Orbit

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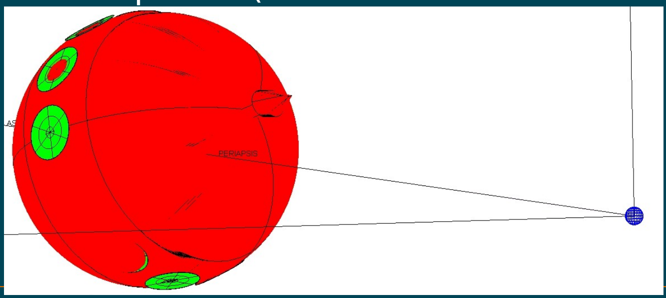
Define Orbit for the MISSION

- In this case mission duration is a few local days
  - Radiative case with 1 day, repeated (in the TMM)
- Use asteroid orbit around the sun but define a very small orbital arc
  - 1 day = 27000 s
  - Orbital arc: 0.355° (per.) / 0.164° (aph.)
- Rotate the planet (360° rotation for the arc)



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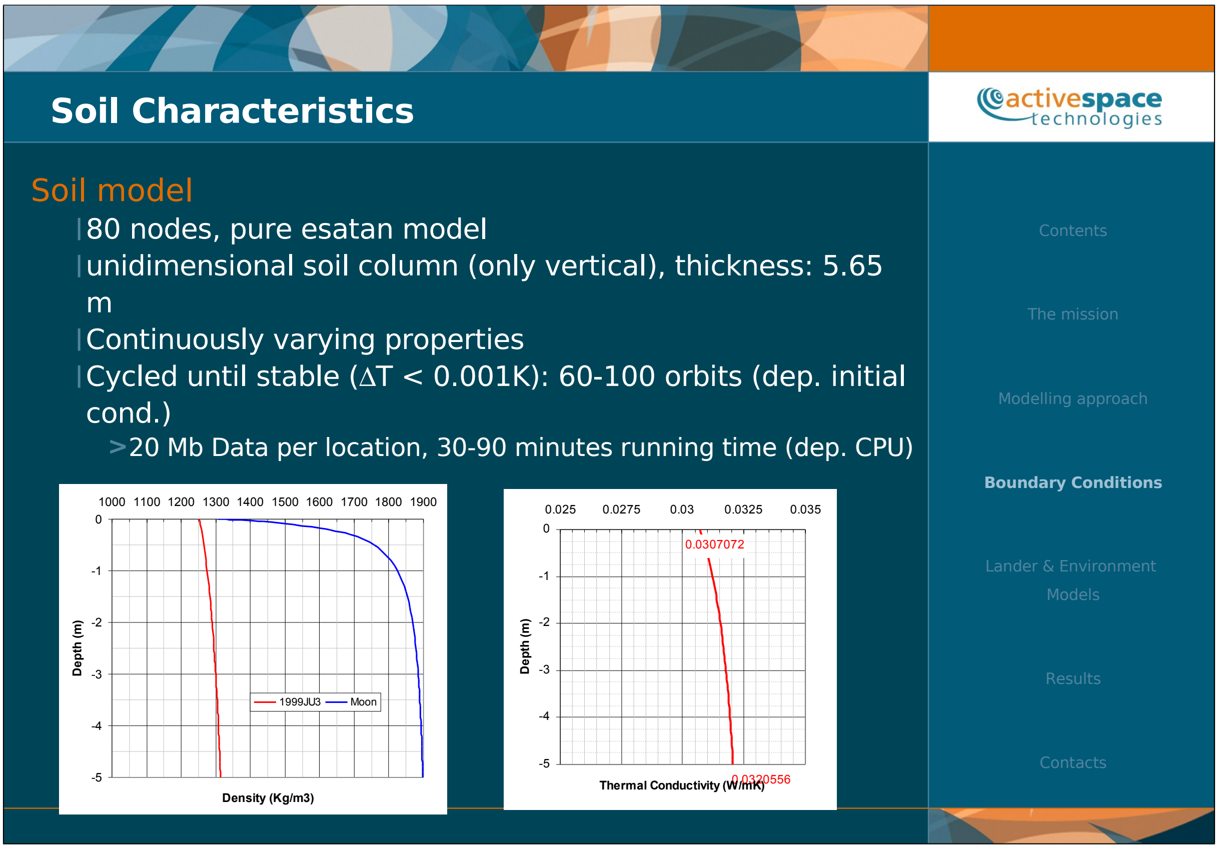
Soil Characteristics
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Soil model
80 nodes, pure esatan model
unidimensional soil column (only vertical), thickness: 5.65 m
Continuously varying properties
Cycled until stable (ΔT < 0.001K): 60-100 orbits (dep. initial cond.)
>20 Mb Data per location, 30-90 minutes running time (dep. CPU)
1000 1100 1200 1300 1400 1500 1600 1700 1800 1900
Depth (m)
1999JU3 Moon
Density (Kg/m3)
0.025 0.0275 0.03 0.0325 0.035
0.0307072
Depth (m)
Thermal Conductivity (W/mK)
0.0320556
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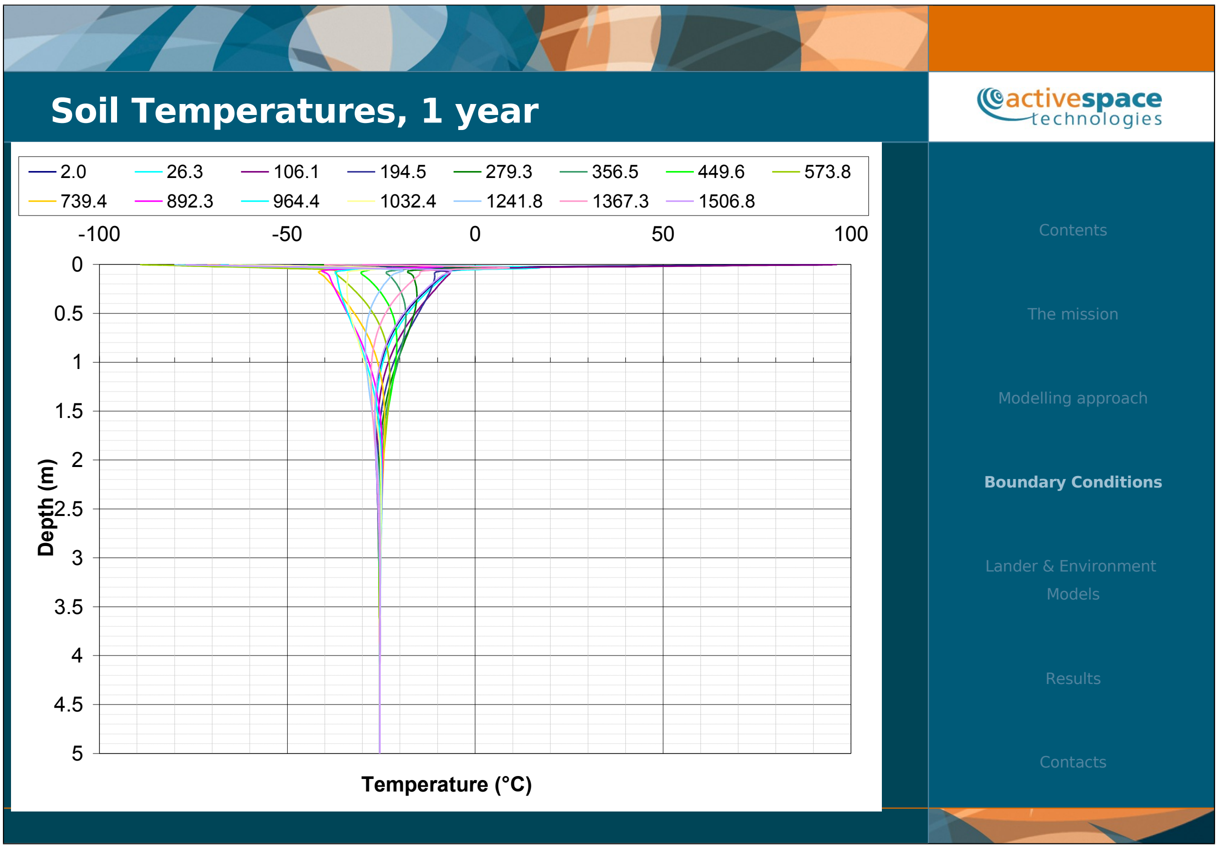
Soil Temperatures, 1 year
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2.0 26.3 106.1 194.5 279.3 356.5 449.6 573.8
739.4 892.3 964.4 1032.4 1241.8 1367.3 1506.8
-100 -50 0 50 100
Depth (m)
Temperature (°C)
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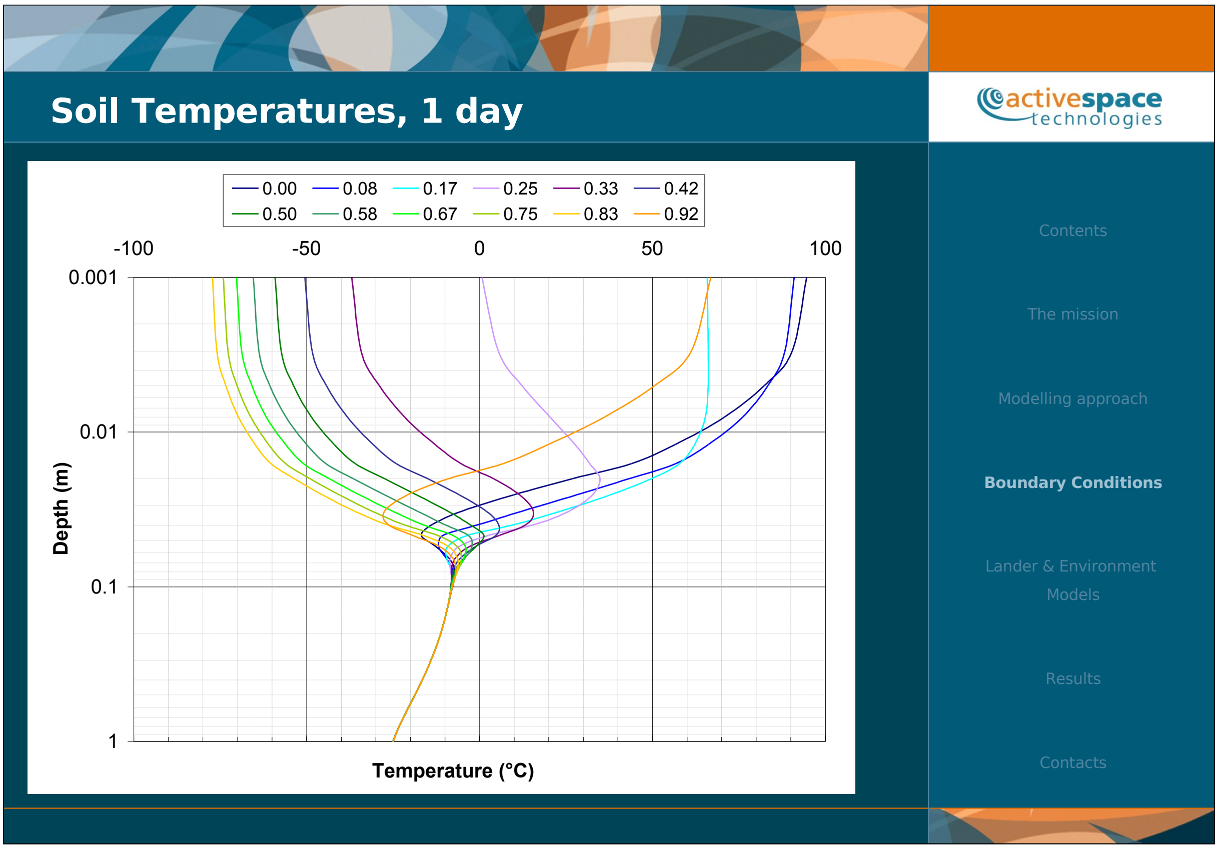
Soil Temperatures, 1 day
activespace technologies
Contents
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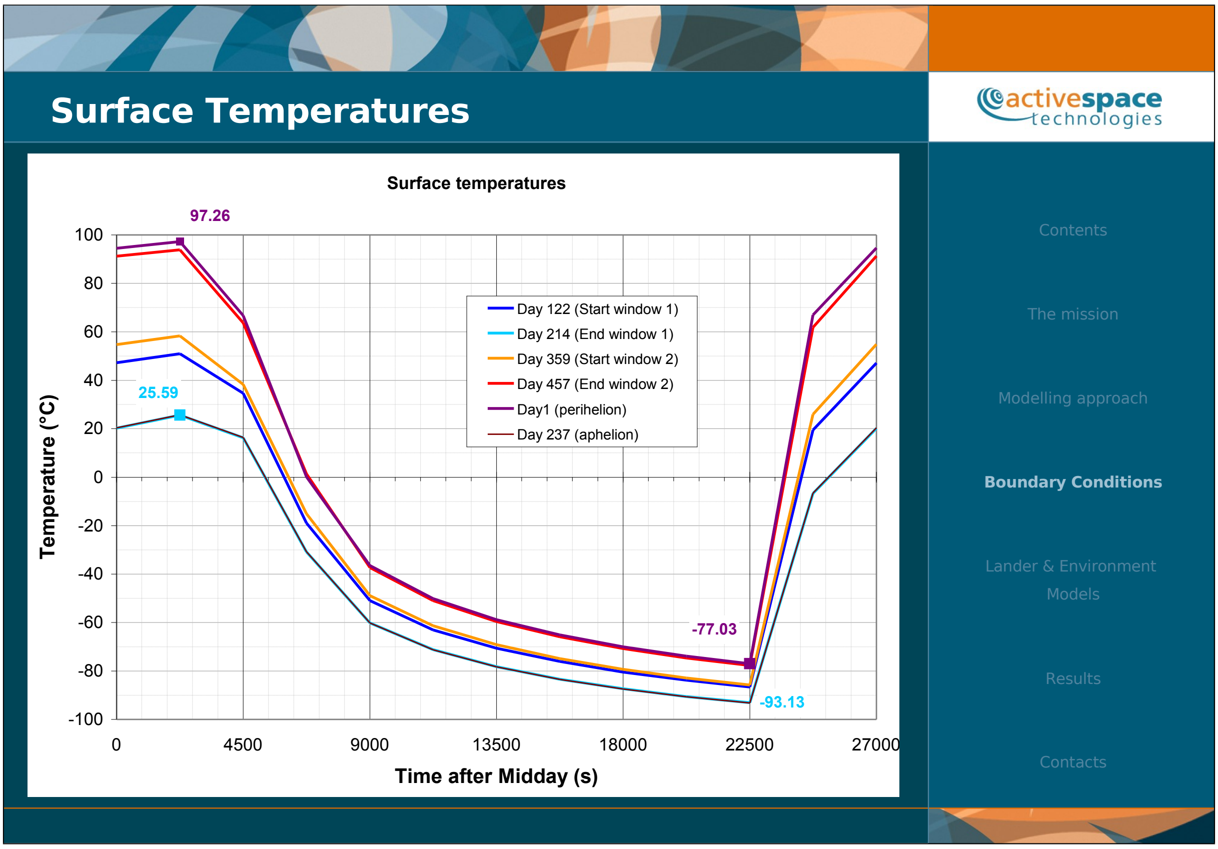
Lander & Environment Models
Results
Contacts
0.00
0.08
0.17
0.25
0.33
0.42
0.50
0.58
0.67
0.75
0.83
0.92
Depth (m)
Temperature (°C)
-100
-50
0
50
100
0.001
0.01
0.1
1


Surface Temperatures
activespace technologies
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Surface temperatures
97.26
25.59
-77.03
-93.13
Day 122 (Start window 1)
Day 214 (End window 1)
Day 359 (Start window 2)
Day 457 (End window 2)
Day1 (perihelion)
Day 237 (aphelion)
Temperature (°C)
Time after Midday (s)
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
4500
9000
13500
18000
22500
27000

Integrated Model

activespace technologies

- Lander + Planet + Surface model
- Soil Model
  - Pure thermal model (no GMM)
  - same model used for boundaries
- 1 geometrical model, with
  - 6 radiative cases
    - each case is one local "day" in different orbital positions
  - 6 analysis cases
- 6 thermal models
  - 6 templates
  - 6 sets of boundary conditions
    - Matrixes
  - external files, import routines

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The Lander Model

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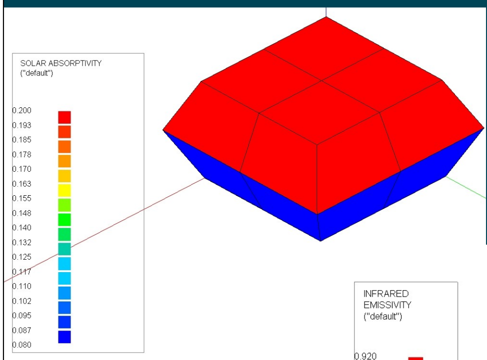
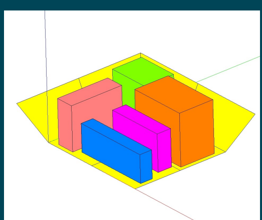
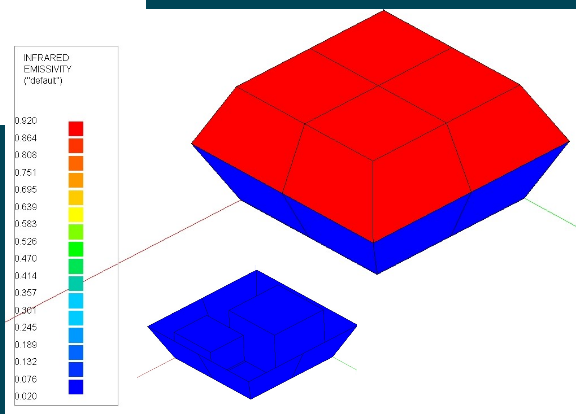


- White Top (low α, high ε) to reject heat
- "Gold" bottom (low α, low ε) to insulate from soil
- Internal Gold (insulate)





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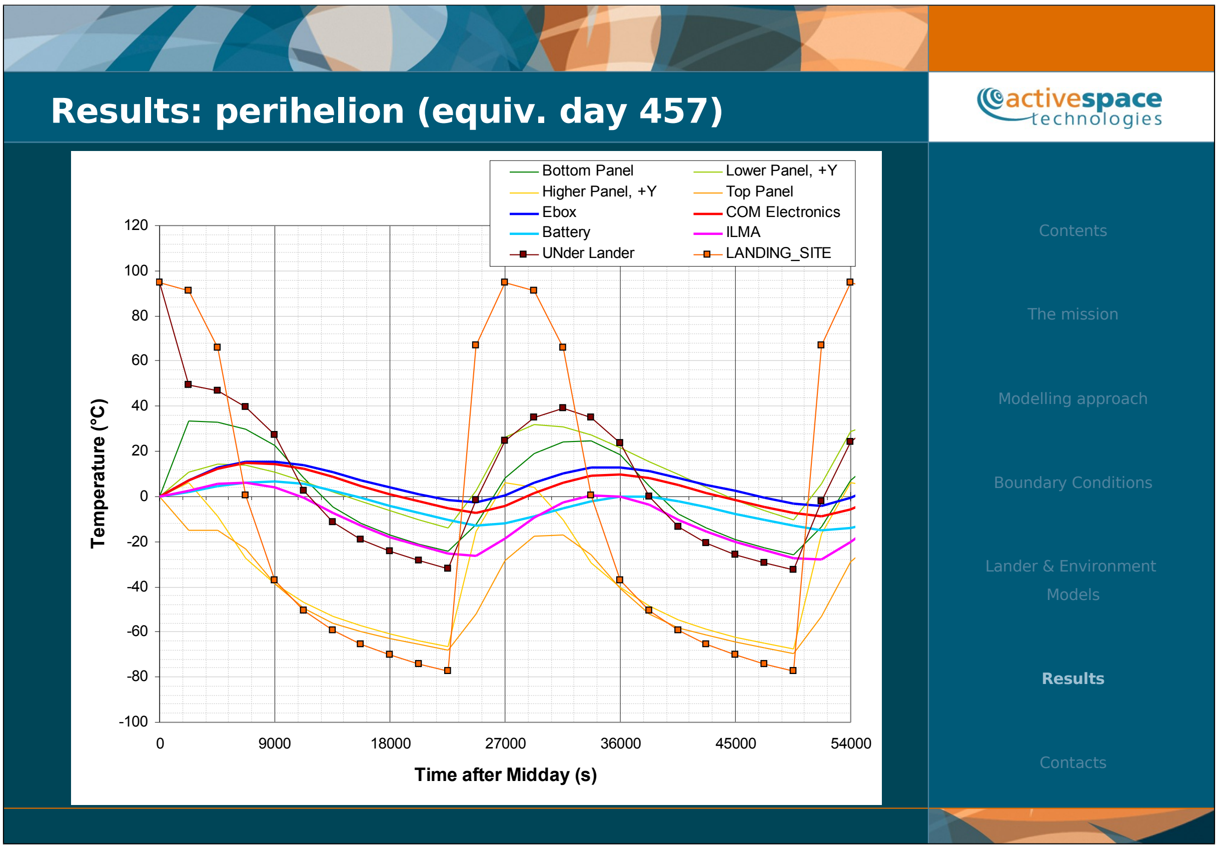
Results: perihelion (equiv. day 457)
activespace technologies
Bottom Panel
Lower Panel, +Y
Higher Panel, +Y
Top Panel
Ebox
COM Electronics
Battery
ILMA
UNder Lander
LANDING_SITE
Temperature (°C)
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
0
9000
18000
27000
36000
45000
54000
Time after Midday (s)
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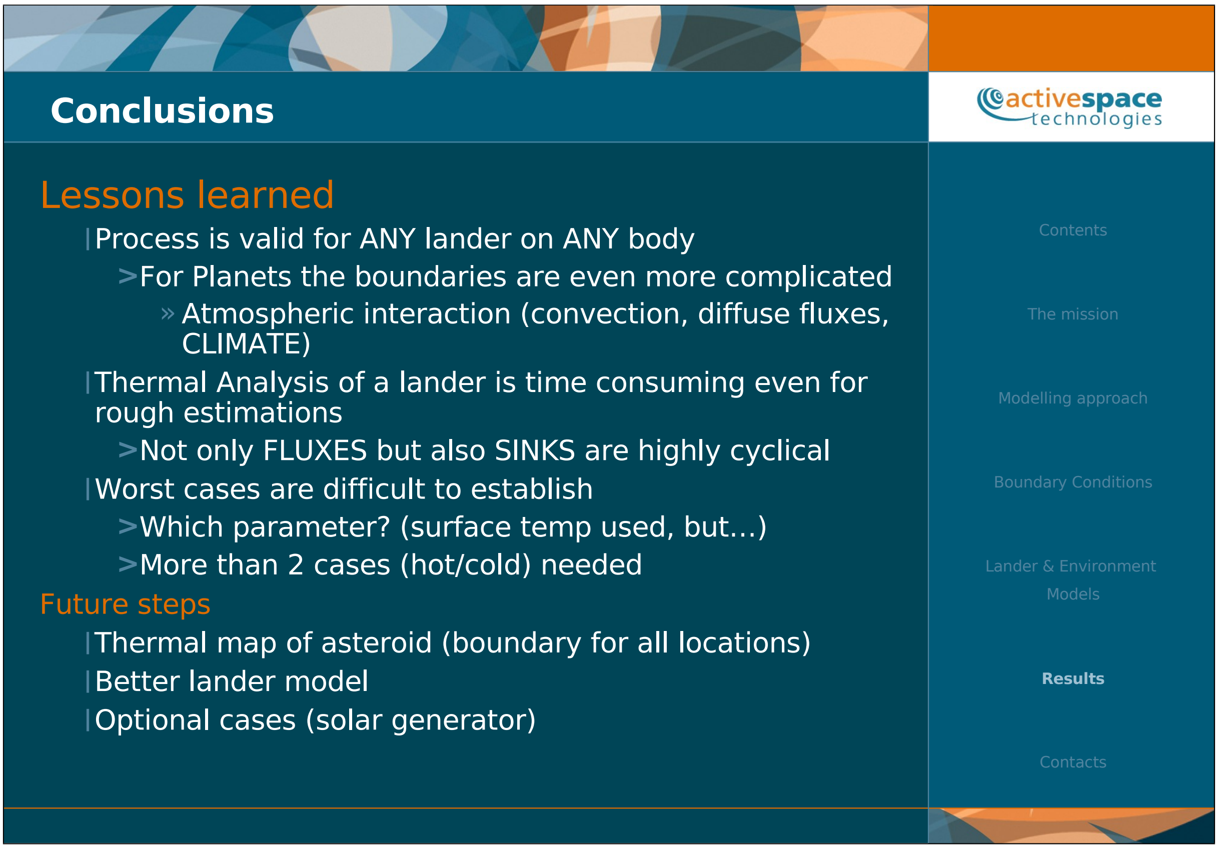
Conclusions
activespace technologies
Lessons learned
Process is valid for ANY lander on ANY body
For Planets the boundaries are even more complicated
Atmospheric interaction (convection, diffuse fluxes, CLIMATE)
Thermal Analysis of a lander is time consuming even for rough estimations
Not only FLUXES but also SINKS are highly cyclical
Worst cases are difficult to establish
Which parameter? (surface temp used, but…)
More than 2 cases (hot/cold) needed
Future steps
Thermal map of asteroid (boundary for all locations)
Better lander model
Optional cases (solar generator)
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Open issues with ESATAN-TMS r1

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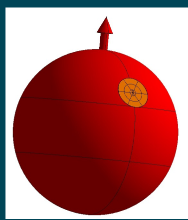
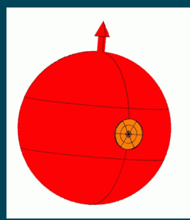
- Different Cases have different boundary temperatures
  - For some boundaries, MATRIX of temperatures instead of an ARRAY, so boundaries must be assigned in the TMM
- No chance to INFORM analysis module which [radiative] case is currently being used
  - Requires generation of MULTIPLE, slightly different templates since Analysis does not know if it is, e.g., a hot or cold day
- Not possible to change geometry in different radiative cases
  - Multiple models for different locations

```
  $INITIAL
      CALL SETSTART
###### Case Selection############################
#       Nr.     Case                            #
#        1      Day 122                         #
#        2      Day 214                         #
#        3      Day 359                         #
#        4      Day 457                         #
#        5      Day 1( Perihelion)              #
#        6      Day 237 (Aphelion)              #
#################################################
      SW1 = 5
#################################################
      II=0
      REPEAT
        ARTSurf(II) = ARTemps(II,SW1)
```





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For further information, please visit our website

www.activespacetech.com

Riccardo Nadalini
riccardo.nadalini@activespacet
ech.com

Tel: +49 (0) 30 6392 6059
Fax: +49 (0) 30 201 632 829

Rudower Chaussee 29
12489 Berlin
Germany

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Appendix N

TCDT
Distribution and maintenance

Andrea Tosetto Matteo Gorlani
(Blue Engineering, Italy)

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

The activities of the 3rd M&D year will be described by focusing on new developments and installation adaptations for ESTEC CDF. A demonstration of the beta TCDT ver.1.3.1 with the new GUI and the 3DViewer with the satellite in orbit will be given. A presentation of a stochastic/parametric analysis by means of the parametric engine of the TCDT will be given in order to demonstrate the usefulness of the parametric approach introduced with version 1.3.0

Thermal Concept Design Tool Distribution & Maintenance

Andrea Tosetto
Matteo Gorlani
Blue Engineering, Torino, Italy
Harrie Rooijackers
European Space Agency, Noordwijk, The Netherlands

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Sheet 1

Overview

- **Background**
- **Version 1.3.0 Improvements**
- **Next Version Improvements**
  - **Required by the Thermal Community**
  - **Required by CDF – ESTEC**
- **Maintenance Activity**

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Sheet 2

Background

3° YEAR OF DISTRIBUTION & MAINTENANCE STARTED APRIL 2009

- TCDT is distributed FREE of CHARGE to the European Thermal Community
- TCDT web pages available for download, PR, FR
- TCDT is regularly maintained by BLUE
- Small developments are regularly implemented to improve operability
- TCDT version 1.3.1 will be available before the end of 2009

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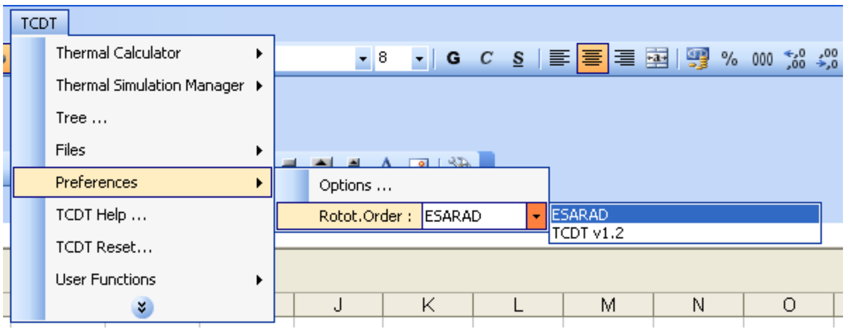
Sheet 3

TCDT 1.3.0 Improvements

- Rototranslation order selection :
  - ESARAD Default
  - TCDT v1.2.x



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Sheet 4

TCDT Improvements (1/7)

IMPROVEMENTS derived from the last year survey

- Improvement of GUIs
- S/C Attitude Visualisation on Orbit
- Nodes and Conductors management

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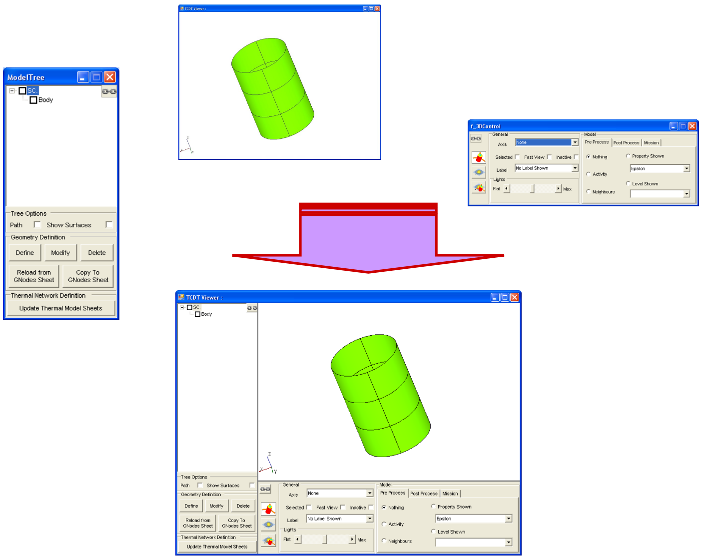
Sheet 5

TCDT Improvements (2/7)

Integration of Model related Controls



- Anchoring
- Show/Hide windows

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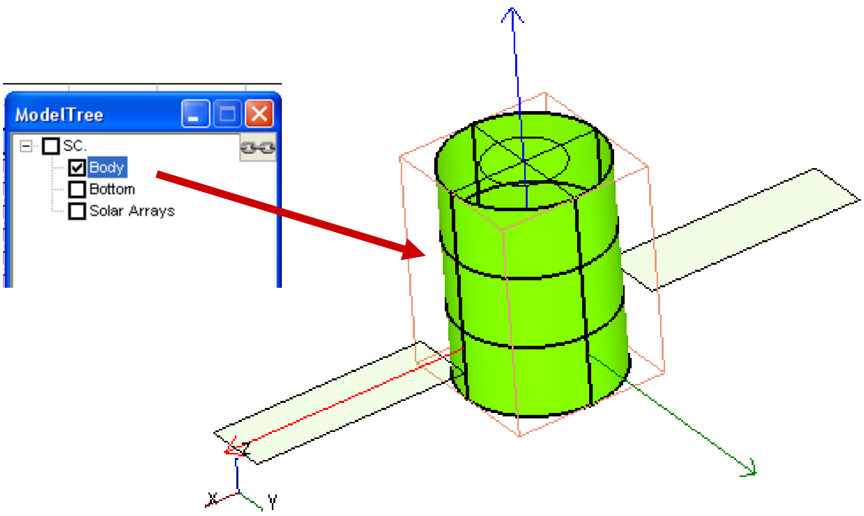
Sheet 6

TCDT Improvements (3/7)

Selected element/assembly main axis and containing box



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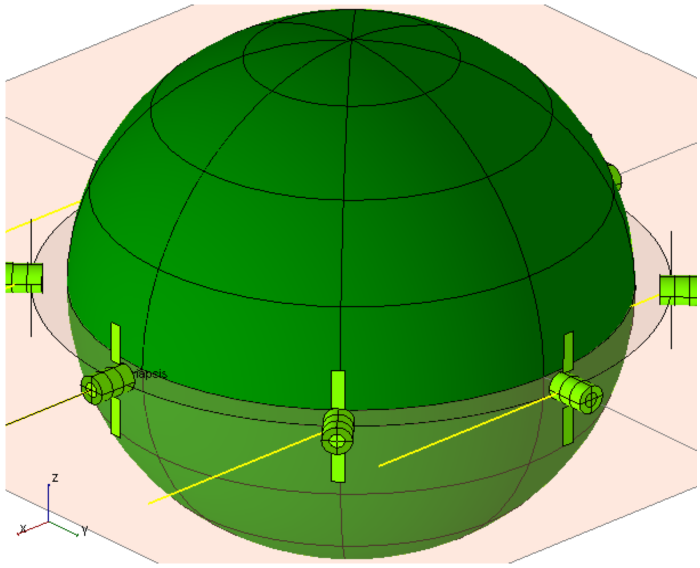
TCDT Improvements (4/7)

Satellite Attitude visual check



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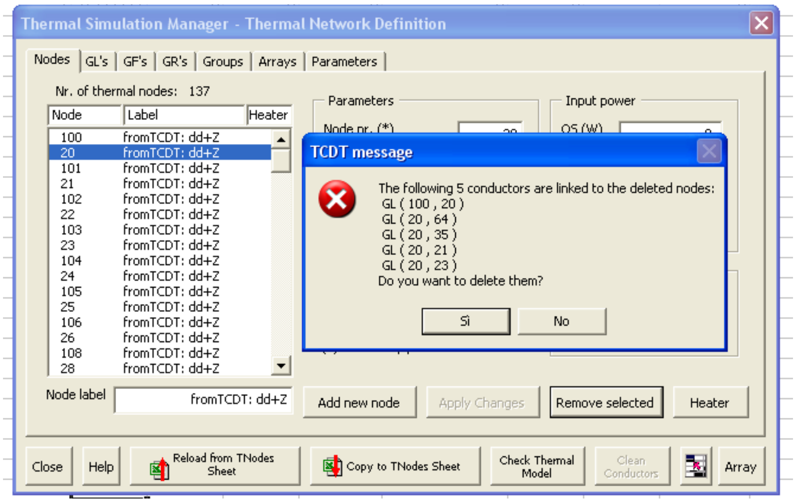
TCDT Improvements (5/7)

Improved Nodes deletion

Automatic deletion of the thermal network conductors after a nodes deletion.



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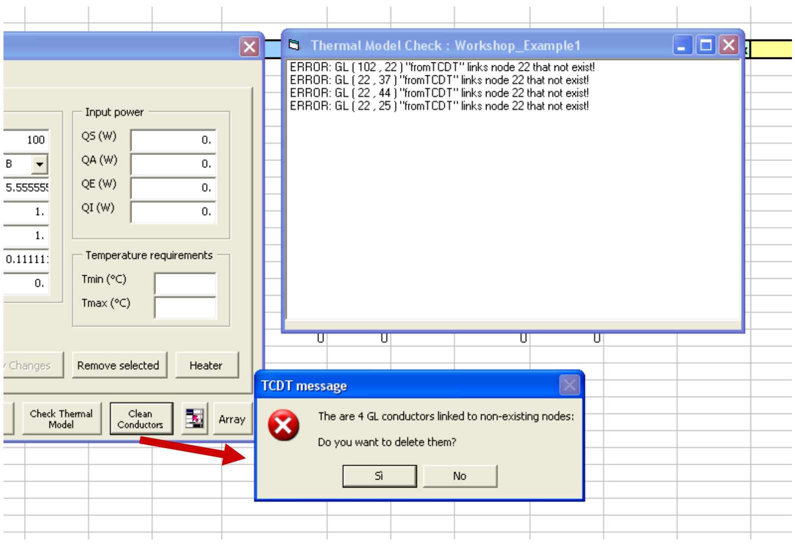
TCDT Improvements (6/7)

Improved Model Check

Automatic deletion of the thermal network conductors not linked to any nodes (after checking the network).



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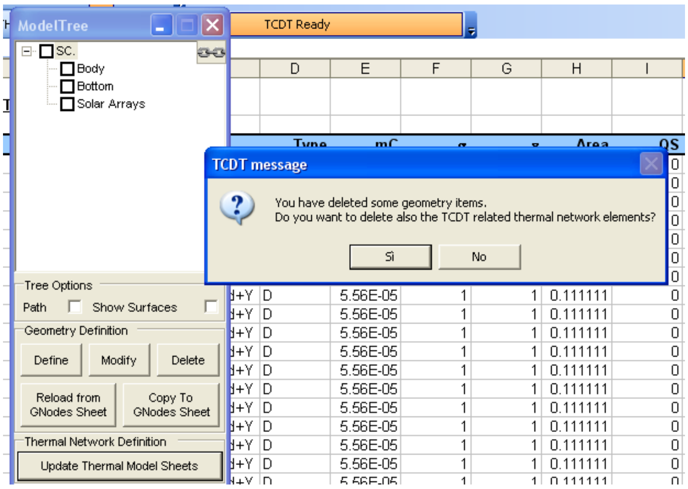
TCDT Improvements (7/7)

Improved Thermal Model Generation

Automatic deletion of the thermal network relevant to the delete GMM's items



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Sheet 11

TCDT CDF Improvements

- Possibility to move the TCDTAddin to different folder
- Evaluating the possibility to use a common addin for PC with ThermXL installed or not.
- Aid users to update their useraddins to new TCDT versions
- Administrator management of the preferences.

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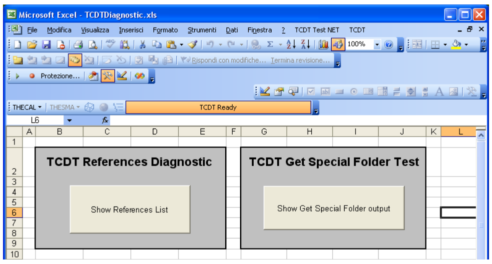
TCDT Maintenance Activity (1/2)

Bugs Diagnosis

- A Diagnostic tool is prepared to be sent to users that encounter problems
- The tool analyze the status TCDT Addin and reports it.
- The tool is an excel file.
- Already successfully used



- Virtual Machines utilization
  - Excel 2000
  - Excel 2003
  - Excel 2007 (future)

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TCDT Maintenance Activity (2/2)

BUGS CORRECTION

Geometry generator :

- The box surfaces +Y and –Y are rotated of 180 degrees when the rototranslations order is "ESARAD"
- Solution: It will be corrected in the next TCDT version

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TCDT Tips

With the TCDT is possible to :

- Model Visual Check
- Postprocess results
- Model Parameterization
- Parametric Analysis

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Sheet 15

TCDT Team

DISTRIBUTION & MAINTENANCE

BLUE ENGINEERING S.R.L.	ESA - ESTEC
Matteo Gorlani - Project Manager m.gorlani@blue-group.it **Andrea Tosetto** - Software Development a.tosetto@blue-group.it **Support** tcdtsw@blue-group.it	**Dr. Olivier Pin** - Head of Thermal Analysis and Verification Section olivier.pin@esa.int **Dr. Harrie Rooijackers** - Project Manager harrie.rooijackers@esa.int
Blue Group - Engineering & Design WEB: http://www.blue-group.it	ESTEC-D/TEC-TEC-MTV WEB: http://www.esa.int

WEB: www.blue-group.it/TCDT
EMAIL: tcdtsw@blue-group.it

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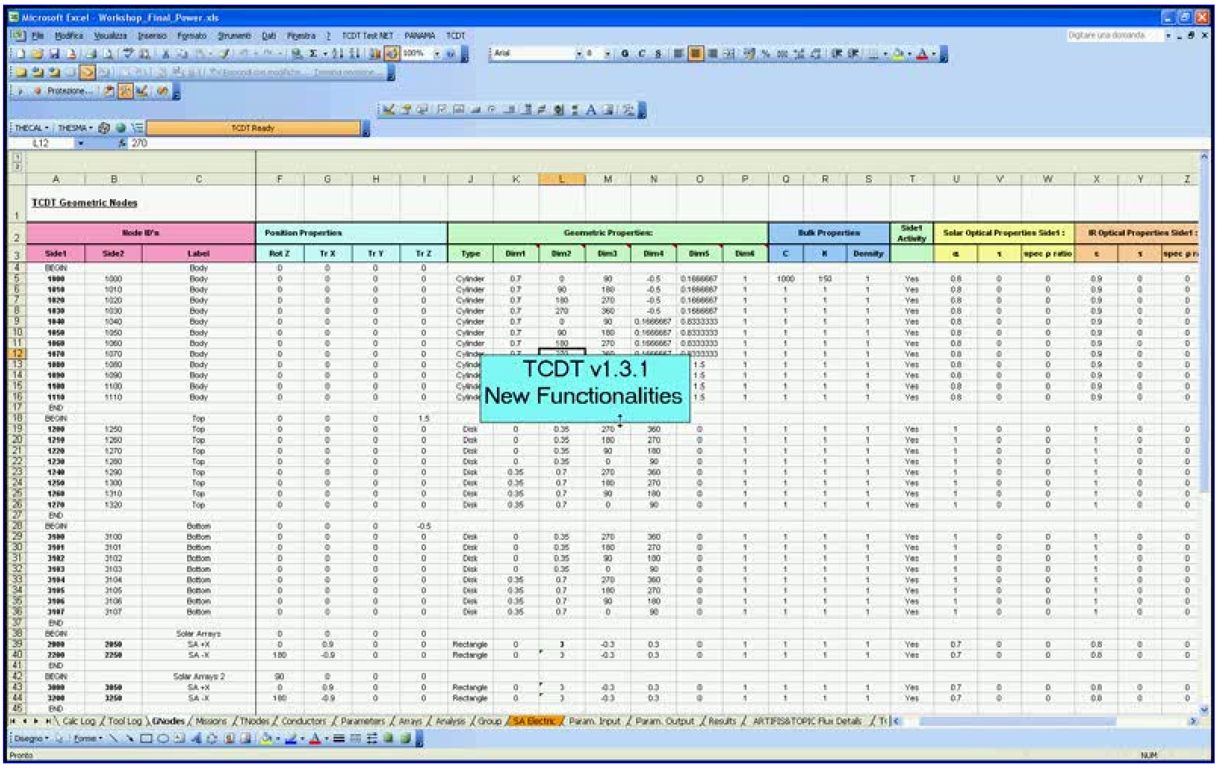


If clicking on the picture above does not run the movie then try opening the file ‘movies/TCDTv131-Demo.html’ manually.

