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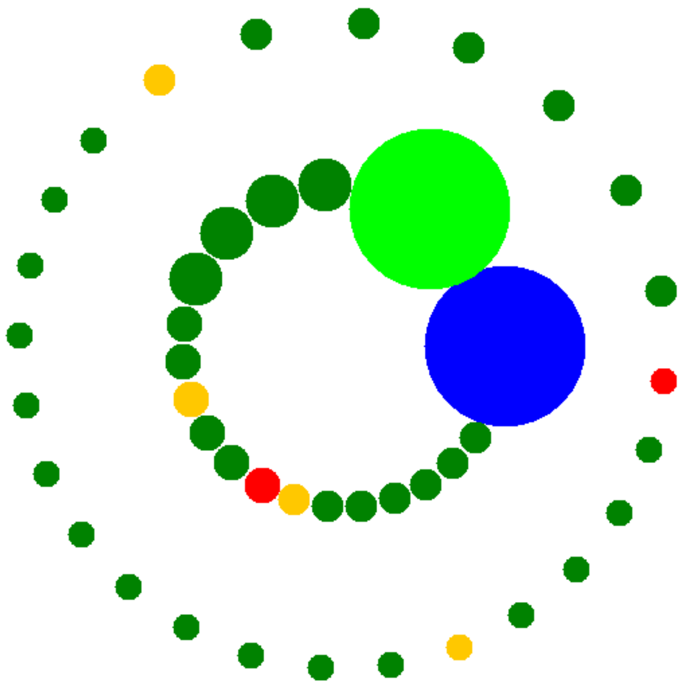
8–9 November 2011



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Abstract

This document contains the minutes of the 25th European Workshop on Thermal and ECLS Software held at ESA/ESTEC, Noordwijk, The Netherlands on 8–9 November 2011. 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'.

Please note that text like this are clickable hyperlinks in the document.

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Programme Day 1

9:00 Registration

9:30 **Opening address**

Constantinos Stavrinidis (ESA/ESTEC, The Netherlands)

9:40 **Welcome and introduction**

Harrie Rooijackers (ESA/ESTEC, The Netherlands)

9:50 **Thermal Analysis for Re-entry Vehicles** — Ablative tool integration in ESATAN

Savino De Palo & Lorenzo Andrioli (ThalesAlenia Space, Italy)
Marco Giardino & Giuseppe Ruscica & Elena Campagnoli (Politecnico di Torino, Italy)

10:20 **The Use of ESATAN-TMS r3 software for Ray Tracing Visualisation**

Roisin Speight & Alex Jacobs (EADS Astrium, UK)

10:50 **First year using ESATAN-TMS** — A newcomer's reflections

Edward Jones (STFC Rutherford Appleton Laboratory, United Kingdom)

11:20 Coffee break in the Foyer

11:45 **Application of ESATAP for automatic thermal model validation**

Stephan-André Kuhlmann (OHB System AG, Germany)

12:05 **ESATAP 2.1.0 evolutions and implementation of new User's requirements**

Mathieu Bernard & Stephane Iugovich (EADS Astrium, France)
Alain Fagot (Dorea, France)
Harrie Rooijackers (ESA/ESTEC, The Netherlands)

12:30 **Thermal Model Reduction using the Super-Face Concept**

Luc Masset & Olivier Brüls & Gaetan Kerschen (University of Liège, Belgium)

13:00 Lunch in the ESTEC Restaurant

14:00 **Wavelength-selective filters in ESATAN-TMS**

Pedro Ferreira (MPS, Germany)

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

Chris Kirtley (ITP Engines UK Ltd, United Kingdom)

15:00 **ESATAN Thermal Modelling Suite** — A New User Interface for CAD Geometry

Henri Brouquet (ITP Engines UK Ltd, United Kingdom)

15:30 Coffee break in the Foyer

16:00 **Prototype demonstration of Thermal Design Module for automated design and temperature calculation of space harness**

Fennanda Doctor & Roel van Benthem (National Aerospace Laboratory, The Netherlands)

16:30 **SYSTEMA-4.5.0**

Maxime Jolliet (EADS Astrium, France)

17:00 **THERMICA-THERMISOL 4.5.0**

Timothée Soriano (EADS Astrium, France)

17:30 **Spatial Infra-red Objective thermal analysis**

Jean-Baptiste Meurisse & Salem Belmana & Remi Gazin (Sodern, France)

18:00 Social Gathering in the Foyer

19:30 Dinner in *Lamme Goedzak*

Programme Day 2

8:30 **STAR-CCM+ for Complex CAE Design Problems**
Ashkan Davoodi & Ian Greig (CD-adapco, United Kingdom)

9:00 **Multi-Physics Simulation Technology in NX**
Christian Ruel (Maya Htt, Canada)

movies/SatMapping

9:30 **Thermal Correlation of BepiColombo MOSIF 10 Solar Constants Simulation Test**
Savino De Palo & Tiziano Malosti (ThalesAlenia Space, Italy)
Gianluca Filiddani (Sofiter System Eng., Italy)

10:00 **Lessons Learned on Modelling of Cryogenic Systems**
Moritz Branco (ESA/ESTEC, The Netherlands)

10:20 **Model reduction of Sentinel 1**
Daniel Kintea (ESA/ESTEC, The Netherlands)

10:40 **Validation of a Method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model**
Lars Hagemann (EADS Astrium - Space Transportation, Germany)

11:00 Coffee break in the Foyer

11:30 **Evaluation of stochastic & statistic methods for spacecraft thermal analysis**
Jean-Paul Dudon (Thales Alenia Space, France)
Hélène-Marie Pasquier (CNES, France)

12:00 **The ESATAN-TMS Finite Element Analysis Method** — User Experiences
Gunnar Sieber & Stefan Kasper (Jena-Optronik GmbH, Germany)

12:30 **Thermal Concept Design Tool** — 5th Year
Matteo Gorlani & Andrea Tosetto (Blue Engineering, Italy)
Harrie Rooijackers (ESA/ESTEC, The Netherlands)

13:00 Closure

13:00 Lunch in the ESTEC Restaurant

14:00 TCDT Training provided by Blue Engineering

Opening address

Good morning Ladies and Gentlemen.

On behalf of the European Space Agency I have the honour and pleasure to address the audience of the 25^{th} European Workshop on Thermal and ECLS Software, here at ESTEC.

I would like to express a warm welcome to all participants coming from various ESA Member States and beyond.

It is fair to mention that the European Workshop on Thermal and ECLS Software is one of the longest running workshops at ESA. It was started as "The ESATAN Workshop" by, the now retired, Mr Charles Stroom in 1985 to introduce the ESATAN space thermal analysis tool to the European thermal community as a replacement for SINDA, and to exchange information between users and developers. This first workshop was attended by 38 participants.

The second workshop was held in 1987 and called "ESATAN Users Meeting". Since then the workshop has been taking place every year and already from the early days it was intended that this event will serve the exchange of information between users. The scope of the workshop has significantly evolved over the years, as ESA's approach to the thermal tools also evolved.

In these 25 events we have had more than 470 presentations and almost 1500 registered participants, some of them attending almost all workshops. Over 70 participants have registered for the present workshop, and confirm the continuous value and use of this workshop to the space thermal community.

The objectives of this workshop are:

- to promote the exchange of views and experiences amongst the users of European and worldwide space thermal analysis tools and related methods
- to provide a forum for contact between end users and software developers
- to present new features of thermal tools and solicit feedback for development
- to present innovative advancements
- to address standardisation activities.

This year's workshop program consists of 22 presentations covering recent developments of thermal analysis tools and methods used by the thermal space community. The presentations cover a wide range of topics, and we are particularly happy to see in this Workshop many colleagues from industry, research institutes, universities, national agencies and thermal analysis tool developers.

Engineering tools are evolving rapidly where the keywords include integration of the workflow, reducing time and effort to build a model from CAD and process the results, multiphysics approaches, concurrent design engineering, model verification and model exchange. These important aspects are addressed in the various presentations.

This 2011 edition might be appropriately called "the user's perspective" since many of the presentations come from users of the various tools. It continues to be a particularly important aspect of this workshop to acquire feedback from the users.
This workshop takes place in a difficult economic period. The financial constraints are affecting not only some of our programs, but also led to various limitations affecting travel budgets in most companies, universities and research institutes. Therefore I especially thank you all for your attendance here today and your participation in this workshop. It demonstrates the importance and continuous interest by the space community in the development and application of space thermal analysis methods and related software.

A very special "thank you" to all colleagues who have contributed in organising this workshop and in particular I would like to thank Mr Rooijackers who has been the main organiser of many of these workshops.

This evening you are all invited by ESA to the welcome drink, which will take place in the Foyer.

For me it is a real pleasure and honour to address such distinguished participants and to declare open the 25^{th} European Workshop on Thermal and ECLS Software here at ESTEC. I would like you to feel at home, and I hope you will find this event both enjoyable and rewarding. I now want to hand over to my colleague Mr Harrie Rooijackers, the main organiser of the workshop, who will provide you with some details on the logistics.

Dr C. Stavrinidis
Head of the Mechanical Engineering Department, TEC- M.

Day 1

Tuesday 8th November 2011

1.1 Welcome and introduction

H. Rooijackers (ESA/ESTEC) welcomed everybody and quickly ran through the main goals of the workshop and various logistical points, such as the Workshop dinner that evening. (See appendix A)

1.2 Thermal Analysis for Re-entry Vehicles — Ablative tool integration in ESATAN

S. de Palo (Thales Alenia Space) presented the work done by his colleagues to create a new tool, integrated with ESATAN, for representing ablative thermal protection systems using a 1D finite volume model. The design of the new tool had used the lessons learnt from a previous tool, `AblaTherm`, so that the results could be much more easily integrated into the `ESATAN` model. (See appendix B)
J. Persson (ESA/ESTEC) asked about the reference cases which had been used: one had used NORCOAT for EXOMARS, but NORCOAT was also used by various launchers. He wondered whether they had considered using a launcher as a reference case. S. de Palo replied that they had not been looking at the material itself but had been focusing on the analysis process. The reference cases had used NORCOAT and AVCOAT but it was important to be able to use the analysis process for any ablative material, and to have a simple way of providing input. S. de Palo said that they had found the `ABLAT` software to be very complex to use due to the input data required. The new tool had been designed to simplify the effort needed to build the model.
G. Chirulli (ESA/ESTEC) asked how many components could be modelled using the Arrhenius Law, because the NASA CMA software had some limits. S. de Palo said that there were three components, so it was similar to the NASA CMA. G. Chirulli asked how the blocking factor was handled: did the user need to give a number? S. de Palo said that the blocking factor was computed by the software. The formulas to describe the physics of blocking were quite complicated. There were pages of equations required to calculate the values. The software took into account the blocking in the pyrolysis cases. The assumption was that any gas produced was instantaneously transferred outside the porous material. This assumption was OK if the material was highly porous: if not porous, then the flow needed to be computed in order not to over-estimate any blocking effects due to trapping of the gas within the system.
G. Chirulli commented that the analysis therefore assumed a certain atmosphere around the

vehicle, in this case the calculations were for Mars, which had a different atmosphere to Earth. He said that the data for the Earth's atmosphere should also be available, and he expected the reaction to be different. S. de Palo said that the data had been collected from the EXOMARS colleagues, and he didn't know the real details about the atmospheric data that had been collected. He could answer any further questions on the boundary modelling by email.
G. Chirulli asked whether it was foreseen to extend the modelling to include swelling of the material layers. S. de Palo didn't think so.

1.3 The Use of ESATAN-TMS r3 software for Ray Tracing Visualisation

R. Speight (Astrium UK) described using the `ESATAN-TMS` r3 feature for displaying the rays striking a particular face during the solar flux ray tracing calculations as part of a design study for the solar array yoke on Sentinel 3. (See appendix C)
H. Isik (Turkish Aerospace Industries) asked about the different specular and diffuse reflectivity values that had been used. R. Speight said that it was possible to create different optical properties in the geometric model. H. Isik continued by saying that each surface had specific reflectivity, absorptivity and emissivity values, and wondered whether the results had been derived from existing materials, or whether the results were from using totally specular and totally diffuse values. R. Speight said that the first analysis shown in the presentation had used fully specular materials on the solar array yoke, and the second had been fully diffuse.
P. Ferreira (Max Planck Institute) asked whether the analysis had been made for a single inclination of the solar array, or for many. R. Speight said that only one orientation had been chosen because this was part of the early analysis phase. The inclination corresponded to the worst case at the closest approach to the Sun.
J. Persson (ESA/ESTEC) wondered whether a method like this would also be useful to see the heat transfer in a molecular regime in a rarefied gas. He could see different applications of this technique. R. Speight said that she did not know about that, and suggested that he talk to ITP directly.

1.4 First year using ESATAN-TMS — A newcomer's reflections

E. Jones (STFC/RAL) presented his experiences of using the `ESATAN-TMS Workbench` after having previously worked with commercial CAD software tools. (See appendix D)
S. de Palo (Thales Alenia Space) commented that he had described his experiences of `FHTS` at a workshop more than 10 years previously, and that he always hoped to see new developments on `FHTS`. He would be interested to see a similar presentation on `FHTS` now.
S. de Palo was curious to know whether E. Jones had taken advantage of the experience of colleagues, and training from ITP, or whether he had started to learn `ESATAN-TMS` from scratch on his own. E. Jones said that his manager had taken him through the use of `ESATAN-TMS`, but had shown him how to use `ESARAD` and `ESATAN` as separate tools. His use of the `Workbench` had come from the `ESATAN-TMS` training course that he had attended in February, and by studying the manual and tutorials. A lot of the details of the GUI he had had to work out on his own. He found it strange that different people in the same department worked in different ways to use the same programs.

H. Rooijackers (ESA/ESTEC) asked whether he had been using the GUI only, or whether he also made use of the batch mode tools. E. Jones said that he had mainly used the GUI, but the MIRI film modelling had already been created by pure coding in the ".erg" and ".d" files, and so for MIRI he had used the batch processes. Initially he had found it difficult to take an established split `ESARAD` and `ESATAN` work flow and implement it in one integrated `Workbench` session.
G. Sieber (Jena-Optronik) asked about the post-processing of results and whether he had used `ThermNV` or the internal `Workbench` visualisation. E. Jones said that in general he had written his results to a CSV file so that he could use Excel. The post-processing for mapping temperature results onto the geometry had been done in the `Workbench`. Some of the ray-tracing and heat load analysis had been done in the `Workbench`, but plotting temperatures had been done in Excel.

1.5 Application of ESATAP for automatic thermal model validation

SA. Kuhlmann (OHB) described the implementation of `ESATAP` components for calculating some overall model properties in order to provide a first check before detailed model verification. (See appendix E)
A. Fagot (DOREA) thanked SA. Kuhlmann for working with the beta version of `ESATAP` and for looking at some of the new functionality. He said that the evaluation shown in the presentation had been completed only shortly before the workshop, and that the initial versions of these new `ESATAP` components had only printed the results to the window. The latest versions of these components now gave better formatted output in HTML, or as CSV files for inclusion in Excel. He said that there would be more improvements to the components before the final version was released.

> B. Laine (ESA/ESTEC) took this opportunity to say something about a current activity on thermal model verification. This is described in the next section.

P. Ferreira (Max Planck Institute) asked whether it had taken SA. Kuhlmann a long time to become acquainted with `ESATAP`. SA. Kuhlmann said that `ESATAP` provided a tool box of components, and the basic drag and drop way to build a tool layout was quite easy. However he had initially found it tricky to set the specifications within the components correctly, when in fact usually only one or two of the fields needed to be filled. `ESATAP` was divided into parts. He had used the super-user GUI where the user could combine tasks, and create new ones, but this only really needed to be done once. After that, all that was needed was to just use the list of tasks, click to select and connect them, and then click on the "run" button to start the model validation task. This activity had shown that if a company wanted to set up a standard set of checks on all of its models it could do so, and then it was possible to click a button to see if the models were OK.
T. Soriano (EADS Astrium) commented that many ordinary users would have difficulties to define the tasks themselves, and wondered whether it would be possible to set up an open source system to share simple tasks of interest to everybody, and to allow people to comment and offer corrections.
A. Fagot said that all components that had been created for `ESATAP` were already shared as they were included in each release. The ESA development had provided tasks that would be useful to everyone, and could be used by everyone. If a company wanted a specific task creating, they could pay to have their own task developed.
A. Fagot said that the expert or super user mode in `ESATAP` for developing tasks was complicated, but once a task had been created and finalised, it was easy for an ordinary user to launch the task. `ESATAP` would ask simple questions about the inputs required. Each task that had been validated

had a wizard, a sort of GUI, to call it in simple mode. Most end users would work with components in simple mode.
B. Laine wanted to go back to the question about sharing tasks and the model verification work. He asked what checks should be done as part of the model verification. He said all ideas would be welcome. If specific model checks already existed in industry, ESA could capitalise on them and get them implemented as part of the contract with DOREA.

1.6 ESA Internal Activity on Thermal Model Verification

B. Laine (ESA/ESTEC) took the opportunity to say something about a current ESA activity on thermal model verification, and which would be discussed further in the NESTA meeting. He pointed out the white papers on the walls which were "mind maps" of the various topics under consideration. He also said that there was a draft paper on Thermal Model Validation and Verification available for comment on the table, (see appendix X) and he invited people to browse through them and add comments. He suggested people add their initials so that they could be consulted afterwards if clarifications were needed. He said that it would be useful if input from company guidelines could be shared too. All input would be welcome. The goal was to have thermal model verification documents that were useful to the whole community.
B. Laine then brought everyone's attention to the other posters which promoted the different facilities available within the Mechanical Systems Laboratory at ESTEC, and asked people to come and see him if there were any tests which the MSL could do for them.

1.7 ESATAP 2.1.0 evolutions and implementation of new User's requirements

M. Bernard (Astrium) described a series of feature requests that ASTRIUM had proposed for `ESATAP`, and A. Fagot (DOREA) described how these has been realised in the latest beta version currently under test at ASTRIUM. (See appendix F)
Someone asked whether there was a user manual and whether `ESATAP` was user friendly. A. Fagot said that there was a user manual with a lot of exercises. The exercises had initially been created for expert mode and were therefore complex, but the new user manual had been rewritten for ordinary thermal users calling tasks via the wizards. He said that anyone wanting to develop tasks could always talk to DOREA. All of the simple tasks and predefined components were already available to everyone and were covered in the user manual.
A. Fagot said that to make it easier for end-users, the new version had involved some re-engineering of `ESATAP` to re-manage tasks to avoid changes to too many links. It was now possible to run `ESATAN` or `THERMISOL` and generate CSV output, and read it into `ESATAP`, and then re-run and re-import the data without changing the task.

1.8 Thermal Model Reduction using the Super-Face Concept

L. Masson (University of Liége) described work on reducing computation time by creating super-faces from finite element models using the METIS algorithm and then using either numerical integration or ray tracing to calculate the view factors. (See appendix G)
S. Leroy (DOREA) asked whether this technique applied only to the radiative part of the thermal model, or whether it included the conductive part as well. L. Masson said that the technique was

only applied to the radiative part, although Open Engineering had proposed a method to ESA to have a sort of thermal super-element to provide model reduction in the conductive part. The work shown only handled the radiative part, but in future he could imagine linking together the two reduction models.
T. Soriano (EADS Astrium) noted that the reduction had focused on view-factors, and was interested to know whether the method would also handle multi-reflection and specularity. L. Masson said that it was not possible at the moment because they had only looked at the numerical integration part so far. It would be possible in the future with the ray-tracing part.
M. Bernard (Astrium) was concerned about the irregular shapes produced and wondered whether it was possible to configure the super-face mesher to give more regular shapes, or to limit the aspect ratio. He said that after the geometrical model reduction the user might want to provide the reduced model containing just the usual simple shapes. L. Masson said that the software currently used the METIS algorithm without any changes, and that this gave irregular shapes. If the software could know that the faces in a plane were regular shapes, then maybe it would be possible to customise the algorithm to give regular super-faces too. He explained that what had been presented was just the start of the research in this area.

1.9 Wavelength-selective filters in ESATAN-TMS

P. Ferreira (Max Planck Institute) described the problems encountered when trying to model instruments on Solar Orbiter that had wavelength dependent optical coatings. (See appendix H)
T. Thiebert (University of Liége) asked whether it would have been possible to couple the thermal analysis with an optical ray-tracing software tool and use an iterative approach, with absorption and reflection handled in one tool, and then applying the heat fluxes in the other model. This would also allow other optical properties to be modelled, such as the refractive index of the glass. P. Ferreira said that he had not thought of using such an iterative approach, and didn't know anyone running any optical software tools. He was familiar with `ESATAN-TMS`, and anyway he had needed to model the instruments in orbit and allow for the finite size of the Sun. Using optical software would remove the solar calculation from the `ESATAN-TMS` analysis.

1.10 ESATAN Thermal Modelling Suite — Product Developments

C. Kirtley (ITP Engines UK) described the time-line of the recent developments leading to the release of `ESATAN-TMS` r4 and how these related to the customer requirements. (See appendix I)
S. Leroy (DOREA) asked about the geometry import from CAD models and wanted to know whether the format of the .erg and .d files had changed. C. Kirtley said that the .d file format had not changed.
J. Etchells (ESA/ESTEC) wondered about the new axi-symmetric geometry features and asked whether radiation exchange was handled. C. Kirtley said that it was not.

1.11 ESATAN Thermal Modelling Suite — A New User Interface for CAD Geometry

H. Brouquet (ITP Engines UK) gave a live demonstration of `CADbench`, the new GUI for actively visualising, selecting and manipulating parts of a finite element CAD model prior to conversion and import into the `ESATAN-TMS Workbench`. (See appendix J)

S. Price (Astrium UK) asked whether CADbench would be available on all of the platforms on which ESATAN-TMS was supported. H. Brouquet said that CADbench would only be available on PC because it made use of Microsoft technology. S. Price asked whether it would be possible to connect it to a Linux installation of ESATAN-TMS. H. Brouquet said that CADbench used the same path variables, and could therefore read from or write into a file system shared between both the PC and Linux systems. H. Rooijackers (ESA/ESTEC) asked whether ITP had tried to run CADbench under the Wine emulator for Windows on Linux. H. Brouquet said that they had not tried.

H. Rathjen (Astrium GmbH) asked what CADbench did with non-regular shapes that did not fit into one of the standard geometric primitives. H. Brouquet said that it would try to recognise the shapes as best it could, otherwise it would mesh them using triangles. H. Rathjen asked whether it was possible to recognise an ellipsoid and convert it to an approximation using cones or spheres. H. Brouquet said that the user could bring the triangle mesh for the complex shape into the Workbench and pick ranges of points from the triangles to re-create the cones or whatever the user wanted. H. Brouquet said that what was important in R4 were the new methods for creating shells using points. It was not always possible to convert complex shapes, but the user could make the most of the points available on the triangles and rectangles to re-create the shells that they wanted.

G. Sieber (Jena-Optronik) said that CADbench looked to be a nice tool for importing the STEP files from the designers and converting from 3D to 2D shapes. He had immediately asked himself whether the process could be used the other way round. He asked whether it could also be used to reverse the mapping, in order to put temperature results on the 3D CAD model to give back to the structural tools. H. Brouquet said that CADbench currently allowed one way conversion from CAD or STEP [AP-203 and AP-204] into ESATAN-TMS. CADbench was a new product, and ITP would try to improve it in the future. H. Brouquet said that if the geometry was imported into ESATAN-TMS as a finite element geometry, then the temperatures could be exported and passed back to the structural engineers via a temperature mapping file. He said that CADbench filled the gap for importing from CAD into ESATAN-TMS. If users wanted specific features, then they should ask.

J. Etchells (ESA/ESTEC) went back to the process of de-featuring, which would be useful to remove feed-through holes on tanks, etc. and asked whether this relied on the feature tree in the CAD model, or was simply based on shape recognition. He wanted to know whether the CAD user had to structure the CAD model in a particular way to allow the feature recognition in CADbench. H. Brouquet said that CADbench worked on what was displayed. The de-featuring only worked on the shapes that were displayed. The export worked in the same way, so the user could control what was exported by only displaying those parts which needed to be exported. The user could therefore create a specific component by selecting and displaying just the parts of interest from the CAD hierarchy.

J. Etchells asked which CAD formats were handled by CADbench. H. Brouquet showed the formats available on the Save-As menu, which included AutoCAD, STEP, IGES, Rhino, Sketchup and SpaceClaim. He said that if the model were saved in SpaceClaim format, this was the native tool format, and so it could be written without conversion to another tool format, which made it much quicker.

G. Jahn (Astrium GmbH) asked whether it was possible to save a history file in CADbench. H. Brouquet admitted that he did not know, as he was not fully trained in the tool. He thought that there might be a log file, and therefore it might be possible to re-use this somehow.

1.12 Prototype demonstration of Thermal Design Module for automated design and temperature calculation of space harness

R. van Benthem (NLR) described how techniques used for designing cable harnesses for the aircraft industry had been applied to the space environment, and how analysis had shown that the standard requirements to limit overheating may be too strict. (See appendix K)
P. Poinas (ESA/ESTEC) had a question about the graph showing relaxation of the ECSS requirements. R. van Benthem clarified that he was not asking for a relaxation, but suggested that it could be a possibility.
P. Poinas asked whether this was the result of an iteration of the model. If you removed convection, this left only radiation. Did this lead to a better temperature? R. van Benthem said they applied a rating factor. The basis was the current in vacuum to give a certain temperature, and then they applied a rating factor when using the same cable in a bundle. If the same cable were used in air then the rating factor would be different. P. Poinas then understood that the rating factor applied to a single cable compared to a cable in a bundle, so they had been looking at the radiation of a single cable compared to the radiation of a bundle. R. van Benthem said that radiation related mainly to the surface area, but if convection was involved there were more factors that came into play.
P. Poinas asked whether the difference was related to the way of measuring the temperature in the cable. He could see that there was a need to validate the Thermal Design Module, and that it had not been possible to see the details, but how had they modelled the conduction and convection in and around the cables? How had they performed the measurements? Based on temperature, or based on dissipation? R. van Benthem said that they had performed an extensive test campaign, in a test facility, using different bundles. The model had then been tuned using the test results. The model had started as an aircraft model with the convection and air conduction taken out in order to model space. However, they had only tested at low pressure and not vacuum.
P. Poinas still wanted to know how they had done the measurements. R. van Benthem said that they measured a lot of things such as the current and the power loss in the cables, and they had used a lot of thermo-couples. The sample bundle was 0.8m long and was the same through the complete section. They had also used pressure sensors. P. Poinas asked about the diameter of the thermo-couples and the dimensions of the wires. R. van Benthem said that they had used the smallest thermo-couples that they could find. These were 40 gauge thermo-couples, and were very thin, and did not affect the test.
JB. Meurisse (Sodern) observed that the test had assumed that the power dissipation in the cable was the same and that the whole system was homogeneous. He wondered about the connectors, as these might dissipate more power. R. van Benthem said that they had only considered the cables. The test took into account the change in resistance due to the change in temperature as part of the power dissipation.

1.13 SYSTEMA-4.5.0

M. Jolliet (Astrium) presented some improvements in `SYSTEMA` to provide a scripting interface so that models and meshes could be programmed in Python; changes to the 3D modelling and rendering; and the introduction of a mission time-line tool. (See appendix L)
M. Bernard (Astrium) asked whether the Python scripts could be executed on their own, outside of `SYSTEMA`. M. Jolliet said that the scripts could be run from within `SYSTEMA`, or from the batch

mode of SYSTEMA. M. Bernard wondered whether the script feature could be used by another software tool to provide a translator from that tool into a THERMICA model directly without having to launch the SYSTEMA user interface. M. Jolliet said that it would be possible to use another tool, and from it generate a Python script to create the model in SYSTEMA, and then use the SYSTEMA command line mode to execute the script just generated and to create and import the model into SYSTEMA.

H. Rooijackers (ESA/ESTEC) asked whether the Python module was fully integrated in the SYSTEMA release or whether it was limited in some way. M. Jolliet said that the complete Python would be delivered with SYSTEMA. It was fully integrated, so it was possible to use all of the standard Python modules from within SYSTEMA.

1.14 THERMICA-THERMISOL 4.5.0

T. Soriano (EADS Astrium) presented developments within THERMICA and THERMISOL, to include non-grey body modelling for multi-spectral analysis; a means of identifying and handling edges; and improvements to the generation of conductors for shape-to-shape couplings. (See appendix M)

JB. Meurisse (Sodern) asked about the grey body and wavelength dependent modelling. The slides had shown emissivity, and specularity, but he wanted to know whether wavelength dependent transmissivity was also taken into account. T. Soriano said that the wavelength dependent properties were not limited to emissivity. All of the infra-red properties could be wavelength dependent.

1.15 Spatial Infra-red Objective thermal analysis

JB. Meurisse (Sodern) described the problems inherent in modelling the thermal gradient in the lenses of an infra-red objective where the wavelength dependent properties of the the lenses needed to be taken into account, and the techniques used to do this in NX 7.5. (See appendix N)

R. Nadalini (Active Space Technologies) asked how they expected to be able to validate the model and all of the assumptions made. JB. Meurisse said that they planned to do a small experimental validation, using a simple case with the equipment in front of a cold plate. They would then measure the structural gradient, as this would be representative of the actual heat flux emitted from the equipment to the cold plate. If the gradient in the structure was calculated correctly then they could assume that the method was validated. They could not measure the temperature of a lens directly because it made no sense to put thermo-couples on it.

R. Nadalini asked whether they had thought of using thermal imaging. JB. Meurisse said they had not used thermal imaging. They had thought that because the spectral wavelength limits of the lenses meant that the lenses would absorb and filter some of the infra-rad radiation, affecting any thermal image of the structure, it would not be possible to use infra-red imaging. [1]

[1] There were new techniques which used software to analyse the actual radiation received in the un-filtered part of the spectrum and then used Wien's displacement law to reconstruct the probable radiation in the missing part of the spectrum to create a representative thermal image.

Day 2

Wednesday 9th November 2011

2.1 STAR-CCM+ for Complex CAE Design Problems

A. Davoodi (CD-adapco) gave a brief history of the company, and then I. Greig (CD-adapco) described the capabilities of `STAR-CCM+` and its application in continuous multi-physics simulations, and showed how it had been used to model heat flow in battery cells and in the passenger cabin of an aircraft. (See appendix O)
M. Molina (POLIMI) asked whether the software could model phase change materials. I. Greig said that they did have some melting and other phase change examples but that these were proprietary models, and that he could not distribute them. They did have tools for circuit board level analysis.
M. Molina asked whether they could handle capillary phenomena, with multi-phase materials, such as a loop heat pipe. I. Greig said they could, but that the problem was one of fidelity. It would probably take a powerful desktop machine a whole day or two to do a steady state analysis depending on how many loops were required, the number of heat exchanges, the number of times through the phase change calculations, etc. The user would probably need to restrict the model: a rough guide would be 1Gb for every million cells.
S. de Palo (Thales Alenia Space) asked whether it was possible to mix 3D modelling with 2D and 1D modelling. `STAR-CCM+` did not have its own coupling API at the moment so there was no nice way to couple tools at the socket level that was accessible to the users. I. Greig said that the next version would provide an API so that `STAR-CCM+` would be open at the socket to allow the exchange of data back and forth between tools. At the moment what `STAR-CCM+` did was to use Java macros to save data to files on hard disk, exchanging data that way and sharing it between codes. It was easy to couple one `STAR-CCM+` model with another, as had been shown in the cabin airflow example.
J. Etchells (ESA/ESTEC) asked whether `STAR-CCM+` supported MPCCI or similar technology for exchange of data between tools. I. Greig said that the examples shown had used Java macros to achieve the exchange. `STAR-CCM+` did have a socket-based coupling with `ABAQUS` which did not use MPCCI. Obviously MPCCI was a generic code, and could theoretically be used to access `STAR-CCM+` in the same way as accessing other tools. There was no restriction; `STAR-CCM+` had not said "no" to the use of MPCCI.
H. Rooijackers (ESA/ESTEC) asked whether the software was only available on Windows. Was it available on both 32- and 64-bit systems? I. Greig said that it was available on both 32- and 64-bit Windows system, and also on Linux systems such as Red Hat Enterprise, OpenSUSE and CentOS, but it was less well tested on Linux.

2.2 Multi-Physics Simulation Technology in NX

C. Ruel (MAYA) presented features of NX that allowed multi-discipline analysis, particularly in the thermal and structural areas where thermal deformation of the structure might change the contact heat paths through the structure. (See appendix P)
J. Persson (ESA/ESTEC) wondered whether the coupling between the CFD and thermal analysis also handled two phase systems. C. Ruel said that two phase systems were not supported.
G. Sieber (Jena-Optronik) asked whether thermal radiation analysis was supported. C. Ruel said that it was and that NX could also calculate solar, albedo and infra-red planet fluxes if required.

2.3 Thermal Correlation of BepiColombo MOSIF 10 Solar Constants Simulation Test

S. de Palo (Thales Alenia Space) described two approaches to correlating the results of the MOSIF thermal balance test held at ESTEC in November 2010 and the results from the thermal mathematical model: the first applied rules from a TAS-I internal procedure, and the second applied stochastic techniques and the iSight software. (See appendix Q)
M. Loche (ESA/ESTEC) asked whether they had considered using STORM. S. de Palo said that STORM did not work any more. They had used it for stochastic optimisation in the past so they were able to compare the performance of the algorithm. The first part involved a reduction of the range for optimisation followed by a refinement using the Simplex method. STORM was no longer sold, and there had always been difficulties in setting up the problems to be optimised. The iSight software offered multi-physics interactions and it was much easier to interface to Excel, Matlab and other tools used in-house.
M. Loche asked whether they had found any benefit for the final results: had the second phase gained any benefit from the first phase work? S. de Palo said that the correlation of the next tests for BepiColombo would use the optimisations to speed up the standard approach. M. Loche asked whether the next test would use both methods. S. de Palo said that the activity had given them an idea of what to optimise.
M. Molina (POLIMI) asked whether the software provided a confidence level in the results that had been identified. S. de Palo replied that it was possible to get any output from iSight that the user wanted. With most output it had to be exported to file, but with the appropriate licence it was possible to view the results via a web interface.
M. Molina commented that he had noticed effective emittance values with four significant figures. He wondered who or what was choosing how many digits to consider, and how this related to the accuracy of the actual temperatures being measured in the LSS during the test. S. de Palo said that this was a good question, but that he would need to ask his colleagues in Turin for the answer.
B. Laine (ESA/ESTEC) commented that in the model of the spacecraft in the LSS, there was more than just the geometry of the beam to consider, like, for instance, the homogeneity of the beam. He said that several models of the beam had been produced in ESTEC. S. de Palo agreed that the model of the LSS could be refined further.
B. Laine asked whether there had been any change in the emissivity between the phases. S. de Palo said that, as far as he knew, only one emissivity was used for the phases. B. Laine was concerned that there could be a change in optical properties under such high illumination. S. de Palo said that there had been discussions in-house about such changes, but he was not aware of the current status.

2.4 Lessons Learned on Modelling of Cryogenic Systems

M. Branco (ESA/ESTEC) described some of the issues that had been encountered when modelling a compact cryostat where the temperatures of the complete chain varied from 300 K to 2 K. (See appendix R)
C. Kirtley (ITP Engines UK) asked whether it would be possible to provide the models to the ITP support group. He was interested in the convergence problems and wanted to see if they could solve the issues raised. M. Branco said that he would provide the model.
C. Kirtley asked about the problem when setting TABS equal to zero: did this cause the solver to crash? M. Branco said that the solver crashed. H. Brouquet (ITP Engines UK) asked whether he had tried to use the new `SOLVCG` instead of `SOLVFM`. M. Branco said that he had not tried `SOLVCG`.

2.5 Model reduction of Sentinel 1

D. Kintea (ESA/ESTEC) described some experiences of trying to apply the Thermal Model Reduction Tool to create a reduced model of the payload module panels of Sentinel-1. (See appendix S)
During the presentation he asked whether anyone could guess why the results from the reduced model were not as close to those of the detailed model as expected. M. Loche (ESA/ESTEC) commented that the meshing of the inner panel of the reduced model did not match that of the detailed model. D. Kintea said that that was not a problem because the `TMRT` would generate non-physical conductors that were still mathematically correct.
M. Bernard (Astrium) said that he had been involved in the development of `TMRT` and his advice was to take the positions of the components into account based on the temperature hot and cold spots. D. Kintea said that this would mean that the reduction would be less effective so he had been obliged to keep more nodes. M. Bernard also suggested that the internal radiative fluxes were negligible, so the model could have been reduced to have only one node on the inside. D. Kintea said that he needed more nodes on the inside to take equipment dissipation into account. M. Bernard argued that this could be handled via the `TMRT` and anyway was not dependent on the meshing on the inside layer of the panel. The radiator powers were the conditioning conductors on the panels. There was no need to group everything into 1K banded groups. D. Kintea said that he had tried this as well. His strategy was based on the proximity of nodes. However, this was not the reason for the temperature difference.
D. Kintea stated that the temperature difference between the detailed and reduced models was due to the snapshot of the detailed thermal mathematical model used as input to the `TMRT`. There had been no power dissipation in the DTMM in the snapshot used, but there was dissipation on this node in the reduced model analysis.
At the end of the presentation S. Husnain (RST Aerospace) asked about the analysis case shown on slide 14. Did it involve a repeating orbit? He wondered about the repeatability of the start and end temperatures, because they appeared to be different. D. Kintea admitted that maybe the criteria for convergence had not been low enough, leading to different temperatures.
S. Husnain was interested in the integration of such a reduced model in the launcher analysis, and asked about the format produced by the reduction. D. Kintea reassured him that the model stayed in the same format, but simply had fewer nodes, and maybe more conductors, so integration was not a problem.

M. Gorlani (Blue Engineering) asked whether the reduced model was only applicable for the one particular case shown in the presentation, or whether it could be used for different thermal cases. D. Kintea said that he had only tried the reduction for one case, but it should be applicable for other cases as well.
M. Gorlani had understood that, for this thermal case, at the end of the loop the reduced model was not within the initial requirements. He asked whether the model needed to be changed if the requirements were not met at the end of the loop, or whether more loops should be run. What he understood was that the loop always had to start again from the beginning: the user could not work on the model at the end of the loop because there was no physical meaning in the conductors, so the user had to create a new snapshot and start again. D. Kintea confirmed that the reduced model was only a mathematical construct, so it was hard to see the physical links in it. As a result, if the initial requirements were not met, the user needed to change the reduction and start over again.
M. Molina (POLIMI) asked about the heaters. The slides had shown a 5% discrepancy between the complete and reduced models. How was the heater power defined in the reduced model? Was it the average, or the peak power? He would expect to choose a sampling rate such that all of the duty cycle effects were averaged out. If the sampling was on a subscale of the duty cycle it was possible to get temperatures that were too hot or too cold and not representative of the average. D. Kintea said that the thermostats were kept in the reduced model, but the dissipations were evaluated at a certain point in time, and if the dissipations are really time dependent this would, of course, lead to deviations. It would be possible to take the average values, but he had not done so. M. Molina summarised that the reduced model had used the peak nominal power dissipations for the heaters, rather than the average. He expected that the deviation would have been closer using the average.
M. Bernard asked whether, after the corrections for the first iteration, there had been any analysis to find the reason for the deviation? D. Kintea repeated that the temperature deviation had been due to the DTMM snapshot that had been used as input.
M. Bernard had some comments on the extended work flow diagram. From the `TMRT` reduced model output file, it appeared that D. Kintea had only considered using the reduced node definition and the reduced conductor list. Had he considered using the power distribution command lines in `ESATAN` in order to implement the varying thermal dissipations and heating powers directly in the reduced model? D. Kintea said that he had only looked at the redistribution for the heating power. M. Bernard said that this would have avoided having different disspiations for the DTMM run and the RTMM run.
M. Bernard had a comment on the generation of the snapshot. Yes, it was necessary to remove the time and temperature dependencies on the conductors. It would have been possible to use the power distribution feature in the `TMRT` and then validate the comparison of the DTMM and RTMM results for each snapshot. Examining the external flux or heat flow through the conductors would have allowed validation of the stabilised case.
M. Bernard understood the need for going further with orbital analysis to include the orbital GRs and external fluxes in the RTMM and that this had to be done outside of the `TMRT`. But he said it would have been possible to validate the reduction process itself by comparing results from thermally stabilized cases with constant external GRs and external heat fluxes. This would then have given an idea of the performance of the reduced model on a stabilised case, and then allowed further work on the orbital analysis.

2.6 Validation of a Method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model

L. Hagemann (Astrium Space Transportation) described the problem of convective heat flow in a cavity within the upper stage of the Ariane V launcher with a forced flow of inert gas; an experimental test set up to investigate the flow and heat transfer; and the coupling of the CFD simulation in FLUENT with ESATAN. (See appendix T)

P. Poinas (ESA/ESTEC) observed that the presentation had shown a comparison of temperatures, but not the results in terms of the heat transfer coefficients, which he felt were more important. He wanted to know what was the lesson learnt from this activity. He could see that the CFD could simplify a given calculation, but everything had to be redone each time, and the shape function was not the same. What had been learnt? Was the simple vertical plate model that had been used in the past still valid? L. Hagemann said that the investigation had been deliberately directed at a typical cavity with one hot and one cold wall. Most cavities were similar. The heat transfer coefficients were very robust. The example shown had contained a wide range of temperatures. The heat transfer coefficient had been extracted for the 310 K case.

P. Poinas said that he understood what had been done, but felt that what was missing from the presentation was what was new that had been learnt from this analysis. He had been involved in a review for Ariane V five years previously, where this problem already existed, and the recommendation had been to perform a CFD analysis and then to derive the heat transfer coefficient from the CFD calculation. He wanted to know what was the conclusion from the current analysis. Did it provide a good simulation and agreement with what existed before, which was horizontal, with Grashof-Prandtl, natural convection and so on, or were the results very different. Were these models different from those presented five years ago? L. Hagemann said that the CFD calculations were now very good, and he had shown that there were no errors in the method. He said that the results depended on the flow in the CFD tool. P. Poinas said that what had been presented was the correlation of the heat transfer coefficients, which were then entered into ESATAN. He wanted to know the values of those heat transfer coefficients. L. Hagemann said that they were between 5 and 6 $W\ m^{-2}\ K^{-1}$.

L. Fusade (Astrium Space Transportation) commented that these heat transfer coefficients had been compared with results derived from classical and analytical sources. L. Hagemann said that the results had been compared with those from other programmes, such as Ariane V/ESC-A.

P. Poinas asked whether they had used CFD because there had been a problem with the previous correlation or the empirical formula. L. Hagemann replied that this work had been an exercise to show that the empirical formula was good. There had been no major discrepancy between the measured temperature and the temperature calculated by the simulation using ESATAN and the old formula.

L. Fusade said that the objective was always to improve the analysis models being used. He admitted that this work had looked at a cavity with a relatively simple shape, where it was easy to apply a formula, but the objective was to deal with far more complex cavities, particularly in cryogenic areas, local effects, etc. and to be able to predict and assess the temperature gradients in the structure. He admitted that the question from P. Poinas was justified, but this work had been needed to validate the method in order to deal with more complex cases.

L. Fusade said that there were many other cavities on the Ariane V upper stage. There were six or seven between the stages, the frames and the rear bulkhead, and so on. The idea was to improve the modelling of these cavities. Up to now it had been sufficient to give a simple empirical formula

to describe the cavity based on models with bulk nodes. The objective had been to optimise the structure and to have more confidence in the assessment of temperatures. The analysis had been related to the design of the structure and whether it would be possible to remove some of the thermal protection. For more complex cavities, or for long duration missions, or for the ballistic flight phase of the Ariane V it would be necessary to master all of the basic cases. Calculating the temperatures within the launchers was therefore very important.
H. Rathjen (Astrium GmbH) commented that the analysis had related to a very particular configuration, with felt insulation and a liner between the cavity and the tank. There was gas in the felt, so it was possible to have convective flow in the cavity, and heat transfer to the cold tank. Therefore there was additional uncertainty and this made it difficult to correlate. He said that they really needed an extra test without this felt layer in order to correlate the model.

2.7 Evaluation of stochastic & statistic methods for spacecraft thermal analysis

JP. Dudon (Thales Alenia Space) described an activity looking at the different options of stochastic, heuristic and meta-modelling techniques, and the use of the OPTIMUS tool, to help with optimisation and sensitivity analysis. (See appendix U)
T. Soriano (EADS Astrium) asked whether the approach could handle complex models. How many nodes or surfaces could be handled? JP. Dudon said that the RSM was correlated with respect to the response of the model. It used the usual model, with inputs for the algorithm, and the expected responses, and then created a best fit of the responses using an analytical formula, which could be stochastic or deterministic. The size of the model only impacted the time to design the inputs.
T. Soriano asked how many parameters, conductors, emissivities, etc. had been handled so far. JP. Dudon said that the process was as shown: the more parameters there were, the more simulations were required in order to create a high quality RSM. The number of simulations depended also on the type of the RSM. Typically when using a least squares RSM, a polynomial RSM, there were no parameters to fit in the code, but it was necessary to perform a certain number of experiments. The number of experiments required, or simulations in this case, effectively depended on the number of inputs. There were different types of design of experiments, which were more or less costly. Therefore the cost of generating a high quality RSM depended on the number of inputs, and the design of the experiments.
M. Molina (POLIMI) asked about the source of the parameter distributions in the 10-parameter study shown. JP. Dudon said that the source was from an ESA study performed by Blue Engineering. M. Molina said that the study was back in 2004, and was surprised that there had been no further work on the distribution of the parameters. JP. Dudon said that was not the purpose of this study, and he had been confident in the results of the previous study that had been presented at the 2004 Workshop by M. Gorlani (Blue Engineering).
M. Molina asked about the validation of the meta-model: did it rely on the DOE tool or some independent method? JP. Dudon said that they referred to the DOE, derived the RSM, and then replayed the optimal point found. If the result differed by more than 0.5°C then it was necessary to add a point and start again. This was an iterative method and therefore a bit heavy. The EGO used in the RSM was powerful, and was self-adaptive during the optimisation process. Therefore the user could have confidence in the result.
M. Gorlani said the presentation had been interesting. It was the first work he had seen that had looked at tackling the drawbacks highlighted by the ESA/Blue study in 2004. He wondered

whether there were plans to address these further. JP. Dudon said that the work on these two test cases had shown that it was possible to gain time. There was a plan to roll out the tool in Cannes and at CNES, and to test the method in their analysis processes.
S. Dolce (ESA/ESTEC) said that the ECSS standards called for requirements on test predictions using sensitivity analysis. The stochastic analysis technique looked interesting, but introduced a potential change in the standard. He wondered, therefore, whether it would be necessary for the standards to change to allow either a classical analysis with margins, or stochastic analysis with probability. He asked the audience what they felt was the long term perspective. JP. Dudon answered that this was not the first work that had been done in the European thermal community on the stochastic approach, and that the community had started to have a view on the use of stochastics for simulation, for meta-modelling, and genetic algorithms, and he felt that it would be a good idea if these ideas were also visible in the standards. S. Dolce said that the current ECSS standards stated that whenever there was an analysis, there was also an uncertainty in the analysis, and the level of uncertainty had to be determined by sensitivity analysis. The standard could be changed to instead say to do the sensitivity analysis and/or a stochastic analysis to define the probability of being within the design range. B. Laine (ESA/ESTEC) felt that one did not necessarily replace the other. It was one way of doing the sensitivity analysis. It was just another tool to help with the sensitivity analysis rather than doing it all by hand. It was not necessarily a choice of using just one method or the other. He felt that the approaches were complementary.
JP. Dudon said that the engineer could use the sensitivity analysis to get a first feeling for the model, and then use iSight or OPTIMUS to check which parameters were important and to give a complementary deeper knowledge of behaviour of the model. B. Laine said that stochastic methods were just another tool to help choose the parameters in a more systematic way. JP. Dudon said it was another tool to help facilitate the design exploration.
L. Fusade (Astrium Space Transportation) said that ECSS did not require specific methods to calculate uncertainty margins. S. Dolce said that sensitivity analysis was there so that the engineer could say that he or she had looked at certain parameters, and had verified them during the thermal balance test results and that therefore the engineer had reduced the uncertainty. In the stochastic analysis case, the results could be used to check the probability. The classical approach involves evolution: check the model against the thermal balance test, and then reduce the uncertainty values. Both methods could be used to help improve the uncertainty levels in specific areas. He felt that the stochastic method provided a good alternative but did not replace the classical approach. JP. Dudon thought it would be a good idea to start to introduce the stochastic approach into the ECSS: not to replace the existing one, but to complement it.
M. Gorlani argued that the new stochastic methods did not provide any requirements on the uncertainties. He felt that what M. Molina had said was important: there was a need to know the uncertainty distributions of certain parameters in order to define the design margins. JP. Dudon admitted that knowing what to add to the results to handle any modelling error was not taken into account in the stochastic approach.

2.8 The ESATAN-TMS Finite Element Analysis Method — User Experiences

G. Sieber (Jena-Optronik) described using the relatively new features in `ESATAN-TMS` for importing Finite Element geometry and how working with such a finite element model differed from the traditional lumped parameter approach. (See appendix V)

S. Husnain (RST Aerospace) said that in the geometry model shown the electronic components had not really been visible. Did that mean that the dissipations of the electronic components had been distributed to the geometric model of the plates? G. Sieber explained that he had modelled the dissipations using non-geometric nodes and then creating links between those nodes and the plate. This was a little different to the lumped parameter modelling where one node was explicitly connected to another node using its node number. He said that the finite element geometry introduced a lot of nodes, and the easiest way to work with them was to identify an area on the panel for the footprint of the component and then create a group of faces corresponding to that area by picking, add the dissipation between the non-geometric node and the group, and not to worry about the explicit node numbering of the finite element geometry parts.
S. Husnain asked about the definition of the conductance between the electronic components and the plate, where there might be fillers between the unit and the panel. G. Sieber had handled electronic units in a similar way. He was no longer sure exactly what he had done, but thought that all he had done was to use the dissipation of the electronic box and apply it to the appropriate area of the panel. He did not think that they had defined explicit conductance.
T. Soriano (EADS Astrium) felt that this approach neglected the radiative aspects of the equipment. G. Sieber admitted that he had only modelled direct dissipation for the electronic components and had not handled the radiative effects. The baffle involved radiative effects for the orbit case, but the electronic components only involved conduction.
JB. Meurisse (Sodern) asked why `ESATAN-TMS` had been used for this sort of analysis. G. Sieber said that it was the standard tool used in Jena, and that it was required by ESA. There was never any time to investigate or learn new tools that could have been more appropriate. He had tried to keep using the new features of the tool in the best way possible for the analysis.

2.9 Thermal Concept Design Tool — 5th Year

M. Gorlani (Blue Engineering) described how the development of the main features of the `TCDT` had been completed, and how the latest capabilities, demonstrated by A. Tosetto (Blue Engineering), had been added at the request of users. (See appendix W)
M. Molina (POLIMI) asked about the long term plan for the maintenance: how long would ESA support the `TCDT`, or would there be a charge for using the tool? M. Gorlani said that the current maintenance contract would end next March, due to the timing of the frame contract. After that, there would need to be some discussions to see what would happen in the future.
B. Laine (ESA/ESTEC) said that plans for the `TCDT` would depend on how much use people will make of it, and this would be discussed at the NESTA meeting after the workshop. Blue Engineering currently promoted the `TCDT`, and were responsible for training, but if the community did not want to use the tool, then ESA would need to think again. He stressed that user feedback was therefore very valuable to ESA.
P. Poinas (ESA/ESTEC) said that he had been encouraging people to use the `TCDT`. He had already been using it for a long time, but he would be going to the hands-on `TCDT` training session being held that afternoon after the Workshop anyway to learn about using the new features, especially the model import. He said that the `TCDT` was very good for quick sensitivity analysis.
P. Poinas then asked how the `TCDT` handled any Boolean surfaces when importing geometry models from `ESARAD`. A. Tosetto said that Boolean surfaces were imported, and had a suffix added to the label to show the sense of the cutting surface, but they were only displayed as normal surfaces. However, when the geometry was exported, any such cutting surfaces were interpreted and output correctly. P. Poinas wondered what happened when the imported geometry contained

a cutting operation such as $c = a - b$; and how would the TCDT show it? A. Tosetto explained that the TCDT would show the shells with labels with a suffix denoting the cutting sense, such as *a* and *b_minus* . Both shells would be displayed in their original, uncut, form by the viewer.
A. Uygur (Turkish Aerospace Industries) asked whether the TCDT could be used to create new geometry, or whether the geometry had to be imported. M. Gorlani said that the TCDT had always been able to create new geometry, but now had added features for importing and exporting geometry.
P. Ferreira (Max Planck Institute) asked how to convince someone to use the TCDT. It looked very good, but even using ESATAN for small analysis could be very quick. The question was how to sell the TCDT to someone who didn't know it very well. M. Gorlani answered that he was not at the workshop to sell the TCDT, but to provide information on its features. It was in Blue Engineering's interest for the TCDT to continue. He was involved in thermal analysis and design, and Blue Engineering used the TCDT internally.
M. Gorlani said that there would be a TCDT training course later in the day, so people would be able to see what it could do. It would be possible for new features to be added to the tool, but that would require a budget from somewhere. He said that the TCDT had not been designed to be used everywhere that ESARAD and ESATAN could be used, but was intended to be used for fast analysis and fast creation of small models. There were lots of features of the thermal calculator which had not been shown, but which allowed the user to make analytical calculation inferences in order to help prepare the model. He recommended that people followed the training course later in order to get a better feel for the tool.
C. Theroude (Astrium Satellites) had difficulties to understand how the TCDT was positioned relative to the more detailed analysis tools. On the one hand it was presented as simple, but it seemed that every year new functionality was included and it was developing into an ever more complex tool. There was a difference between simple and detailed analysis, but he felt that where the TCDT was going was not clear. M. Gorlani said that the first four years of maintenance Blue Engineering had added functionality that had been identified at the end of the first year by a survey of users, where they were also asked to give priorities to new functionalities. During the last year they, along with ESA, had decided to add the import/export features in order to close the functionality. He felt it would be interesting to have a new survey to understand what the users would still like to have.
F. Bodendieck (OHB) commented that the TCDT was not really a stand-alone tool as it required the user to have ESATAN-TMS. He wondered how it would work with the latest release of ESATAN-TMS r4. M. Gorlani said that the TCDT had no solver of its own, so it relied on the user also having ESATAN-TMS installed. He said that all of the TCDT testing had been done using the last version of ESATAN-TMS. F. Bodendieck wondered whether the TCDT was really a free tool because there was the cost of the ESATAN-TMS licence.
F. Bodendieck asked what was the advantage of using the TCDT over a simple Excel model? P. Poinas wanted to answer that point. He said that from the ESA side he had seen lots of input for design studies from industry provided via Excel sheets, which therefore confirmed that a lot of initial design was done with Excel and simple tools. The TCDT allowed everyone to use something that was more advanced, more standard, and not hand-made, on-purpose and specific to each design. The engineer could do the initial design using the TCDT and then export it and refine the model in ESARAD and ESATAN. The big advantage of the TCDT is the level of integration and validation of the features, and also the fact that the user could work very quickly with the Excel sheet. The TCDT was useful for pre-design and start of a design. The image of the ISS model in the TCDT was certainly impressive, but once all of the couplings were taken into account, the

TCDT would be too slow for real analysis work. His experience was that once the model went beyond 40 nodes the TCDT was no longer easy to use. P. Poinas also felt that Blue Engineering should not have to answer questions about the position of the TCDT compared to the other thermal tools. He felt that the users should determine for themselves when it was appropriate to use the TCDT in their analysis chain.
B. Laine emphasised that the TCDT had been developed as a tool for use in the Concurrent Design Facility at ESTEC, and there was a need to promote the TCDT with those users. It was an early design tool for use in the ESTEC CDF, but as he knew of several companies with their own CDF, he could see that the TCDT could also be useful in a company CDF.

2.10 Workshop Close

H. Rooijackers (ESA/ESTEC) said that there had been a lot of interesting presentations about different applications of both old and new tools. He wanted to thank all of the authors and presenters, especially the new and young presenters, whose contributions were very valuable, and to all the participants for their questions and discussions, as these were what made the Workshop come alive. It had been a pleasure to organise this Workshop. He hoped to see everyone at the Workshop next year.

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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25th European Workshop on Thermal and ECLS Software 2/12

ESA Team

Benoit Laine	Head of Section
James Etchells	
Bastien Bonnafous	
Duncan Gibson	Workshop Secretary
Harrie Rooijackers	Workshop Organiser

Workshop organised by the Thermal Analysis and Verification Section TEC-MTV with help from the ESA Conference Bureau

European Space Agency

25th European Workshop on Thermal and ECLS Software 3/12

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
- TCDT training session 2nd day after lunch, approval ESA required

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25th European Workshop on Thermal and ECLS Software 4/12

Practical information

esa

- Presenters:
  If not done already please leave your presentation (PowerPoint or Impress 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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25th European Workshop on Thermal and ECLS Software 5/12

Practical information

esa

- Lunch: 13:00 - 14:00
- Cocktail today at 18:00 in the Foyer
- Check your details on the list of participants and inform the Conference Bureau of any modifications.
  Leave your email address!
- Taxi service and Shuttle service to Schiphol Airport
  contact ESTEC Reception ☎ ext. 54000, ESTEC.Reception@esa.int
  or Taxi Brouwer ☎ +31(0)71 361 1000, info@brouwers-tours.nl
- Workshop dinner tonight!

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Workshop diner

- in “Lamme Goedzak", Parallelboulevard 18, 2202 HP Noordwijk, ☎ +31(0)7136 12083
- fixed menu with choice of main course (fish, meat or vegetarian) for €35,00 p.p. incl. 1 drink
  additional drinks are charged individually.
- Restaurant booked today for 20:00
- Please arrange your own transport
- "Dutch" dinner == to be paid by yourself
- If you would like to join, then fill in the form on the last page of your hand-outs and drop it at the registration desk today **before 13:00**, to let the restaurant know what to expect

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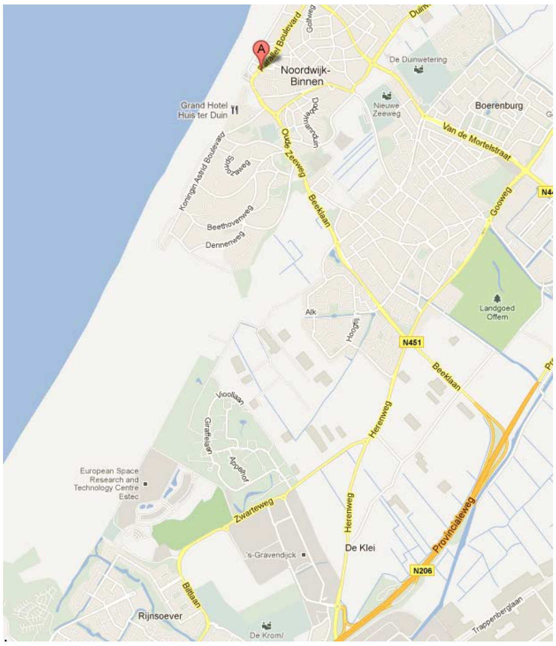
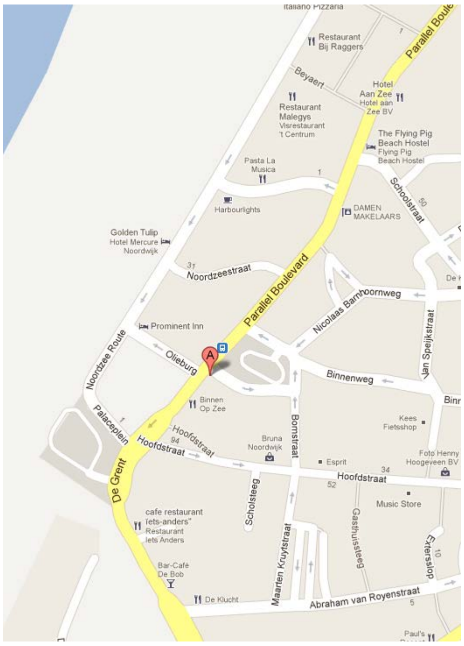
Restaurant “Lamme Goedzak”





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Menu (€ 35,00 p.p. Including 1 drink)

esa

Beef carpaccio with a pesto sauce, grano padano cheese and nuts
or
Goat cheese with honey and fresh nuts from the oven
or
French onion soup with cheese crust

~~~~~~~~~~~~

Fried fillet of chicken with pineapple and curry sauce
or
Stir-fry steak tips with a teriyaki sauce and fresh leek
or
Fried pangasius fillet with small shrimps and a creamy lobster sauce

~~~~~~~~~~~~

"Dame Blanche" vanilla ice-cream with warm chocolate sauce and whipped cream
or
Hot apple pie white vanilla sauce and cinnamon ice-cream

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ICES 2012

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- The 42nd International Conference on Environmental Systems (ICES) will be held 15-19 July, 2012, San Diego, California, USA.
- Deadline for submitting abstracts: Monday 15 November, 2011
- Abstracts must include paper title, author(s) name(s), mailing and e-mail addresses, phone and fax numbers
- Abstracts may be submitted online at www.aiaa.org/events/ices

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Workshop

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22 very interesting presentations covering:

- Existing thermal tools
  - Enhancements
  - Applications
  - User experiences
- New tools
- Range of general applications

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Workshop

esa

Listen, Ask, Discuss

most of all: Enjoy

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Appendix B

Thermal Analysis for Re-entry Vehicles
Ablative tool integration in ESATAN

Savino De Palo Lorenzo Andrioli
(ThalesAlenia Space, Italy)

Marco Giardino Giuseppe Ruscica Elena Campagnoli
(Politecnico di Torino, Italy)

Abstract

ThalesAlenia Space Italia (TAS-I) works since many years on re-entry vehicle programs and studies like IXV, Expert and ASA (2007) just to mention a few, for which the critical components is represented by the Thermal Protection Systems (TPS).
For the ablative shields analysis and sizing a first stand alone tool was developed and validated together with Politecnico di Torino and named AblaTherm. This cooperation with university has been extended to develop a new tool able to run directly into ESATAN the ablative analysis: this will allow a full integration of ablative shield model with the thermal model of the host vehicle and give a weight reduction through a less conservative heat conduction evaluation. This new tool takes advantage of the AblaTherm heritage, uses a state of the art analytical model and is implemented using a 1D Finite volume discretization with contracting grid. The work is ongoing, and the latest developments and achievements will be illustrated in this presentation.

THERMAL ANALYSIS FOR RE-ENTRY VEHICLES:
ABLATIVE TOOL INTEGRATION IN ESATAN

Written by: Marco Giardino (Politecnico di Torino, Italy)
Elena Campagnoli (Politecnico di Torino, Italy)
Lorenzo Andrioli (ThalesAlenia Space, Italy)

Presented by: Savino De Palo (ThalesAlenia Space, Italy)

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Index

- Introduction
- Analytical model
- Numerical implementation
- Material data and environmental data
- Apollo 4 test case:
  - Test definition
  - Results
- Mars Entry Vehicle test case
  - Test definition
  - Results
- Conclusions
- What's next ?

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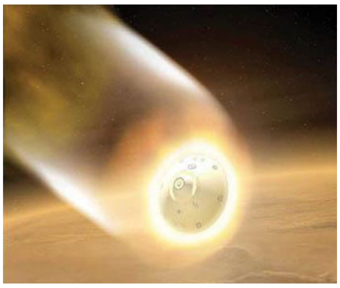
Introduction

- ThalesAlenia Space – Italy (TAS-I) involved in ESA/ASI re-entry vehicles programs
  - IXV (with ablative)
  - Expert (without ablative)



- Ablative heat shields sizing is a key factor for good vehicle design
- Ablative tools (CMA, AblaTherm, Samcef Amaryllis) not integrated with vehicle TMM (ESATAN) ⇨ iterations required

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Introduction

- TAS-I in cooperation with Politecnico di Torino developed a 1-D FEM tool named AblaTherm (24th European Workshop Thermal & ECLS S/W)
- Cooperation extended to:
  - develop a new tool able to run directly into ESATAN the ablative analysis
  - full integration of ablative shield model with the thermal model of the host vehicle
  - weight reduction through a less conservative heat conduction evaluation
  - save run time (avoid iterations)
  - take advantage of AblaTherm heritage

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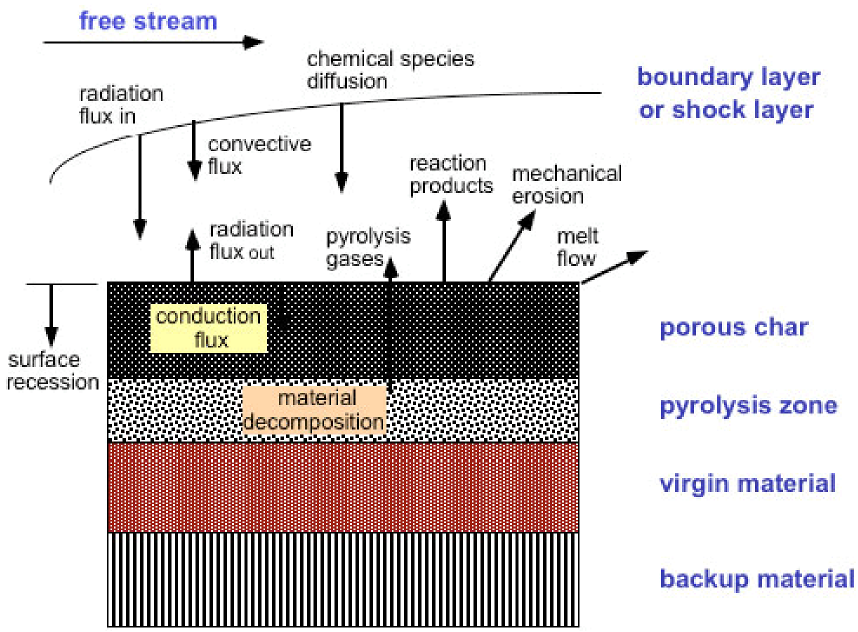
Analytical model



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Analytical model

- Modified CMA material model
- Local 1D assumption
- One equation model (energy conservation), without gas effects + BC:

$$\begin{cases} (\rho c_v(\rho,T))\dfrac{\partial T}{\partial t} + \dfrac{\partial}{\partial x}\left(-\lambda(\rho,T)\dfrac{\partial T}{\partial x}\right) + \dfrac{\rho_v h_v(T) - \rho_c h_c(T)}{\rho_v - \rho_c}\dfrac{\partial \rho}{\partial t} = 0 \\ T(t=0) = T_0(x) \\ \lambda \dfrac{\partial T}{\partial x}(x=0,t) = q_c(t) \\ \lambda \dfrac{\partial T}{\partial x}(x=s(t),t) = q_w(t) \end{cases}$$

- Charring material (Arrhenius equation with different material constituents).

$$\rho = \sum_{i=1}^{N} c_i \rho_i \qquad \frac{\partial \rho}{\partial t} = \sum_{i=1}^{N} c_i \frac{\partial \rho_i}{\partial t} \qquad \frac{\partial \rho_i}{\partial t} = k_i \left(\frac{\rho_i - \rho_{i_c}}{\rho_{i_v} - \rho_{i_c}}\right)^{n_i} e^{-B_i/T}$$

- Surface heat flux boundary condition:

$$\underbrace{q_w}_{\text{Net wall heat flux}} = \underbrace{\left(\underbrace{\psi}_{\text{Blocking}} q_{conv_0} + q_{rad_0}\right)}_{\text{External flux}} - \underbrace{q_{rad}}_{\text{Surface radiative heat flux}} \underbrace{- Q_{rece}\,\rho_{carb}\,\Delta s}_{\text{Recession heat}}$$

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Numerical implementation

- Implementation through ESATAN global file system: local parameters set through "$SUBSTITUTIONS"
- Material properties and environmental data read from file at runtime
- Automatic grid generation (uniform or with defined height ratio)
- Contracting grid implementation (to account for surface recession)

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Numerical implementation

- Different simplified geometries: plate, circular section, spherical cap, pyramid
- Finite Volume Method (FVM) discretization is translated in a lumped parameter network
- Nodes capacitances, thermal resistances and local heat fluxes updated at each time step
- Blocking evaluation at run time (simplified gas model)
- Coupled with ESATAN solver set-up ($EXECUTION)

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Material and environmental data

Following input data are required:

- Material properties (in a dedicated file):
  - Number of components
  - Virgin and charred sub-densities
  - Arrhenius coefficients for each material component
  - Pyrolysis reaction enthalpy at a provided temperature
  - Temperature dependence of specific heat, thermal conductivity, surface emissivity, both for virgin and charred material.
  - Surface recession model data (different models available)
- Heat flux data (external convective and radiative fluxes) and recovery enthalpy (1 file each)

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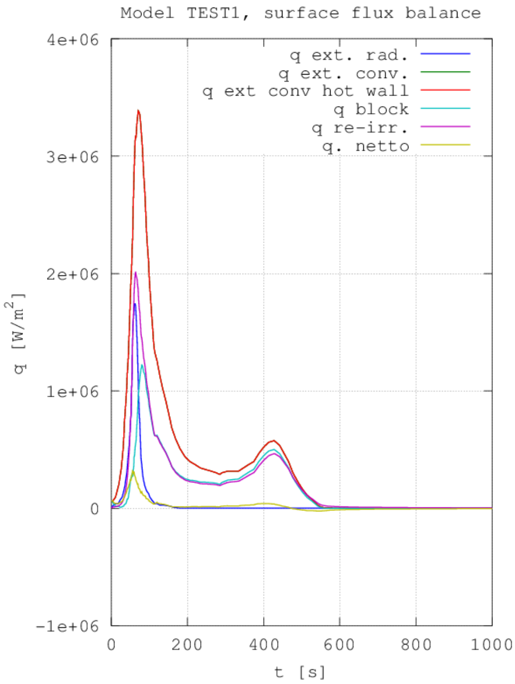
Apollo 4 test - Definition

- Entry fluxes from Apollo 4 capsule (see the flux balance graph on the right) near front shield's stagnation point
- Shield's material: Avcoat
- Shield thickness: 5.3 cm.



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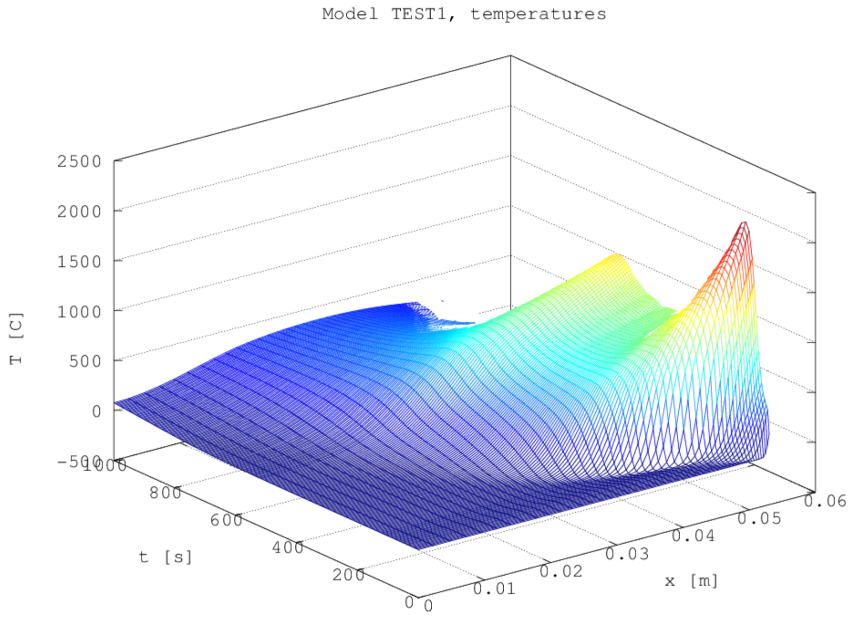
Apollo 4 test – Results 1
Temperatures



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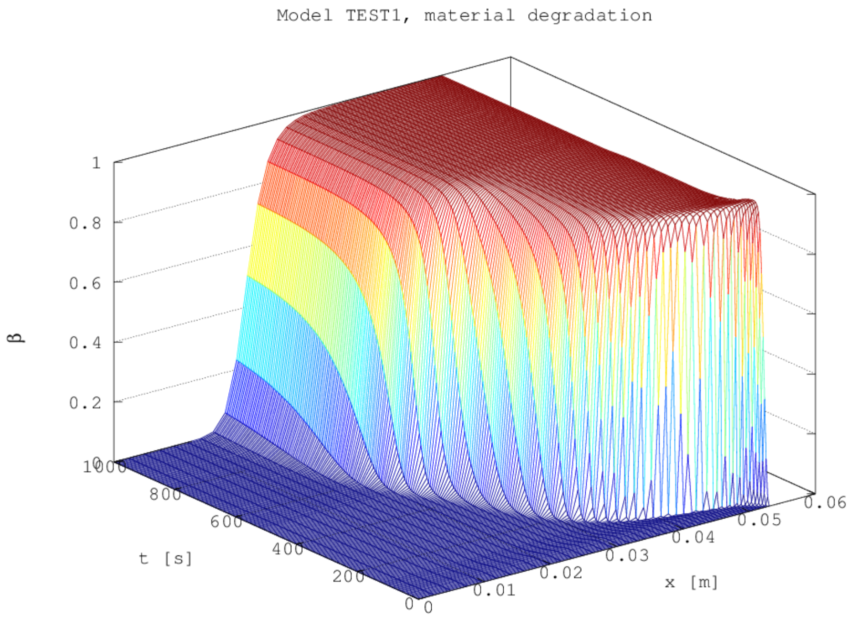
Apollo 4 test – Results 2
Material degradation



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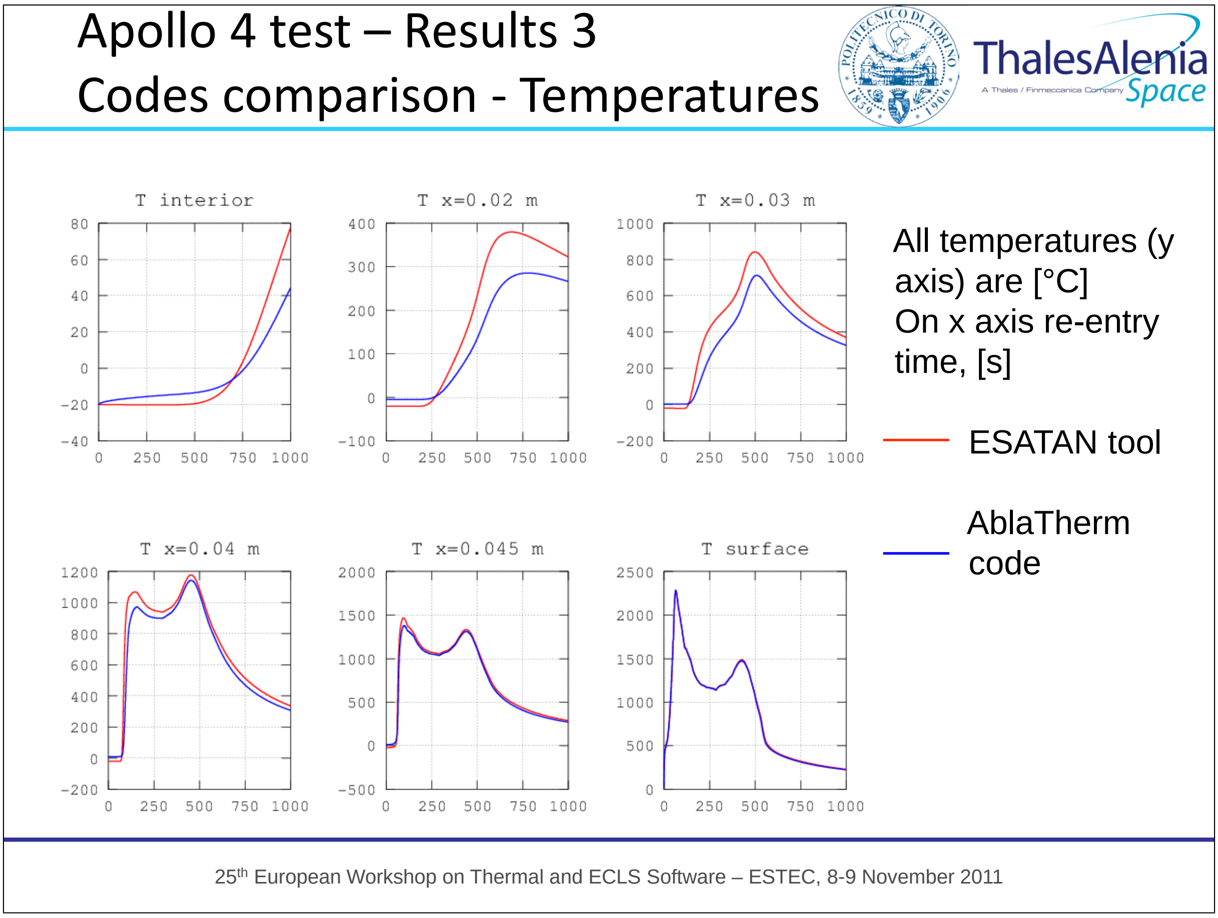
Apollo 4 test – Results 3
Codes comparison - Temperatures
ThalesAlenia Space
A Thales / Finmeccanica Company
T interior
T x=0.02 m
T x=0.03 m
T x=0.04 m
T x=0.045 m
T surface
All temperatures (y axis) are [°C]
On x axis re-entry time, [s]
ESATAN tool
AblaTherm code
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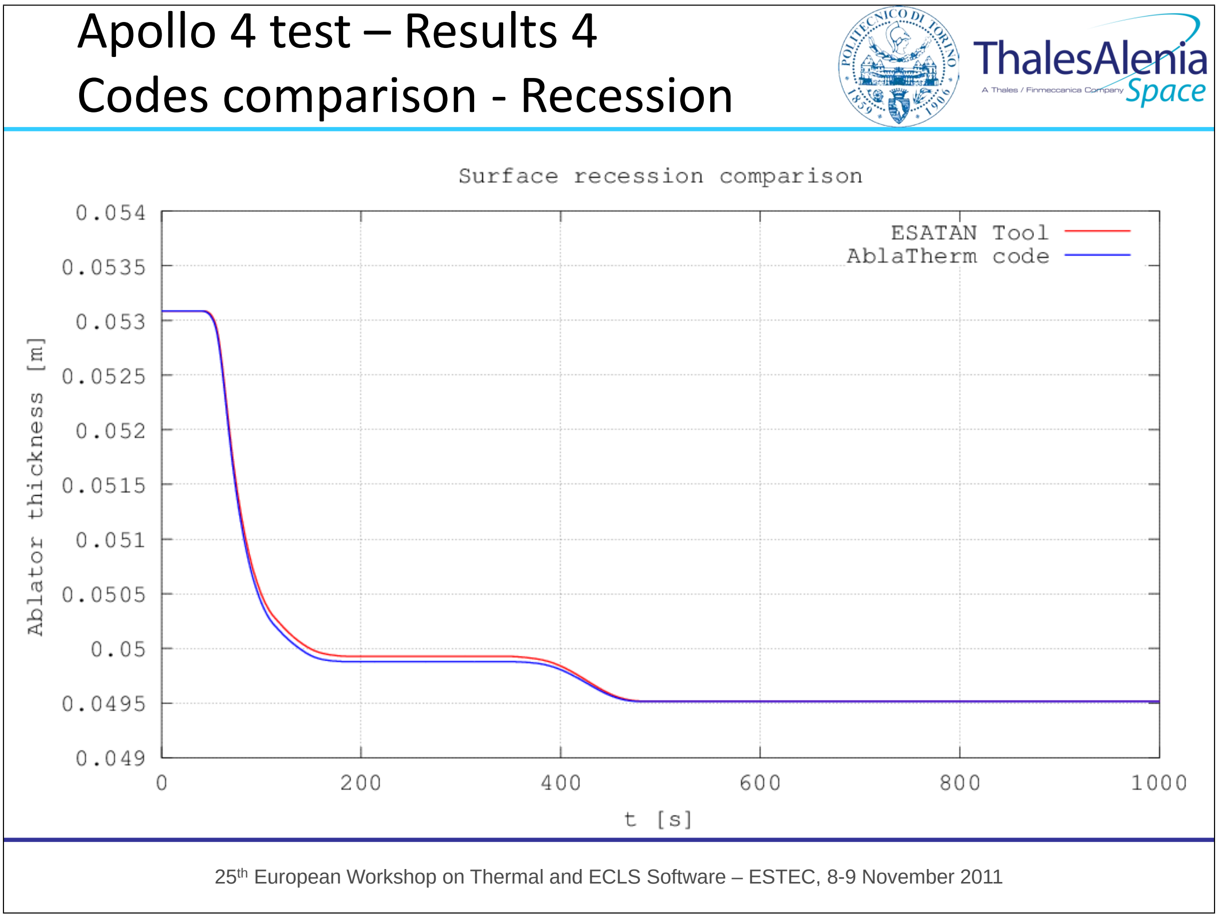
Apollo 4 test – Results 4
Codes comparison - Recession
ThalesAlenia Space
A Thales / Finmeccanica Company
Surface recession comparison
ESATAN Tool
AblaTherm code
Ablator thickness [m]
t [s]
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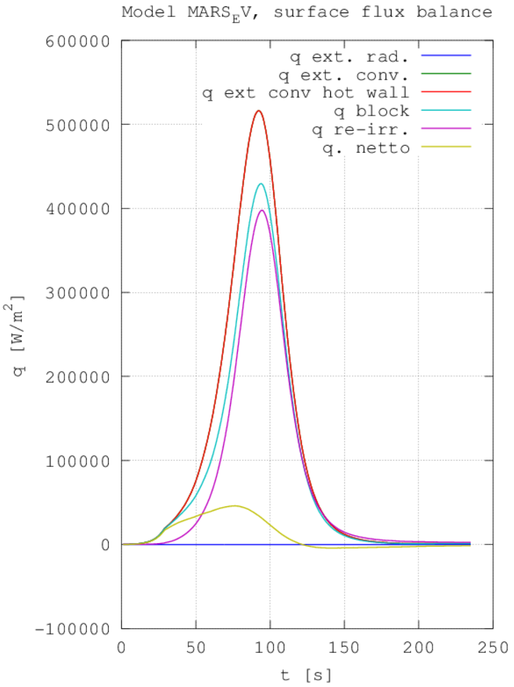
Mars entry capsule test case
Definition

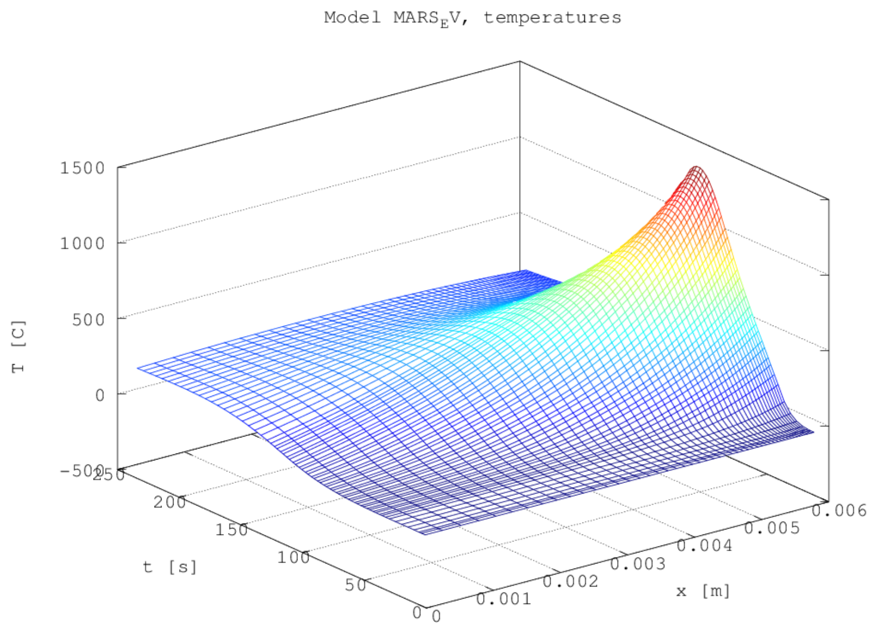
- Entry fluxes from MER trajectory.
- Material: Norcoat Liege.
- Shield layers (from Exomars EV):

Layer material	Thickness
Saffil Insulator	1 cm
CFRP	0.03 cm
Alluminium Honeycomb	4 cm
CFRP	0.03 cm
Norcoat Liege	0.58 cm
Total thickness	5.64 cm

- The ablative tool simulates the ablative layer: the underlying structure is simulated through a normal ESATAN model.



Mars entry capsule test case
Results 1 - Temperatures



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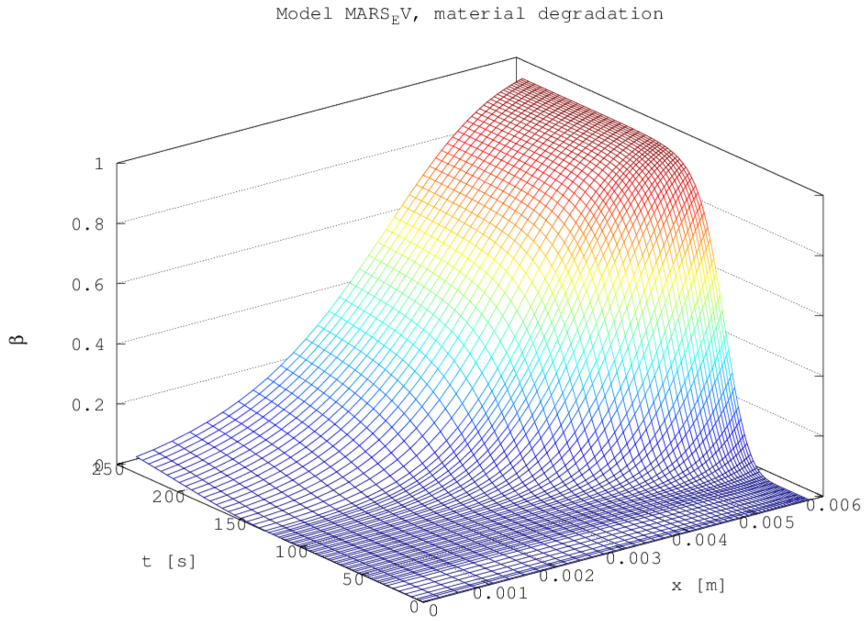
Mars entry capsule test case
Results 2 - Degradation



Conclusions

- New ablative tool has been implemented in ESATAN
- Verification (numerical checks) & validation (vs CMA, Samcef Amaryllis & test data) is undergoing but first results gave positive feedback
- Use advanced numerical methods and user friendly
- ESATAN TMM + Ablative shield in one shot !!

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What's next ?

- Implementation of pyrolysis gas effects through gas mass conservation equation: evaluation of the energy transfer through gas convection (blowing) and the external convective heat flux reduction (blocking)
- Activation/deactivation of the ablative behavior at runtime (memory and execution time reduction)
- Complex surface recession model implementation

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THANKS FOR YOUR ATTENTION

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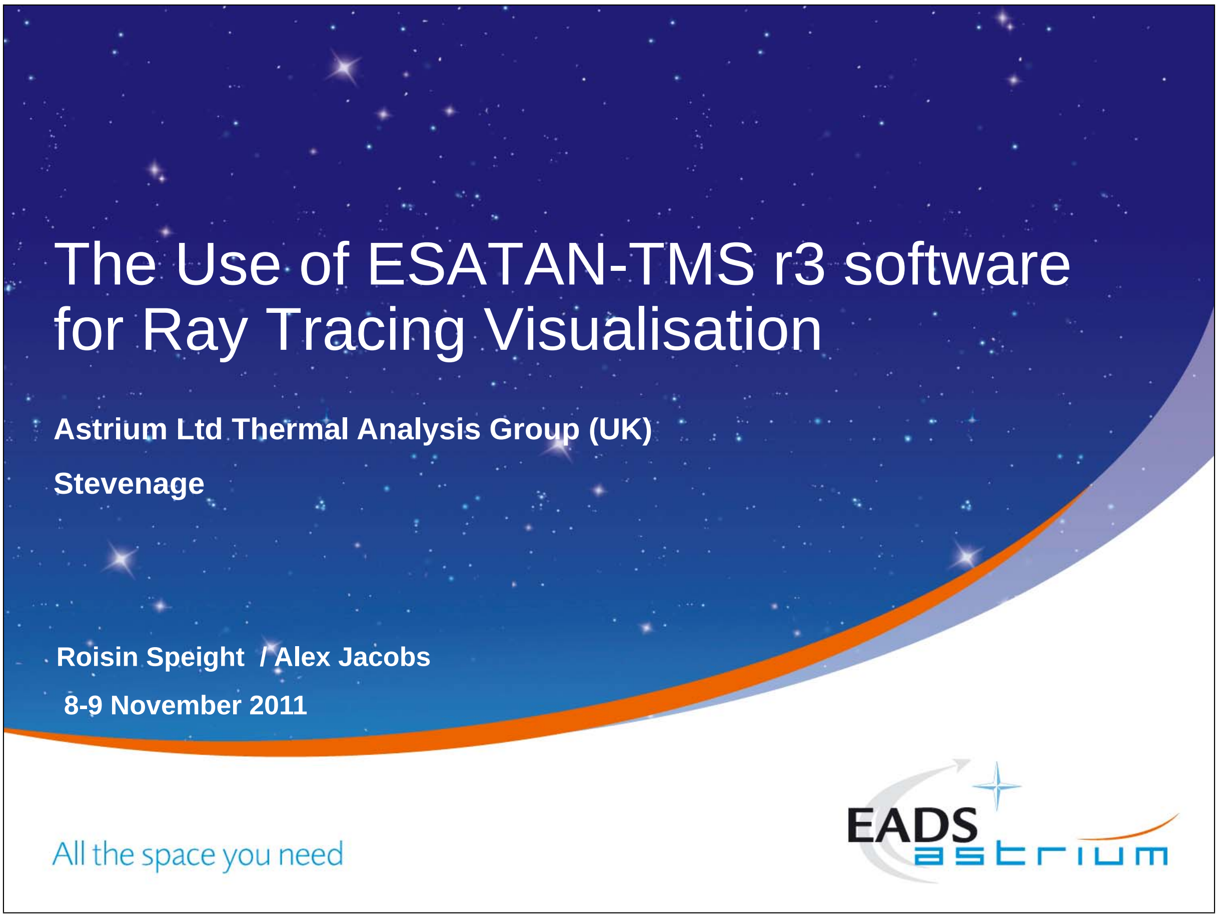
Appendix C

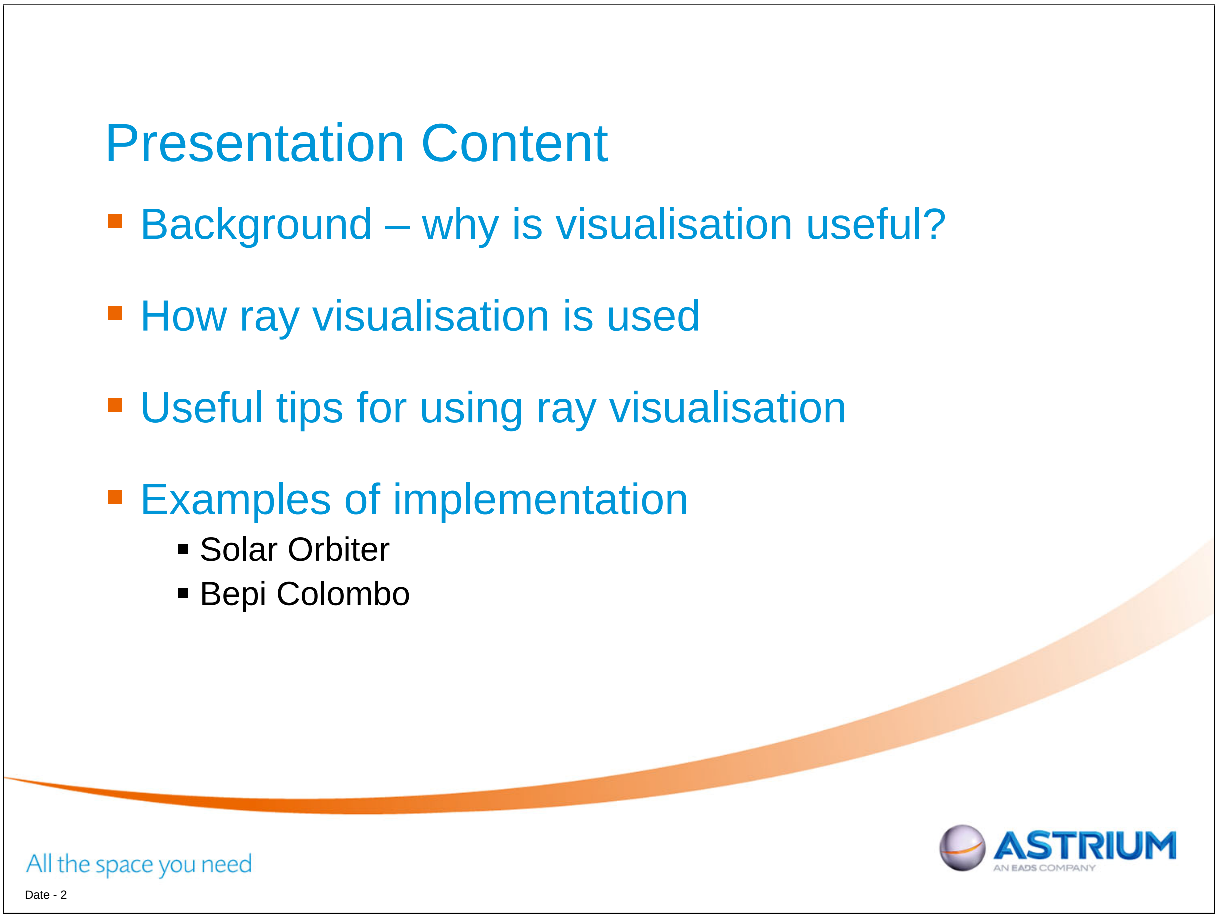
The Use of ESATAN-TMS r3 software for Ray Tracing Visualisation

Roisin Speight Alex Jacobs
(EADS Astrium, UK)

Abstract

The presentation will demonstrate the benefits of the ray tracing visualisation software, briefly describe how it works and discuss how it has been beneficial to current projects.


The Use of ESATAN-TMS r3 software for Ray Tracing Visualisation
Astrium Ltd Thermal Analysis Group (UK)
Stevenage
Roisin Speight / Alex Jacobs
8-9 November 2011
All the space you need
EADS astrium


Presentation Content
Background – why is visualisation useful?
How ray visualisation is used
Useful tips for using ray visualisation
Examples of implementation
Solar Orbiter
Bepi Colombo
All the space you need
Date - 2
ASTRIUM
AN EADS COMPANY

Why use ray visualisation?

- All spacecraft are sensitive to reflected light from appendages
- On its closest approach to the sun, at 0.28 AU, Solar Orbiter will be particularly sensitive to such reflections
- The paths of reflected rays between components are not always easy to identify
- Multiple reflections are extremely difficult to understand without some form of visualisation

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Date - 3

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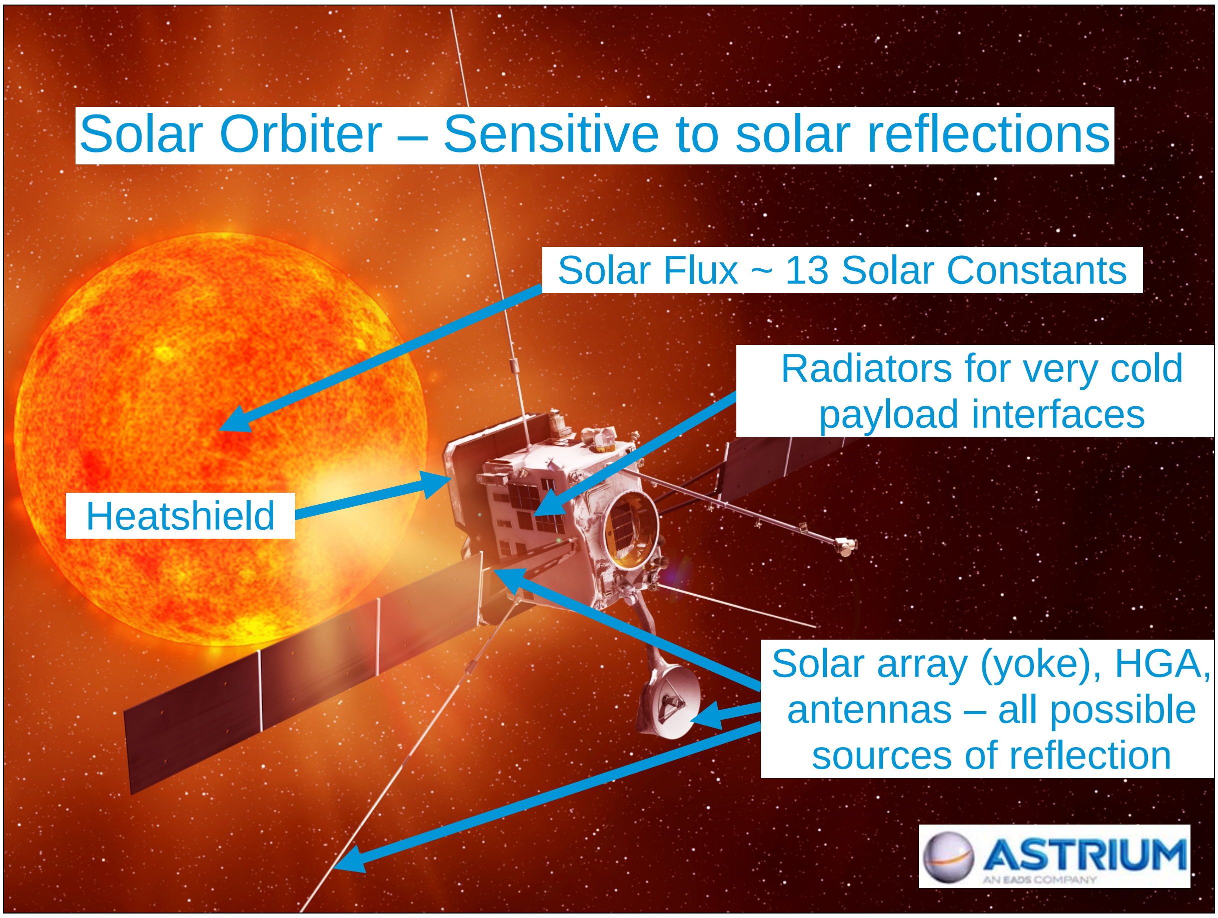
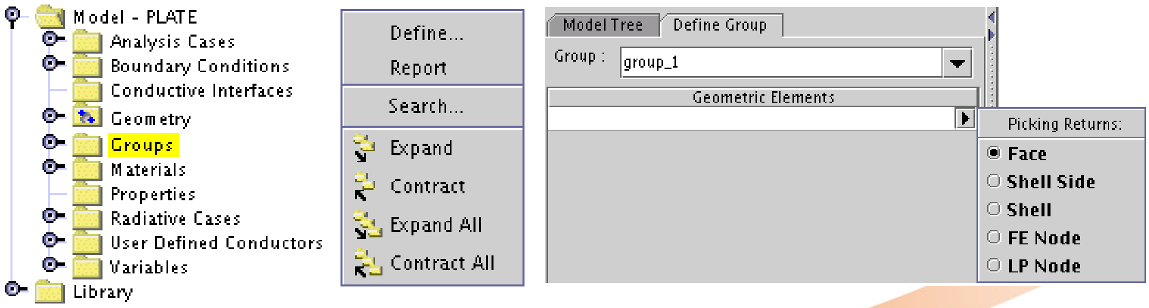


Using ESATAN-TMS r3 software for Ray Tracing Visualisation

Defining a group:

- Groups must be defined by face or shell
  - I.e. NOT by node – ray information is not stored for nodes only faces



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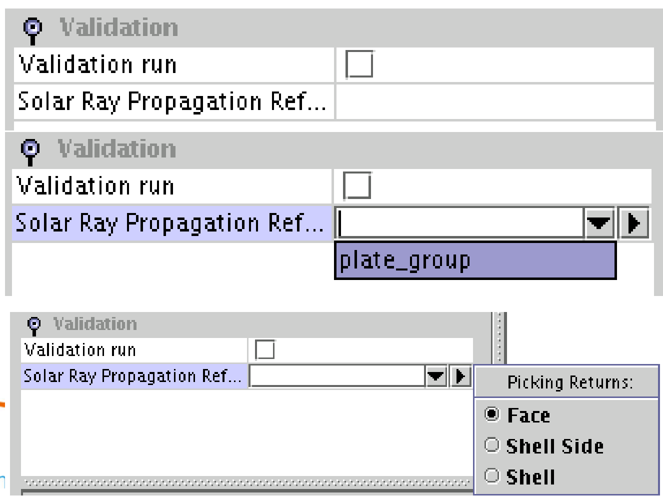
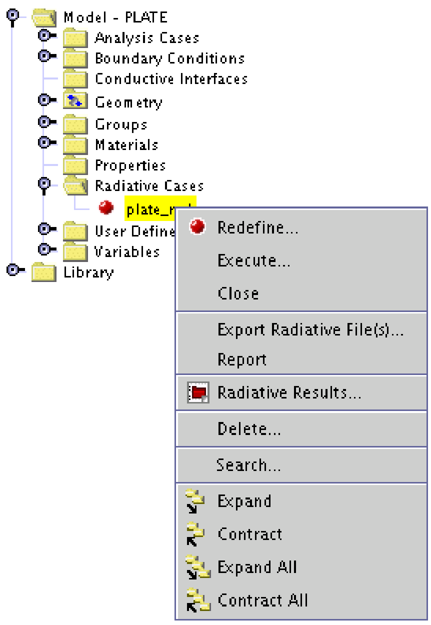
Date - 5

Using ray visualisation - GUI

Executing radiative case:

- Open radiative case
- Select «Execute»
  - Opens «Execute» dialogue box





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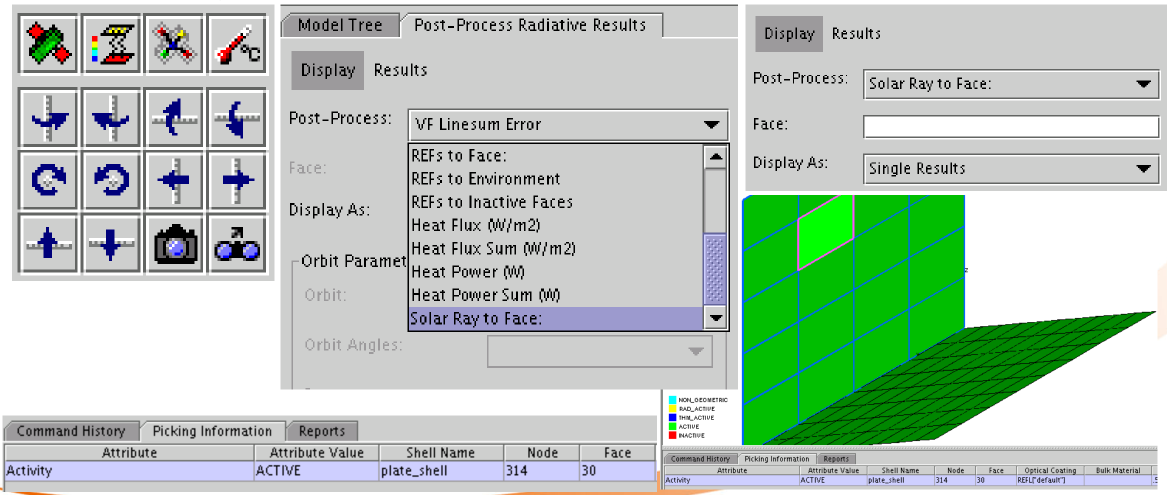
Date - 6

Using ray visualisation - GUI

- Visualising rays:
  - Ray visualisation



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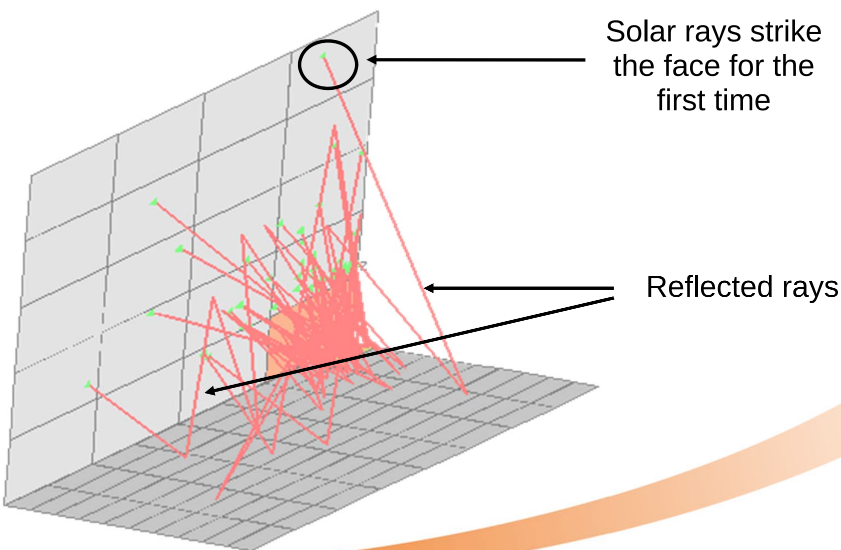
Using ray visualisation - GUI



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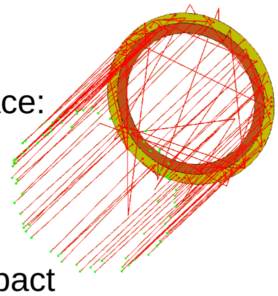
Using ray visualisation - GUI

- Terminology
  - Solar Ray Propagation Reference/Reference Face:
    - Individual Face
    - Individual Shell
    - Group of Faces
    - All solar rays (direct and reflected) which impact these shells/faces are stored for post-processing



  - Selected face:
    - Face of interest - chosen during post-processing to display all rays which impact it.

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Date - 9

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General User Tips

- Things to be aware of:
  - Number of rays
  - Ray tracing alogrithms are performed based on geometry.
  - Cannot define reference or selected face by node number.
- Good practices:
  - Always check the apparent results from ray visualisation against solar flux and temperature maps.
  - Also check against hand calculations.

All the space you need

Date - 10

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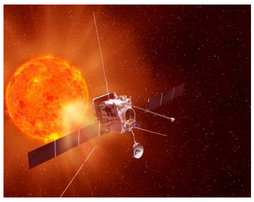
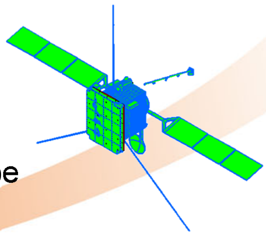
Example of implementation – Solar Orbiter

Solar Orbiter Problem:

- Investigate the specular reflections from the solar array yoke onto the spacecraft Y walls at the point where the reflections will be most critical
  - With the solar array at 75.5 degree inclination
  - At closest approach to the sun (0.28 AU)



- Determine the optimum baseline yoke design which will minimise the reflected flux and subsequent increase in temperature of the critical components and therefore have minimal thermal impact on the spacecraft.

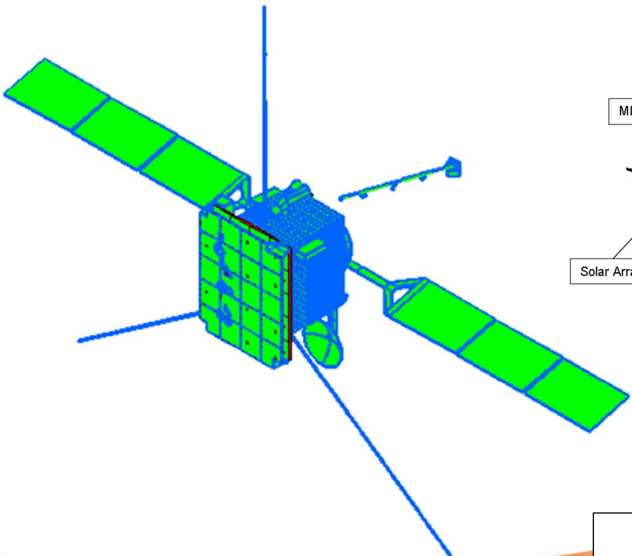


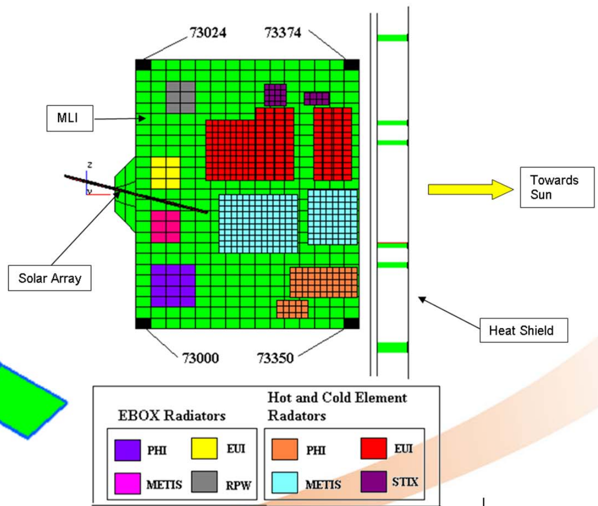
- This investigation was carried out pre-PDR. The purpose to identify the magnitude of the problem (if any) so that it can be discussed with the selected supplier and the risk minimised at an early stage.

All the space you need

Date - 11

Example of implementation – Solar Orbiter



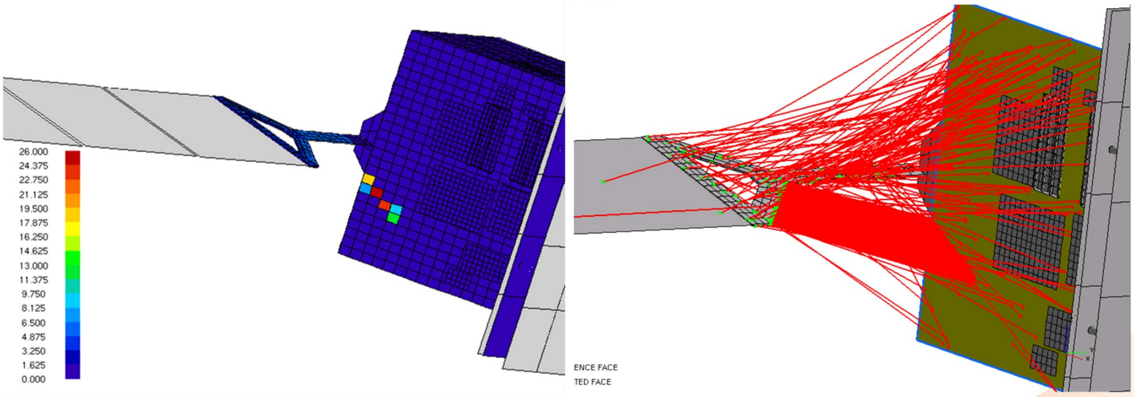


-Y Wall Hot and Cold Element Radiators are critical elements

All the space you need

Date - 12

Example of implementation – Solar Orbiter



- Solar array yoke assumed coated in fully specular OSRs
- Reflected rays are concentrated in a localised region

All the space you need

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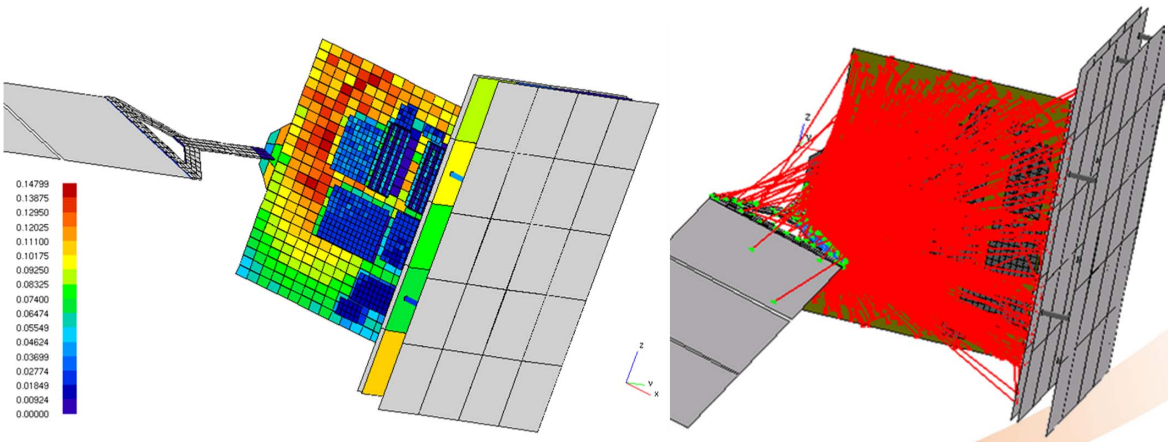
Date - 13

Example of implementation – Solar Orbiter



- Solar array yoke assumed coated in fully diffuse OSRs
- Reflected rays are scattered

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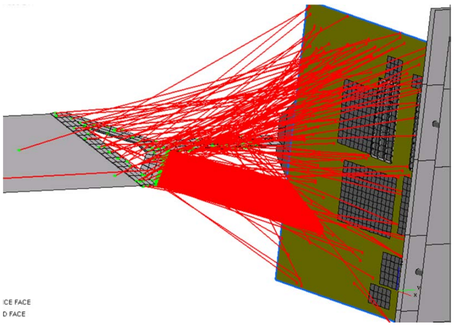
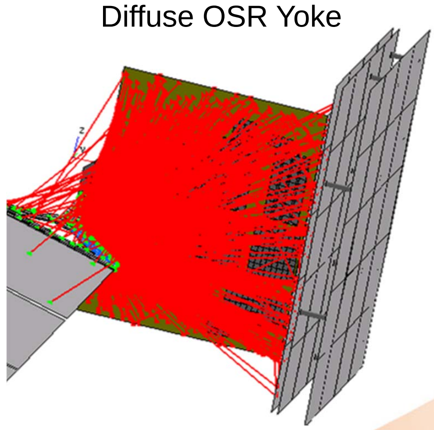
Date - 14

Example of implementation – Solar Orbiter

Specular OSR Yoke



Diffuse OSR Yoke



For solar orbiter the reflected flux from specular OSR yoke is the preferred baseline solution. Although the flux concentration is higher, the effect is localised and therefore easier to thermally control.

All the space you need

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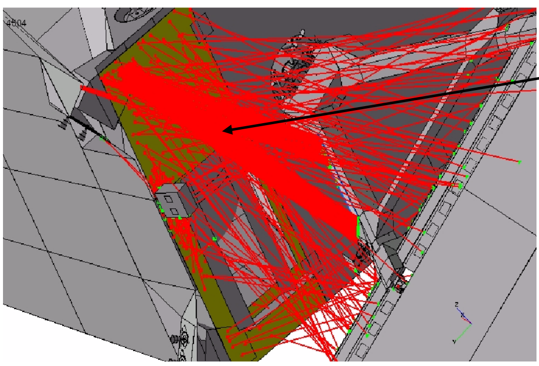
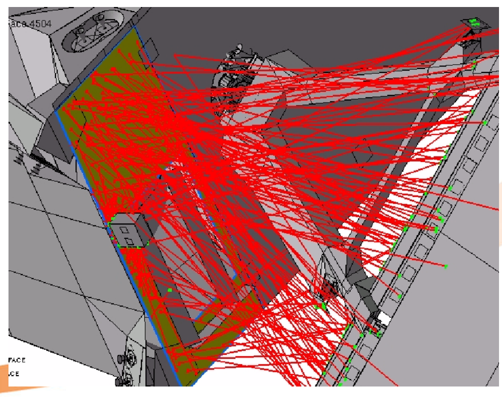
Date - 15

Example of implementation – Bepi Columbo



Ray tracing software shows that the solar array yoke angle causes flux concentration on the radiator panel.



With this information the thermal engineer can show how a design change will reduce the flux concentration problem

All the space you need

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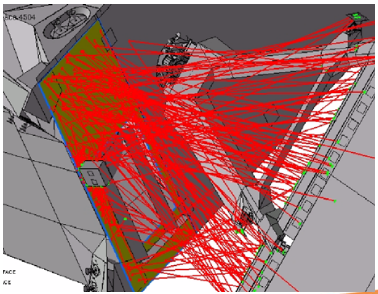
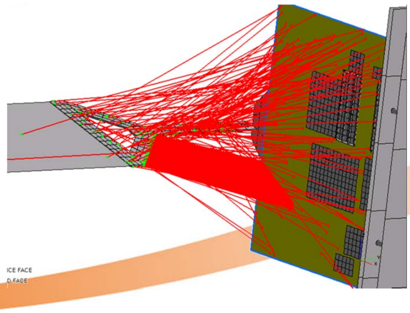
Date - 16

Conclusion

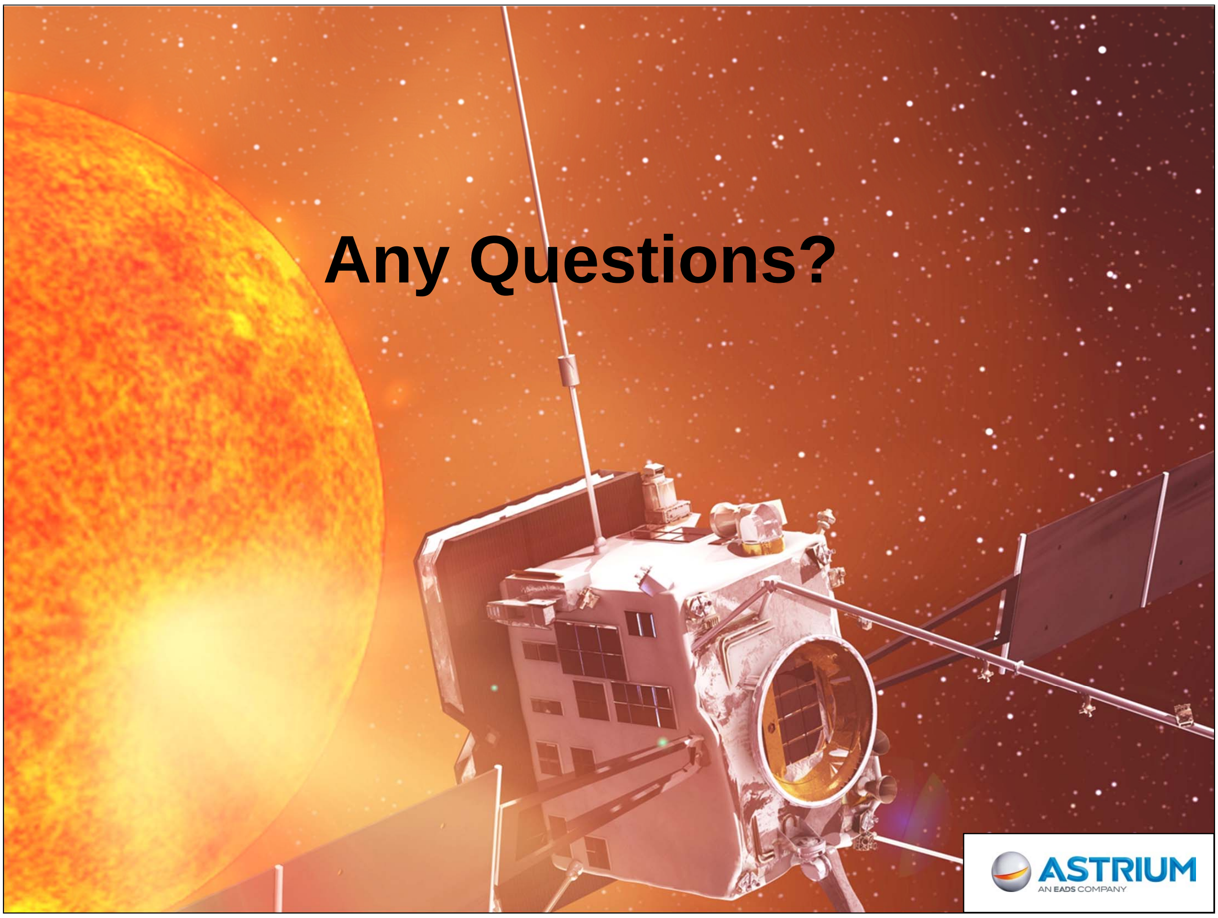
- ESATAN-TMS r3 software for Ray Tracing Visualisation has proven to be a very useful tool for Astrium UK
- The visualisation of rays enables the ‘problem face’ to be easily identified
- The tool has enabled further understanding of solar flux reflections at close proximity to the sun where additional reflections from appendages are thermal design drivers





All the space you need

Date - 17



Appendix D

First year using ESATAN-TMS
A newcomer's reflections

Edward Jones
(STFC Rutherford Appleton Laboratory, United Kingdom)

Abstract

This presentation provides an overview of the experiences of a recent Mechanical Engineering graduate during his first year using the thermal analysis software ESATAN-TMS. An overview of the variety of different models that have been created and analysed within the software will be provided, along with the key successes (and many lessons learned) along the way. The ease, or otherwise, with which the software has been picked up will be described, and some areas for improvement of the software will be identified.