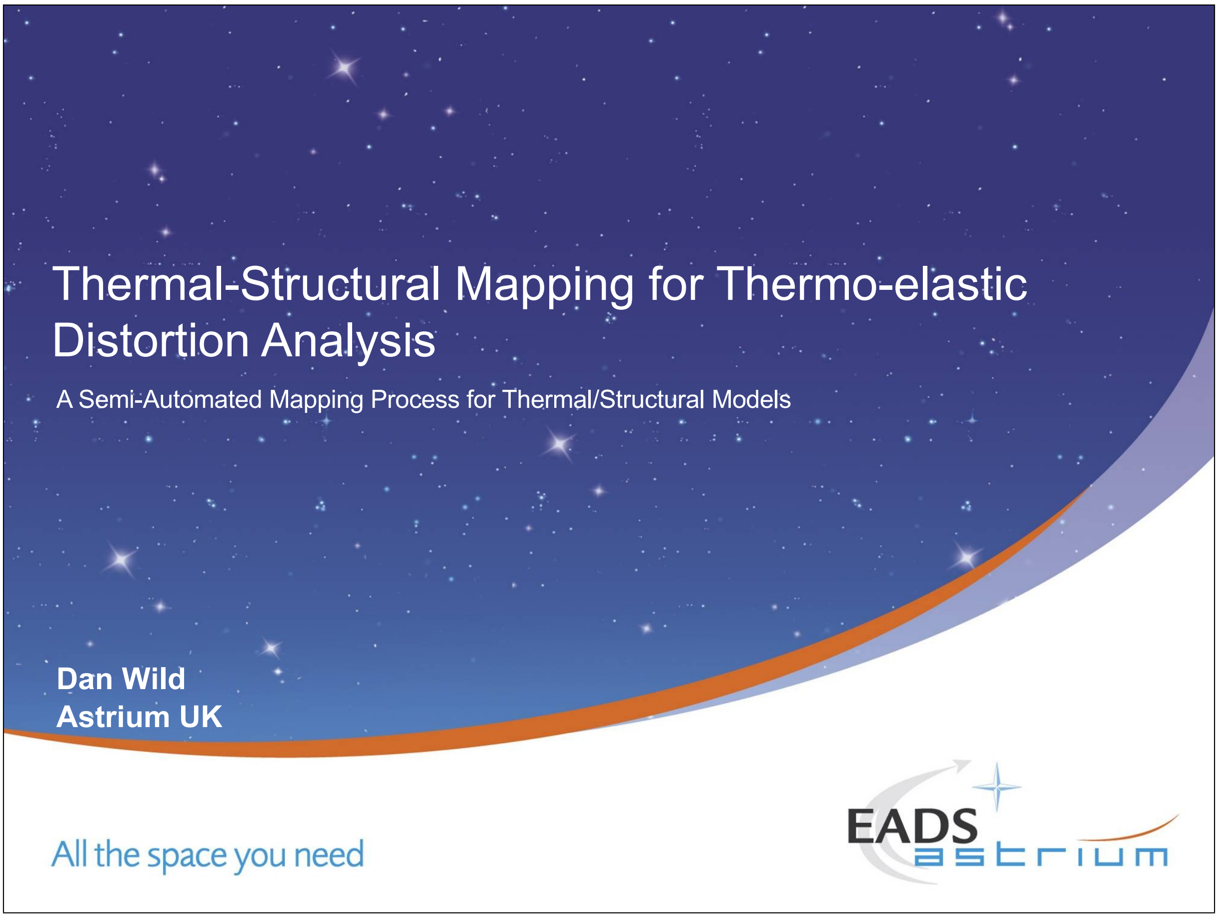
Appendix O

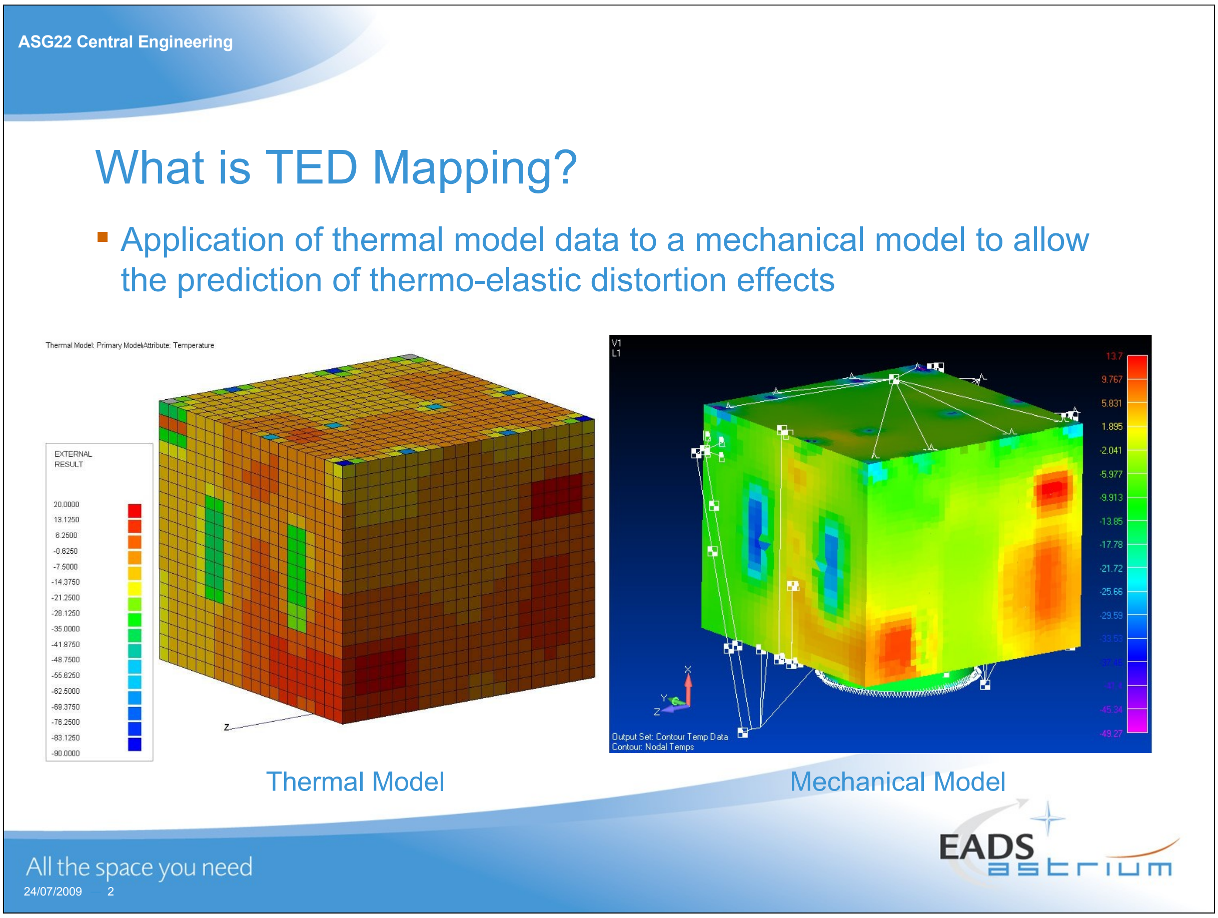
A thermal/structural mapping tool for thermo-elastic distortion analysis

Daniel Wild
(EADS Astrium, United Kingdom)

Abstract

As thermal and structural models become larger and more complex, the labour involved in mapping temperatures from thermal to structural models has naturally increased. This presentation describes a method that has been developed to aid the process of temperature mapping to structure models for thermo-elastic distortion. The process is centred on a mapping tool that allows the semi-automatic mapping of temperature data to structure models, independent of analysis software, thus reducing the hours required for this task. The presentation will provide an overview of the key aspects of the process, issues that may arise, their solution and potential future developments.


Thermal-Structural Mapping for Thermo-elastic Distortion Analysis
A Semi-Automated Mapping Process for Thermal/Structural Models
Dan Wild
Astrium UK
All the space you need
EADS astrium


ASG22 Central Engineering
What is TED Mapping?
Application of thermal model data to a mechanical model to allow the prediction of thermo-elastic distortion effects
Thermal Model
Mechanical Model
All the space you need
24/07/2009 2
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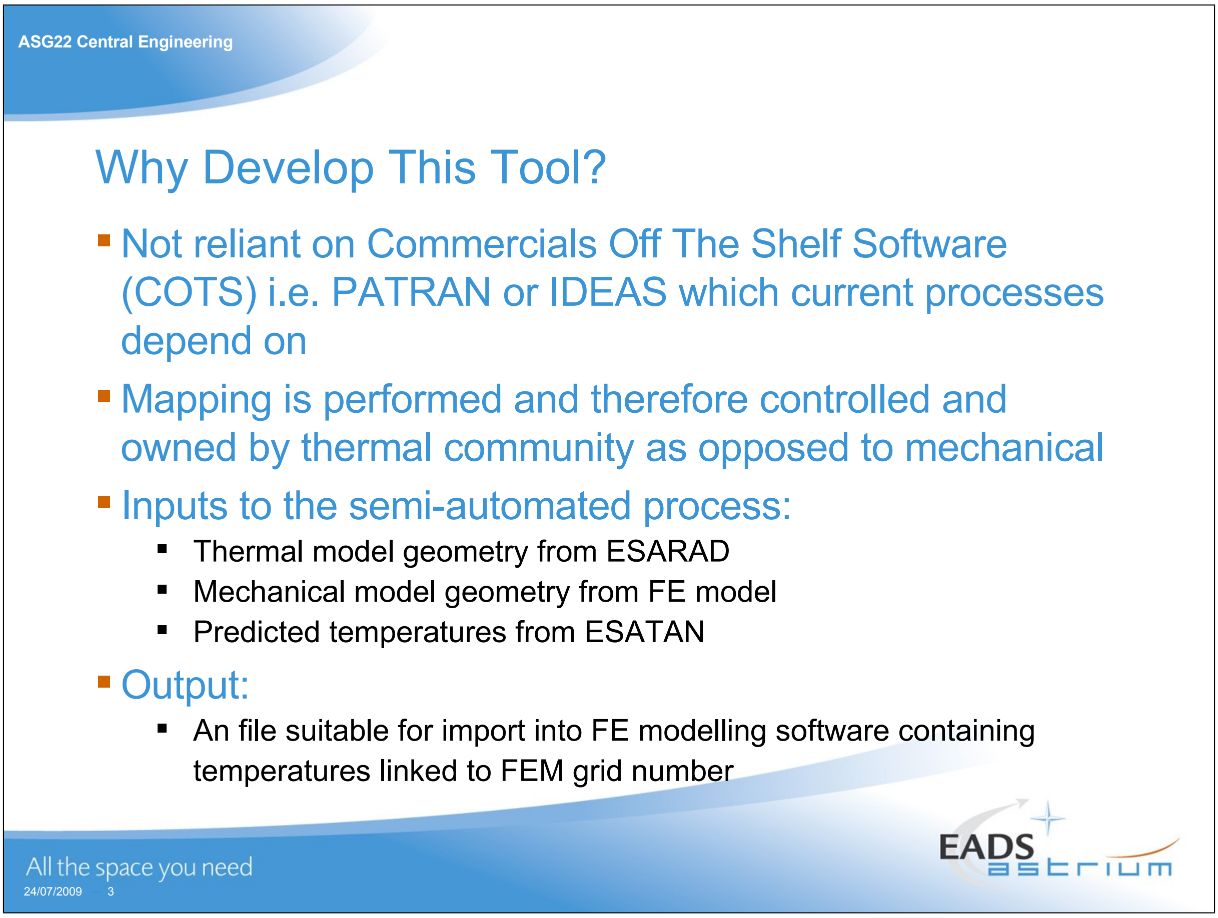
ASG22 Central Engineering
Why Develop This Tool?
Not reliant on Commercials Off The Shelf Software (COTS) i.e. PATRAN or IDEAS which current processes depend on
Mapping is performed and therefore controlled and owned by thermal community as opposed to mechanical
Inputs to the semi-automated process:
Thermal model geometry from ESARAD
Mechanical model geometry from FE model
Predicted temperatures from ESATAN
Output:
An file suitable for import into FE modelling software containing temperatures linked to FEM grid number
All the space you need
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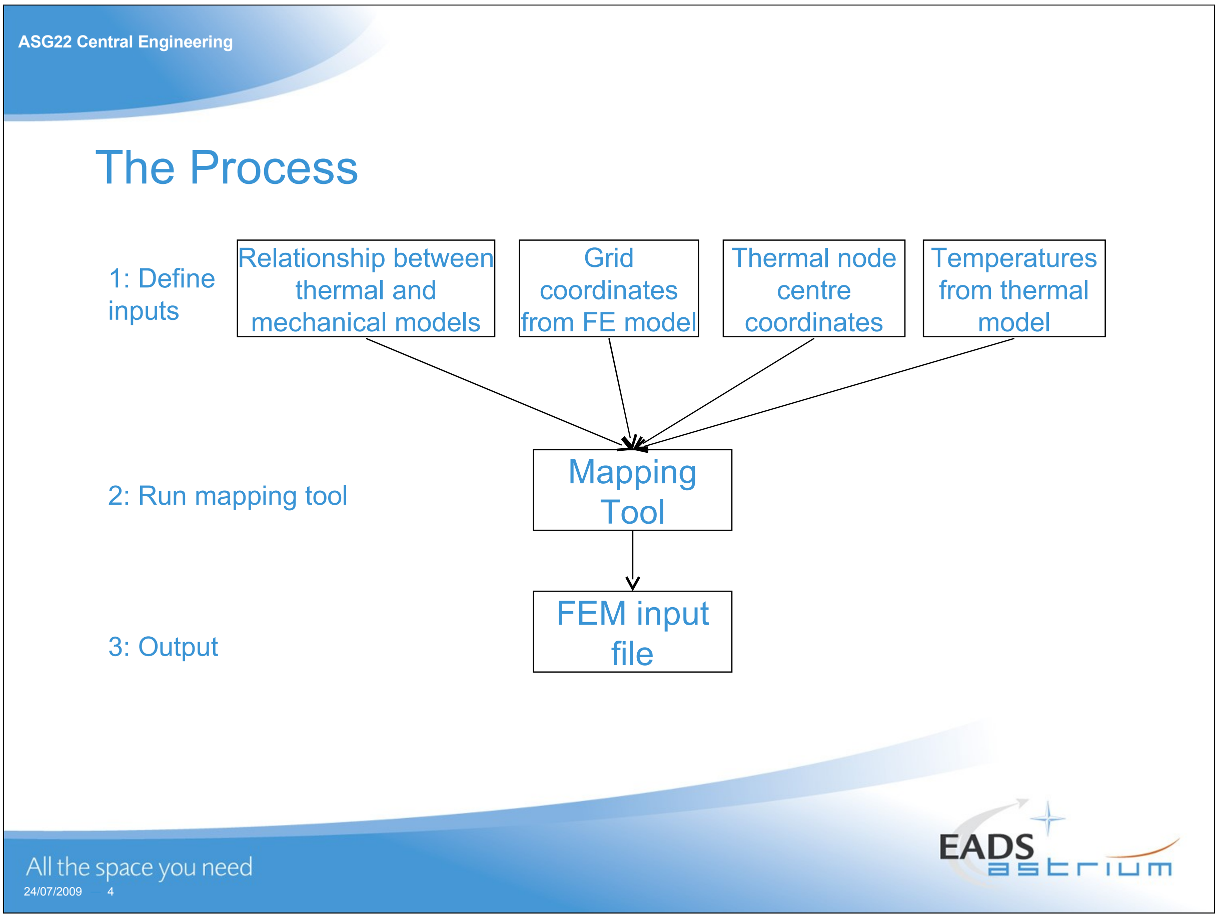
ASG22 Central Engineering
The Process
1: Define inputs
Relationship between thermal and mechanical models
Grid coordinates from FE model
Thermal node centre coordinates
Temperatures from thermal model
2: Run mapping tool
Mapping Tool
3: Output
FEM input file
All the space you need
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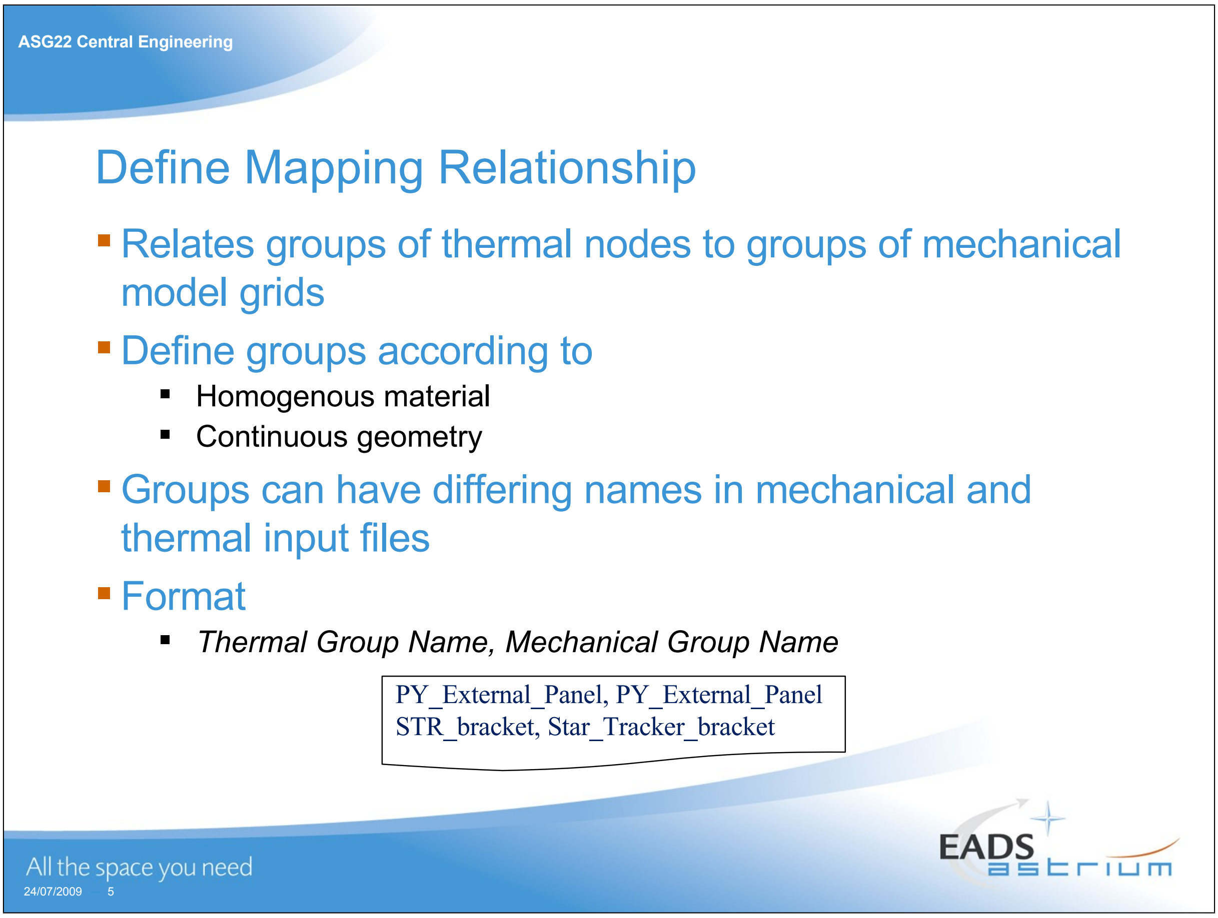
ASG22 Central Engineering
Define Mapping Relationship
Relates groups of thermal nodes to groups of mechanical model grids
Define groups according to
Homogenous material
Continuous geometry
Groups can have differing names in mechanical and thermal input files
Format
Thermal Group Name, Mechanical Group Name
PY_External_Panel, PY_External_Panel
STR_bracket, Star_Tracker_bracket
All the space you need
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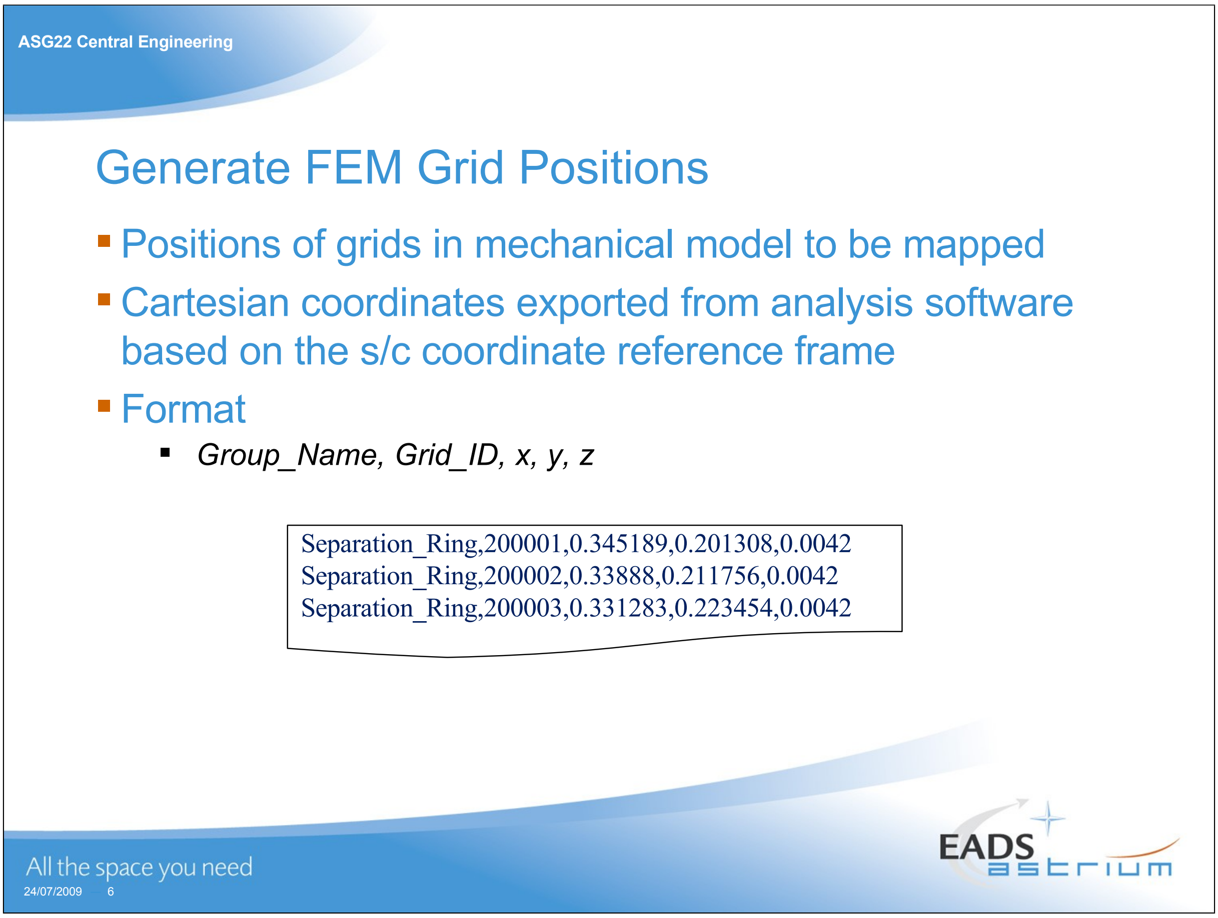
ASG22 Central Engineering
Generate FEM Grid Positions
Positions of grids in mechanical model to be mapped
Cartesian coordinates exported from analysis software based on the s/c coordinate reference frame
Format
Group_Name, Grid_ID, x, y, z
Separation_Ring,200001,0.345189,0.201308,0.0042
Separation_Ring,200002,0.33888,0.211756,0.0042
Separation_Ring,200003,0.331283,0.223454,0.0042
All the space you need
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ASG22 Central Engineering

Thermal Node Centre Positions

- Need the coordinates of thermal model shells in spacecraft coordinates
  - Export ESARAD geometry file (.erg)
  - Use TASverter to convert .erg file to .SYSBAS file (suitable for Thermica)
  - Import .SYSBAS file into Thermica
  - Export geometry in universal file format (.unv)
- Format
  - *Group_Name, Grid_ID, x, y, z*

```
16101,LOWER_CLOSURE_PANEL,0.394667,-0.190500,0.121500
16101,LOWER_CLOSURE_PANEL,0.394667,-0.190500,0.121500
16101,LOWER_CLOSURE_PANEL,0.394667,-0.190500,0.121500
```

All the space you need

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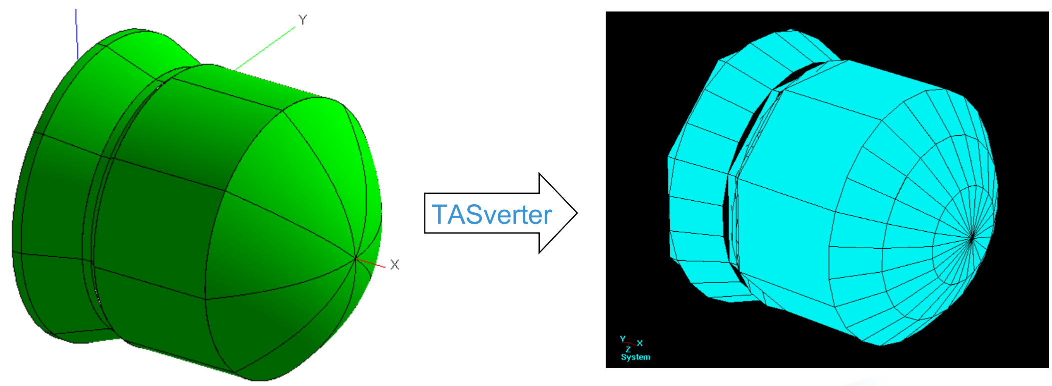
Generate Thermal Node Centres

- Complex shells in ESARAD split into many shells by TASverter during conversion to .SYSBAS



ESARAD

Thermica

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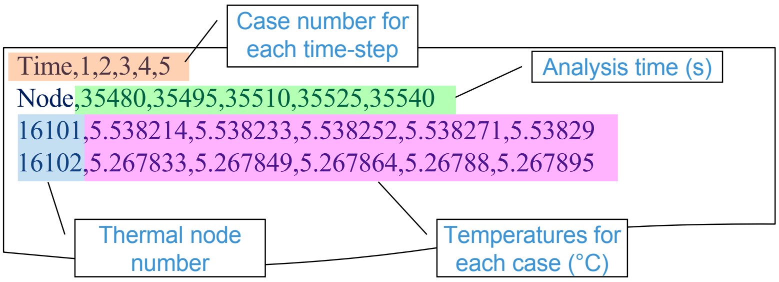
Temperature History

- Extracted from the results of the thermal analysis for the relevant case
- Can contain steady-state or transient data



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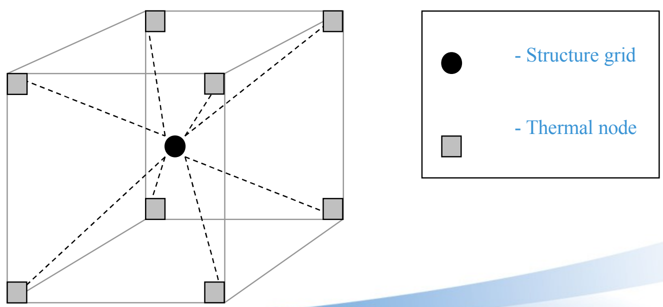
The Mapper

- Performs linear interpolation in three dimensions between relevant thermal nodes to calculate grid point temperature
- Area surrounding each node divided into eight regions (+x+y+z, -x+y+y, +x-y+z…….)
- Thermal node closest to the FEM grid in each region used for interpolation



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The Mapper

- Results can be interrogated to look at individual or multiple groups and time-steps
- Very quick to run
- Produces output file suitable for import into FEM software, e.g. Nastran

```
TEMP,1,200001,-2.6054
TEMP,1,200002,-2.5946
TEMP,1,200003,-2.5563
```

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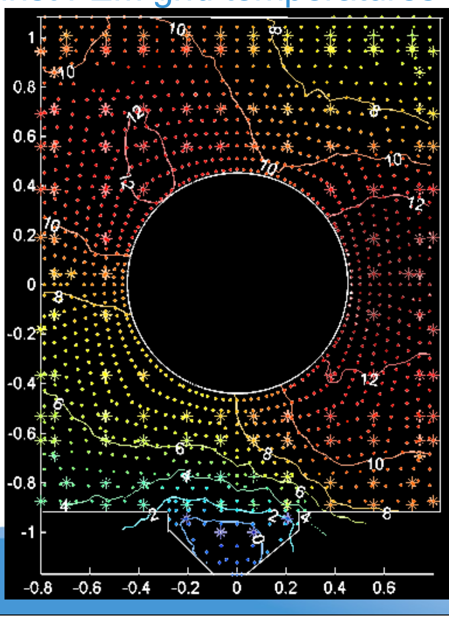
The Mapper

- Visualiser can be used to check temperatures in the thermal model against FEM grid temperatures



* - Thermal node

· - FEM Grid

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Future Developments

- Groups
  - Mapping of many groups to one group
- Recognition of complex boundaries
  - Non-uniform discontinuities, for example panel edges, currently need to be mapped using targeted groups
- Visualiser
  - Further development of MATLAB as a post-processing tool, e.g 3-D contour plots

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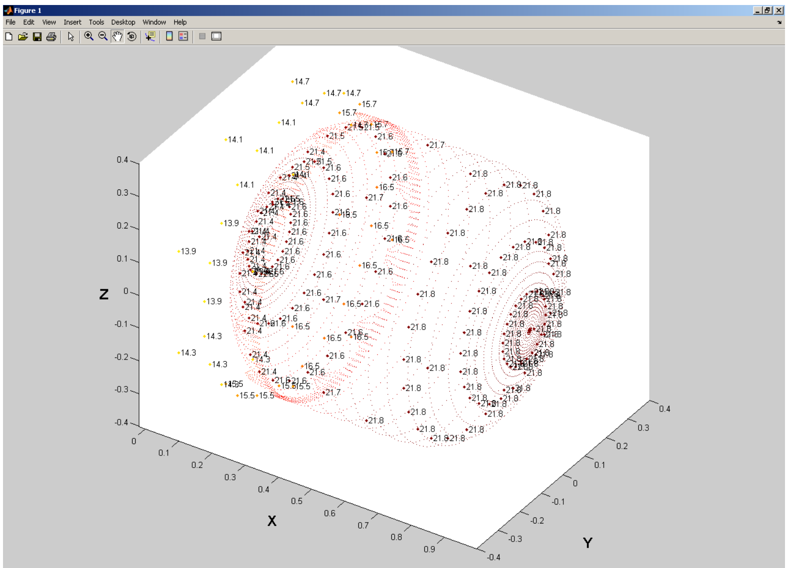
Future Developments



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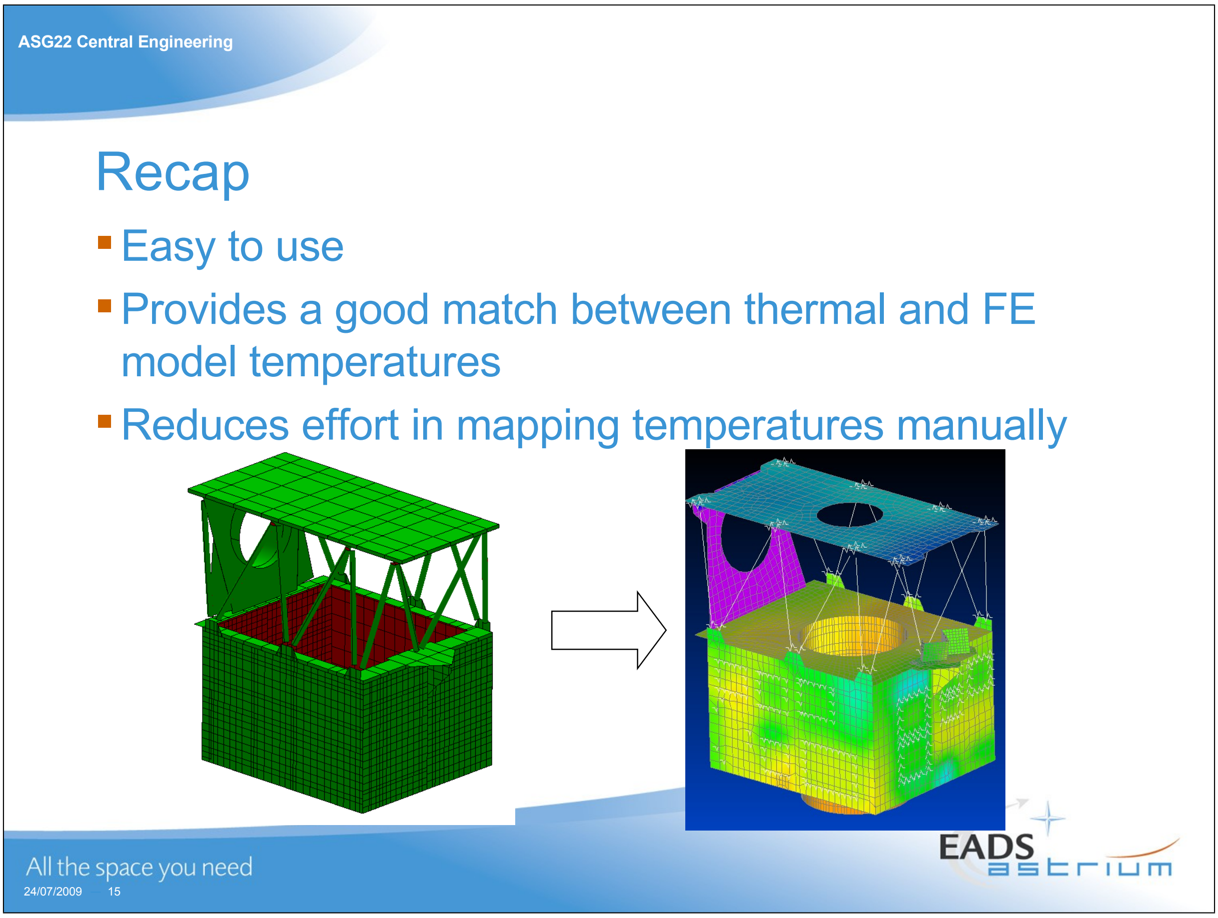
ASG22 Central Engineering
Recap
Easy to use
Provides a good match between thermal and FE model temperatures
Reduces effort in mapping temperatures manually
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astrium

Appendix P

Updates to the SINAS tool for mapping of lumped parameter temperatures onto a structural FE models

Simon Martin James Etchells Simon Appel
(ESA/ESTEC, The Netherlands)

Abstract

SINAS is a software tool that enables lumped parameter temperatures (e.g. ESATAN results) to be mapped onto a structural FE model for thermo-elastic analysis. This tool was originally developed under a series of ESA contracts with Dutch Space (previously Fokker Space) but is now maintained by ESA D/TEC-MTV (Thermal Analysis and Verification Section).

This presentation will describe the work that has been done to update SINAS and present current status of the tool. In particular the following topics will be covered:

- Re-engineering of several old SINAS modules into a single Python module
- Development of FE algorithms to allow the SINAS process to be independent of NASTRAN
- Application of the new SINAS module to an industrial model

Updates to SINAS Modules

Presented by : James Etchells[2]
Prepared by : Simon Martin[1], James Etchells[2], Simon Appel[3]

23rd European Workshop on Thermal & ECLS Software

1 : Stagiaire ESA Thermal Division (D/TEC-MTV), University of Cambridge
2 : ESA Thermal Division (D/TEC-MTV)
3 : ESA Structures and Mechanisms Division (TEC-MSS), AOES Group BV

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Overview of Presentation

- Introduction to SINAS and discussion of functionality
- Motivation for updating the tool
- Description of the updates:
  - Updated module architecture
  - Updates to NASTRAN Reader
  - Implementation of FEM algorithms
  - Implementation of SINAS modules in Python
- Testing approach
- Application to a real industrial model: LISA Pathfinder
- Conclusions and Future Work

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Updates to SINAS Modules
7th October 2009
Sheet 2

Introduction to SINAS (1)

- SINAS is a S/W tool for mapping thermal node temperatures (e.g. ESATAN results) onto a Finite Element (FE) mesh (e.g. NASTRAN model)
  - Typically used to prepare temperature load data for thermo-elastic analysis
  - Other applications of SINAS are also possible e.g. automatic conductor generation
- Project was initiated by structures section at ESA circa 1985
  - Developed by Dutch Space (formerly Fokker) under a series of ESA contracts
  - Last development contract was 1998
  - IPR handed to ESA in 2004
- Freely available on TEC-MTV exchange portal (exchange.esa.int)

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Introduction to SINAS (2)

- When preparing a thermo-elastic analysis usual inputs are:
  - Geometrical Mathematical Model (GMM) for radiative calculations (e.g. ESATAN-TMS)
  - Thermal Mathematical Model (TMM) for temperature computation (e.g. ESATAN)
  - Structural FE model adapted for thermo-elastic analysis (e.g. NASTRAN)
- Objective is to map TMM results (at lumped parameter nodes) to FEM model grid points *but there are challenges*:
  - GMM and FE model almost always use different geometry (FE uses much finer mesh)
  - Not all nodes in TMM are modeled in GMM (e.g. purely conductive nodes)
  - Specific H/W usually missing in FE model (e.g. MLI)
  - Units usually modelled as lumped (point) masses in FE model
- Purpose of SINAS is to help overcome these challenges and enable a high quality mapping of lumped parameter temperatures onto FE mesh

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SINAS Functionality

- Functionality to build *overlap* (mapping) between thermal nodes and FE mesh
  - MSC Patran add-in (written in PCL) to aid the overlapping process
  - Automated overlap where thermal and structural geometry are (almost) coincident
  - Manual overlap supported for:
    - non-coincident thermal and structural geometry
    - thermal nodes with no geometric representation (conductive nodes)
- Any thermal lumped parameter code is supported (ESATAN, SINDA etc.)
  - User provides temperatures in SINAS format (convertors provided for ESATAN .csv)
- Supported FEM codes are MSC NASTRAN, ASKA:
  - Generates FE nodal temperature loads
  - Generates element temperature loads for transverse temperature gradients such as honeycomb panels (e.g. NASTRAN TEMPP1)

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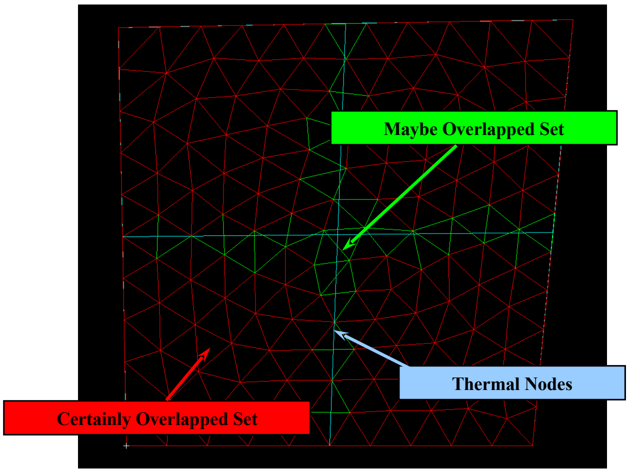
SINAS Method: Step 1 - Overlap

- Overlapping is process of building a mapping/correspondence between:
  - Lumped parameter thermal nodes
  - Structural finite elements
- Carried out using MSC Patran GUI
  - GMM mapped to Patran using TASverter
  - Automatic generation possible
- For gradient areas shell elements will overlap 2 thermal nodes



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SINAS Method: Step 2 - Matrix Generation

- Next step is to mathematically link thermal nodes and FE nodes using *Prescribed Average Temperature Method*:
  - Weighted average temperature of FE nodes of elements overlapping a thermal node is equal to the thermal node temperature
- FE shape functions are used to obtain weighting coefficients:

$$T^t_j = \sum_i a_i T^f_i \quad \Longrightarrow \quad \mathbf{T^t} = \mathbf{A}\,\mathbf{T^f}$$

$$1 = \sum_i a_i$$

constraint matrix (A)

T^f_i = FE node temperature

T^t_j = Thermal Node Temperature

a = weighting coefficient

- Derive conduction matrix from structural FE mesh
  - Replace structural materials with thermal ones (e.g. MAT1 with MAT4)
  - Use FE tool (NASTRAN or ASKA) to generate conduction matrix

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SINAS Method: Step 3 - Solve

- Assemble the following partitioned system of interpolation equations
  - Thermal node temperatures put in vector form $\mathbf{T^t}$
  - Solve the system of interpolation equations for $\mathbf{T^f}$

$$\begin{bmatrix} C & A^T \\ A & 0 \end{bmatrix} \begin{Bmatrix} T^f \\ q \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ T^t \end{Bmatrix}$$

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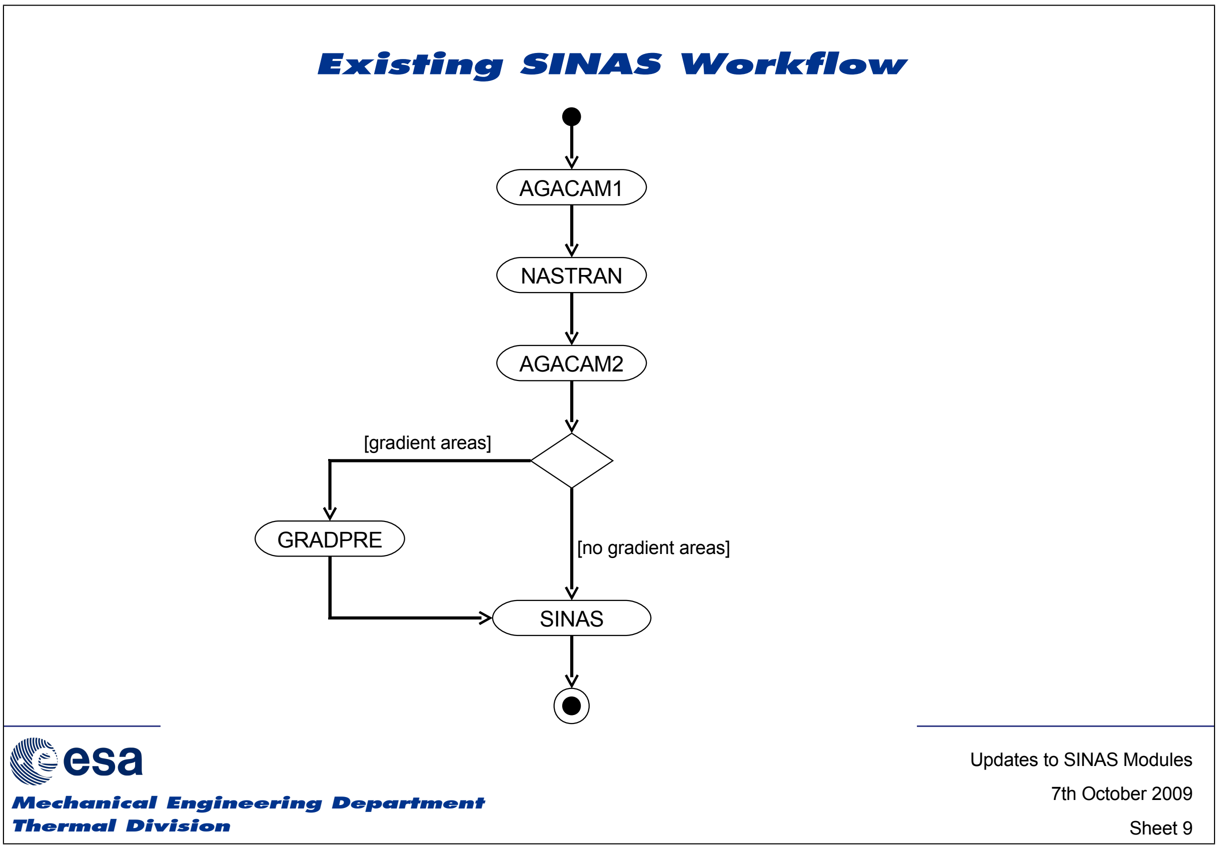
Existing SINAS Workflow
AGACAM1
NASTRAN
AGACAM2
[gradient areas]
GRADPRE
[no gradient areas]
SINAS
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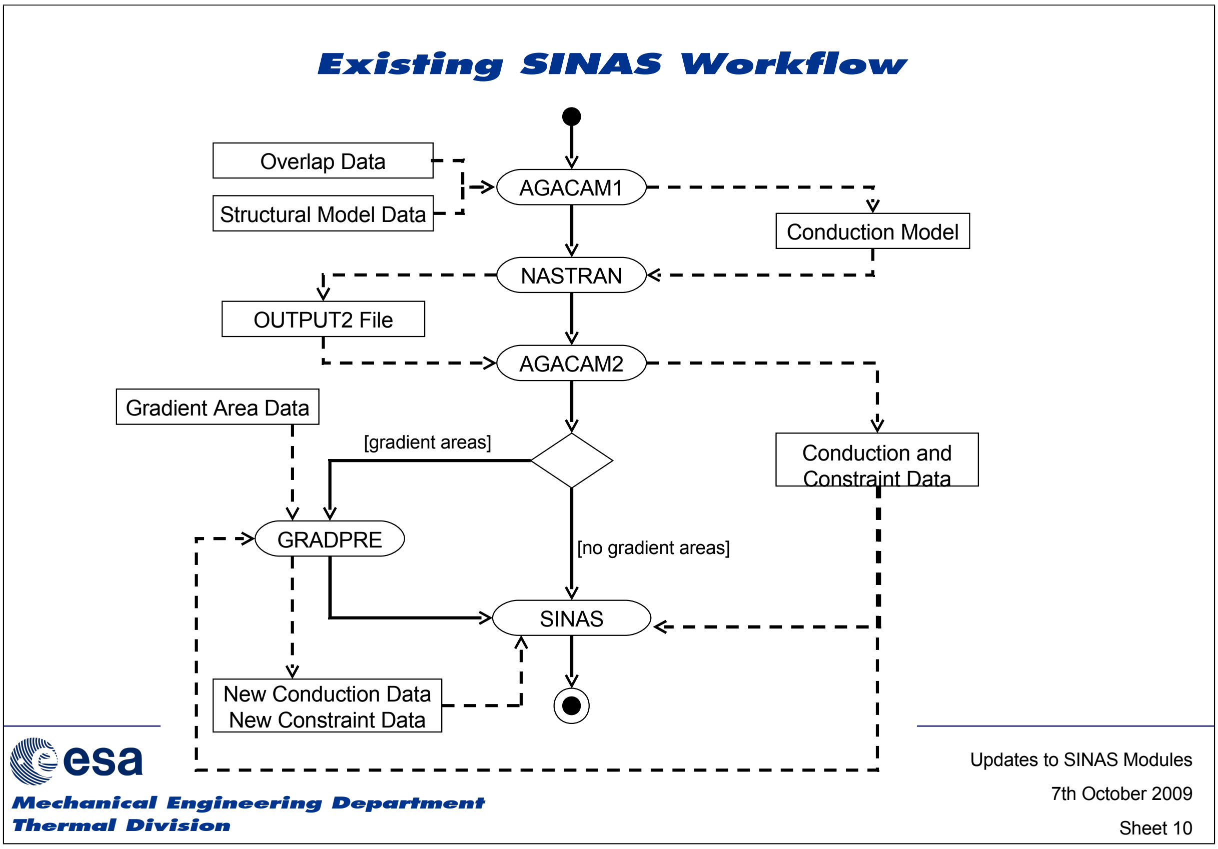
Existing SINAS Workflow
Overlap Data
Structural Model Data
AGACAM1
Conduction Model
NASTRAN
OUTPUT2 File
AGACAM2
Gradient Area Data
[gradient areas]
Conduction and Constraint Data
GRADPRE
[no gradient areas]
SINAS
New Conduction Data
New Constraint Data
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Motivation for Updating SINAS

- Simplification of existing SINAS workflow
  - Consolidation of four modules into a single one
- Opportunity to improve performance using modern programming methods and languages (Python in this case)
  - Implementing same mathematical methods based on SINAS technical documentation
- Remove dependence on NASTRAN
  - NASTRAN was only used to generate conduction/constraint matrices
  - Extra NASTRAN DMAP license is required in existing SINAS
  - Gradient area functionality unusable due to changes in NASTRAN DMAP
- Much of the required code already existed from previous work
  - NASTRAN reader from TASverter
  - FE methods in fe2tan module

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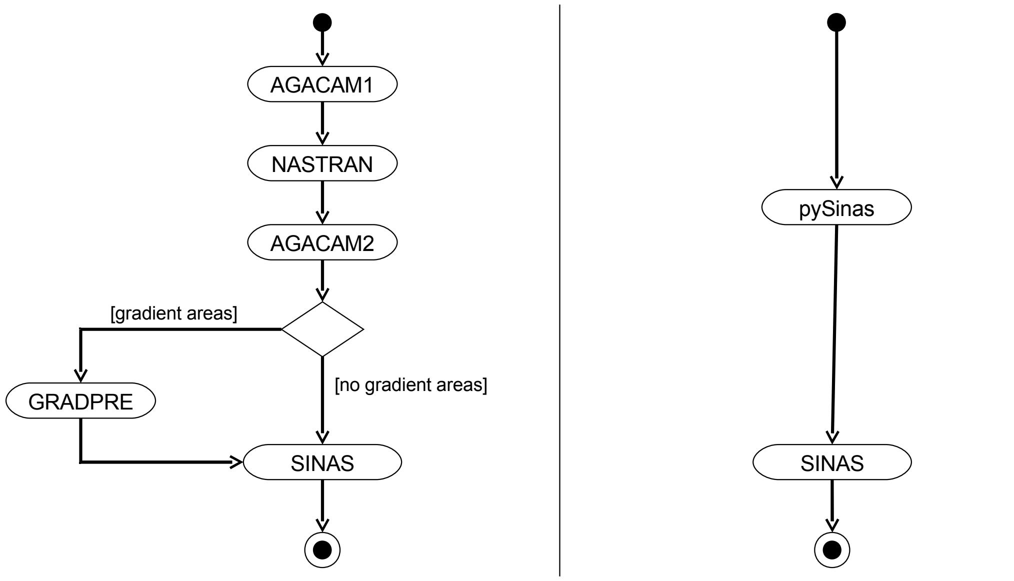
Updated SINAS Workflow



Existing Activity Diagram **Updated Activity Diagram**

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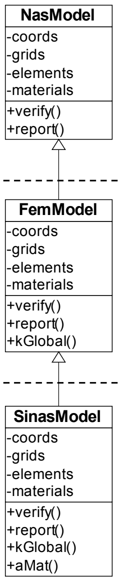
pySinas Architecture

- NASTRAN Reader
  - Methods to read bulk data file, verify and report
  - Reuse TASverter NASTRAN reader
- FE Code
  - Classes containing generic FE code
  - Co-ordinate transformations
  - Calculation of conduction/capacitance matrix
- SINAS Code
  - Classes containing SINAS specific code
  - Generation of constraint matrix
  - Gradient area code



Updates to NASTRAN Reader: Automatic Code Generation

CTRIA3 Triangular Plate Element Connection

Defines an isoparametric membrane-bending or plane strain triangular plate element.