RAL Space

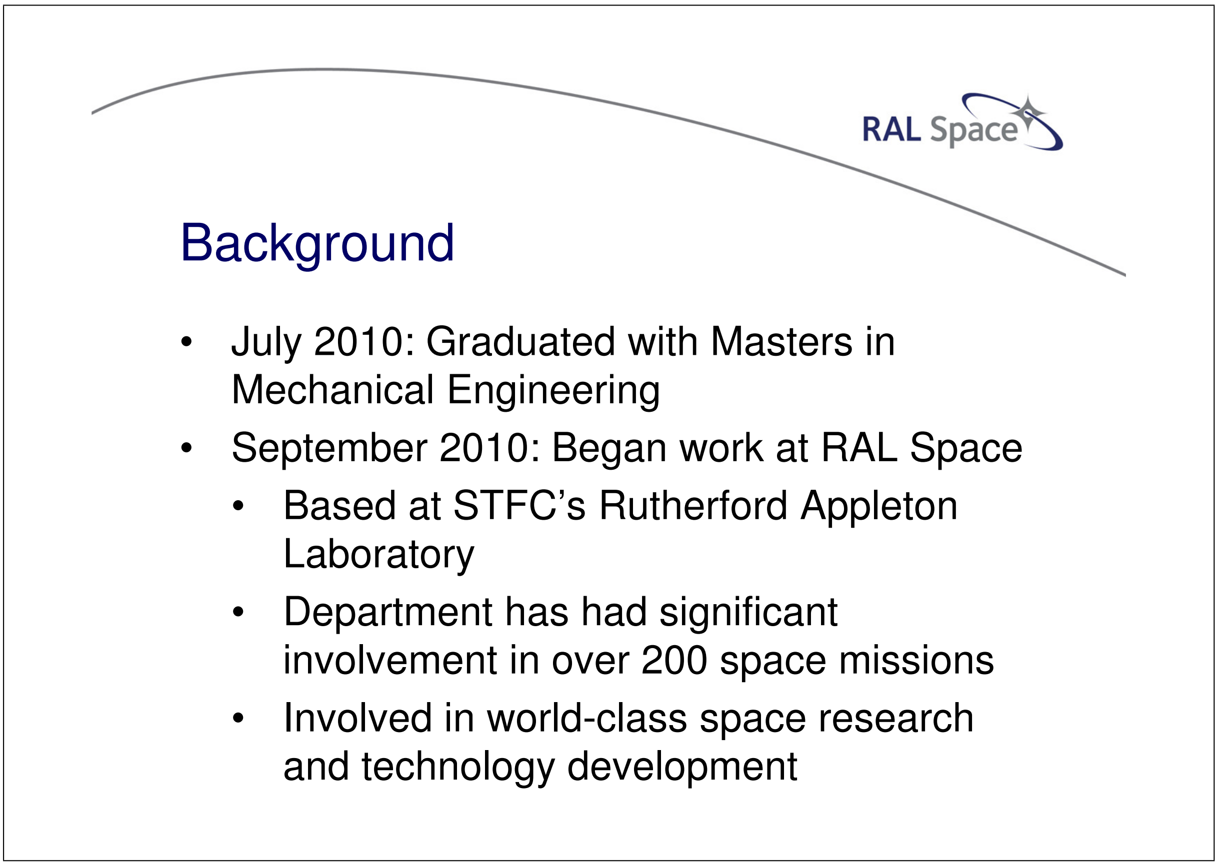
First year using ESATAN-TMS: A newcomer's reflections

Edward Jones
(RAL Space, STFC Rutherford Appleton Laboratory, United Kingdom)

RAL Space

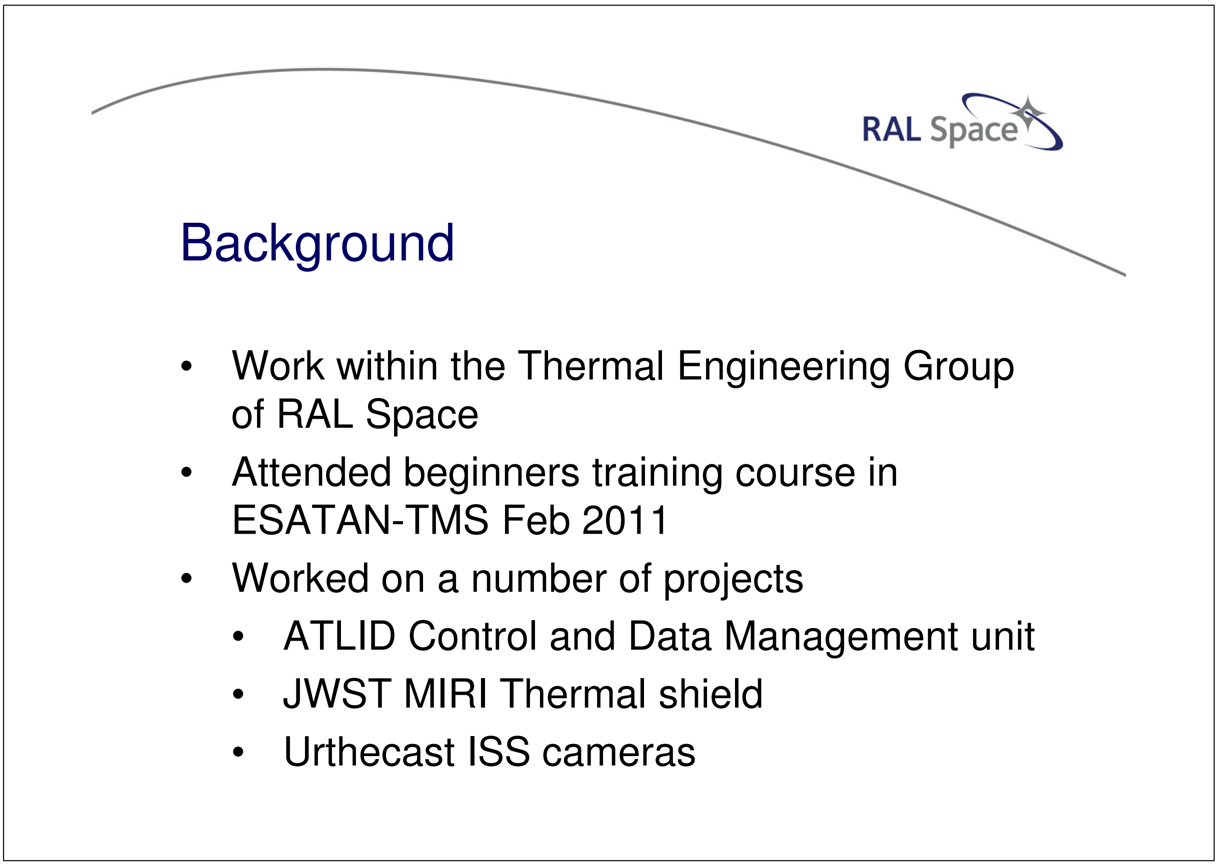
Overview

- Background
- Projects in ESATAN-TMS
  - Overview
  - Impressions of ESATAN-TMS
- Areas for improvement
- Overall Impression
- Q&A



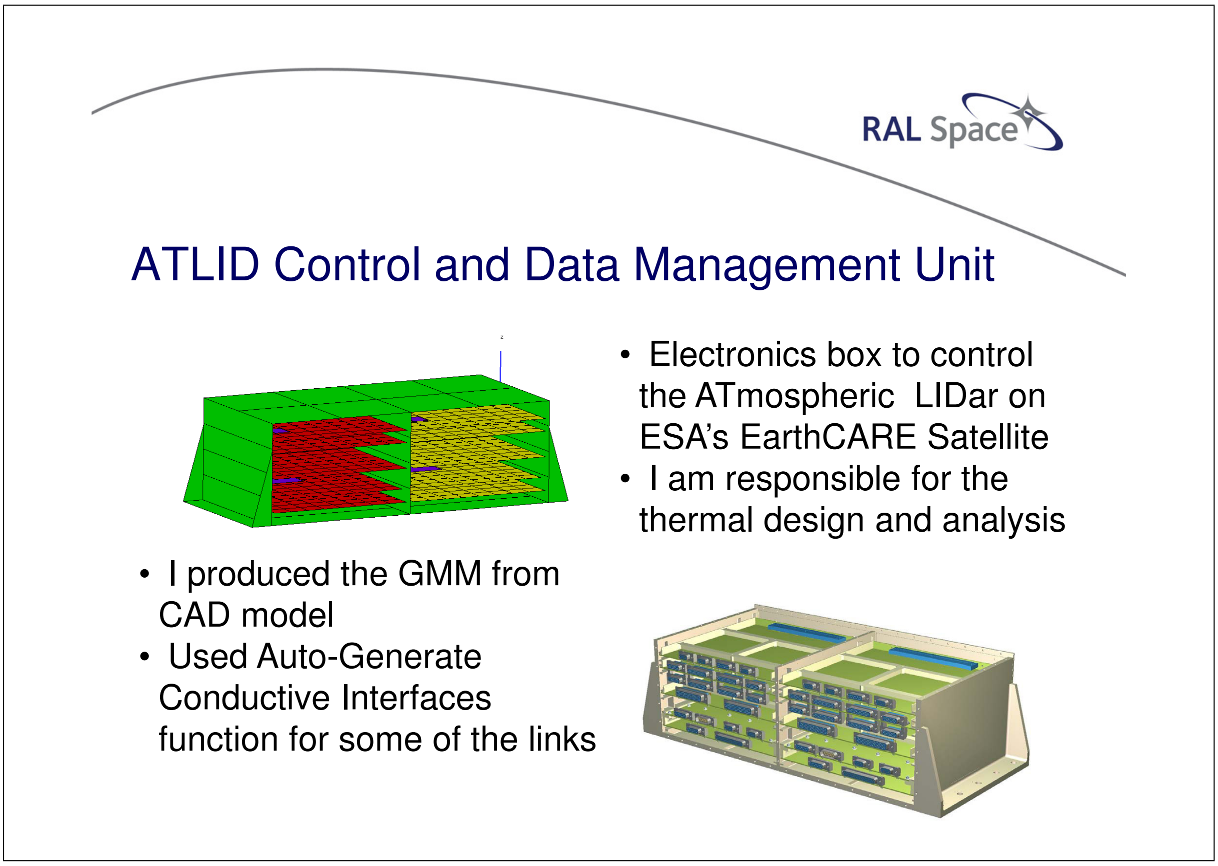
I graduated with a Masters in Mechanical Engineering from the University of Leicester in July 2010. Although during my degree I covered two modules on Thermodynamics and Heat Transfer I had little experience of thermal modelling before starting work at RAL Space in September 2010.

RAL Space, based at STFC's Rutherford Appleton Laboratory, has had significant involvement in over 200 space missions, and is at the forefront of world-class space research and technology.



I work within the Thermal Engineering Group of RAL Space, and am involved in all aspects of thermal design, from initial analysis, detailed design, thermal testing and MLI manufacture. Since ESATAN-TMS is extensively used within the department, I attended the beginners' training course on ESATAN-TMS in February 2011.

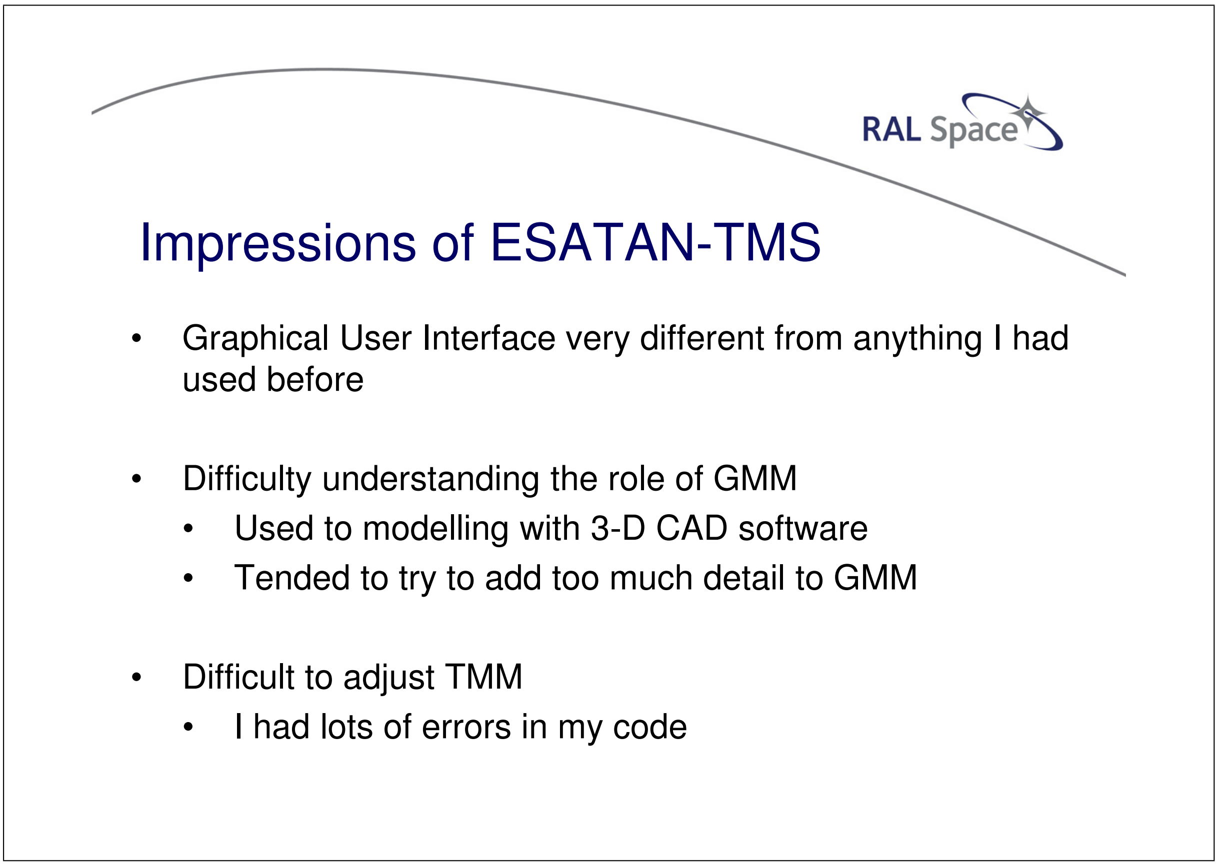
During the past year working for RAL Space, I have been involved in a number of different projects. The three main projects that I have worked on, however, have been the ATLID CDM unit, the MIRI heat shield and the Urthecast ISS cameras project. Each of these projects has required extensive modelling within ESATAN-TMS, and each has allowed me to explore the features of ESATAN further.



Before beginning work on my first project, the ATLID Control and Data Management Unit, I used the tutorials provided within the manuals to learn how to use ESATAN-TMS. After completing the set examples within the tutorials, I moved on to trying to modify the models in order to reinforce my understanding of thermal analysis and ESATAN-TMS.

After spending a week working on the tutorials, I was ready to begin the modelling of the ATLID Control and Data Management Unit. This is the electronics box which controls the Atmospheric LIDar on ESA's EarthCARE satellite, and I was responsible for the thermal design and analysis of the unit.

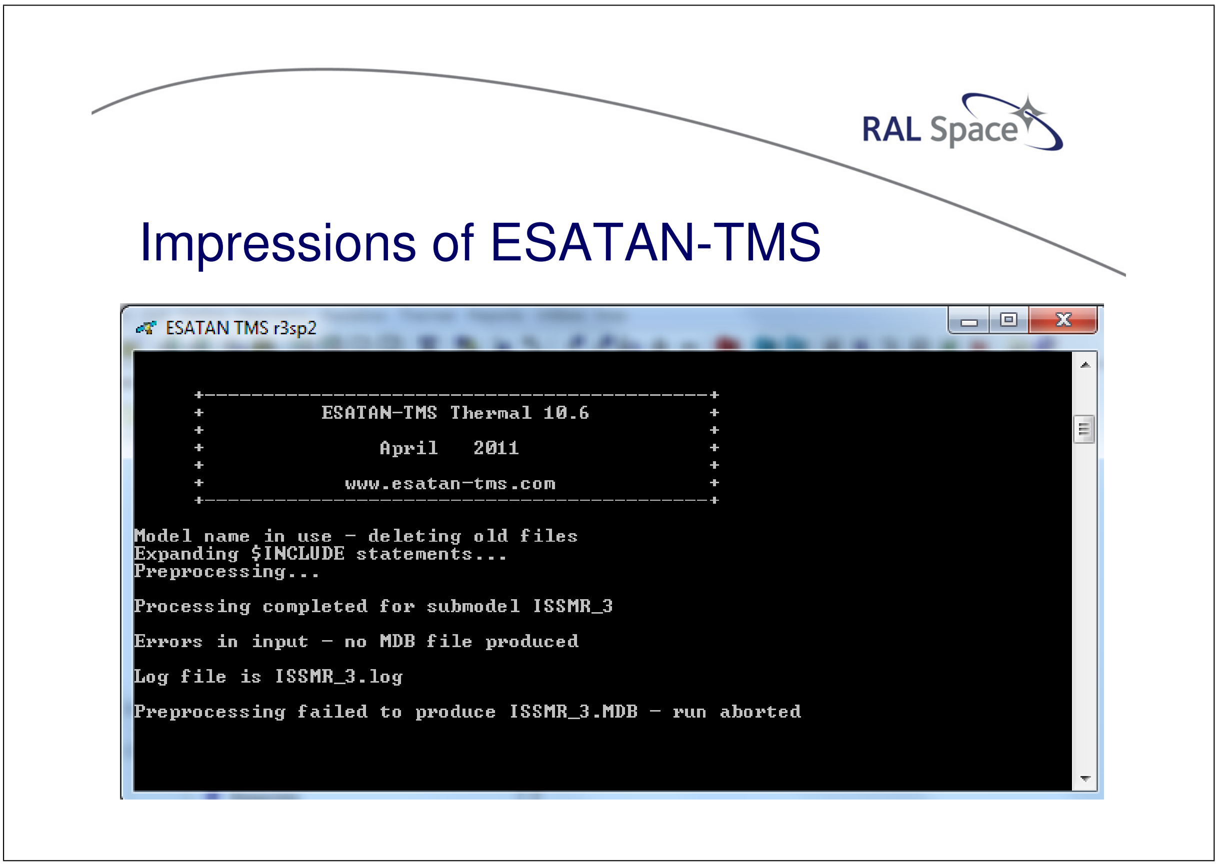
I produced the GMM from the CAD model, and used a coarse node definition for the metal work of the unit and a finer node definition for the PCBs, since were the key areas of interest. Although I used the Auto-Generate Conductive Links function to generate some of the links within the model, a large portion of the links were coded directly within the TMM.



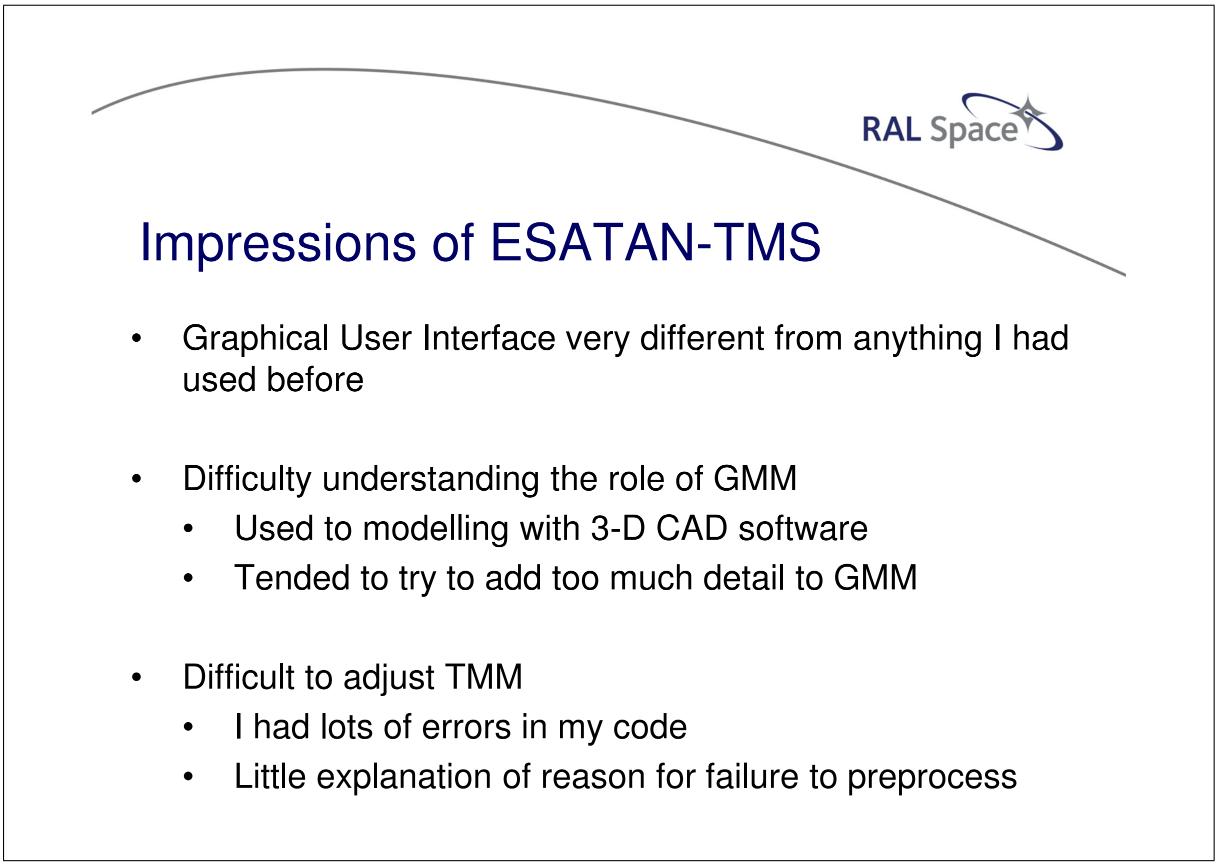
My first impression of ESATAN-TMS was that the Graphical User Interface was very different from anything I had used before. Throughout my degree I had predominantly used 3D CAD software in which the philosophy for creating models was to produce a 2D sketch and then extrude this to create the 3D geometry. The process of creating flat areas to build up a 3D geometry was very different.

This experience I had had with 3-D CAD software meant that to begin with I had difficulty in understanding the role of the GMM. My instinct was to try to add too much detail, such as modelling the PCB stiffeners and Connectors within the GMM. With experience, and by reviewing models created by other members of the department, I am now much better at simplifying the geometry.

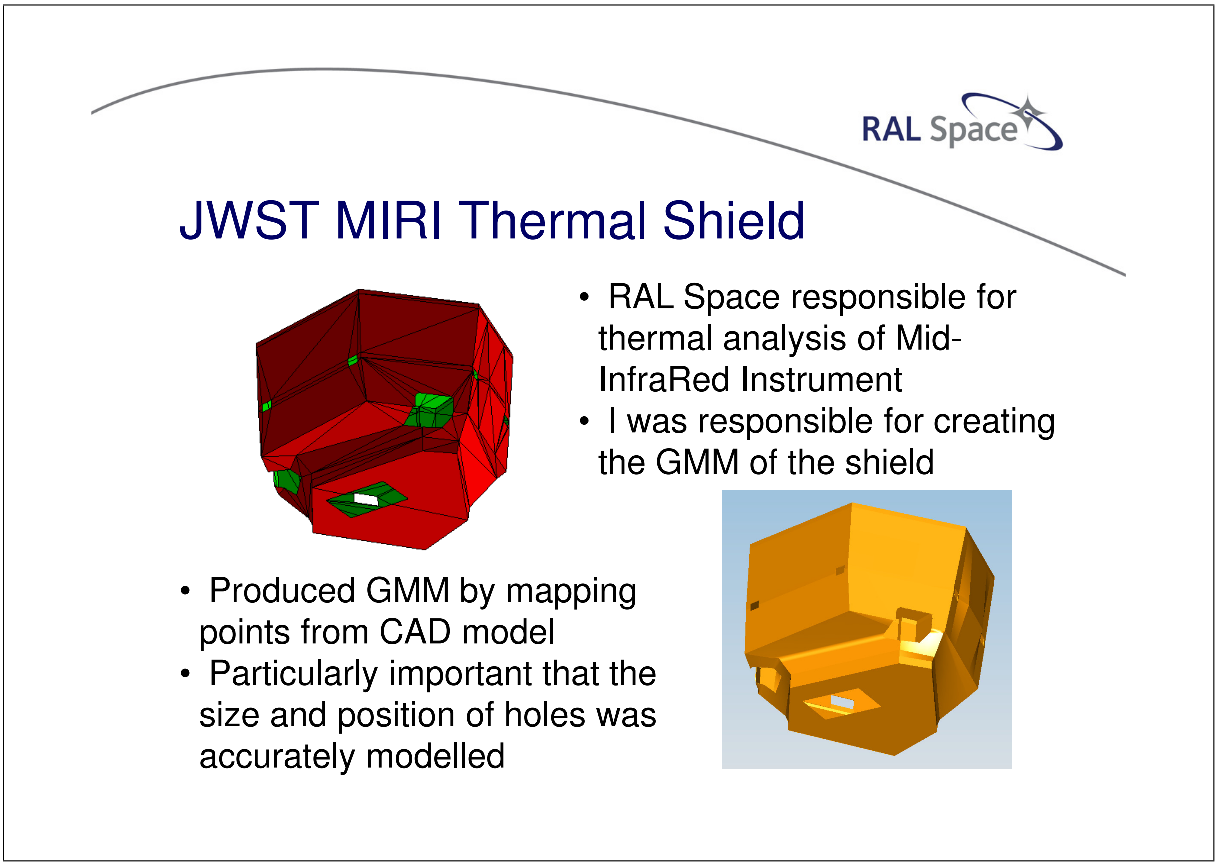
Initially I found it quite difficult to successfully modify the TMM. Within the ATLID project I had to write a large amount of the TMM code within a text editor, and as a result made lots of errors within my code.



It seemed that every time I tried to preprocess the code it would fail and if I had a pound for every time that I saw the 'run aborted' message within the DOS screen I would be a very rich man! The majority of the problems I had were syntax errors; either forgetting to include a semicolon where it was needed or including one where it wasn't; or forgetting to ensure that I had 6 spaces before commands within the Execution Block.



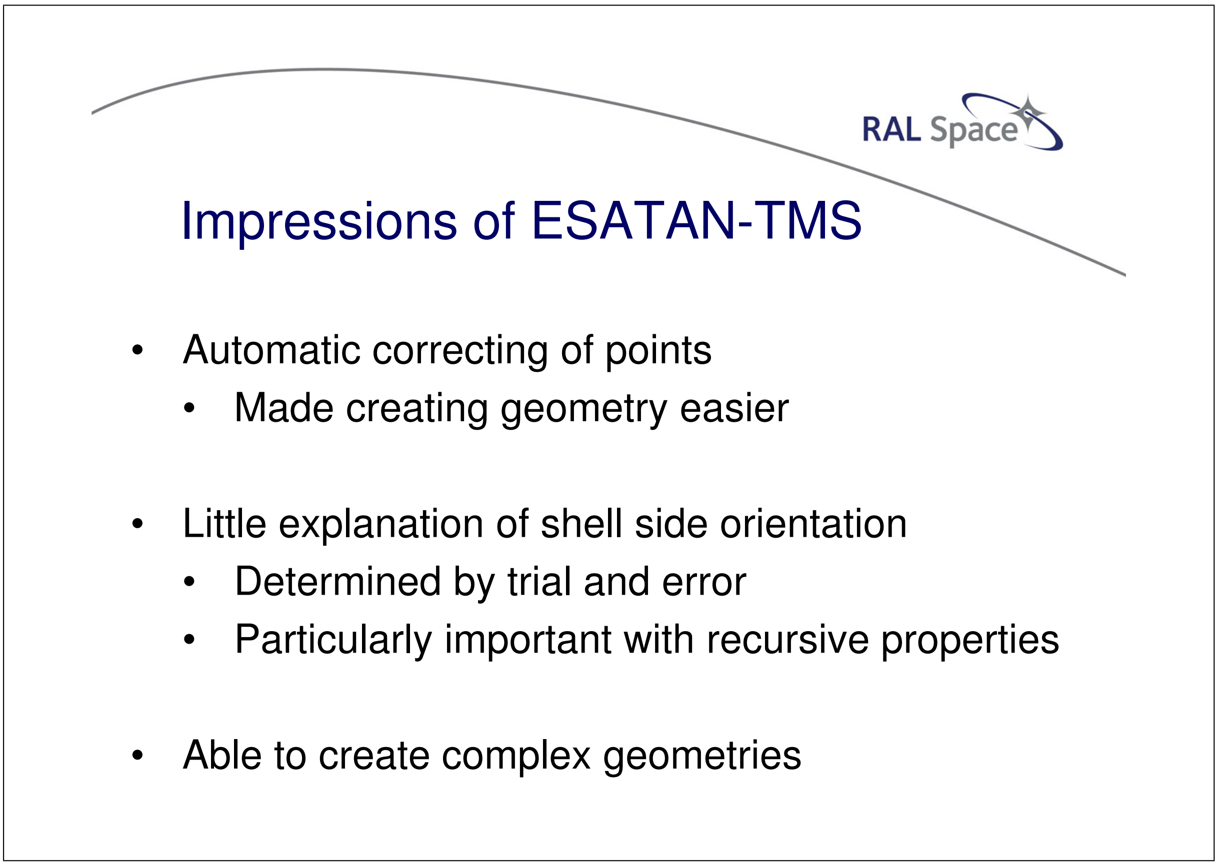
I found that the error messages given within the log files gave no clear explanation of the causes of the file not pre-processing, and there was no detail within the user manuals about potential causes of the errors. I therefore found it very difficult to debug my code, and think that if there had been a clear description within the user manual or training guide of the possible causes of certain common error messages then I would have been able to save a lot of time during this project.



The second project that I worked on was the Thermal shield for the Mid-InfraRed Instrument on the James Webb Space Telescope. The instrument's Optical module fits inside the shield. The geometry and apertures must be accurately represented to ensure the correct radiative boundary conditions.

RAL Space was responsible for the thermal design, as well as for the Assembly, Integration and Verification testing of the instrument. I was responsible for creating the GMM of the thermal shield.

I created the GMM from the CAD geometry by mapping points from the CAD model into ESATAN-TMS. I then used these points to define shells to create the geometry. It was important that the geometry was accurately mapped, but a minimal number of shells used in order to reduce the complexity of the model once it was combined with the MIRI GMM. It was particularly important that the positions and sizes of the holes within the shield were accurately modelled, since these had to coincide with features on the instrument.

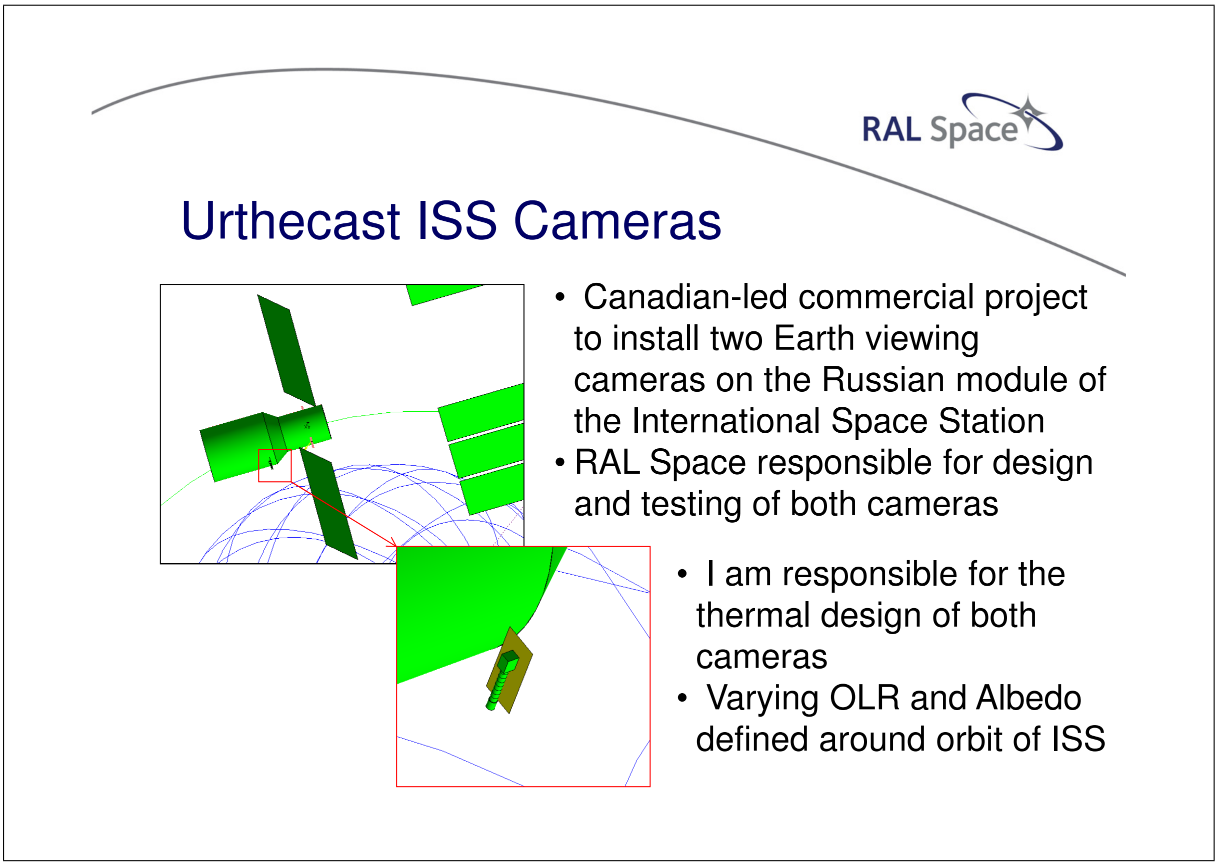


As may be seen, the MIRI thermal shield was a significantly more complex geometry than the ATLID unit, and therefore this greatly increased my understanding of the features of GMM creation within ESATAN-TMS.

I was particularly impressed with the automatic creating of points, when the points originally selected were not compatible due to, for example, not being in-plane or not being perpendicular. Since ESATAN-TMS specified the translation that had been applied to the point, it was possible for me to work out whether it was an error in inputting the co-ordinates of the point, or if the wrong choice of shell had been chosen i.e. two triangles should be used rather than a single quadrilateral. This made it easy for me to create an acceptable geometry, without incompatible shells.

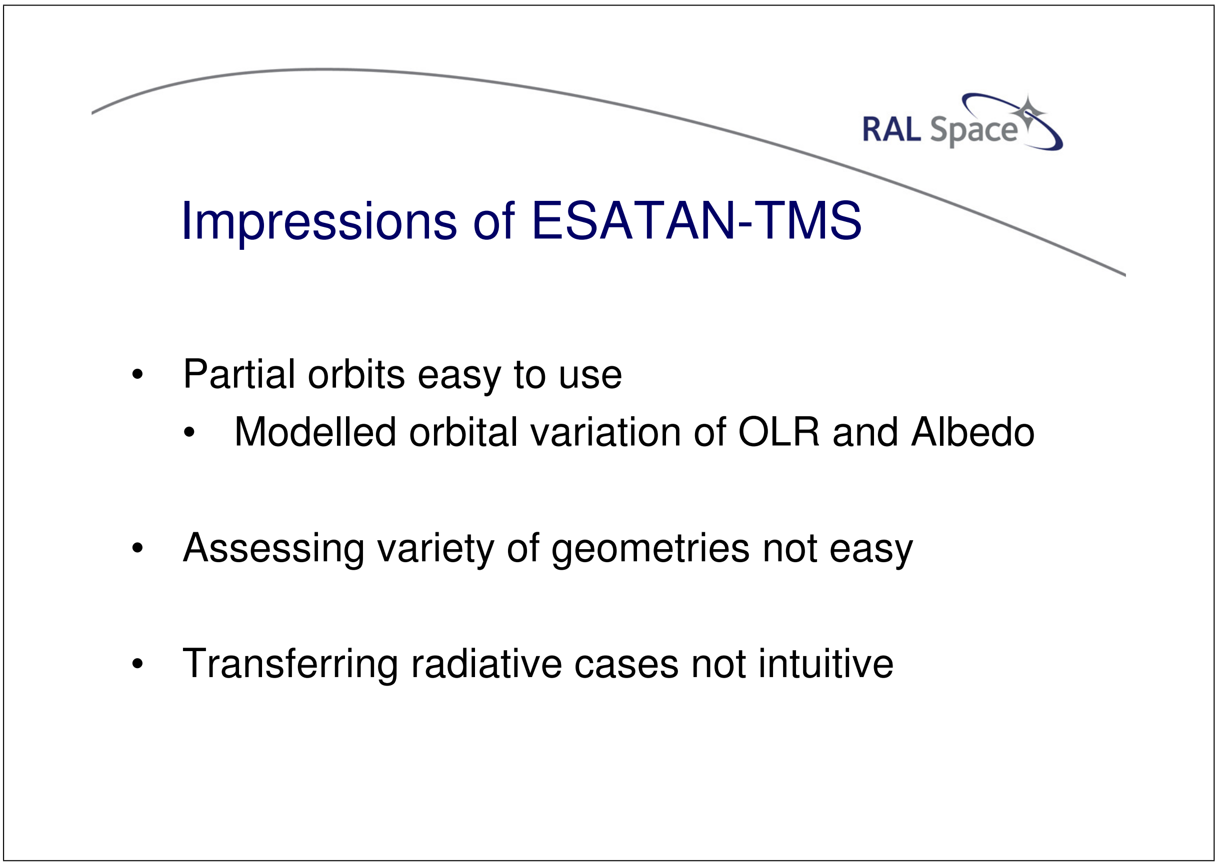
I did find it very difficult when specifying shells to work out which would be side 1 and which would side 2. At first I had to determine this by trial and error, before realising that the diagrams within the help are orientated with Side 1 facing forwards. A clearer, easier method for defining side 1 and side 2, or else the is particularly important now that the recursive shell property function has been included within ESATAN-TMS.

Finally I was impressed by how it is possible to create complex geometries by building up discrete geometric shapes. I feel that this process of building up the GMM forces the user to consider how best to simplify the geometry, and hence to create efficient models. Though this creation process makes it more difficult to produce complex geometries, I do think it serves a useful purpose.



The final project that I am going to talk about is the Urthecast ISS project. This is a Canadian-led commercial project to install two Earth-viewing cameras on the International Space Station. These cameras will provide a continuous feed to a freely accessible website. RAL Space is responsible for the design, manufacture and testing of both of the cameras, and I am responsible for the thermal design of both cameras.

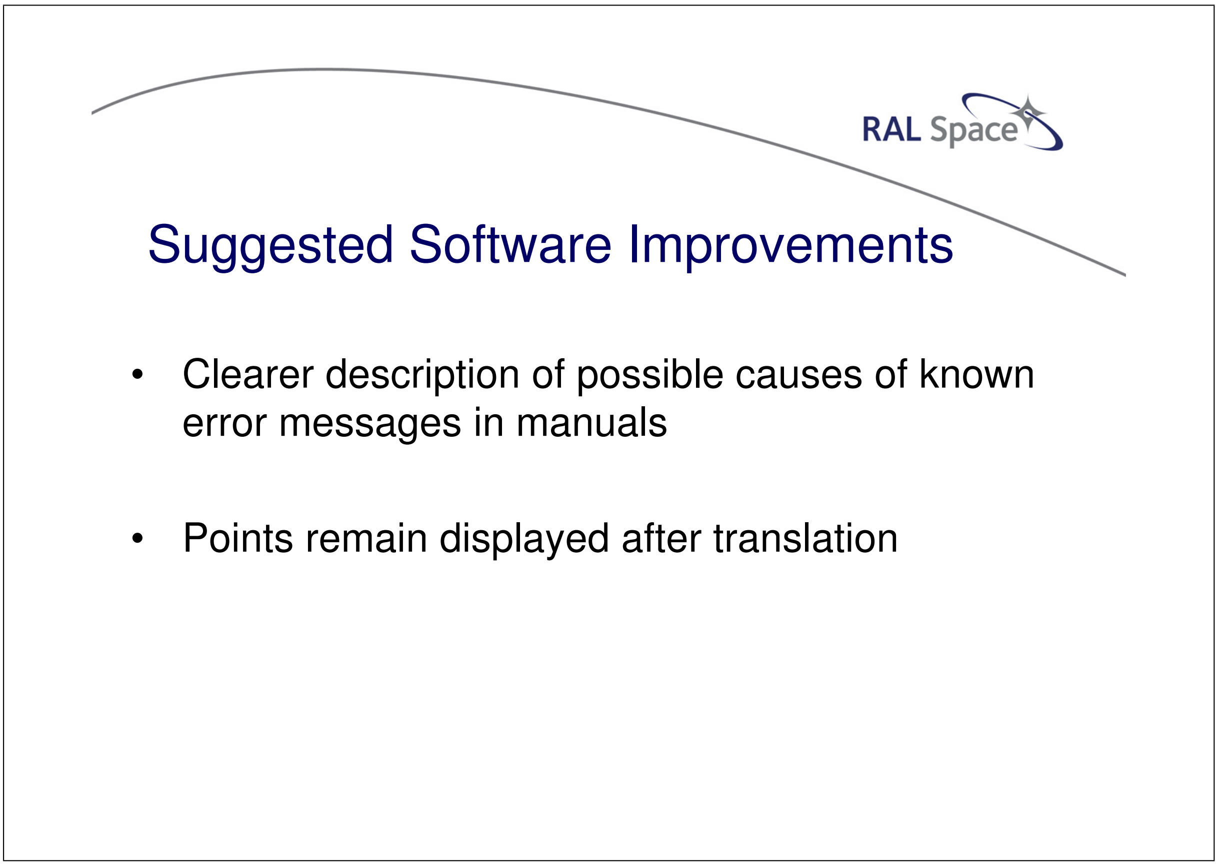
This is the first project that I have worked on which requires orbital modelling, and the hot and cold case orbits of the ISS are defined as having a changing OLR and albedo around the orbit. I therefore have to model a complex geometry with a complex orbit definition.



The orbit variation of the ISS is defined within the standard by beta angle, which is the angle between the solar vector and the orbital plane. Around the orbit there is a variation in OLR and albedo specified, so I used the partial orbit function within ESATANTMS to model each period of constant OLR and Albedo. I calculated the Earth temperature that would be required for each value of OLR, and determined the initial and final true anomaly for each case from the period of the orbit. Since there were 4 worst cases specified, 2 Hot and 2 Cold, and three different values of OLR and Albedo for each case, a total of 12 different radiative cases were created. I was very impressed with the ease with which this potentially complicated orbit scenario could be modelled through the use of partial orbits, though it would have been easier if it had been possible to directly specify the Earth IR.

Since the geometry of the cameras and their associated radiators have not yet been fully defined it is necessary to assess a number of different geometries and orientations. In my experience modelling different geometries within ESATAN-TMS is not easy. Having to create a separate model for each change of geometry does not seem particularly easy to me, especially since the process of transferring the analysis and radiative cases between models is not intuitive.

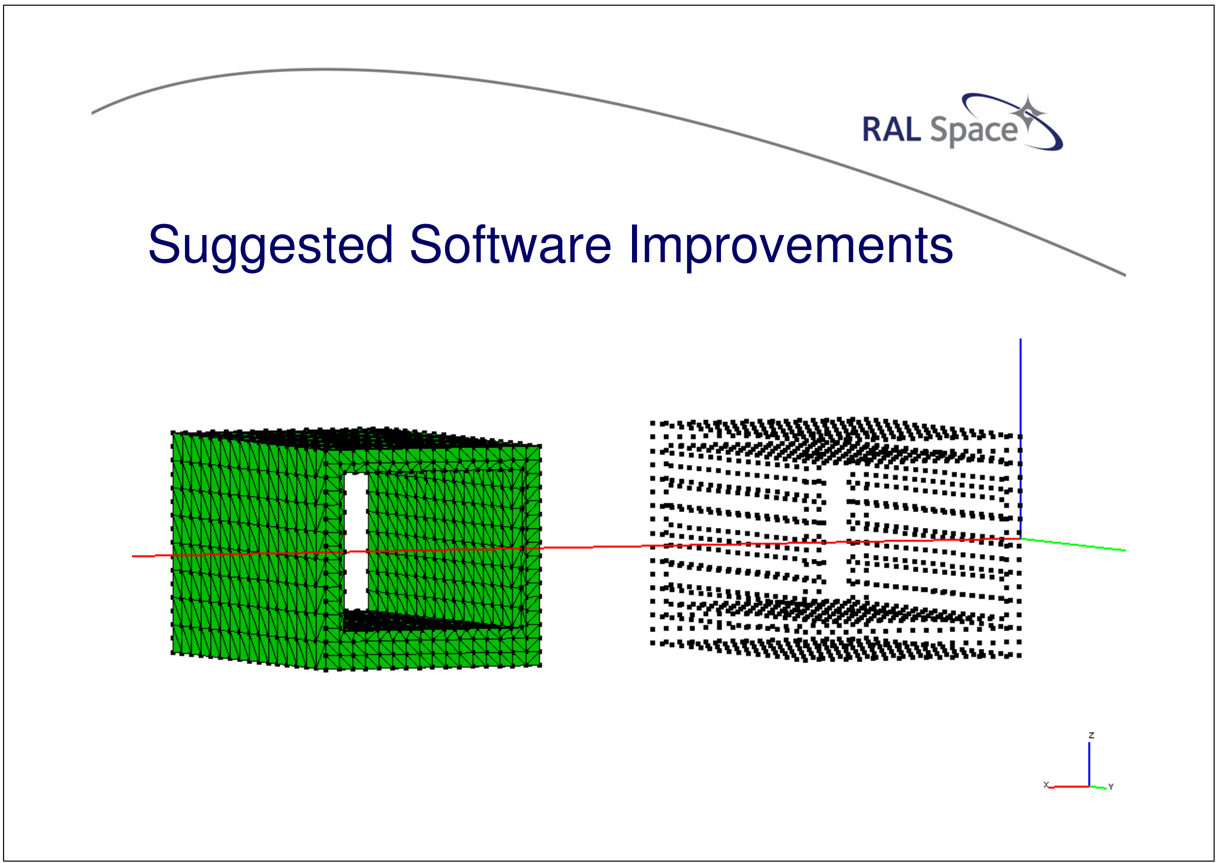
Currently it is necessary to either go through the process of defining the radiative cases within the GUI for each model, or else to find the appropriate part of the log file relating to the definition of the radiative case and then paste that into the command line. With 12 radiative cases for each model this makes for quite a cumbersome process. Therefore a simpler method of transferring the radiative cases between models would be very useful.



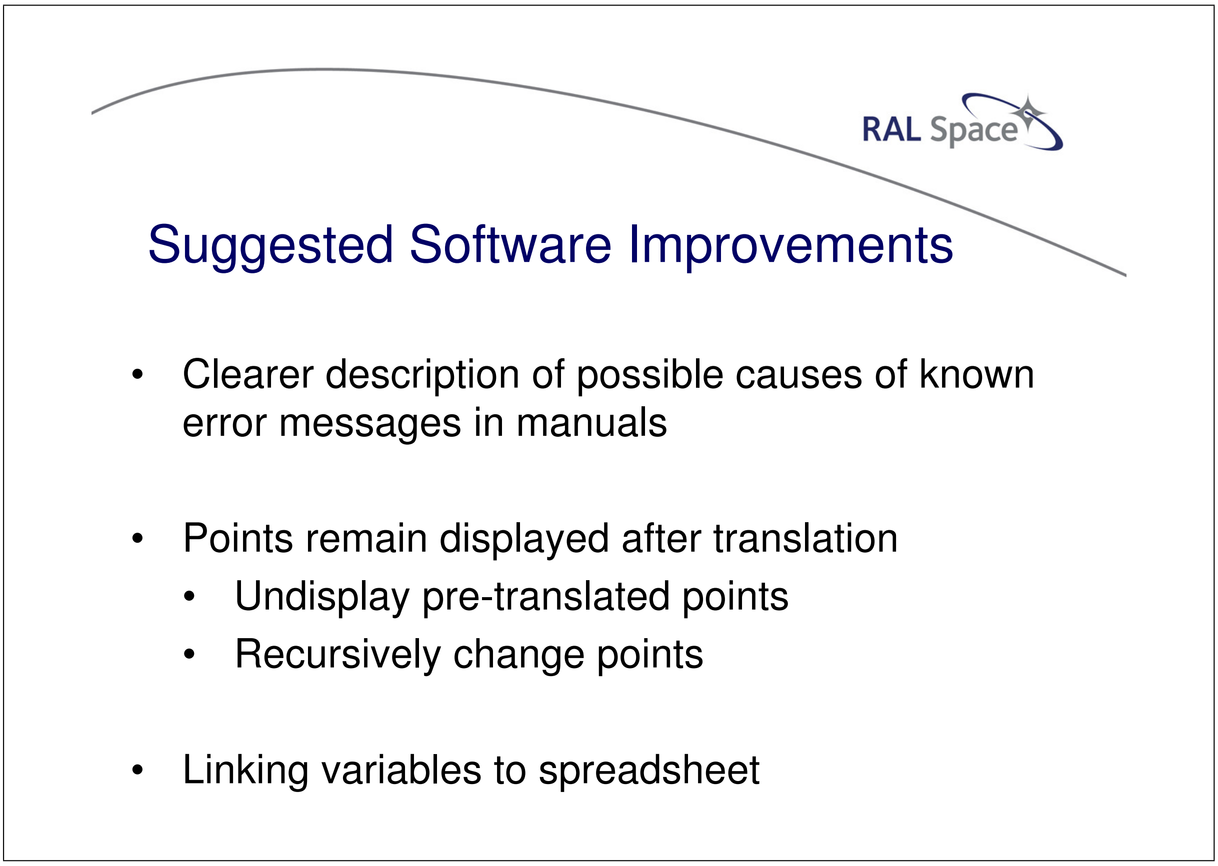
Through the work that I have completed using ESATAN-TMS over the past year, I have identified a few areas that I feel would benefit from improvement.

From my difficulties in getting the TMM to pre-process successfully, I think that it would be very useful to have descriptions of the causes of the most commonly encountered error messages, along with an overview of the key syntax for the models, within the training manual. As many computer programs move away from coding, and more into Graphical User Interfaces, it becomes more important to have this since new users may have less experience in coding, and particularly in using FORTRAN. Had these descriptions been within the user manual, I would have saved a considerable amount of time during the ATLID project.

Though I have not used it extensively I have been impressed with the CAD convertor for importing complex geometries. One of my colleagues needed to model a double sided concave mirror, and through the CAD convertor was able to import a good representation of the geometry into the GMM. The major disadvantage I see with the CAD convertor, however, is the heritage of points after a translation is performed.

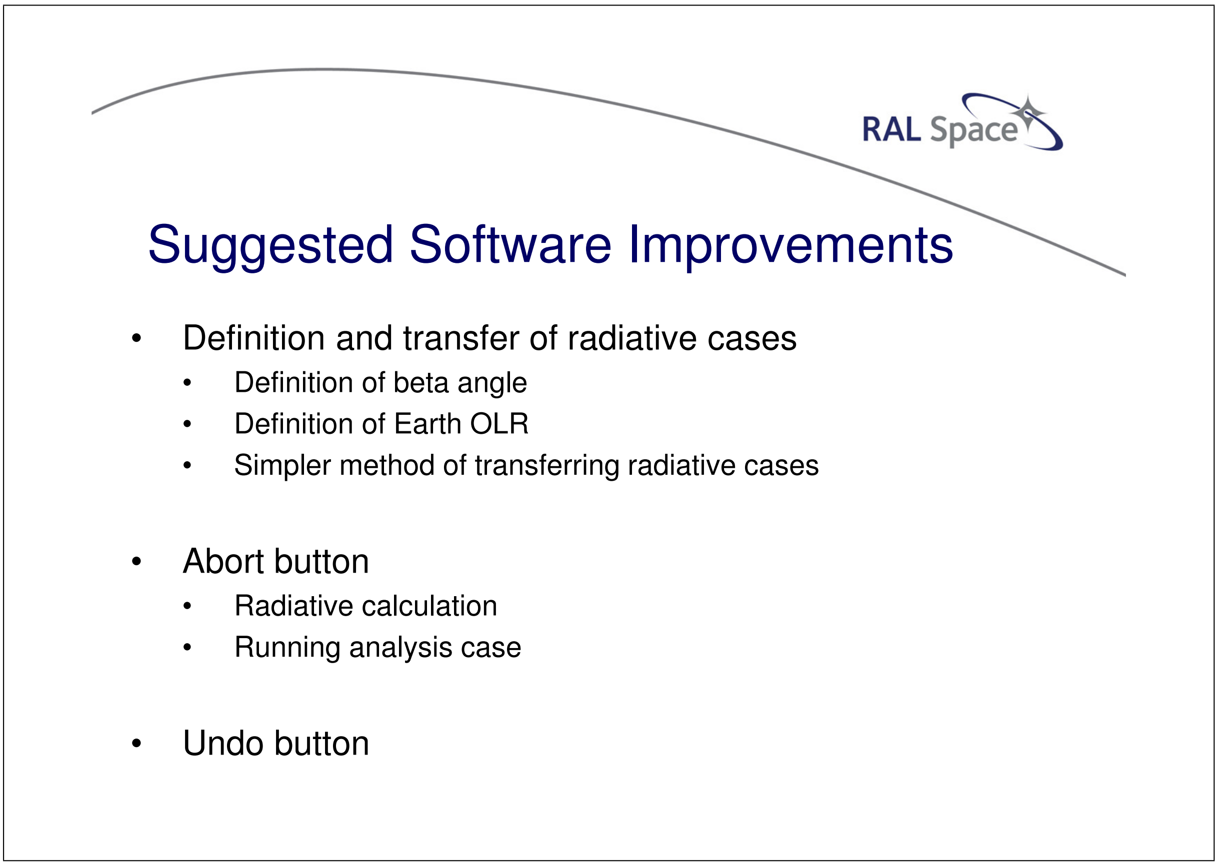


As may be seen in this simple geometry that I imported, after a translation the original points remain displayed within the GMM. This not only makes the GMM untidy, but could get very confusing if the CAD convertor is used to import a number of different geometries into a single model. Currently it is not possible to undisplay individual points; the user has only a selection between displaying all points or none. If it were possible to either automatically undisplay all pre-translated points or else to select points to undisplay, I think that this would make the CAD convertor a significantly better tool and the GMM tidier.



In addition to the ability to undisplay selected points, I think that it would be useful to be able to recursively change point co-ordinates. If a geometry has been defined through user defined points, and then the dimensions of the geometry change, it would be useful to be able to redefine one of the co-ordinates of a number of points simultaneously.

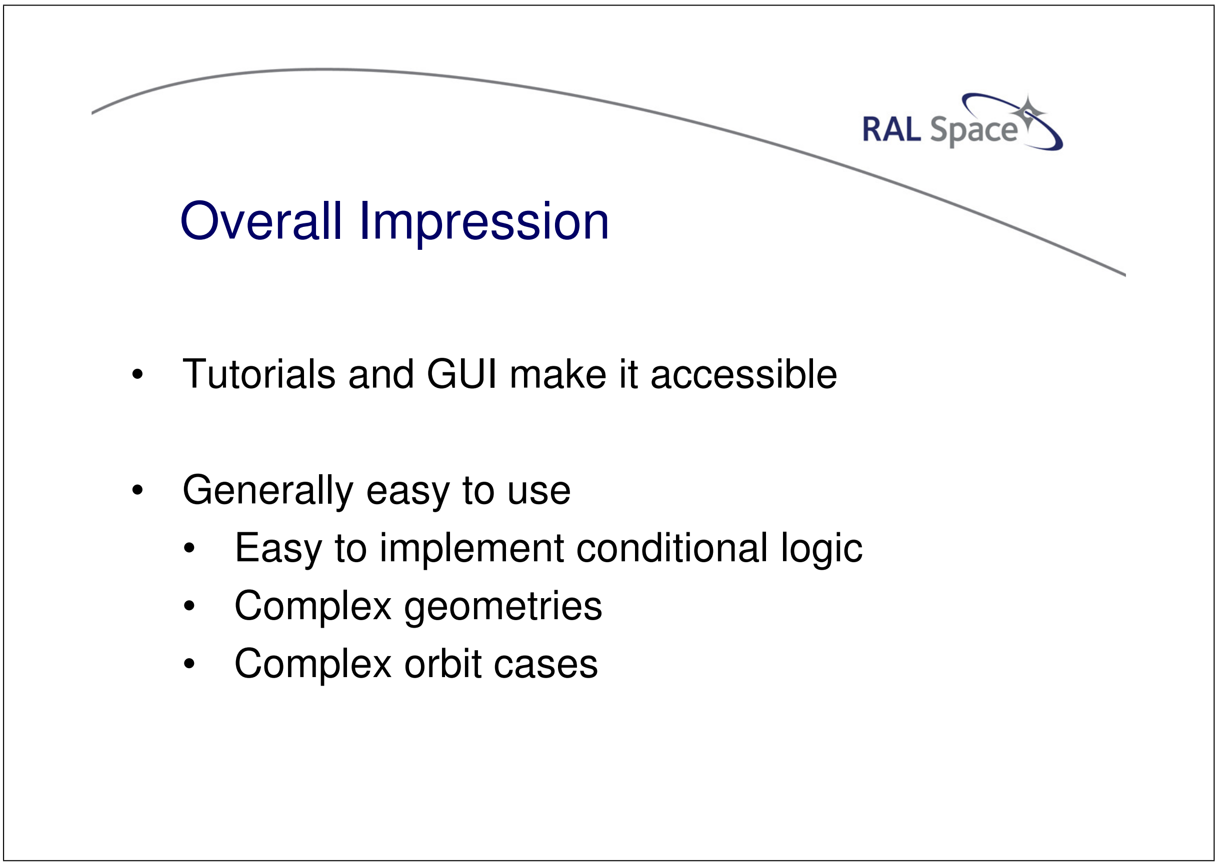
Another potential improvement that I have identified for the software, from parallels to CAD programs that I have used, is the ability to link points or variables to a spreadsheet. These variables could be reloaded periodically, and updates to the geometry identified. This would improve the link between CAD packages and ESATAN, allowing changes in geometry to be easily updated within ESATAN, and would also make it easy to keep a track of the variables used within the models.



Whilst working on the orbit definitions for the Urthecast ISS cameras project, I have identified a couple of areas in which the definition and transfer of the radiative cases could be improved. One of the sources that I have read about orbital modelling for thermal analysis suggested that considering orbits in terms of Beta angle offers an easier way for defining the worst case hot and cold cases to consider. Since the hot case is the maximum absolute beta angle and the cold case is the minimum, considering the orbit in this way removes the complexities of variation due to precession of the orbit. I think that it would be useful if it were possible to define the orbit inclination, the solar declination and the beta angle to be considered, and for ESATAN-TMS to then automatically align the orbit to achieve this beta angle. The other improvements, which I have already mentioned, are the ability to directly define the Earth OLR value and a simpler method of transferring radiative cases between different models.

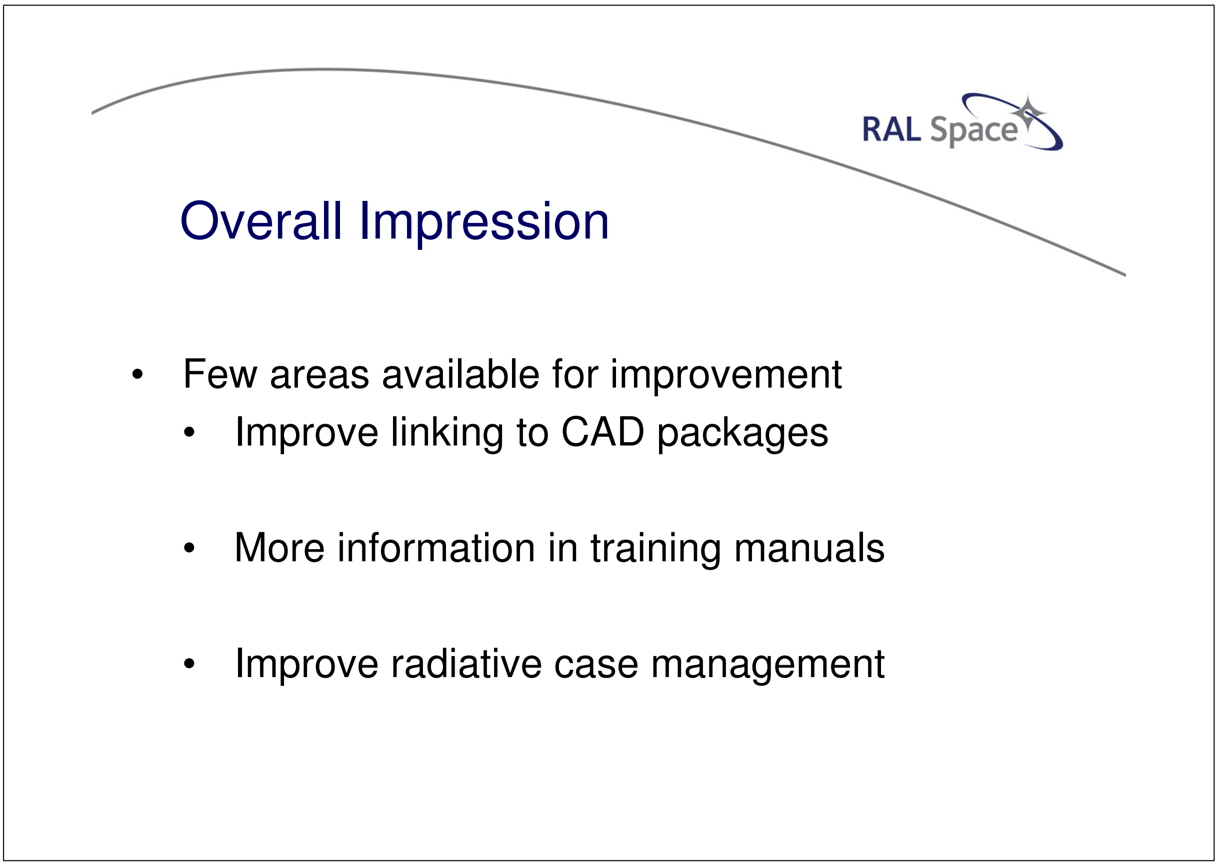
Another feature that I think would be a useful addition to the software is an abort button, to stop the radiative calculation and the analysis cases running. As the models I have produced have got larger and more complicated, the time taken for these two actions has increased. It is annoying when you realise shortly after pressing the pre-process and solve button, that you have forgotten to regenerate the analysis file, or after executing the radiative case, realising a change you should have made to the GMM, and then having to wait for the program to produce results that are of no use to you. The current method I adopt for aborting in these cases is to close the DOS window, but this is rather a dramatic method. An abort button to safely stop the process would reduce the time wasted after making a mistake.

The final feature that I often wish ESATAN-TMS had is an undo button. After changing the wrong variable or unassigning the wrong shell it would be very useful to be able to undo the action. This was something I was particularly keen for after trying to return to a previous geometry and using the reload geometry function. This resulted in my analysis cases disappearing from the screen and the radiative cases being deleted, and so at that time I desperately wanted to press cntrl+Z and have it all reappear!



Despite these few areas for improvement, overall I am impressed with ESATAN-TMS. The user interface means that it is a very accessible program, and with the tutorials it is easy to begin creating simple models. I was able to produce an initial model of the ATLID unit within a week of starting to use the program.

I find the program generally easy to use, and since a large portion of the model may be generated through the GUI, it is easy to initially set up the different elements of the model. It is easy to include complex transient cases, such as heater control through the use of conditional logic, and whilst being simple enough to pick up quickly, it is powerful enough to model complex geometries and orbital cases.



To summarise, the few areas that I feel would benefit from improvement are an improved linking to CAD packages, more information within the training manuals about common errors made by new users, and improvements to the definition and management of radiative cases.

RAL Space

Thank You

Any Questions?

Appendix E

Application of ESATAP for automatic thermal model validation

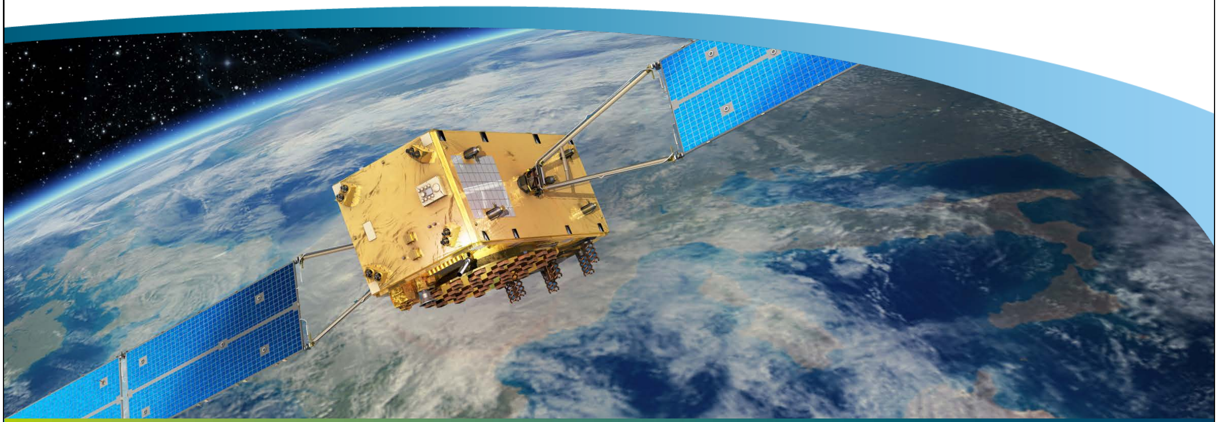
Stephan-André Kuhlmann
(OHB System AG, Germany)

Abstract

Obviously the quality of a thermal analysis depends on the quality of the thermal model used. Complexity and size of thermal models have been increased in the last years. Due to this also the model validation became more complex and time consuming. This presentation is focused on the evaluation of the capabilities provided by ESATAP to automate the model validation process. Based on a simple example it is shown how ESATAP can perform some automatic checks on thermal models to assist the validation process.

Stephan-André Kuhlmann
08.11.2011, Noordwjik

OHB SYSTEM



SPACE SYSTEMS

Application of ESATAP for Automatic Thermal Model Validation

OHB SYSTEM

Background

- Quality of thermal analysis depends on the quality of the model used
- Thermal model sizes increase in the last years
- Thermal model validation becomes more complex and time consuming
- Automatic model verification is desirable
- New ESATAP version (2_1 beta1) is available for testing

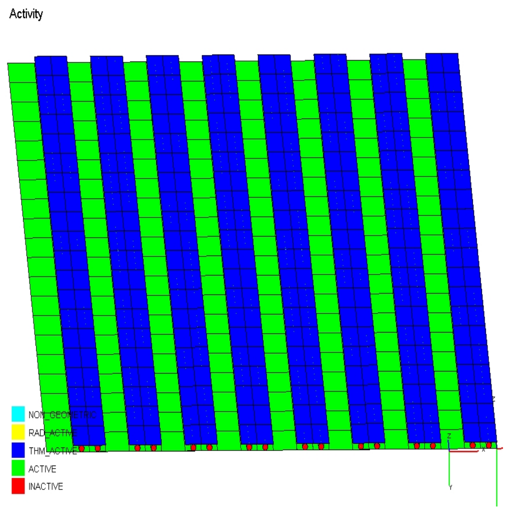
→Why not evaluate, how ESATAP can be used for automatic thermal model validation??

Seite 2

OHB SYSTEM

Simple example model

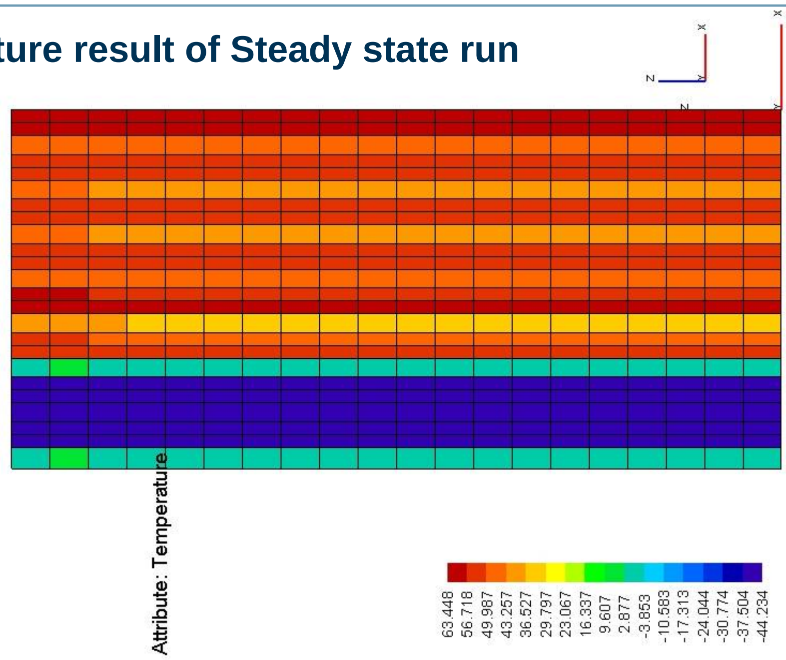
- Radiator Panel
  - 20 mm Honeycomb
  - 0.2 mm Facesheets
  - Outer side OSR covered
- For Groups of interest
  1. Radiator outer side
  2. Radiator inner side
  3. SMHP's
  4. Interface nodes



Seite 3

OHB SYSTEM

Temperature result of Steady state run



Seite 4

OHB SYSTEM

Basic checks for model validation

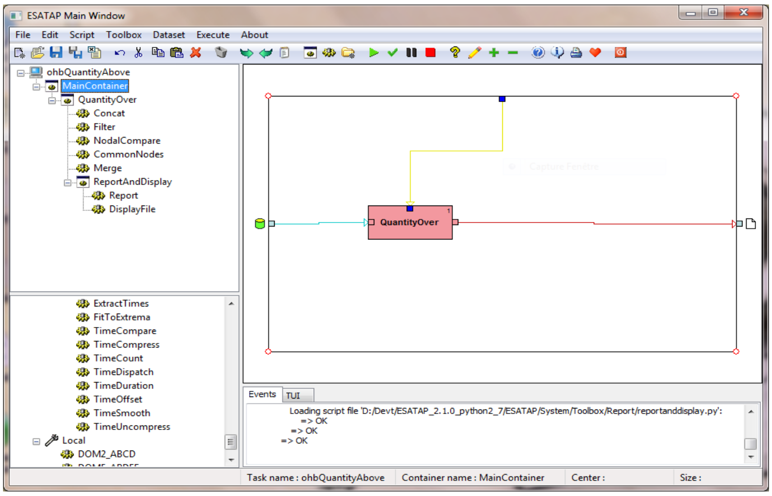
1. Heat balance for each group of interest and to the environment.
2. Report all nodes with an entitiy above a given value, e.g. all nodes with a capacitance above 400 J/(kgK)
3. Report all nodes where conductors with different order of magnitude are connected
4. Do a rough mass check by: Sum mC_p over all nodes (per group) and divide the sum by a given Cp
5. On structure panels, report thermal doubler nodes and nodes with reduced coupling.

Seite 5

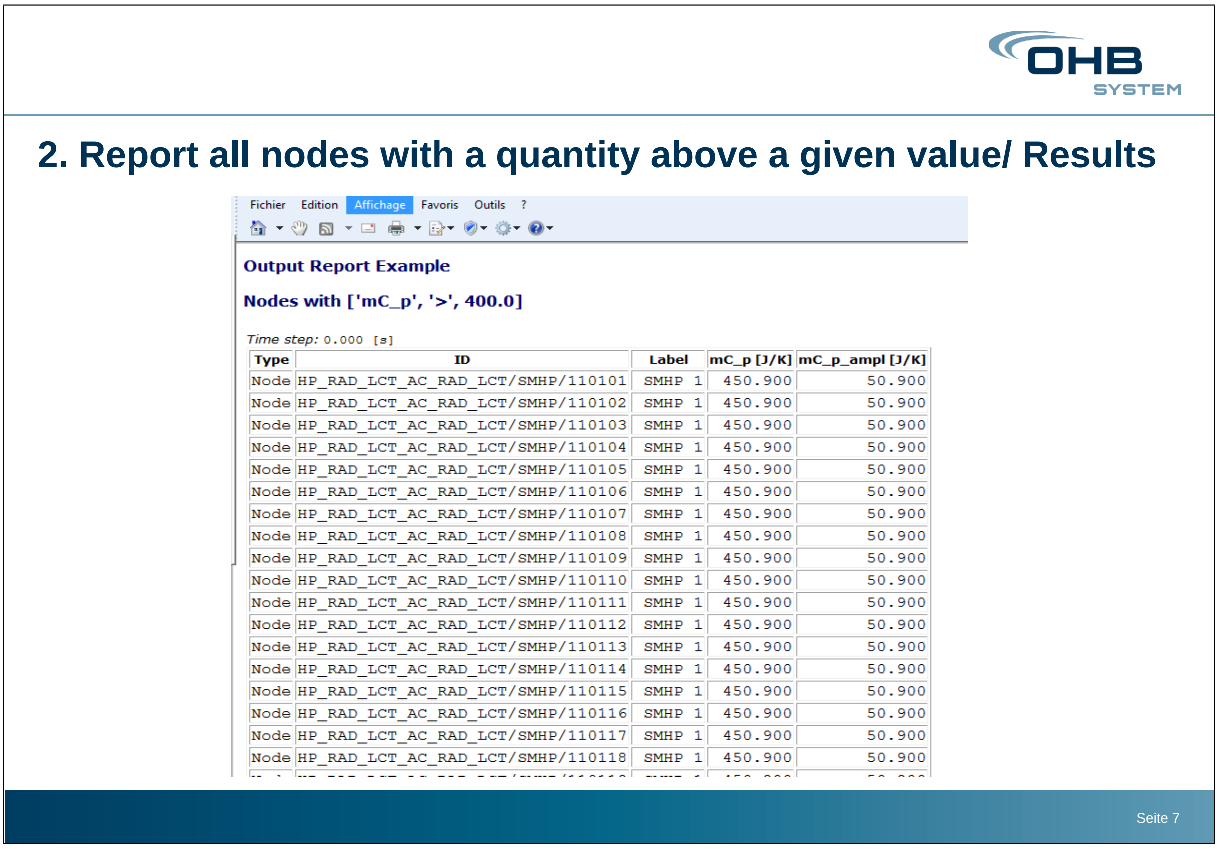
OHB SYSTEM

2. Report all nodes with a quantity above a given value

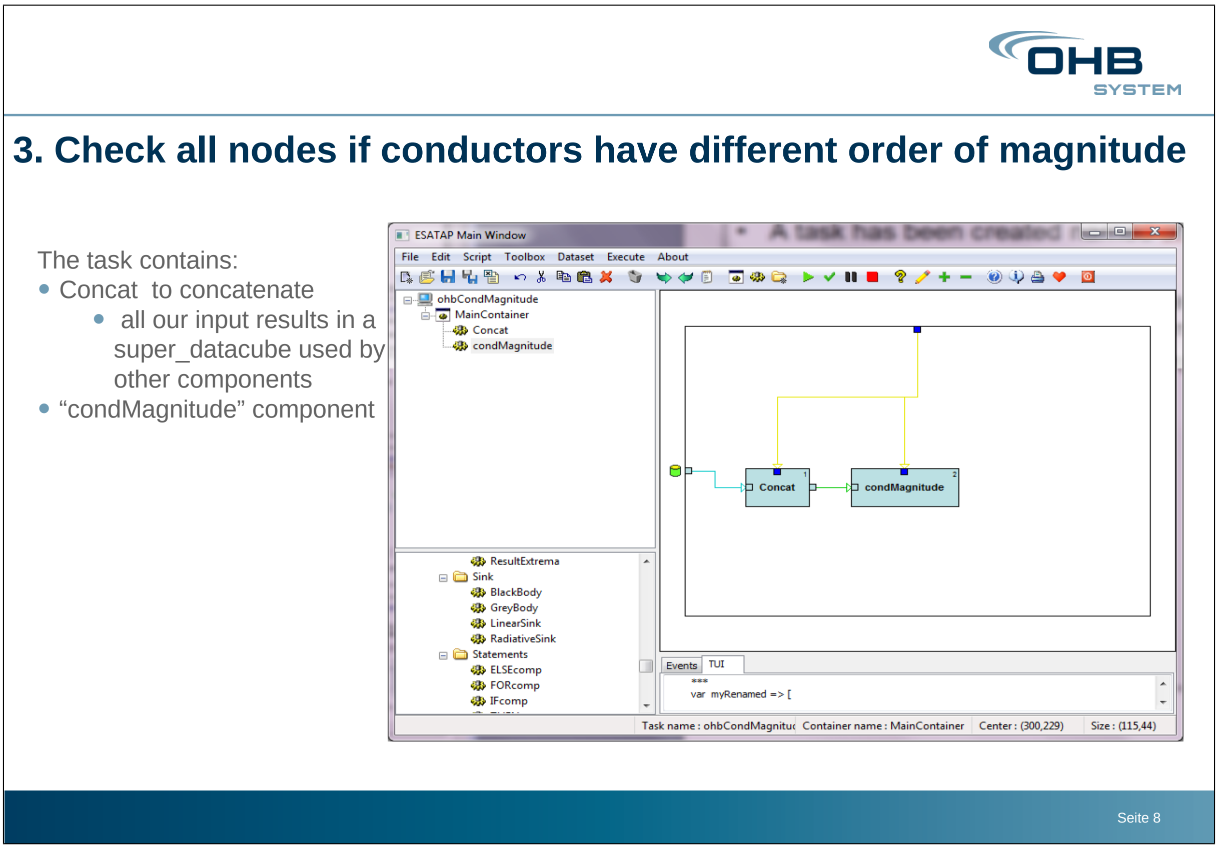
- Example report all nodes with m_Cp above 400
- The task contains a call to the single container QuantityOver



Seite 6

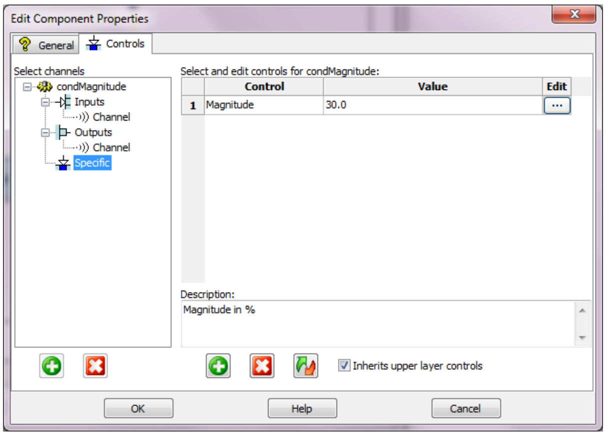


Type	ID	Label	mC_p [J/K]	mC_p_ampl [J/K]
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110101	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110102	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110103	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110104	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110105	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110106	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110107	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110108	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110109	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110110	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110111	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110112	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110113	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110114	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110115	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110116	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110117	SMHP 1	450.900	50.900
Node	HP_RAD_LCT_AC_RAD_LCT/SMHP/110118	SMHP 1	450.900	50.900



OHB SYSTEM

3. Check all nodes if conductors have different order of magnitude



INFO : Processing component condMagnitude

INFO : **WARNING Time step:0.000 Node :HP_RAD_LCT_AC_RAD_LCT/SMHP/110102 has GR with magnitude greater than 30.0 % Delta is 39.8541639171 %**

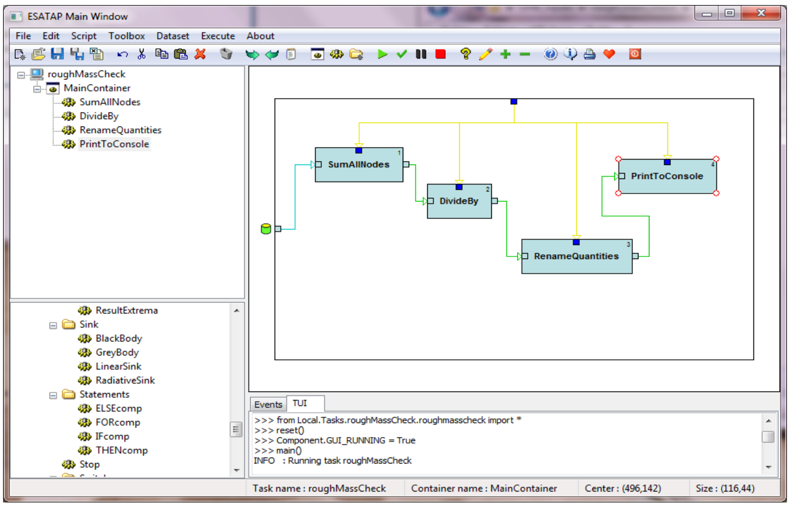
Seite 9

OHB SYSTEM

4. Do a rough mass check

This task sums mC_p over all nodes (per group) and divide the sum by a given Cp to compute a rough mass check

- SumAllNodes compute the mC_p sum of nodes of the group
- The DivideBy component divides the group mC_p by our Cp
- RenameQuantities: rename the resulting quantity to m(Kg)



Seite 10

OHB SYSTEM

4. Do a rough mass check / result

With a Cp of 900 J/(kgK) →

PrintToConsoleResult is:

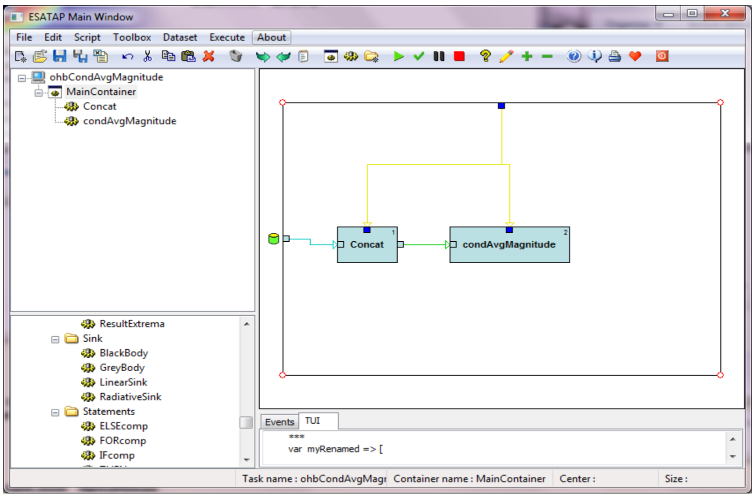
```
INFO   : PrintToConsole(Input1): 'myRenamed'
        ***
        var  myRenamed => [
        [  Time: 0.000 [s]=
            Group: RADIATOR OUT (4002)= m: 1.352 [kg],

        ]
        ]
        ***
```

Seite 11

OHB SYSTEM

5. Report thermal doublers and nodes with reduced coupling



Sum the GLs for each node a group and report the ones where the sum is less than ‘magnitude’ times the average values of the sums

Seite 12

OHB SYSTEM

5. Report thermal doublers and nodes with reduced coupling / results

- The result of the task is the following for a model were no problem is identified is:

INFO : Processing component condAvgMagnitude

INFO : Time :0.0 CHECK OK: The sums of the **GLs** for each node differs less than 80.0% of the GLs sum average

INFO : Time :8612.76464844 CHECK OK: The sums of the **GLs** for each node differs less than 80.0% of the GLs sum average

- The result of the task is the following for a model were a problem or doubler is identified:

INFO : Processing component condAvgMagnitude

INFO : WARNING Time :0.0 Node :HP_RAD_LCT_AC_RAD_LCT/RADIATOR/222118 GL sums 0.3368772 differs more than 30.0% GLs sum average 0.258922145455 Delta is 30.1075268817 %

INFO : WARNING Time :0.0 Node :HP_RAD_LCT_AC_RAD_LCT/RADIATOR/222119 GL sums 0.3368772 differs more than 30.0% GLs sum average 0.258922145455 Delta is 30.1075268817 %

Seite 13

OHB SYSTEM

Summary

- Application of ESATAP successfully tested for automatic model validation
- With already existing components easy check like a rough mass check can be performed
- Due to the high flexibility the user can combine existing components for own model checks
- New components like “CondAvgMagnitude” have been implemented on request

Seite 14

Appendix F

ESATAP 2.1.0 evolutions and implementation of new User's requirements

Mathieu Bernard Stephane Iugovich
(EADS Astrium, France)

Alain Fagot
(Dorea, France)

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

Since version 2.0.0 thermal analysts emitted interest for new functionalities to be integrated in ESATAP. Version 2.1.0 of ESATAP aims to provide an answer to these new needs. We can mention:

- providing easy handling of multiple cases post-processing,
- Integration of the notion of equipment,
- New report and plot components dealing with multiple cases and multiple specifications
- Archiving of tasks for quality aspects.


ESATAP
ASTRIUM Contribution
ACE24
M. BERNARD , S. IUGOVICH 08-11-2011
All the space you need
DOREA TECHNOLOGY
EADS astrium


Overview
Introduction
ASTRIUM interest for ESATAP
ASTRIUM post-processing needs
Timeline
All the space you need
Date - 2
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ASTRIUM AN EADS COMPANY

Introduction

- Thermal models get more and more complex:
  - => post-process more complex too
  - => synthesis need
- ASTRIUM has seen in ESATAP ways of improving analysis:
  - Efficiency
  - Reliability
  - "Quality"

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Date - 3

ASTRIUM interest for ESATAP

- Improving efficiency:
  - High computation performances
  - "Infinite" computation possibilities
  - "All-in-one" post-processing tool
- Improving reliability:
  - Automatic post-process avoiding "manual" intervention.
  - Input / output consistency.
- Improving "Quality":
  - Post-process procedure configurable
  - Post-process re-doable at will

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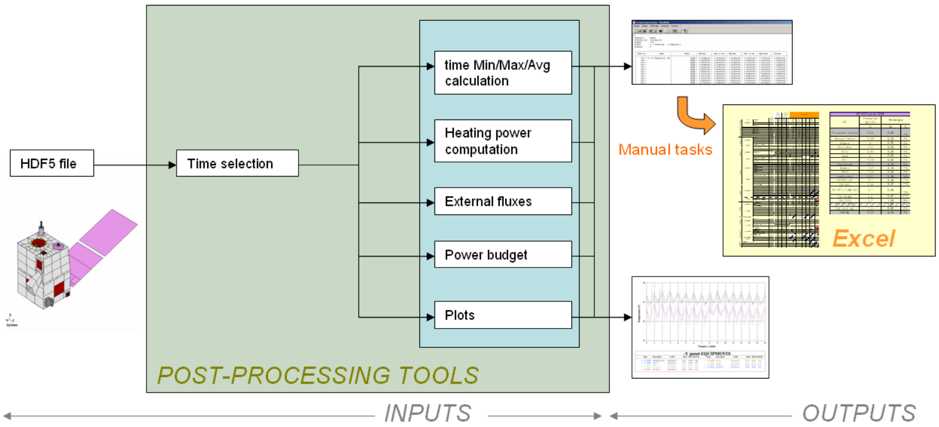
ASTRIUM post-processing needs

- Existing in-house standardized post-process procedure involving many tools and also manual sub-tasks:



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Date - 5

ASTRIUM post-processing needs

- Temperature results presented at component level:
  - Which node(s) to consider for component temperature?
  - Which uncertainty should be applied?
  - Which temperature specification should be considered (operating or non-operating)?
- Component notion to be implement in ESATAP => DOREA development.

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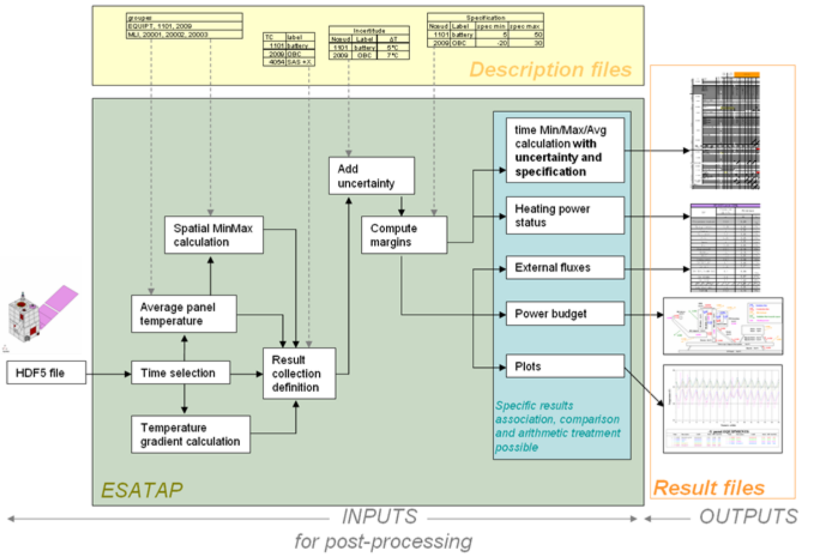
ASTRIUM post-processing needs

- Process using ESATAP (without any manual modification of results):



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Date - 7

Timeline

- ASTRIUM specification for ESATAP development:
  - Specification & associated developments to be shared with the thermal analysts community
  - Specification delivered to ESA & DOREA: November 2009
  - DOREA first answer to specification including Matrix of Compliance: February 2010
  - ASTRIUM/DOREA spec discussion/evolution/clarification: Spring 2010
- Post-process use case for development & validation:
  - Delivered by ASTRIUM to DOREA: February 2011
- ESATAP developments wrt ASTRIUM specification:
  - Beginning: February 2010
  - End of major components developments (equipt…): Summer 2011
  - Internal evaluation: still to be done

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Date - 8

THERMISOL to STEP-NRF Converter

- THERMISOL does not directly generate STEP-NRF output files.
- A file converter has been developed and validated to generate STEP-NRF file (compatible with ESATAP) from the THERMISOL H5 file.
- Validated in June 2011

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Date - 9

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esa
Mechanical Engineering Department
Thermal Division
25th European Workshop on Thermal & ECLS Software
ESA/ESTEC, 08-09 November 2011
ESATAP 2.1.0 Evolutions
Implementation of
new User's requirements
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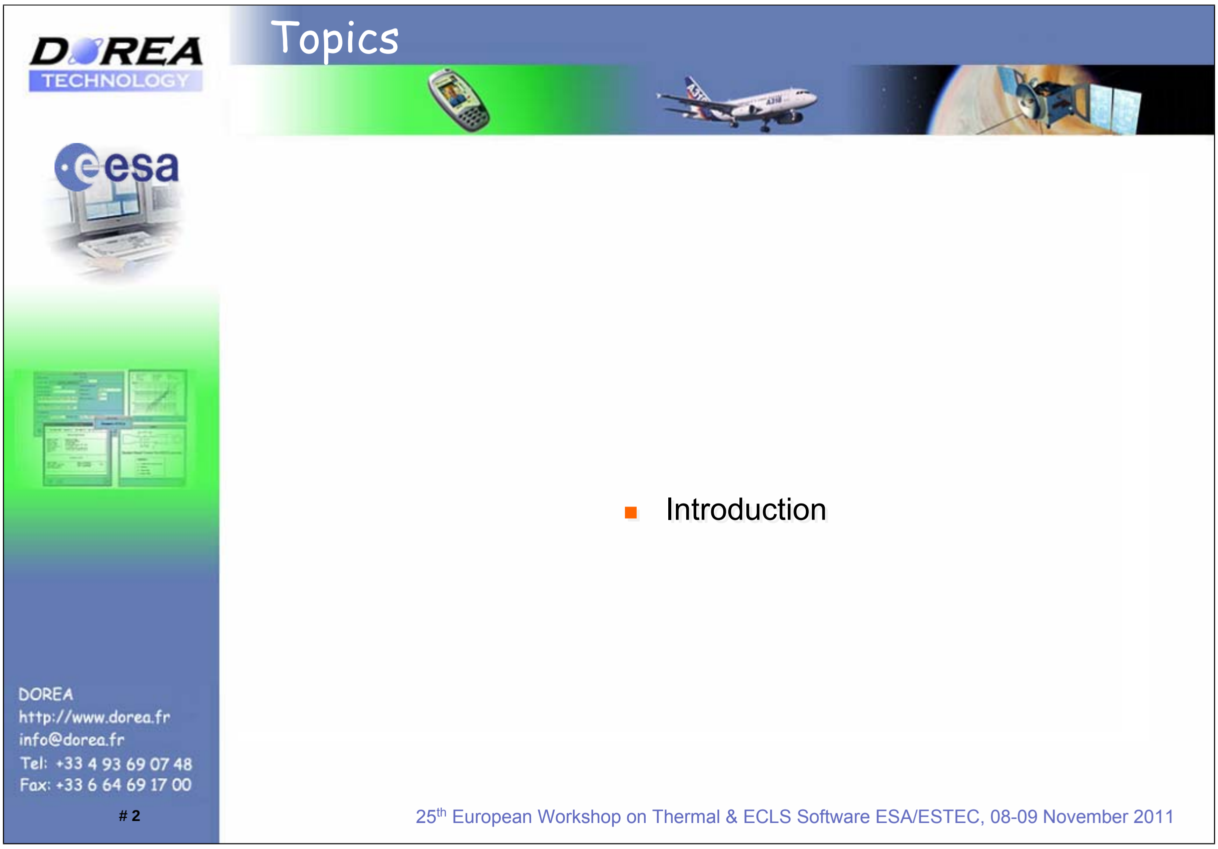
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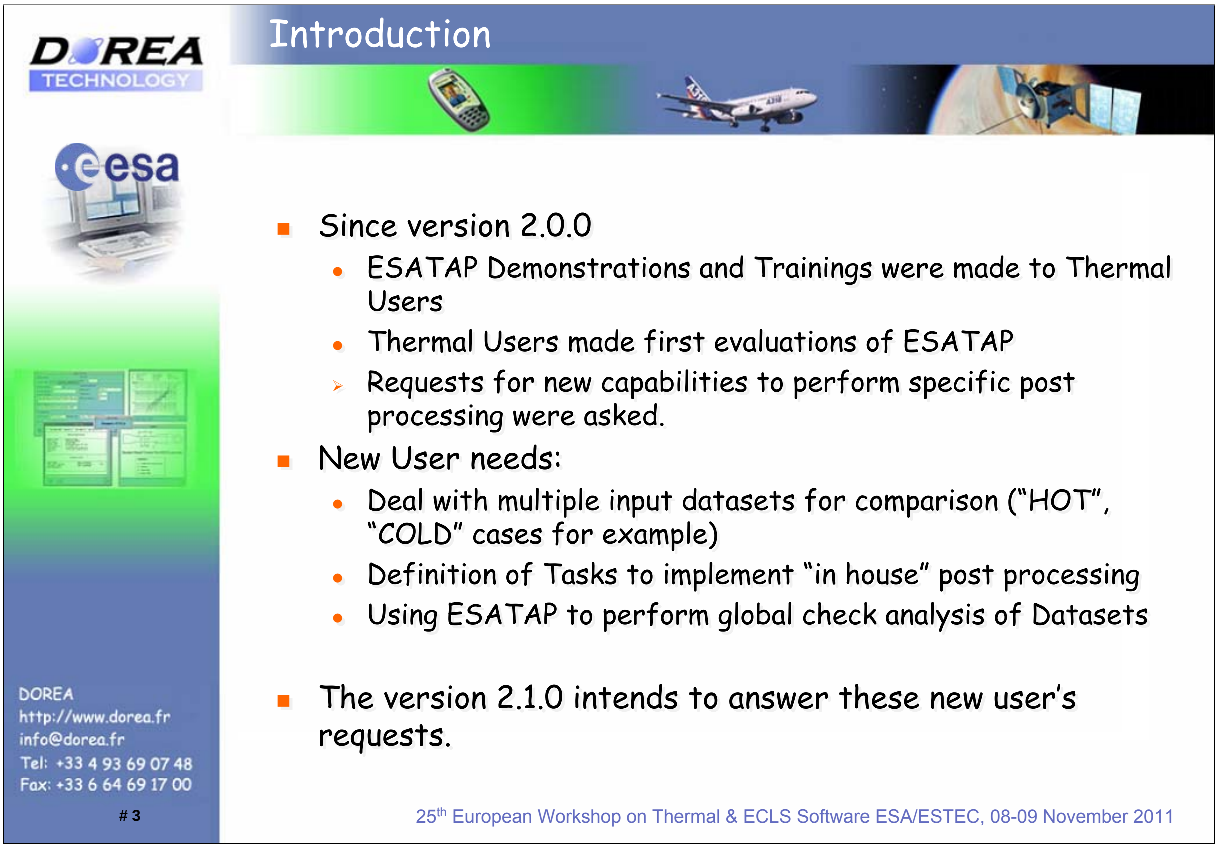
Introduction
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Since version 2.0.0
ESATAP Demonstrations and Trainings were made to Thermal Users
Thermal Users made first evaluations of ESATAP
Requests for new capabilities to perform specific post processing were asked.
New User needs:
Deal with multiple input datasets for comparison ("HOT", "COLD" cases for example)
Definition of Tasks to implement "in house" post processing
Using ESATAP to perform global check analysis of Datasets
The version 2.1.0 intends to answer these new user's requests.
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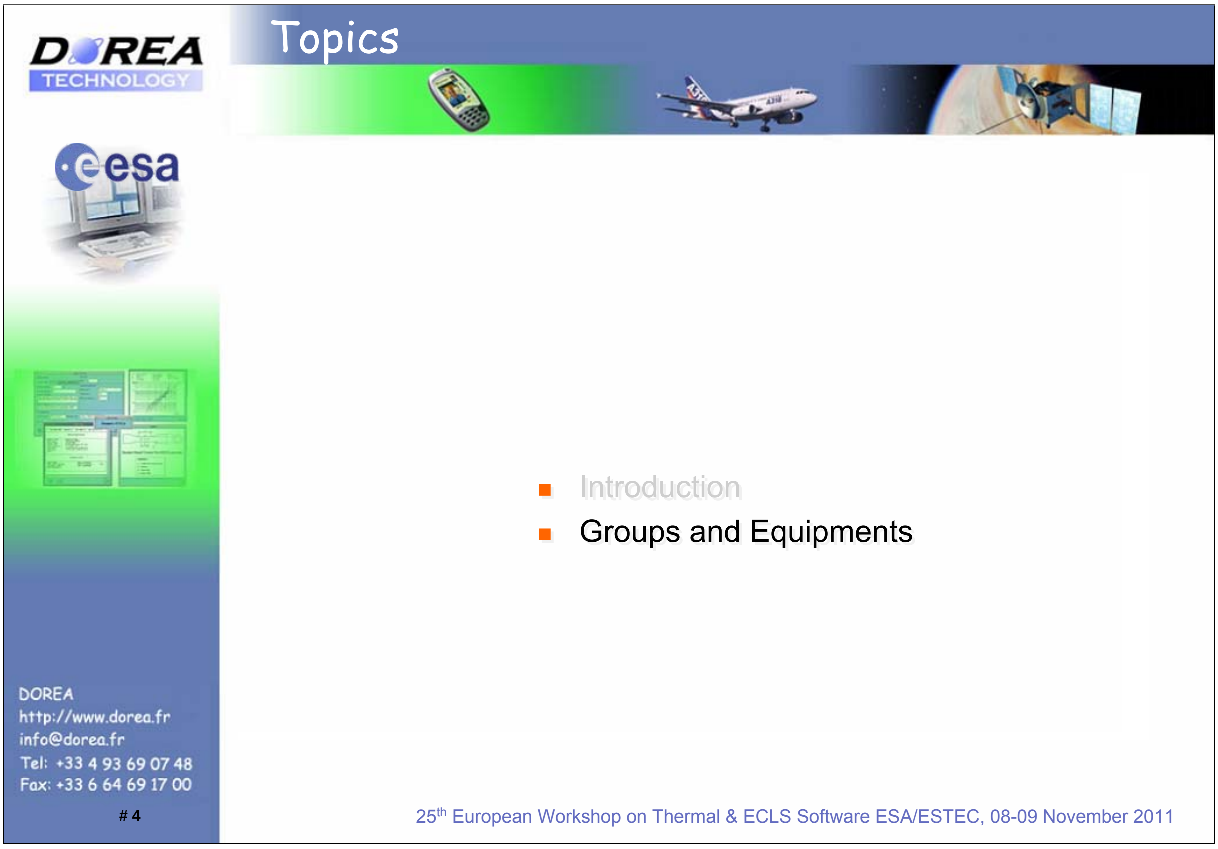
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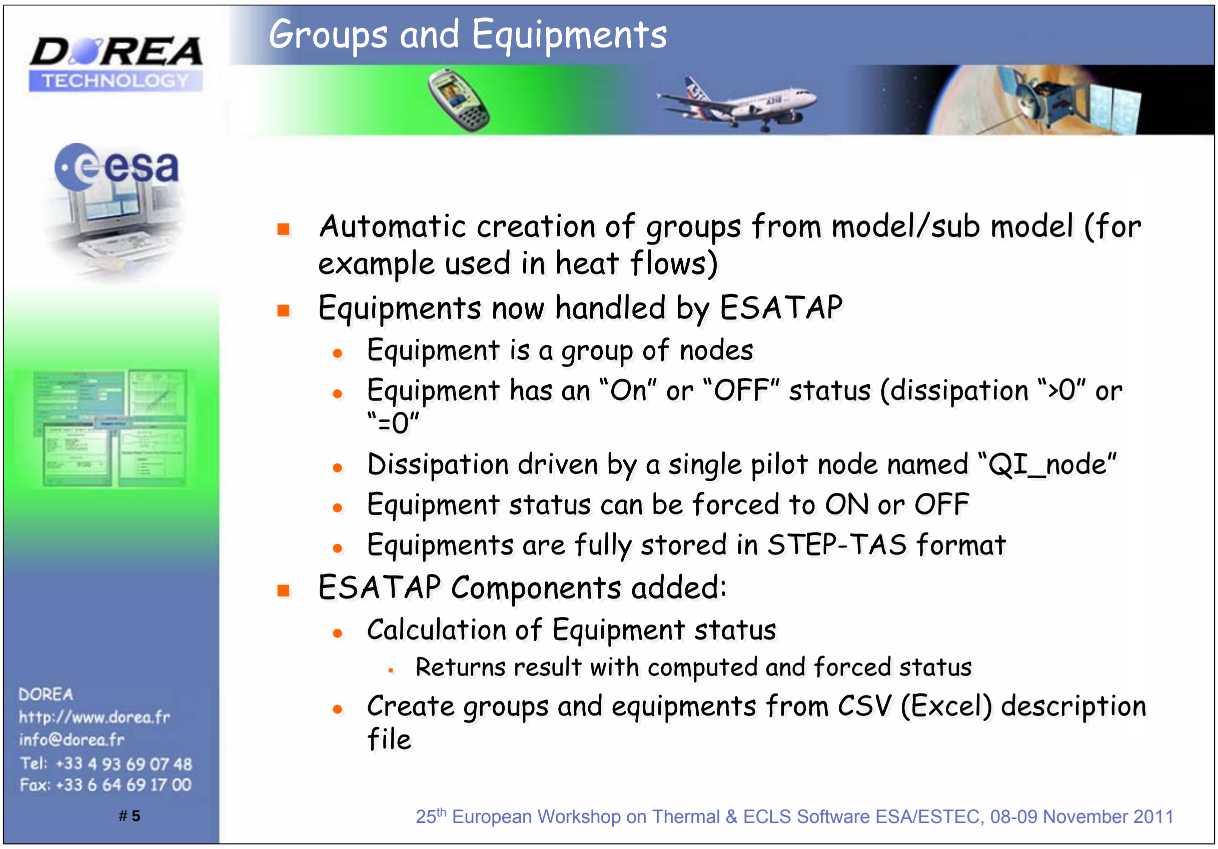
Groups and Equipments
DOREA TECHNOLOGY
esa
- Automatic creation of groups from model/sub model (for example used in heat flows)
- Equipments now handled by ESATAP
  - Equipment is a group of nodes
  - Equipment has an "On" or "OFF" status (dissipation ">0" or "=0"
  - Dissipation driven by a single pilot node named "QI_node"
  - Equipment status can be forced to ON or OFF
  - Equipments are fully stored in STEP-TAS format
- ESATAP Components added:
  - Calculation of Equipment status
    - Returns result with computed and forced status
  - Create groups and equipments from CSV (Excel) description file
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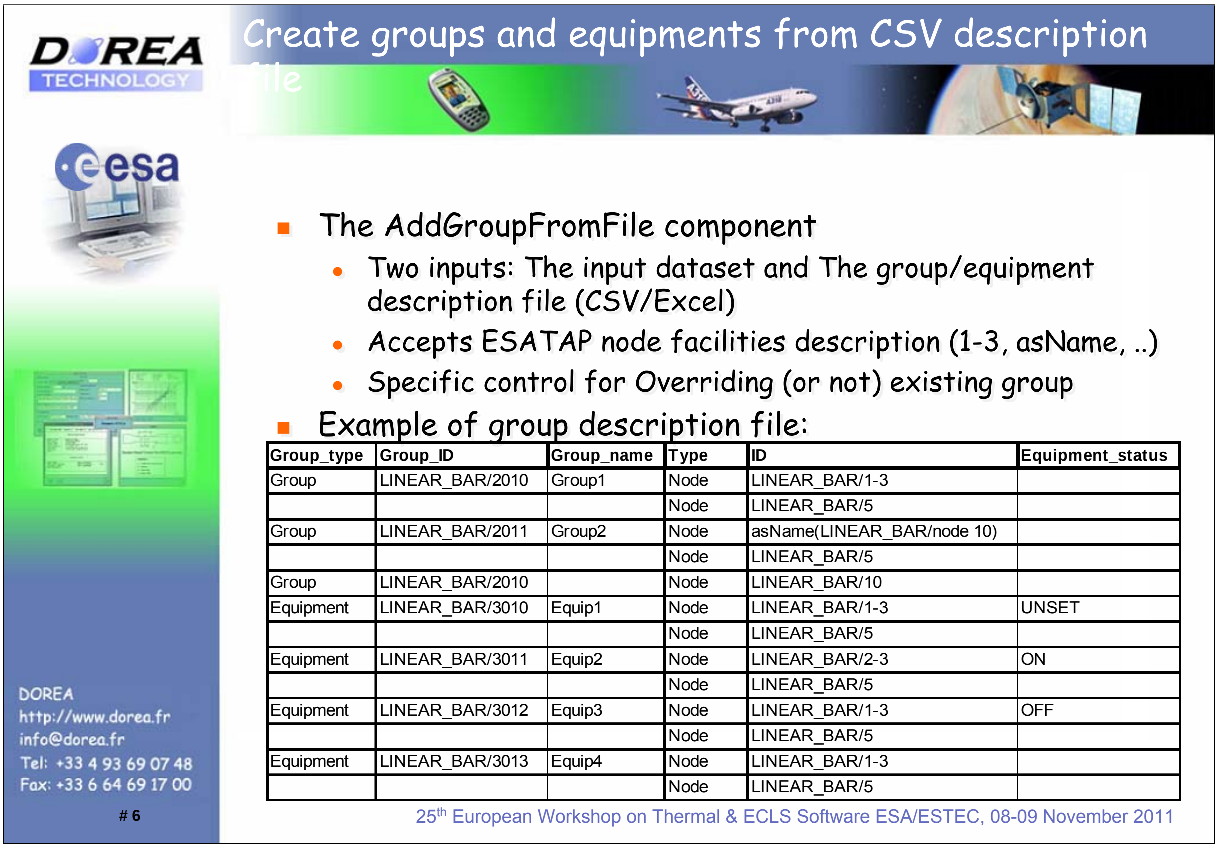
Create groups and equipments from CSV description file
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esa
- The AddGroupFromFile component
  - Two inputs: The input dataset and The group/equipment description file (CSV/Excel)
  - Accepts ESATAP node facilities description (1-3, asName, ..)
  - Specific control for Overriding (or not) existing group
- Example of group description file:

Group_type	Group_ID	Group_name	Type	ID	Equipment_status
Group	LINEAR_BAR/2010	Group1	Node	LINEAR_BAR/1-3	
			Node	LINEAR_BAR/5	
Group	LINEAR_BAR/2011	Group2	Node	asName(LINEAR_BAR/node 10)	
			Node	LINEAR_BAR/5	
Group	LINEAR_BAR/2010		Node	LINEAR_BAR/10	
Equipment	LINEAR_BAR/3010	Equip1	Node	LINEAR_BAR/1-3	UNSET
			Node	LINEAR_BAR/5	
Equipment	LINEAR_BAR/3011	Equip2	Node	LINEAR_BAR/2-3	ON
			Node	LINEAR_BAR/5	
Equipment	LINEAR_BAR/3012	Equip3	Node	LINEAR_BAR/1-3	OFF
			Node	LINEAR_BAR/5	
Equipment	LINEAR_BAR/3013	Equip4	Node	LINEAR_BAR/1-3	
			Node	LINEAR_BAR/5	

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Topics

- Introduction
- Groups and Equipments
- New plot task

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Plot multiple cases with specifications

- Inputs:
  - 1 or more CASES, outputs of Thermisol or ESATAN (ex. "Hot" and "Cold" cases.
  - 1 or more specifications defined in CSV files (Ex.Design, Acceptance, Qualification, Non operational)
    - Specification example

Time [s]	Type	ID	T_lower_bound [K]	T_upper_bound [K]
ALL	asList	ThermisolMainModel/2003	218.15	348.15
ALL	asList	ThermisolMainModel/3001	278.15	308.15
ALL	asList	ThermisolMainModel/3002	278.15	308.15
ALL	asList	ThermisolMainModel/3003	248.15	328.15
ALL	asList	ThermisolMainModel/3004	258.15	303.15

- Output:
  - A bar chart plot of min/max Temperatures for each required node.
  - For all cases
  - With Display of required specifications.

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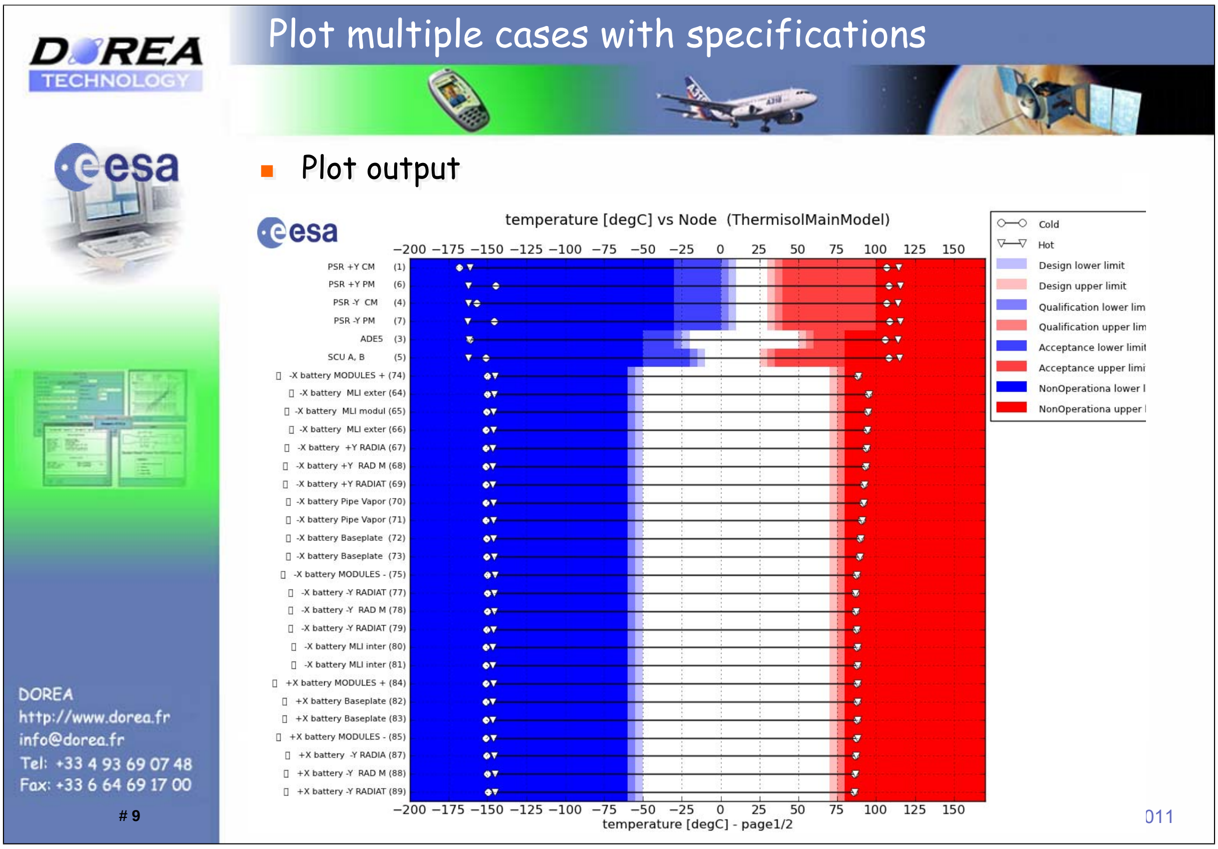
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Plot multiple cases with specifications
Plot output
temperature [degC] vs Node (ThermisolMainModel)
Cold
Hot
Design lower limit
Design upper limit
Qualification lower lim
Qualification upper lim
Acceptance lower limit
Acceptance upper limi
NonOperationa lower l
NonOperationa upper l
temperature [degC] - page1/2
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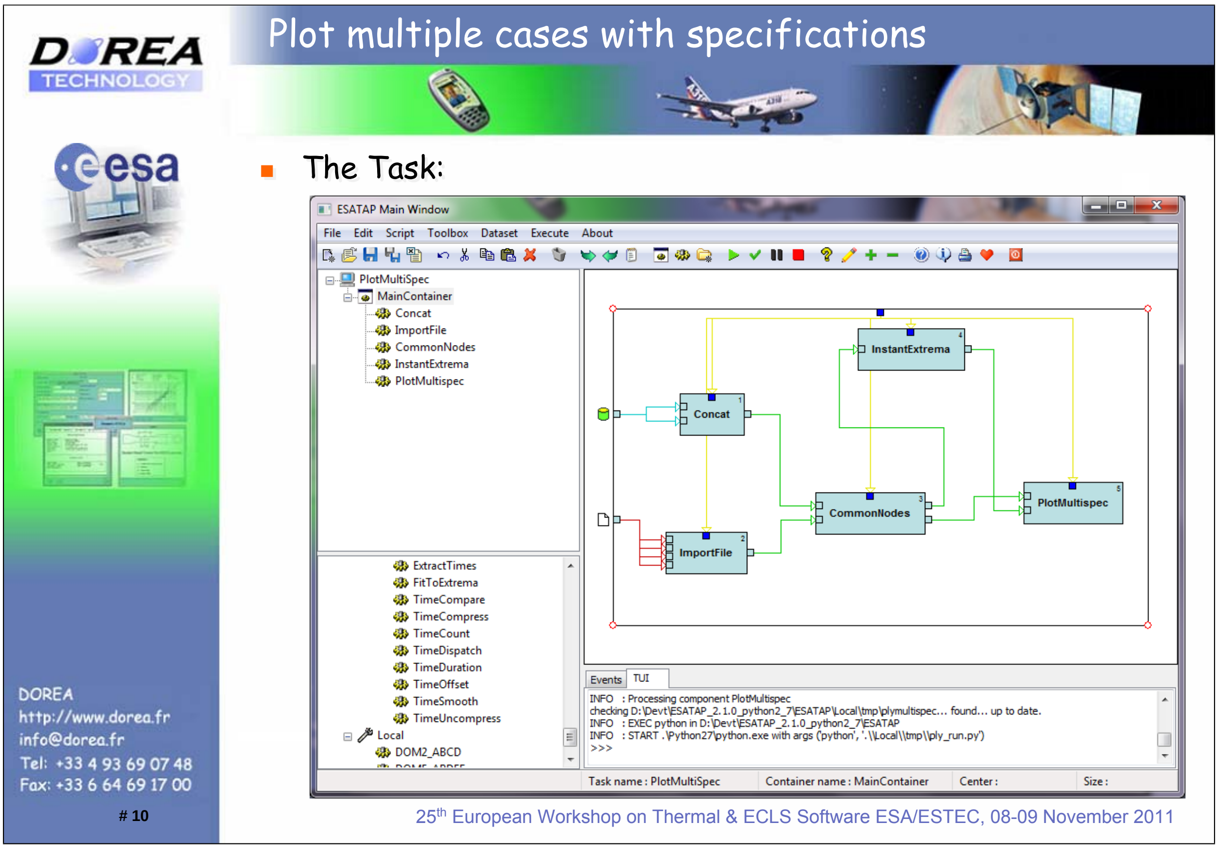
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Plot multiple cases with specifications
The Task:
ESATAP Main Window
File Edit Script Toolbox Dataset Execute About
PlotMultiSpec
MainContainer
Concat
ImportFile
CommonNodes
InstantExtrema
PlotMultispec
ExtractTimes
FitToExtrema
TimeCompare
TimeCompress
TimeCount
TimeDispatch
TimeDuration
TimeOffset
TimeSmooth
TimeUncompress
Local
DOM2_ABCD
InstantExtrema
Concat
CommonNodes
PlotMultispec
ImportFile
Events TUI
Task name : PlotMultiSpec Container name : MainContainer Center : Size :
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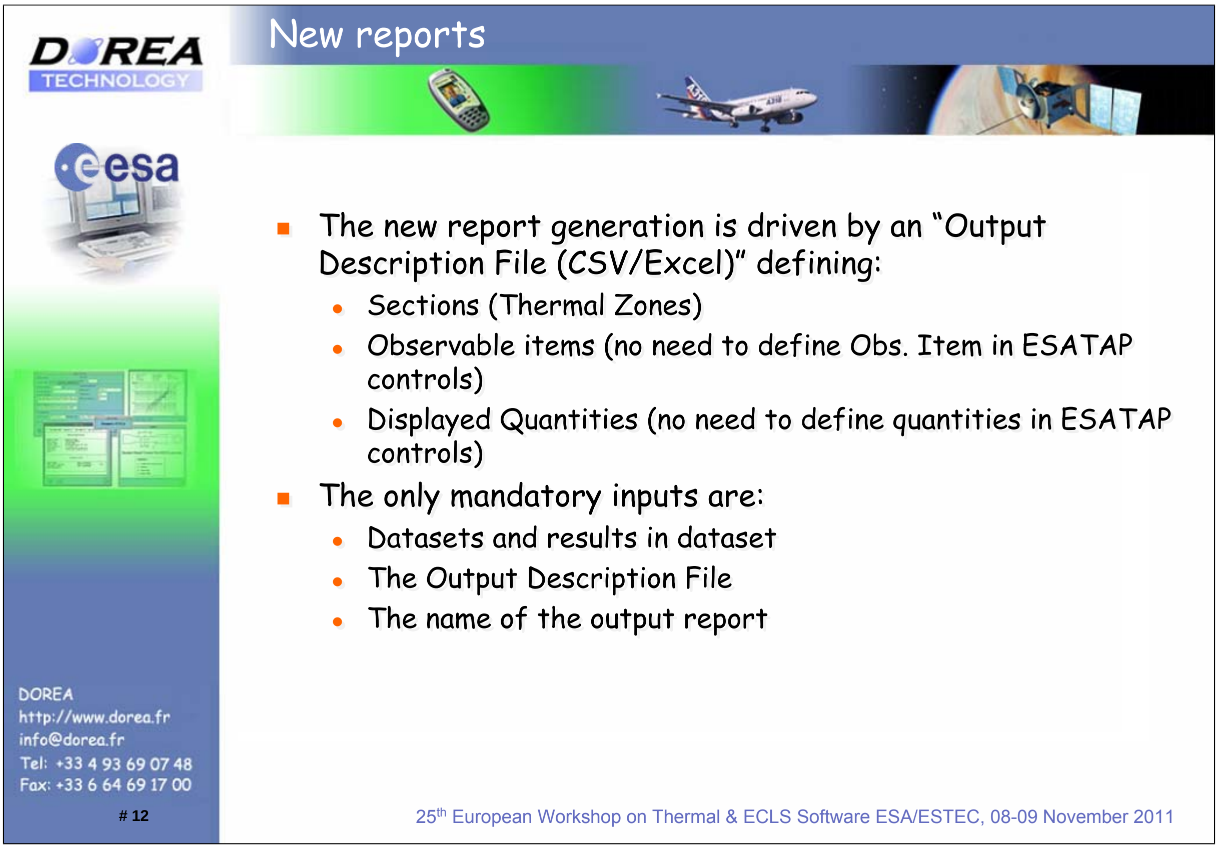
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New reports
The new report generation is driven by an "Output Description File (CSV/Excel)" defining:
Sections (Thermal Zones)
Observable items (no need to define Obs. Item in ESATAP controls)
Displayed Quantities (no need to define quantities in ESATAP controls)
The only mandatory inputs are:
Datasets and results in dataset
The Output Description File
The name of the output report
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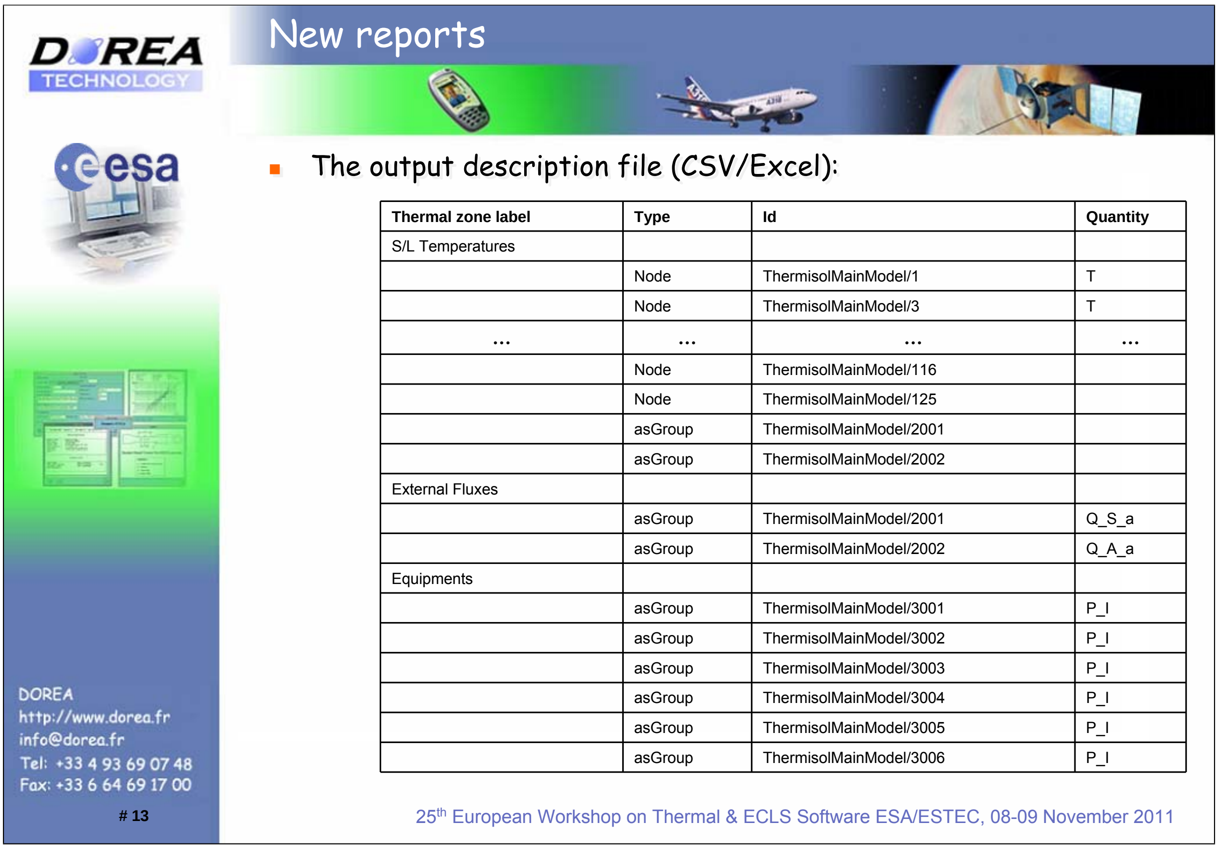

New reports

- The output description file (CSV/Excel):

Thermal zone label	Type	Id	Quantity
S/L Temperatures			
	Node	ThermisolMainModel/1	T
	Node	ThermisolMainModel/3	T
...	...	...	...
	Node	ThermisolMainModel/116	
	Node	ThermisolMainModel/125	
	asGroup	ThermisolMainModel/2001	
	asGroup	ThermisolMainModel/2002	
External Fluxes			
	asGroup	ThermisolMainModel/2001	Q_S_a
	asGroup	ThermisolMainModel/2002	Q_A_a
Equipments			
	asGroup	ThermisolMainModel/3001	P_I
	asGroup	ThermisolMainModel/3002	P_I
	asGroup	ThermisolMainModel/3003	P_I
	asGroup	ThermisolMainModel/3004	P_I
	asGroup	ThermisolMainModel/3005	P_I
	asGroup	ThermisolMainModel/3006	P_I