Format:

1	2	3	4	5	6	7	8	9	10
CTRIA3	EID	PID	G1	G2	G3	THETA or MCID	ZOFFS		
		TFLAG	T1	T2	T3				

Microsoft Excel - class_generator

File Edit View Insert Format Tools Data Window Help Adobe PDF

C9 fx val>0

	A	B	C	D	E	
1						
2	Create Python Code					
3						
4	**Title**	Triangular Plate Element Connection				
5	**Description**	Defines an isoparametric membrane-bending or plane strain triangular plate element.				
6	**Class Name**	Ctria3				
7						
8	**Attribute**	**Type**	**Test**	**Can Be Blank**	**Default**	**Description**
9	eid	int	val>0	no		Element identification number.
10	pid	int	val>0	no		Property identification number of a PSHELL, PCOMP or PLPLANE entry
11	g1	int	val>0	no		Grid point identification number of connection point.
12	g2	int	val>0	no		Grid point identification number of connection point.
13	g3	int	val>0	no		Grid point identification number of connection point.
14	theta	float		yes	0.0	Material property orientation angle in degrees
15	**OR**					
16	mcid	int	val>=0	yes		Material coordinate system identification number
17	zoffs	float		yes		Offset from the surface of grid points to the element reference plane.
18	**BLANK**					
19	**BLANK**					
20	tflag	int	0<=val<=1	yes		An integer flag signifying the meaning of Ti values.
21	t1	float	val>0.0	yes		Membrane thickness of element at grid points G1
22	t2	float	val>0.0	yes		Membrane thickness of element at grid points G2
23	t3	float	val>0.0	yes		Membrane thickness of element at grid points G3
24						

Finite Element Code: Overview

- Objective of FE code is to replace NASTRAN in the role of generating the *conduction* matrix for the structural model
  - Builds on knowledge gained and work done during previous studies
  - Reverse engineer NASTRAN behaviour for consistency with existing SINAS

$$\begin{bmatrix} C & A^T \\ A & 0 \end{bmatrix} \begin{Bmatrix} T^f \\ q \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ T^t \end{Bmatrix}$$

- New conductive FE functionality was required:
  - Rectangular and Cylindrical coordinate systems now supported
  - Supported conductive elements: CBAR, CTRIA3, CTRIA6, CQUAD4, CQUAD8, CTETRA, CHEXA, CPENTA, CELASx (1st and 2nd order 3D elements supported)
  - All elements now use isoparametric formulations – CPENTA previously degenerate HEX
  - Orthotropic material properties now supported
  - Numerical integration performed using Gaussian quadrature

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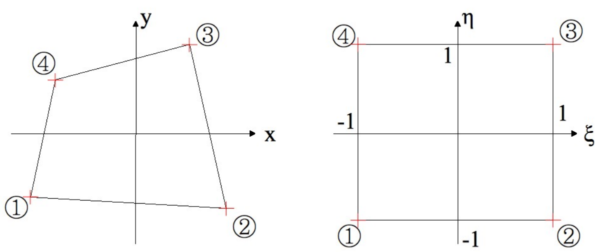
Finite Element Code: Shell Element Example



$$N_1 = \frac{1}{4}(1-\xi)(1-\eta) \qquad N_2 = \frac{1}{4}(1+\xi)(1-\eta)$$

$$N_3 = \frac{1}{4}(1+\xi)(1+\eta) \qquad N_4 = \frac{1}{4}(1-\xi)(1+\eta)$$

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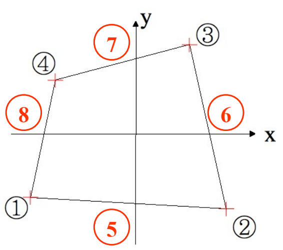
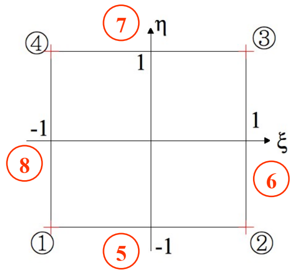
Finite Element Code: Shell Element Example





$$N_1 = \frac{1}{4}(1-\xi)(1-\eta) \qquad N_2 = \frac{1}{4}(1+\xi)(1-\eta)$$

$$N_3 = \frac{1}{4}(1+\xi)(1+\eta) \qquad N_4 = \frac{1}{4}(1-\xi)(1+\eta)$$

- Edge node (5-8) shape functions calculated as before
- Corner node (1-4) shape functions found by subtracting half the edge shape functions for connected nodes
- Implementation complicated because nodes 5-8 are optional - user could provide 1,2,3,4,7

$$N_1 = \hat{N}_1 - \frac{1}{2}N_5 - \frac{1}{2}N_8$$

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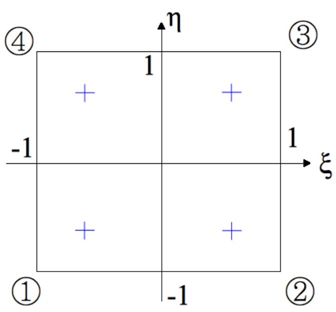
Finite Element Code: Numerical Integration

- Standard Gaussian quadrature rules used for all elements *except* CQUAD4
  - NASTRAN implements CQUAD4 using corner points for integration so this approach was also used for consistency
  - Reason for this behaviour in NASTRAN is unknown – accuracy is comparable to standard Gauss
  - Standard Gauss locations and weights are used – order is comparable to NASTRAN



$$\int_{-1}^{1} f(x)dx \approx \sum_{i=1}^{n} w_i f(x_i)$$

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SINAS Code: Overview

- Two key areas to be addressed in SINAS code:

Computation of Constraint Matrix

- Matrix represents the proportion of the volume of a thermal node occupied by each structural node it overlaps – the A matrix
- Volumes calculated using shape functions

$$\begin{bmatrix} C & A^T \\ A & 0 \end{bmatrix} \begin{Bmatrix} T^f \\ q \end{Bmatrix} = \begin{Bmatrix} \mathbf{0} \\ T^t \end{Bmatrix}$$

Gradient Areas

- Plate or beam elements of the structural model are overlapped by multiple thermal nodes
- Used to represent different temperatures on different sides of elements.

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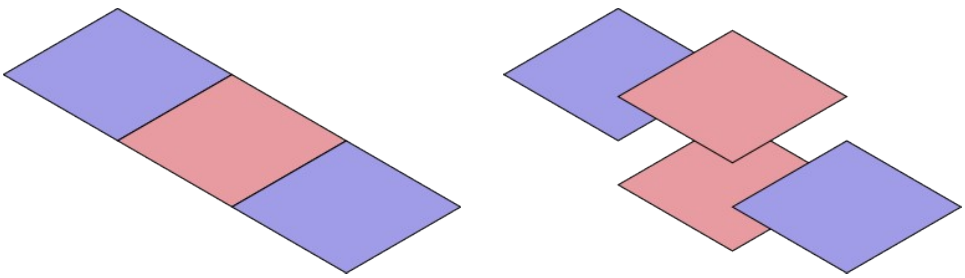
SINAS Code: Gradient Areas



- Fictitious nodes created for elements in gradient area
- Fictitious model created and analysed as before
- Layer definition file contains relationships between fictitious and FEM nodes
  - Implemented via application of linear constraints (e.g. Lagrange Multipliers)

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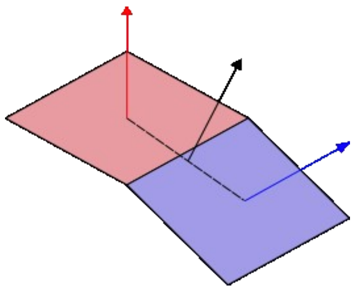
SINAS Code: Element Orientation for Gradient Areas

- Connection table created
  - Lists fewest comparisons between elements required to cover the gradient area
- Orientation of elements compared to supplied reference element to determine the layers of the gradient area



$$P_c = \frac{\vec{n^*} \cdot \vec{n_c}}{|\vec{n^*} \cdot \vec{n_c}|} P_r$$

P = 1 or P = -1

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Testing Approach

- Testing for overlap with no gradient areas
  - Structural model file and overlap file used as input for AGACAM/Nastran and PYSINAS
  - Constraint and conduction matrices output by the two methods compared
- Testing for overlap with gradient areas
  - SINAS modules cannot perform gradient area analysis so direct comparison not possible
  - Solid model created and analysed using SINAS modules to produce displacements due to an applied thermal load
  - Equivalent shell model created using gradient areas and analysed using PYSINAS
  - The same thermal load is applied and the resulting displacements compared
- Only end-to-end testing carried out so far
  - No unit testing carried out at module level

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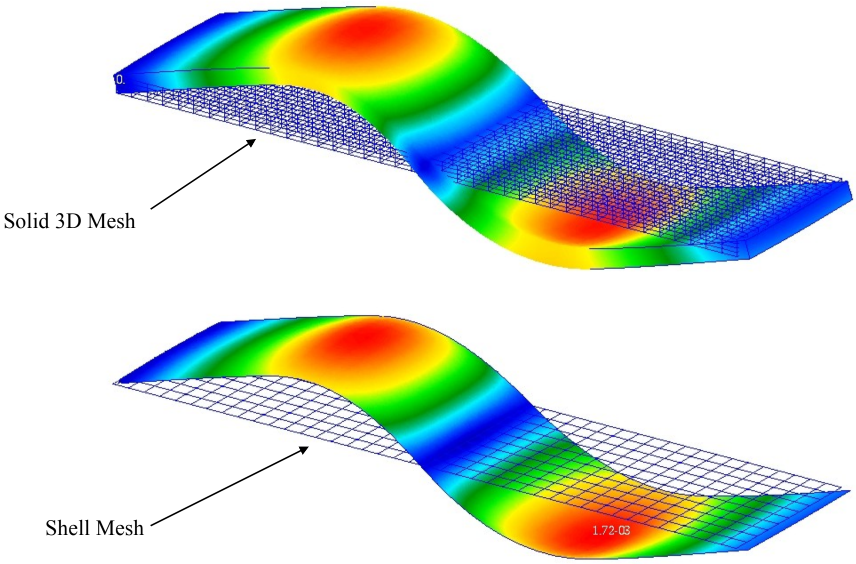
Testing Gradient Areas: Example Case



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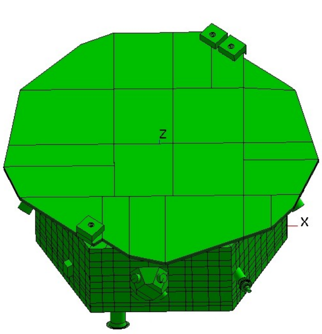
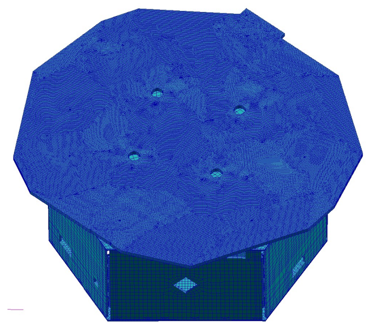
Industrial Application : LISA Pathfinder

- Combined SCM and LTP Thermal Model – approx 10,000 thermal nodes
- Full S/C structural FE model – approx 400,000 nodes, 500,000 elements
- Model was run with and without gradient area for solar array



Thermal Model



FE Model

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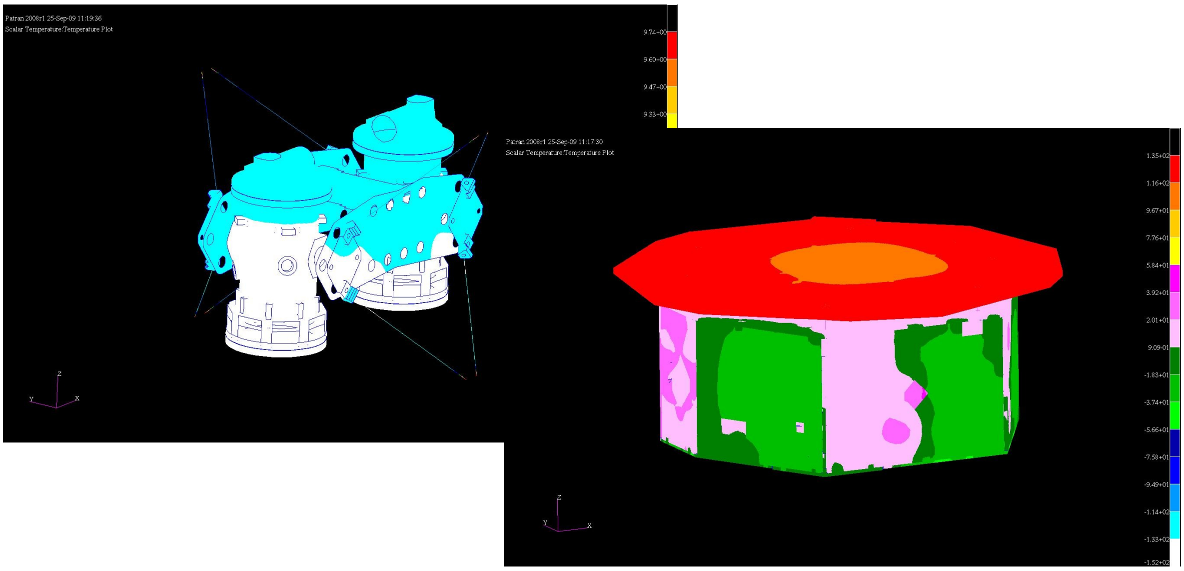
Industrial Application : LISA Pathfinder



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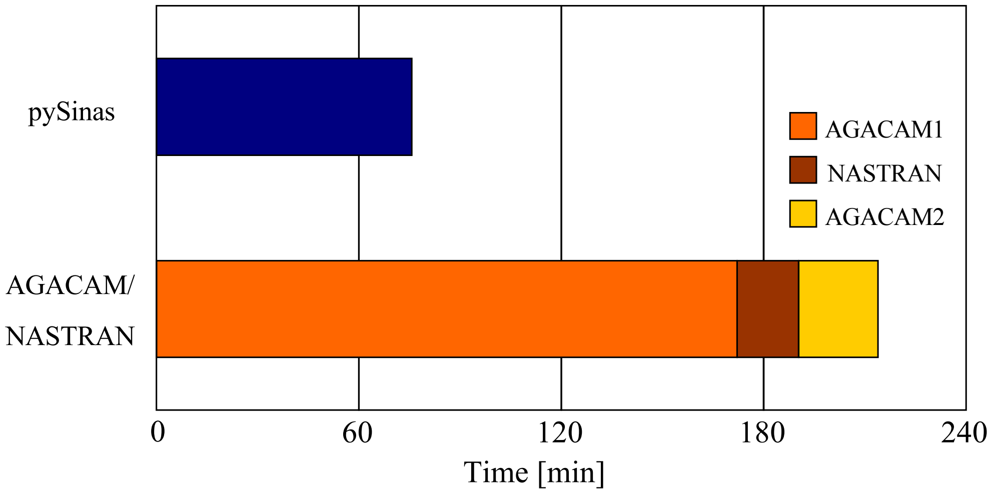
Industrial Application: Performance

- Significant performance improvement with updated module
  - Simplification of workflow and processes
  - Replace FORTRAN linear searches with Python dictionaries



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Conclusions and Future Work

- Functionality of modules AGACAM1, Nastran, AGACAM2 and GRAD-Pre replaced by a single python module
- Code arranged so that generic Nastran input and FE code can be reused
  - SINAS specific classes inherit from FE classes
- Gradient area functionality restored
- Significant performance increase achieved
- Difficulties encountered often caused by trying to replicate Nastran behaviour
- Before distributing new tool to community more work required:
  - More extensive testing including unit testing – using pyUnit module
  - Not all elements implemented – but framework exists and now quick to implement
  - Add checks on element quality to the FE module (e.g. skew, aspect ratio)

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Appendix Q

ESATAP 2.0.0

Status and evolution of developments dedicated to thermal end users

Alain Fagot François Brunetti
(DOREA, France)

Harrie Rooijackers Hans Peter de Koning
(ESA/ESTEC, The Netherlands)

Abstract

ESATAP is a post processing tool for large sets of thermal result data in STEP-TAS/STEP-NRF datasets. ESATAP 1.0.2 was presented at the last workshop.

Since last year feedback and requests of users have been taken into account to make the new version more robust and user friendly.

ESATAP 2.0.0 will be released end of 2009 and will provide:

- A Wizard mode to guide the user step by step while processing a task.
- New plot component allowing faster and easier analysis of min-max temperatures on single or multiple cases.
- A check mode simulating and validating processes (tasks) before launching the real execution.
- Enhanced performance for handling large datasets (enhanced loading and merging capabilities).


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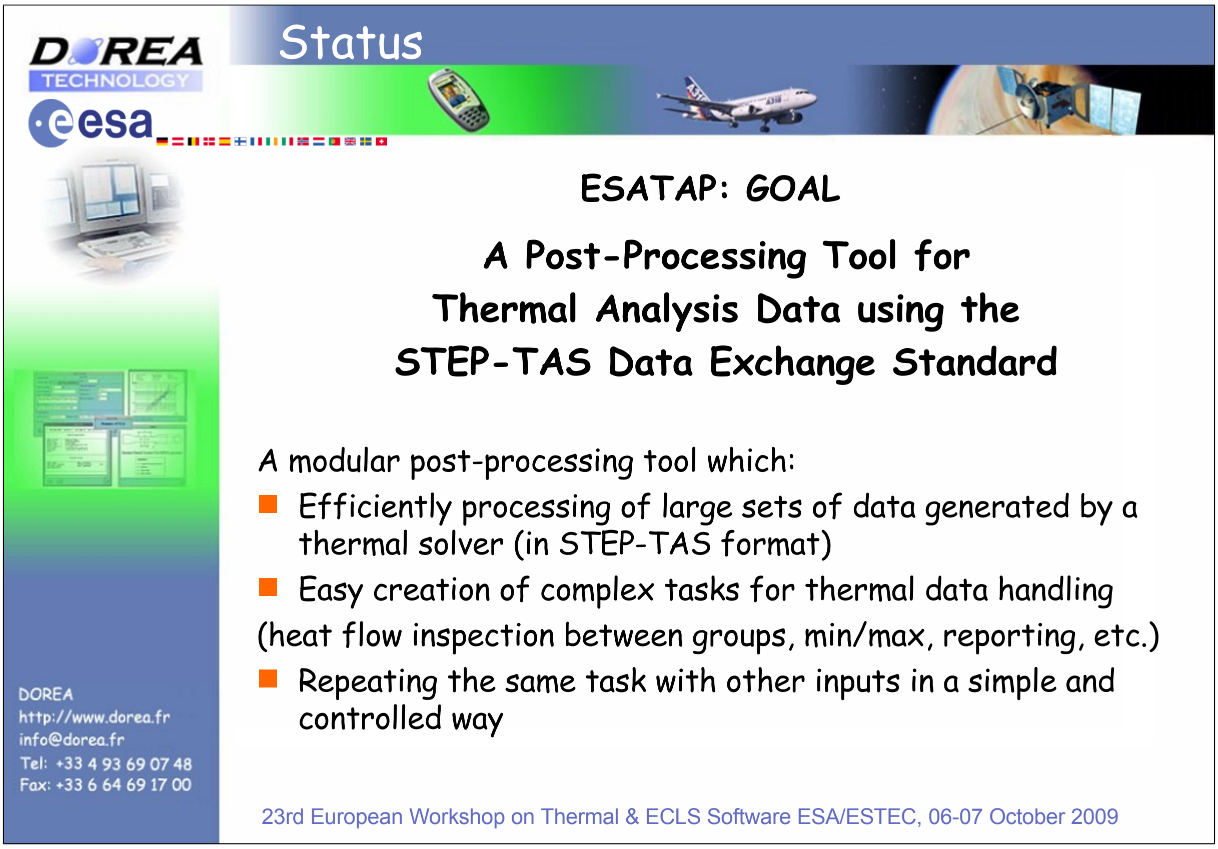
Harrie ROOIJACKERS
ESA
Hans Peter DE KONING
ESATAP 2.0.0
Status and evolution of developments dedicated
to thermal end users
Authors:
alain.fagot@dorea.fr
francois.brunetti@dorea.fr
23rd European Workshop on Thermal & ECLS Software ESA/ESTEC, 06-07 October 2009
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00


Status
DOREA TECHNOLOGY
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ESATAP: GOAL
A Post-Processing Tool for
Thermal Analysis Data using the
STEP-TAS Data Exchange Standard
A modular post-processing tool which:
Efficiently processing of large sets of data generated by a thermal solver (in STEP-TAS format)
Easy creation of complex tasks for thermal data handling
(heat flow inspection between groups, min/max, reporting, etc.)
Repeating the same task with other inputs in a simple and controlled way
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
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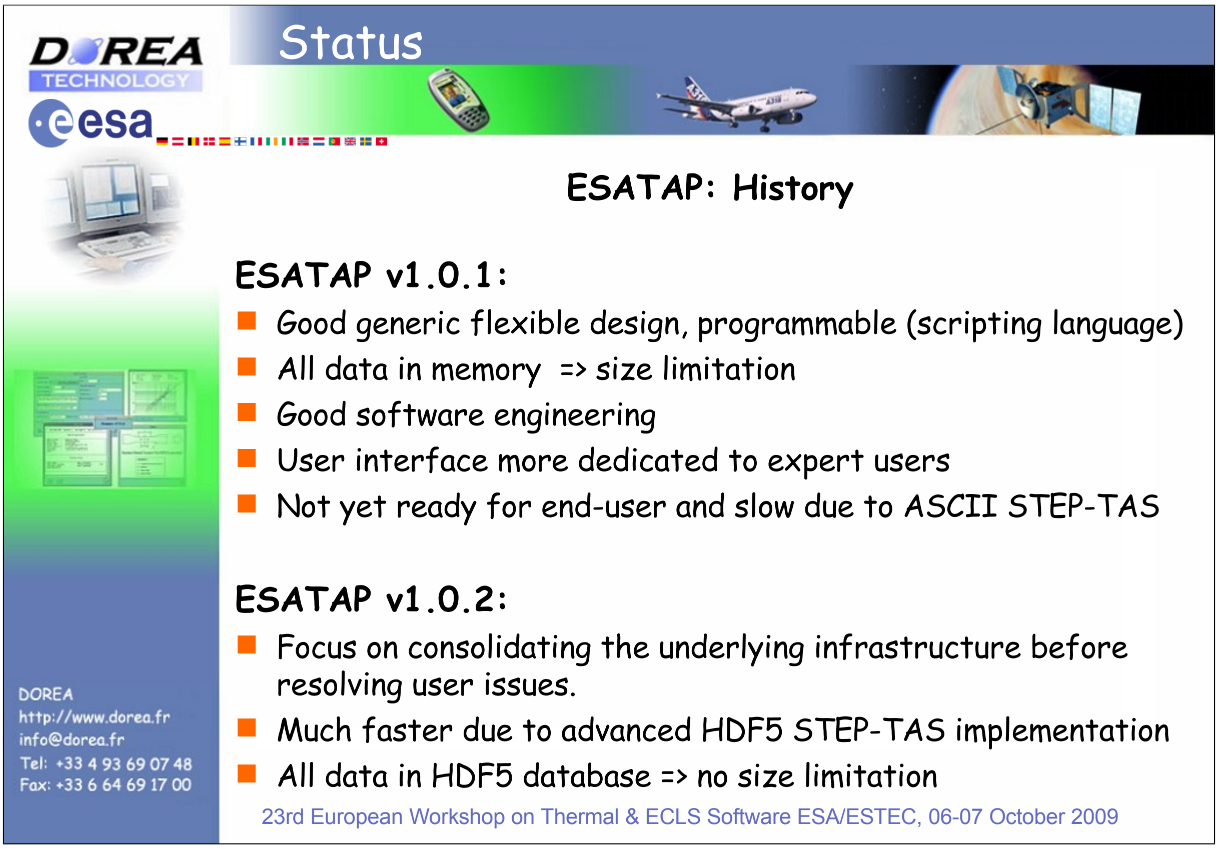
DOREA TECHNOLOGY
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Status
ESATAP: History
ESATAP v1.0.1:
Good generic flexible design, programmable (scripting language)
All data in memory => size limitation
Good software engineering
User interface more dedicated to expert users
Not yet ready for end-user and slow due to ASCII STEP-TAS
ESATAP v1.0.2:
Focus on consolidating the underlying infrastructure before resolving user issues.
Much faster due to advanced HDF5 STEP-TAS implementation
All data in HDF5 database => no size limitation
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info@dorea.fr
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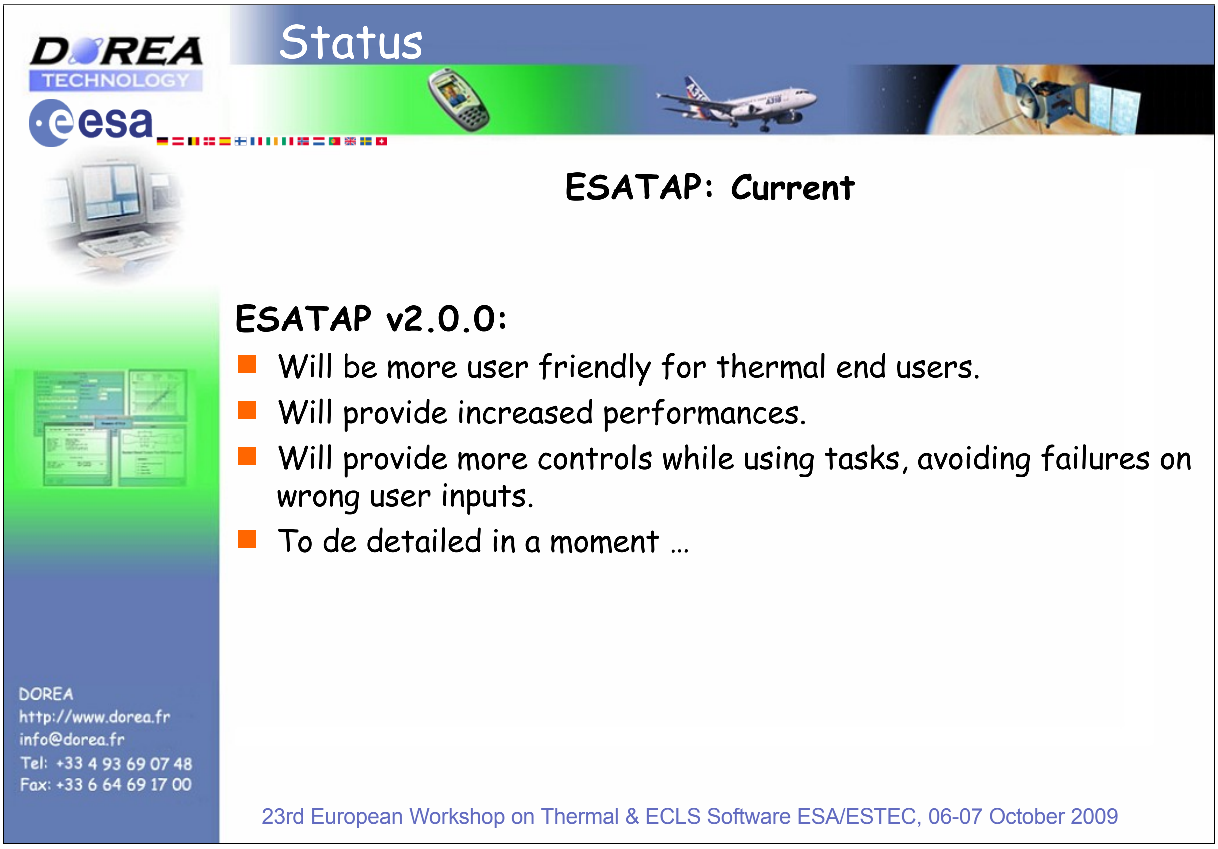
DOREA TECHNOLOGY
esa
Status
ESATAP: Current
ESATAP v2.0.0:
Will be more user friendly for thermal end users.
Will provide increased performances.
Will provide more controls while using tasks, avoiding failures on wrong user inputs.
To de detailed in a moment …
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http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
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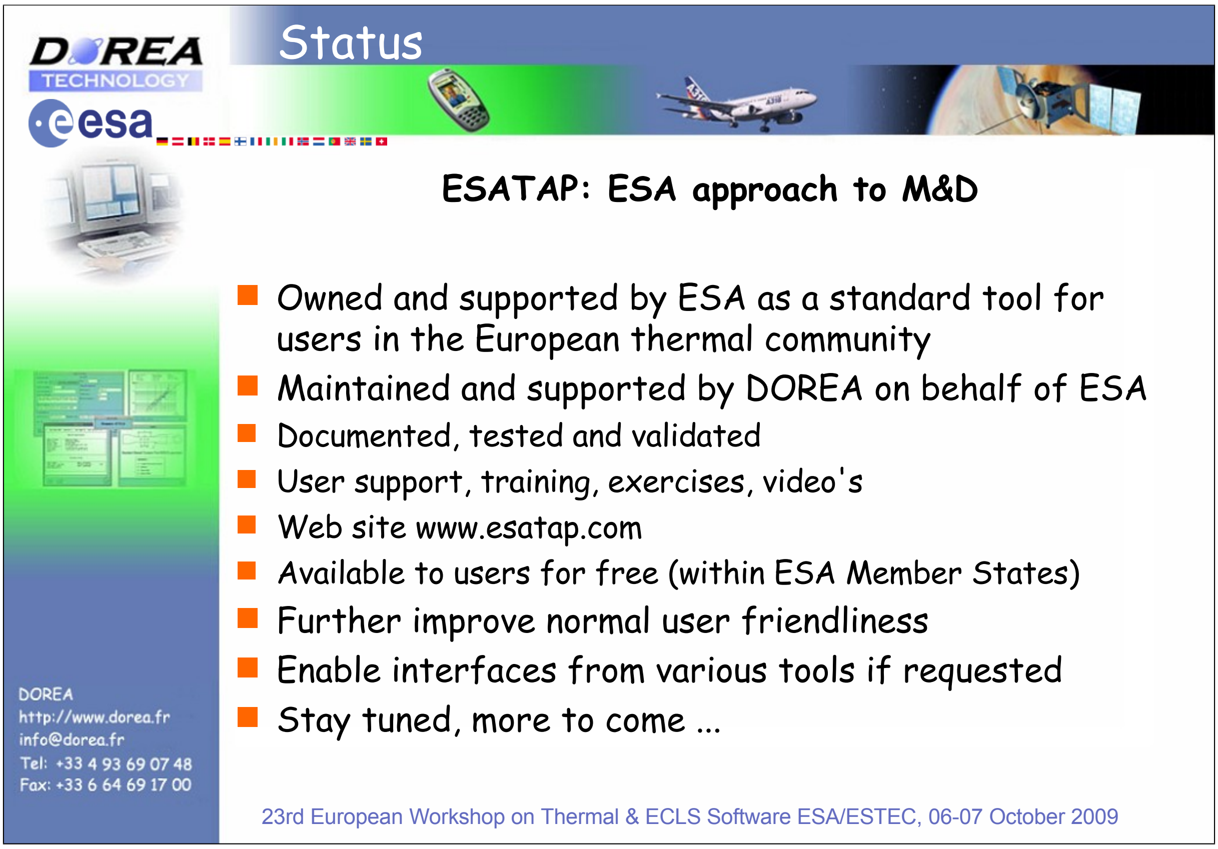
Status
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ESATAP: ESA approach to M&D
Owned and supported by ESA as a standard tool for users in the European thermal community
Maintained and supported by DOREA on behalf of ESA
Documented, tested and validated
User support, training, exercises, video's
Web site www.esatap.com
Available to users for free (within ESA Member States)
Further improve normal user friendliness
Enable interfaces from various tools if requested
Stay tuned, more to come ...
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http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
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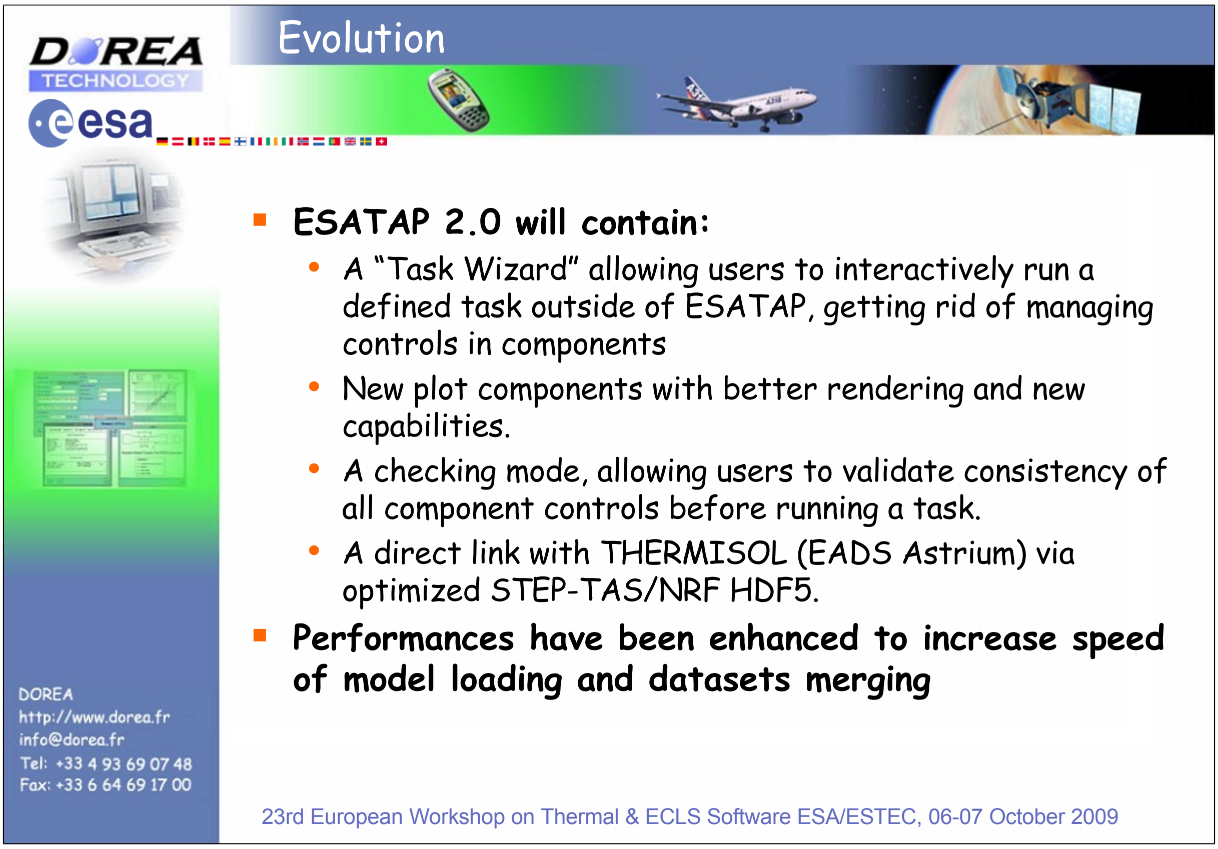
Evolution
DOREA TECHNOLOGY
esa
ESATAP 2.0 will contain:
A "Task Wizard" allowing users to interactively run a defined task outside of ESATAP, getting rid of managing controls in components
New plot components with better rendering and new capabilities.
A checking mode, allowing users to validate consistency of all component controls before running a task.
A direct link with THERMISOL (EADS Astrium) via optimized STEP-TAS/NRF HDF5.
Performances have been enhanced to increase speed of model loading and datasets merging
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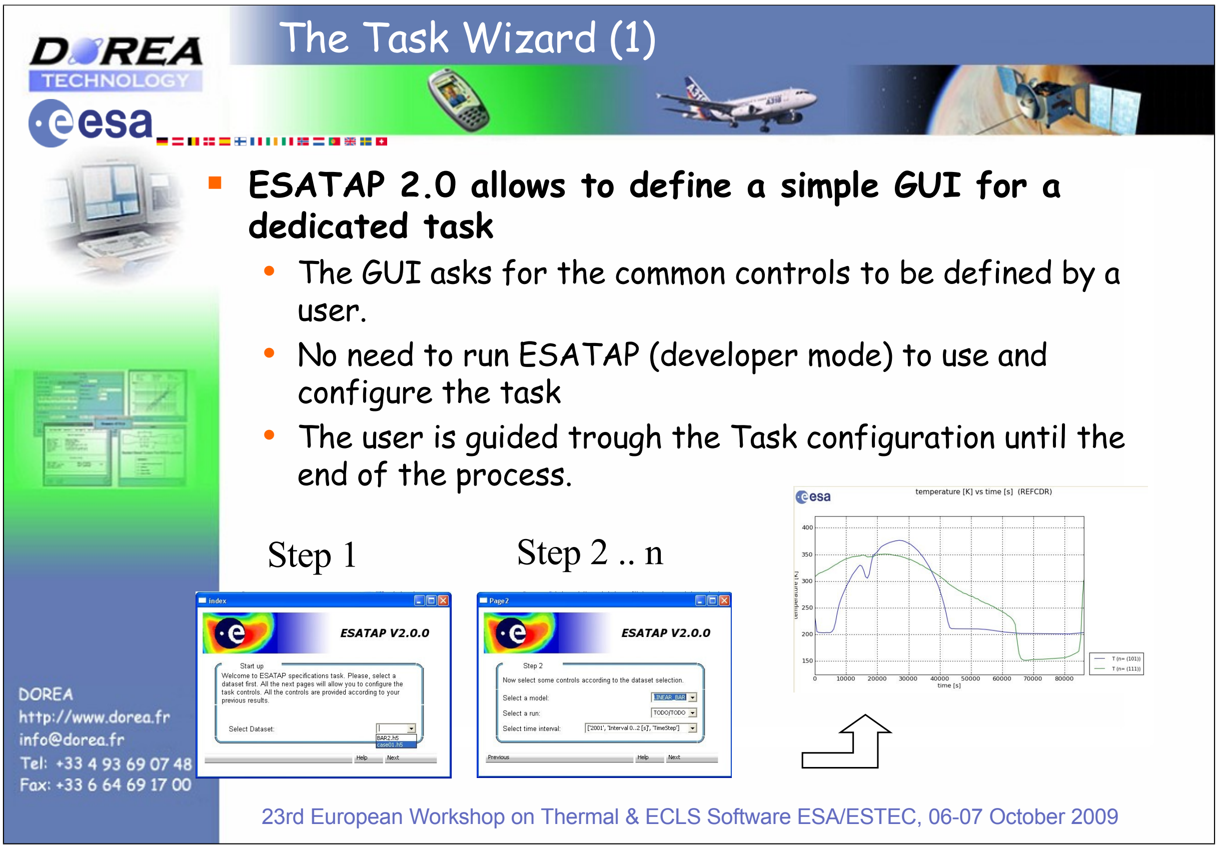
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
23rd European Workshop on Thermal & ECLS Software ESA/ESTEC, 06-07 October 2009