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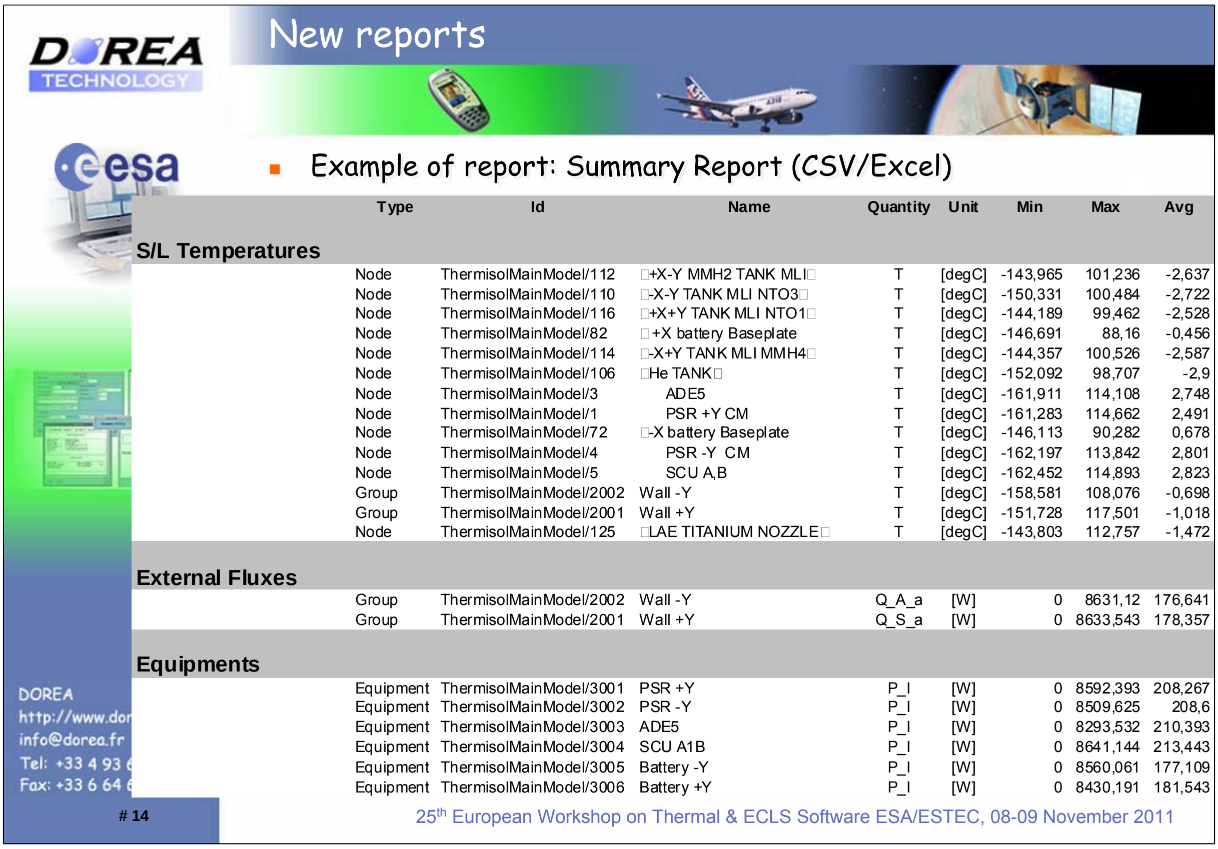

New reports

- Example of report: Summary Report (CSV/Excel)

	Type	Id	Name	Quantity	Unit	Min	Max	Avg
S/L Temperatures								
	Node	ThermisolMainModel/112	□+X-Y MMH2 TANK MLI□	T	[degC]	-143,965	101,236	-2,637
	Node	ThermisolMainModel/110	□-X-Y TANK MLI NTO3□	T	[degC]	-150,331	100,484	-2,722
	Node	ThermisolMainModel/116	□+X+Y TANK MLI NTO1□	T	[degC]	-144,189	99,462	-2,528
	Node	ThermisolMainModel/82	□ +X battery Baseplate	T	[degC]	-146,691	88,16	-0,456
	Node	ThermisolMainModel/114	□-X+Y TANK MLI MMH4□	T	[degC]	-144,357	100,526	-2,587
	Node	ThermisolMainModel/106	□He TANK□	T	[degC]	-152,092	98,707	-2,9
	Node	ThermisolMainModel/3	ADE5	T	[degC]	-161,911	114,108	2,748
	Node	ThermisolMainModel/1	PSR +Y CM	T	[degC]	-161,283	114,662	2,491
	Node	ThermisolMainModel/72	□-X battery Baseplate	T	[degC]	-146,113	90,282	0,678
	Node	ThermisolMainModel/4	PSR -Y CM	T	[degC]	-162,197	113,842	2,801
	Node	ThermisolMainModel/5	SCU A,B	T	[degC]	-162,452	114,893	2,823
	Group	ThermisolMainModel/2002	Wall -Y	T	[degC]	-158,581	108,076	-0,698
	Group	ThermisolMainModel/2001	Wall +Y	T	[degC]	-151,728	117,501	-1,018
	Node	ThermisolMainModel/125	□LAE TITANIUM NOZZLE□	T	[degC]	-143,803	112,757	-1,472
External Fluxes								
	Group	ThermisolMainModel/2002	Wall -Y	Q_A_a	[W]	0	8631,12	176,641
	Group	ThermisolMainModel/2001	Wall +Y	Q_S_a	[W]	0	8633,543	178,357
Equipments								
	Equipment	ThermisolMainModel/3001	PSR +Y	P_I	[W]	0	8592,393	208,267
	Equipment	ThermisolMainModel/3002	PSR -Y	P_I	[W]	0	8509,625	208,6
	Equipment	ThermisolMainModel/3003	ADE5	P_I	[W]	0	8293,532	210,393
	Equipment	ThermisolMainModel/3004	SCU A1B	P_I	[W]	0	8641,144	213,443
	Equipment	ThermisolMainModel/3005	Battery -Y	P_I	[W]	0	8560,061	177,109
	Equipment	ThermisolMainModel/3006	Battery +Y	P_I	[W]	0	8430,191	181,543

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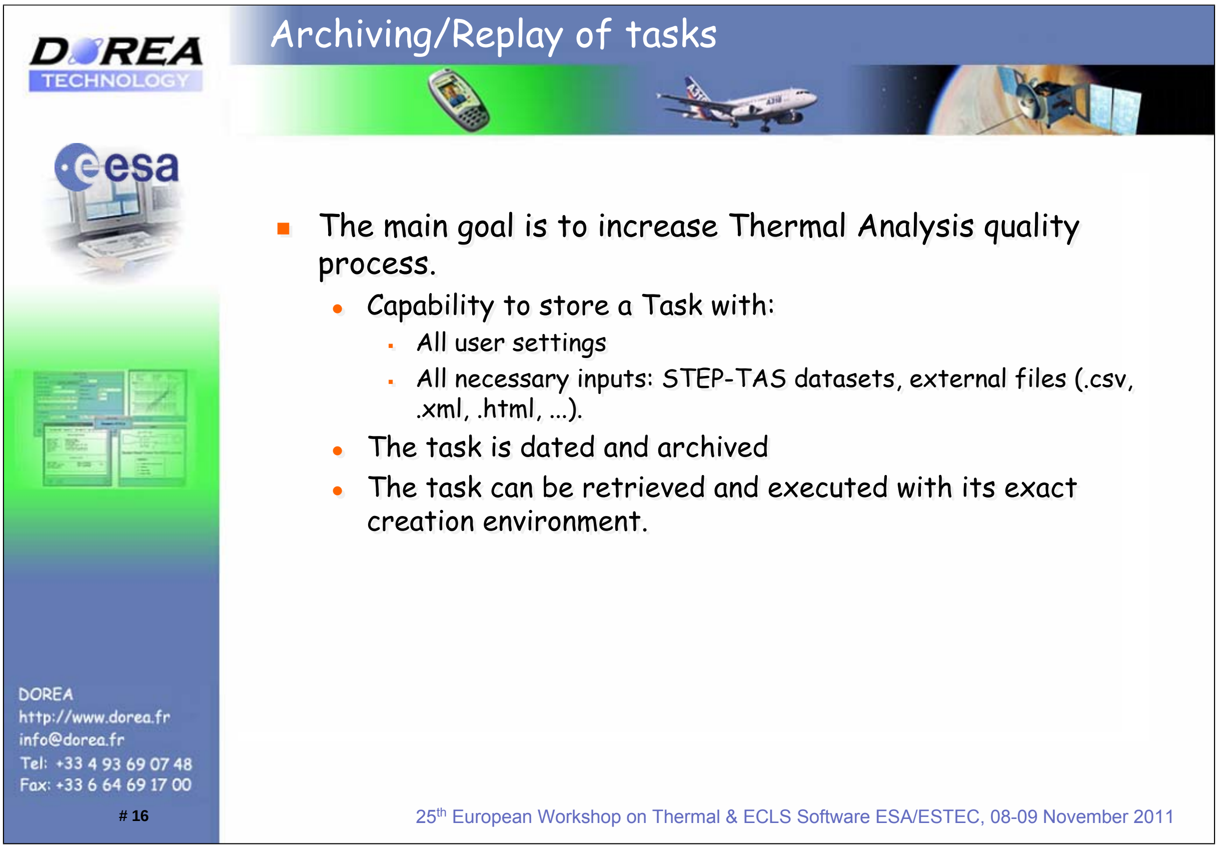
Archiving/Replay of tasks
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The main goal is to increase Thermal Analysis quality process.
Capability to store a Task with:
All user settings
All necessary inputs: STEP-TAS datasets, external files (.csv, .xml, .html, ...).
The task is dated and archived
The task can be retrieved and executed with its exact creation environment.
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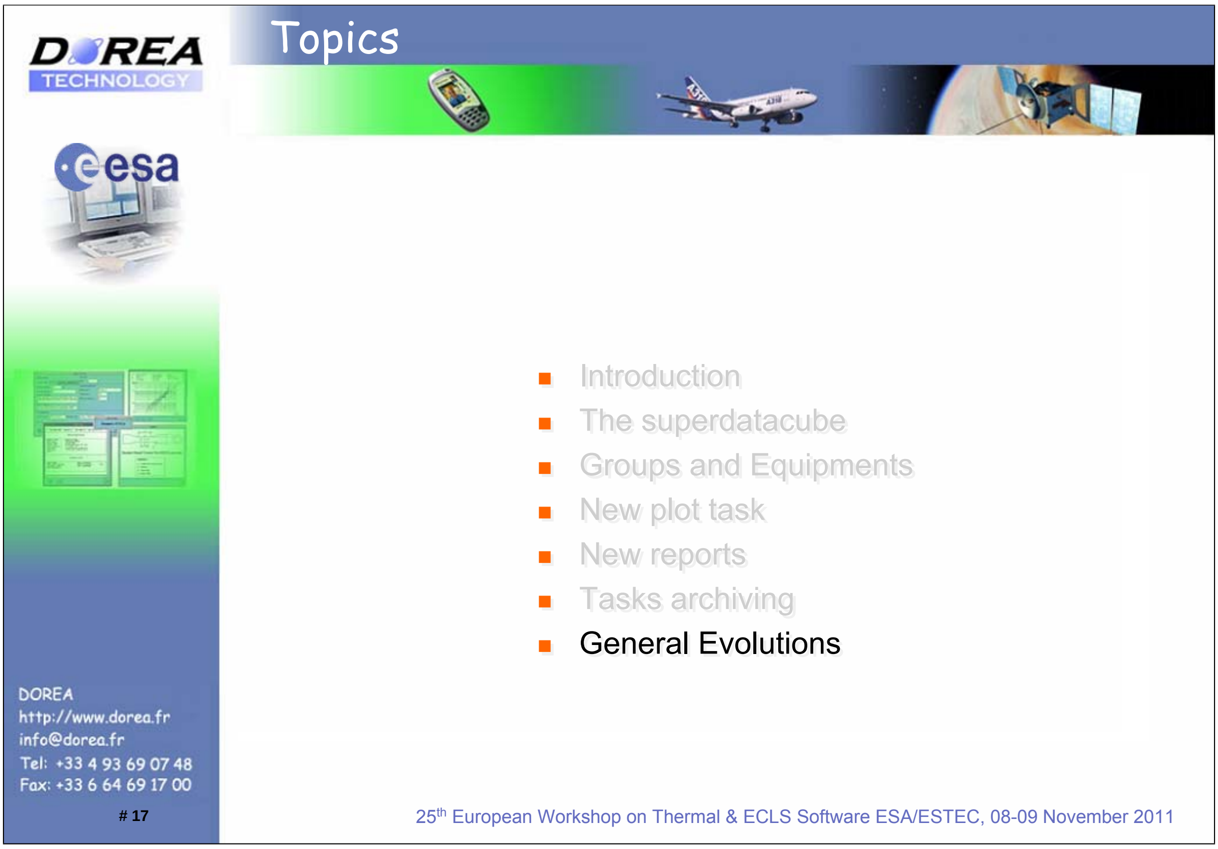
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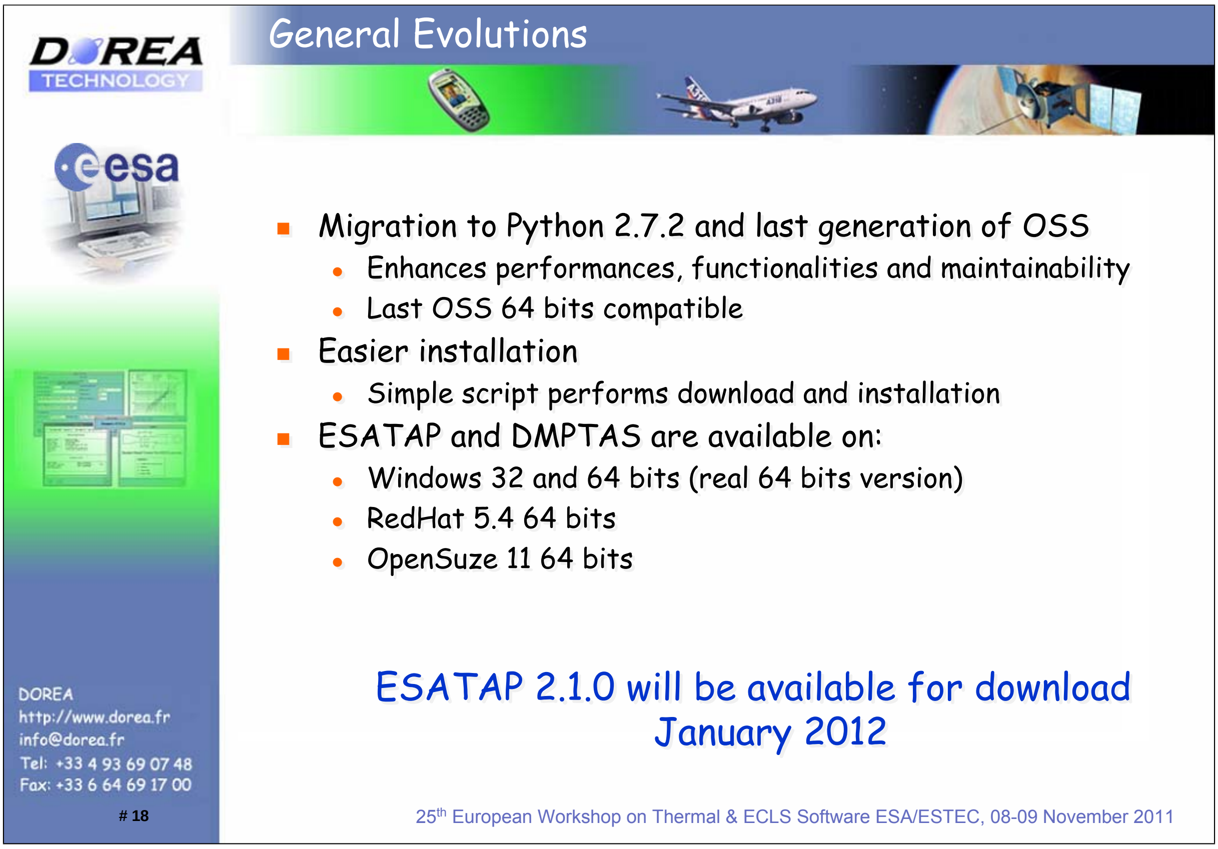
General Evolutions
DOREA TECHNOLOGY
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Migration to Python 2.7.2 and last generation of OSS
Enhances performances, functionalities and maintainability
Last OSS 64 bits compatible
Easier installation
Simple script performs download and installation
ESATAP and DMPTAS are available on:
Windows 32 and 64 bits (real 64 bits version)
RedHat 5.4 64 bits
OpenSuze 11 64 bits
ESATAP 2.1.0 will be available for download
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Appendix G

Thermal Model Reduction using the Super-Face Concept

Luc Masset Olivier Brüls Gaetan Kerschen
(University of Liège, Belgium)

Abstract

The objective of this presentation is to carry out model reduction of radiative problems in the context of the finite element method. The finite element model is decomposed into several sets of adjacent faces called super-faces. Specialized algorithms such as the METIS partitioning algorithm are used to automatically generate the super-faces. Several constraints may be imposed, e.g., the size of the super-face, its aspect ratio or its aperture angle. Once the model is decomposed, view factors between super-faces are calculated with direct numerical integration or ray-tracing methods. This method offers a very substantial reduction of the computational burden compared to the full model, which is particularly interesting for pre-design studies or specific applications such as deployable structures.

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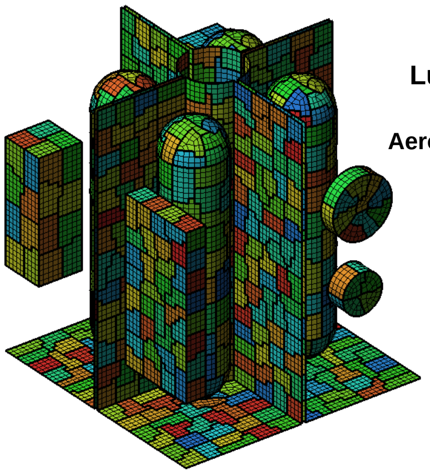
Thermal Model Reduction Using the Super-Face Concept



Luc Masset, Olivier Brüls, Gaëtan Kerschen

Aerospace and Mechanical Engineering Department
University of Liège, Belgium

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Research framework

- Research project funded by the Walloon Region
- Developments of multiphysics tools
- Efficient modeling of thermal problems, especially radiative problems
- Collaboration with Simulation Software Editors
  - Samtech, **Samcef**, FE solution (www.samtech.com)
  - Open Engineering, **OOfelie**, multiphysics FE solution (http://www.open-engineering.com)

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Industrial Collaboration

Open Engineering

- Belgian company
- Member of the SAMTECH Group
- Focused on multiphysics CAE activities
  - OOFELIE::Multiphysics software
  - Engineering services

OOFELIE::Multiphysics is a CAE solution for applications in

- **Vibro Acoustics**: Piezo loudspeaker, muffler noise prediction, acoustic response
- **Electro Technics**: Joule heating, EM devices, piezo actuators
- **FSI-CFD**: Conduction, convection, cooling
- **Optics devices**: Impact of thermomechanical deformations on optical perf
- **MEMS Design**: Accelerometer, gyrometer, sensors, energy harvesting
- **Thermo Mechanics**: Package/Board Heat mgmnt, deformation, stresses

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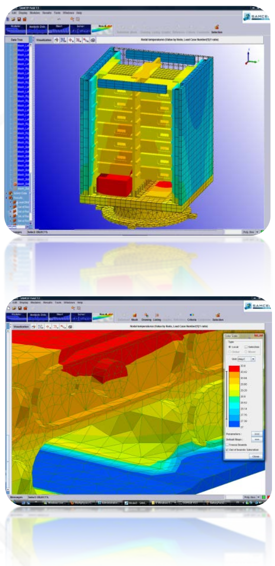
Industrial Collaboration

- COMPONENT RELIABILITY
  - Low Temperatures
- SENSITIVITY OF DETECTORS AND UNITS
  - Narrow Temperature Ranges
- POINTING OF INSTRUMENTS
  - Small Temperature Gradients
- MODELING TAKES INTO ACCOUNT
  - Magneto-Torque
  - Satellite Orbit, Satellite Rotation
  - Solar Radiation, Earth Albedo, Cooling
  - Electronic Component Dynamic Power Dissipation



Work performed under contract for LUXSPACE

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Why thermal model reduction ?

Solving radiative problems require the view factors between faces.

View factors are computed with ray-tracing methods.

Ray-tracing is easy to implement and general (diffuse, specular, transparency).

But ray-tracing requires lots of computer resources (time, memory).

⇨ Need for reduction techniques (approximate but fast solution)

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Available solutions

Coarse finite element mesh

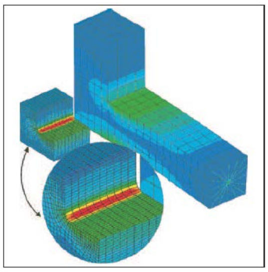
Low precision

Multi-resolution meshes (in PERMAS software)

Automatic simplification of a hi-res mesh

Local refinement (high gradient zones)

Degraded geometry



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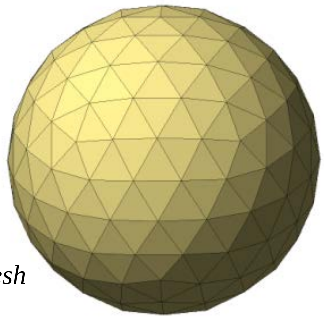
Proposed solution: decomposition in super-faces

A super-face is a group of N_s adjacent faces of the original mesh.

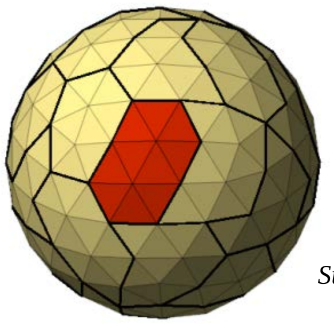
Decomposition in super-faces is fully automatic.

It preserves object geometry (plane/curved zones).

N faces ⇨ M super-faces



Original mesh



Super-faces

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Step 1: decomposition according to material properties

We should avoid mixing faces corresponding to different materials, e. g. purely diffuse and purely specular faces.

The original mesh is pre-decomposed in S sub-meshes, S being the number of different materials.

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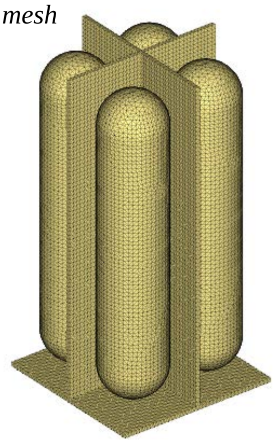
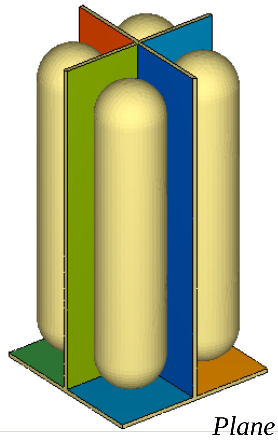
Step 2: find plane surfaces

We need to avoid mixing faces belonging to different planes and curved surfaces.

An automatic algorithm based on adjacency table and face normal vectors is used to find the plane surfaces.

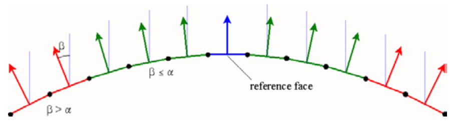
Original mesh





Plane surfaces

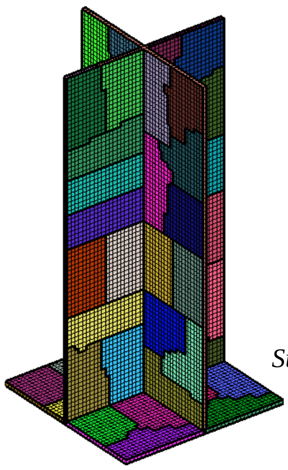
Selection algorithm



Step 3: decompose each plane surface in super-faces

Each plane surface is automatically decomposed using METIS algorithms.

We may impose constraints on the min/max number of faces for a super-face and on the super-faces aspect ratio.

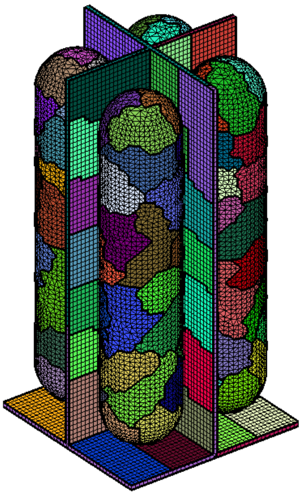


Super-faces on planes

Step 4: decompose the remaining faces

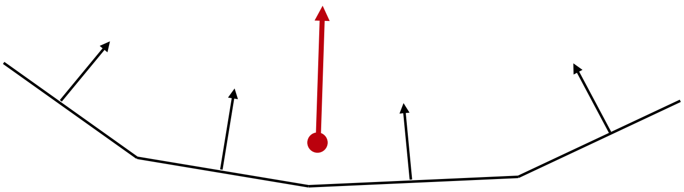
The decomposition is also performed by METIS algorithms. We may add an additional constraint on super-faces aperture angle.

Super-faces on curved surfaces

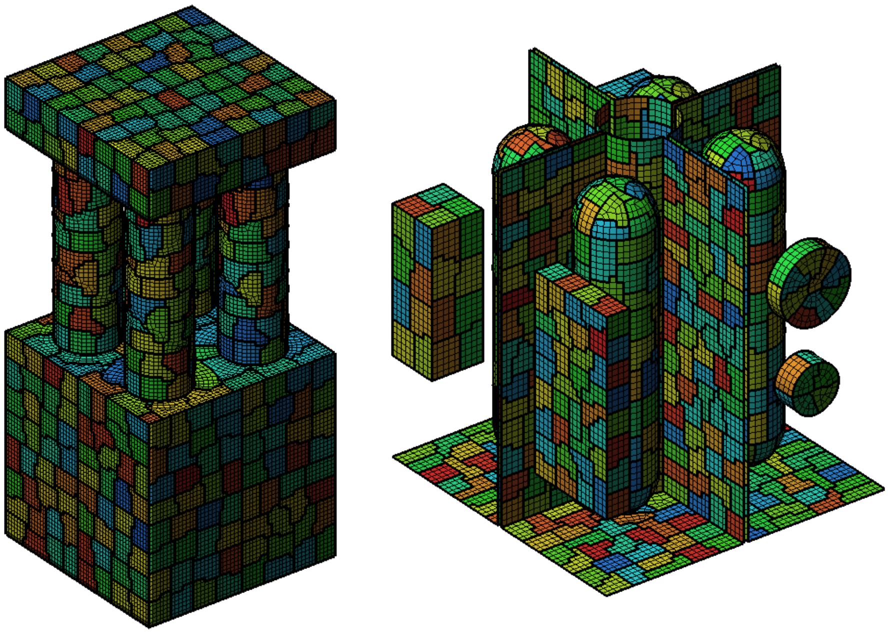


Super-face properties

- Set of N_s faces of original mesh
- Made of a single material (unique properties, emission, reflectivity …)
- Super-face center (centroid of faces)
- Super-face normal vector (mean of face normal vectors)



Examples



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Applications of the super-face method

1. Estimation of the view factor matrix sparsity
2. Thermal model reduction
3. Estimation of ray number in order to reach a given accuracy

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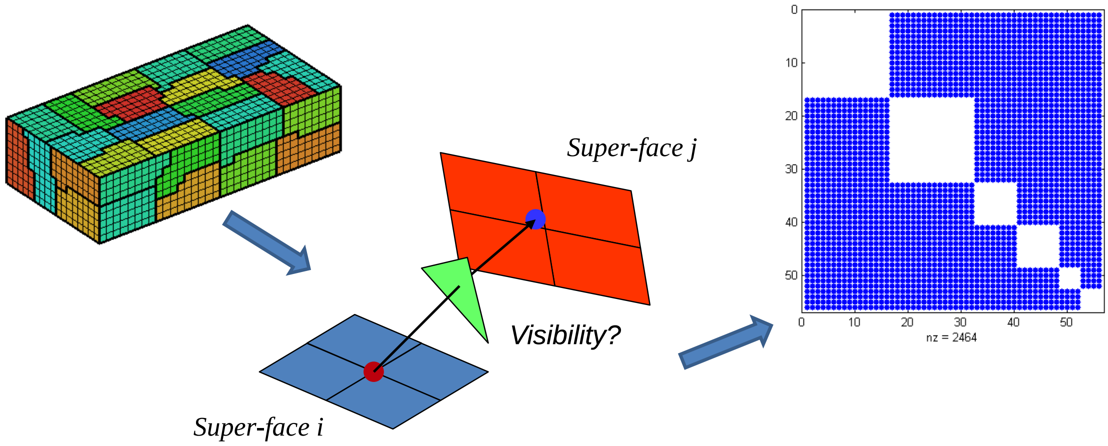
App. 1 - Sparsity estimation

We check the visibility between super-faces.

All the faces of two visible super-faces are assumed to be visible.

We may estimate the sparsity of the view factor matrix of the original mesh.



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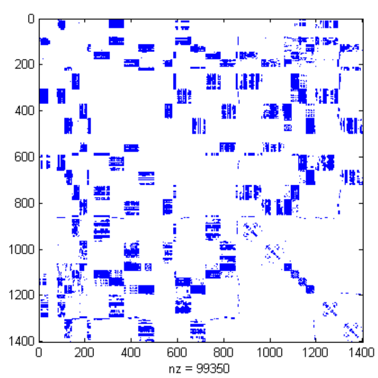
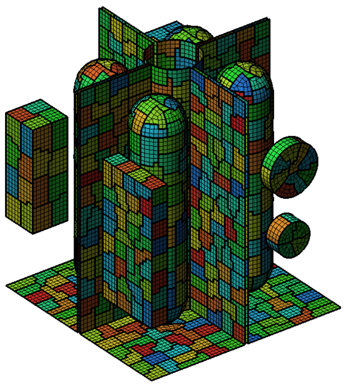
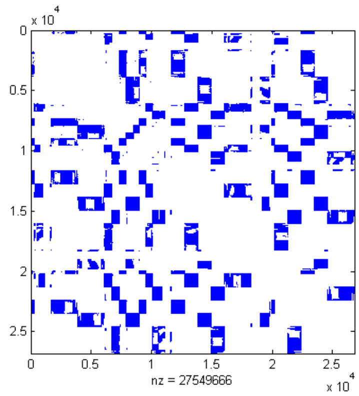
App. 1 - Sparsity estimation

1400 super-faces





26818 faces



Estimated sparsity: 4.81 %

Time: 54 sec.

Actual sparsity: 3.83 %

Time: 1900 sec.

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App. 2 - Thermal model reduction

We compute the view factors between super-faces by numerical integration (purely diffuse case) or by ray-tracing (general case).

We obtain a reduced system described by a set of super-faces and radiative links between them.

The required time is the order of a minute while the required time for the original system is the order of an hour or more.

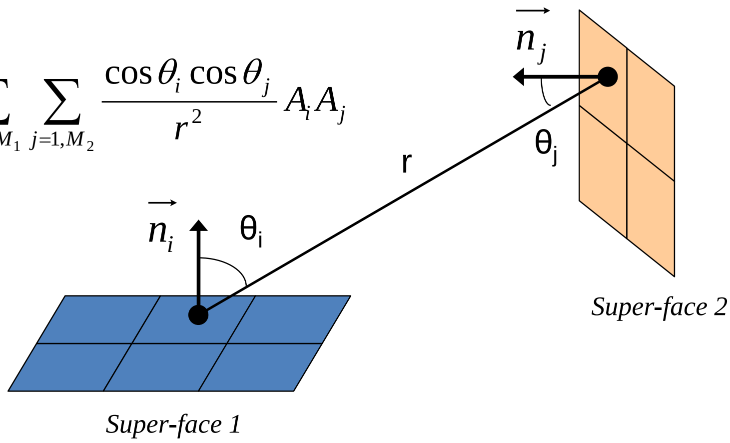
The reduced system may be solved alone (e.g. to compute the radiative heat fluxes) or linked to other thermo-mechanical systems for a coupled analysis.

App. 2 - Numerical integration

We compute the view factors only between visible super-faces.

The computation is very fast (order of a second).

$$F'_{1\to 2} = \frac{1}{\pi A'_1} \sum_{i=1,M_1} \sum_{j=1,M_2} \frac{\cos\theta_i \cos\theta_j}{r^2} A_i A_j$$

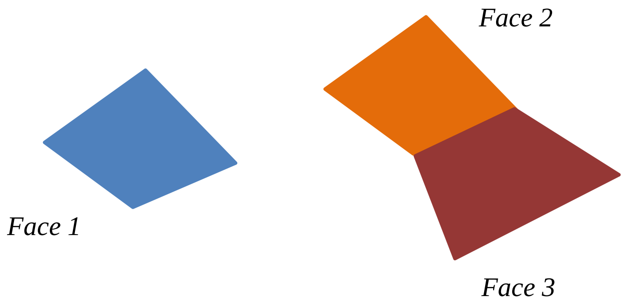


App. 2 - Check model reduction accuracy

We compute the view factors between super-faces by numerical integration.

We compute view factors between faces by ray-tracing.

We use view factor “algebra” to find back view-factors between super-faces.



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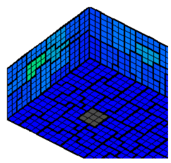
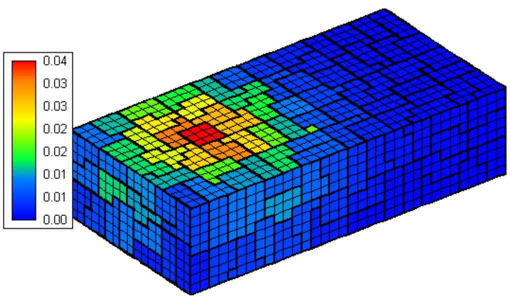
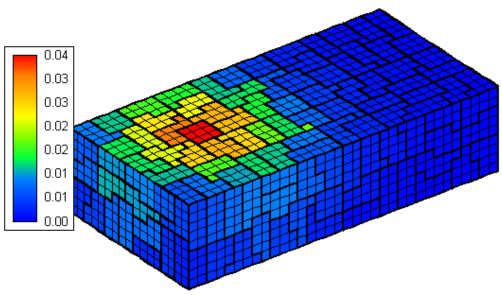
App. 2 - Check model reduction accuracy



Super-face 30



View factors between super-face 30 and super-faces (numerical integration)



View factors between super-face 30 and super-faces (ray-tracing + view factor algebra)

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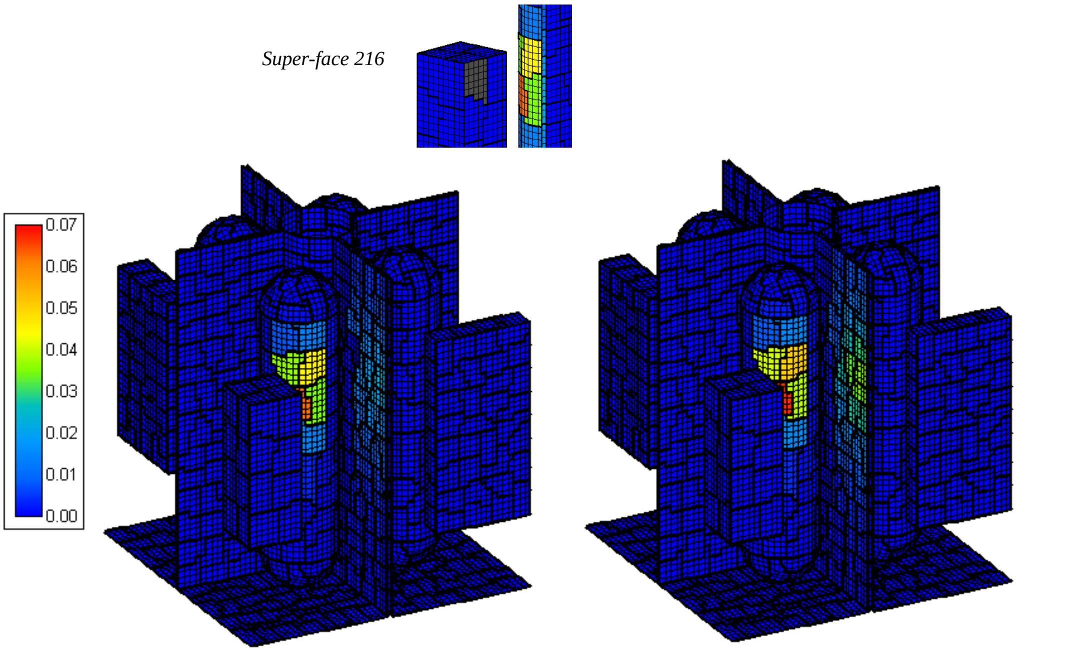
App. 2 - Check model reduction accuracy



View factors (numerical integration) *View factors (ray tracing)*

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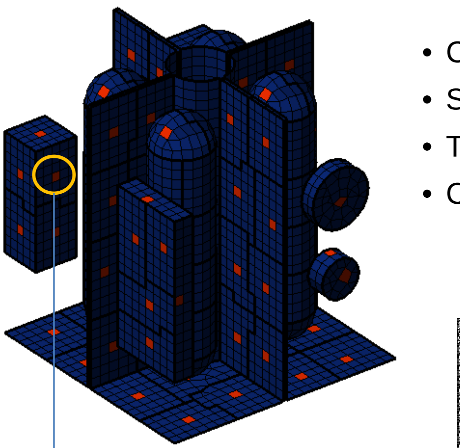
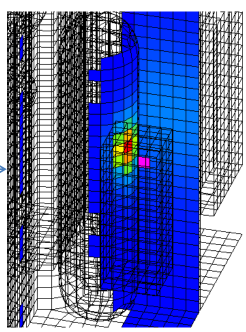
App. 3 - Estimation of the number of rays



- Central face of each super-face (in red)
- Shoot 1000, 2000, 4000, … from the central faces
- Take the x greatest view factors per face
- Compute the view factor relative error ε



(%)

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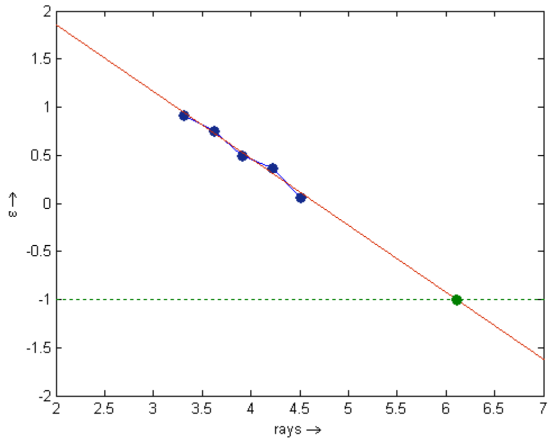
App. 3 - Estimation of the number of rays

- Plot mean value of ε against number of rays
- Linear fitting of the obtained points (log-log axes)
- Ray number estimation for a given precision



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Conclusions

Advantages:

- Easily customized (number of super-faces, aspect ratio, aperture angles …)
- Geometry preserved

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Conclusions

Applications:

- Sparsity estimator
- Estimation of the number of rays
- Thermal model reduction
  - Pre-design
  - Adaptative simulations
  - Objects in various configurations (deployable antenna, solar panels …)
  - Large deformations (need to update view factors several times)
  - Study of mechanism (robots, complex machines …)

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Perspectives

Further works:

- Implement local refinement (adapt the super-faces size locally)
- Implement ray-tracing method for super-faces
- Test on real spacecraft problems
- Perform coupled thermal analyses within a FE code framework

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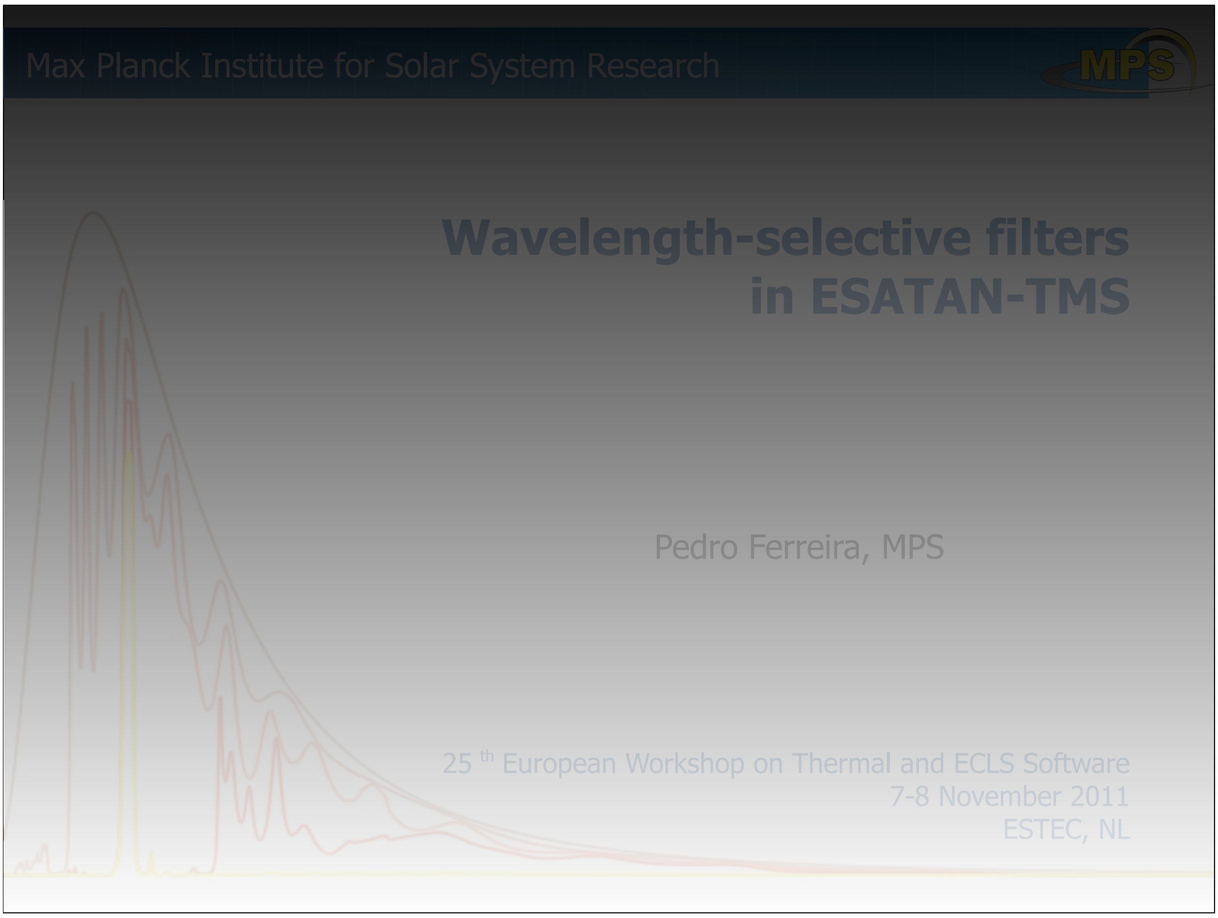
Appendix H

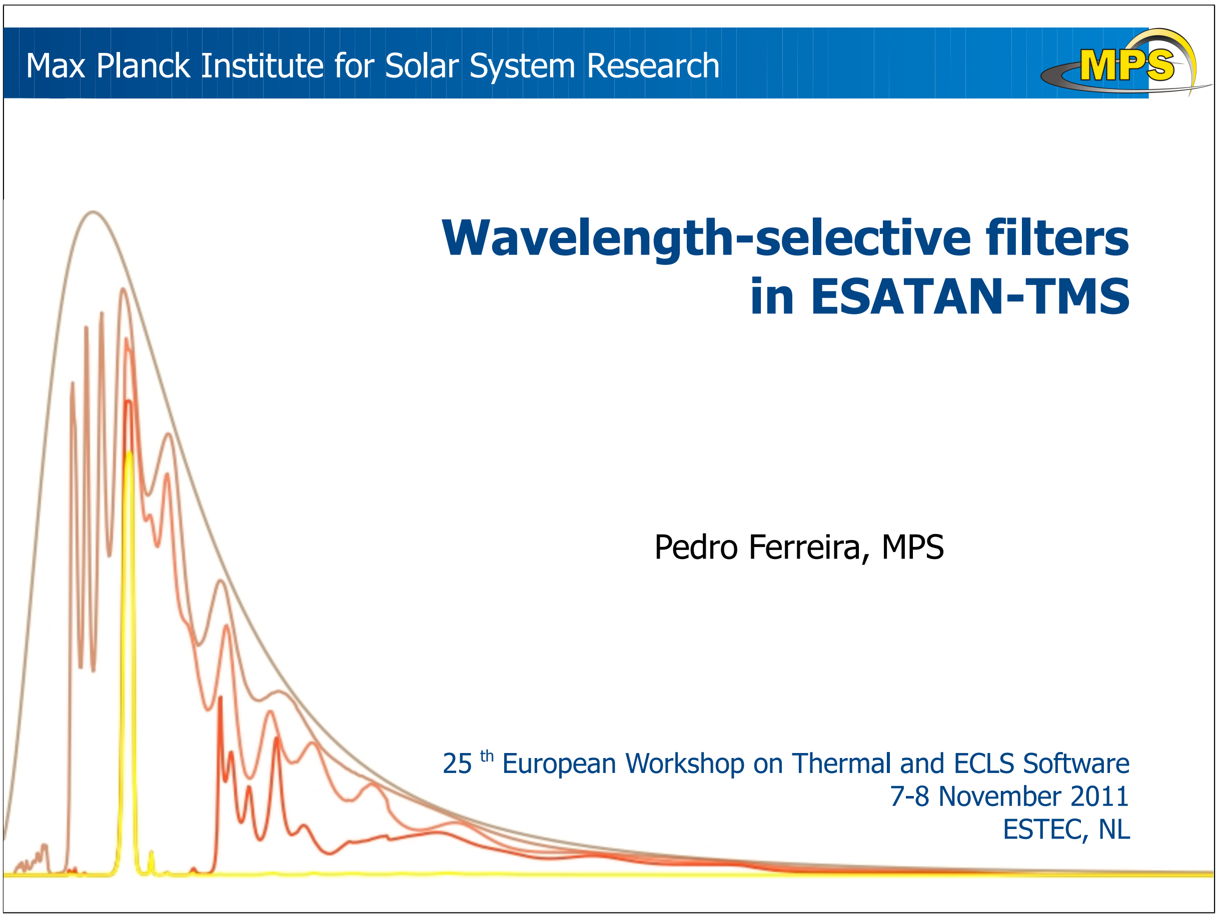
Wavelength-selective filters in ESATAN-TMS

Pedro Ferreira
(MPS, Germany)

Abstract

The ESA mission Solar Orbiter will approach the Sun closer than ever before. Among other instruments in its payload is the Polarimetric and Helioseismic Imager (PHI) lead by the Max Planck Institute for Solar System Research (MPS) in Germany. PHI will observe the Sun through a so-called entrance window whose purpose is to block all radiation outside the 617.3 $\pm$ 30 nm science interval corresponding to 96% of the total incident solar flux. To this purpose it uses a combination of four wavelength-selective filters/coatings on two glass substrates. An accurate thermal analysis of the window is critical to the determination of stresses/birefringence (among other effects) in the substrates for input to the instrument's optical design. This presents several challenges for implementation in ESATAN-TMS.
Integrating with the ongoing ESA Technology Research Program (ESA-TRP) on wavelength-dependent thermo-optical surfaces and starting from the technique presented at the 2009 Workshop by Simone del Togno a method will be derived to simulate wavelength dependency in ESATAN-TMS for the specific case of the PHI window.


Max Planck Institute for Solar System Research
Wavelength-selective filters
in ESATAN-TMS
Pedro Ferreira, MPS
25 th European Workshop on Thermal and ECLS Software
7-8 November 2011
ESTEC, NL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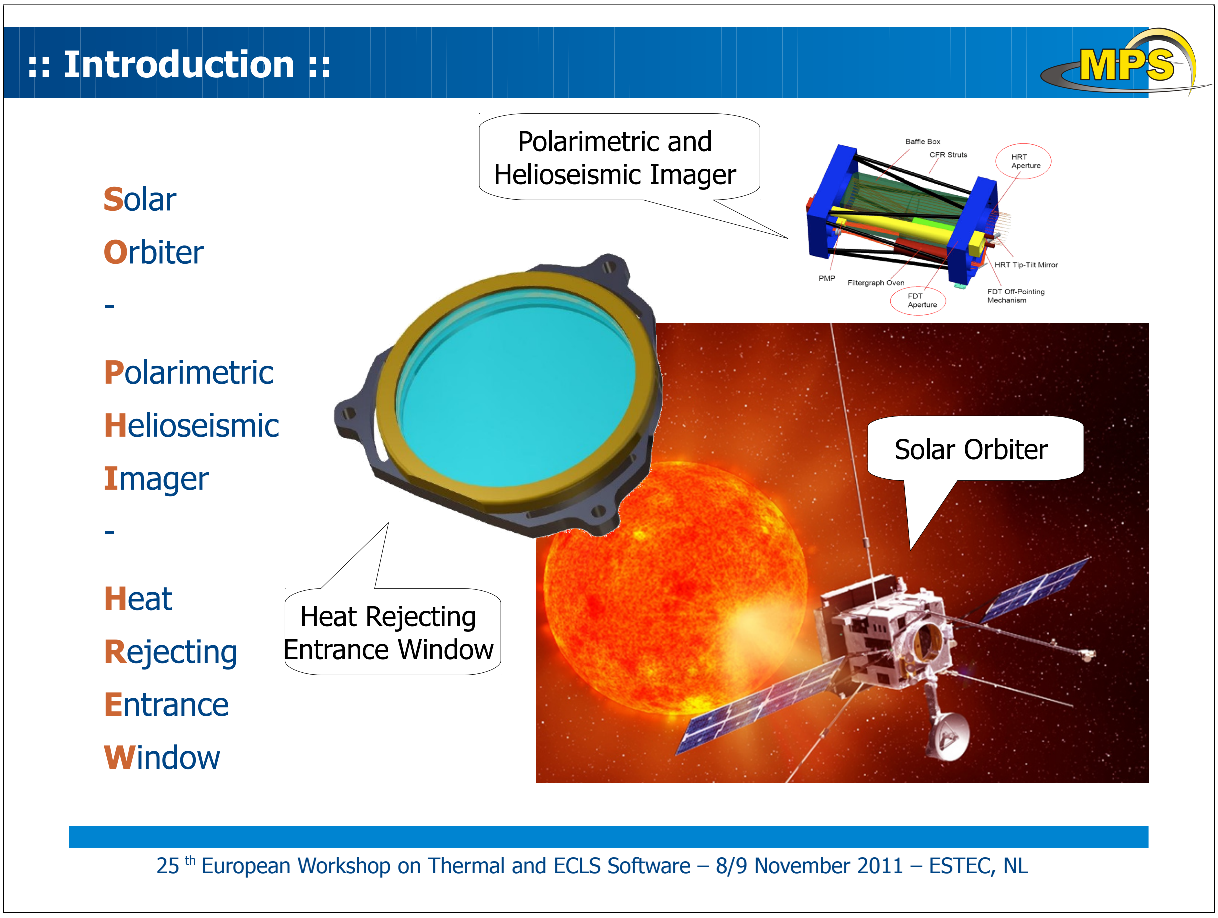
:: Introduction ::
MPS
Solar
Orbiter
-
Polarimetric
Helioseismic
Imager
-
Heat
Rejecting
Entrance
Window
Polarimetric and Helioseismic Imager
Baffle Box
CFR Struts
HRT Aperture
HRT Tip-Tilt Mirror
PMP
Filtergraph Oven
FDT Aperture
FDT Off-Pointing Mechanism
Heat Rejecting Entrance Window
Solar Orbiter
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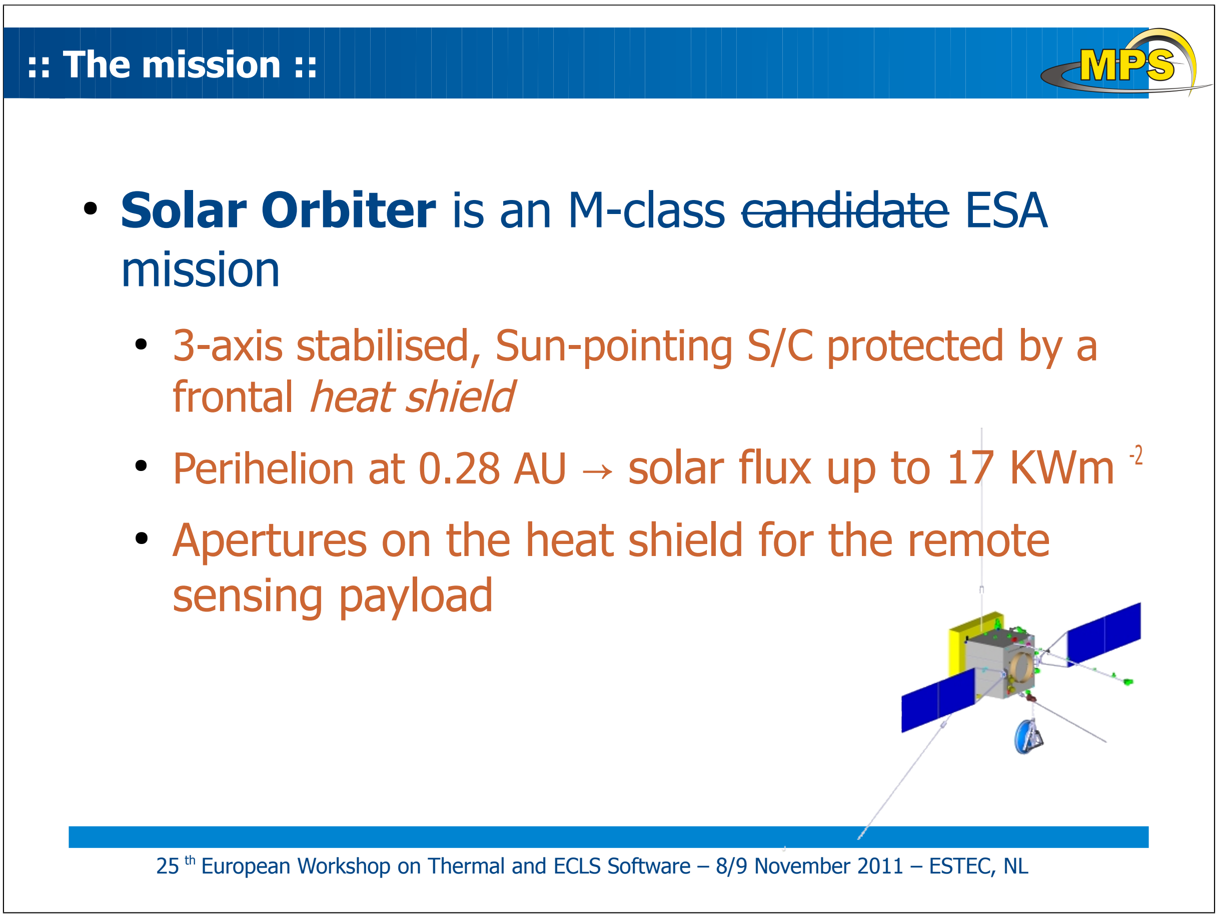
:: The mission ::
MPS
• **Solar Orbiter** is an M-class ~~candidate~~ ESA mission
• 3-axis stabilised, Sun-pointing S/C protected by a frontal *heat shield*
• Perihelion at 0.28 AU → solar flux up to 17 KWm $^{-2}$
• Apertures on the heat shield for the remote sensing payload
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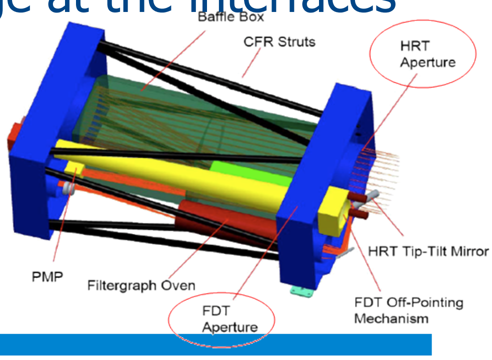
:: The instrument ::

- PHI (Polarimetric and Helioseismic Imager) is an optical remote sensing instrument
  - Perform polarimetry of the solar surface
  - Perform data reduction on board
- Operating temperature range at the interfaces between -20°C and +50°C



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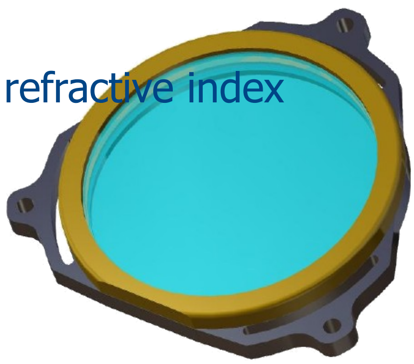
:: The entrance window ::

- The HREW (Heat Rejecting Entrance Window) is the eye of PHI
  - Designed to block **96%** of the incident solar flux
  - Consists of two glasses with 4 wavelength-selective filters
    - Glasses are 9 mm thick and separated by a 3 mm gap
  - Is attached at the feedthrough with a conductive sink temperature of 280 °C (hot case)
- Temperature gradients will induce refractive index changes and optical deformations



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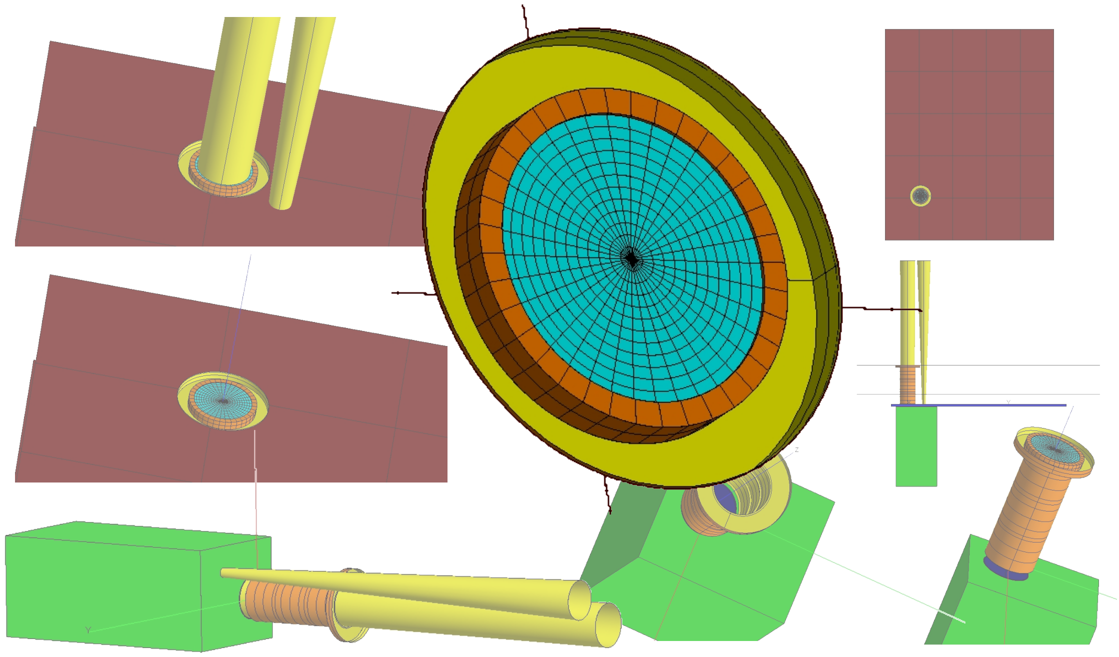
:: Thermal modeling ::

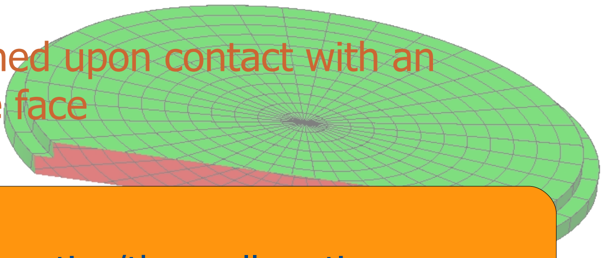


:: The thermal model :: (1/3)

- High level of detail required by the optical engineers
  - Must represent glasses as 3D bodies
  - Need large number of nodes to detect gradients
- Each glass is a **semi-transparent solid body** built using two-dimensional shells (two discs and one cylinder)
- What about the shells activity and coatings?

:: The thermal model :: (2/3)

- Use shells inactive on the inside
  - Don't expect radiation inside the substrate (opaque above 3500 nm)
- But inactive faces become an obstacle for the solar ray propagation!
  - Solar rays are extinguished upon contact with an inactive/thermally active face



Feature request:
Allow solar raytracing through inactive/thermally active surfaces (?)

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:: The thermal model :: (2/3)

- Use shells inactive on the inside
  - Don't expect radiation inside the substrate (opaque above 3500 nm)
- But inactive faces become an obstacle for the solar ray propagation!
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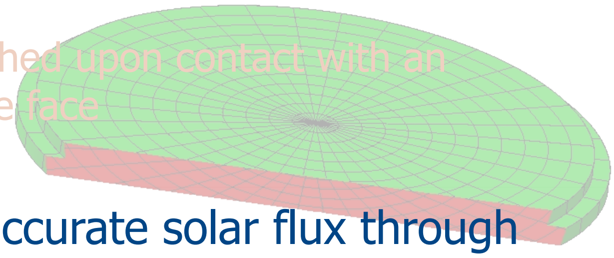

- How to guarantee an accurate solar flux through the glass while omitting the GRs inside it?