The Task Wizard (1)
DOREA TECHNOLOGY
esa
ESATAP 2.0 allows to define a simple GUI for a dedicated task
The GUI asks for the common controls to be defined by a user.
No need to run ESATAP (developer mode) to use and configure the task
The user is guided trough the Task configuration until the end of the process.
Step 1
Step 2 .. n
ESATAP V2.0.0
ESATAP V2.0.0
temperature [K] vs time [s] (REFCDR)
DOREA
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info@dorea.fr
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Fax: +33 6 64 69 17 00
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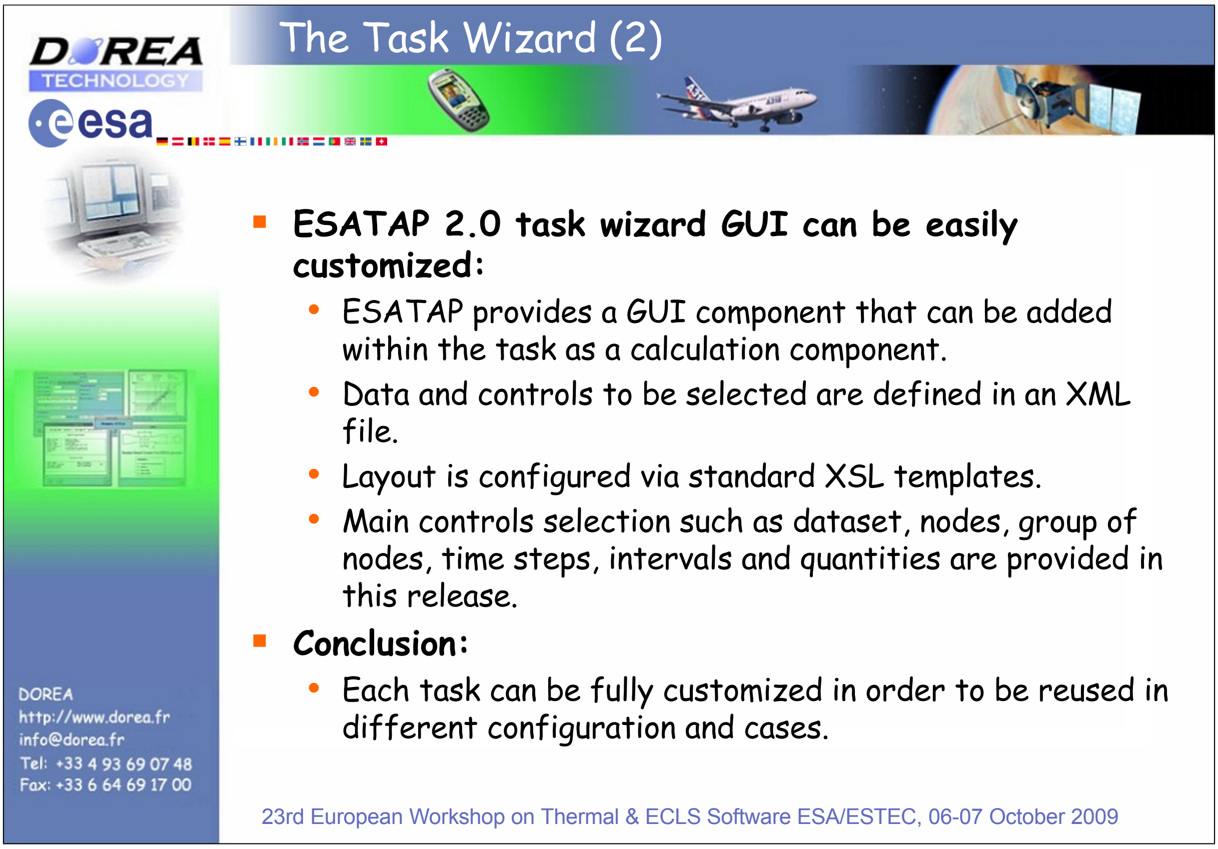
The Task Wizard (2)
DOREA TECHNOLOGY
esa
ESATAP 2.0 task wizard GUI can be easily customized:
ESATAP provides a GUI component that can be added within the task as a calculation component.
Data and controls to be selected are defined in an XML file.
Layout is configured via standard XSL templates.
Main controls selection such as dataset, nodes, group of nodes, time steps, intervals and quantities are provided in this release.
Conclusion:
Each task can be fully customized in order to be reused in different configuration and cases.
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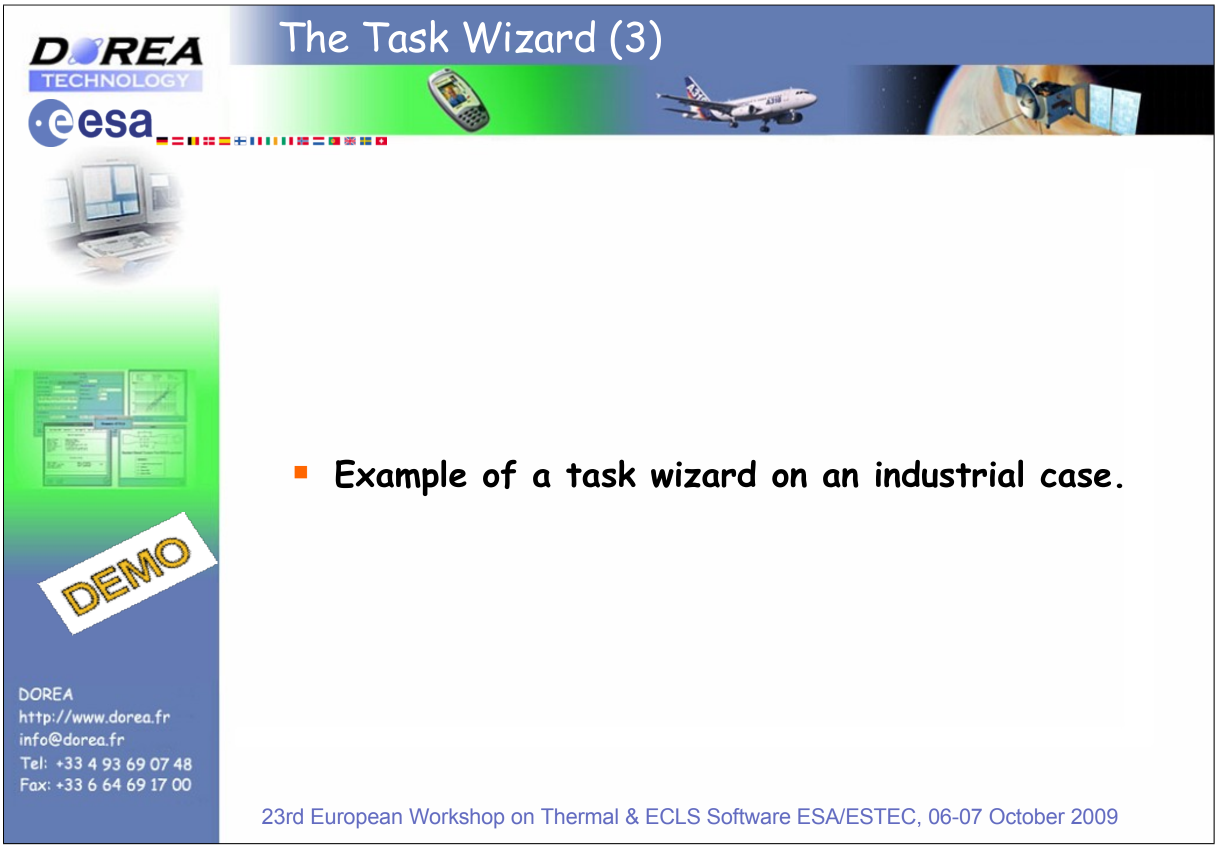
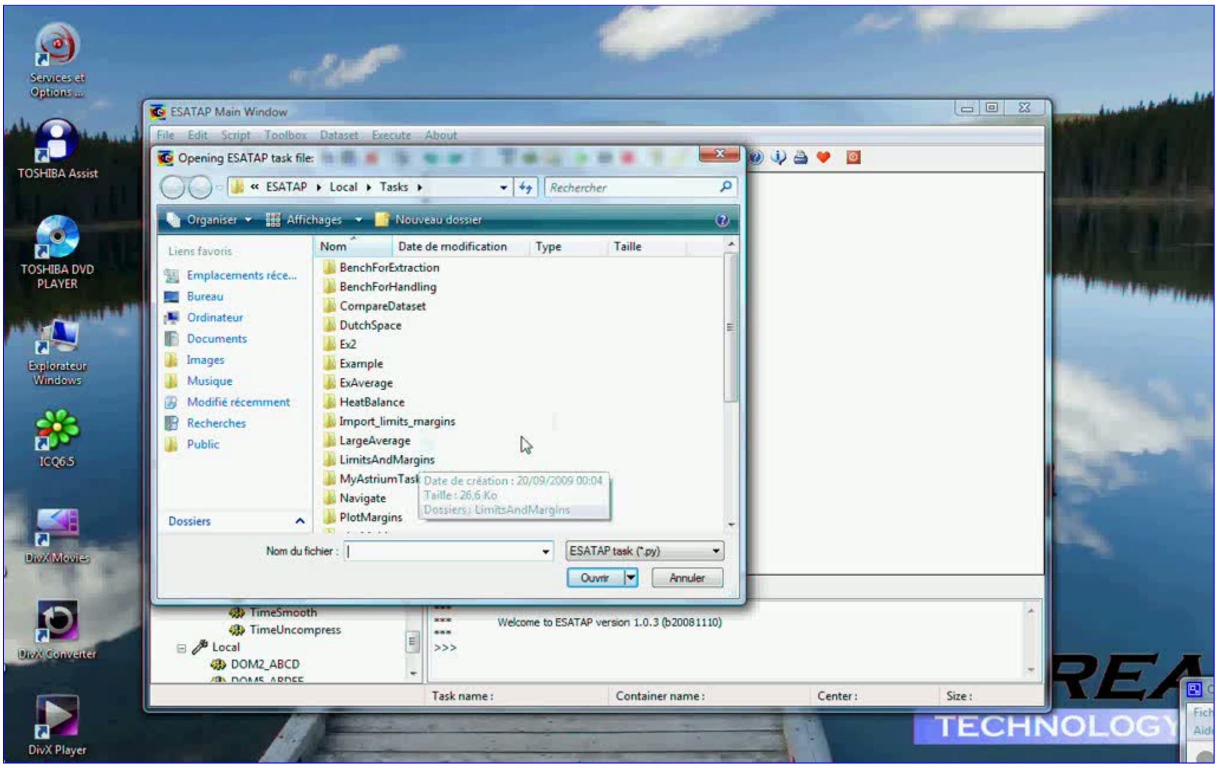
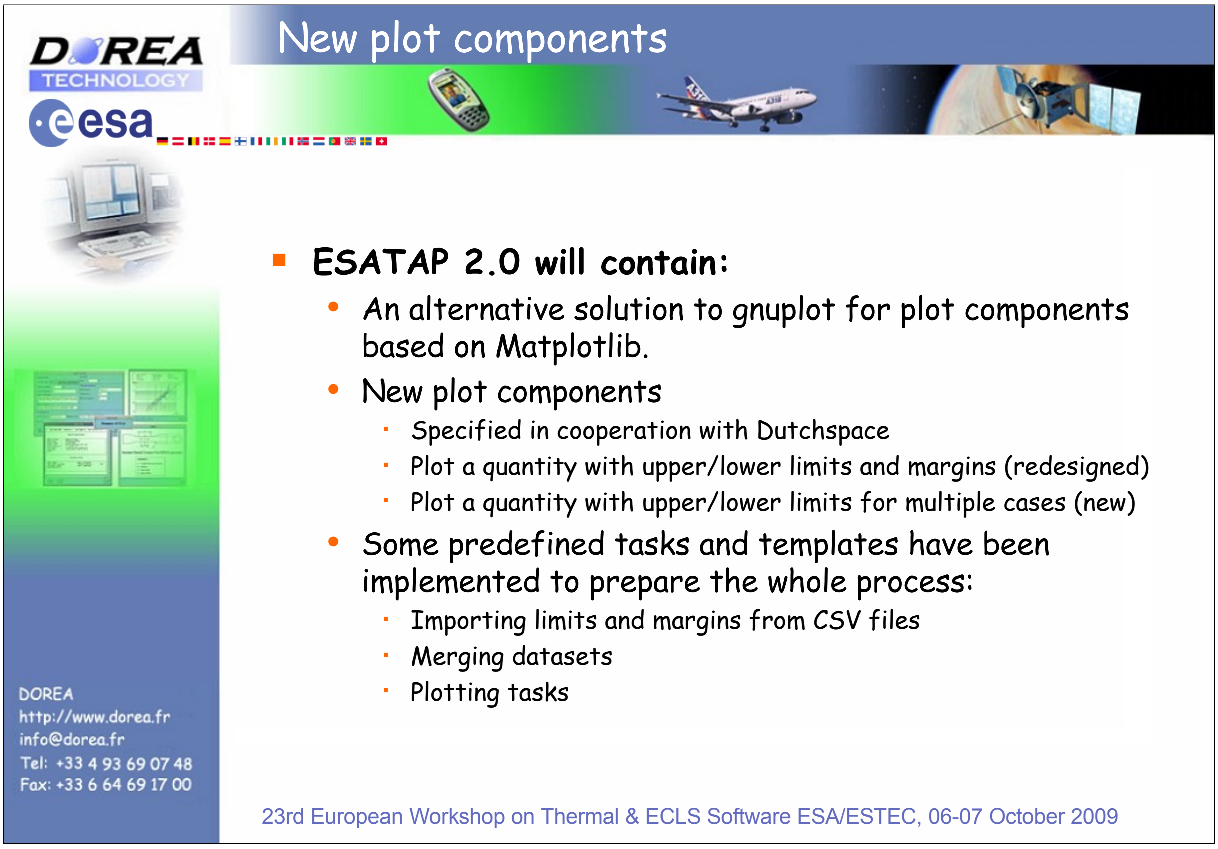




If clicking on the picture above does not run the movie then try opening the file ‘movies/ESATAP-video.html’ manually.


New plot components
DOREA TECHNOLOGY
esa
ESATAP 2.0 will contain:
An alternative solution to gnuplot for plot components based on Matplotlib.
New plot components
Specified in cooperation with Dutchspace
Plot a quantity with upper/lower limits and margins (redesigned)
Plot a quantity with upper/lower limits for multiple cases (new)
Some predefined tasks and templates have been implemented to prepare the whole process:
Importing limits and margins from CSV files
Merging datasets
Plotting tasks
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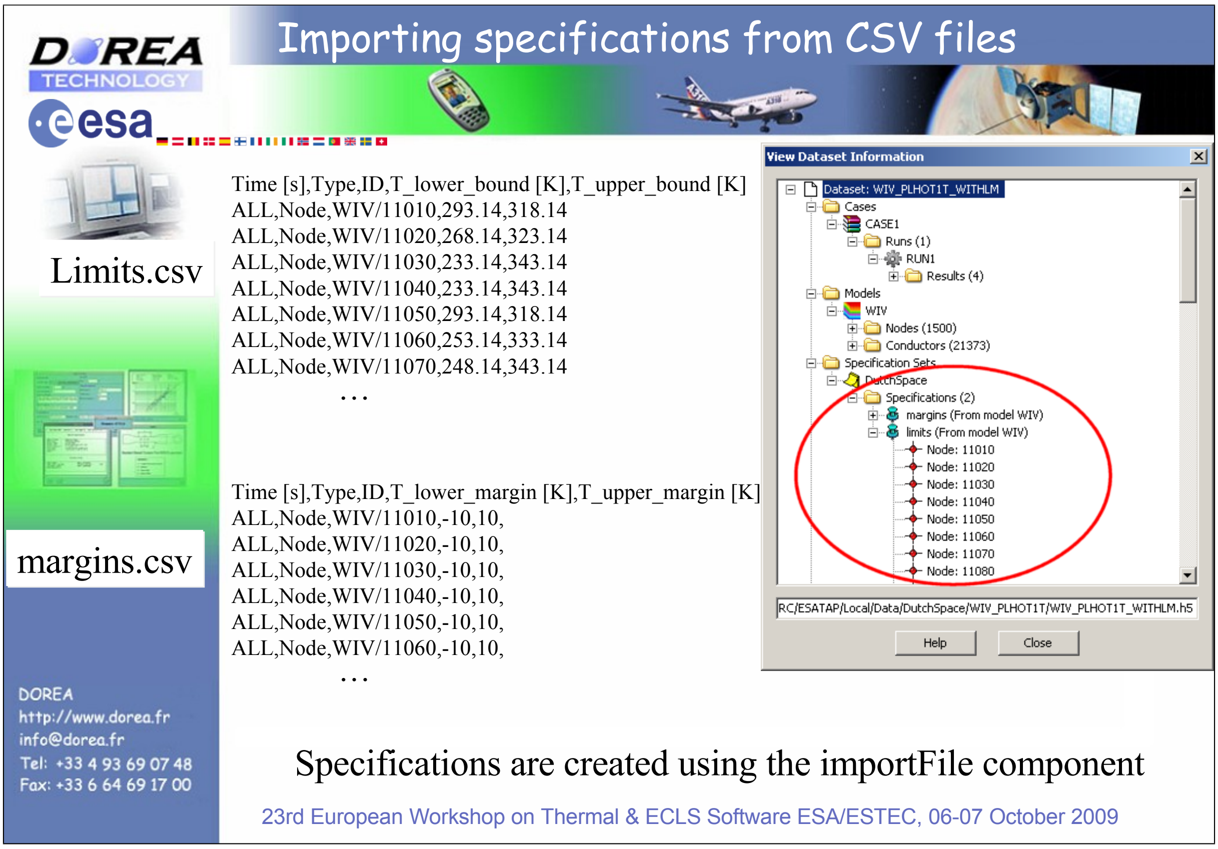
Importing specifications from CSV files
DOREA TECHNOLOGY
esa
Limits.csv
Time [s],Type,ID,T_lower_bound [K],T_upper_bound [K]
ALL,Node,WIV/11010,293.14,318.14
ALL,Node,WIV/11020,268.14,323.14
ALL,Node,WIV/11030,233.14,343.14
ALL,Node,WIV/11040,233.14,343.14
ALL,Node,WIV/11050,293.14,318.14
ALL,Node,WIV/11060,253.14,333.14
ALL,Node,WIV/11070,248.14,343.14
...
margins.csv
Time [s],Type,ID,T_lower_margin [K],T_upper_margin [K]
ALL,Node,WIV/11010,-10,10,
ALL,Node,WIV/11020,-10,10,
ALL,Node,WIV/11030,-10,10,
ALL,Node,WIV/11040,-10,10,
ALL,Node,WIV/11050,-10,10,
ALL,Node,WIV/11060,-10,10,
...
View Dataset Information
Dataset: WIV_PLHOT1T_WITHLM
Cases
CASE1
Runs (1)
RUN1
Results (4)
Models
WIV
Nodes (1500)
Conductors (21373)
Specification Sets
DutchSpace
Specifications (2)
margins (From model WIV)
limits (From model WIV)
Node: 11010
Node: 11020
Node: 11030
Node: 11040
Node: 11050
Node: 11060
Node: 11070
Node: 11080
RC/ESATAP/Local/Data/DutchSpace/WIV_PLHOT1T/WIV_PLHOT1T_WITHLM.h5
Help
Close
Specifications are created using the importFile component
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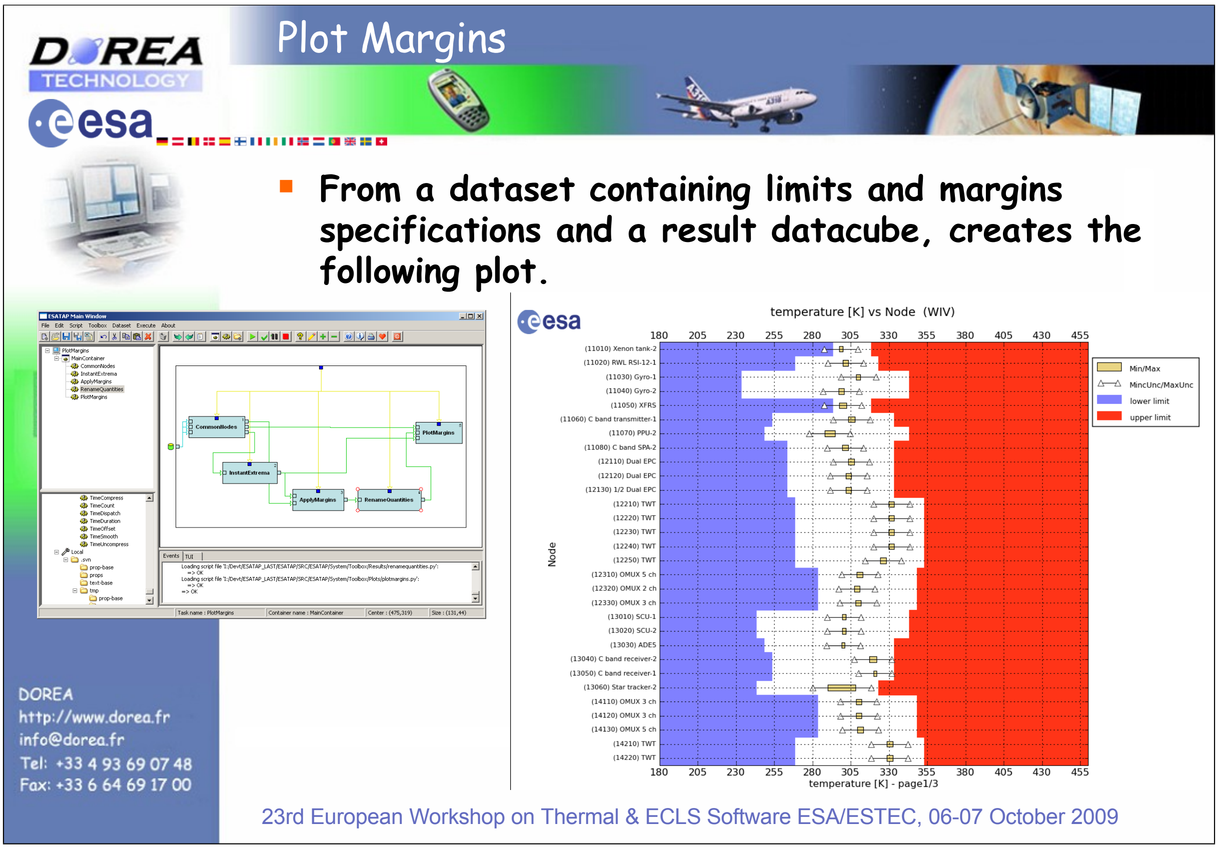
Plot Margins
DOREA TECHNOLOGY
esa
From a dataset containing limits and margins specifications and a result datacube, creates the following plot.
temperature [K] vs Node (WIV)
Node
temperature [K] - page1/3
Min/Max
MincUnc/MaxUnc
lower limit
upper limit
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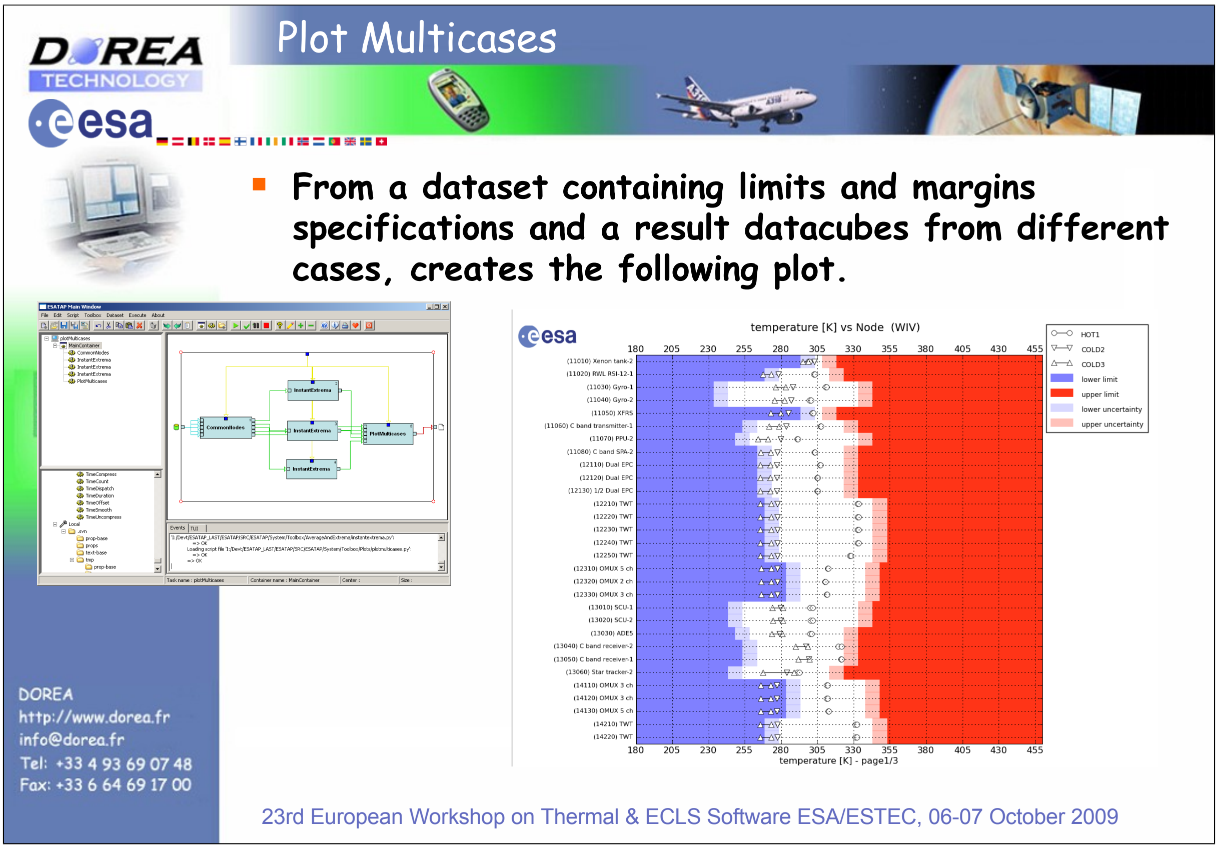
Plot Multicases
DOREA TECHNOLOGY
esa
From a dataset containing limits and margins specifications and a result datacubes from different cases, creates the following plot.
temperature [K] vs Node (WIV)
temperature [K] - page1/3
HOT1
COLD2
COLD3
lower limit
upper limit
lower uncertainty
upper uncertainty
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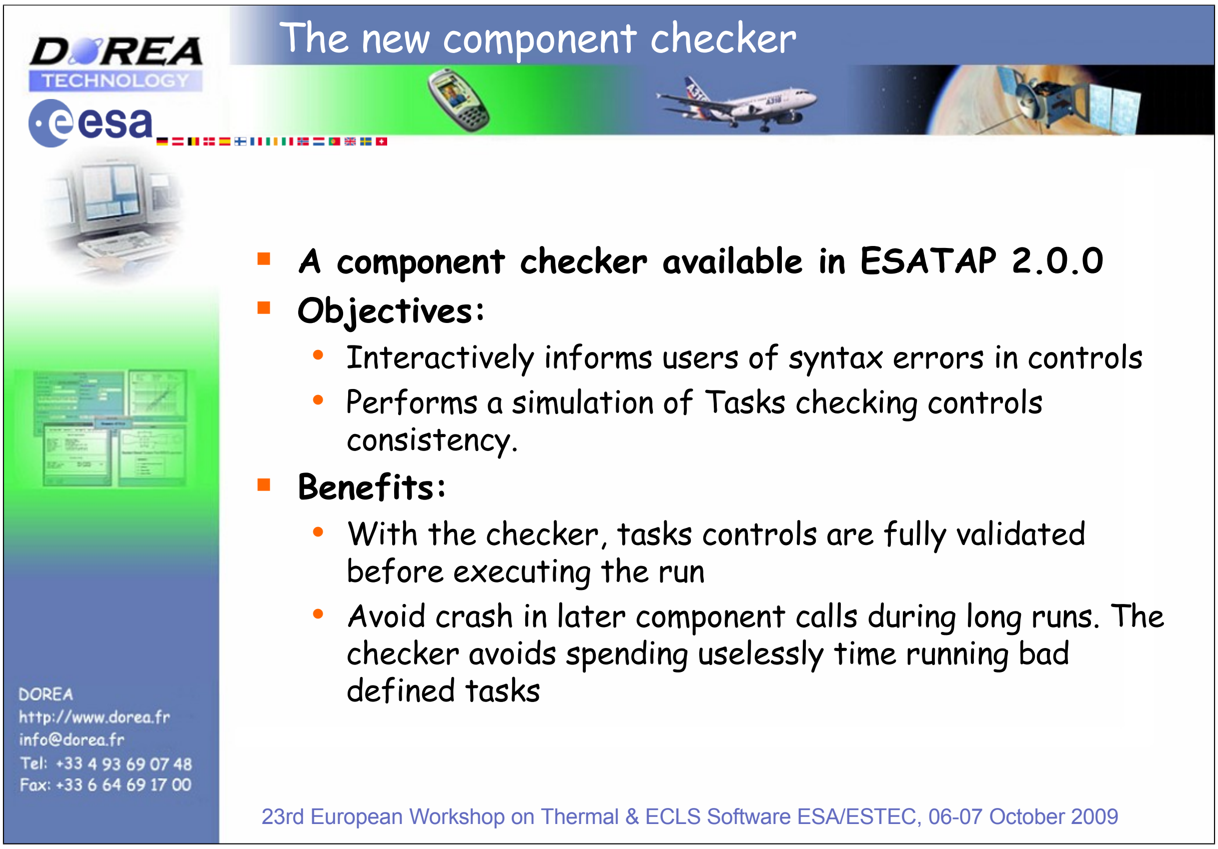
The new component checker
DOREA TECHNOLOGY
esa
A component checker available in ESATAP 2.0.0
Objectives:
Interactively informs users of syntax errors in controls
Performs a simulation of Tasks checking controls consistency.
Benefits:
With the checker, tasks controls are fully validated before executing the run
Avoid crash in later component calls during long runs. The checker avoids spending uselessly time running bad defined tasks
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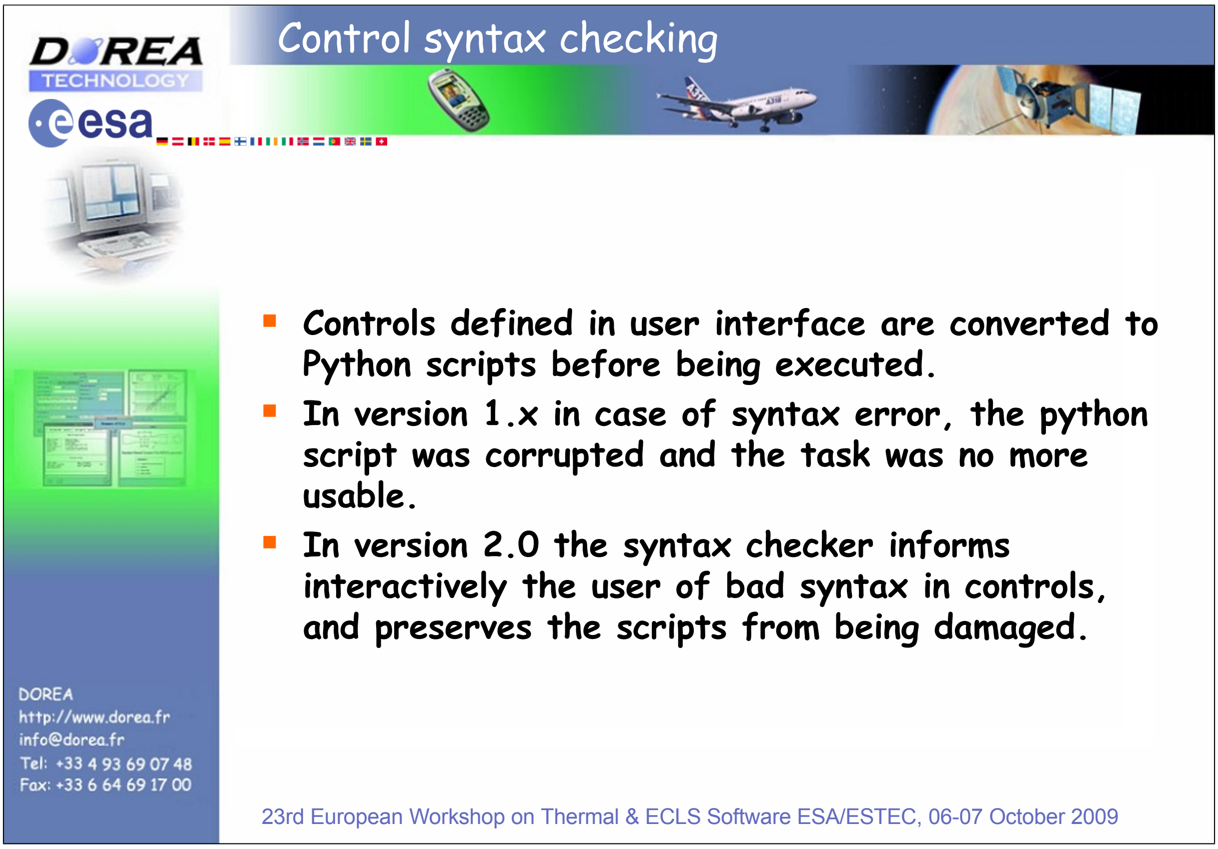
Control syntax checking
DOREA TECHNOLOGY
esa
Controls defined in user interface are converted to Python scripts before being executed.
In version 1.x in case of syntax error, the python script was corrupted and the task was no more usable.
In version 2.0 the syntax checker informs interactively the user of bad syntax in controls, and preserves the scripts from being damaged.
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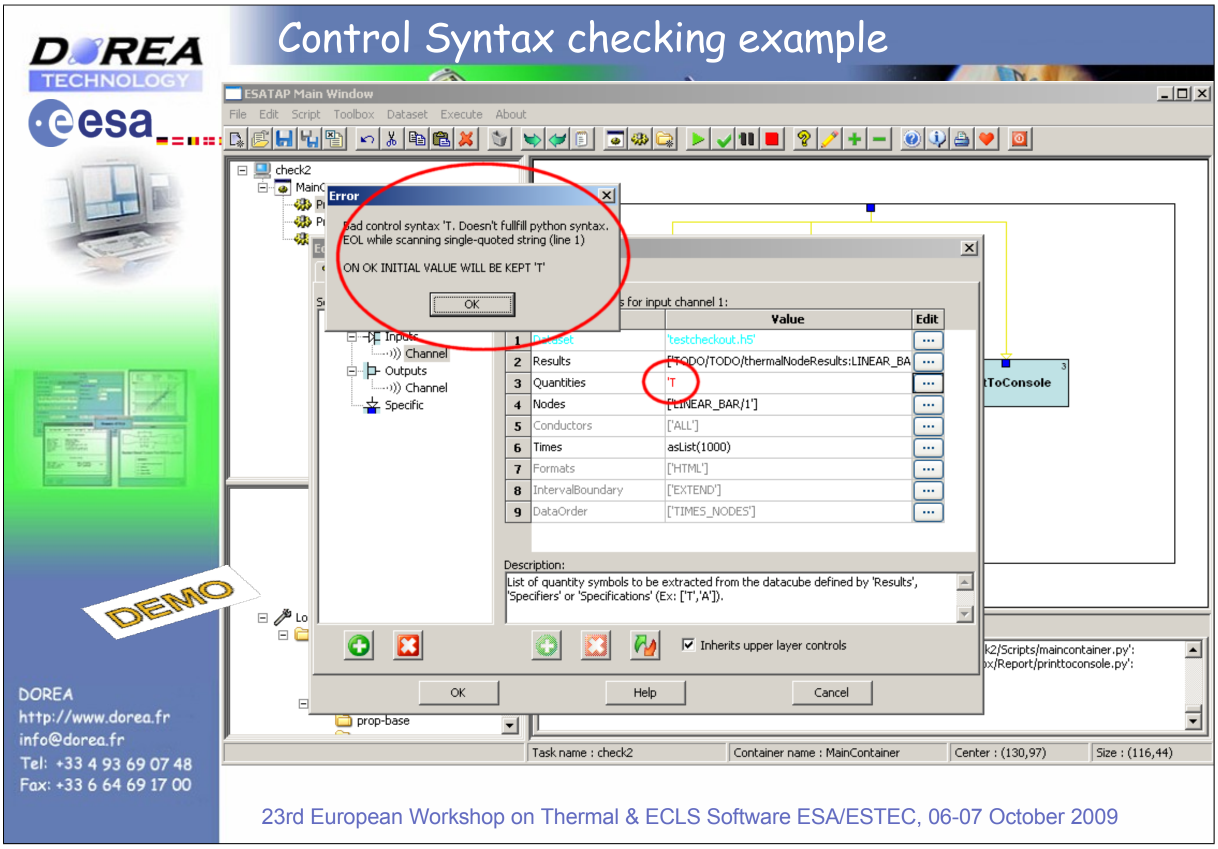

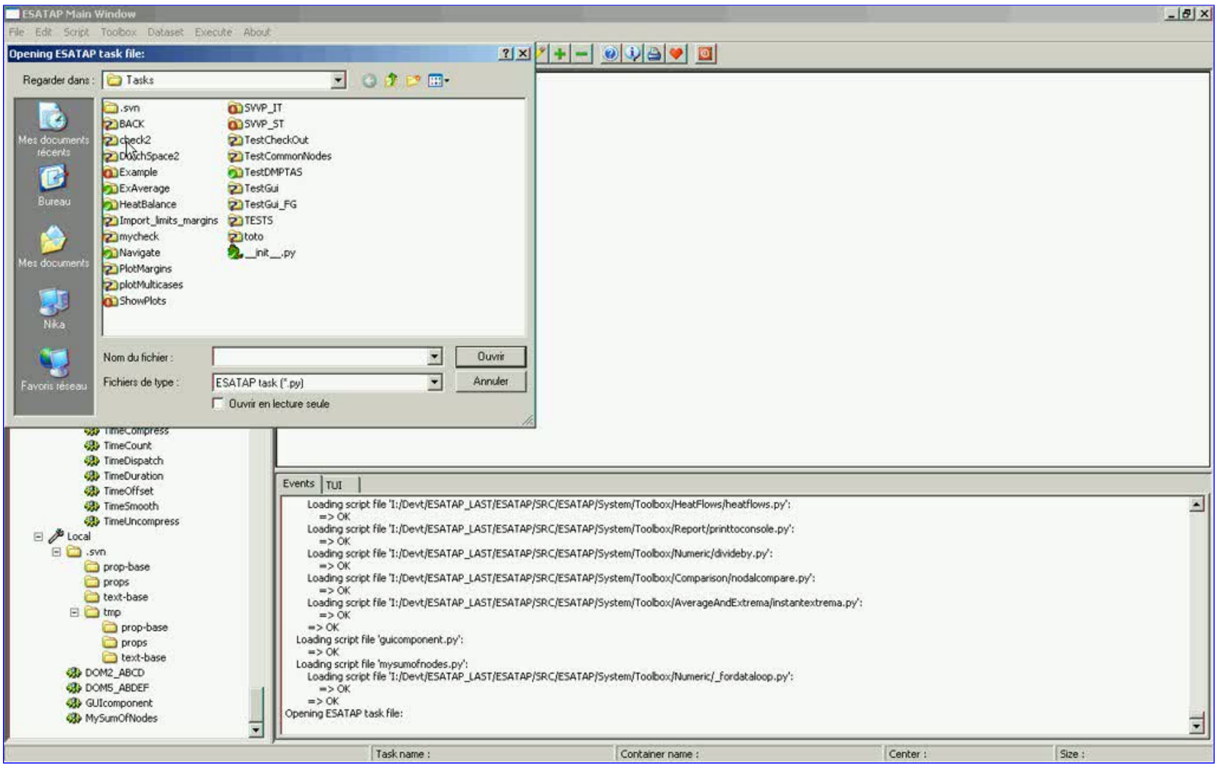

If clicking on the picture above does not run the movie then try opening the file ‘movies/check-syntax.html’ manually.