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:: The thermal model :: (3/3)

- Use two models:
  - **UV model** outputs the correct solar flux on each face by using only active faces in the glasses
  - **IR model** outputs the GRs between all surfaces accounting for the opaque substrate
- **TMM** uses the QSs from the UV model and the GRs from the IR model
- Process is made automatic with a script:
  - `ReplaceInFile( `File.TAN` , `OriginalBlock.data` , `...\Path\To\UV\Model\SubroutinesBlock.data` )`
  - The script simply looks for and replaces the call to `$SUBROUTINES` (where the QSs are attributed through `QAVERG`)

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:: Interlude ::

- An alternative starting approach is to make the shells opposite the solar flux transparent in the UV
  (based on a model from C. Damasio, ESA)
  - This gives the correct absorbed solar flux in each layer/coating
  - It **eliminates multiple reflections** between the layers and thus might underestimate the total transmission and additional absorbed flux in the layers
- Results from this approach will be used for comparison

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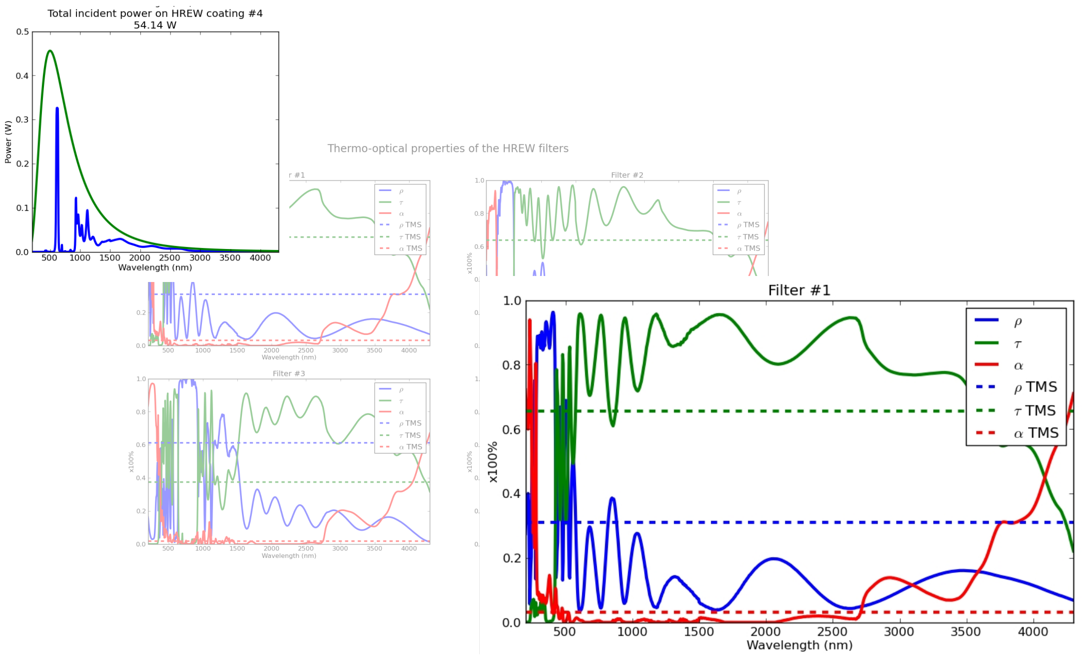
:: Averaging the thermo-optical properties ::



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:: Averaging the thermo-optical properties ::

- First step:
  - Use basic theory to estimate the expected fluxes:
    - Spectral analysis of reflection, absorption and transmission
    - Algorithm calculates the incident power on each surface and uses simple multiplication to estimate the overall transmission
    - 3.4% transmission in the range 200-3000 nm (within 4% specification)
- Second step:
  - Weigh the filters' properties on the incident fluxes for the range of interest
  - Use the average properties for the solar band in ESATAN-TMS
    - Same approach as Simone del Togno (2009 Workshop)

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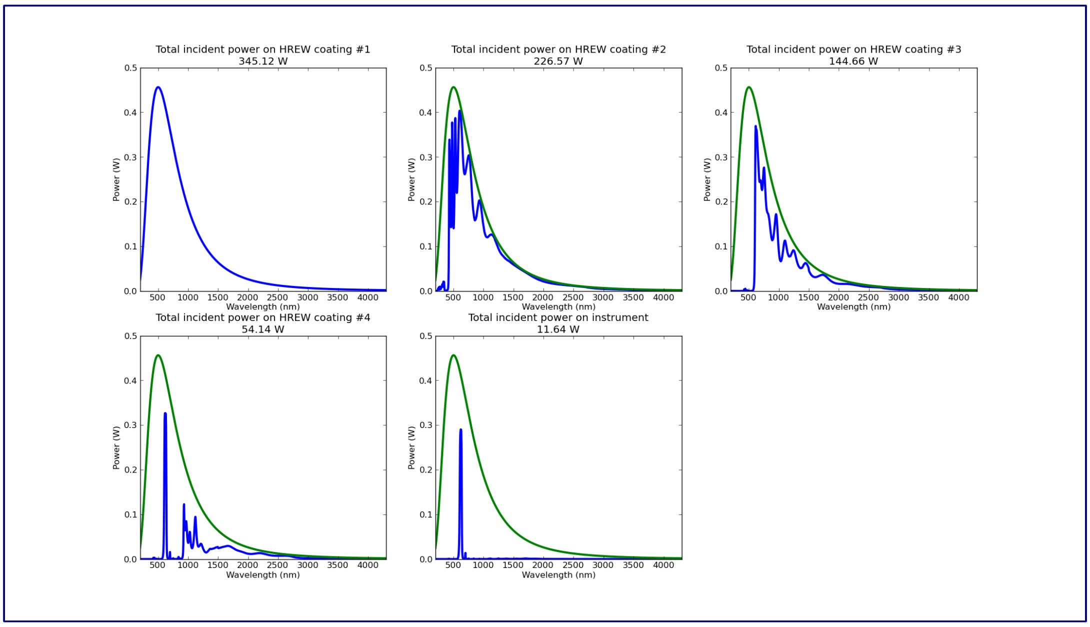

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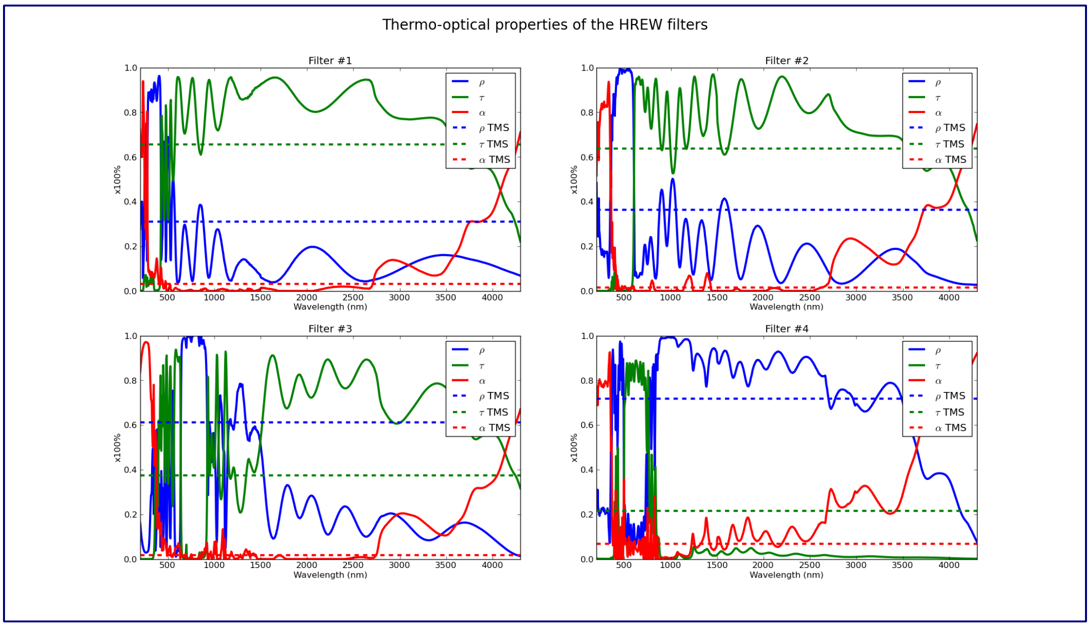

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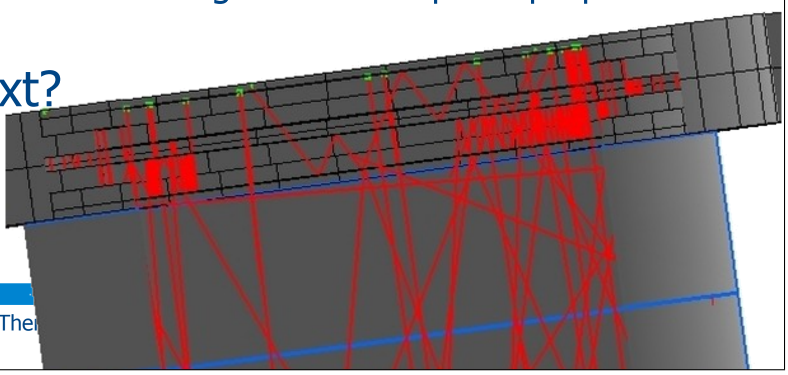
:: Results from the two-model approach ::

- Not the expected results in ESATAN-TMS
  - Transmitted flux amounts to 9% → out of specification and incompatible with test results
  - Inspection reveals that additional flux comes from multiple reflections between the surfaces
    - Probably due to the averaged thermo-optical properties
- What to do next?



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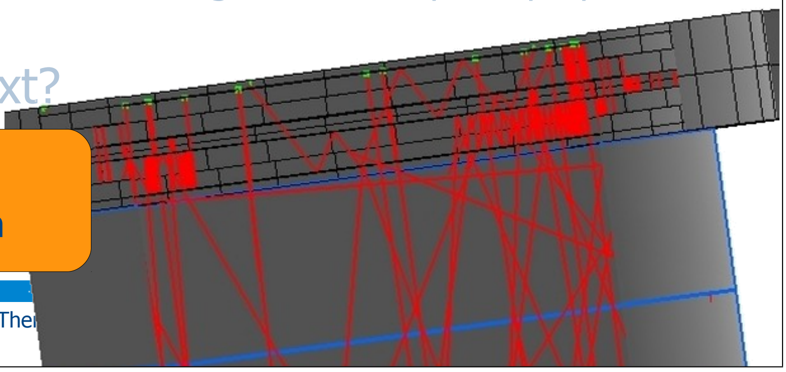
- What to do next?

Feature appraisal :
Solar ray visualization



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:: Tentative explanation for the results :: (1/2)

- The **basic theory** predicts 3.4% transmission...
  - ... but **ignores all reflections** between the surfaces
  - ESATAN-TMS on the other hand reflects light with *λ=617 nm* the same way as light with *λ=350 nm*
    - But the wavelength-dependent reflectivity says there should be much less reflection at *λ=617 nm* than at *λ=350 nm*
    - This behaviour is captured in the calculation of the thermo-optical properties through weighing on the solar spectrum, **but it is only correct for the first surface**
- What does this mean for the results?

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:: Tentative explanation for the results :: (2/2)

- At some wavelengths there should be a very small amount of reflection
  - If these wavelengths represent a high power/flux, then ESATAN-TMS is overestimating the total flux reflected...
  - ... and the multi-reflections between surfaces amplify the effect further!

Reflectivity	617 nm	350 nm	Average TMS
Filter #2	7 %	55 %	36 %
Filter #3	4 %	23 %	62 %
‛ Level of interaction‛	**0.3 %**	**13 %**	**22 %**

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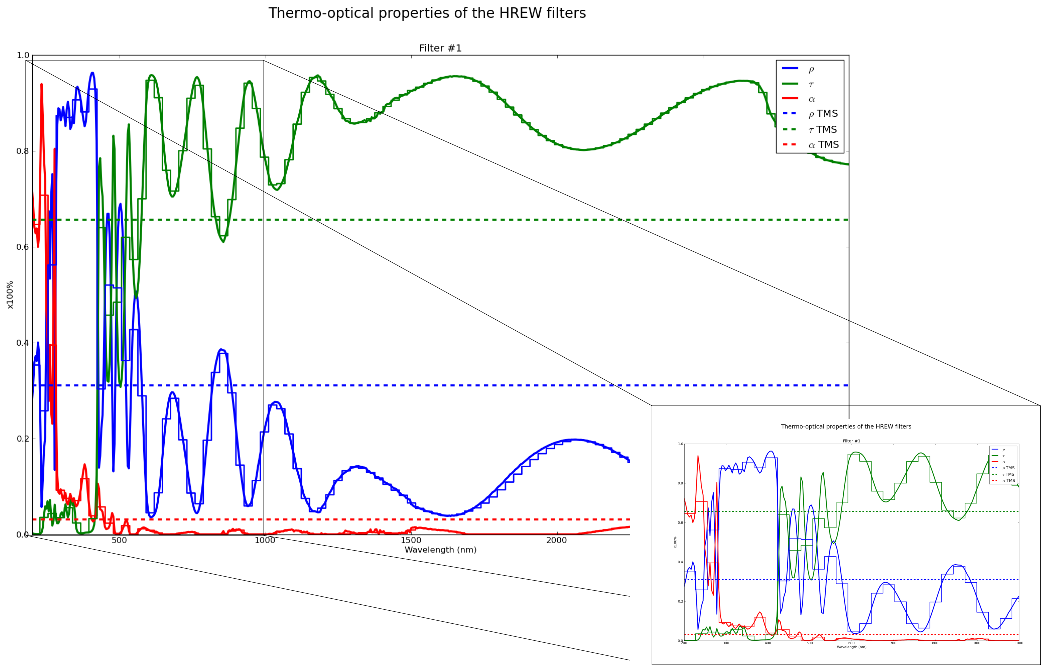
:: Wavelength-dependency ::



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:: Wavelength-dependency implementation ::

- Simulate wavelength-dependency in ESATAN-TMS !
  - Effectively divide the solar band in small intervals
  - Accurately model the flux and interactions in each interval
    - Calculate expected **solar power** in interval and **equivalent solar distance** that gives that power
    - Average the thermo-optical properties in the interval **only**
    - Put all in an .erg/.erk file and solve
  - Rinse and repeat for the whole solar band (used 200-3000 nm)
  - Add the QS contributions from each interval
- How many intervals to use?

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:: Wavelength-dependency implementation ::

- Simulate wavelength-dependency in ESATAN-TMS !
  - Effectively divide the solar band in small intervals

```
/*                        emissivi,refIR,traIR,   absorpti,refUV,   transmUV,speIR, speculUV */
optHREWcoat1[acaaXacch] = [[illegible] 0.64621435, 0.00, 0.00072810, 0.25, 0.35305755];
optHREWcoat2[acaaXacch] = [illegible] 0.73319983, 0.00, 0.00054767, 0.15, 0.26625250];
optHREWcoat3[acaaXacch] = [0.05, 0.00, 0.70, 0.88743141, 0.00, 0.00061853, 0.25, 0.11195006];
optHREWcoat4[acaaXacch] = [0.15, 0.00, 0.05, 0.76000169, 0.00, 0.00155332, 0.80, 0.23844499];

optHREWcoat1[acciXacff] = [0.75, 0.00, 0.00, 0.70718593, 0.00, 0.03521760, 0.25, 0.25759647];
optHREWcoat2[acciXacff] = [[illegible] 0.78763197, 0.00, 0.00011339, 0.15, 0.21225464];
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optHREWcoat4[acciXacff] = [[illegible] 0.78580593, 0.00, 0.00126157, 0.80, 0.21293250];
(...)
```

200 - 227 nm

228 - 255 nm

- How many intervals to use?

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:: Wavelength-dependency implementation ::

MPS

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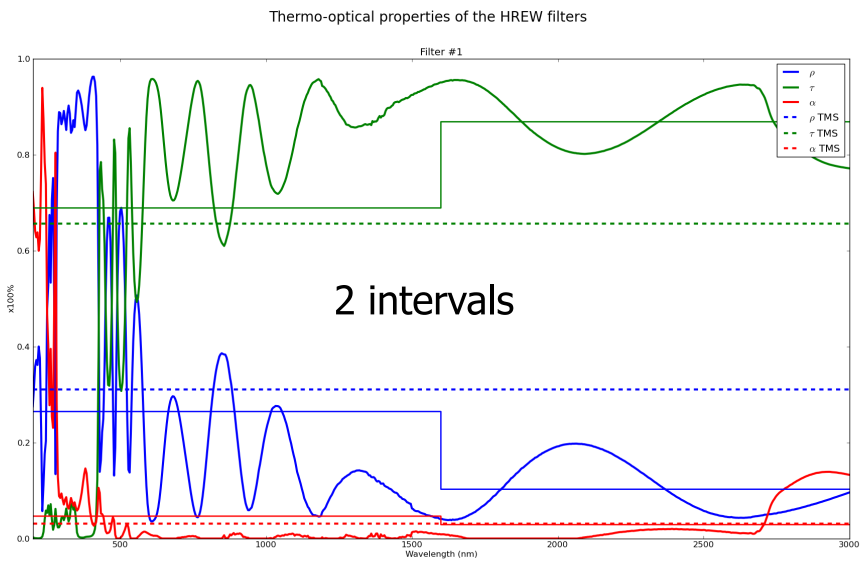
:: Wavelength-dependency implementation ::

MPS



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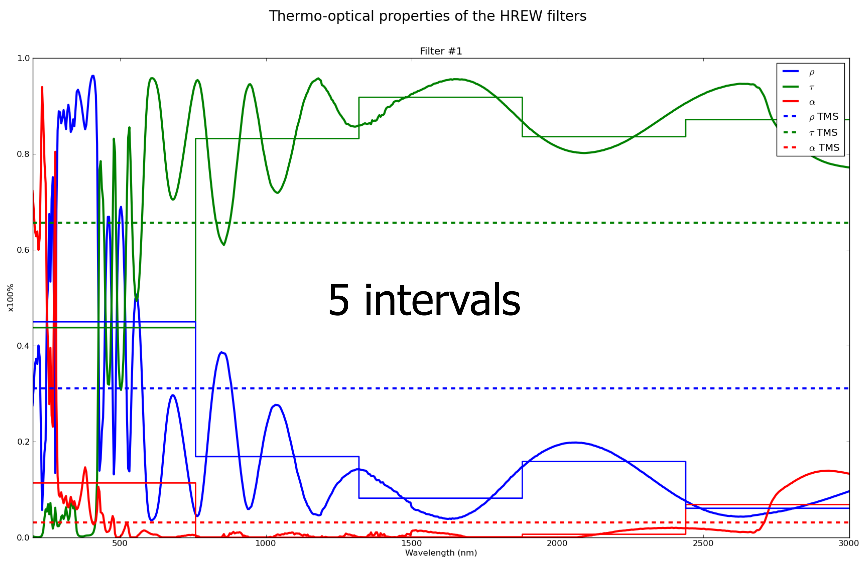

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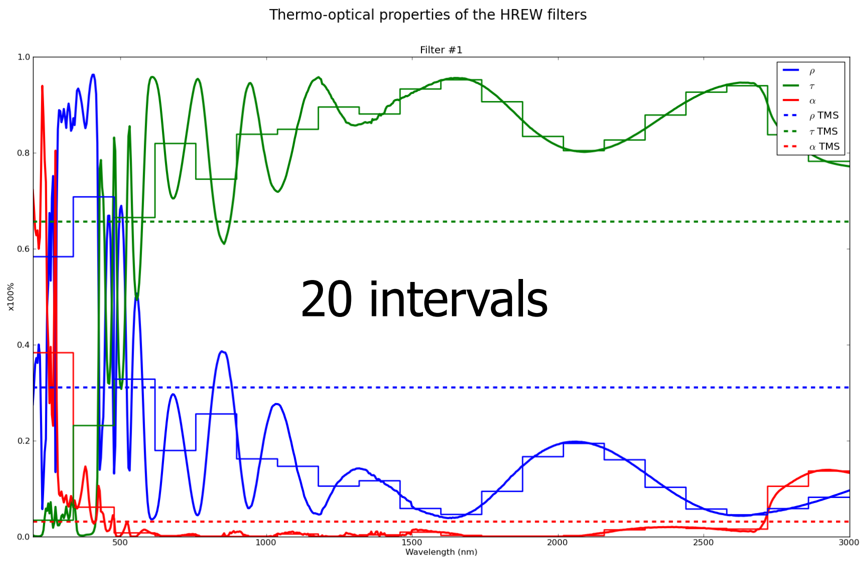

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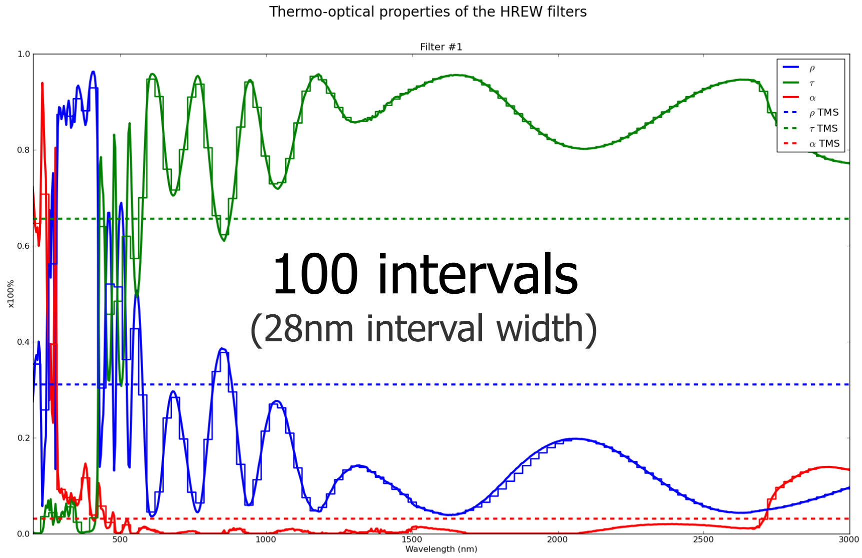

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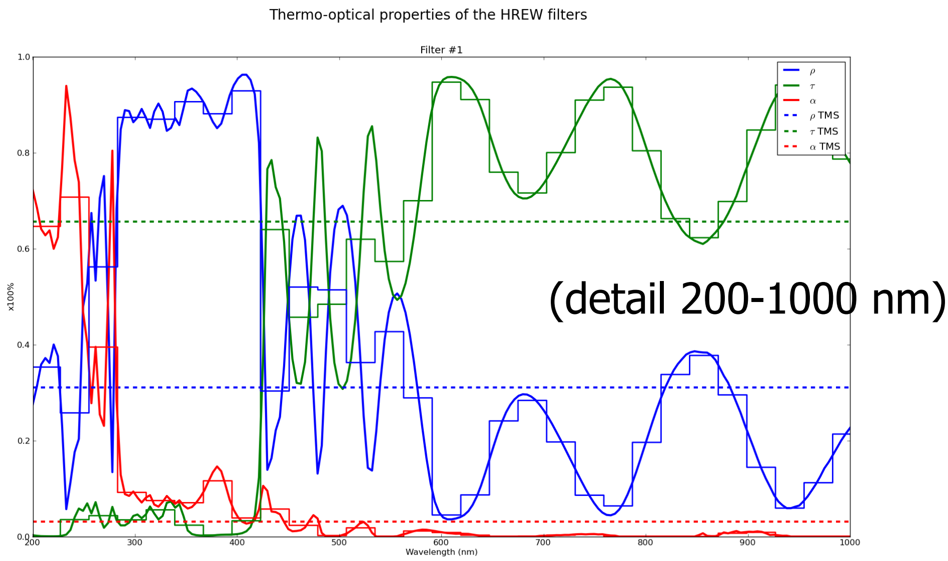

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:: Wavelength-dependency obstacles ::

MPS

- ESATAN-TMS reports the QSs with two decimal places → too few for small areas where flux is <0.004 W
  - Results in QS_{SUM} = 0 and artifacts later on
- Instead report QSs in the form:

```
QS:9000 = QS(W/m²) * A:9000
```

  - Eliminates the "two-decimal point" precision problem since relevant surfaces are much smaller than 1 m²
  - Artifacts only visible for the smallest surfaces with the lowest irradiation – why?

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:: Wavelength-dependency obstacles ::

MPS

- ESATAN-TMS
too few for s
  - Results in Q
- Instead repo

QS:9000 = QS

  - Eliminates t
relevant surfaces are much smaller than 1 m²

page 7-12

User Manual

density is specified in rays/metre². The ray density method is not used for solar heat flux calculations.

c. **Use accuracy control:** LINE_ACCURACY

Each criticality class is assigned a desired accuracy and a required confidence level. Workbench then decides how many rays to fire to reach the required line sum accuracy. Accuracy control is not used for solar heat flux calculations.

> Using accuracy control with very strict desired line sum accuracies, for example, more accurate than 1%, can significantly increase run times for radiative calculations.

For more details on how Workbench performs its accuracy control, see Subsection 7.6.1: "Calculation accuracy".

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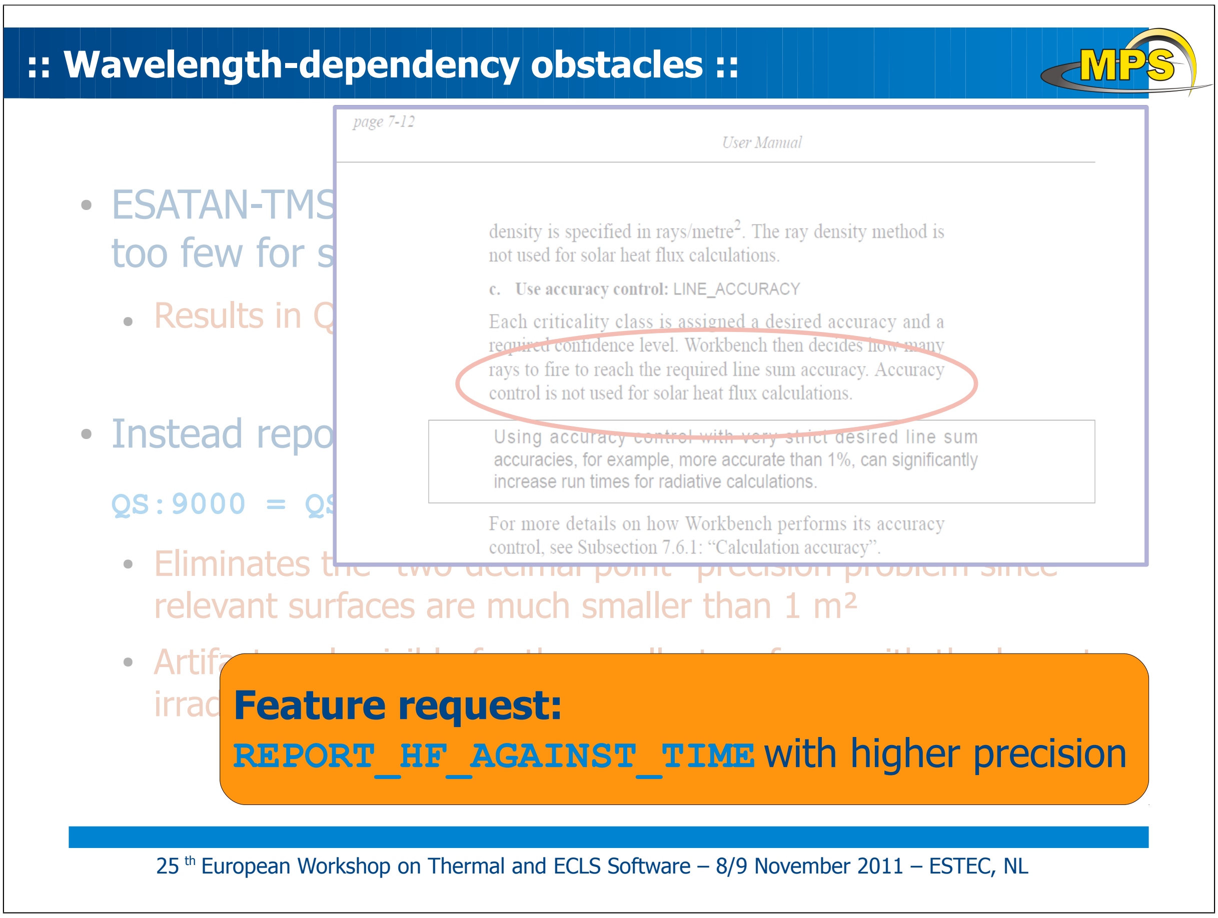
:: Wavelength-dependency obstacles ::
MPS
• ESATAN-TMS
too few for s
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Feature request:
REPORT_HF_AGAINST_TIME with higher precision
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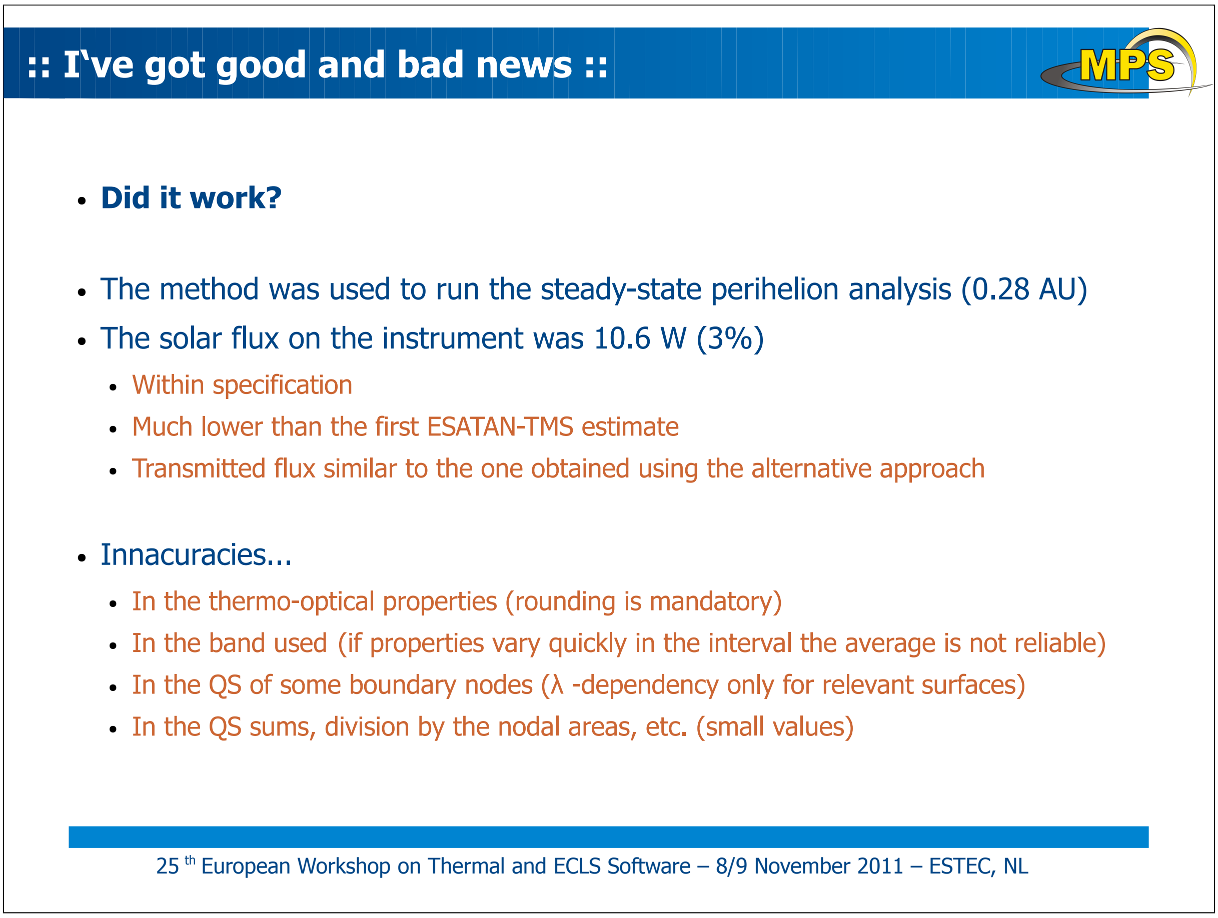
:: I've got good and bad news ::
MPS
• Did it work?
• The method was used to run the steady-state perihelion analysis (0.28 AU)
• The solar flux on the instrument was 10.6 W (3%)
• Within specification
• Much lower than the first ESATAN-TMS estimate
• Transmitted flux similar to the one obtained using the alternative approach
• Innacuracies...
• In the thermo-optical properties (rounding is mandatory)
• In the band used (if properties vary quickly in the interval the average is not reliable)
• In the QS of some boundary nodes (λ -dependency only for relevant surfaces)
• In the QS sums, division by the nodal areas, etc. (small values)
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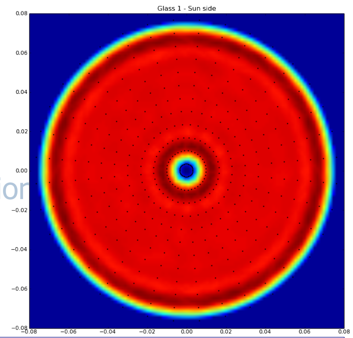
:: I‘ve got good and bad news ::



- Did it work?

- The method was used to run the steady-state perihelion
- The solar flux on the instrument was 10.6 W (3%)
  - Within specification
  - Much lower than the first ESATAN-TMS estimate

```
Average absorbed heat flux in external face: 280 Wm-2
Std. var. of absorbed heat flux in external face: 25 Wm-2
Half-width of interval: 13 %
Histogram: [ 72   0   0   0   0   0   0   0   0 360]

Average absorbed heat flux in external face EXC. WORST LAYERS: 291 Wm-2
Std. var. of absorbed heat flux in external face EXC. WORST LAYERS : 0.3 Wm-2
Half-width of interval EXC. WORST LAYERS : 0.3 %
Histogram EXC. WORST LAYERS : [ 6 12 30 41 69 86 64 33 11  6]
```

  - In the QS of some boundary nodes
  - **In the QS sums, division by the nodal areas, etc. (small values)**

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:: Is it worth to correct the smaller QSs? ::

- Correcting the QSs means
  - using the average QS value on the surface (adds another uncertainty...)
  - or making larger nodes

- Replaced the individual QSs in a node for the average QS on the surface
  - No noticeable change in the relevant quantities
  - Proceeded with same approach
  - **To do:** replace central nodes for a single node

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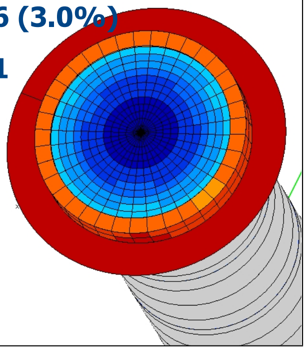
:: Comparison of results ::

	First approach (UV + IR model)	Single model (transparency on Sun-opposite surfaces) (C. Damasio, ESA)	**Wavelength-dependent**
Max temperature in glass (°C)	322	267	**265**
Max gradient in glass (°C)	107	114	**117**
QS - flux to unit (W)	31.3 (9.3%)	9.4 (2.8%)	**10.6 (3.0%)**
IR - flux to unit (W)	10.4	10.2	**10.1**



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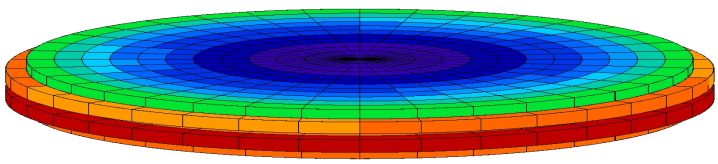
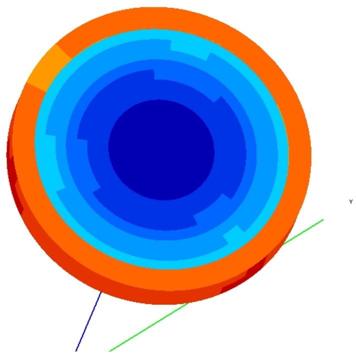
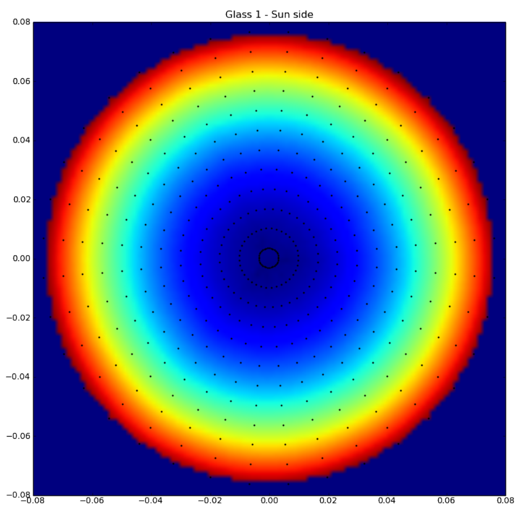
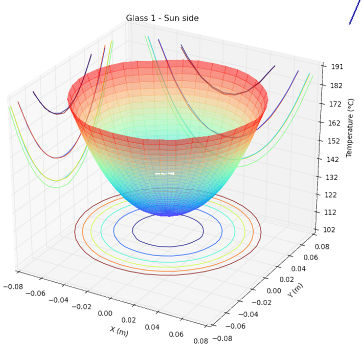
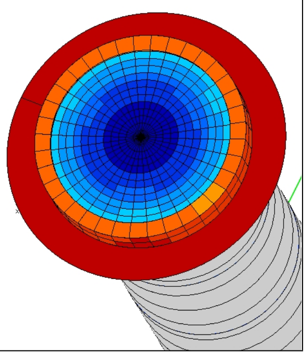
:: Temperature profiles ::











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:: And they lived ~~happily~~ ever after ::

MPS

- There is a need for wavelength-dependent optical properties in space thermal analysis
- The method presented is not foolproof since many innacuracies arise in the process and are not tracked down
  - It remains as an interesting exercise on how to tweak ESATAN-TMS to suit one's purposes

Feature request:
Wavelength-dependent definition of the thermo-optical properties

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Max Planck Institute for Solar System Research

MPS

Wavelength-selective filters in ESATAN-TMS

Thank you for your attention !

Questions? Tips? Praises?

Pedro Ferreira

25 th European Workshop on Thermal and ECLS Software
7-8 November 2011
ESTEC, NL

Appendix I

ESATAN Thermal Modelling Suite
Product Developments

Chris Kirtley
(ITP Engines UK Ltd, United Kingdom)

Abstract

ESATAN-TMS provides a powerful, integrated thermal modelling environment. Since the release of ESATAN-TMS r3 in January 2011, major developments have been undertaken in the area of importing CAD geometry and interactive geometry creation. New functionality include an automated facility to define and generate contact conductances between surfaces, the ability to include wavelength dependent thermo-optical properties and a mechanism to perform axisymmetric analysis. This presentation outlines the developments going into the next release of the product.

25th European Thermal & ECLS Software Workshop
ESA/Estec, Noordwijk, the Netherlands

ITP
the power of talent

ESATAN Thermal Modelling Suite

Product Status

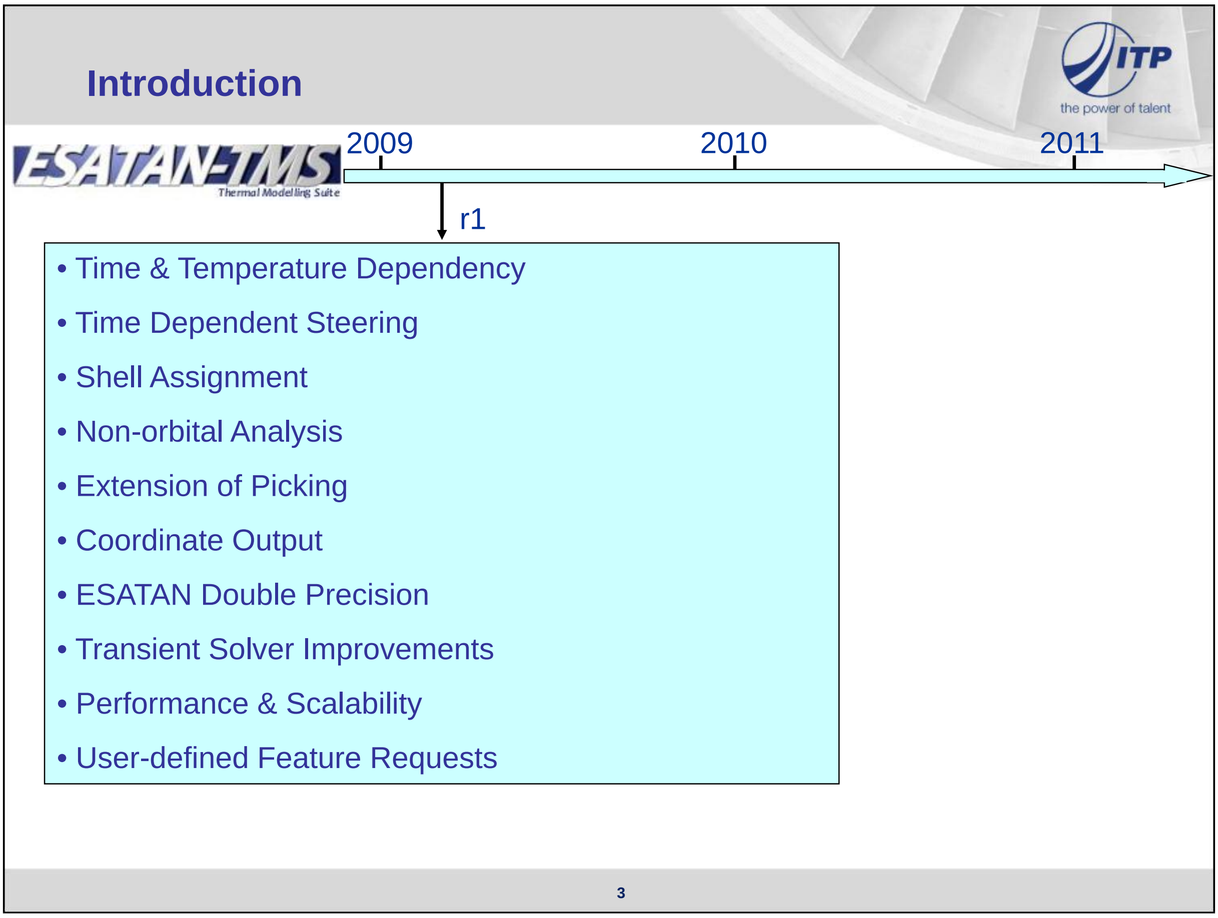
Author: Chris J Kirtley
Date: 8th November 2011

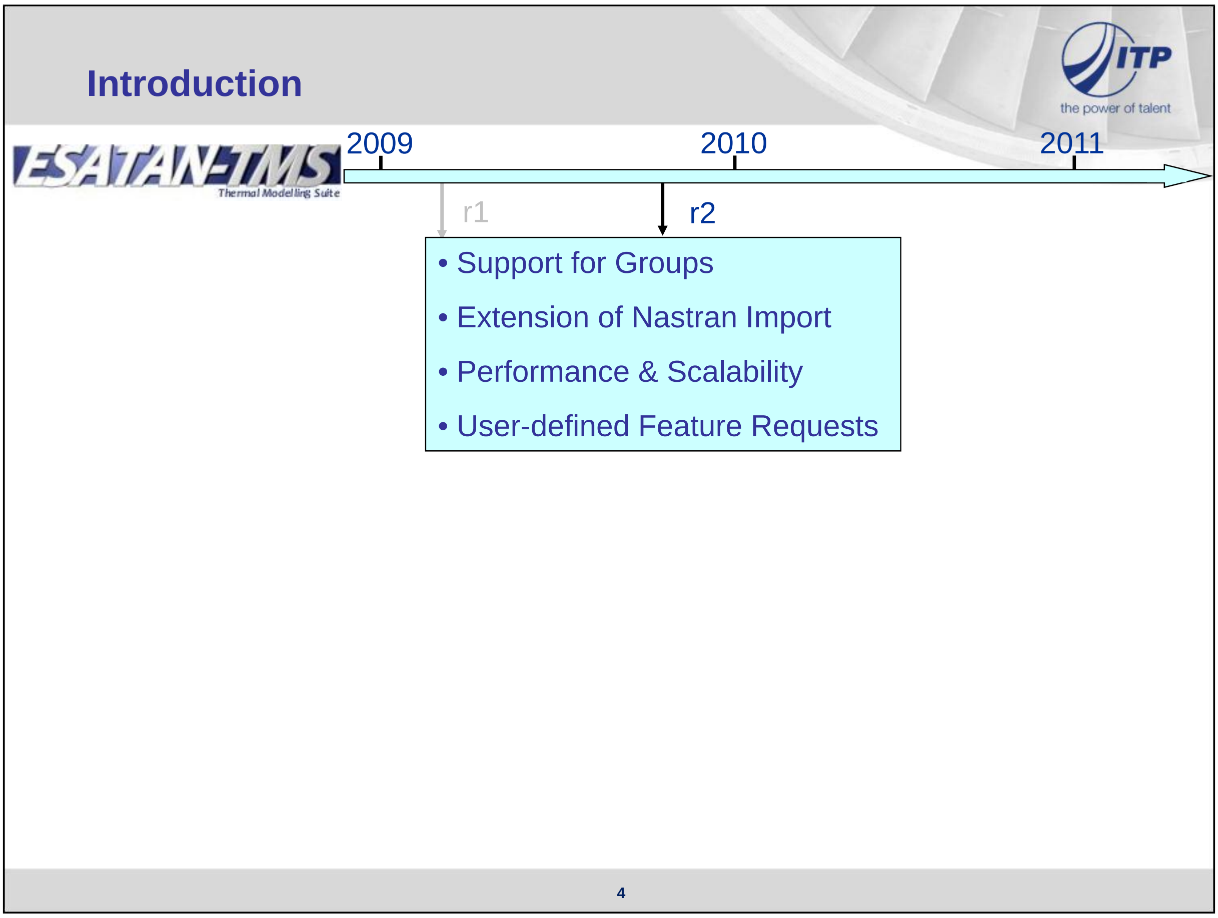
Introduction

ITP
the power of talent

- Our vision remains unchanged,
  - Provide a complete and effective thermal modelling environment
    - Functionality to meet your current & future modelling requirements
    - Provide a high-quality and fully validated product
  - Efficient end-to-end integration within a multi-disciplinary engineering environment
  - Backing this up with professional customer support services

2


Introduction
ESATAN-TMS
Thermal Modelling Suite
ITP
the power of talent
2009
2010
2011
r1
• Time & Temperature Dependency
• Time Dependent Steering
• Shell Assignment
• Non-orbital Analysis
• Extension of Picking
• Coordinate Output
• ESATAN Double Precision
• Transient Solver Improvements
• Performance & Scalability
• User-defined Feature Requests
3


Introduction
ESATAN-TMS
Thermal Modelling Suite
ITP
the power of talent
2009
2010
2011
r1
r2
• Support for Groups
• Extension of Nastran Import
• Performance & Scalability
• User-defined Feature Requests
4

Introduction

ESATAN-TMS Thermal Modelling Suite

2009 — 2010 — 2011

r1 r2 r3

- Improved Import of CAD Geometry
- Combined FE / LP Analysis
- Enhanced Model Tree Component
- New Conjugate Gradient Thermal Solver
- Contour Plotting
- Extension of Post-processing (ThermNV)
- Post-processing ThermNV derived data in Workbench
- User-defined Feature Requests

5

Introduction

- Current developments
  - Improved Geometry Modelling
  - Performance Enhancement
  - Face-to-Face Conduction Support
  - Wavelength Dependent Thermo-optical Properties
  - Axisymmetric Analysis
  - User-defined Feature Requests

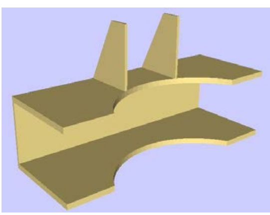
- ESATAN-TMS r4 is now available

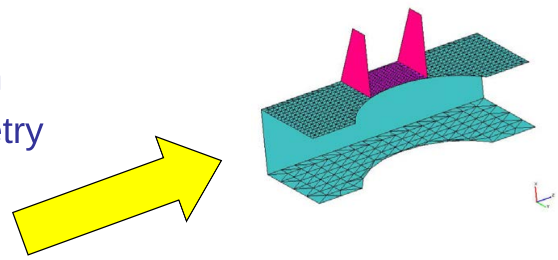
6

Improved Geometry Modelling

Improved Geometry Modelling

- Aim - Reduce the model creation time
- Geometry created in Workbench or imported from CAD
- Last year presented developments to CAD import
  - Mesh refinement
  - Shape recognition
  - De-feature geometry

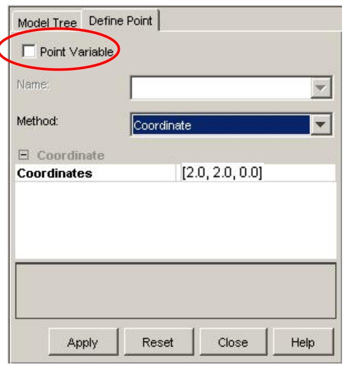




- Focus on geometry creation process within Workbench

Improved Geometry Modelling

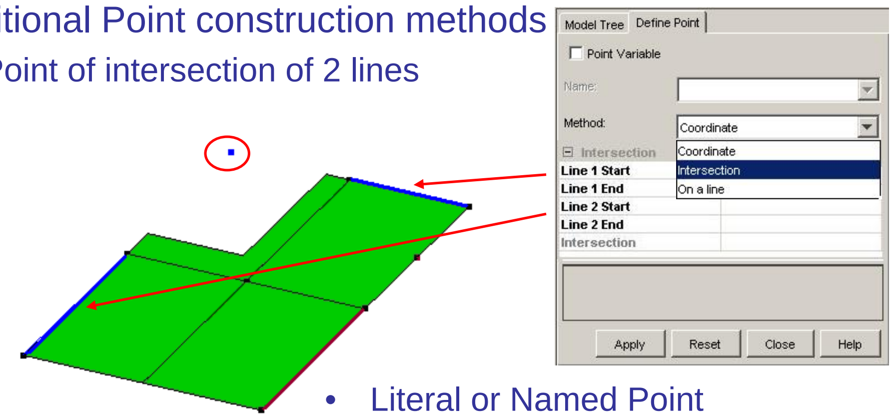
- Additional construction points to facilitate creation of geometry
  - Construction points at Shell centres & Face vertices
  - Concept of literal Points
    - No name assigned
    - Specify coordinate position
    - Not listed on the model tree
    - Not associated with a shell
    - Can be deleted by picking



9

Improved Geometry Modelling

- Additional construction points to facilitate creation of geometry
  - Construction points at Shell centres & Face vertices
  - Additional Point construction methods
    - Point of intersection of 2 lines

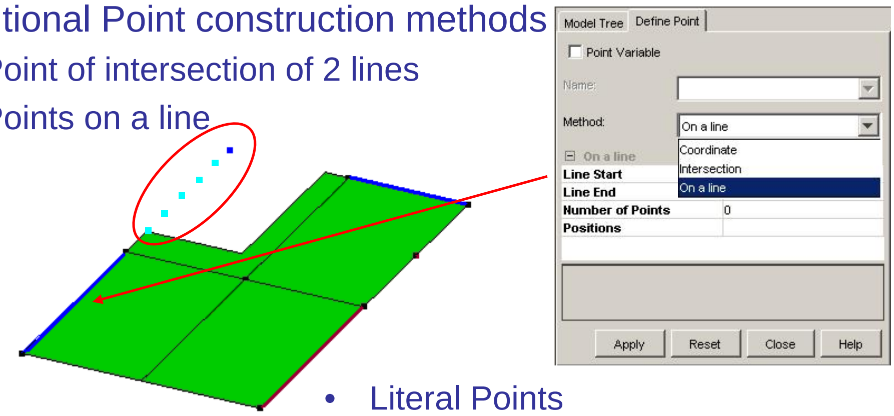


- Literal or Named Point
- Closest point, line 1 if do not intersect

10

Improved Geometry Modelling

- Additional construction points to facilitate creation of geometry
  - Construction points at Shell centres & Face vertices
  - Additional Point construction methods
    - Point of intersection of 2 lines
    - Points on a line

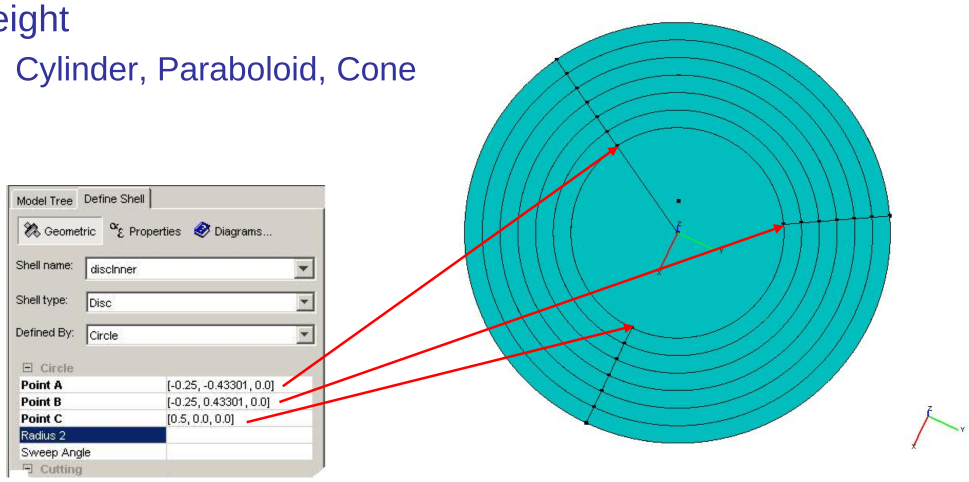


- Literal Points
- Defined by No. points or positions

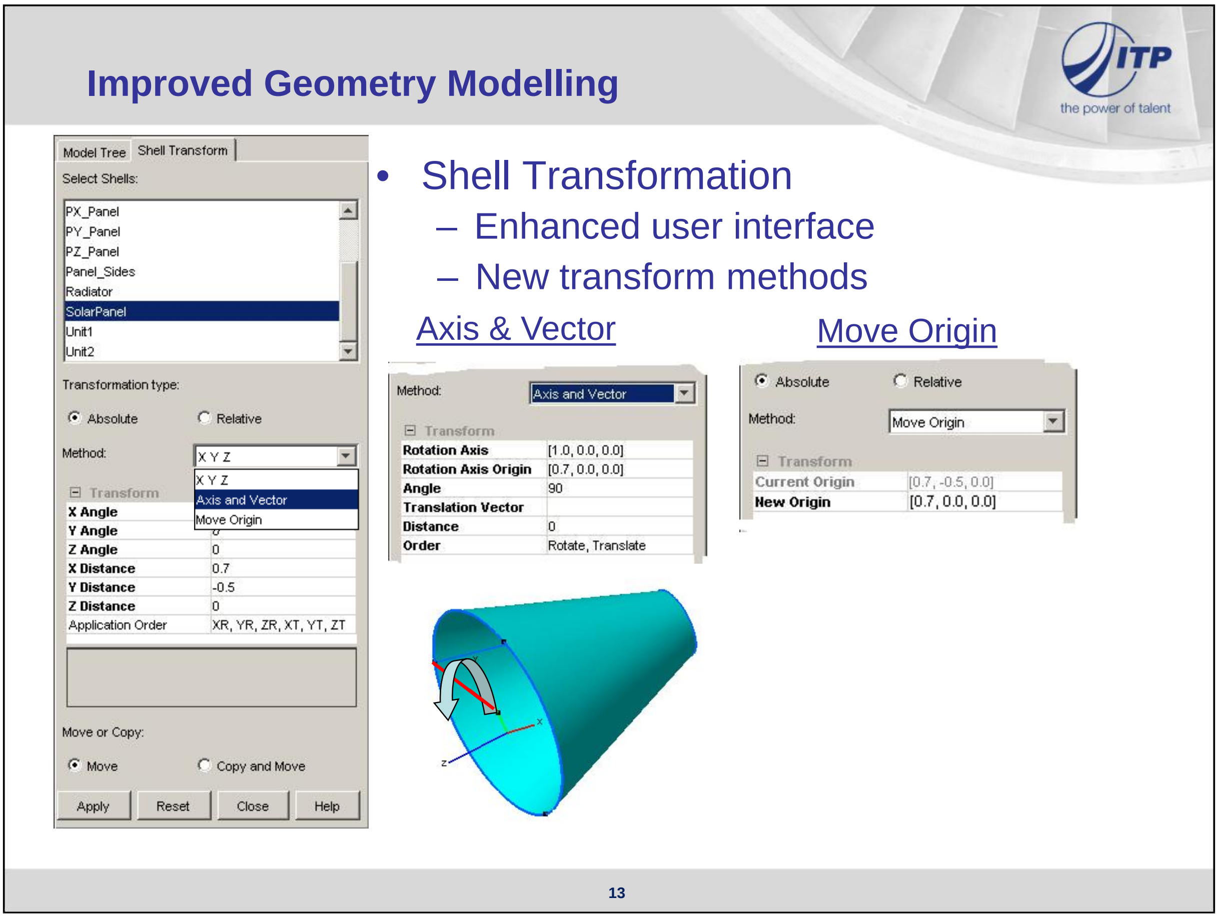
11

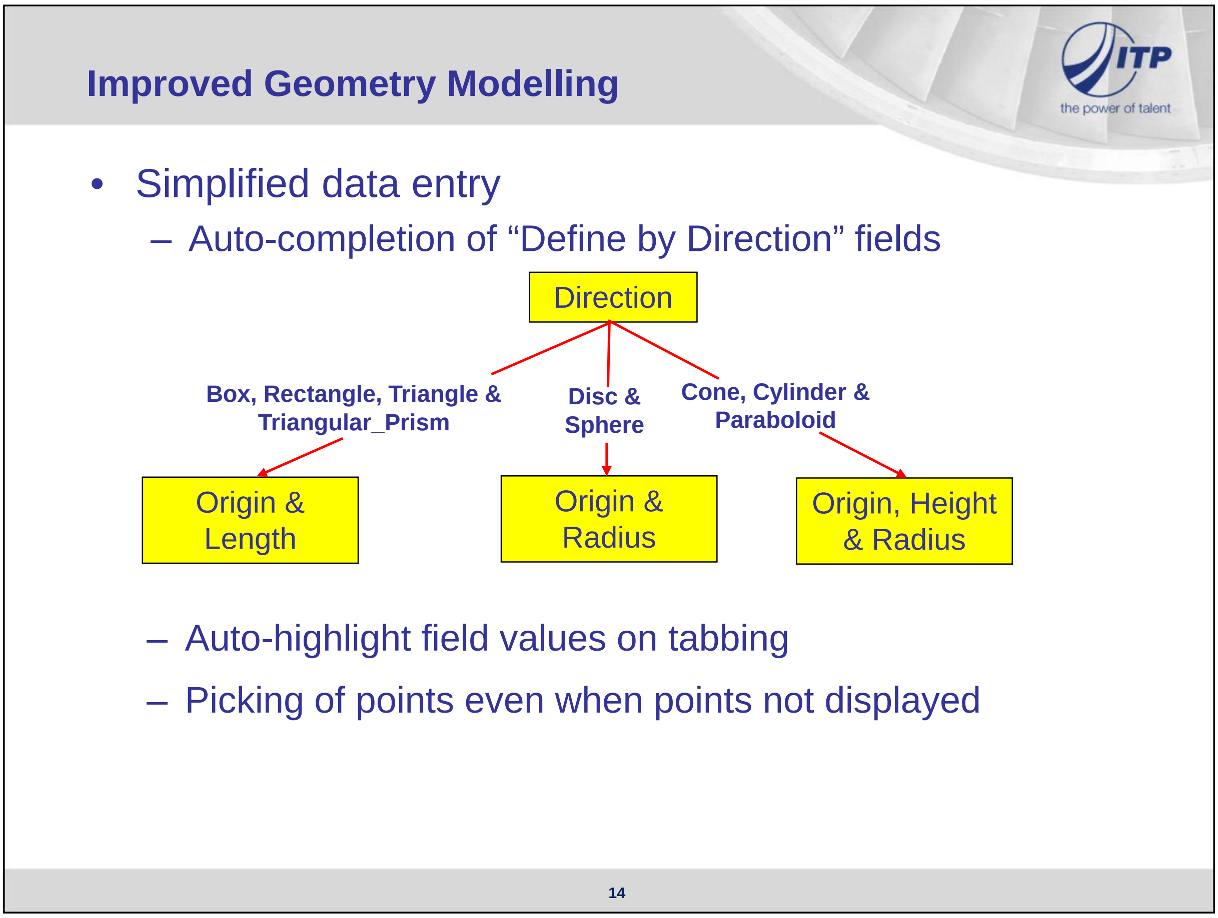
Improved Geometry Modelling

- New shell definition method “Define by Circle”
  - 3 points to define a circle
    - Disc, sphere
  - Height
    - Cylinder, Paraboloid, Cone