Control content checking

- **Some controls may be defined with inconsistent values:**
  - As regard as dataset content (ex. bad node number)
  - As regard as what a component is expecting (ex. Group of nodes)
- **In version 1.x, in case of entering bad content, the task stopped, but user time was wasted if the error occurred in later components calls.**
- **In version 2.0, a checking has been added prior to execute the task to validate consistency of all controls**
- **A simulation mode has been added to check a task without any execution.**

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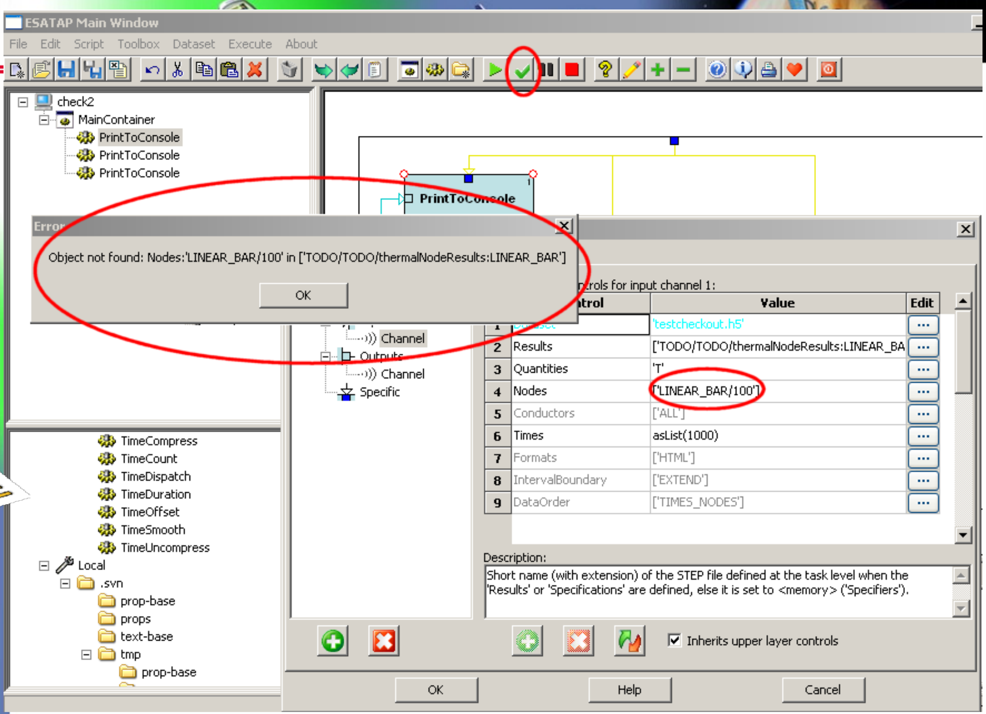
Control content Checking example



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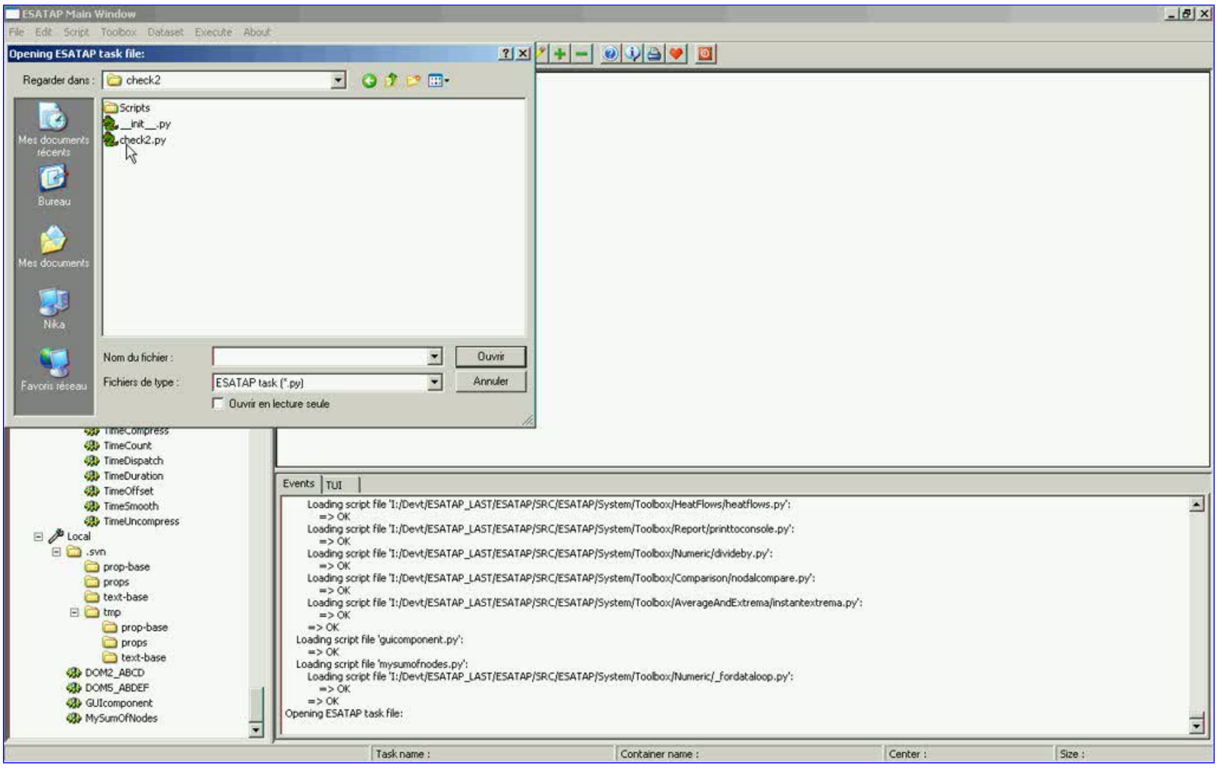
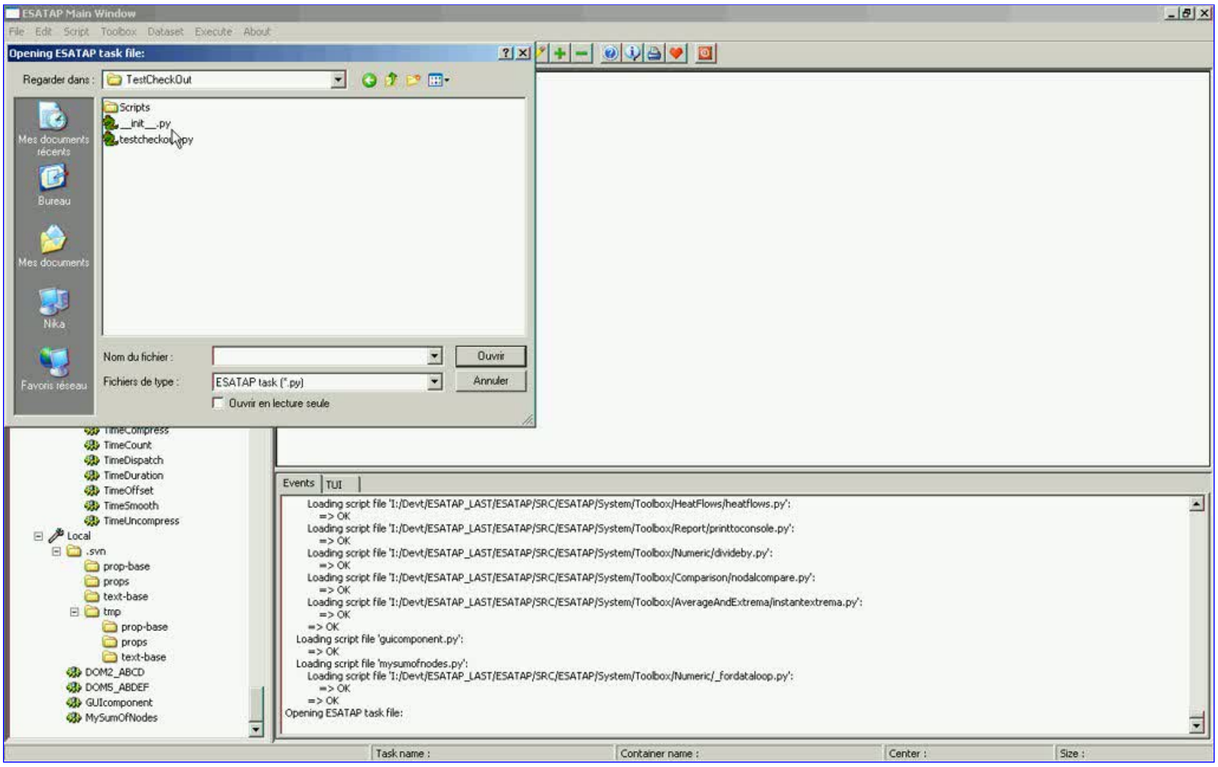
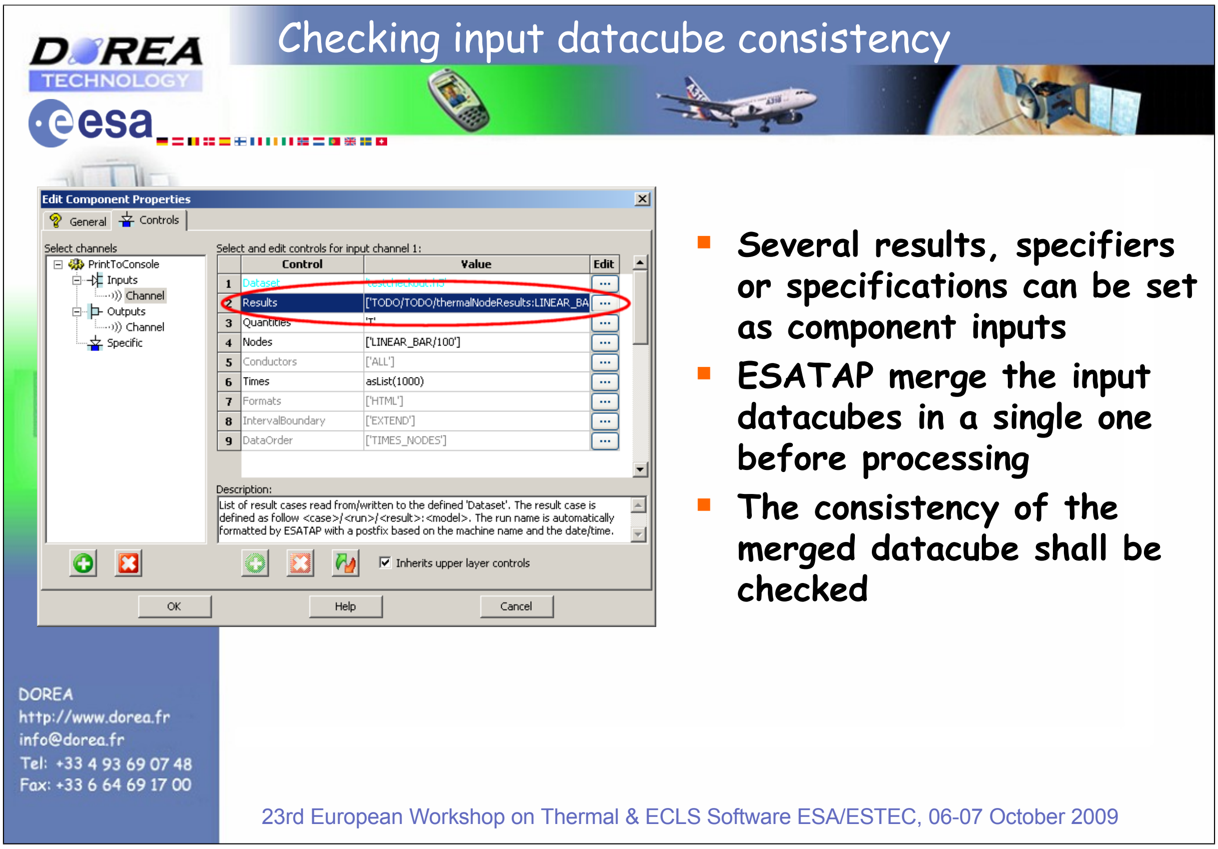


If clicking on the picture above does not run the movie then try opening the file ‘movies/check-Control-1.html’ manually.



If clicking on the picture above does not run the movie then try opening the file ‘movies/more-check.html’ manually.



Checking input datacube consistency
DOREA TECHNOLOGY
esa
Edit Component Properties
General
Controls
Select channels
PrintToConsole
Inputs
Channel
Outputs
Channel
Specific
Select and edit controls for input channel 1:
Control
Value
Edit
Results
['TODO/TODO/thermalNodeResults:LINEAR_BA
Quantities
Nodes
['LINEAR_BAR/100']
Conductors
['ALL']
Times
asList(1000)
Formats
['HTML']
IntervalBoundary
['EXTEND']
DataOrder
['TIMES_NODES']
Description:
List of result cases read from/written to the defined 'Dataset'. The result case is defined as follow <case>/<run>/<result>:<model>. The run name is automatically formatted by ESATAP with a postfix based on the machine name and the date/time.
Inherits upper layer controls
OK
Help
Cancel
Several results, specifiers or specifications can be set as component inputs
ESATAP merge the input datacubes in a single one before processing
The consistency of the merged datacube shall be checked
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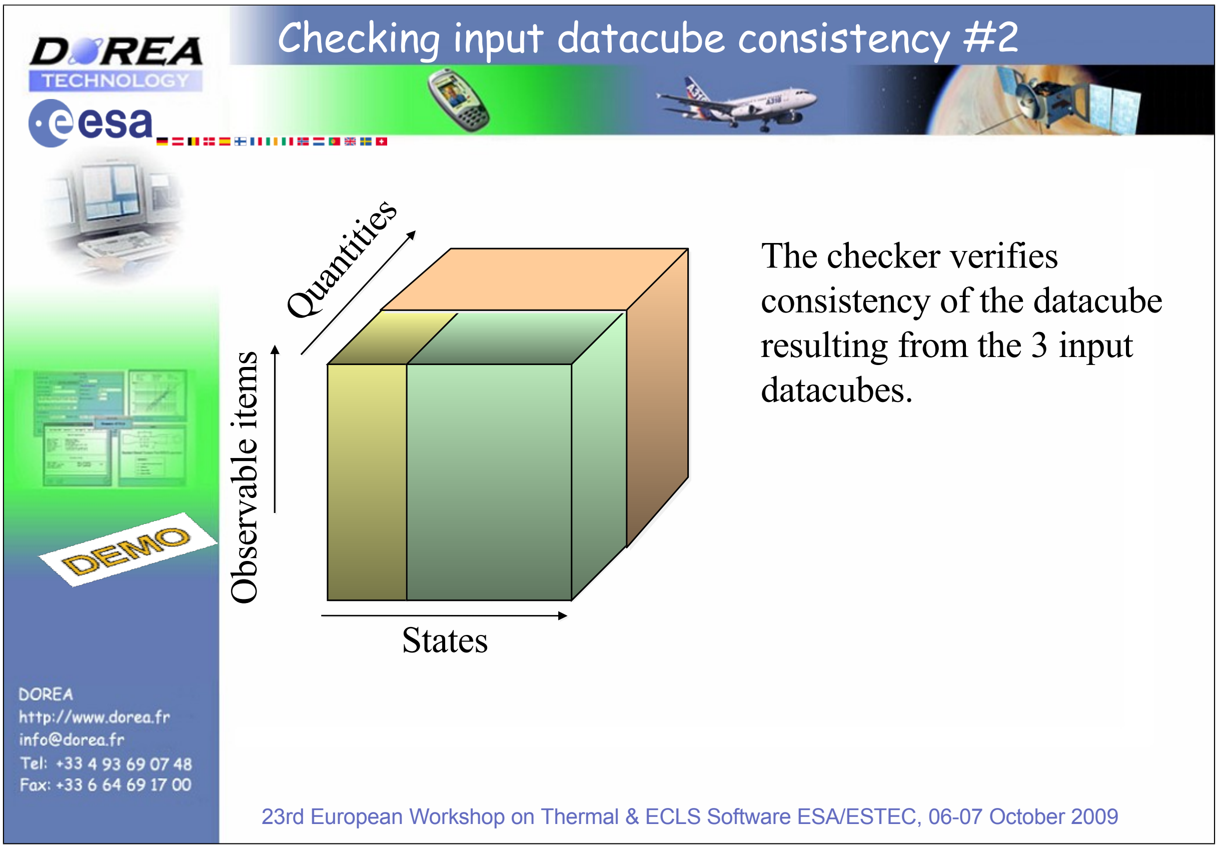

Checking input datacube consistency #2
DOREA TECHNOLOGY
esa
DEMO
Quantities
Observable items
States
The checker verifies consistency of the datacube resulting from the 3 input datacubes.
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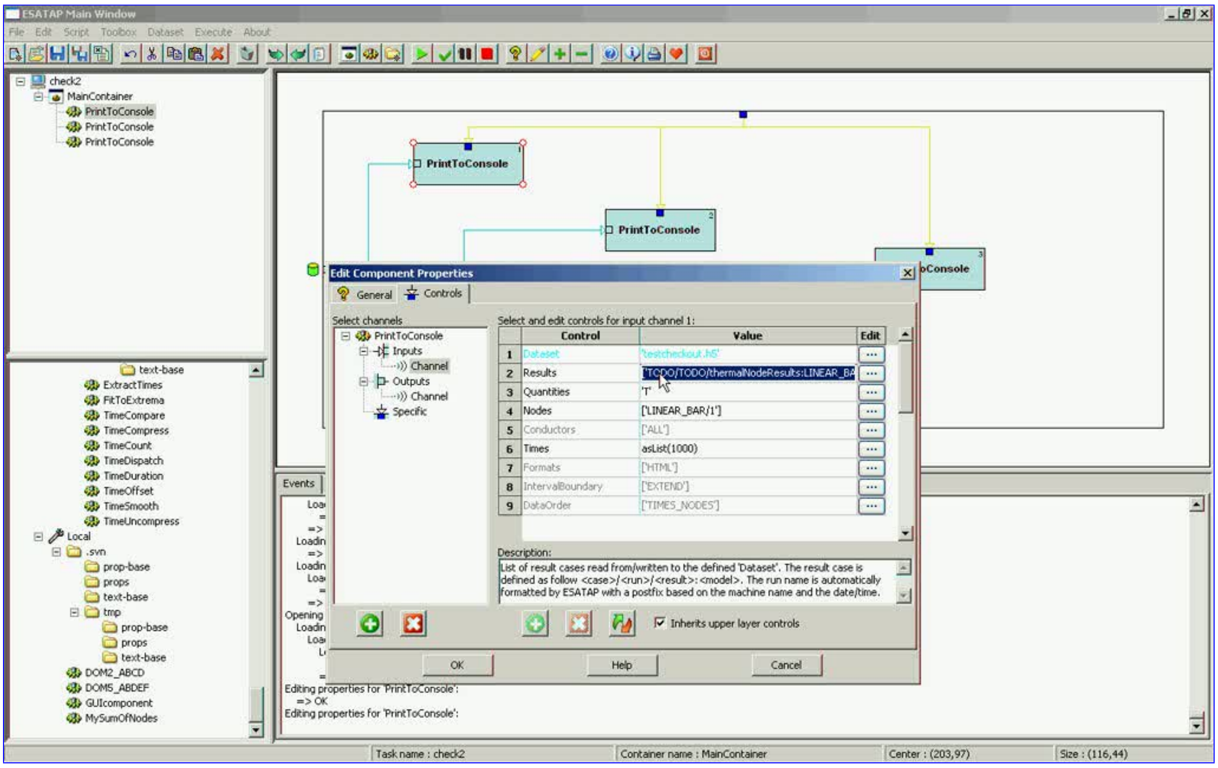
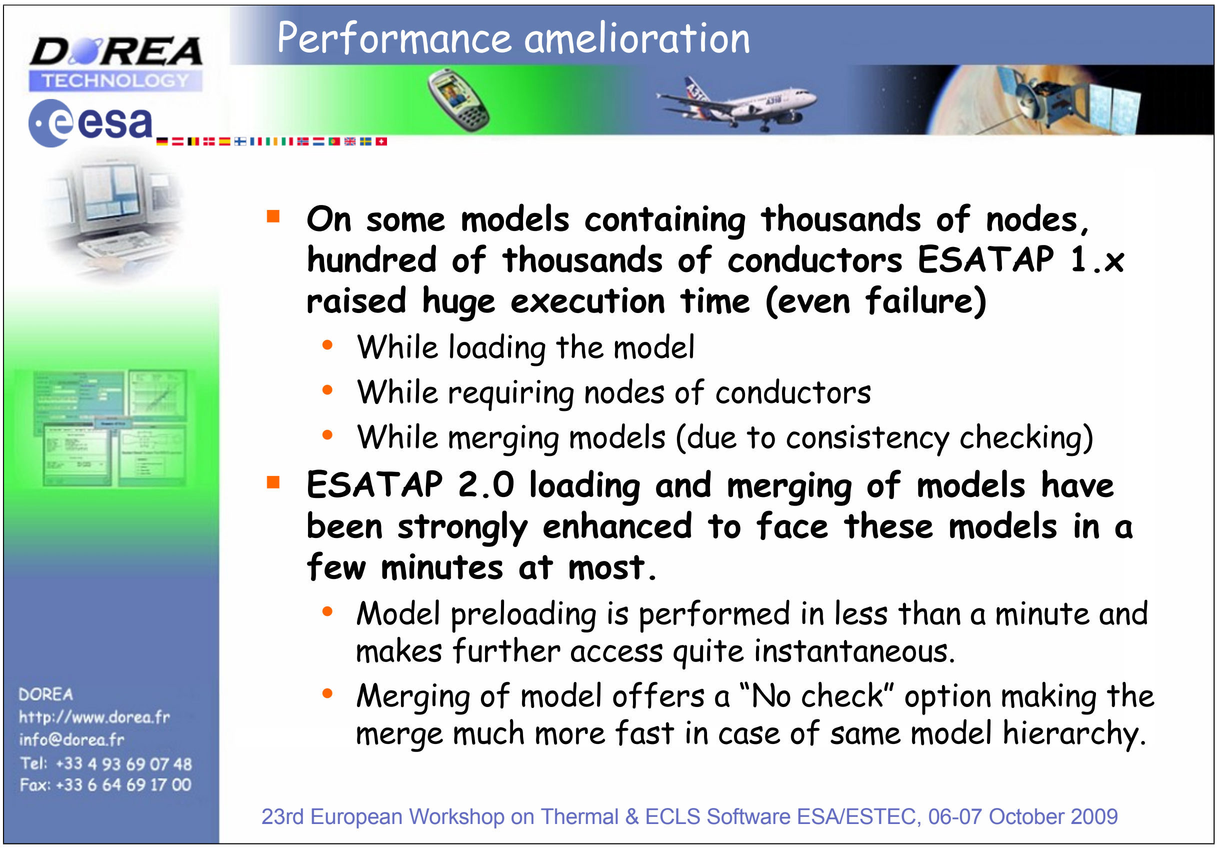
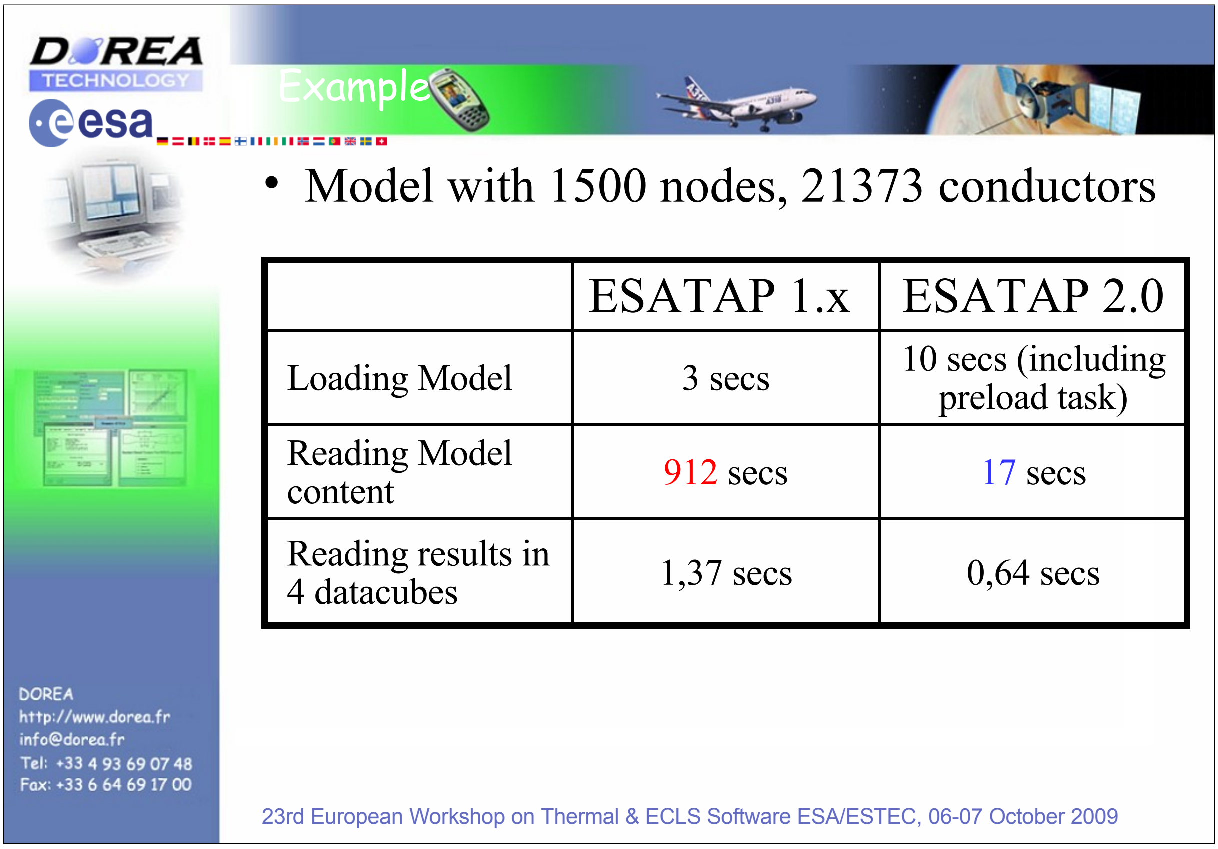


If clicking on the picture above does not run the movie then try opening the file ‘movies/check-datacube-consistent.html’ manually.




DOREA TECHNOLOGY
esa
Example
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Fax: +33 6 64 69 17 00
• Model with 1500 nodes, 21373 conductors

	ESATAP 1.x	ESATAP 2.0
Loading Model	3 secs	10 secs (including preload task)
Reading Model content	912 secs	17 secs
Reading results in 4 datacubes	1,37 secs	0,64 secs

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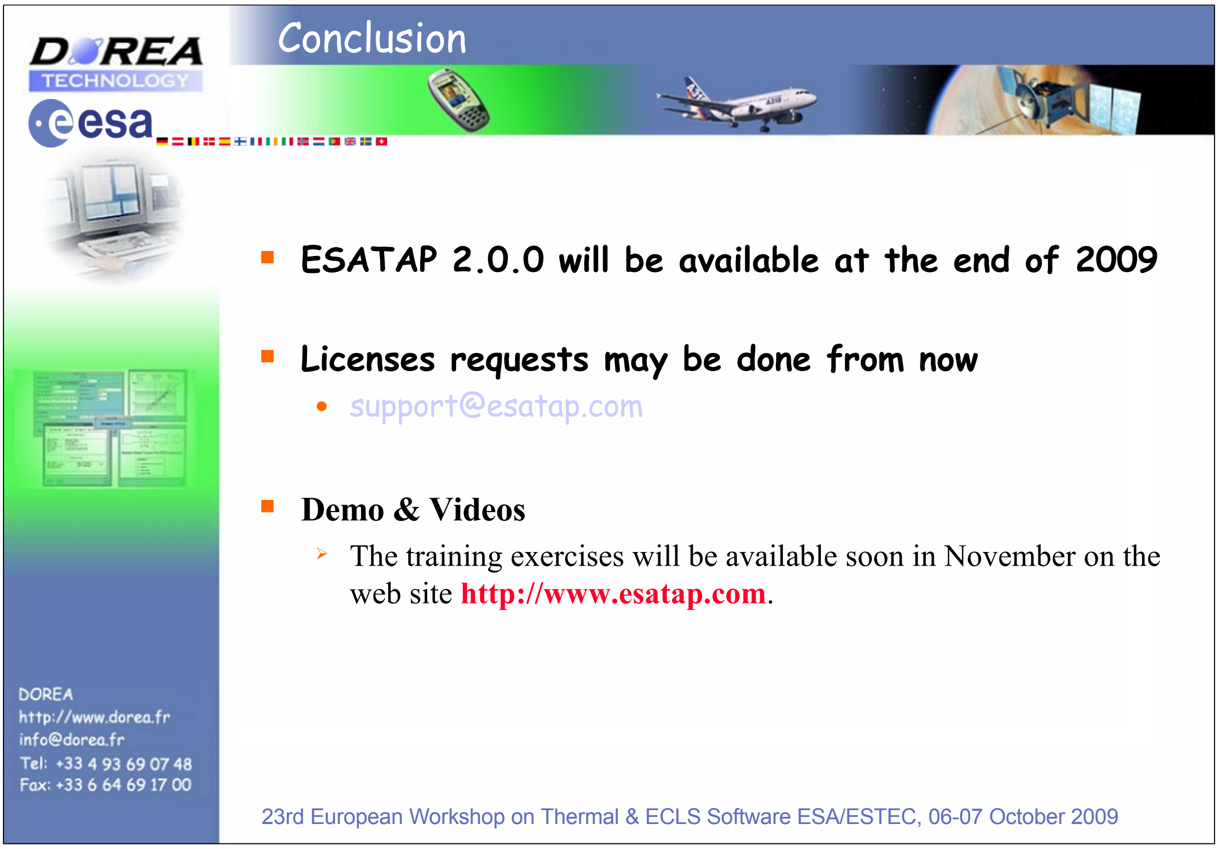
DOREA TECHNOLOGY
esa
Conclusion
DOREA
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Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
ESATAP 2.0.0 will be available at the end of 2009
Licenses requests may be done from now
support@esatap.com
Demo & Videos
The training exercises will be available soon in November on the web site http://www.esatap.com.
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Appendix R

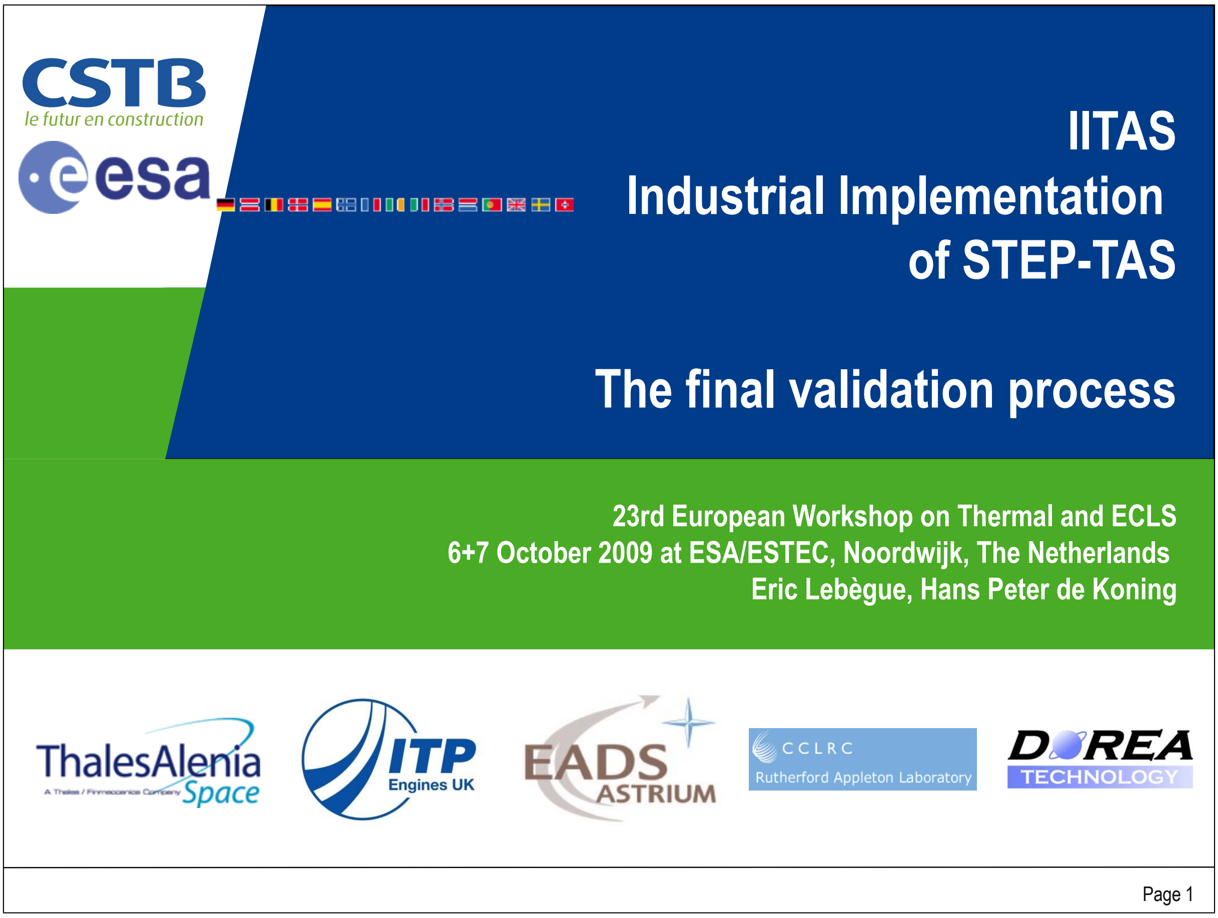
Final validation phases of the IITAS project for Industrial Implementation of STEP-TAS

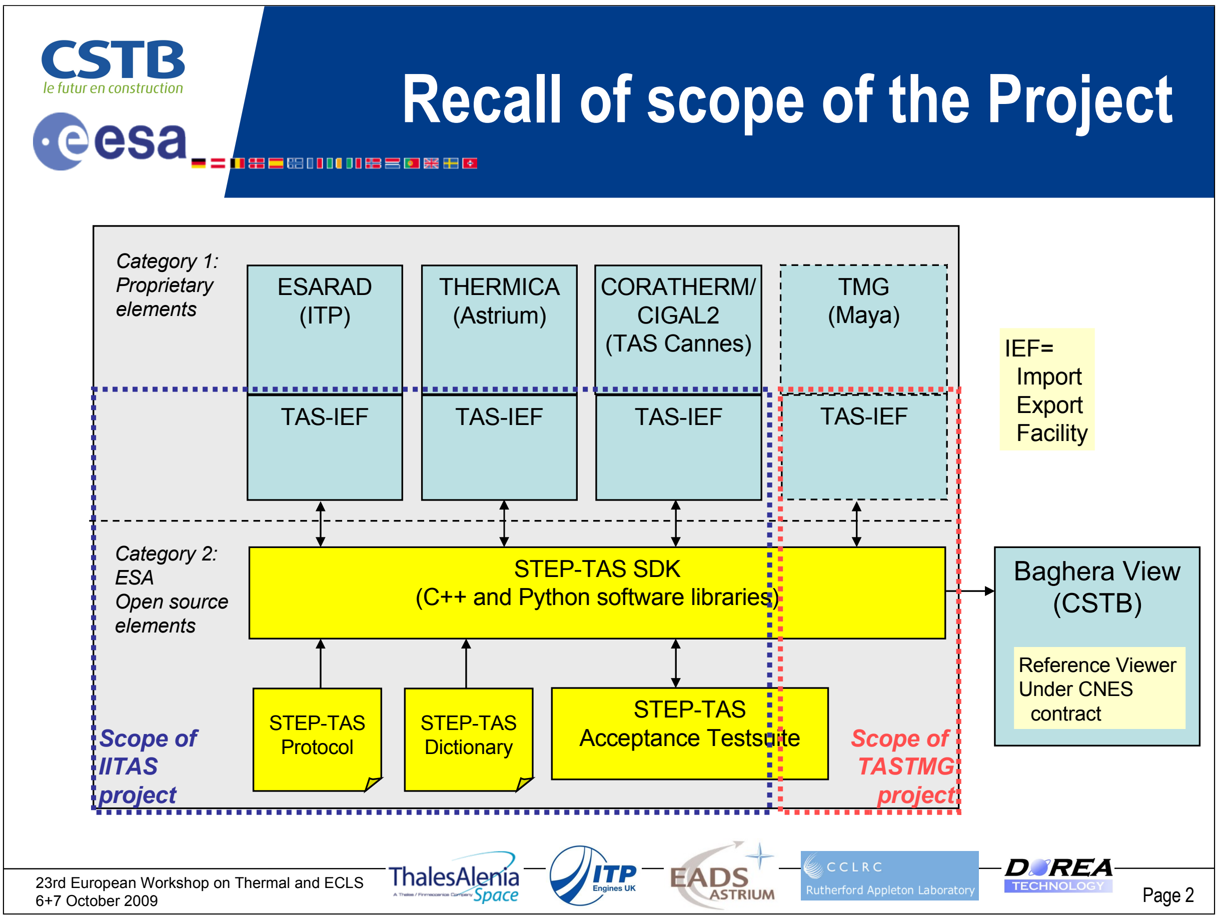
Eric Lebègue
(CSTB, France)

Hans Peter de Koning
(ESA/ESTEC, The Netherlands)

Abstract

This presentation presents the status of the industrial STEP-TAS converters integrated within ESARAD, THERMICA and CIGAL2. It presents the final phases of the IITAS project with particular focus on the validation performed by Astrium, ITP, Thales Alenia Space, Dorea, CSTB and ESA and based on automatic and manual validation.


CSTB
le futur en construction
esa
IITAS
Industrial Implementation
of STEP-TAS
The final validation process
23rd European Workshop on Thermal and ECLS
6+7 October 2009 at ESA/ESTEC, Noordwijk, The Netherlands
Eric Lebègue, Hans Peter de Koning
ThalesAlenia Space
ITP Engines UK
EADS ASTRIUM
CCLRC Rutherford Appleton Laboratory
DOREA TECHNOLOGY
Page 1


CSTB
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esa
Recall of scope of the Project
Category 1: Proprietary elements
ESARAD (ITP)
THERMICA (Astrium)
CORATHERM/ CIGAL2 (TAS Cannes)
TMG (Maya)
TAS-IEF
TAS-IEF
TAS-IEF
TAS-IEF
IEF= Import Export Facility
Category 2: ESA Open source elements
STEP-TAS SDK (C++ and Python software libraries)
Baghera View (CSTB)
Reference Viewer Under CNES contract
STEP-TAS Protocol
STEP-TAS Dictionary
STEP-TAS Acceptance Testsuite
Scope of IITAS project
Scope of TASTMG project
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Page 2

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esa

Validation procedures

- **Acceptance Testsuite (ESA validated STEP-TAS files)**
  - 140 unit test cases
  - + 3 industrial representative models
    - "RALSAT" modelled in ESARAD by RAL
    - "AS1SAT" modelled in THERMICA by Astrium Satellites (Friedrichshafen)
    - "TASSAT" modelled in CIGAL2 by Thales Alenia Space (Cannes)
- **Automatic validation**
  - STEP-TAS syntax validation
  - Image (screenshot) comparisons – produced by Baghera View in batch mode
- **Manual validation**
  - Cross-tool import and checking of the industrial test models

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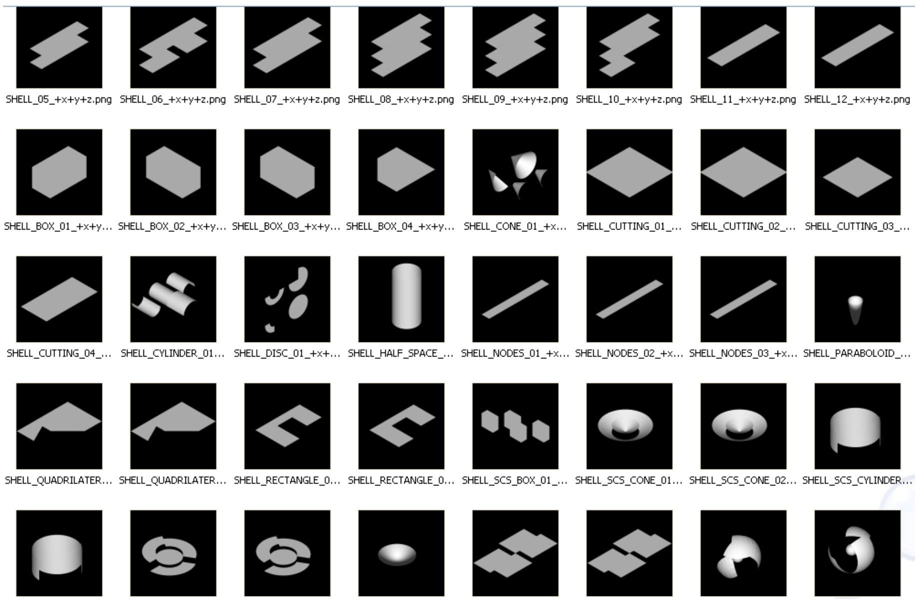
Unit test cases



...

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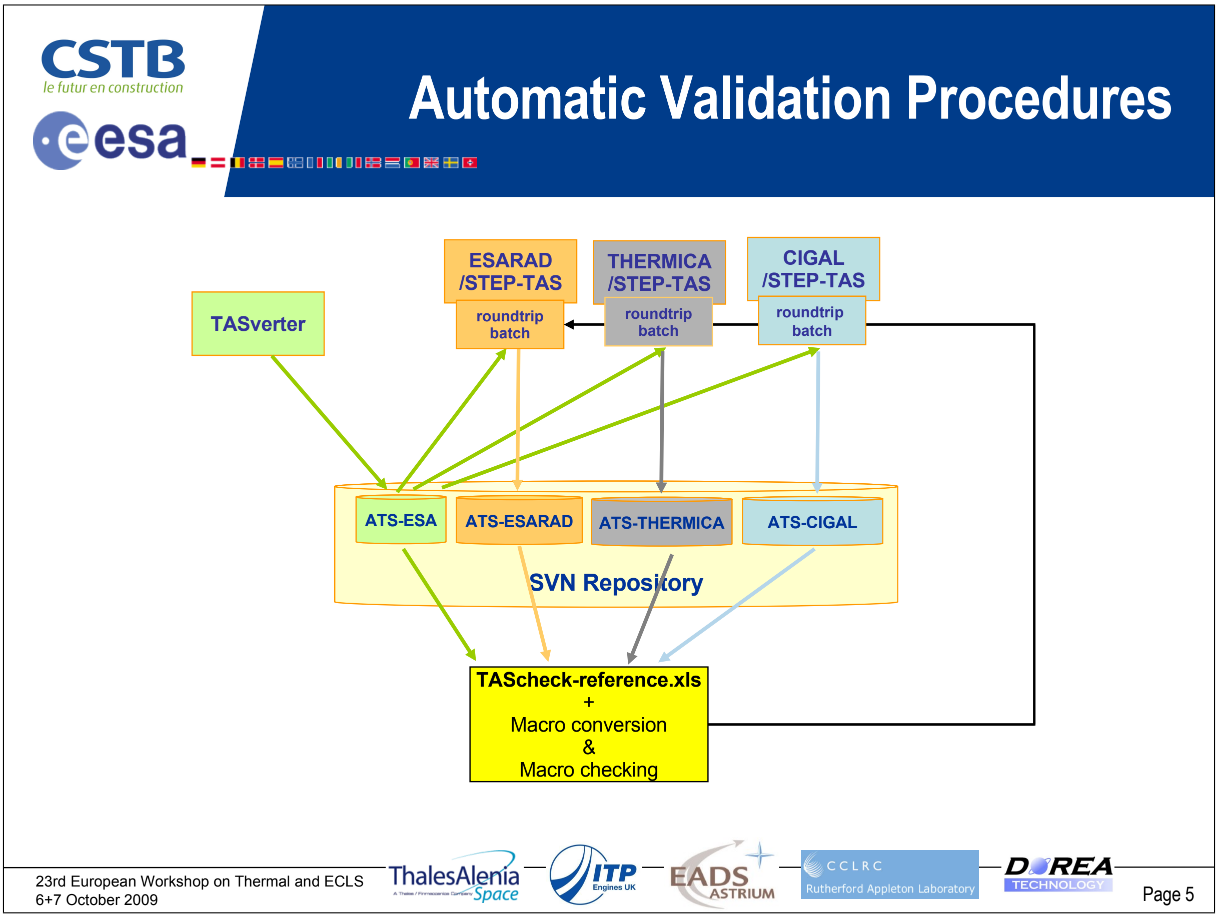
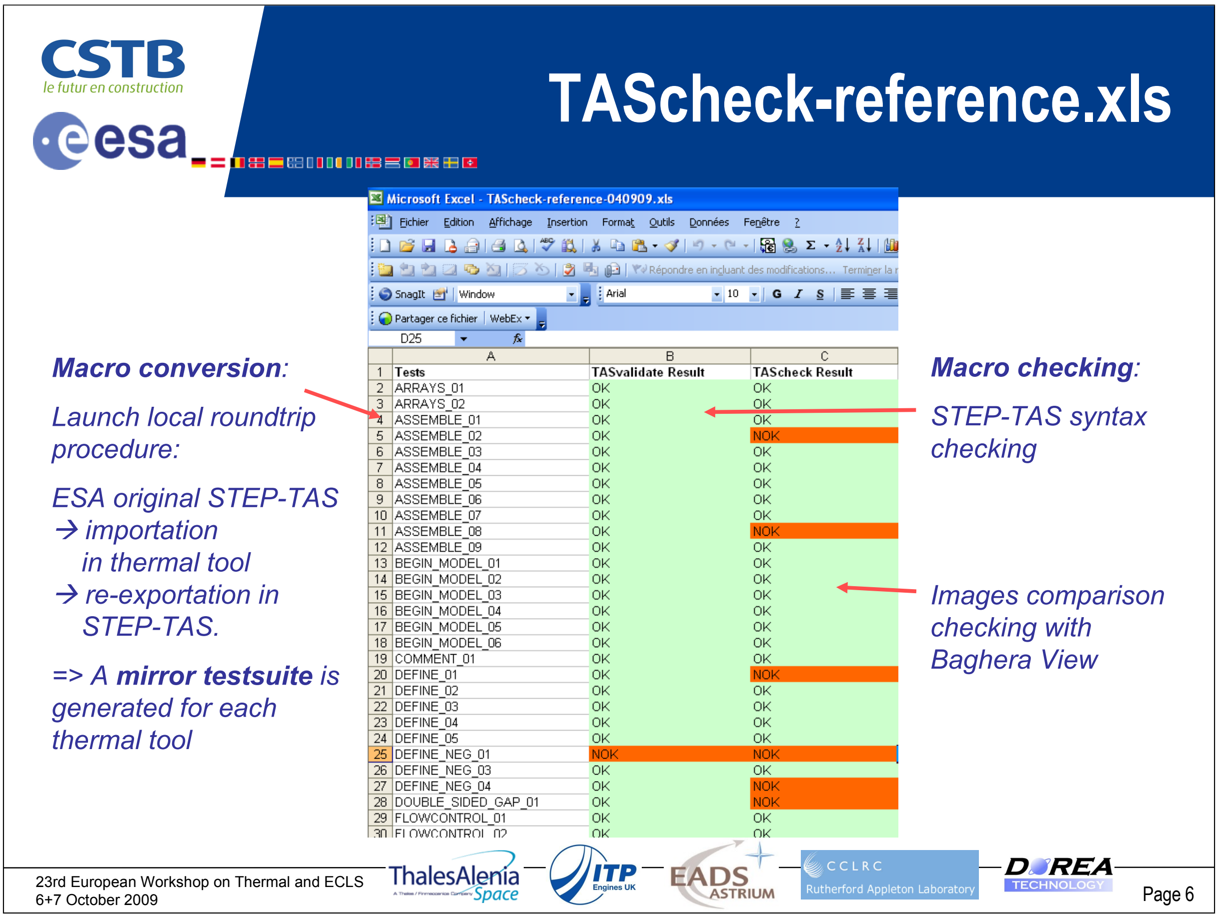
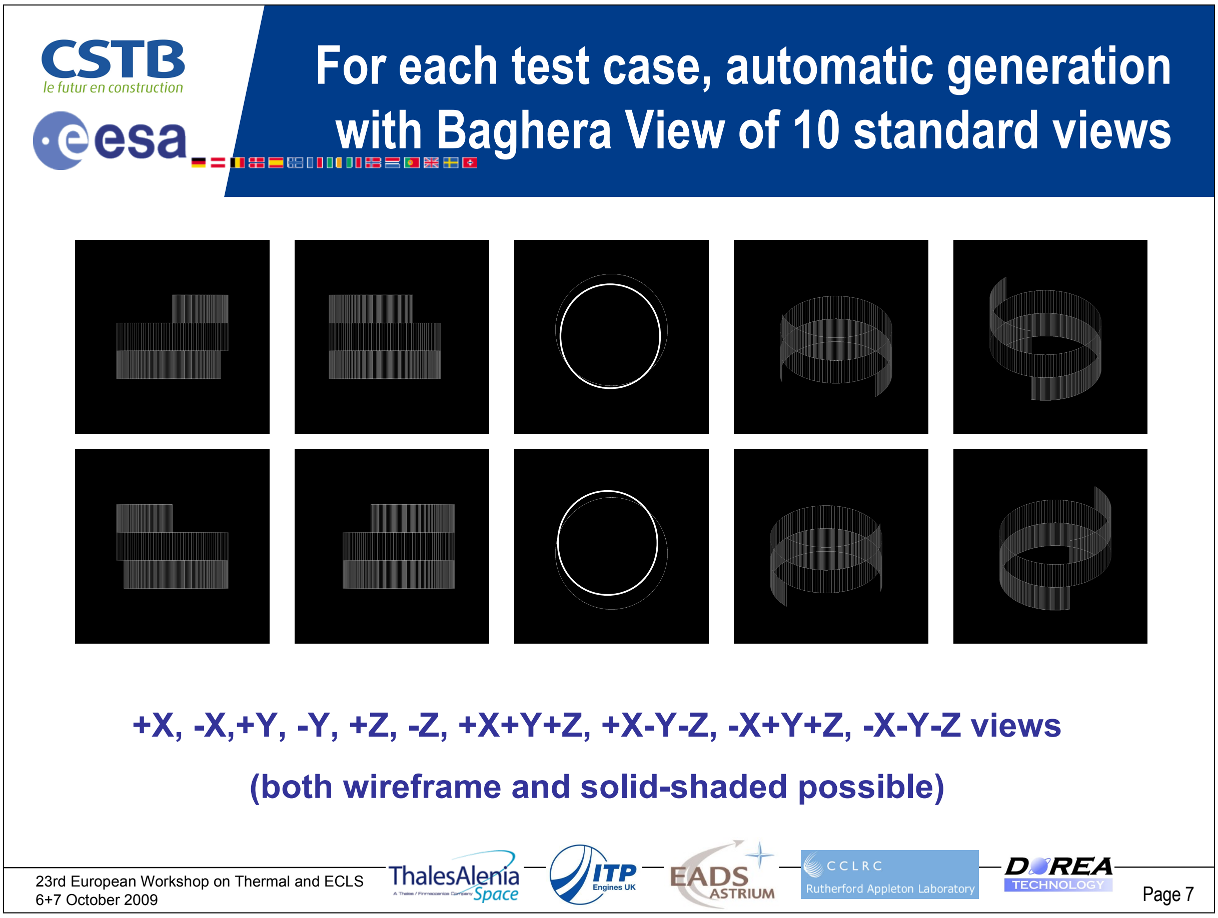
Page 4





	A	B	C
1	Tests	TASvalidate Result	TAScheck Result
2	ARRAYS_01	OK	OK
3	ARRAYS_02	OK	OK
4	ASSEMBLE_01	OK	OK
5	ASSEMBLE_02	OK	NOK
6	ASSEMBLE_03	OK	OK
7	ASSEMBLE_04	OK	OK
8	ASSEMBLE_05	OK	OK
9	ASSEMBLE_06	OK	OK
10	ASSEMBLE_07	OK	OK
11	ASSEMBLE_08	OK	NOK
12	ASSEMBLE_09	OK	OK
13	BEGIN_MODEL_01	OK	OK
14	BEGIN_MODEL_02	OK	OK
15	BEGIN_MODEL_03	OK	OK
16	BEGIN_MODEL_04	OK	OK
17	BEGIN_MODEL_05	OK	OK
18	BEGIN_MODEL_06	OK	OK
19	COMMENT_01	OK	OK
20	DEFINE_01	OK	NOK
21	DEFINE_02	OK	OK
22	DEFINE_03	OK	OK
23	DEFINE_04	OK	OK
24	DEFINE_05	OK	OK
25	DEFINE_NEG_01	NOK	NOK
26	DEFINE_NEG_03	OK	OK
27	DEFINE_NEG_04	OK	NOK
28	DOUBLE_SIDED_GAP_01	OK	NOK
29	FLOWCONTROL_01	OK	OK
30	FLOWCONTROL_02	OK	OK


CSTB
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esa
For each test case, automatic generation with Baghera View of 10 standard views
+X, -X,+Y, -Y, +Z, -Z, +X+Y+Z, +X-Y-Z, -X+Y+Z, -X-Y-Z views
(both wireframe and solid-shaded possible)
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6+7 October 2009
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ITP Engines UK
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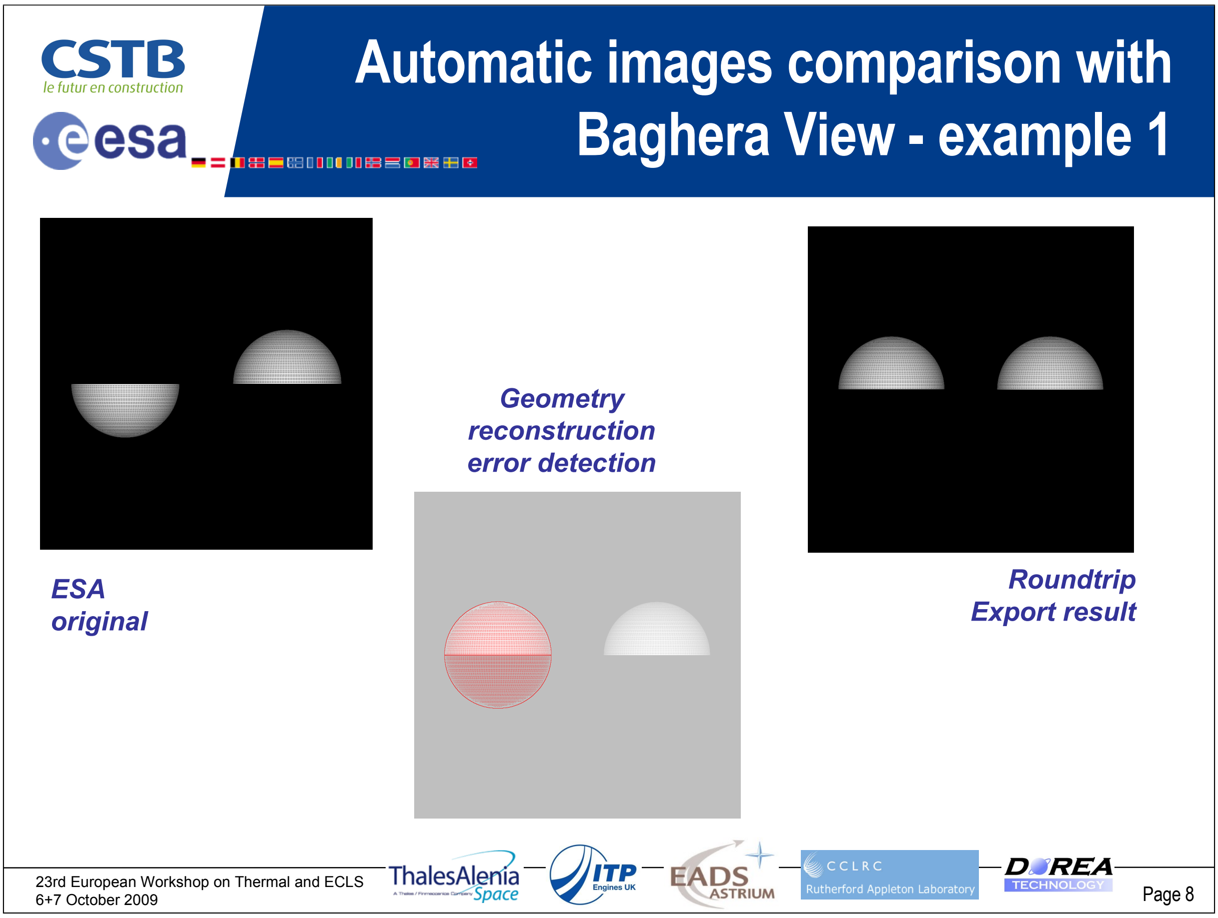
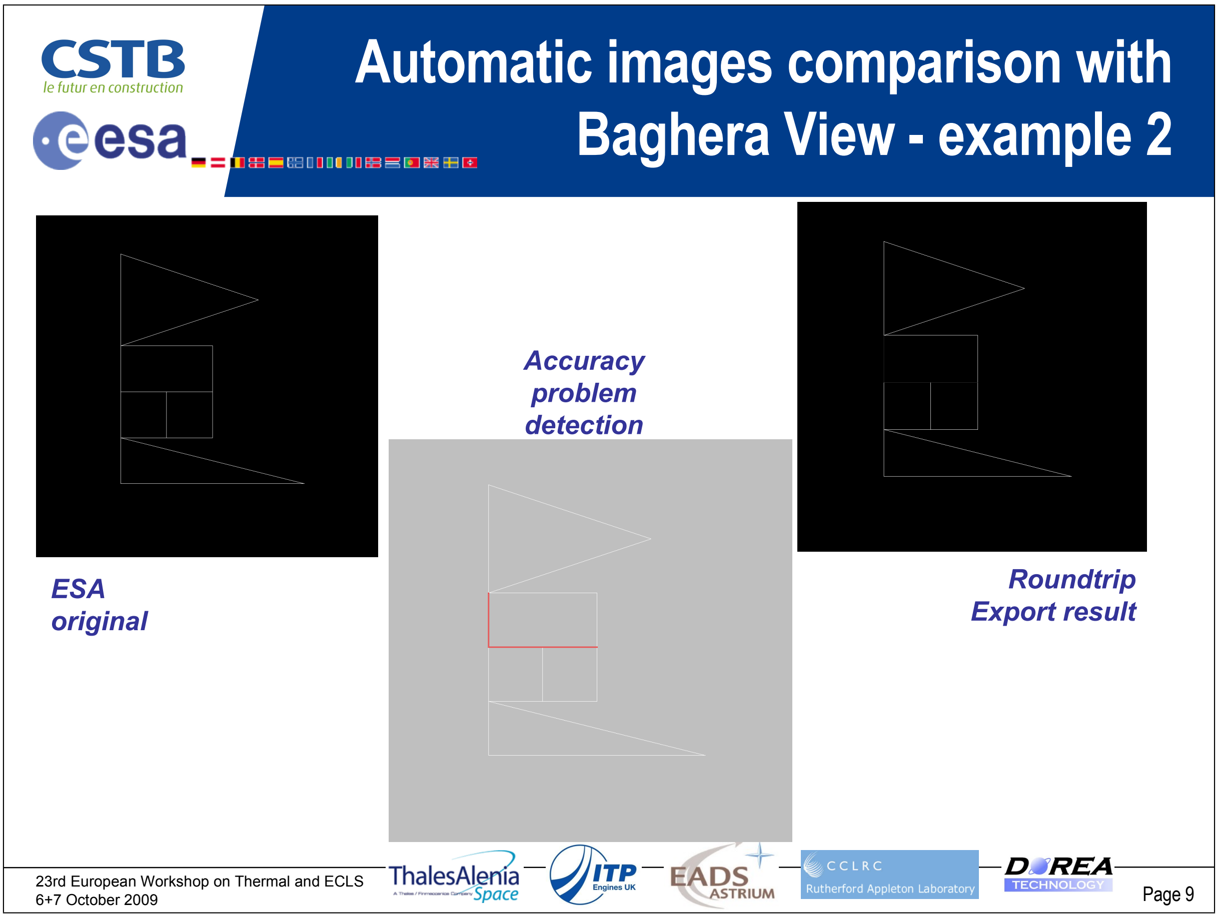
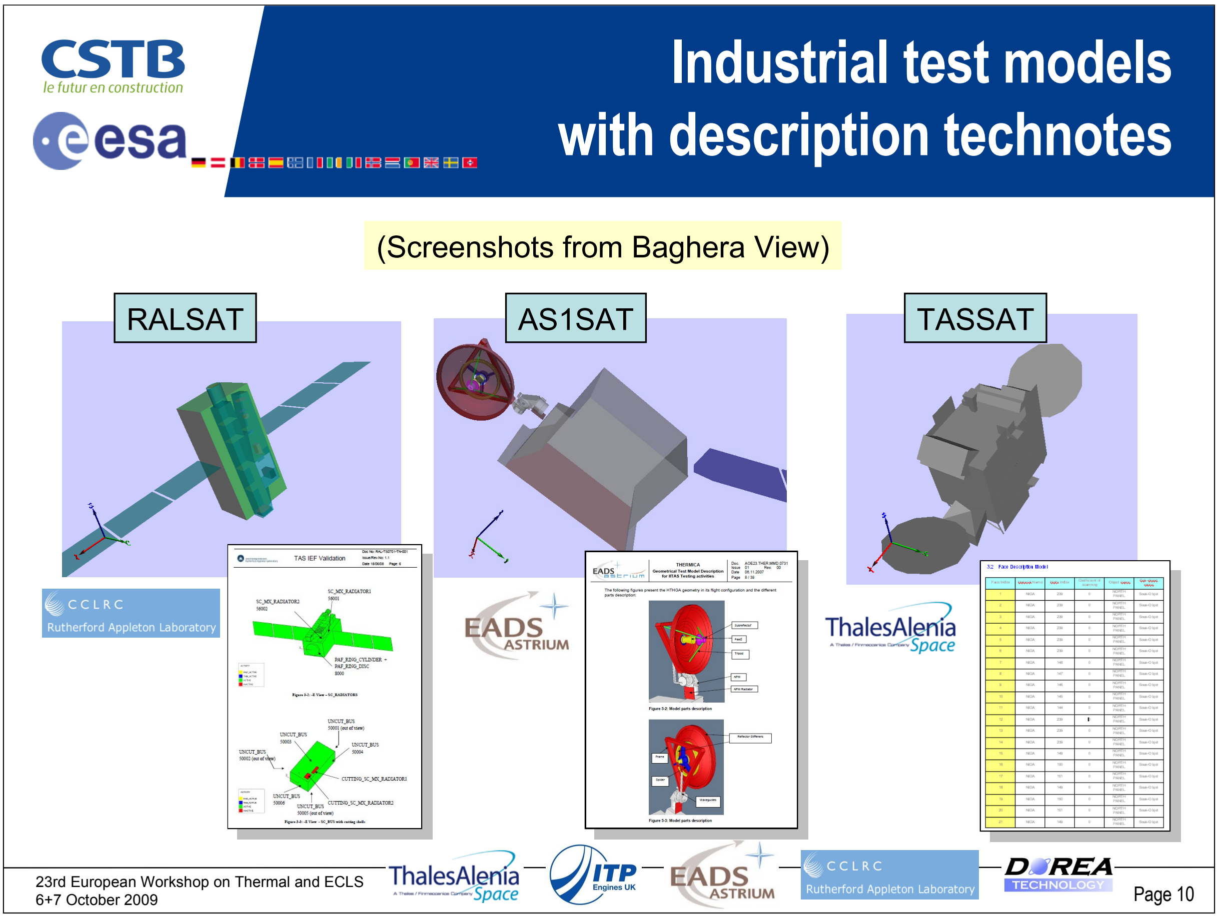
DOREA TECHNOLOGY
Page 7


CSTB
le futur en construction
esa
Automatic images comparison with Baghera View - example 1
ESA original
Geometry reconstruction error detection
Roundtrip Export result
23rd European Workshop on Thermal and ECLS
6+7 October 2009
ThalesAlenia Space
ITP Engines UK
EADS ASTRIUM
CCLRC Rutherford Appleton Laboratory
DOREA TECHNOLOGY
Page 8


CSTB
le futur en construction
esa
Automatic images comparison with Baghera View - example 2
Accuracy problem detection
ESA original
Roundtrip Export result
23rd European Workshop on Thermal and ECLS
6+7 October 2009
Page 9


CSTB
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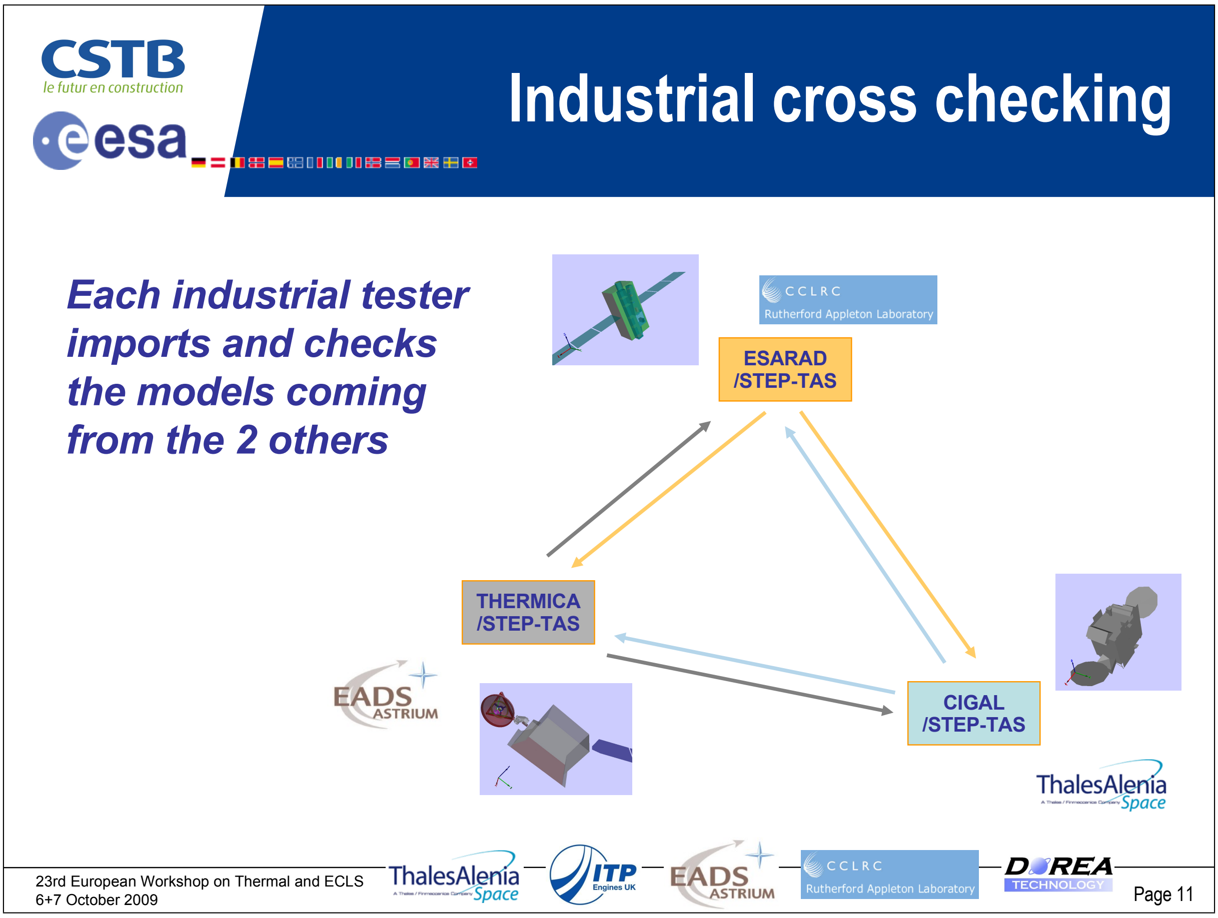
esa
Industrial test models with description technotes
(Screenshots from Baghera View)
RALSAT
AS1SAT
TASSAT
23rd European Workshop on Thermal and ECLS
6+7 October 2009
Page 10


CSTB
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esa
Industrial cross checking
Each industrial tester imports and checks the models coming from the 2 others
CCLRC
Rutherford Appleton Laboratory
ESARAD /STEP-TAS
THERMICA /STEP-TAS
CIGAL /STEP-TAS
EADS ASTRIUM
ThalesAlenia Space
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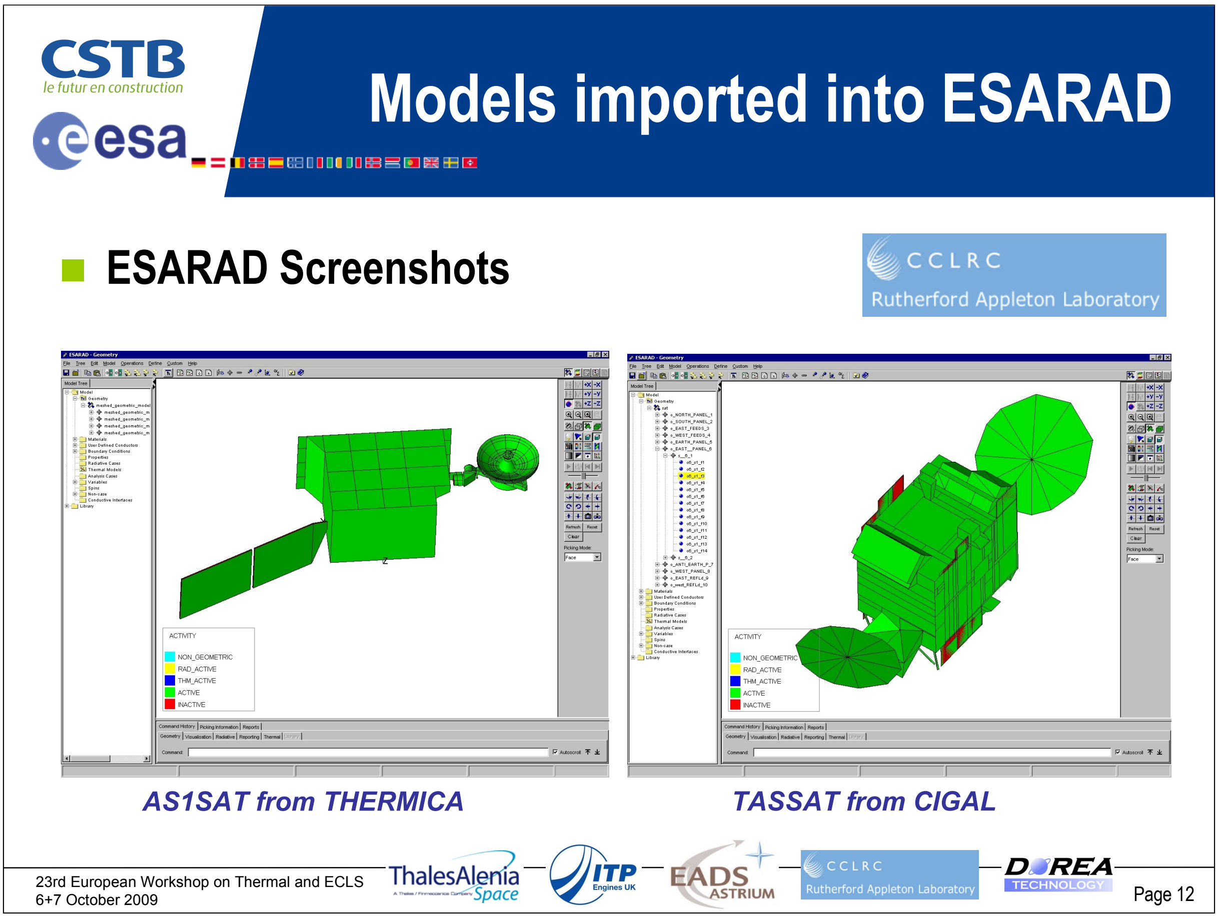
CSTB
le futur en construction
esa
Models imported into ESARAD
ESARAD Screenshots
CCLRC
Rutherford Appleton Laboratory
AS1SAT from THERMICA
TASSAT from CIGAL
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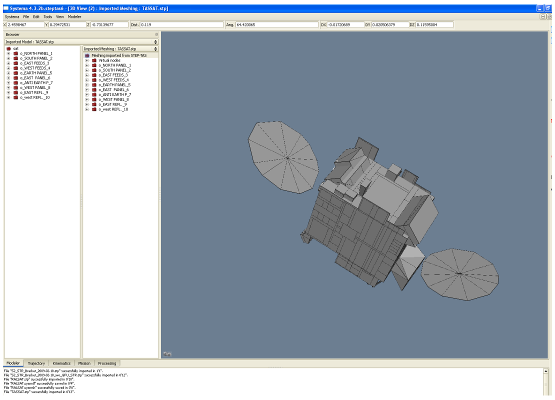
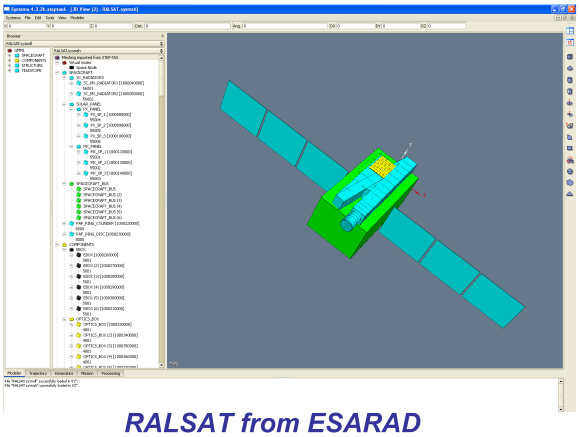
Models imported into THERMICA

- THERMICA Screenshots

EADS ASTRIUM



TASSAT from CIGAL



RALSAT from ESARAD

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Models imported into CIGAL

- CIGAL Screenshots

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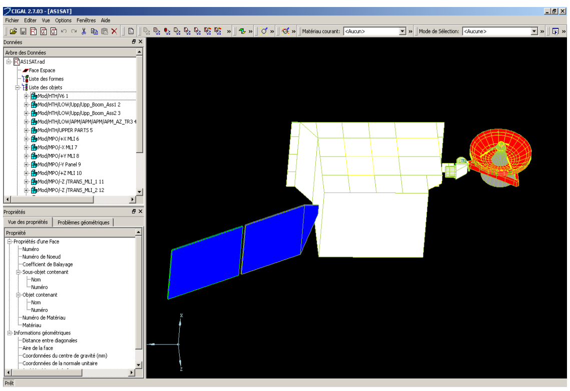

AS1SAT from THERMICA

Did not succeed yet

RALSAT from ESARAD

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Current status w.r.t. planning presented last year

Completion of IITAS and IITAS-TMG ▪Emphasis on testing and obtaining robustness of imports/exports	IITAS will be completed this year, for GMM / geometric model (CC1 and CC3). TASTMG progressing well, will complete early 2010 at same level as IITAS.
Full validation of STEP-TAS Kinematics and Mission Aspects	Validated by ESA using ESARAD. Will not be implemented by vendors in current IITAS. Effort cannot be accommodated in current contract.
First validation STEP-TAS for TMMs (ESATAN, SINDA, …) ▪Model structure basically done under ESATAP ▪Includes approach to exchange user defined logic (MORTRAN, …)	Proof of concept done with DOREA. All needed technology in place: ESATAN and SINDA MORTRAN parsers, neutral representation of algorithms in STEP-TAS. Expect implementation in 2010.
Formalisation of STEP-NRF/TAS under ISO TC184/SC4 ▪Was planned for 2008 but put on-hold due to lack of resources – shifted to 2009	Not started yet. Looking for internal resources to complete this in 2010.
Support continuation of STEP-TAS for Thermal Desktop with C&R and NASA (hopefully)	No news yet. Talks with NASA/JPL resume in November.
Consolidate support software and test suites as true open source software ▪Depending on ESA open source software policy that is currently being finalised	Depends on ESA OSS Policy. Initial policy formulated and accepted by IPC. For time being will continue with ad-hoc repository and provide access on case-by-case basis.

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Teams

IITAS

- **CSTB**
  - Eric Lebègue, Mathieu Marache, Elisa Ciuti
- **ITP Engines UK**
  - John Hurdle, Henri Brouquet
- **Astrium Satellites (Toulouse)**
  - Timothée Soriano, Marc Baucher, Mehdi Hanna
- **Thales Alenia Space (Cannes)**
  - Thierry Basset
- **Rutherford Appleton Laboratory**
  - Bryan Shaughnessy, Olly Poyntz-Wright
- **Astrium Satellites (Friedrichshafen)**
  - Gerd Jahn, Raphael Naire, Jens-Oliver Fischer
- **DOREA**
  - Francois Brunetti, Alain Fagot, Sandrine Leroy

TASTMG

- Maya Heat Transfer Technologies
  - Mouloud Bourbel, Christian Ruel
- Astrium Space Transport (Bremen)
  - Harald Rathjen, Burkhard Behrens

- ESA
  - Hans Peter de Koning, Duncan Gibson

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Appendix S

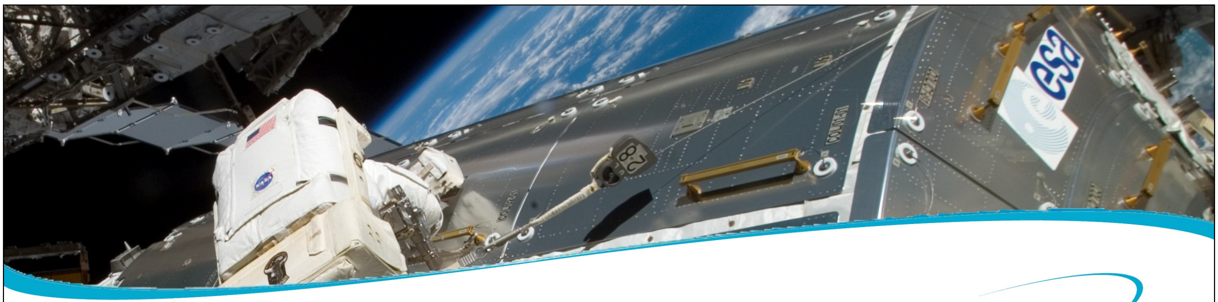
Mathematical models for the Columbus engineering support team

Savino De Palo Gaetana Bufano Albina Quaranta
(ThalesAlenia Space, Italy)

Marco Bruno
(Sofiter System Engineering, Italy)

Abstract

Columbus module started its operations on early 2008 as European element of the ISS. Mathematical models originally developed for CDR/FAR phases and fitted to current flight configuration play a key role for the engineers supporting the on-orbit operations.
This presentation provides an overview of the Thermal-Hydraulic Mathematical Models (THMM) running in TAS-I Torino by thermal control team, focusing then on the water loop Active Thermal Control System (ATCS) element, by comparing flight telemetries with models outcome for some relevant cases. Conclusions summarize this first year of experience covering also s/w needs and expectation for next future.



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MATHEMATICAL MODELS FOR THE COLUMBUS ENGINEERING SUPPORT TEAM

Template reference : 100181685K-EN

Savino DE PALO, Gaetana BUFANO, Albino QUARANTA - ThalesAlenia Space

Marco BRUNO - Sofiter System Engineering

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TOC

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- INTRODUCTION
- MODELS OVERVIEW
  - IOTMM
  - ECTMM
  - PCTMM
  - ATCS
- CHX DRYOUT
- CONCLUSION

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INTRODUCTION

Page 3

- Columbus module started its operations on early 2008 as European element of the ISS
- TAS-I as part of the industrial team supporting the mission provides engineering support to on-orbit operations
- Mathematical models originally developed for CDR / FAR phases fitted to flight configuration

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MODELS OVERVIEW

Page 4

The TMMs / THMMs used to predict the thermal-hydraulic behavior of Columbus and P/Ls during on orbit operations are:

1. IOTMM (Integrated Overall THMM)
2. ECTMM (External Complement TMM)
3. PCTMM (Pressurized Complement THMM)
4. ATCS THMM

All models have been developed in ESARAD and ESATAN software tools

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IOTMM

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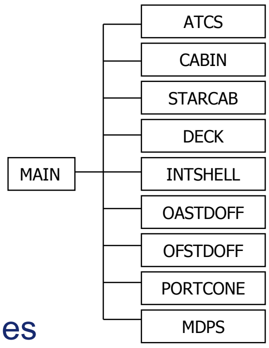
IOTMM has one main model and nine sub-models and simulates the interactions between:

- water loop
- cabin environment and air loop
- external environment

Model size = 2714 Thermal Nodes + 378 Fluidic Nodes



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IOTMM

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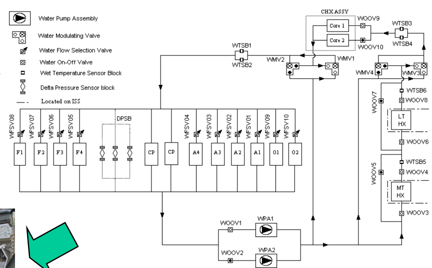
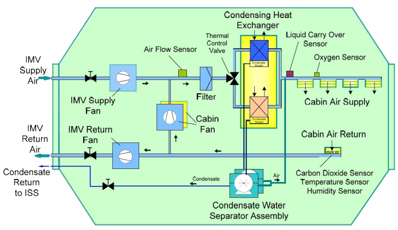
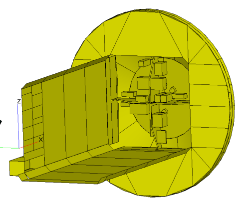
Used to:

- analyze risky deviations from nominal functioning
- responding to E-Chits, SPRs requests
- provide inputs for Flight Rules / Procedures







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ECTMM

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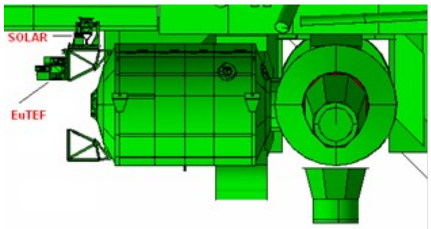
ECTMM → thermal behavior of Columbus + external P/Ls (e.g., SOLAR, EuTEF)

- ECTMM = simplified IOTMM (ATCS FHTS → GF) + external P/Ls detailed models
- External P/Ls are sub-models both at ESARAD and ESATAN level

Model size = 5107 Thermal Nodes



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ECTMM

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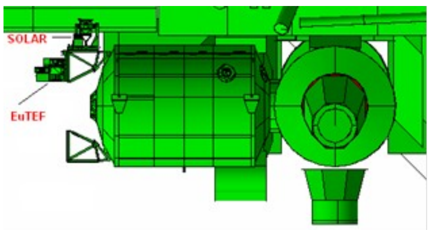
Used during 1E Mission to provide the Columbus Thermal Clock (time window in which the Columbus Module could survive without any risk of condensation without any heaters power) for a dedicated Flight Rule

Currently used to complete the thermal Flight Rule related to the Payloads behavior in contingency situation during EVA activities or in case of loss of power to the External Payloads to provide thermal clock for each equipment and experiments



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PCTMM

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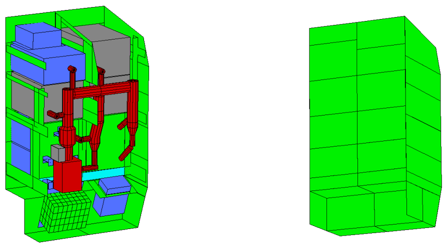
PCTMM → thermal behavior of Columbus + internal P/Ls

- PCTMM = IOTMM + reduced models of EDR, FSL, EPM with experiments (according to the relevant stages)
- Internal P/Ls are sub-models both at ESARAD and ESATAN level

Model size = 3174 Thermal Nodes + 568 Fluidic Nodes



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PCTMM

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Some convergence issues due to integration of sub-models into IOTMM with simultaneous hydraulic loops (water, air)

Currently used for the Stage Analyses to:

- demonstrate the compliance of the payload complement with requirements
- define operational guidelines where necessary
- define constraints if element level conflicts are identified

Used for stages 1E, 1JA, 1J, 2JA, ULF2, 15A, 17A, ULF3 & 20A

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ATCS

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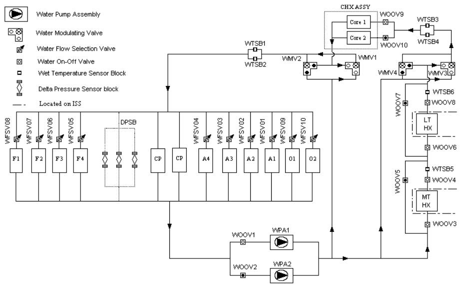
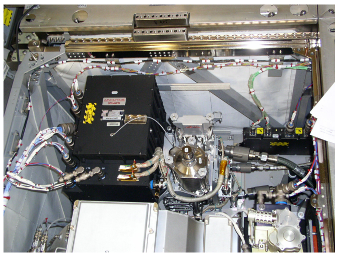
ATCS → thermal-hydraulic behavior of Columbus water loop (feedback controls included)

- ATCS can run stand-alone or as part of the IOTMM
- Water cooled P/Ls can be included to ATCS

Model size = 99 Thermal Nodes + 410 Fluidic Nodes





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ATCS

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Currently used for the Stage Analyses to:

- demonstrate the compliance of the payload complement with requirements, provide WFSV positions
- define operational guidelines (where necessary)
- define constraints if element level conflicts are identified