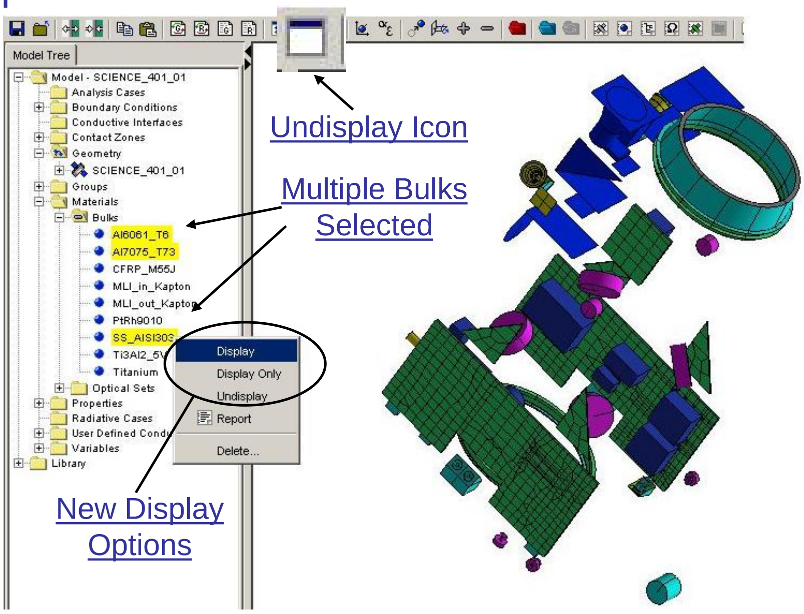
12


Improved Geometry Modelling
ITP
the power of talent
• Shell Transformation
– Enhanced user interface
– New transform methods
Axis & Vector
Move Origin
Model Tree
Shell Transform
Select Shells:
PX_Panel
PY_Panel
PZ_Panel
Panel_Sides
Radiator
SolarPanel
Unit1
Unit2
Transformation type:
Absolute
Relative
Method:
X Y Z
Axis and Vector
Move Origin
Transform
X Angle
Y Angle
Z Angle 0
X Distance 0.7
Y Distance -0.5
Z Distance 0
Application Order XR, YR, ZR, XT, YT, ZT
Move or Copy:
Move
Copy and Move
Apply
Reset
Close
Help
Rotation Axis [1.0, 0.0, 0.0]
Rotation Axis Origin [0.7, 0.0, 0.0]
Angle 90
Translation Vector
Distance 0
Order Rotate, Translate
Current Origin [0.7, -0.5, 0.0]
New Origin [0.7, 0.0, 0.0]
13


Improved Geometry Modelling
ITP
the power of talent
• Simplified data entry
– Auto-completion of "Define by Direction" fields
Direction
Box, Rectangle, Triangle & Triangular_Prism
Disc & Sphere
Cone, Cylinder & Paraboloid
Origin & Length
Origin & Radius
Origin, Height & Radius
– Auto-highlight field values on tabbing
– Picking of points even when points not displayed
14

Improved Geometry Modelling

- Control of displayed shells on Groups, Bulks & Opticals



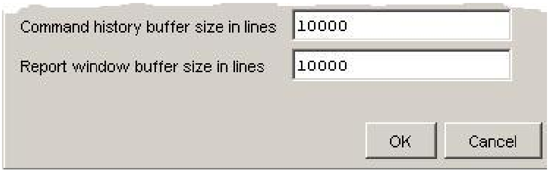
15

Performance Enhancements

16

Performance Enhancements

- General performance improvements
  ≈ Doubling of speed over r3
- Reduction of memory requirements
  – Limit on Reporting & Command window buffer
    - Buffer size user preference (*default 10,000*)



    - Redirect reports to a named file

17

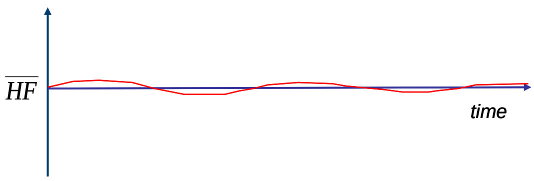
Performance Enhancements

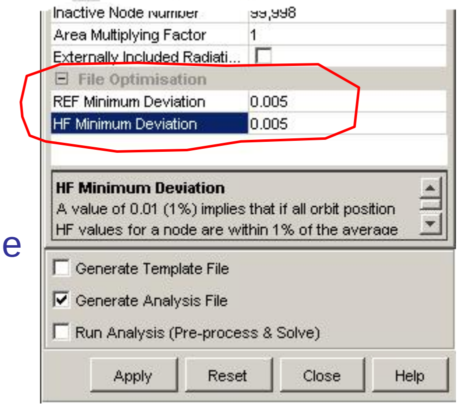
- New solution parameters to control of analysis
  – Limit the REFs via "Ray Total Cutoff" (*default 0.005 / 0.5%*)
    - Percentage of the total energy emitted from a face
    - VFs/REFs omitted after the radiative run
    - Reduces the memory usage
    - Improve the performance of the Analysis Case
    - Reduced thermal analysis file size
    - Reduced thermal solution time

18

Performance Enhancements

- New solution parameters to control of analysis
  - Analysis Case parameter “HF Minimum Deviation”
  - HF assumed constant if deviation < HF Minimum Deviation





  - Default 0.005 / 0.5%
  - Reduced thermal analysis file size
  - Reduced thermal solution time
  - File Optimisation parameters grouped

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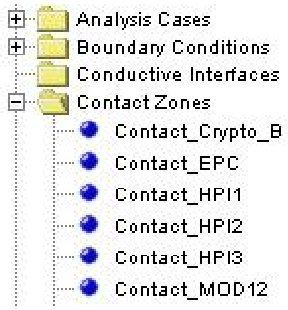
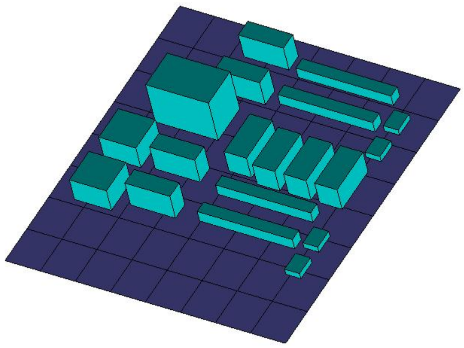
Face-to-Face Conduction Support

20

Face-to-Face Conduction Support

- Automatically generate conductances between surfaces in contact
  - New variable Contact Zones

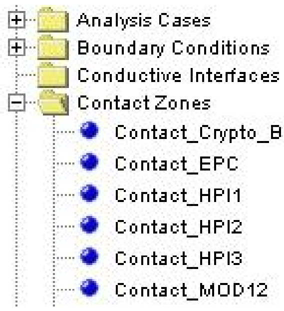


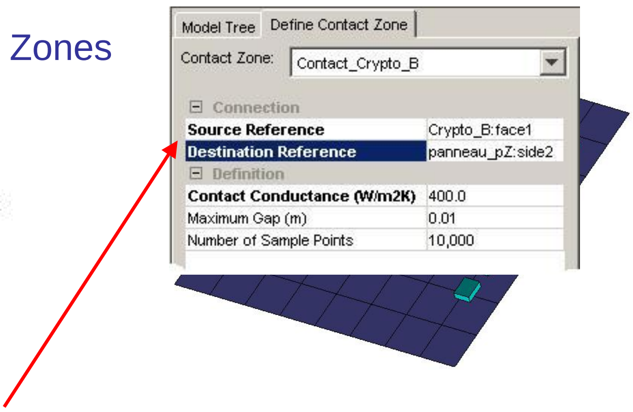


21

Face-to-Face Conduction Support

- Automatically generate conductances between surfaces in contact
  - New variable Contact Zones



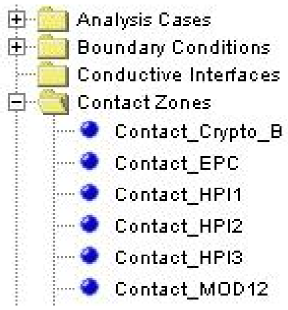


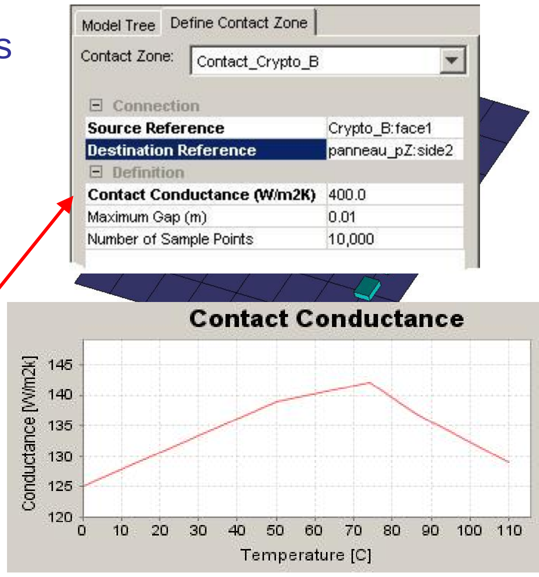
- Define surfaces in contact
  - Select a Shell side, Face or Group (of Faces or Shell Sides)
  - Congruent mesh not required

22

Face-to-Face Conduction Support

- Automatically generate conductances between surfaces in contact
  - New variable Contact Zones



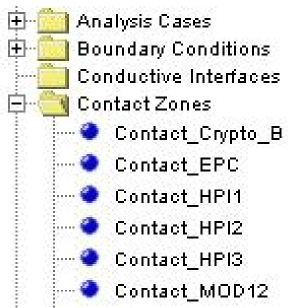


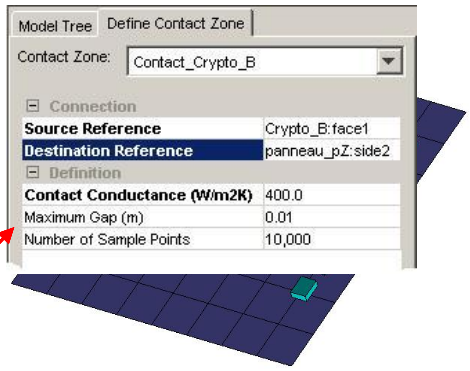
- Define contact conductance
  - Literal or a Property

23

Face-to-Face Conduction Support

- Automatically generate conductances between surfaces in contact
  - New variable Contact Zones





- Ray-trace to determine Faces in contact / associated area
  - Define sample points (*default 10,000*)
  - Define maximum gap (*default 0.01m*)

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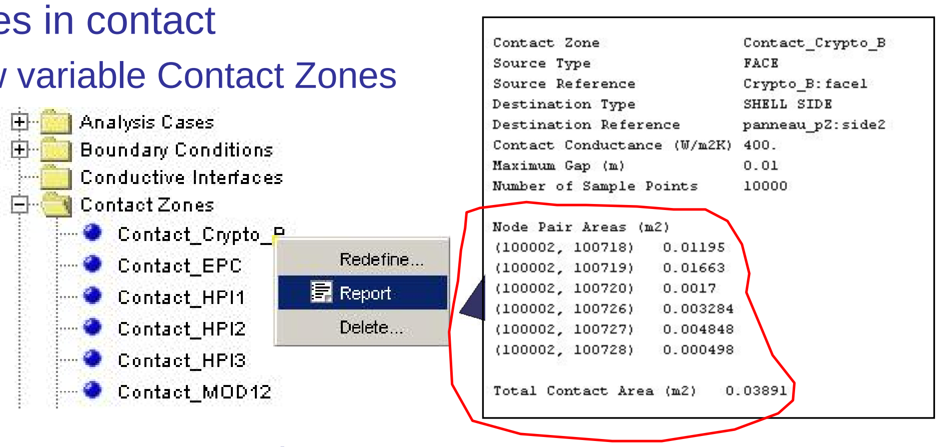
Face-to-Face Conduction Support

- Automatically generate conductances between surfaces in contact
  - New variable Contact Zones



- Report Contact Zone data
  - Node pairs & calculated contact area
  - Total contact area

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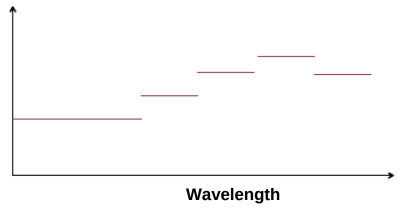
Wavelength Dependent Thermo-optical Properties

26

Wavelength Dependent Thermo-optical Properties

- For systems with significantly varying temperatures the “semi-grey body” idealisation no longer sufficient
- Support definition of wavelength dependent optical properties
  - Piece-wise Grey Body method
  - IR spectrum divided into bands
  - Steady state and transient analysis supported
  - Moving or non-moving geometry supported



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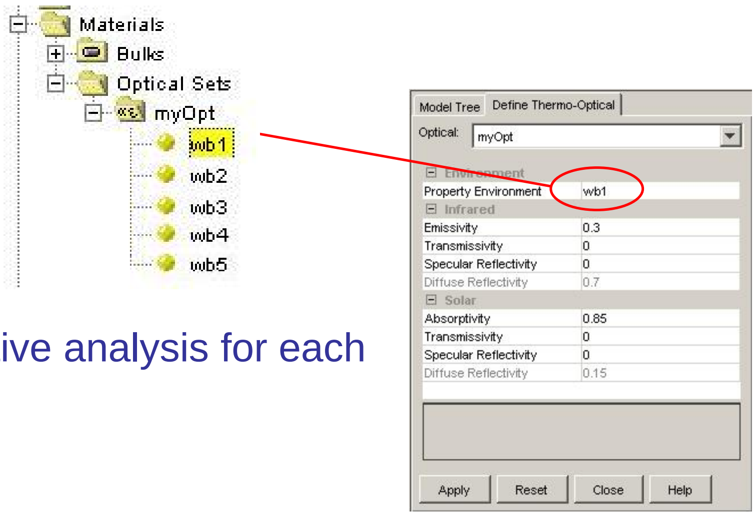
Wavelength Dependent Thermo-optical Properties

- Optical data defined using Property Environments



- Run radiative analysis for each waveband

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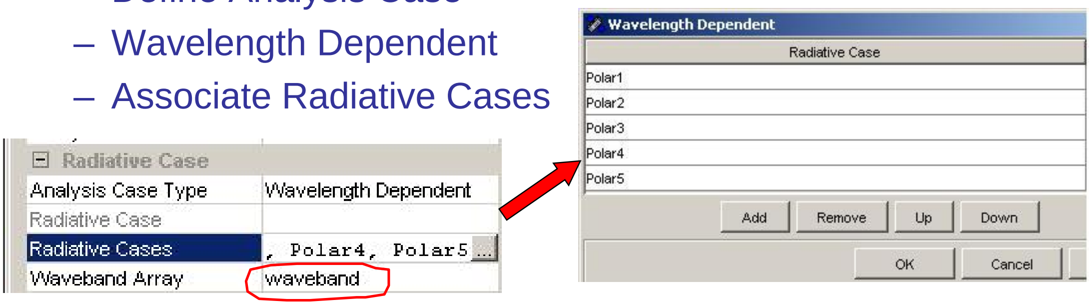
Wavelength Dependent Thermo-optical Properties

- Run thermal analysis
  - Define Analysis Case
  - Wavelength Dependent
  - Associate Radiative Cases



  - Define waveband array
  - Run analysis
- Post-process thermal results in Workbench

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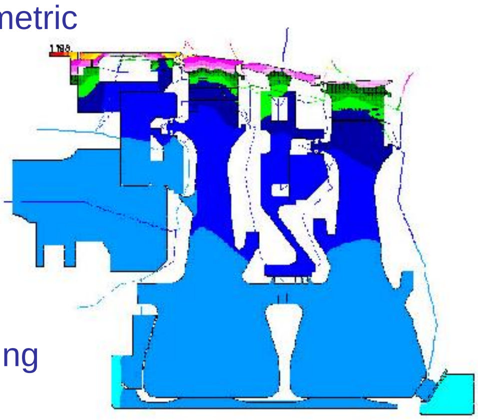
Axisymmetric Analysis

30

Axisymmetric Analysis

- Development to meet customer requirements
  - Workbench used to perform axisymmetric analysis
  - Model defined within the X-Y plane
    - Y – Axial direction
    - X – Radial direction
  - Planar shells used to represent the section geometry
  - Thermal model generated representing the 3D model



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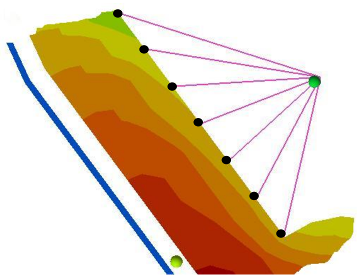
Axisymmetric Analysis

- Additional boundary conditions supported
  - Volumetric heat load
    - Shell side, Face or Group
  - Convection to an edge
    - Edge defined by a contiguous Group of Thermal Nodes



- First release of functionality
  - Further GUI support
  - Input on further requirements

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User-defined Feature Requests

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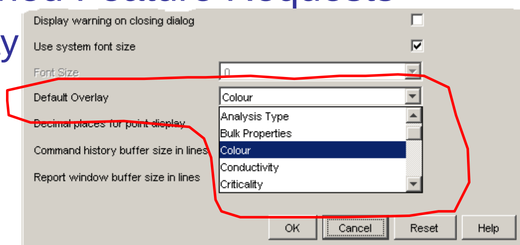
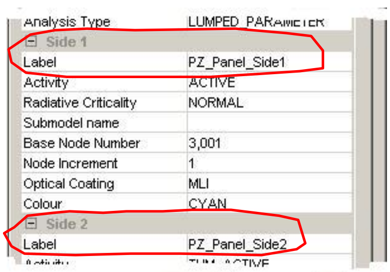
User-defined Feature Requests

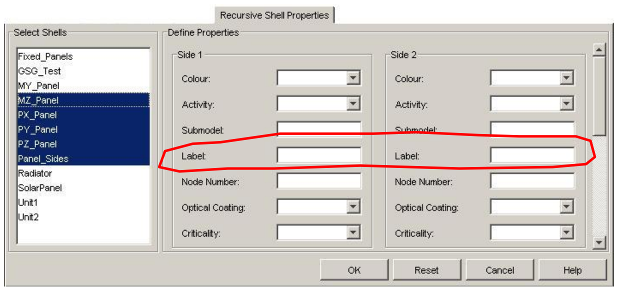
- Focus on addressing user-defined Feature Requests
  - Ability to set the default overlay
    - Model Preferences
    - Default changed to Colour



Label per Shell side



Recursive attribute editing on Label



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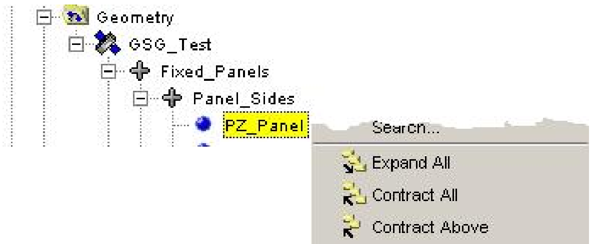
User-defined Feature Requests

- Focus on addressing user-defined Feature Requests
  - Clear button on Command History window
    - Clears specified area

  - Auto-section of results / time steps on pre- & post-process
  - Run directly parametric solution from Workbench
  - Default Analysis File name
  - Contract Above menu item



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Conclusion

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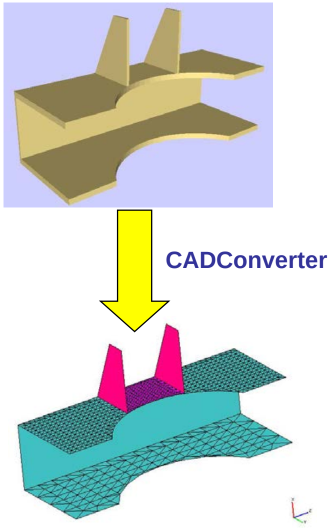
Conclusion



- ESATAN-TMS r3 extended CAD Import capability
- ESATAN-TMS r4 extends the interactive geometry modelling capability
- Process still requires a *clean* CAD geometry

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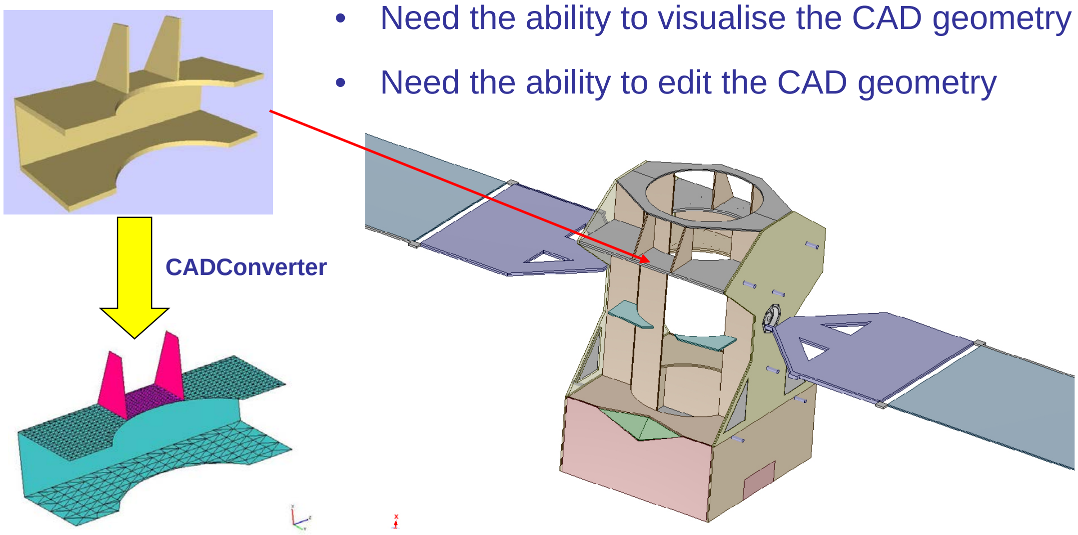
Conclusion

- Need the ability to visualise the CAD geometry
- Need the ability to edit the CAD geometry



Henri will talk more about this

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Appendix J

ESATAN Thermal Modelling Suite
A New User Interface for CAD Geometry

Henri Brouquet
(ITP Engines UK Ltd, United Kingdom)

Abstract

When generating thermal analysis models from CAD geometry it is common practice to simplify the geometry, removing unnecessary detail, such as holes and fillets and extracting mid-plane surfaces. ESATAN Thermal Modelling Suite now includes a dedicated component which provides the thermal engineer with an environment to view and modify the CAD geometry and generate the analysis model. A combined presentation and demonstration of the CAD interface shall be given.

25th European Thermal & ECLS Software Workshop
ESA/Estec, Noordwijk, the Netherlands

CADbench – A New User Interface for CAD Geometry

Author: Henri Brouquet
Date: 8th November 2011

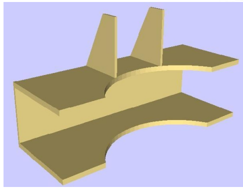
Introduction

- Our vision remains unchanged,
  - Provide a complete and efficient thermal modelling environment
    - Functionality to meet your current & future modelling requirements
    - Provide a high-quality and fully validated product
  - Efficient end-to-end integration within a multi-disciplinary engineering environment

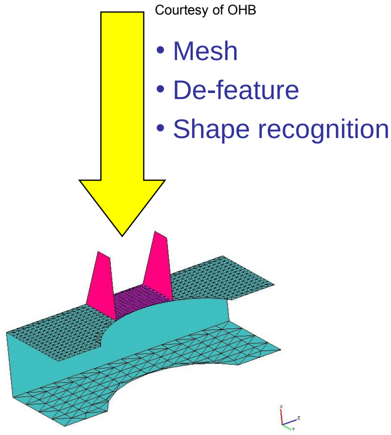
2

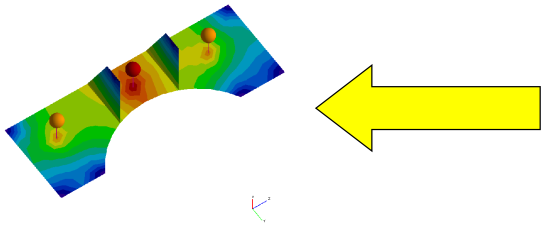
ESATAN-TMS r3 - Import of CAD Geometry

- Improved CAD import process
  - Import geometry
    - Mesh refinement
    - Remove features
    - Shape recognition
  - New CADconverter interface
    - Visualise CAD hierarchy
    - Select/Extract sub-hierarchy
    - Direct include of geometry



Courtesy of OHB





3

CADConverter – User Feedback

- Easy to use
- Simplify the CAD geometry (de-featuring options)
- Reduce the model time creation

- File format limited support
- “Blind” process
- Dependent on CAD geometry quality

Need to **visualise** and **edit** the CAD geometry

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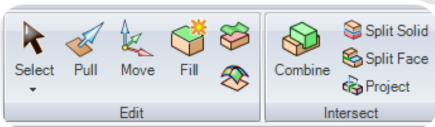
CADbench – New User Interface for CAD Geometry

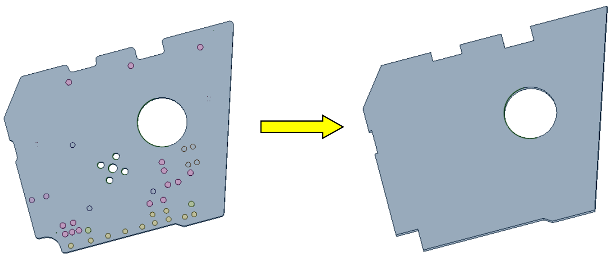
- New environment to visualise and modify CAD geometry
- Repair & Prepare CAD geometry for analysis process
- Direct export to ESATAN-TMS

5

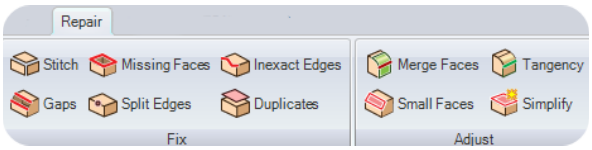
CADbench – New User Interface for CAD Geometry

- Clean Geometry
  - Edit geometry
  - Remove holes
  - Combine component





- Repair Geometry
  - Remove small faces
  - Remove duplicates
  - Stitch geometry



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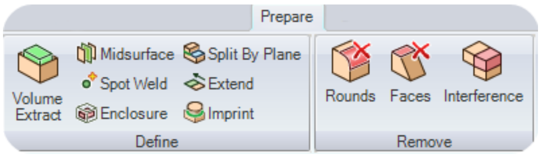
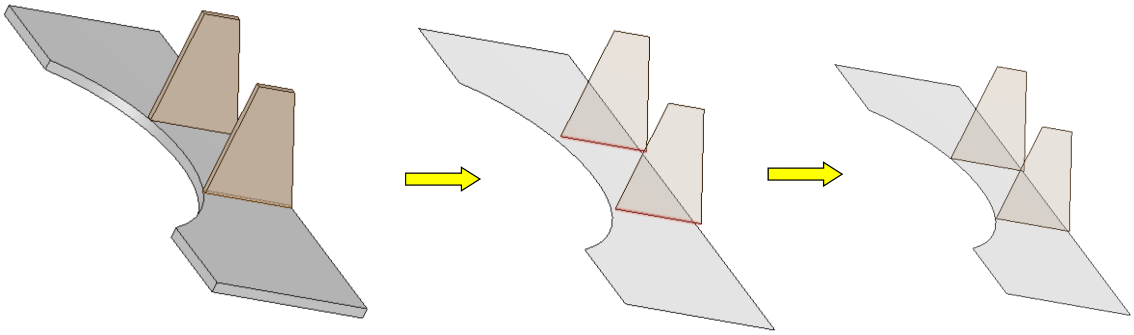
CADbench – New User Interface for CAD Geometry

- Prepare for thermal analysis
  - Midsurface identification
  - Extend capability
  - Remove fillets





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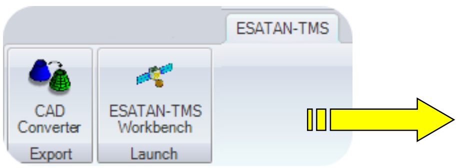
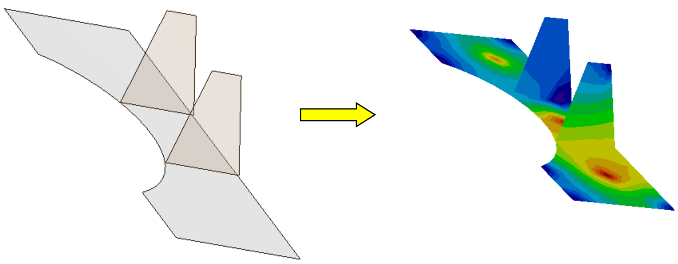
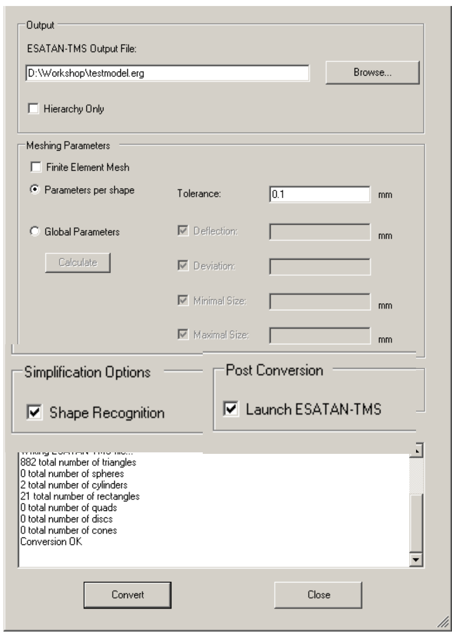
CADbench – Export to Workbench

- Direct Export to Workbench
  - CADconverter menu
  - ESATAN-TMS launch option







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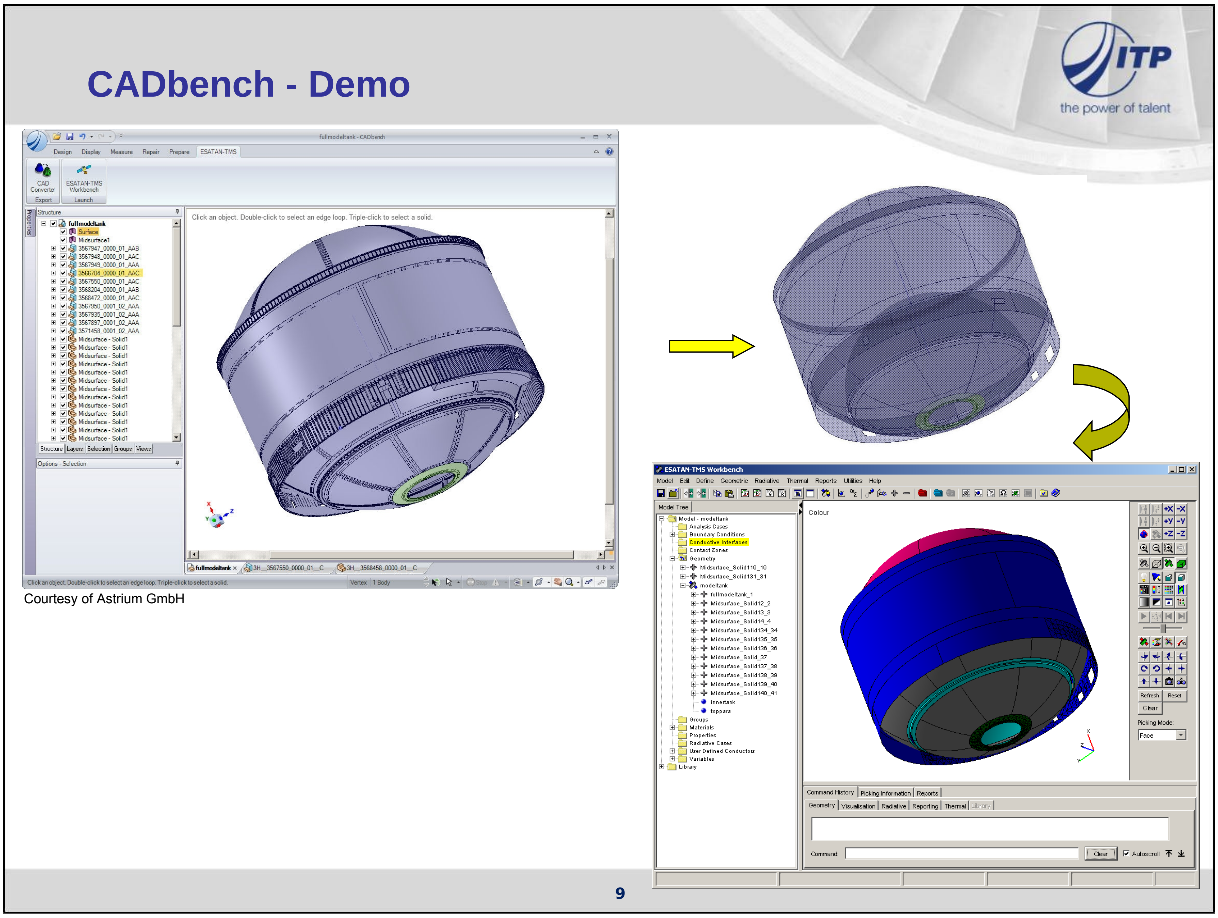

CADbench - Demo
the power of talent
Courtesy of Astrium GmbH
9

Appendix K

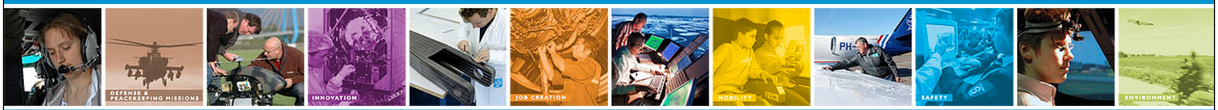
Prototype demonstration of Thermal Design Module for automated design and temperature calculation of space harness

Fennanda Doctor Roel van Benthem
(National Aerospace Laboratory, The Netherlands)

Abstract

Design of space harness is based on ECSS-Q-30-11C assuming a thermal balance between heat losses and heat radiation cooling in a worst case environment in spacecraft. A JAVA thermal analyser (Thermal Design Module) was developed and validated for wire temperature prediction for aircraft applications that is extended towards an automatic generation of bundles designs for space. A demonstration of a prototype TDM2.0.1 shows user inputs and output graphs for space harness designs. The TDM supports optimization of harness designs with respect to weight reduction and improved safety.

NLR *Dedicated to innovation in aerospace*



Prototype Thermal Design Module for automated designs of space harness

European Workshop on Thermal & ECLS Software
ESTEC 7-8 November 2011

F. Doctor, fennanda.doctor@nlr.nl, +31 88 511 4260
R. C. van Benthem, roel.van Benthem, +31 88 511 4231

Thermal Control Section , NLR Space Department, The Netherlands

Nationaal Lucht- en Ruimtevaartlaboratorium – National Aerospace Laboratory NLR

Contents

- Electrical wiring design practice in aerospace applications
- Why thermal analysis of wiring bundle designs?
- Prototype Thermal Design Model (TDM) demonstration
- Outlook for space applications

NLR - Dedicated to innovation in aerospace Prototype Thermal Design Module for space harness optimization 2

Why thermal analysis?

- **Typical harness weight in**
  - aircraft (150 seats) > 1500 Kg
  - satellites (Artimes) > 50 Kg (ca 40Kg power + 10Kg data-cable)*
- **Typical cost of wiring**
  - Life cycle cost (per aircraft) >10.000 Euro/kg
  - Launch cost 12.000-32.000 Euro/Kg (LEO/GEO)

=> *For instance a 5% weight reduction of a satellite harness gives a launch cost reduction between 30.000 Euro (LEO) and 80.000 Euro (GEO).*

- In 2007 NLR started research for the aircraft industry (Fokker Elmo) to investigate weight reductions and improved safety (structural integrity) of wiring designs by thermal analysis.

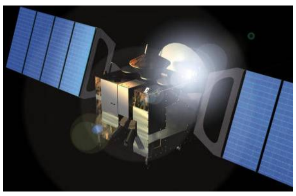
=> *On average a 5% temperature elevation increase should save about 5% weight*

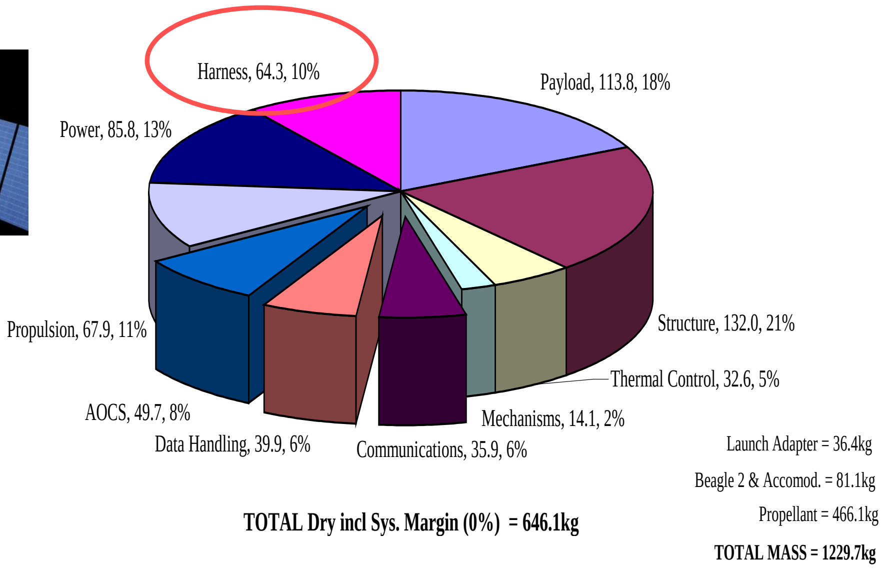
- **Extension towards space applications?**

* **Workshop on Spacecraft Data Systems, 5-7 May 2003, ESTEC, Noordwijk,** rodger.magness@esa.int

NLR - Dedicated to innovation in aerospace **Prototype Thermal Design Module for space harness optimization** 3

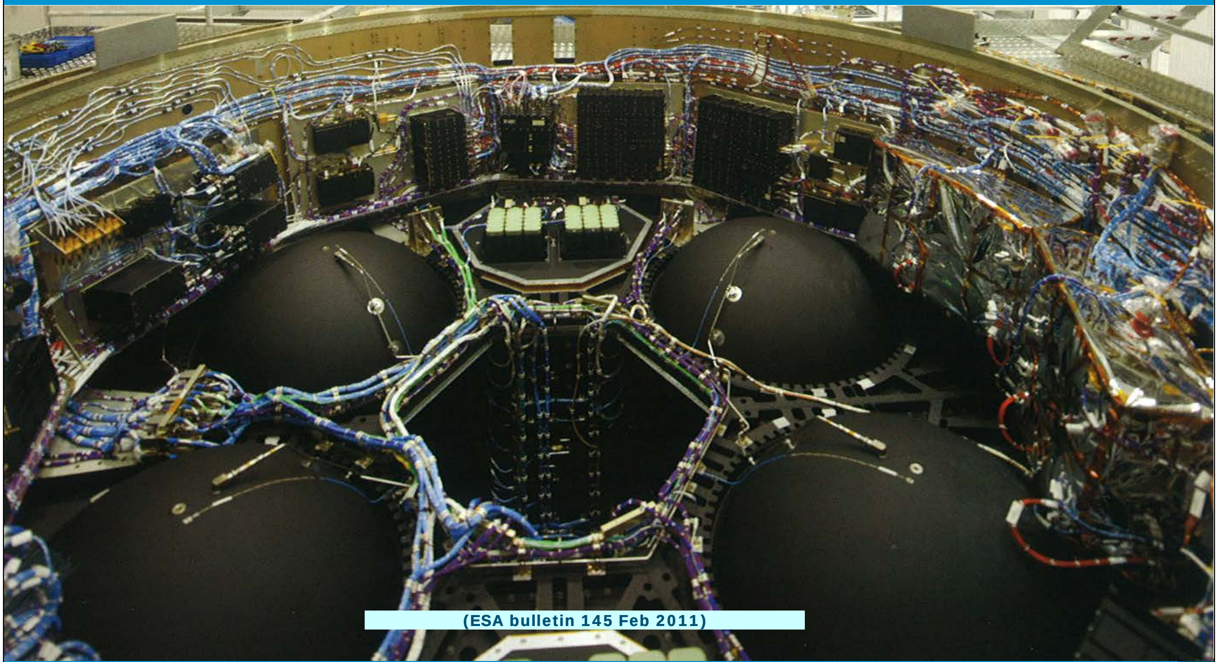
Harness weight in space systems





NLR - Dedicated to innovation in aerospace **Prototype Thermal Design Module for space harness optimization** 4

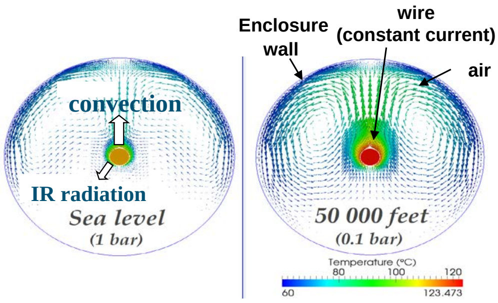
Wiring of ATV *Johannes Kepler's* Cargo Carrier



NLR - Dedicated to innovation in aerospace Prototype Thermal Design Module for space harness optimization 5

Harness design requirements

- Wires sizing in the aeronautical standards is based on a thermal equilibrium between heat loss (I^2R) and natural cooling of a wire segment.
- Cooling is provided by air convection & conduction, heat radiation and axial conduction.



(*Oofelie: Multiphysics, Open Engineering*)

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Current derating in ECSS-Q-30-11C

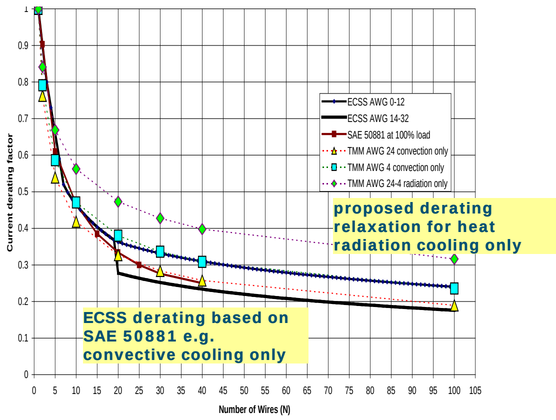
Parameters	Load ratio or limit														
Voltage	50 %														
Wire size (AWG)	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4
Maximum current Cu (I) (A) [a]	1,2	1,3	1,5	2,5	3,5	5	7,5	10	13	17	25	32	45	60	81
Maximum current Al (I) (A) [a]						4	6	8	10,4	13,6	18,4	25,6	36		
Wire surface temperature	Manufacturer's maximum rating Tmax-50°C.														

[a] The derating on current for bundles with N wires is calculated as follows IBW = ISW × K for ambient temperature of 40°C.

Wires AWG 14 to AWG 32		Wires AWG 0 to AWG 12	
Number of wires (N)	K	Number of wires (N)	K
$1 < N \leq 3$	$1{,}1 - (0{,}1 \times N)$	$1 < N \leq 3$	$1{,}1 - (0{,}1 \times N)$
$3 < N \leq 7$	$1{,}01 - (0{,}07 \times N)$	$3 < N \leq 7$	$1{,}01 - (0{,}07 \times N)$
$7 < N \leq 19$	$0{,}81 - [0{,}15 \times \ln(N)]$	$7 < N \leq 52$	$0{,}81 - [0{,}15 \times \ln(N)]$
$19 < N \leq 331$	$0{,}59 - [0{,}076 \times \ln(N)]$	$52 < N \leq 331$	$0{,}467 - [0{,}0632 \times \ln(N)]$

I_{BW}: maximum current for an individual wire in a bundle.
I_{SW}: maximum current for a single wire as given in the derating table above.
ln: Natural log.

In case of wires in cold redundancy or wires non used in the same bundle (one with current, the other without current) the number of wires to take into account is calculated as follows : N equivalent bundle = N wire with current + 0,5 x N wire without current with IBW which shall not overpass ISW.



NLR - Dedicated to innovation in aerospace **Prototype Thermal Design Module for space harness optimization** 7

Development of Thermal Design Module

- ***Development of Thermal Design Module for thermal analysis of wiring in aircraft to investigate potential weight saving and safety risks:***
  - *TDM1.0 validated in 2009 for 15-16 mm bundles in a 200mm cylindrical enclosure (Fokker Elmo)*
  - *TDM2.0 validated in 2011 for 5-35 mm bundles in 4" aircraft enclosures (Fokker Elmo)*
- ***Investigation of extension towards space applications by switching 'off' convective and conductive heat transfer.***

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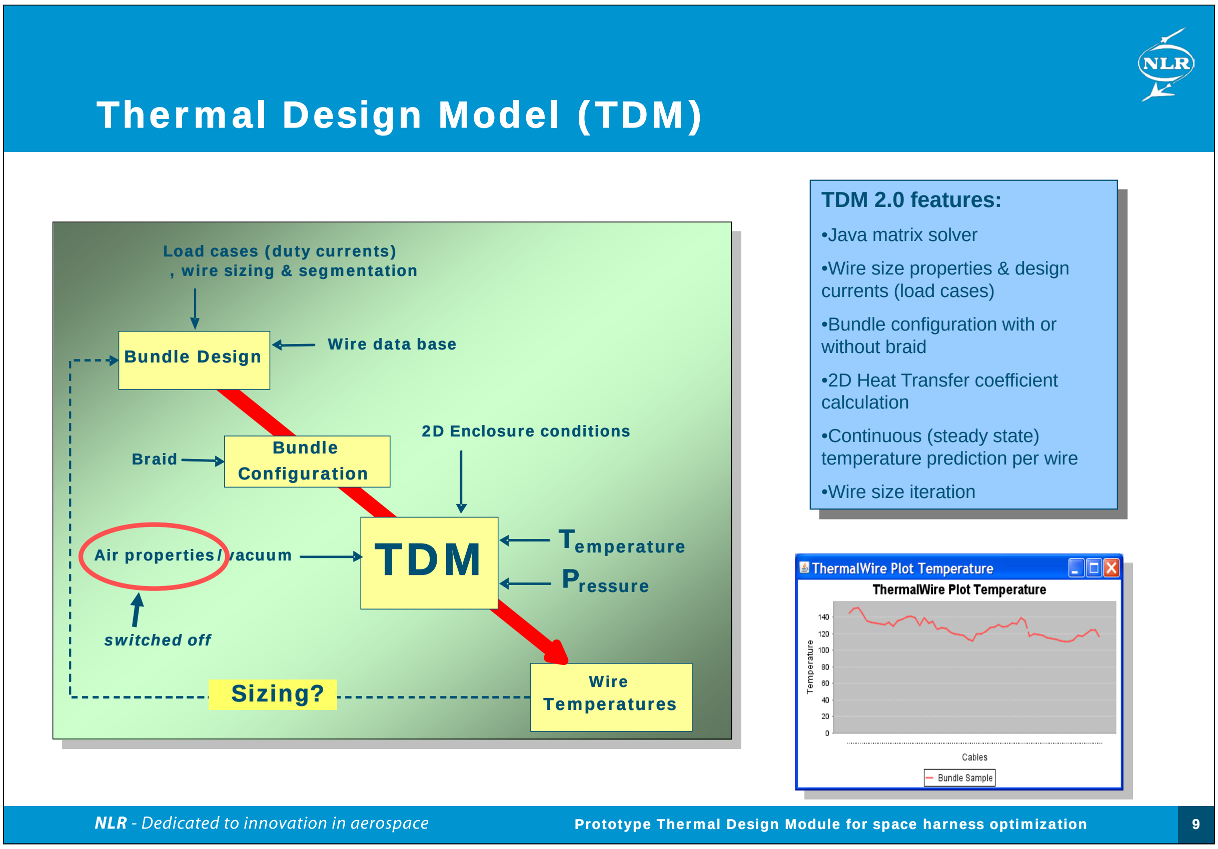
Thermal Design Model (TDM)
NLR
Load cases (duty currents) , wire sizing & segmentation
Bundle Design
Wire data base
Braid
Bundle Configuration
2D Enclosure conditions
TDM
Air properties/vacuum
switched off
Temperature
Pressure
Sizing?
Wire Temperatures
TDM 2.0 features:
•Java matrix solver
•Wire size properties & design currents (load cases)
•Bundle configuration with or without braid
•2D Heat Transfer coefficient calculation
•Continuous (steady state) temperature prediction per wire
•Wire size iteration
ThermalWire Plot Temperature
Temperature
Cables
Bundle Sample
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Prototype Thermal Design Module for space harness optimization
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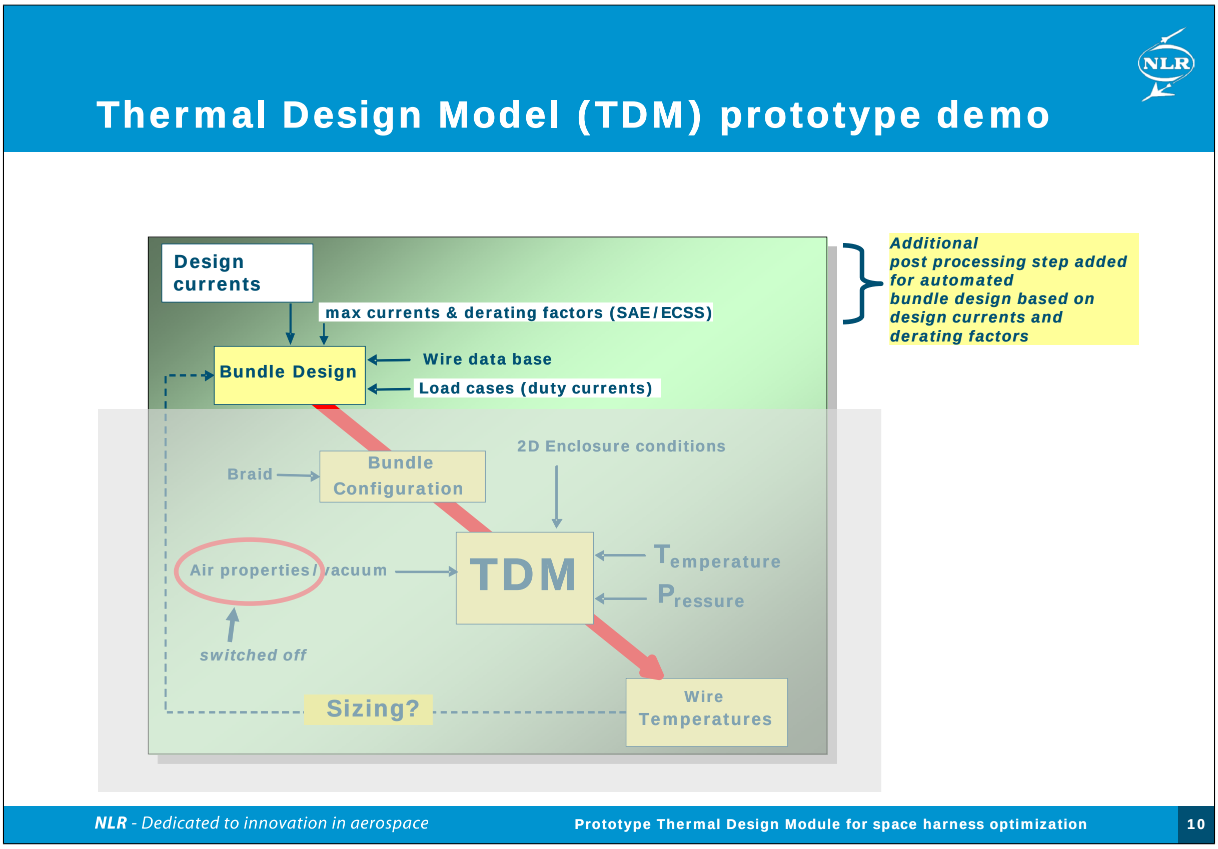
Thermal Design Model (TDM) prototype demo
NLR
Design currents
max currents & derating factors (SAE/ECSS)
Bundle Design
Wire data base
Load cases (duty currents)
Additional post processing step added for automated bundle design based on design currents and derating factors
2D Enclosure conditions
Braid
Bundle Configuration
TDM
Air properties/vacuum
switched off
Temperature
Pressure
Sizing?
Wire Temperatures
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10

Thermal Design Module demonstration (0)

Example design...

Gauge	Number of cables	ECSS max current [Amp]	ECSS Derating	Design current [Amp]
4	2	81	0.24	19.4
12	4	25		6.0
16	6	13	0.48	6.2
18	14	10		4.8
20	18	7.5		3.6
Total	44			

Design Current = Maximum current x derating

Calculation Current = Design Current x Load-factor

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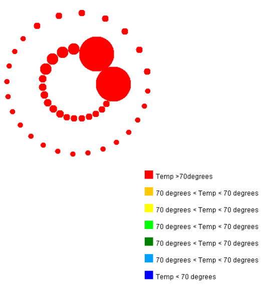
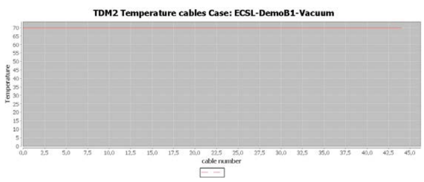
Thermal Design Module demonstration (1)

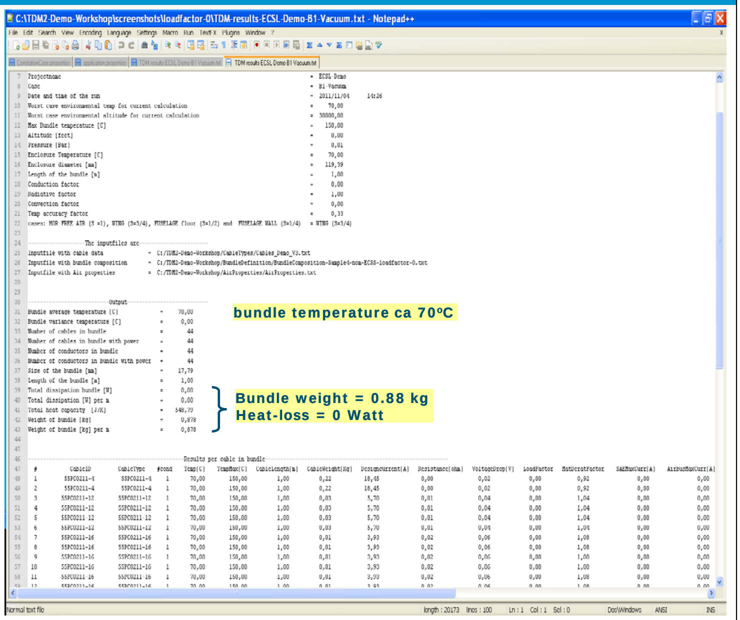
Example design with all load-factors = 0

(no load)

T_{env}=70°C, P=0 BAR, L=1 m







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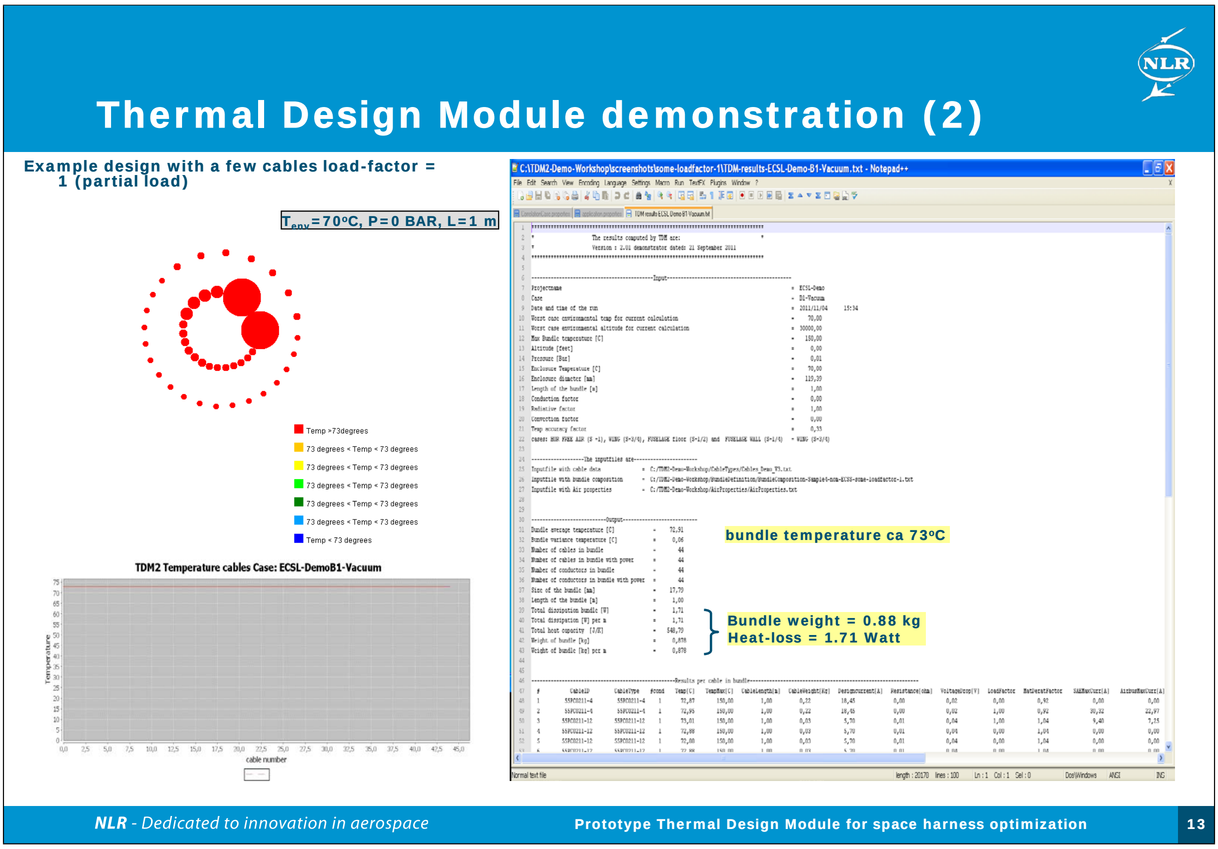
Thermal Design Module demonstration (2)
Example design with a few cables load-factor = 1 (partial load)
Tenv=70ºC, P=0 BAR, L=1 m
Temp >73degrees
73 degrees < Temp < 73 degrees
Temp < 73 degrees
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
cable number
bundle temperature ca 73ºC
Bundle weight = 0.88 kg
Heat-loss = 1.71 Watt
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Prototype Thermal Design Module for space harness optimization
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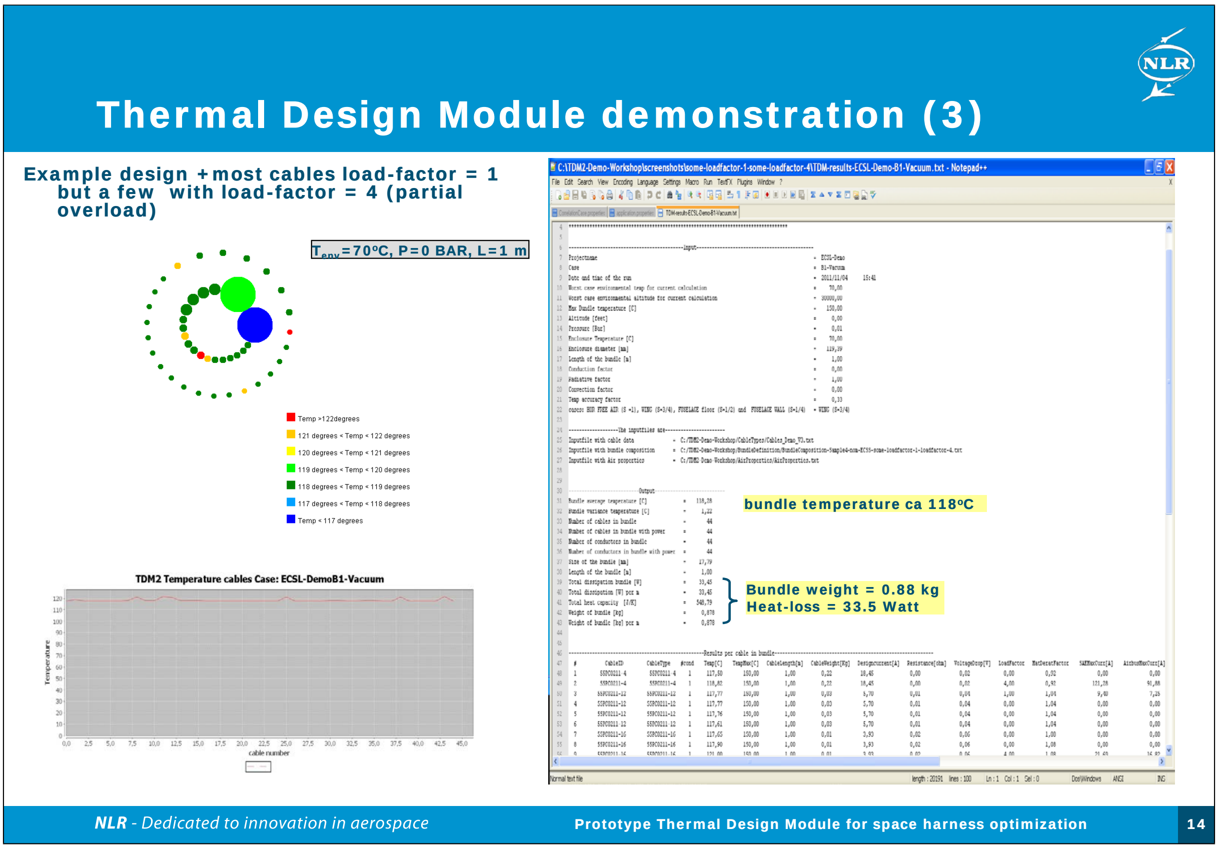
Thermal Design Module demonstration (3)
Example design +most cables load-factor = 1 but a few with load-factor = 4 (partial overload)
Tenv=70ºC, P=0 BAR, L=1 m
Temp >122degrees
121 degrees < Temp < 122 degrees
120 degrees < Temp < 121 degrees
119 degrees < Temp < 120 degrees
118 degrees < Temp < 119 degrees
117 degrees < Temp < 118 degrees
Temp < 117 degrees
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
cable number
bundle temperature ca 118ºC
Bundle weight = 0.88 kg
Heat-loss = 33.5 Watt
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Prototype Thermal Design Module for space harness optimization
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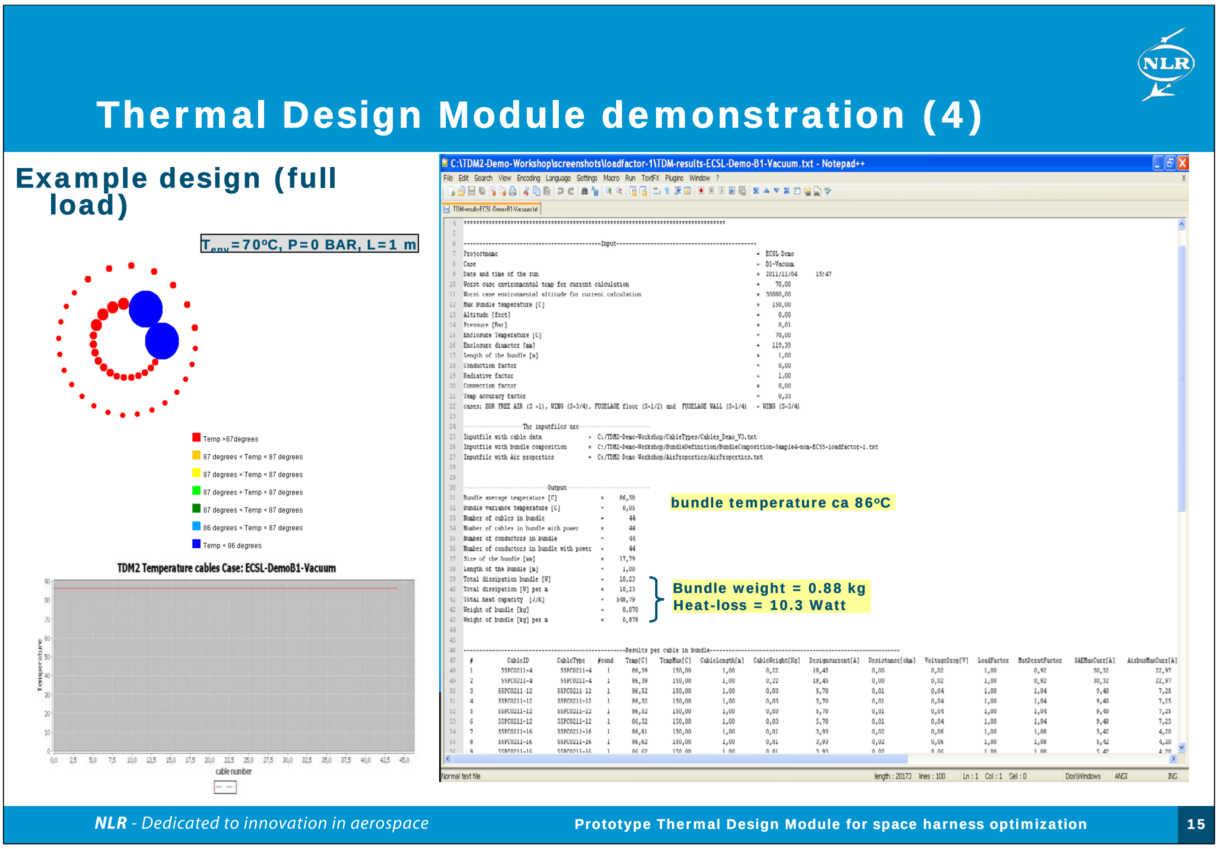
Thermal Design Module demonstration (4)
Example design (full load)
T_env=70°C, P=0 BAR, L=1 m
bundle temperature ca 86°C
Bundle weight = 0.88 kg
Heat-loss = 10.3 Watt
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
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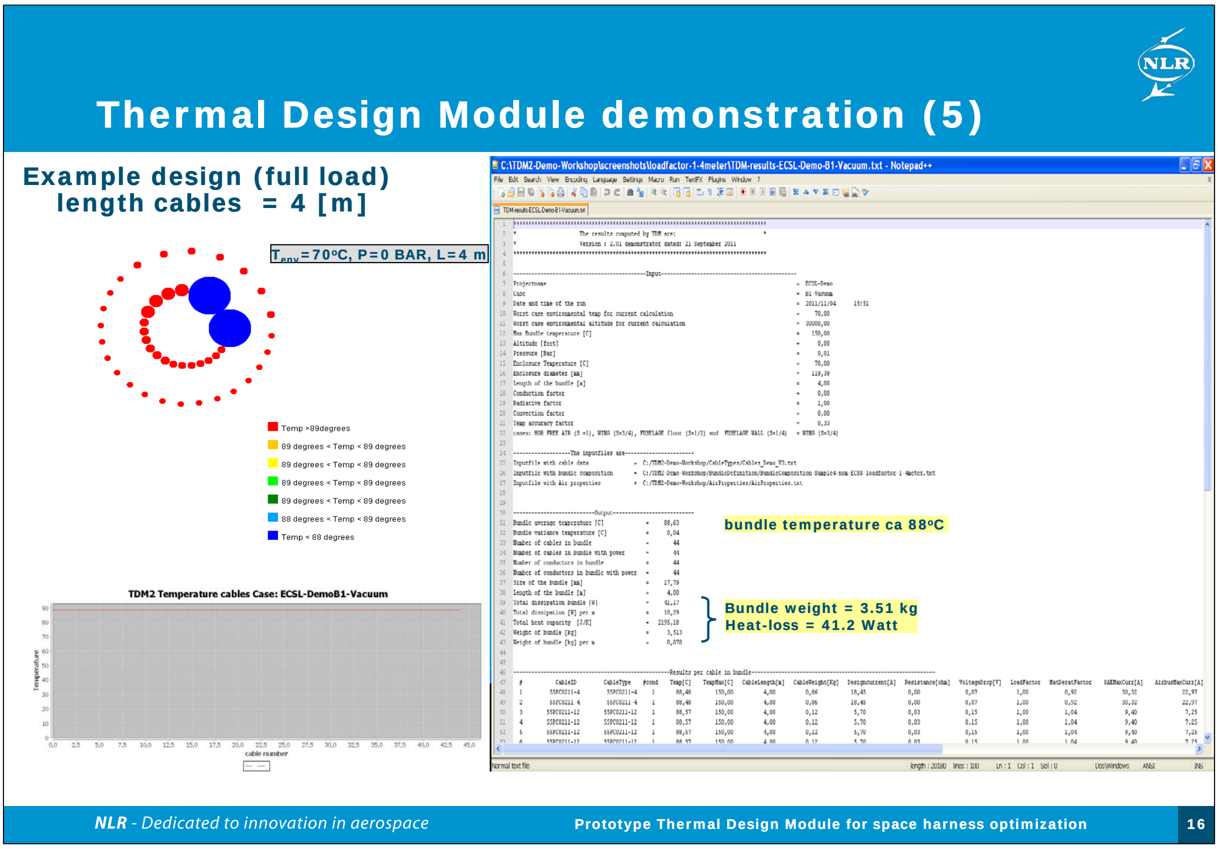
Prototype Thermal Design Module for space harness optimization
15