Used for stages 1E, 1JA, 1J, 2JA, ULF2, 15A, ULF3 and 17A

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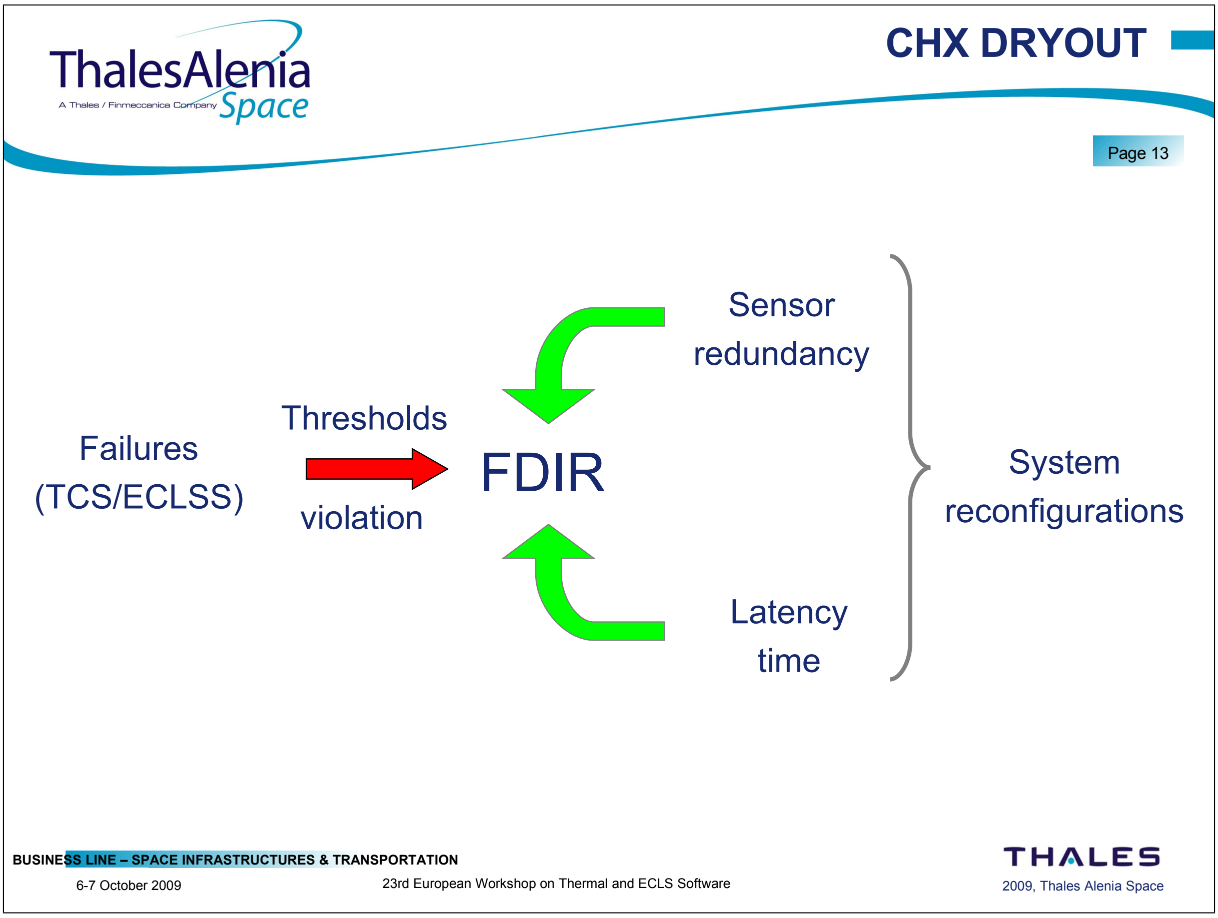
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CHX DRYOUT
Page 13
Sensor
redundancy
Thresholds
Failures
(TCS/ECLSS)
FDIR
violation
System
reconfigurations
Latency
time
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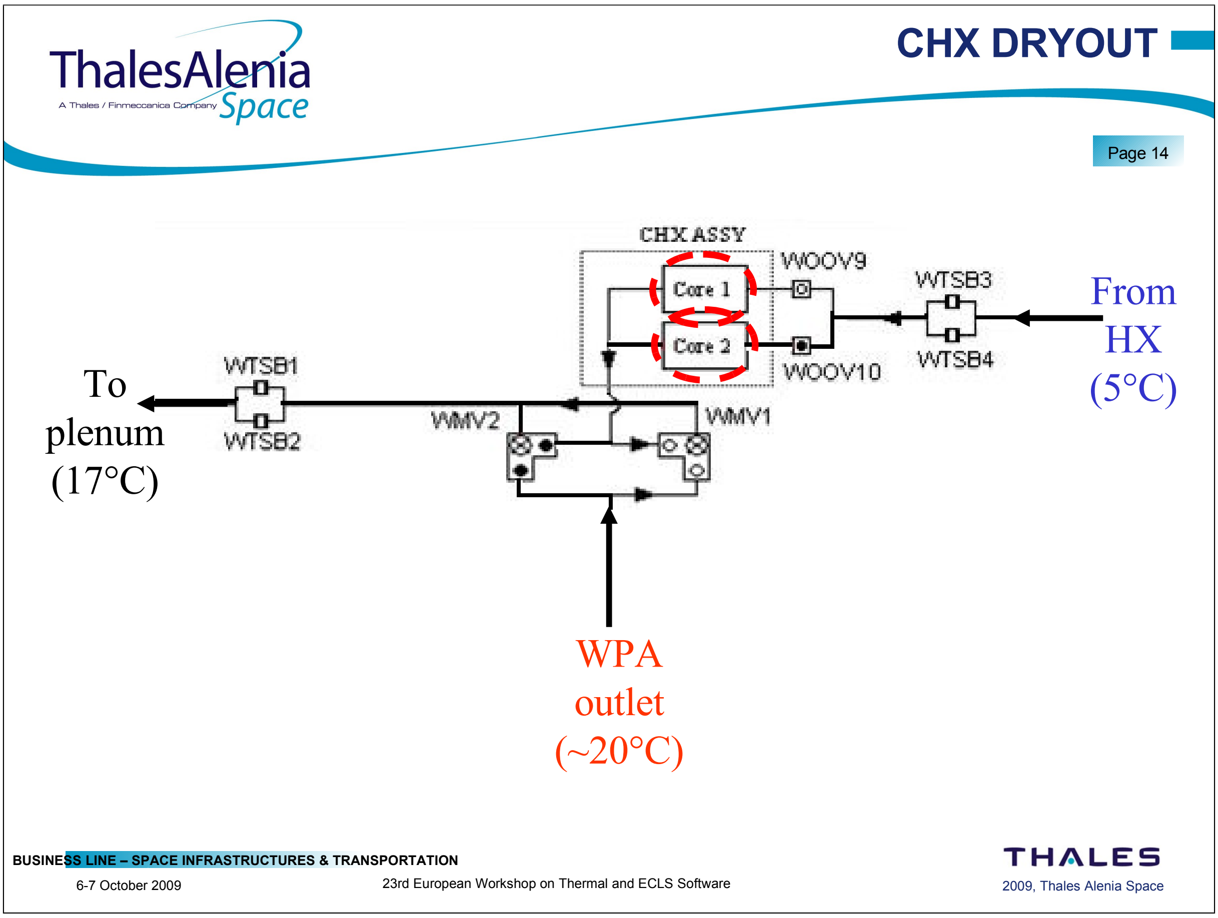
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CHX DRYOUT
Page 14
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB3
WTSB4
From
HX
(5°C)
WTSB1
WTSB2
To
plenum
(17°C)
WMV2
WMV1
WPA
outlet
(~20°C)
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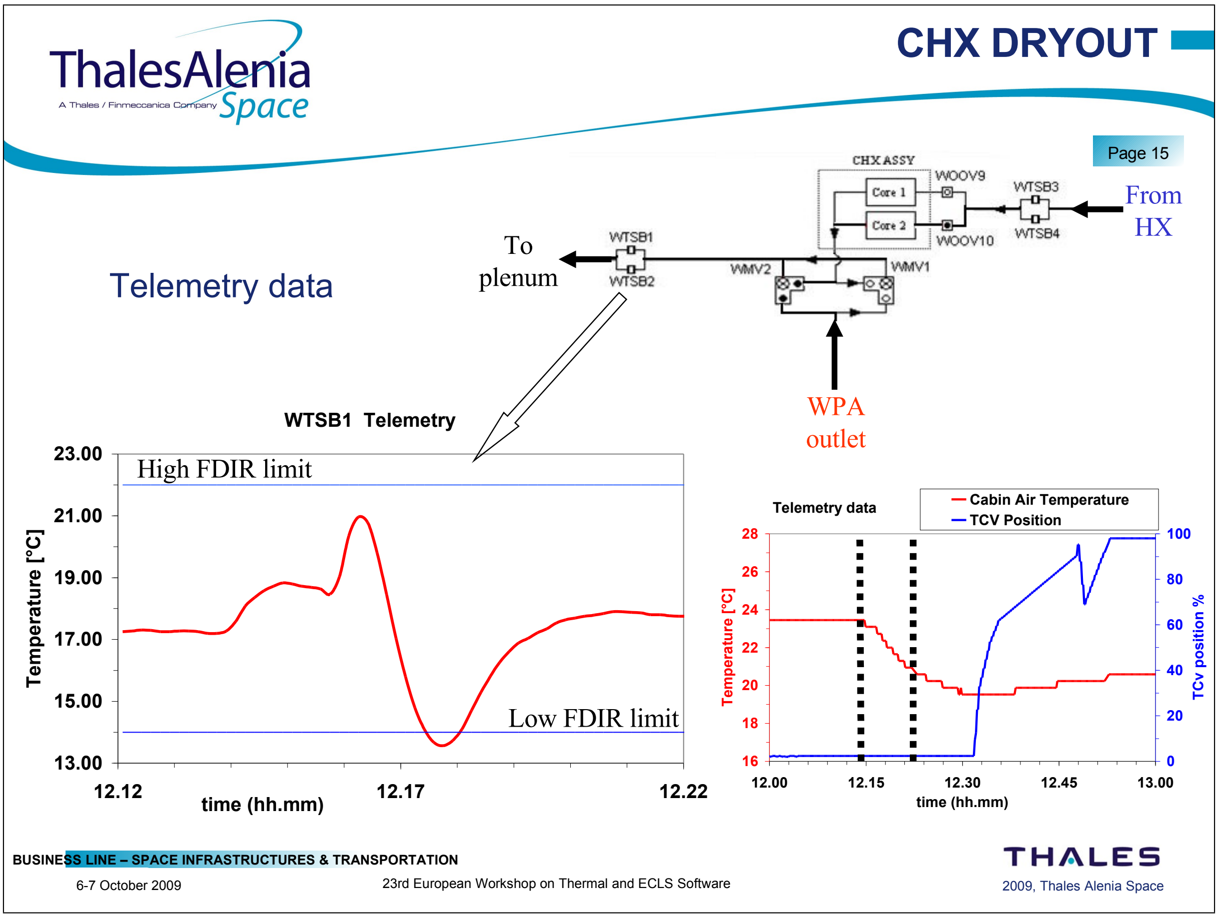
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CHX DRYOUT
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Telemetry data
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB3
WTSB4
From HX
To plenum
WTSB1
WTSB2
WMV2
WMV1
WPA outlet
WTSB1 Telemetry
High FDIR limit
Low FDIR limit
Temperature [°C]
23.00
21.00
19.00
17.00
15.00
13.00
12.12
12.17
12.22
time (hh.mm)
Telemetry data
Cabin Air Temperature
TCV Position
Temperature [°C]
TCv position %
28
26
24
22
20
18
16
100
80
60
40
20
0
12.00
12.15
12.30
12.45
13.00
time (hh.mm)
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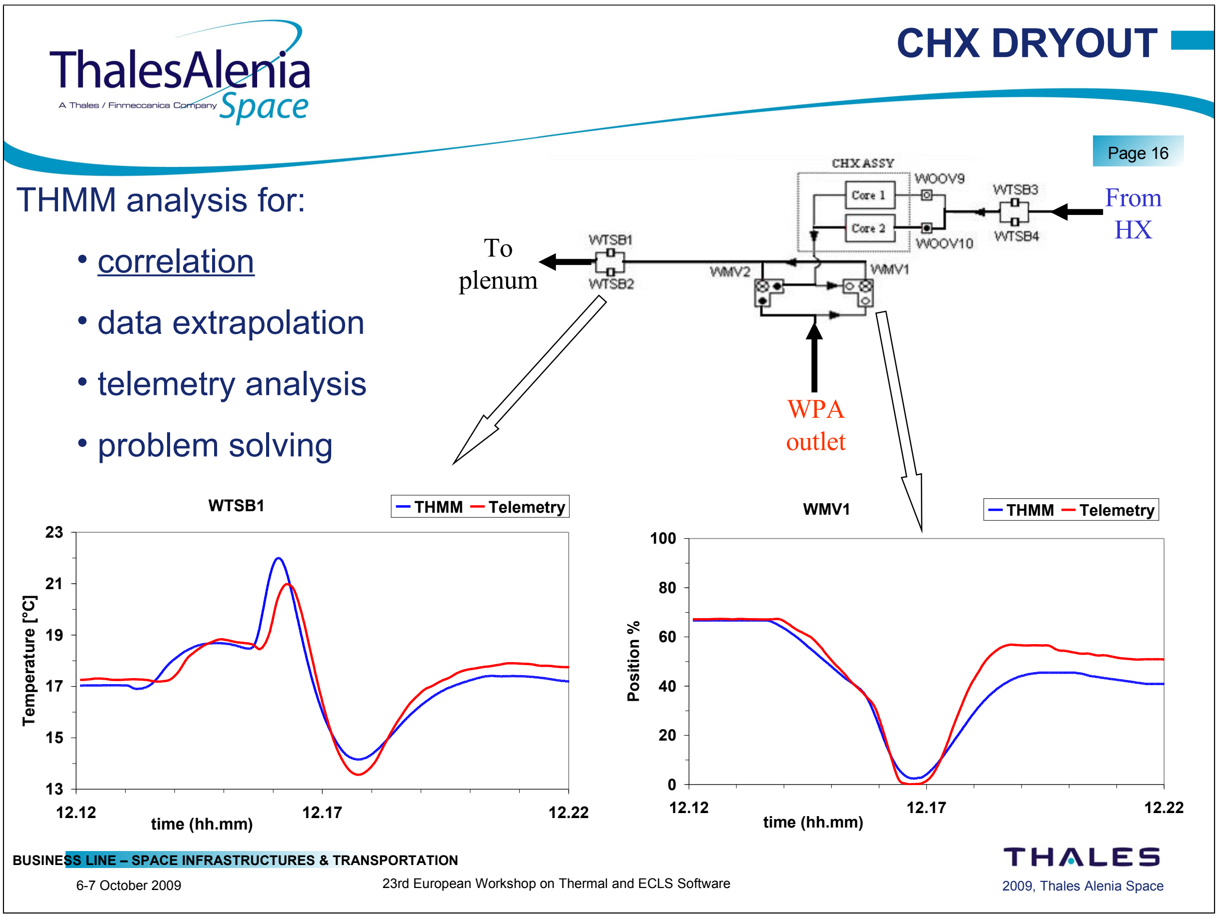
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CHX DRYOUT
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THMM analysis for:
• correlation
• data extrapolation
• telemetry analysis
• problem solving
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB3
WTSB4
From HX
To plenum
WTSB1
WTSB2
WMV2
WMV1
WPA outlet
WTSB1
THMM
Telemetry
Temperature [°C]
23
21
19
17
15
13
12.12
12.17
12.22
time (hh.mm)
WMV1
THMM
Telemetry
Position %
100
80
60
40
20
0
12.12
12.17
12.22
time (hh.mm)
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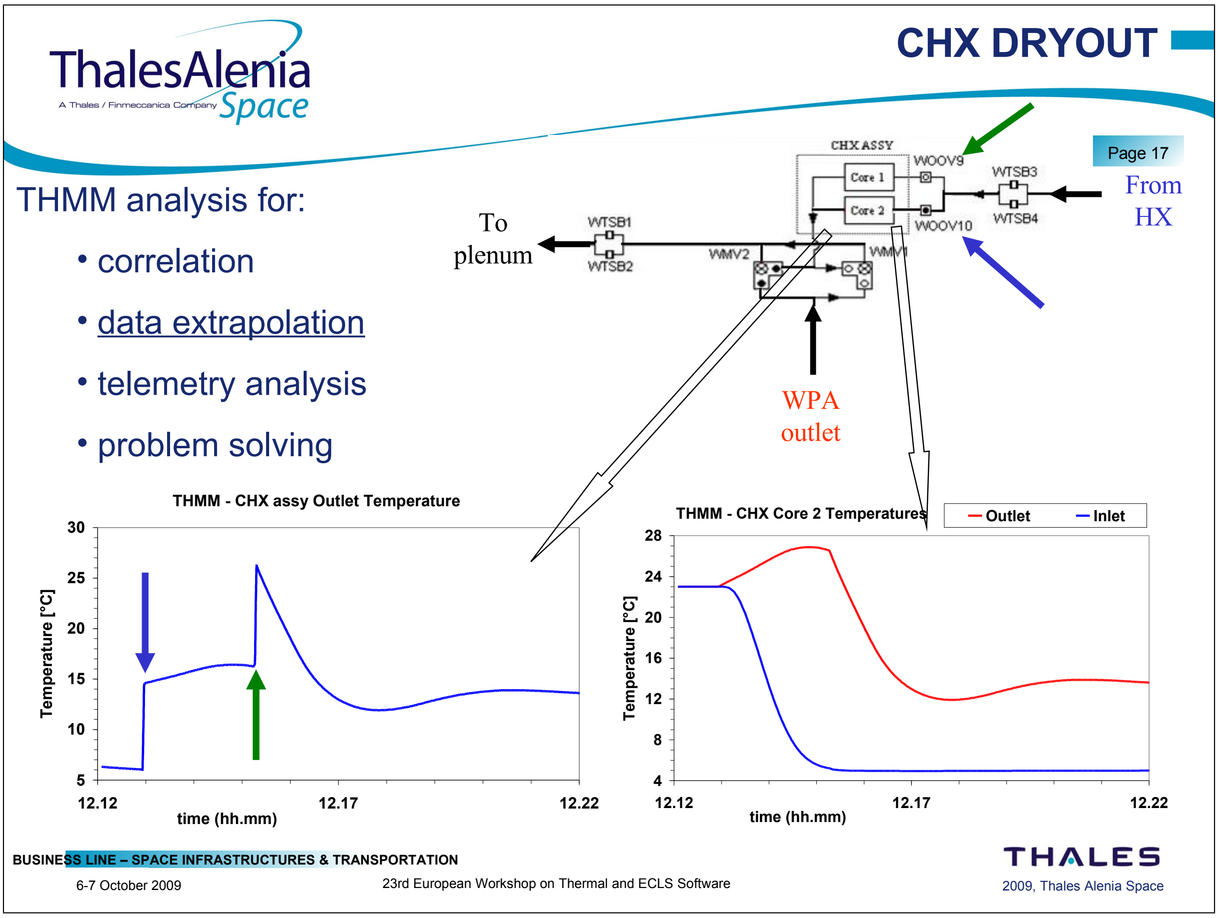
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CHX DRYOUT
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THMM analysis for:
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• problem solving
To plenum
From HX
WPA outlet
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB1
WTSB2
WTSB3
WTSB4
WMV1
WMV2
THMM - CHX assy Outlet Temperature
Temperature [°C]
time (hh.mm)
THMM - CHX Core 2 Temperatures
Outlet
Inlet
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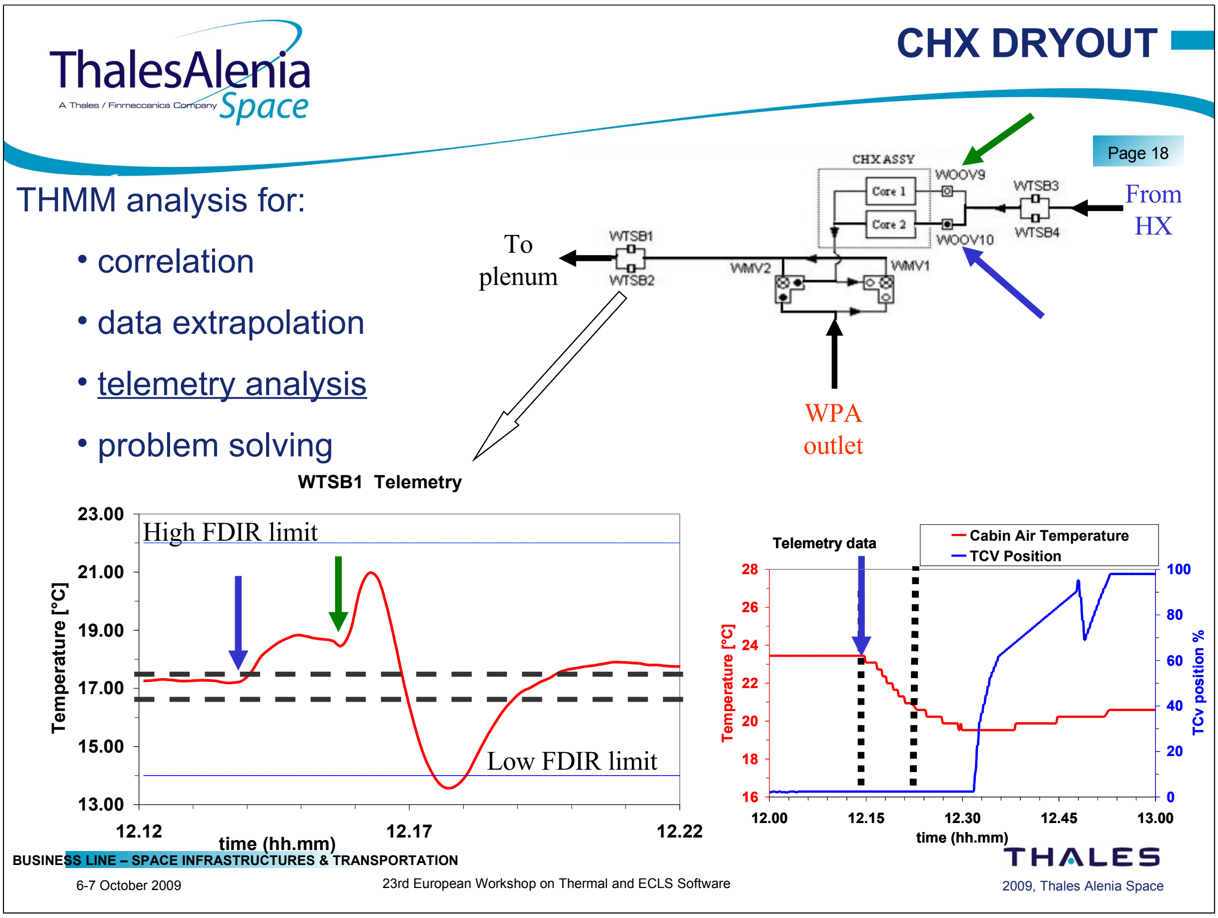
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CHX DRYOUT
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THMM analysis for:
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• data extrapolation
• telemetry analysis
• problem solving
To plenum
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CHX ASSY
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Core 2
WOOV9
WOOV10
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WTSB2
WTSB3
WTSB4
WMV1
WMV2
WTSB1 Telemetry
High FDIR limit
Low FDIR limit
Temperature [°C]
time (hh.mm)
Telemetry data
Cabin Air Temperature
TCV Position
TCv position %
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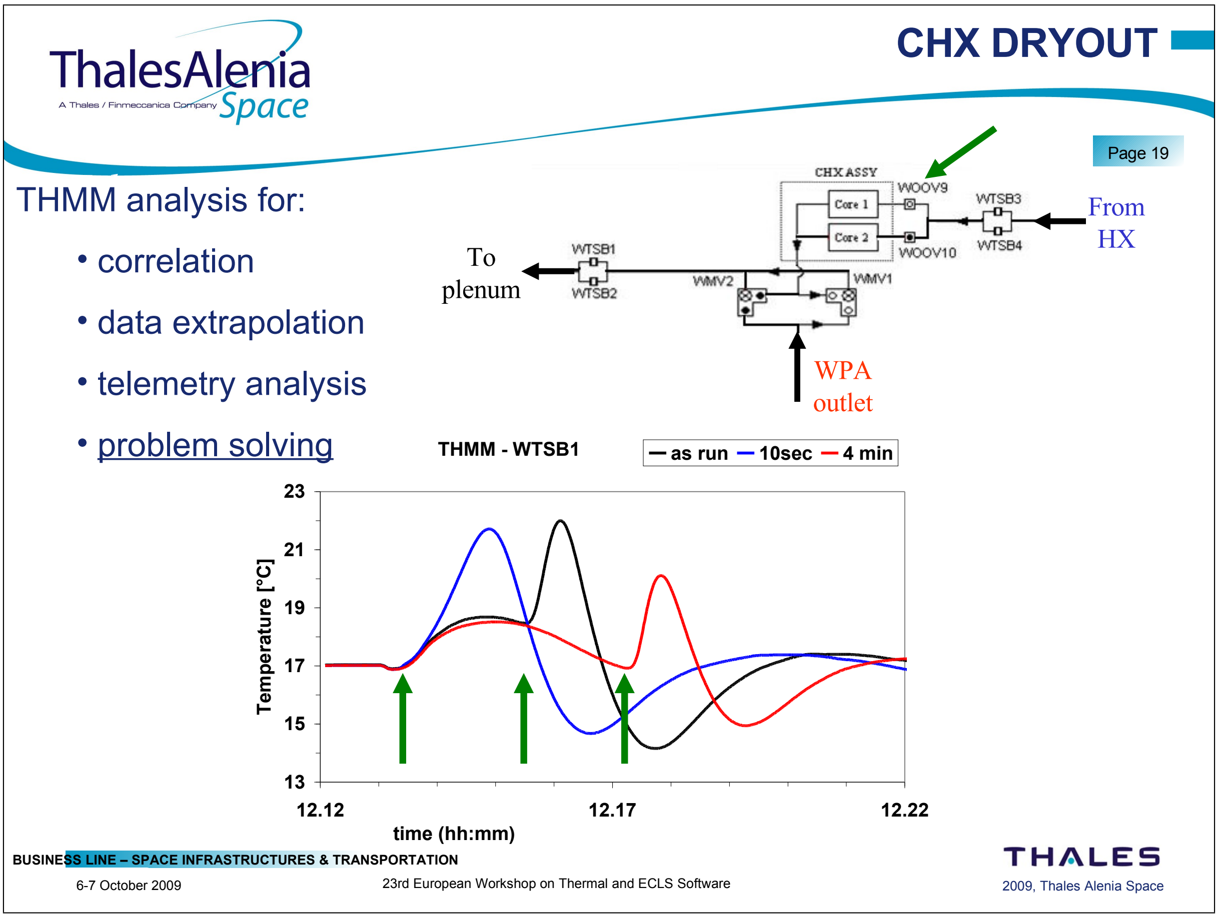
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CHX DRYOUT
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THMM analysis for:
• correlation
• data extrapolation
• telemetry analysis
• problem solving
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB3
WTSB4
From HX
To plenum
WTSB1
WTSB2
WMV2
WMV1
WPA outlet
THMM - WTSB1
as run
10sec
4 min
Temperature [°C]
23
21
19
17
15
13
12.12
12.17
12.22
time (hh:mm)
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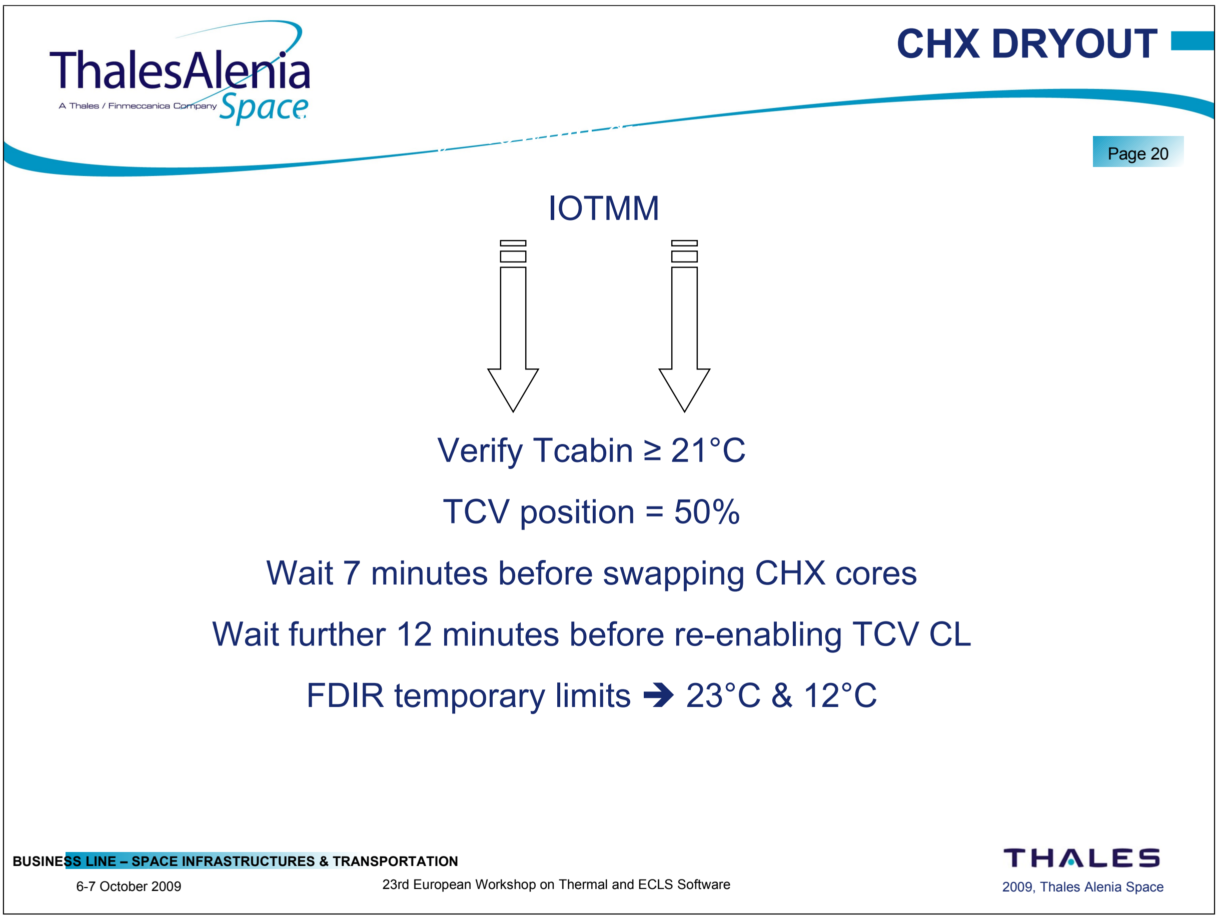
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CHX DRYOUT
Page 20
IOTMM
Verify Tcabin ≥ 21°C
TCV position = 50%
Wait 7 minutes before swapping CHX cores
Wait further 12 minutes before re-enabling TCV CL
FDIR temporary limits ➔ 23°C & 12°C
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CHX DRYOUT

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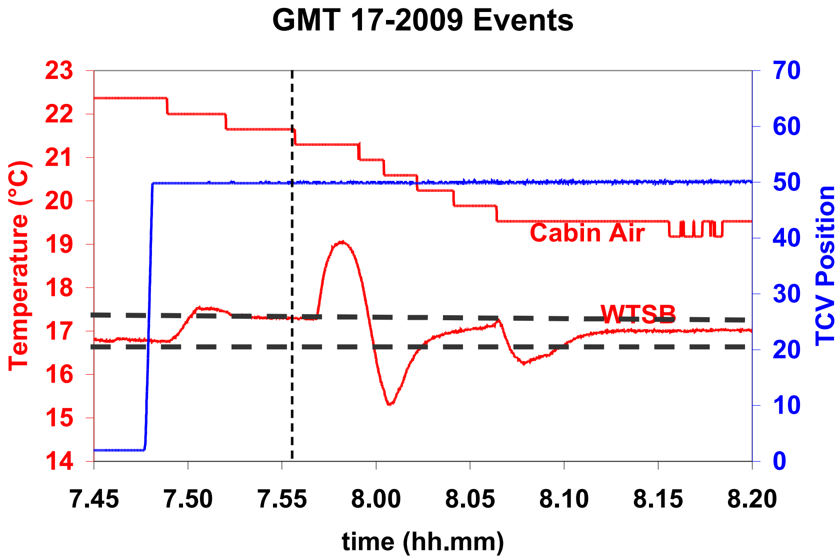

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CONCLUSIONS

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- TMM / THMMs provide insight of system behaviour
- Models correlation with telemetry necessary but time consuming (huge amount of data)
- Flight conditions vs CDR / FAR assumptions → real loads vs design margin (e.g. crew heat load)
- Need for rapid evaluation is sometime requested vs huge/complex models
- Real time simulations ?

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Appendix T

On orbit performance of the EuTEF thermal control system
1 Year on board the ISS

Alberto Franzoso Marco Molina Paolo Ruzza F. Tominetti M. Grilli
(Carlo Gavazzi Space, Italy)

Abstract

EuTEF is an ESA platform for technological research, designed and built by Carlo Gavazzi Space.
It was launched onboard the Space Shuttle on February 2008 with 10 experiments to be exposed to Space Environment for 15 months. It was installed as an attached payload of the Columbus module by astronaut EVA.
EuTEF is experiencing the typical ISS outer environment, dominated by LEO sun-eclipse phases on a medium inclination orbit (52°), with the additional effect of the International Space Station moving appendages. Thermal modelling with SINDA/TRASYS code has been used for sizing of the payload: the NASA-provided ISS model (in SINDA) has been used for flight predictions, which are compared with flight data.
Within the 1 year mission, the seasonal variations in the thermal environment of EuTEF are identified, and signs of degradation of the thermo-optical properties of the thermal coatings, such as silvered Teflon, have been investigated from telemetry data.
Moreover, it is calculated how much the ISS elements dominate the environment for payloads attached outside Columbus module, compared to free-flying satellites in a similar orbit. Simple thermal tools such as ARTIFIS and TOPIC have been used to derive an equivalent effective thermal environment of the outer ISS, with solutions implemented in MINITAN. These extremely simplified models allow making considerations for preliminary thermal design of future missions on the ISS.
EuTEF returned safely on the Earth in September 2009: thermal requirements about the return are briefly presented as well.


ON ORBIT PERFORMANCE OF THE
EUTEF THERMAL CONTROL SYSTEM:
1 YEAR ON BOARD THE ISS
6-7 October 2009, ESTEC - 23rd THERMAL AND ECLS WS
A. Franzoso, M. Molina, P. Ruzza, F. Tominetti, M. Grilli
CARLO GAVAZZI
Carlo Gavazzi Space SpA
Headquarters: Via Gallarate 150 - 20151 Milano (Italy)
Tel: +39.02.380481 - Fax: +39.02.3086458
Web site: www.cgspace.it - E-mail: cgs@cgspace.it


Introduction
EuTEF (EUropean Technology Exposure Facility)
• Launched on 07/02/2008 with STS-122 (Atlantis)
• Design operative life 3 years, nominal mission = 1 year
• Landed on 11/09/2009 with with STS-128 (Discovery)
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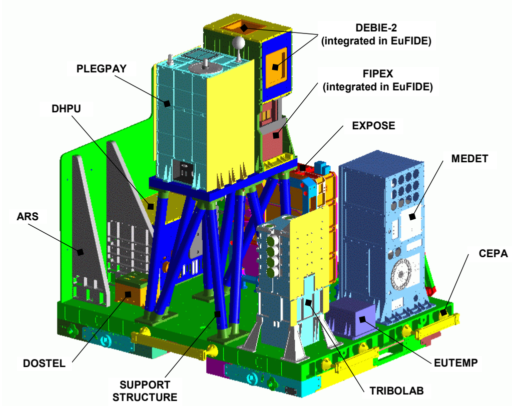
INTRODUCTION

- EuTEF (EUROPEAN TECHNOLOGY EXPOSURE FACILITY) is an ESA external platform that was installed on Columbus
- EuTEF provides stardardized mechanichal accommodation, electrical and data handling services for nine instruments



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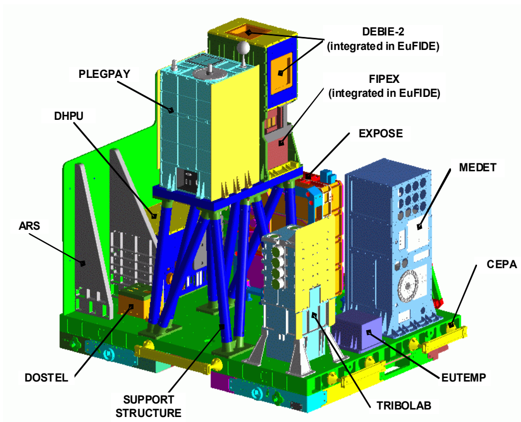
EuTEF Instruments

- EuTEF accomodates several instrument:
  - PLEGPAY: Plasma contactor experiment
  - MEDET: Materials Exposure experiments
  - TRIBOLAB: Lubrication Materials / Tribology experiment
  - DEBIE-2: Orbital Debris measurement
  - FIPEX: Atomic Oxygen measurement
  - EXPOSE: UV effects investigation experiment
  - DOSTEL: Radiation environment investigation.
  - EuTEMP: Autonomous Temperature Recording U
  - EVC: Earth Viewing Camera



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EuTEF TCS and ISS environment

EuTEF TCS :

- Passive TCS
  - Silvered teflon and white painted radiators
  - MLI
  - Heaters for survival and start-up.
- EuTEF TCS has been designed for the typical ISS environment:
  - Flight altitude between 278km and 420km
  - Orbit Inclination angle 51°-> beta angle (angle between the orbit plane and the Sun) variation between -75°and +75°
- SINDA/FLUINT used for thermal analysis
  - ISS MODEL = SINDA / TRASYS (~1500 nodes)
  - EUTEF MODEL = SINDA / THERMAL DESKTOP (~700 nodes)
    - VALIDATED by means of a TB solar beam test

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Flight data analysis

The following qualitative analyses have been performed on the collected telemetry data:

- Long Period analyses:
  - Temperature variation due to the beta angle variation in time;
  - Temperature variation due to the different ISS flight altitude;
  - Temperature variation due to Thermo-optical properties degradation;
- Comparison between collected data and performed numerical analyses in transient conditions:
  - Installation phase;
- ISS - SUPER SIMPLIFIED MODEL (ISS-SSMODEL) developed using T.O.P.I.C. for the environmental data generation: model has been built fitting numerical results with telemetry data.

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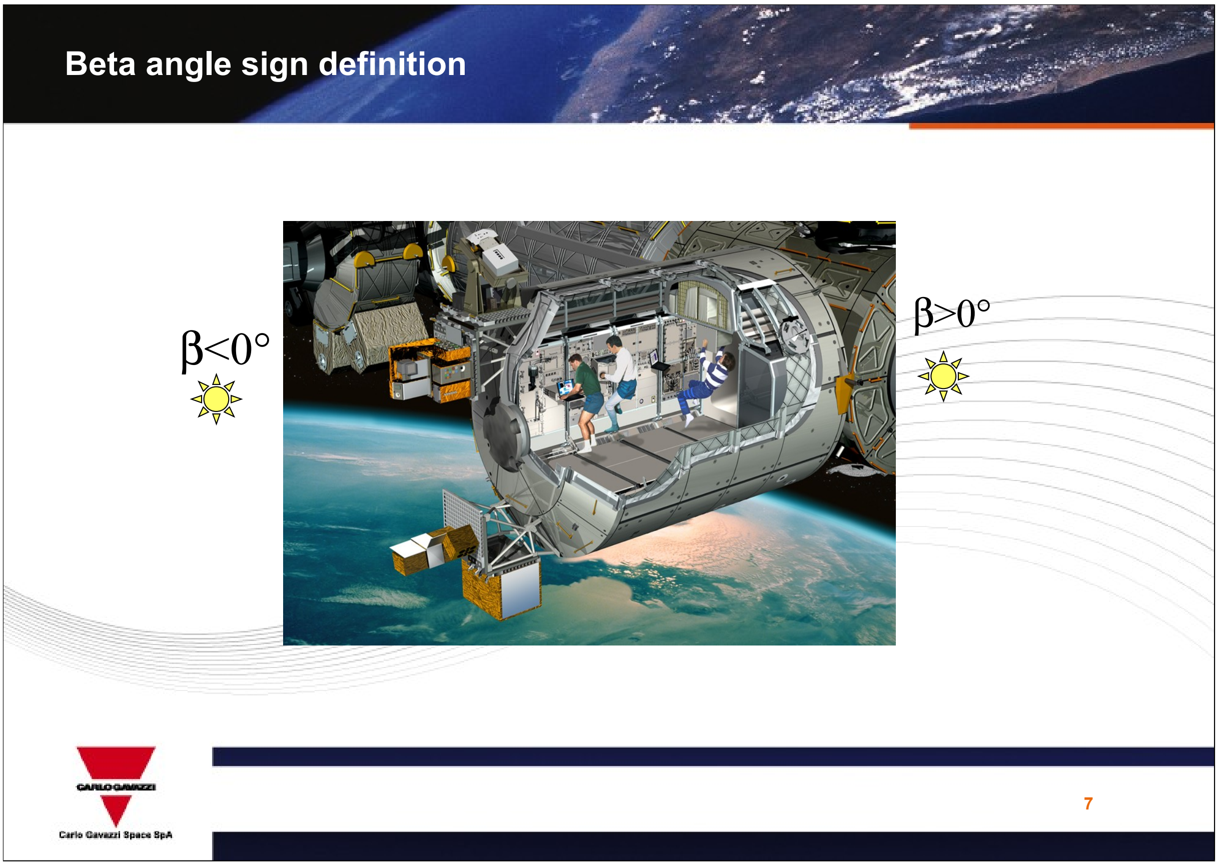
Beta angle sign definition
β<0°
β>0°
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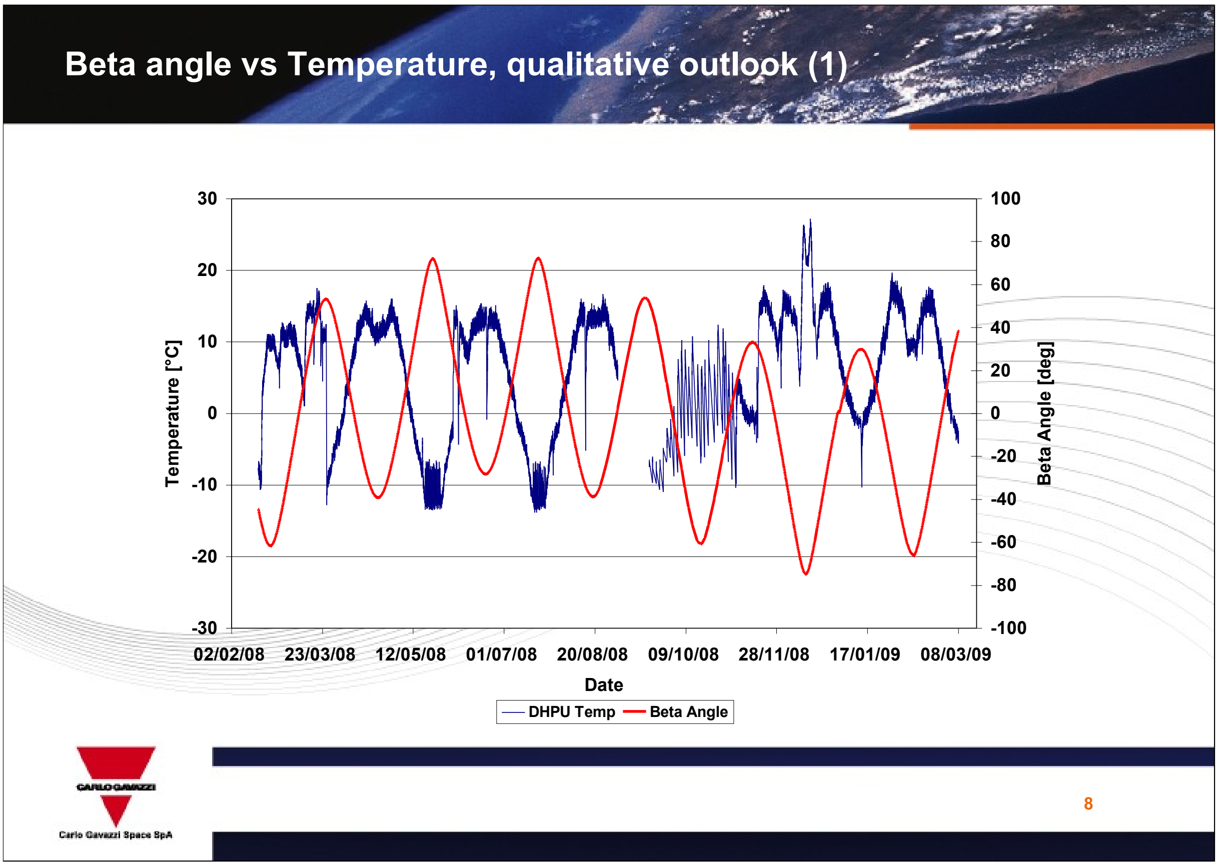
Beta angle vs Temperature, qualitative outlook (1)
Temperature [°C]
30
20
10
0
-10
-20
-30
Beta Angle [deg]
100
80
60
40
20
0
-20
-40
-60
-80
-100
02/02/08
23/03/08
12/05/08
01/07/08
20/08/08
09/10/08
28/11/08
17/01/09
08/03/09
Date
DHPU Temp
Beta Angle
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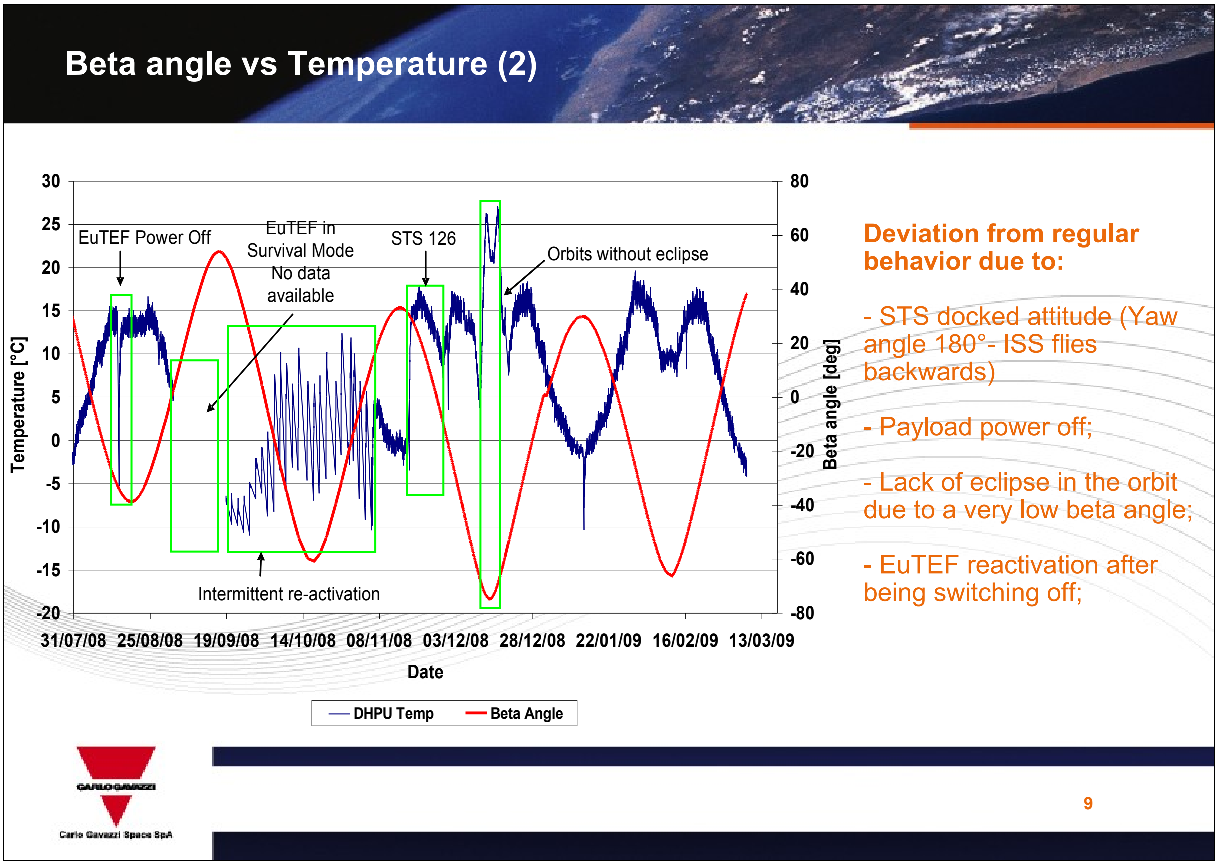
Beta angle vs Temperature (2)
EuTEF Power Off
EuTEF in Survival Mode No data available
STS 126
Orbits without eclipse
Intermittent re-activation
Temperature [°C]
Beta angle [deg]
Date
31/07/08 25/08/08 19/09/08 14/10/08 08/11/08 03/12/08 28/12/08 22/01/09 16/02/09 13/03/09
DHPU Temp
Beta Angle
Deviation from regular behavior due to:
- STS docked attitude (Yaw angle 180°- ISS flies backwards)
- Payload power off;
- Lack of eclipse in the orbit due to a very low beta angle;
- EuTEF reactivation after being switching off;
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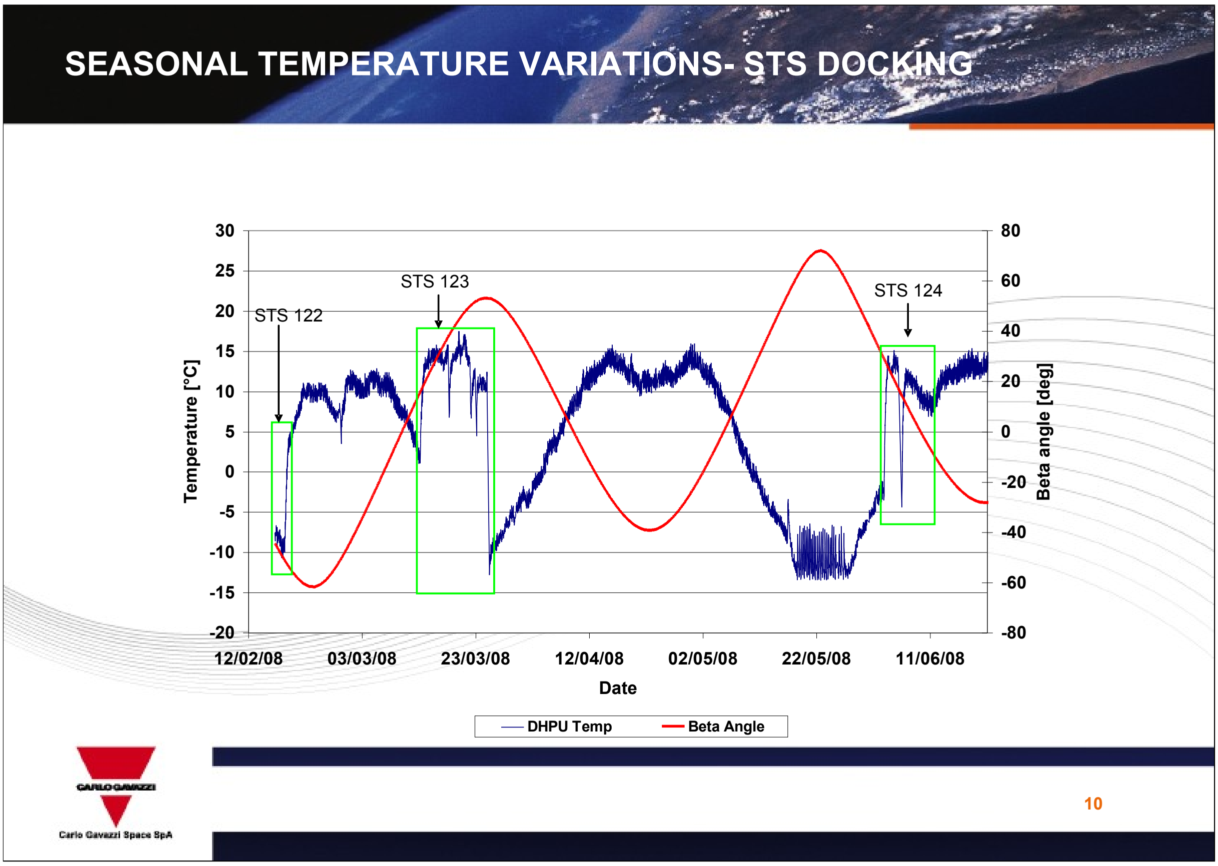
SEASONAL TEMPERATURE VARIATIONS- STS DOCKING
STS 122
STS 123
STS 124
Temperature [°C]
Beta angle [deg]
Date
12/02/08 03/03/08 23/03/08 12/04/08 02/05/08 22/05/08 11/06/08
DHPU Temp
Beta Angle
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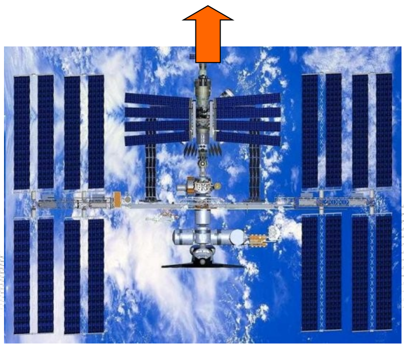
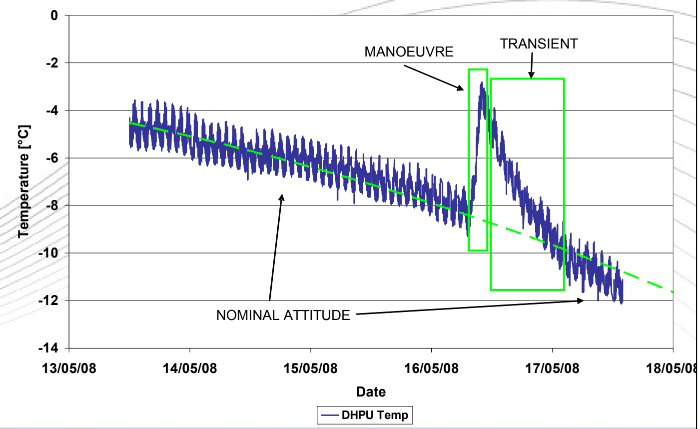
STS DOCKING MANOUVERS

- Normally ISS flies with +XVV / +ZLV attitude, indicates that the ISS positive x-axis is toward the velocity vector, the z-axis is towards nadir.
- Before STS docks, the ISS changes its attitude, rotating with a yaw angle of 180° and passing to – XVV attitude





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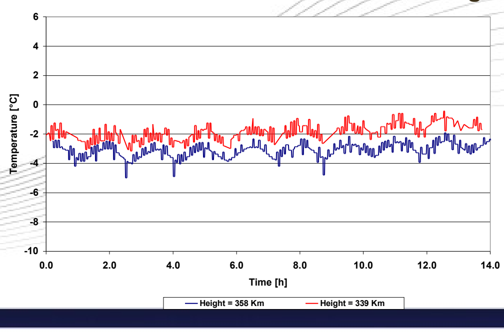
ISS HEIGHT: TEMPERATURE VARIATIONS

- ISS constantly loses altitude due to atmospheric drag and needs to be boosted to a higher altitude several times each year.
- Two orbits has been selected, to analyze affect of altitude variation on EuTEF, at 339km and at 358km.
  - Mean temperature difference is 1.3°C.
- Change in environmental fluxes has been calculated by using the Thermal desktop model in combination with a least square error method in SINDA
  - Environmental heat fluxes increase of ~6% when orbit height decreases by 19 km



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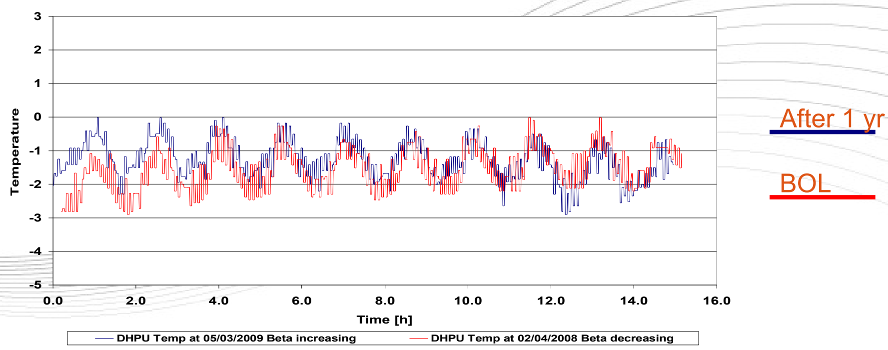
TEMPERATURE VARIATIONS DUE TO THERMO-OPTICAL DEGRADATION

A small increase of the average temperature (about 0.3°C) due to degradation of thermo-optical properties of the DHPU radiator (Silver Teflon) has been observed in 11 months (2nd april 2008 – 3rd march 2009).

Assuming it is mainly a change in absorptivity, model has been validated using SINDA/FLUINT least square error data fit routines.

Two cases have been chosen with the same attitude, environment (season) and Beta angle for comparison

9% relative increase in the solar absorptivity from BOL conditions (validated model in TB solar test) has been found.



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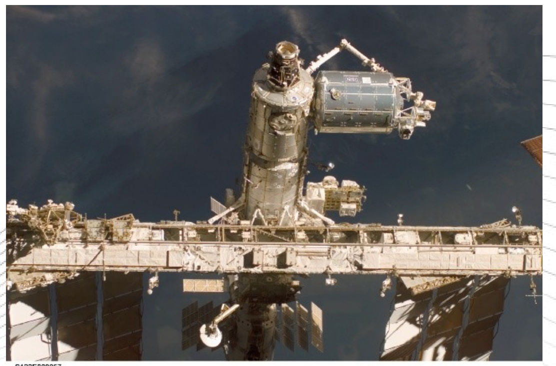
EUTEF IN THE STS CARGO BAY AND ON THE ISS

S122E006275



S122E009957

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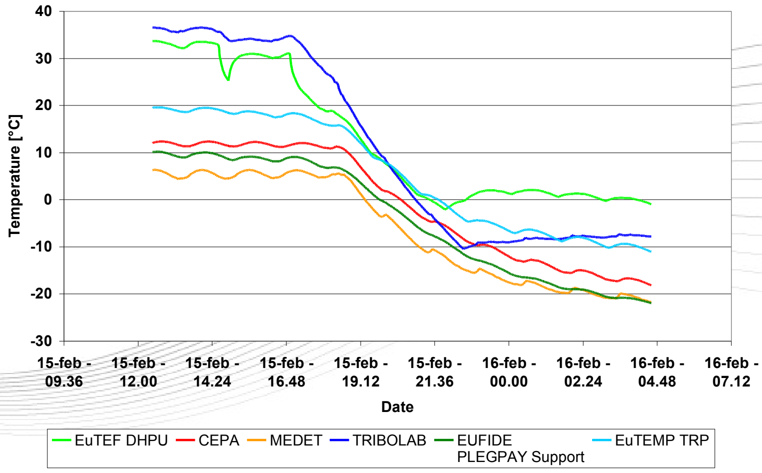
TRANSIENT THERMAL ANALYSIS: EuTEF INSTALLATION FROM STS TO ISS

- THE TRANSFER FROM CARGO BAY TO COLUMBUS TOOK ABOUT 1 HOUR. HEATERS REMAINED SWITCHED OFF FOR 3 HOURS.
- SINK TEMPERATURE IN SHUTTLE CARGO BAY WAS HIGHER THAN SINK TEMP ON COLUMBUS



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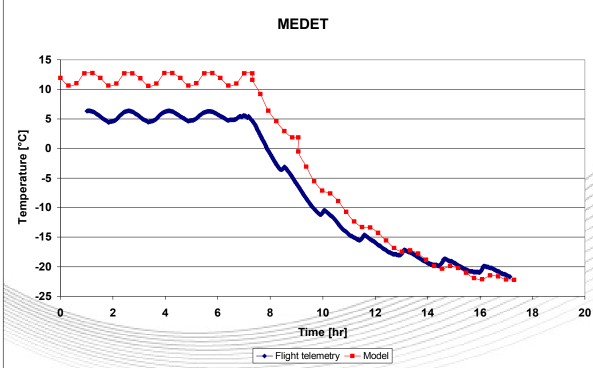
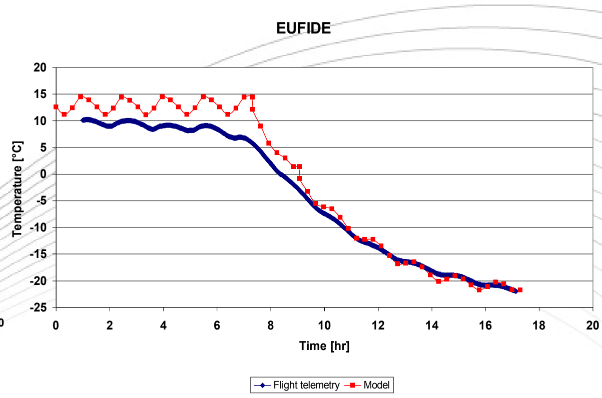
EuTEF INSTALLATION FROM STS TO ISS

- THE DETAILED THERMAL LUMPED PARAMETER MODEL HAS BEEN SOLVED WITH SINDA VALIDATED MODEL, USING ACTUAL ORBITAL DATA.
- THE RESULTS OF THIS MODEL IS COMPARED WITH TELEMETRY DATA





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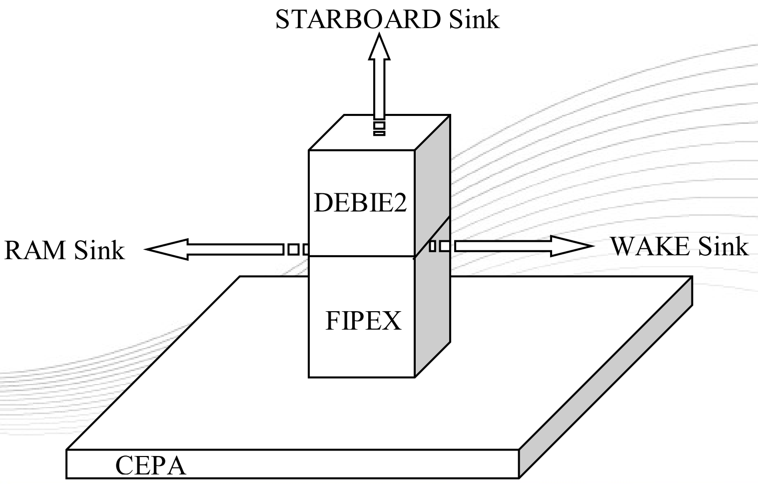
ISS-SUPER SIMPLIFIED MODELING WITH T.O.P.I.C.

- How much ISS elements influence the environment around EUTEF vs. a free flyer?
- A very simple SINDA / T.O.P.I.C. model (1 node per face) of some instruments have been built.



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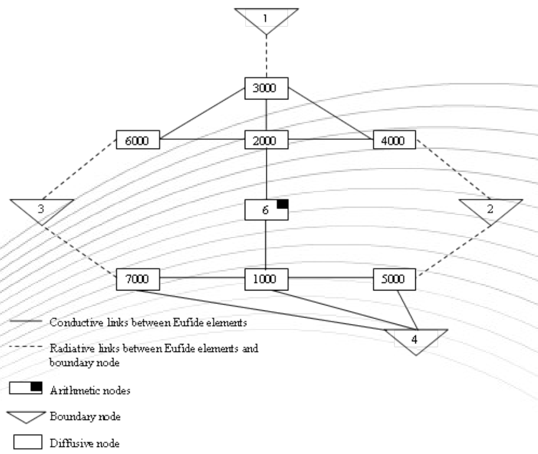
PAYLOAD MODEL EXAMPLE

- 3 radiative sink nodes (3 exposed sides of the payload)
- CEPA temperature taken from on-orbit measurement
- 8 nodes for the payload
  - 6 walls
  - 1 MLI
  - 1 instrument core



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WHY T.O.P.I.C. AND NOT TCDT? PURPOSE AND ADVANTAGES

- For a very quick work (2 weeks), TOPIC is simpler to install, learn and use
- Despite less fancy graphic, results accuracy is the same
- Data in tabular form forces to check them more thoroughly when formatting, before inputting to a thermal solver

PURPOSE

- To find effective sink temperature
  - in various directions
  - at a given Beta angle

for quick assessments on attached payloads.

ADVANTAGES

- 6 nodes instead of 1500 with articulators of the ISS
- Run time = few seconds vs. 12 hours

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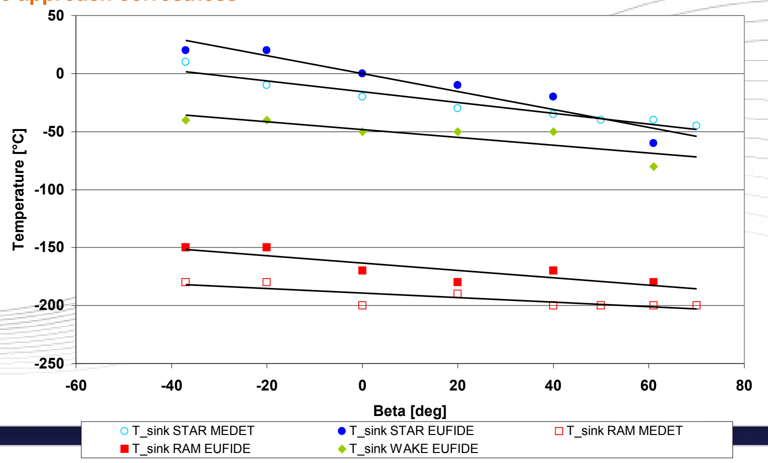
T.O.P.I.C. ISS-SSMODEL (ISS SUPER-SIMPLIFIED MODEL)

- Sink temperatures on STARBOARD, WAKE and RAM side have been identified with SINDA Least Square Error routines fitting
  - analyses results with TOPIC/SINDA ISS-SSMODEL and
  - EuTEF flight data
- Sink temperature computed for different payloads, in the same directions, are similar one another, confirming the approach correctness



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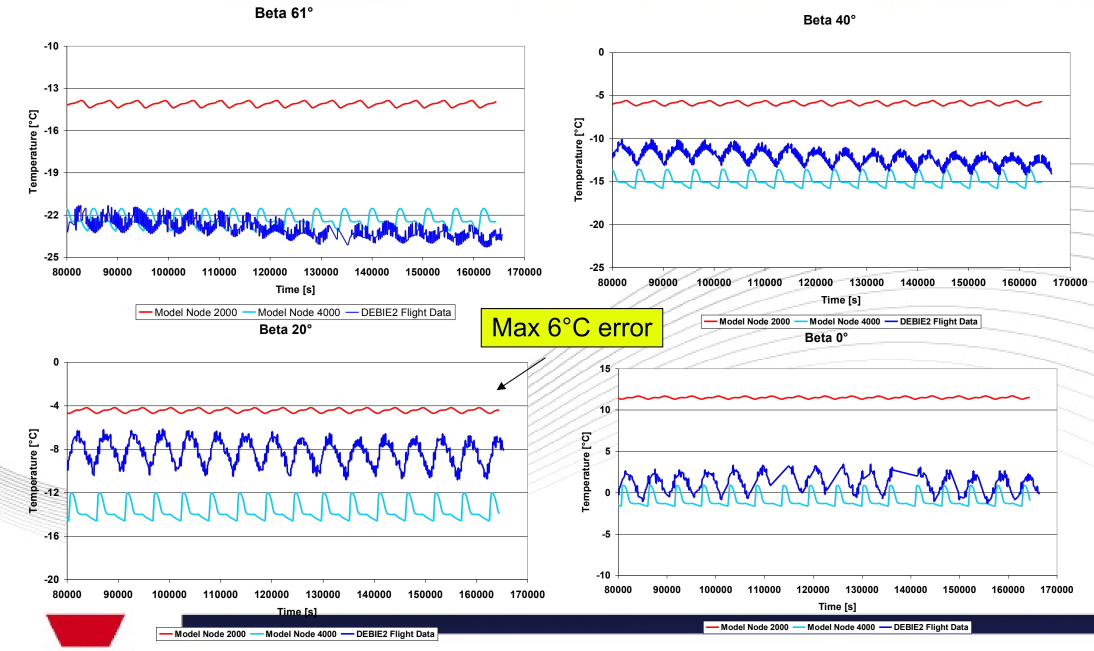
ISS-SSMODEL Results (TOPIC/SINDA) vs. Flight Data



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CONCLUSIONS

- First order effects have been observed
  - beta angle
- Second order effects have been confirmed negligible but measurable
  - Solar constant (not shown in the presentation)
  - ISS altitude
  - Thermo-optical properties
- Comparison between detailed thermal mathematical model and flight data, confirm good and conservative modelling approach also for thermal masses definition, useful for transfer analysis
- EuTEF simple thermal model has been developed and fluxes calculated with T.O.P.I.C. (ISS-SSMODEL)
- This simplified model can be useful for quick assessments of other external payloads thermal behaviour with a good accuracy for phase-A studies (6°C max error)

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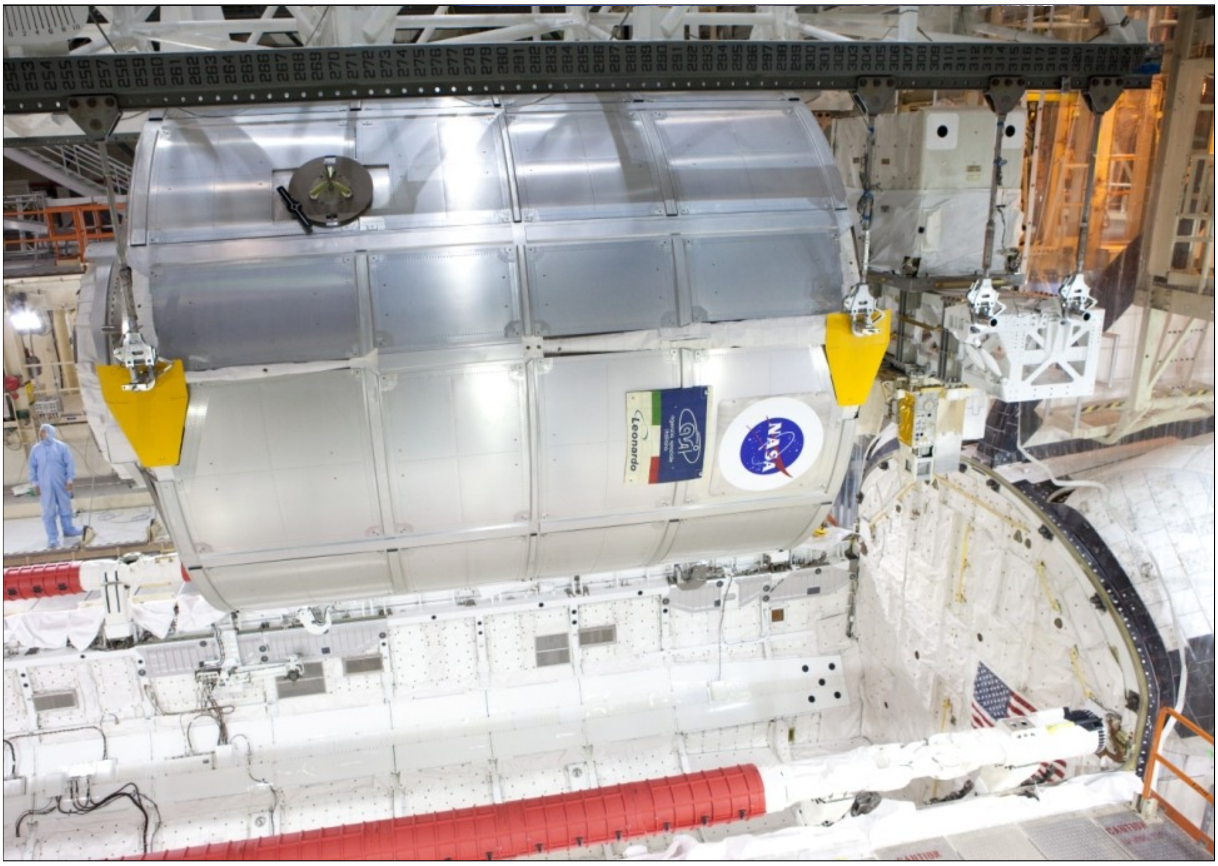
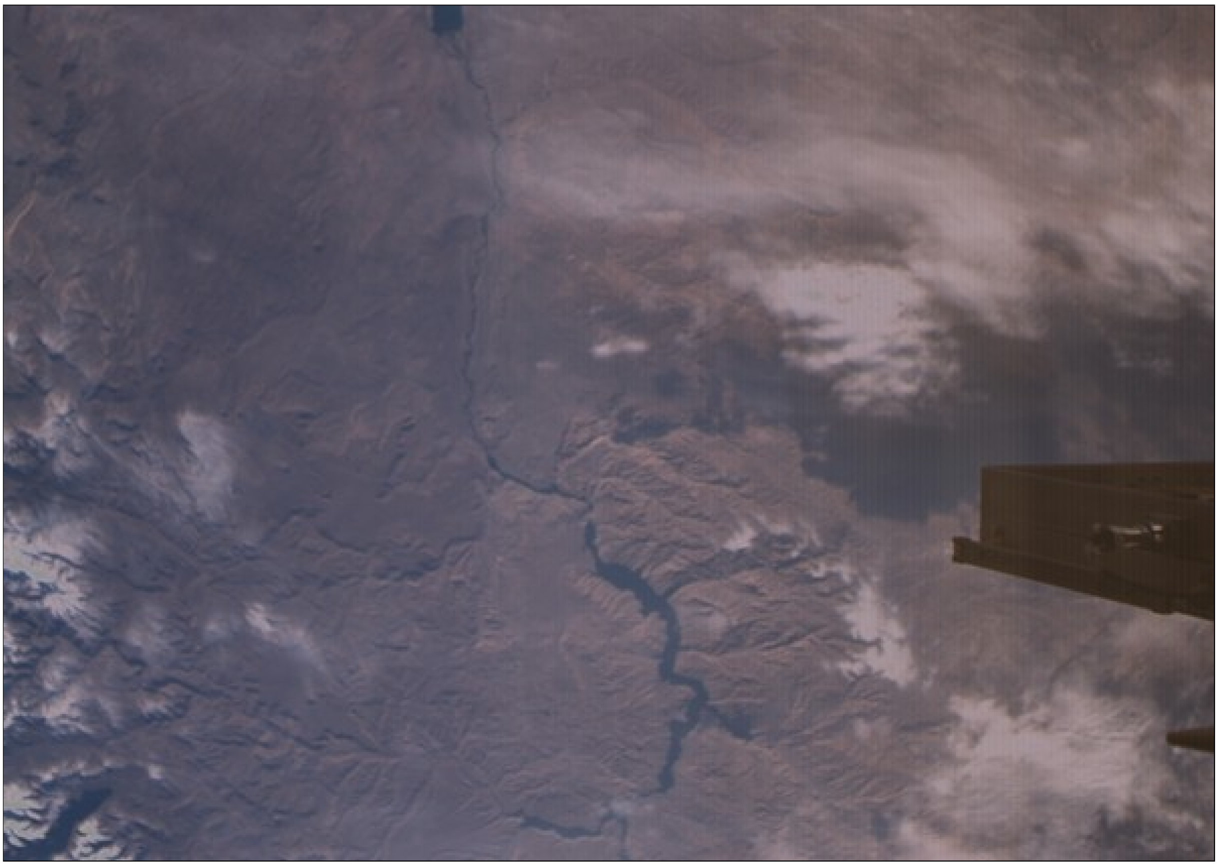
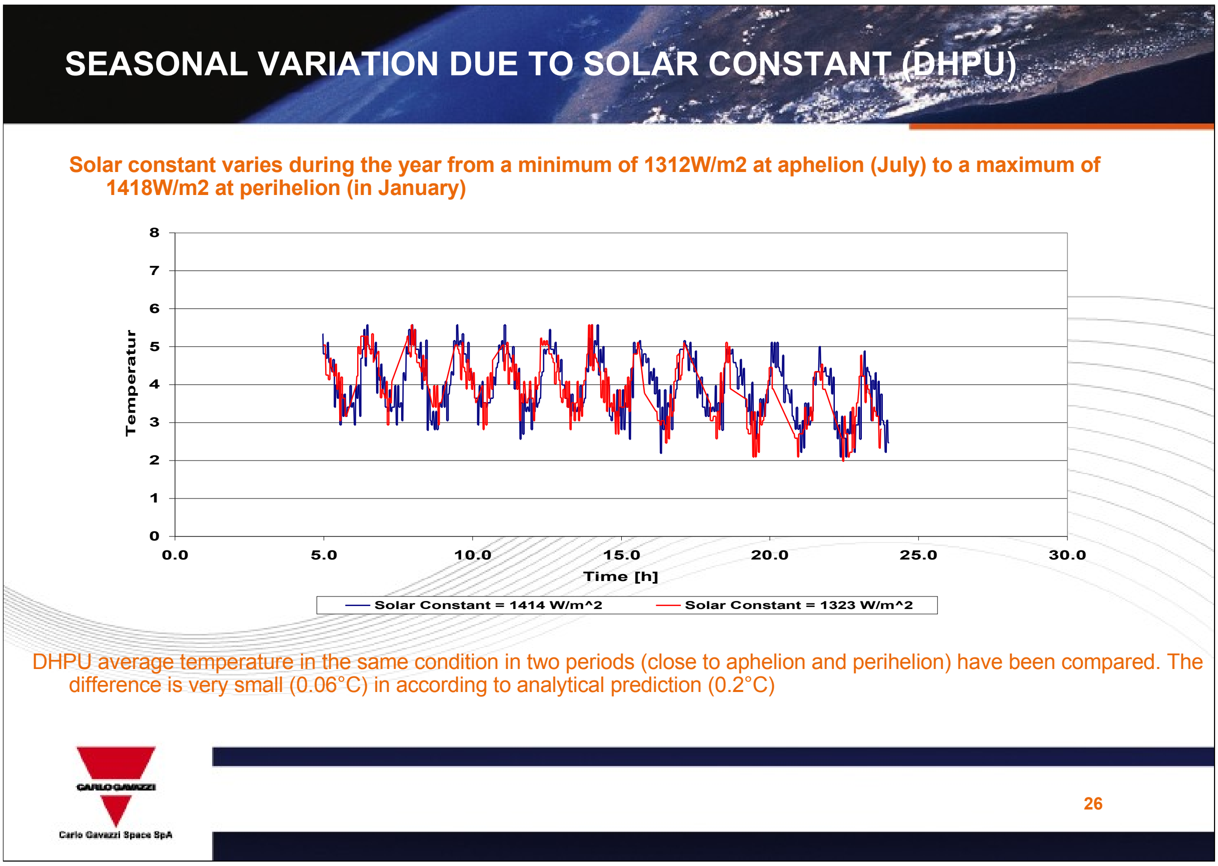

Leonardo
NASA




CARLO GAVAZZI
Carlo Gavazzi Space SpA
Headquarters: Via Gallarate 150 - 20151 Milano (Italy)
Tel: +39.02.380481 - Fax: +39.02.3086458
Website: www.cgspace.it - E-mail: cgs@cgspace.it
Other offices in Italy: Benevento - Bologna - Perugia
Rivalta Scrivia (AL) - Roma - S. Giorgio del Sannio (BN)


SEASONAL VARIATION DUE TO SOLAR CONSTANT (DHPU)
Solar constant varies during the year from a minimum of 1312W/m2 at aphelion (July) to a maximum of 1418W/m2 at perihelion (in January)
Temperatur
Time [h]
Solar Constant = 1414 W/m^2
Solar Constant = 1323 W/m^2
DHPU average temperature in the same condition in two periods (close to aphelion and perihelion) have been compared. The difference is very small (0.06°C) in according to analytical prediction (0.2°C)
CARLO GAVAZZI
Carlo Gavazzi Space SpA
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Appendix U

List of Participants

Altenburg, M.
Astrium GmbH - Satellites
Thermal Engineering and Analysis
Claude-Dornier-Straße
88039 Friedrichshafen
GERMANY
☎ +49 (0) 7545 8 2494
🖷 +49 (0) 7545 8 18 2494
🖂 martin.altenburg@astrium.eads.net

Ancuta, I
ESA/ESTEC
D/TEC-MTV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 56 55248
🖂 carmen.gina.ancuta@esa.int

Battaglia, D.
Thales Alenia Space Italy - Turin
Thermal Control
Strada Antica di Collegno, 253
10100 Turin
ITALY
☎ 0039- 011- 7180430
🖂 domenico.battaglia@thalesaleniaspace.com

Baucher, M.
EADS Astrium
31 rue des cosmonautes
31402 Toulouse Cedex 2
FRANCE
☎ 05.62.19.62.19
🖂 marc.baucher@astrium.eads.net

Beaumont, H
ITP Engines UK
Thermal Engineering and Software Products
Cambridge Road
LE8 6LH Leicester
UNITED KINGDOM
☎ 00441162845748
🖂 helen.beaumont@itp-engines.co.uk

Beck, T.
University of Bern
Space Research and Planetary Sciences
Sidlerstrasse 5
3012 Bern
SWITZERLAND
☎ +41 31 631 55 46
🖂 thomas.beck@space.unibe.ch

Bernard, M
ASTRIUM
ASG24
31 rue des Cosmonautes
31402 Toulouse Cedex 4
FRANCE
☎ +33 5 62 19 61 44
🖷 +33 5 62 19 77 44
🖂 Mathieu.BERNARD@astrium.eads.net

Bodendieck, F.
OHB-System AG
Thermal Department
Universitaetsallee 27-29
28359 Bremen
GERMANY
☎ +49 421 2020 626
🖷 +49 421 2020 900
🖂 bodendieck@ohb-system.de

Brouquet, H
ITP Engines UK
Thermal Engineering and Software Products
Cambridge Road
LE8 6LH Leicester
UNITED KINGDOM
☎ 00441162845764
🖷 00441162845462
✉ henri.brouquet@itp-engines.co.uk

Brunetti, F.
DOREA
Résidence de L'olivet Bat F, 75 chemin de l'Olivet
06110 Le Cannet
FRANCE
☎ +33 (0)4 93 69 07 48
🖷 +33 (0)6 64 69 17 00
✉ francois.brunetti@dorea.fr

CAPITAINE, A.
Astrium Toulouse
Analyses & Tests en Mécanique / Thermique / Fluidi
31, avenue des Cosmonautes
31402 Toulouse Cedex 4
FRANCE
☎ 33-05.62.19.75.22
🖷 33-05.62.19.77.44
✉ andre.capitaine@astrium.eads.net

Checa Cortes, E
ESA/ESTEC
TEC-MTT
keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ 0031715656606
✉ Elena.Checa@esa.int

Damasio, CD
ESA ESTEC
TEC MTT
keplerlaan 1
2201 AZ noordwijk
NETHERLANDS
☎ 0715656276
✉ claudio.damasio@esa.int

de Koning, H.P.
ESA/ESTEC
D/TEC-MTV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 3452
✉ Hans-Peter.de.Koning@esa.int

De Palo, S.
thalesalenia space
thermal
strada antica di collegno 253
10146 torino
ITALY
☎ +39-011-7180875
🖷 +39-011-7180873
✉ savino.depalo@thalesaleniaspace.com

Del Togno, S
DLR - German Aerospace Center
Institute for Planetary Research
Rutherfordstrasse 2
DE-12489 Berlin
GERMANY
☎ +49 30 67055 579
✉ simone.deltogno@dlr.de

Di Carmine, E
Galileo Avionica
Space LoB
Via Einstein 35
50013 Campi Bisenzio
ITALY
☎ +39 055 8950550
🖷 +39 055 8950606
✉ emiliano.dicarmine@selexgalileo.com

Dolce, Silvio
ESA
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
✉ silvio.dolce@esa.int

Doledec, M.A.
EPSILON
10 rue Jean Bart
31674 LABEGE cedex
FRANCE
☎ 05 61 00 19 19
✉ madoledec@epsilon-alcen.com

Dudon, Jean-Paul
THALES ALENIA SPACE
Research
100 Bd du midi
06156 cannes la bocca
FRANCE
☎ 04 92 92 67 13
✉ jean-paul.dudon@thalesaleniaspace.com

Etchells, James
ESA
D/TEC-MTV
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
✉ james.etchells@esa.int

Fagot, A.
DOREA
Résidence de l'Olivet Bat F - 75 chemin de l'Olive
06110 Le Cannet
FRANCE
☎ +33 (0)870256405
📠 +33 (0)6 64 69 17 00
✉ alain.fagot@dorea.fr

Franzoso, A.
Carlo Gavazzi Space
Mech/Thermal
VIA GALLARATE 150
20151 MILANO
ITALY
☎ +39 02 38048243
✉ AFRANZOSO@CGSPACE.IT

Gabarain, D.
ESA/ESTEC
TEC-MTT
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ 0031 7156 58602
✉ david.gabarain@esa.int

Gibson, D.
ESA/ESTEC
D/TEC-MTV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 4013
✉ Duncan@thermal.esa.int

Giunta, D.
ESA
P.O. Box 299
2200AG Noordwijk
NETHERLANDS
☎ +31715653863
✉ domenico.giunta@esa.int

Gorlani, M.
BLUE GROUP
Engineering
via Albenga 98
10098 Cascine Vica, Rivoli (TO)
ITALY
☎ +39 0119504211
📠 +39 0119504216
✉ m.gorlani@blue-group.it

Huermann, B.
Jena-Optronik
Prüssingstraße 41
07745 Jena
GERMANY
☎ +49 176 23877930
✉ brian.huermann@jena-optronik.de

Isik, H. G.
Turkish Aerospace Industries, Inc.
Satellite Technologies
TAI B Blok ODTU Teknokent
06530 Ankara
TURKEY
☎ +903128111800/3674
✉ hisik@tai.com.tr

Jahn, G.
Astrium GmbH
Central Engineering - ASG23
Claude-Dornier-Straße
88090 Immenstaad
GERMANY
☎ +49-7545-83472
Fax +49-7545-8183472
✉ Gerd.Jahn@astrium.eads.net

Kasper, S.
Jena-Optronik GmbH
JEM
Pruessingstrasse 41
D-07745 Jena
GERMANY
☎ +49 3641 200176
✉ stefan.kasper@jena-optronik.de

Kirtley, C
ITP Engines UK
Thermal Engineering and Software Products
Cambridge Road
LE86LH Leicester
UNITED KINGDOM
☎ 00441162845653
✉ chris.kirtley@itp-engines.co.uk

Komarek, M.
L.K. Engineering
Srbska 53
61200 Brno
CZECH REPUBLIC
☎ +420 543 215 682
✉ komarek@lke.cz

Lapensee, S.
ESA
ESTEC TEC-MTT
Keperlaan 1
2200AG Noordwijk
NETHERLANDS
☎ 71 565 8733
✉ stephane.lapensee@esa.int

Lebegue, E.
CSTB
290 route des Lucioles
06904 SOPHIA-ANTIPOLIS
FRANCE
☎ +33.4.93.95.64.23
✉ eric.lebegue@cstb.fr

Leroy, S
DOREA
Residence de L'Olivet Bat F- 75 Chemin de l'Olivet
06110 Le Cannet
FRANCE
☎ +33 (0)6 33 05 25 46
Fax +33 (0)6 64 69 17 00
✉ sandrine.leroy@dorea.fr

Loetzke, H.-G.
DLR German Aerospace Centre
Institue of Space Systems
Rutherfordstr. 2
12489 Berlin
GERMANY
☎ 493067055617
✉ horst-georg.loetzke@dlr.de

Messina, G.
DLR - German Aerospace Center
Instutute for Planetary Research
Rutherfordstr. 2
12489 Berlin
GERMANY
☎ 0049 30 67055 420
✉ gabriele.messina@dlr.de

Münstermann, R.
Astrium Space Transportation
Airbus-Allee 1
28199 Bremen
GERMANY
☎ +49 421 539 5011
✉ rolf.muenstermann@astrium.eads.net

Nadalini, R
Active Space Technologies GmbH
Rudower Chaussee 29
12489 Berlin
GERMANY
☎ +49 30 63926059
✉ riccardo.nadalini@activespacetech.com

Pasquier, H.
CNES
BPI 1716 - 18 avenue Edouard Belin
31401 TOULOUSE Cedex 9
FRANCE
☎ 0561283544
✉ helenem.pasquier@cnes.fr

Petersen, H.
Dutch Space
Mendelweg 30
2333 CS Leiden
NETHERLANDS
☎ 071-5245852
✉ h.petersen@dutchspace.nl

Pin, O.
ESA/ESTEC
D/TEC-MTV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 5878
✉ Olivier.Pin@esa.int

Price, S G
Astrium UK
Thermal Engineering
Gunnels Wood Road
SG1 2AS Stevenage
UNITED KINGDOM
☎ +44 (0) 1438 778536
✉ steve.price@astrium.eads.net

Pucci, E
Galileo Avionica
Space LoB
Via Einstein 35
50013 Campi Bisenzio
ITALY
☎ +39 055 8950550
📠 +39 055 8950606
✉ egidio.pucci@selexgalileo.com

Rathjen, H.
Astrium Space Transportation
Airbus-Allee 1
28199 Bremen
GERMANY
☎ +49 421 539 4173
✉ harold.rathjen@astrium.eads.net

Romera Perez, J.A.
ESA/ESTEC
TEC
Keplerlaan, 1
2200 AG Noordwijk
NETHERLANDS
☎ +31 71 5653979
📠 +31 71 5656240
✉ jose.antonio.romera.perez@esa.int

Rooijackers, H.
ESA/ESTEC
D/TEC-MTV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 3453
✉ Harrie.Rooijackers@esa.int

Santoni, M.
Galileo Avionica
Space LoB
Via Einstein 35
50013 Campi Bisenzio
ITALY
☎ +39 055 8950796
📠 +39 055 8950606
✉ massimo.santoni@selexgalileo.com

Siemer, M.
DLR German Aerospace Centre
Institute of Space Systems
Robert-Hooke-Str. 7
28359 Bremen
GERMANY
☎ 49 421 24420157
📠 49 421 24420120
✉ Martin.Siemer@DLR.DE

Sorensen, John
ESA
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
✉ john.sorensen@esa.int

Soriano, T.
EADS Astrium
31 rue des cosmonautes
31402 Toulouse Cedex 4
FRANCE
☎ (+33)562199176
✉ timothee.soriano@astrium.eads.net

Stroom, C.
private
Gerrit van der Veenstraat
1077EB Amsterdam
NETHERLANDS
☎ +31-6-4284.9092
✉ charles@stremen.xs4all.nl

Supper, Wolfgang
ESA
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
✉ wolfgang.supper@esa.int

Tentoni, L.
Thales Alenia Space Italia
THERMAL CONTROL
STRADA ANTICA DI COLLEGNO 253
10146 TURIN
ITALY
☎ +39 011 7180 981
📠 +39 011 7180 873
✉ luca.tentoni@thalesaleniaspace.com

Theroude, C.
Astrium Satellites
ASG42
31 rue des cosmonautes
31402 Toulouse
FRANCE
☎ +33 5 62 19 68 85
📠 +33 5 62 19 77 90
✉ christophe.theroude@astrium.eads.net

Tonellotto, G.
ESA/ESTEC
TEC-MTT
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 4817
✉ giulio.tonellotto@esa.int

Tosetto, A.
Blue Engineering
via Albenga 98
10098 Turin
ITALY
☎ +39 011 9504211
✉ a.tosetto@blue-group.it

Tralli, A.
BuNova Development BV
eekwal 22a
8011LD Zwolle
NETHERLANDS
☎ +31 (0)38 4237474
✉ a.tralli@bunova.nl

Uygur, A. B.
Turkish Aerospace Industries, Inc.
Satellite Technologies
TAI B Blok, ODTU Teknokent
06530 Ankara
TURKEY
☎ +903128111800/3674
✉ auygur@tai.com.tr

van Baren, C
SRON
Sorbonnelaan 2
3584 CA Utrecht
NETHERLANDS
☎ 0887775621
✉ C.van.Baren@sron.nl

van Eekelen, T.
Samtech s.a.
Analysis department
B-4031 ANGLEUR-LIEGE
BELGIUM
☎ +32-43616969
✉ Tom.vanEekelen@samtech.com

Varewijck, G.
ESTEC
TEC-MTV
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ +31715655080
✉ george.varewijck@esa.int

Vey, S
ESA - ESTEC
TEC-MTT
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ +31715658309
✉ sylvain@thermal.esa.int

Vigouroux, J.M.
DOREA
Résidence de l'Olivet Bat B, 75 chemin de l'Olivet
06110 Le Cannet
FRANCE
☎ +33 (0)4 93 69 07 48
📠 +33 (0)6 64 69 17 00
✉ jean-michel.vigouroux@dorea.eu

Wild, D
EADS Astrium
Gunnels Wood Road
SG1 2AS Stevenage
UNITED KINGDOM
☎ +44 1438 778565
✉ daniel.wild@astrium.eads.net

Zevenbergen, P.
Dutch Space B.V.
Thermal Engineering
Mendelweg 30
2333 CS Leiden
NETHERLANDS
☎ 071 5245018
✉ p.zevenbergen@dutchspace.nl