Thermal Design Module demonstration (5)
Example design (full load)
length cables = 4 [m]
T_env=70°C, P=0 BAR, L=4 m
bundle temperature ca 88°C
Bundle weight = 3.51 kg
Heat-loss = 41.2 Watt
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
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Prototype Thermal Design Module for space harness optimization
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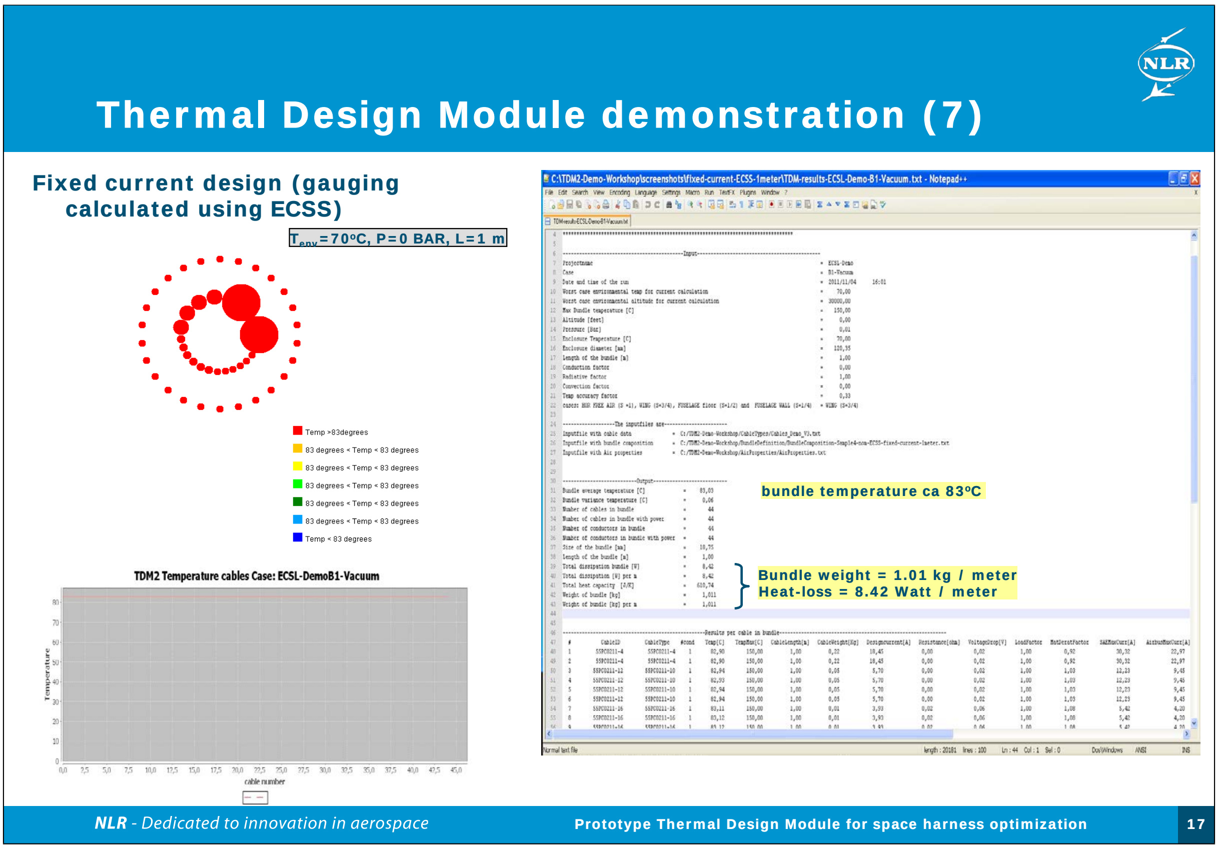
Thermal Design Module demonstration (7)
NLR
Fixed current design (gauging calculated using ECSS)
T_{env}=70°C, P=0 BAR, L=1 m
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
bundle temperature ca 83°C
Bundle weight = 1.01 kg / meter
Heat-loss = 8.42 Watt / meter
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Prototype Thermal Design Module for space harness optimization
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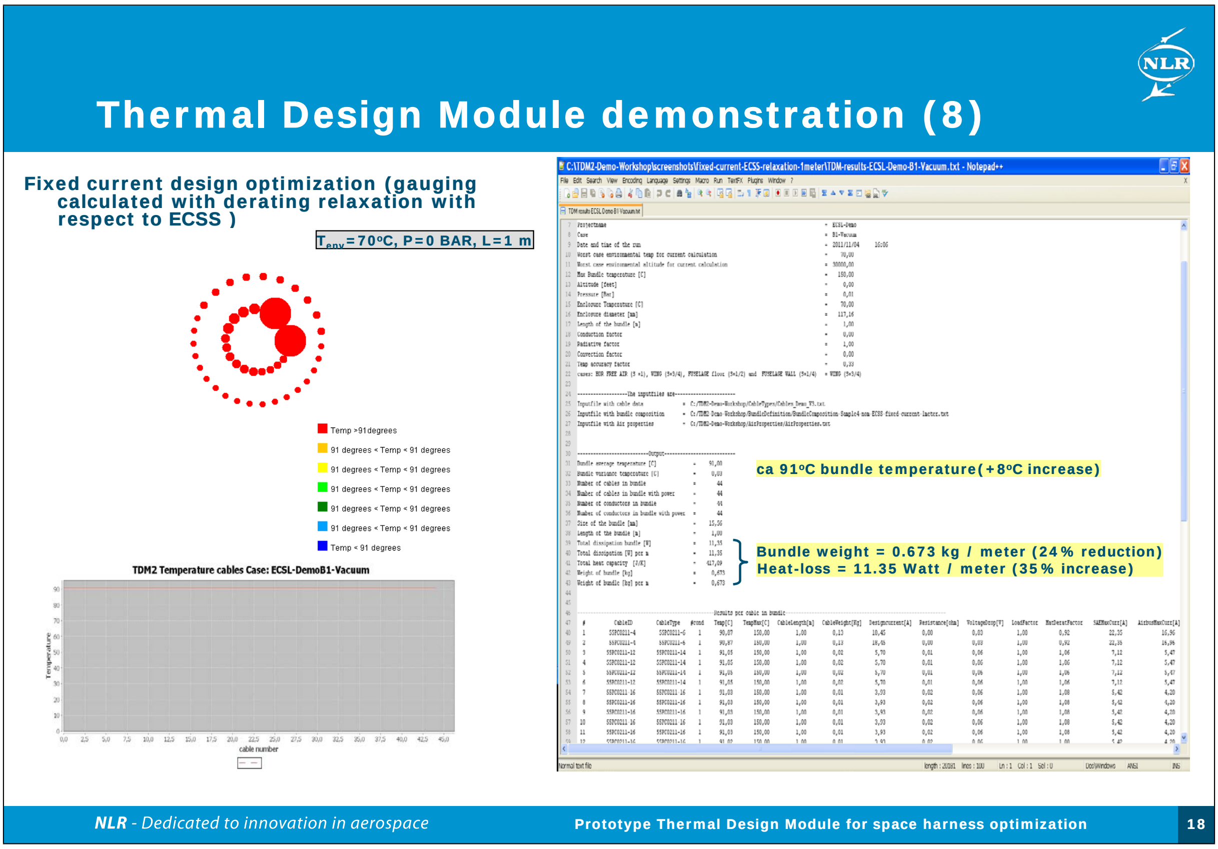
Thermal Design Module demonstration (8)
NLR
Fixed current design optimization (gauging calculated with derating relaxation with respect to ECSS)
T_{env}=70°C, P=0 BAR, L=1 m
TDM2 Temperature cables Case: ECSL-DemoB1-Vacuum
ca 91°C bundle temperature(+8°C increase)
Bundle weight = 0.673 kg / meter (24% reduction)
Heat-loss = 11.35 Watt / meter (35% increase)
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Prototype Thermal Design Module for space harness optimization
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Prototype Thermal Design Module

- **Outlook for space applications:**
  - Space harness weight reduction by derating relaxation e.g. allow a higher wire temperature with respect to ECSS (see also *ESA ITT 6839 , 22/07/2011, Evaluation and qualification of high temperature cable)*
  - Validation tests for vacuum or low pressures conditions (CO_2, Mars)
  - Space harness design optimization tool for CDF
  - Investigation of S/C structural integrity
  - Axial heat conduction prediction (heat leak minimization)

⇒ **Space harness examples needed to investigate potential of the TDM**

⇒ **Questions??**

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Acknowledgements

- **The research on the thermal analysis of aircraft wiring was sponsored by the Dutch Aeronautical Institute, Fokker Elmo and the National Aerospace Laboratory**
- **NLR was responsible for the development of the Thermal Design Module and the validation testing**

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Appendix L

SYSTEMA-4.5.0

Maxime Jolliet
(EADS Astrium, France)

Abstract

Model & meshing scripted access

SYSTEMA 4.5.0 allows the automation of all the model & meshing commands, such as geometry creation and modification, thermal properties, all the meshes parameters, through a Python script. This powerful feature is very useful to automatically modify the geometry (for symmetries or homotheties, for instance), to create reduced model, or to ease model creation by using variables, loops or logical instructions. It also facilitates all interfaces with external model format.
SYSTEMA is shipped with a library of scripted functions to help the user to easily reach the full potential of this new functionality. Basic modules are provided, such as model tree scan; examples are also given and will be demonstrated: surface activity automated change, creation of a parameterized honeycomb structure, meshing reduction...

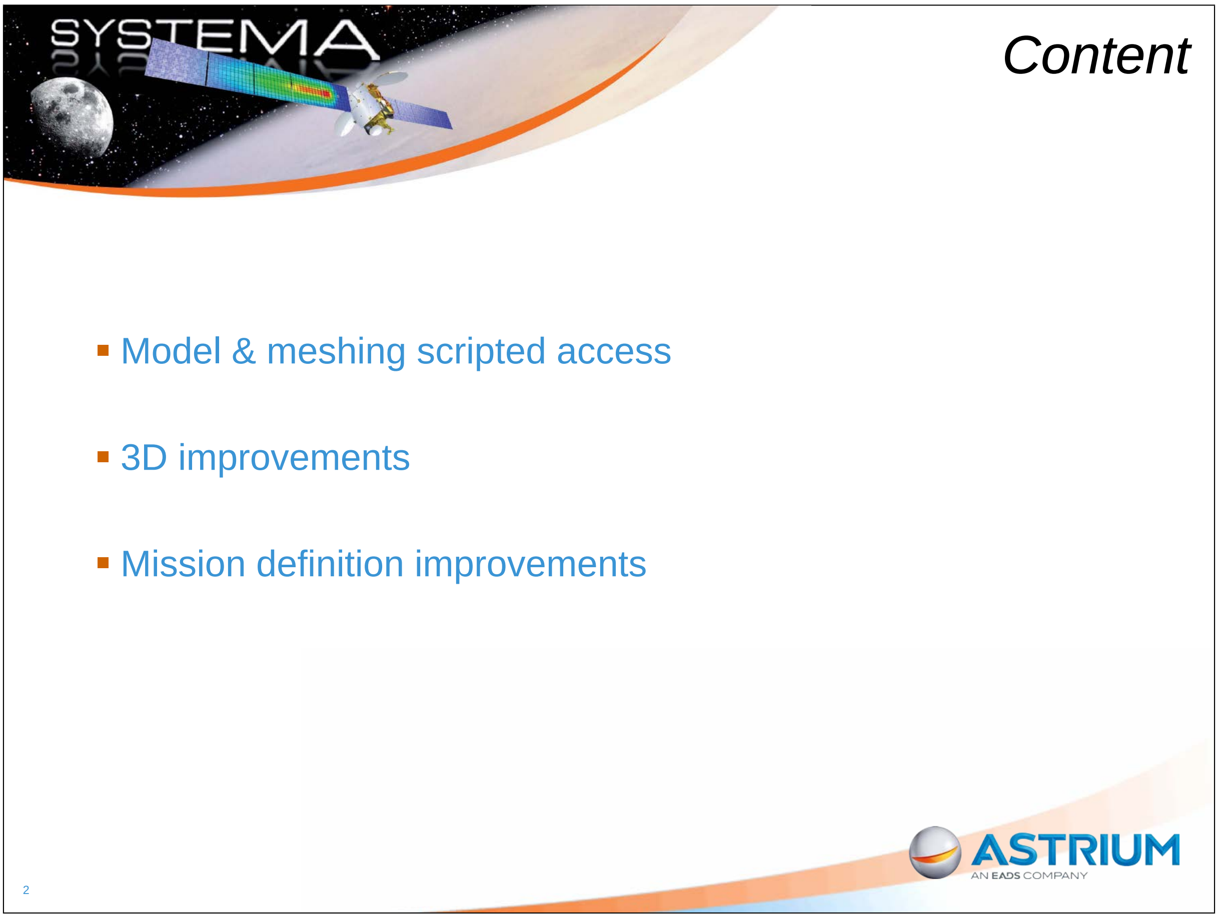
3D improvements

The SYSTEMA 3D engine is both more realistic and more precise: it proposes now a real size solar system. It also provides new tools to help the understanding of the 3D scene and to visualize the different orientations of the satellite shapes. Moreover, the quality of the rendering has been upgraded, improving dramatically the videos generated by SYSTEMA.

Mission definition improvements

One of our ongoing development goals is to ease the creation of a mission. The mission module has been revamped around a new timeline widget that presents to the user all time data in a very intuitive way. With this tool, it will be very easy to synchronize trajectories, kinematics phases, mission events...


SYSTEMA v4.5.0
25th European Workshop on Thermal and ECLS Software
Maxime Jolliet – EADS Astrium, France
SYSTEMA


SYSTEMA
Content
Model & meshing scripted access
3D improvements
Mission definition improvements
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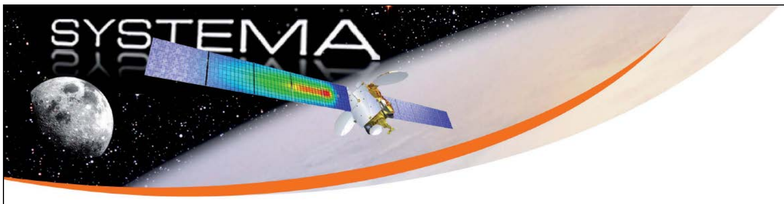

Content

SYSTEMA – 4.5.0

Model & meshing scripted access

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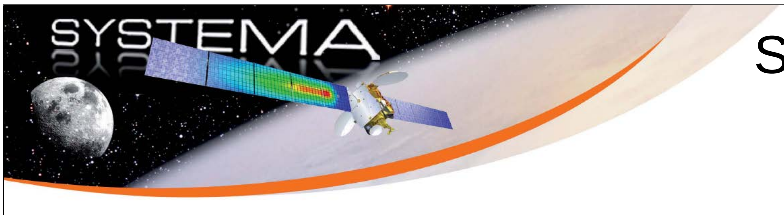

SYSTEMA – 4.5.0

Scripting

Objectives

To allow the user to manipulate the model / meshing outside the Systema interface:

- External tools interface
- Meshing reduction…

To allow the user to define a set of reusable functions, automating complex tasks:

- Repetitive structures
- Model parametrization
- Symmetries & homotheties
- Activity change…

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SYSTEMA – 4.5.0
Scripting

What is the scripting?

- Possibility to execute Python scripts inside a Systema execution
- Python API to control Systema
- Programmatic access to all of Systema model & meshing data and features

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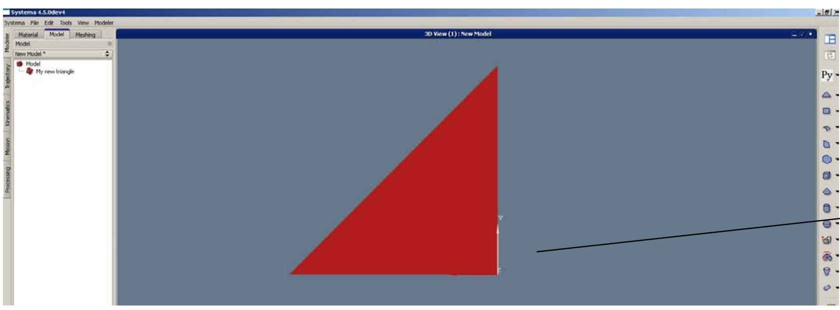
SYSTEMA – 4.5.0
Scripting

Your first Systema script

```
model = ModelFile()
geometry = createGeometry("triangle",[Point(0,0,0),Point(1,0,0),Point(0,1,0)],[])
shape = ModelShape("My new triangle", geometry)
shape.insertInto(model.getRoot())
```



Select and execute your script using the « Py » button

The result appears immediately !

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SYSTEMA – 4.5.0

Scripting

How does it work?

The Systema Python interface provides intuitive objects and methods

- Same services as the Systema graphical interface:
  - Systema’s file management
  - Object and shape management
  - Access to geometrical data
  - Thermal properties
  - Meshing & numbering parameters
- And more!
  - Variables, loops, logical instructions
  - File reading/writing, network, other Python modules

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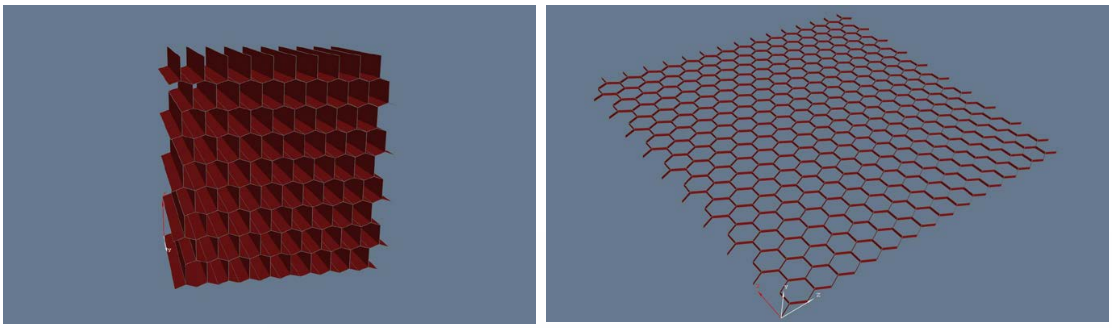
SYSTEMA – 4.5.0

Scripting

What can I do with it?

- Repetitive structures
- Parametrization



Two exemples of the function *honeycomb(nx,nz,height,width,depth)*

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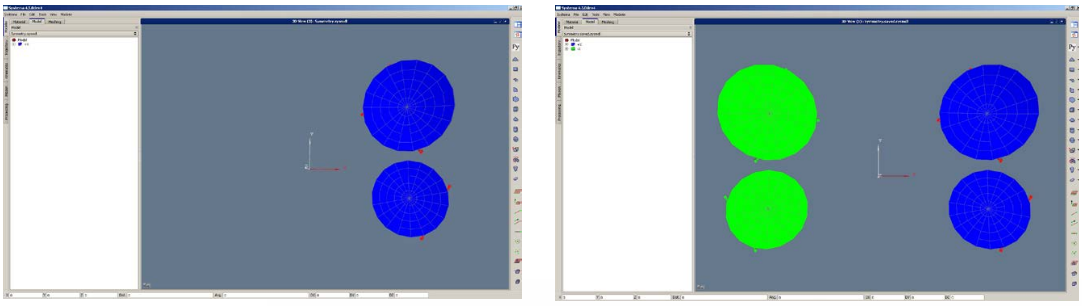
SYSTEMA – 4.5.0
Scripting

What can I do with it?

- Symmetries



Application of a symmetry function on antennas: *symmetry(origin, destination, a, b, c, d)*

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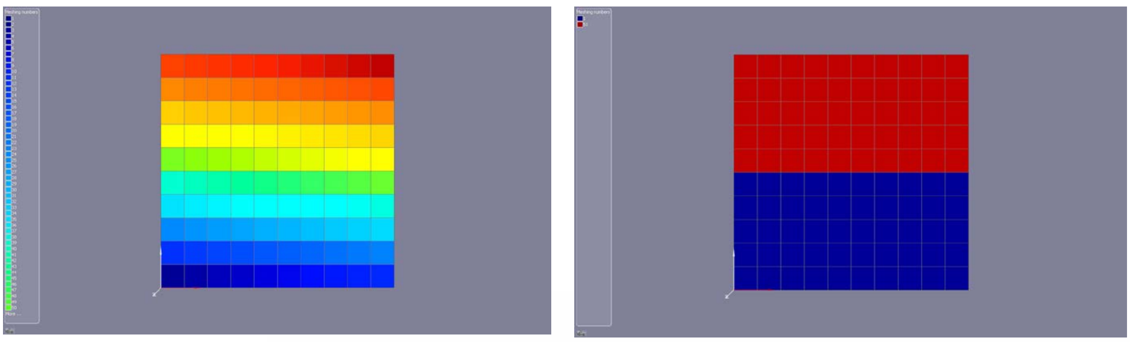
SYSTEMA – 4.5.0
Scripting

What can I do with it?

- Meshing reduction



Example of a rectangle, meshed 10 by 10. The script read a file that indicates the correspondence between old and new meshes number. Here, the meshing is condensated in 2 nodes.

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SYSTEMA – 4.5.0
Scripting

- Delivered with high-level libraries (tree scan, search, …)
- An open-source platform will be set up, dedicated to the enrichment of these libraries, and to the promotion of the tool
- Complete examples and tutorials
- Complete documentation
- Will be implemented in the other Systema modules

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SYSTEMA

SYSTEMA – 4.5.0
Scripting

The scripting

- Python interface to control Systema
- A set of reusable functions to automate complex tasks
- Existing libraries are provided, as well as documentation and support

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SYSTEMA

Content

SYSTEMA – 4.5.0

3D improvements

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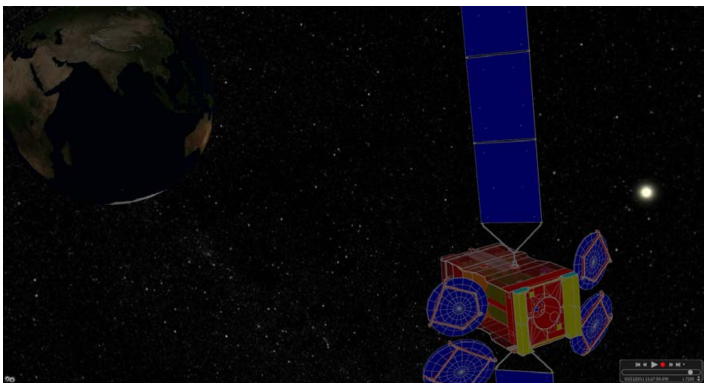
SYSTEMA

SYSTEMA – 4.5.0

3D improvements

General 3D improvements

- Rendering of the sun
- Real size solar system
- Better precision
- High-definition textures of the earth



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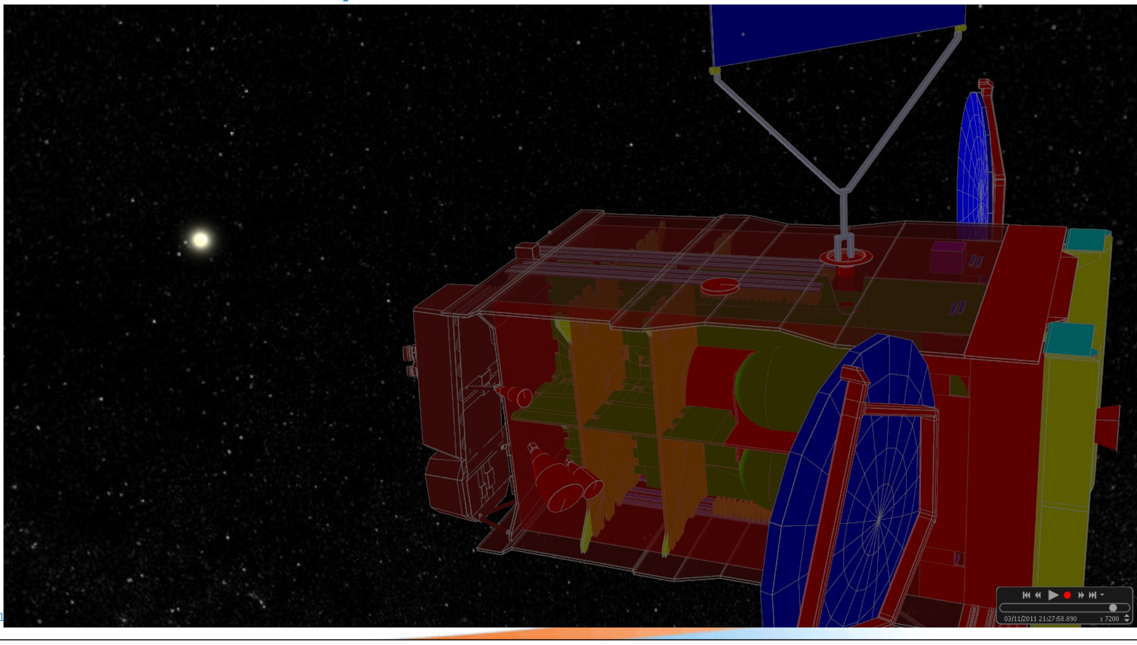
SYSTEMA – 4.5.0

3D improvements

General 3D improvements



SYSTEMA – 4.5.0

3D improvements

Ergonomics

Objectives:

- Help the user to understand the orientation of the shapes
- Help the user to understand the orientation of the satellite in the solar system

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SYSTEMA – 4.5.0

3D improvements

Ergonomics

A new functionality: “orientation frames”

- To easily see interesting frames and directions
- To add and compose these frames

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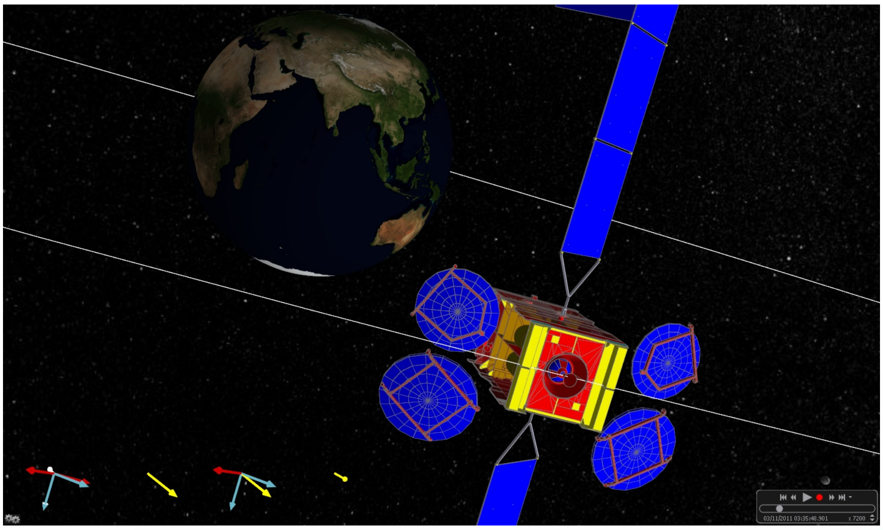
SYSTEMA – 4.5.0

3D improvements

Ergonomics



See attached video

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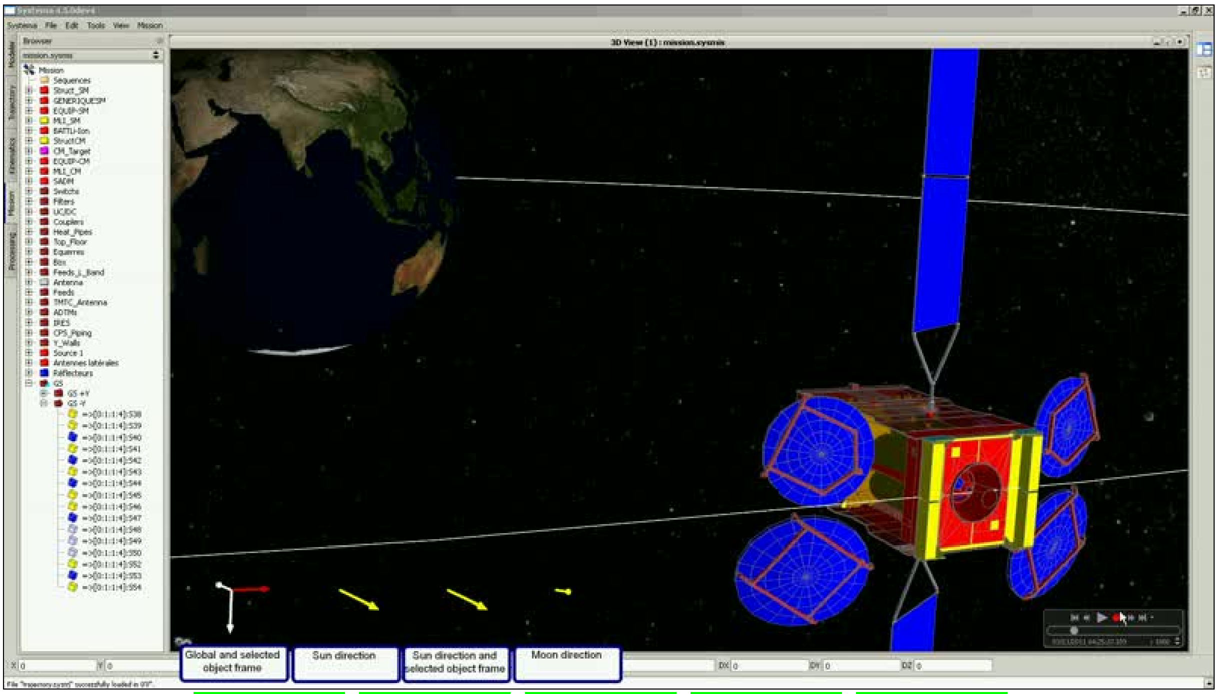
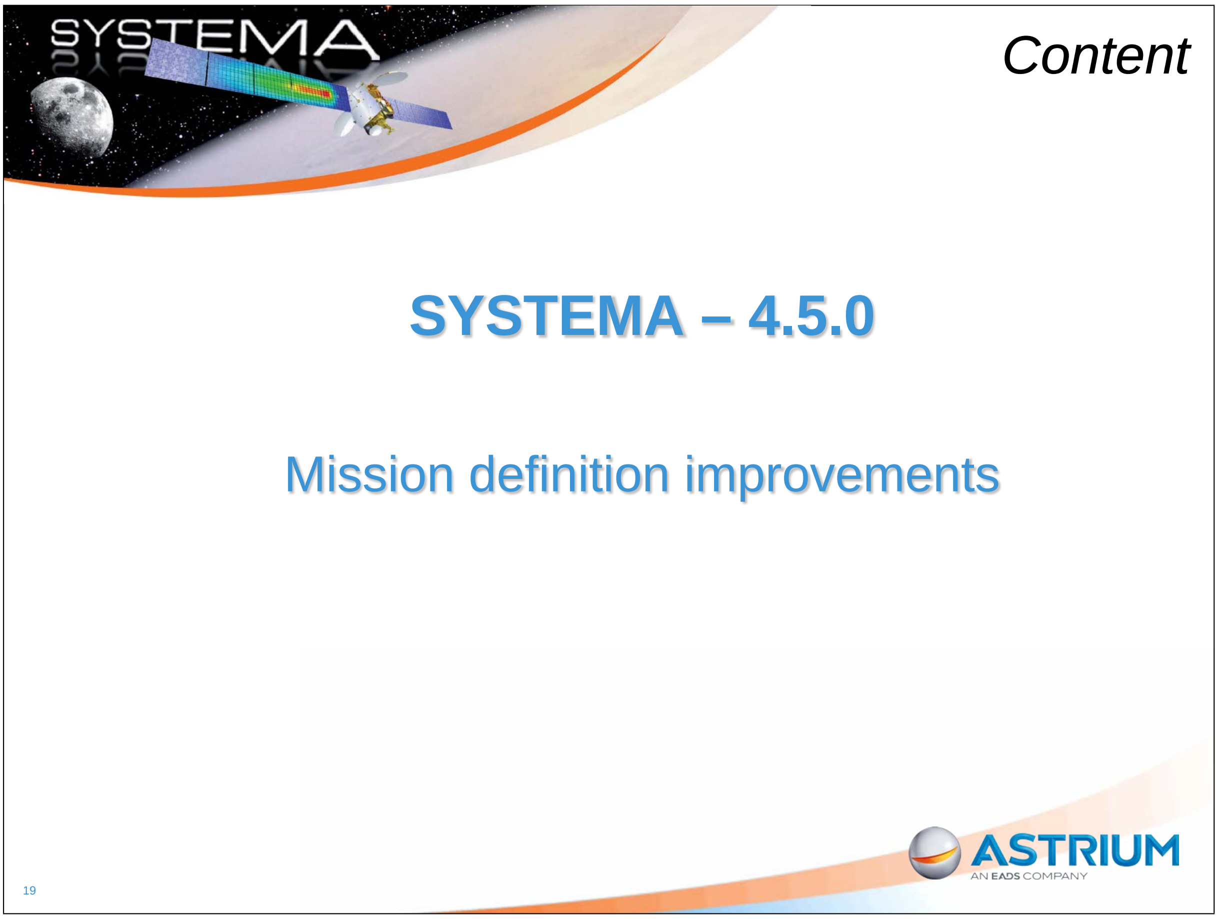
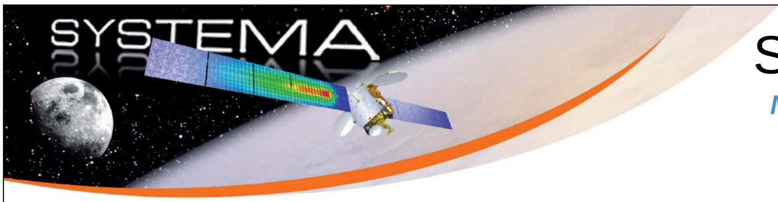


Slow Normal Fast Play/Pause Stop





SYSTEMA – 4.5.0

Mission definition improvements

Objectives

To allow the user to interactively define a complex mission composed of successive maneuvers (imaging, sun pointing…):

- Synchronize the different events of a mission
- Visualize all relevant information

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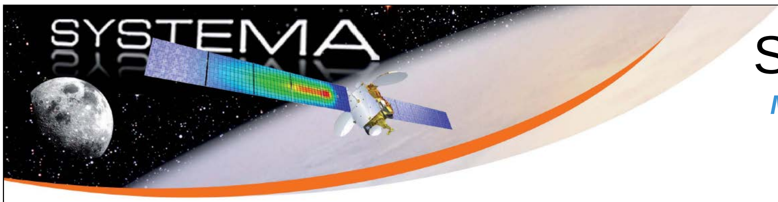

SYSTEMA – 4.5.0

Mission definition improvements

The timeline

To see and modify all time-related data of a mission

- Trajectory arcs beginning and end
- Eclipse and penumbra intervals
- Kinematics sequences
- Computation points
- User-defined events and intervals

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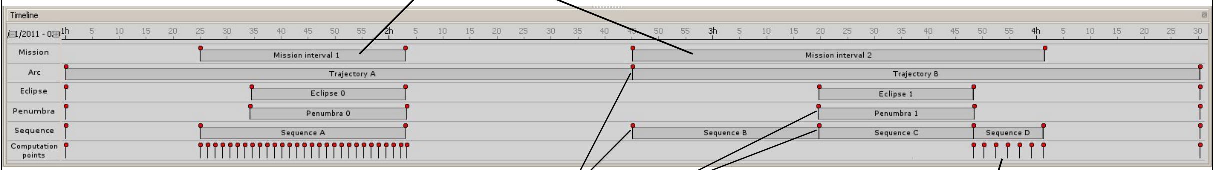
SYSTEMA – 4.5.0

Mission definition improvements

The timeline

User-defined intervals, corresponding to a specific time interval in the mission (manoeuvre, image acquisition period, …)



Synchronization between intervals

Computation points defined during an interval of interest

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Mission definition improvements

The timeline

- Complex “generation rules” for events like computation points: time interval and frequencies of the events
- Events based on non-temporal data:
  - Crossing of a specified latitude, anomaly..
  - Perigee or apogee dates
  - Kinematic angle reaching

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Technical details
Applications
Smart2
Quartz
Support
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
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 M

THERMICA-THERMISOL 4.5.0

Timothée Soriano
(EADS Astrium, France)

Abstract

Non-Grey Body Implementation

Under an ESA contract, Astrium has enhanced THERMICA-THERMISOL functionalities by implementing multi-spectral analysis. This new functionality is presented and the interest of using non-grey bodies will be demonstrated on a simple example.

Edges management in THERMISOL

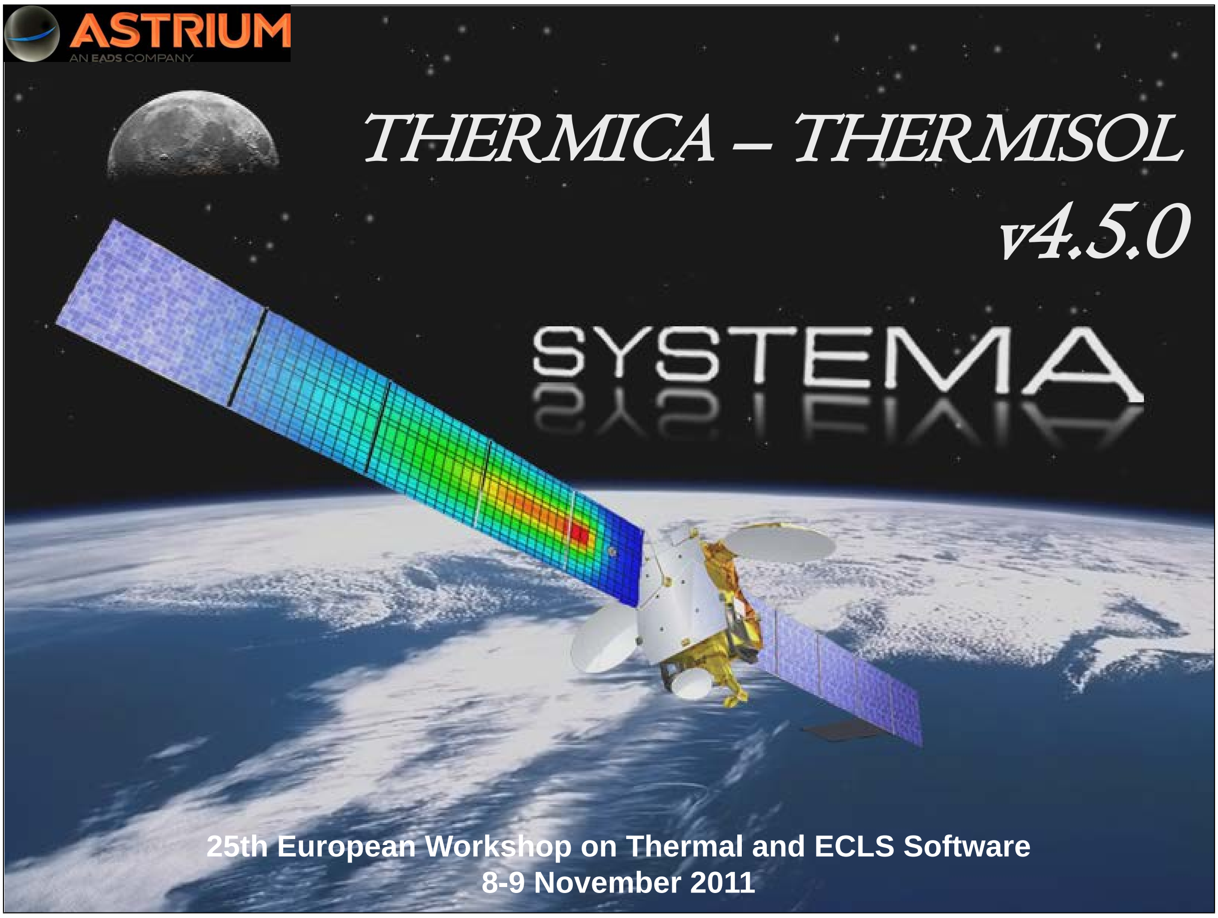
In order to allow easy handling of edges, a new notion of EDGES has been implemented in THERMISOL in order to have a definition of edges corresponding to their purpose and usage, not to increase the number of thermal nodes and especially to compute automatically the conductive flux between thermal nodes.

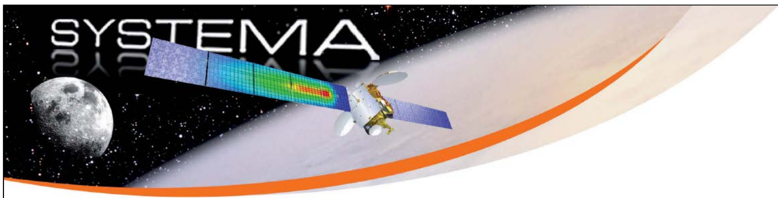
Simplified conductive method

An extension of the RCN method leading to shape-to-shape couplings has been developed. It solves the conductive flux crossing the frontiers by using a spatial extrapolation of a linearized temperature profile between the edge and the shape's center. This method is less accurate than the RCN method itself because it assumes linear temperature and the real direction of the conductive flux is lost. However, on many cases this approximation may be sufficient and THERMICA now proposes this possibility in order to get an approximated conductive method using the classical shape-to-shape topology of couplings.

Other THERMICA Improvements

The other implemented features of the v4.5.0 concerns **Incident Angle Dependencies**, **Parametric Outputs from THERMICA** and the **Management of Coplanar Shapes** in ray-tracing computations.





Content

- Non-Grey Bodies
- Edges Management
- Simplified Conductive Method
- THERMICA improvements

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SYSTEMA

THERMICA – THERMISOL V4.4.2

Current Status

25th European Workshop on Thermal and ECLS Software - 8–9 November 2011

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SYSTEMA

THERMICA

Current Status

- THERMICA 4.4.2
  - Fast **Multi-threaded** Ray-Tracing
  - **CAD** geometry directly supported for analysis
  - State-of-the-art **Ray-Tracing Visualization**
  - Accurate **Conductive** Method (RCN)
  - Plus many user's required features
    (flip shape orientations, undo/redo functions,
    contact zones, contact resistances…)

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SYSTEMA

THERMISOL

Current Status

- THERMISOL 4.4.2
  - **Smart** Pre-Processor with error checking and **automatic correction**
  - **Powerful** Mortran language extension (implicit accesses and macros)
  - **Fast**, **Robust** and **Accurate** Temperature Solver
  - **Intuitive** Pre-Processing Tool (*Skeleton*)
  - **Useful** Post-Processing Tools (*Posther, B-Plot*)

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THERMICA – THERMISOL v4.5.0

Non-Grey Bodies

(under ESA contract)

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Non-Grey Bodies

▪ Non-Grey Body

- **Objective:** Implementation of wavelength dependent IR properties
  Preservation of CPU time Performances

- **Development Performed:**
  Wavelength dependence setting in SYSTEMA
  Multi-Spectral Radiative couplings computation
  Multi-Spectral Planet IR flux computation
  THERMISOL language extension for wavelength dependent data
  Multi-Spectral Temperature computation

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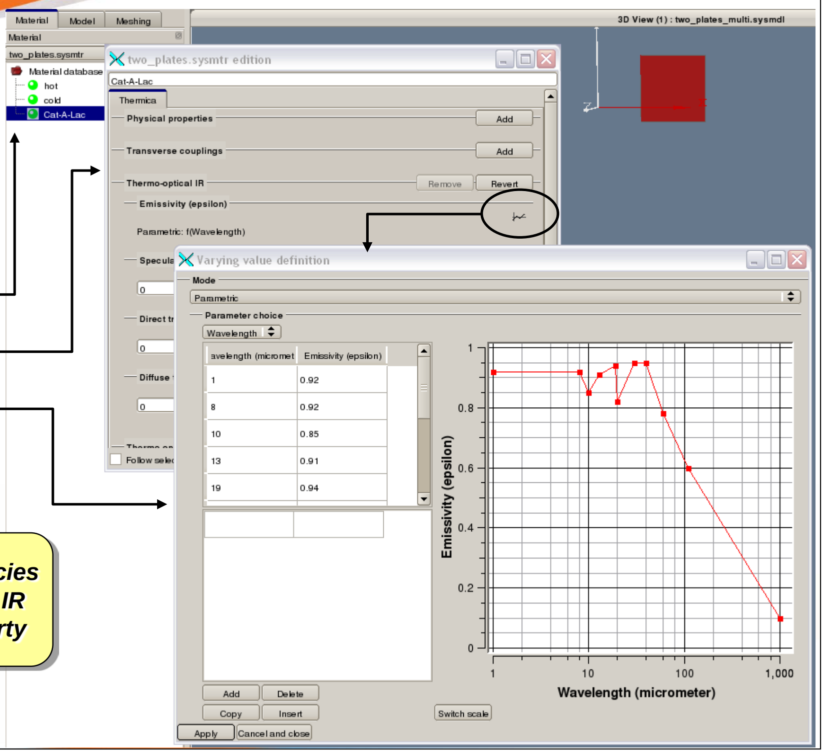
▪ Wavelength Dependent Material Properties

Material Database

Material Edition Window

Dependencies Edition Window



Wavelength Dependencies are available for each IR Thermo-optical property

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THERMICA
Non-Grey Bodies

Non-Grey Body in THERMICA

- **Automatic filtering of multi-spectral / mono-spectral couplings**
- **Preserved CPU performances:**

Industrial PDR Case of 1600 mesh and 76 orbital positions

Modules	Computation Time (seconds)		
	Mono-Spectral	*4 Bands*	*5 Bands*
GR Radiative Couplings	47	92	112
QE-QA Planet Fluxes	148	176	236
QS Solar Fluxes	261	263	277
Total	456	531	625

Computation Time Increase contained to a minimum thanks to efficient multi-spectral Ray-Tracing

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THERMISOL
Non-Grey Bodies

Non-Grey Body in THERMISOL

- New Entities **EPSWLB** and **GRWLB** for wavelength dependent properties
  Those are valued as arrays for an easy reading and a better understanding of the data
- New function **EPSWLBEF()** to automatically update the equivalent EPS at the node's temperature
- CPU Time for temperature integration contained to a minimum raise

Industrial PDR Case with 1939 nodes, more than 92000 radiative couplings including more than 42000 wavelength dependent couplings (multi-spectral case)

Modules	Computation Time (seconds)		
	Mono-Spectral	*4 Bands*	*5 Bands*
THERMISOL SS + TR	51	-	376

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THERMISOL

Non-Grey Bodies

Example of THERMISOL language

Declaration of Wavelength Discretization

Declaration of Wavelength Dependent Epsilons

Declaration of Wavelength Dependent Couplings

```
$MODEL   SATWLB

$ENTITIES
   # Addition of wavelength dependent entities EPSWLB and GRWLB
  WLBANDS (NWLBANDS = 4)   0.000000, 0.100, 10.000, 100.000, 10000.000;

$NODES

   # Geometrical Nodes

   [...]

  D 100165 = 'housing_MLI_ext/ExtMLI_PY     ', T= 0.000, A= 1.888E+00, ALP= 0.230, EPS= 0.800;
  D 100166 = 'housing_MLI_ext/ExtMLI_PX     ', T= 0.000, A= 2.005E+00, ALP= 0.230, EPS= 0.800;
  D 100169 = 'Separation/external_face      ', T= 0.000, A= 7.322E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
  D 100171 = 'housing_MLI_int/IntMLI_tel_PZ ', T= 0.000, A= 9.729E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
  D 100172 = 'housing_MLI_int/IntMLI_tel_MY ', T= 0.000, A= 8.154E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
  D 100173 = 'housing_MLI_int/IntMLI_tel_PY ', T= 0.000, A= 8.154E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
  D 100174 = 'housing_MLI_int/IntMLI_tel_PX ', T= 0.000, A= 9.849E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
  D 100175 = 'housing_MLI_int/IntMLI_OA_MY  ', T= 0.000, A= 1.065E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
  D 100176 = 'housing_MLI_int/IntMLI_OA_MZ  ', T= 0.000, A= 1.241E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
  D 100177 = 'housing_MLI_int/IntMLI_OA_PY  ', T= 0.000, A= 1.065E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
  D 100178 = 'housing_MLI_int/IntMLI_OA_PX  ', T= 0.000, A= 1.008E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
  D 100179 = 'Separation/internal_face      ', T= 0.000, A= 7.322E-01, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];

   [...]

$CONDUCTORS

   [...]

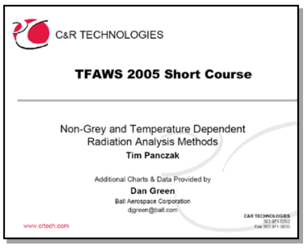
   # Couplings from node 100010
     GRWLB( 100010 , 100145 )   =   5.920884E-03, 5.225500E-03, 4.923324E-03, 4.923327E-03;
     GRWLB( 100010 , 100151 )   =   3.527201E-05, 3.668320E-05, 3.725704E-05, 3.725704E-05;
     GRWLB( 100010 , 100152 )   =   1.462086E-06, 4.218896E-06, 5.503530E-06, 5.503530E-06;
     GRWLB( 100010 , 100169 )   =   3.260020E-04, 3.009593E-04, 2.905687E-04, 2.905687E-04;
     GRWLB( 100010 , 100171 )   =   1.460778E-04, 1.539887E-04, 1.571416E-04, 1.571416E-04;
     GR   ( 100010 , 100172 )   =   1.716643E-04;
     GR   ( 100010 , 100173 )   =   1.780994E-04;
     GRWLB( 100010 , 100174 )   =   3.787272E-04, 3.588089E-04, 3.501261E-04, 3.501261E-04;
     GRWLB( 100010 , 100181 )   =   3.380370E-05, 3.734133E-05, 3.885305E-05, 3.885305E-05;
     GRWLB( 100010 , 100183 )   =   3.279740E-05, 3.585170E-05, 3.719668E-05, 3.719668E-05;
     GRWLB( 100010 , 99999999 ) =   1.561184E-04, 1.672259E-04, 1.726167E-04, 1.726167E-04;

   [...]
```

THERMICA

Non-Grey Bodies

Non-Grey Body: Example



- **Two Parallel Plates:**
  1x1 rectangles separated by a distance of 16
  One rectangle held at 250 K
  Spectral Emissivity Data for Cat-A-Lac black paint used for analysis

- **Cases executed:**
  1st case: constant emissivity of .92 for both surfaces
  2nd case: constant emissivity of .92 for hot surface,
  .50 for cold surface
  3rd case: wavelength dependent for both surface (using 10 spectral bands)

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Non-Grey Bodies

Non-Grey Body: Example

- **Results:** (Hot surface maintained at 250K)

1st case, .92/.92:	Cold surface at 46.492 K
2nd case, .92/.50:	Cold surface at 46.492 K
3rd case, wave/wave	Cold surface at 50.874 K

- **Analysis of results:**

  Cold surfaces comes to equilibrium based on
  - heat absorbed from the hot surface
  - radiation to space

  With classical grey materials the ratio between absorbed radiated flux remains constant

  In reality, the cold surface absorbs at .92 but radiates at .5

  ➢ Modeled correctly only using a wavelength dependent analysis

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Edge Management

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Edge Management

Origin of Edges

- **Conductive Analysis:**
  - An accurate conductive analysis cannot be efficient knowing only the shape's average temperature
  - Edges have been introduced to reconstitute the temperature profile at the node's frontiers
- **They are used by:**
  - Many Finite Element implementation of the conduction
  - The powerful 2nd order **RCN** method implemented in THERMICA
- **They allow:**
  - To get an accurate modelling of the conduction, consistent with radiation and other flux sources

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Edge Management

Edge Management: Requirements

- **Edges are not Classical Nodes:**
  - The same heat balance equations apply to them but…
  - They have no mass, no capacitance, no internal or external fluxes…
  - They are only used to transfer the conductive flux
  - They are not directly managed by the user
- **Difficulties to identify the Edges:**
  - The numbering of edges is not controlled by the user
  - Knowing which edges belong to which shapes is not trivial
- **Difficulties to get conductive fluxes between surface nodes**
  - The conductive flux shall be computed by a sum of coupling contributions
  - This requires to identify the edges of the nodes

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Edge Management

New Edge Data Block: Solution

- **Edges are declared in a new $EDGES block:**
  - It does not increase the number of thermal nodes
  - They are known by the solver as being edges
- **The identification of edges becomes easy**
  - No global numbering of edges
  - ID related to nodes *(edge 1 of node 100, edge 2 of node 100, edge 1 of node 200…)*
- **The connectivity between nodes and edges is given in their definition**
  - To compute the conductive flux exchanged between nodes
  - So the routines FLUXL, FLUXT, FLUXGL… automatically takes into account the edge flux at the interfaces between the node groups

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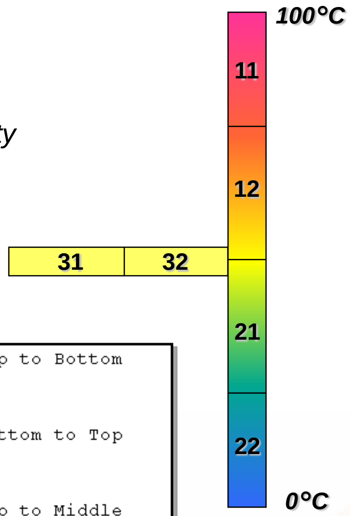
Edge Management

Standard FLUX routines with Edges

- **Example of a bar:**
  The standard FLUX functions knowing the edge connectivity are able to compute correctly the flux exchanged between groups of nodes




```
WRITE(*,*) 'Flux From Top to Bottom'
WRITE(*,*) '   ', FLUXL(N21,N22,N11,N12)
WRITE(*,*) '   ', FLUXGL('#21-22',CURRENT,'#11-12',CURRENT)

WRITE(*,*) 'Flux From Bottom to Top'
WRITE(*,*) '   ', FLUXL(N11,N12,N21,N22)
WRITE(*,*) '   ', FLUXGL('#11-12',CURRENT,'#21-22',CURR

WRITE(*,*) 'Flux From Top to Middle'
WRITE(*,*) '   ', FLUXL(N31,N32,N11,N12)
WRITE(*,*) '   ', FLUXGL('#31-32',CURRENT,'#11-12',CURR

WRITE(*,*) 'Flux From Middle to Bottom'
WRITE(*,*) '   ', FLUXL(N21,N22,N31,N32)
WRITE(*,*) '   ', FLUXGL('#21-22',CURRENT,'#31-32',CURR
```

```
Flux From Top to Bottom
   25.0
   25.0
Flux From Bottom to Top
   -25.0
   -25.0
Flux From Top to Middle
   0.
   0.
Flux From Middle to Bottom
   0.
   0.
```

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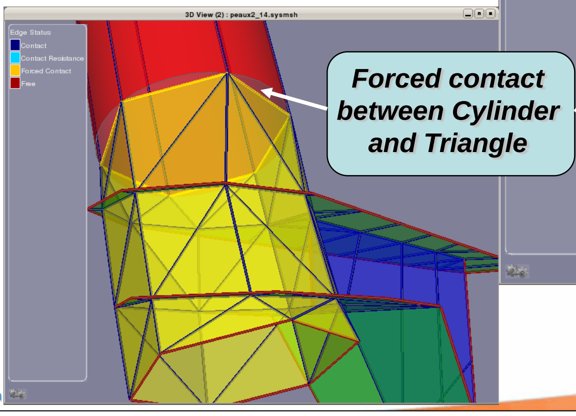
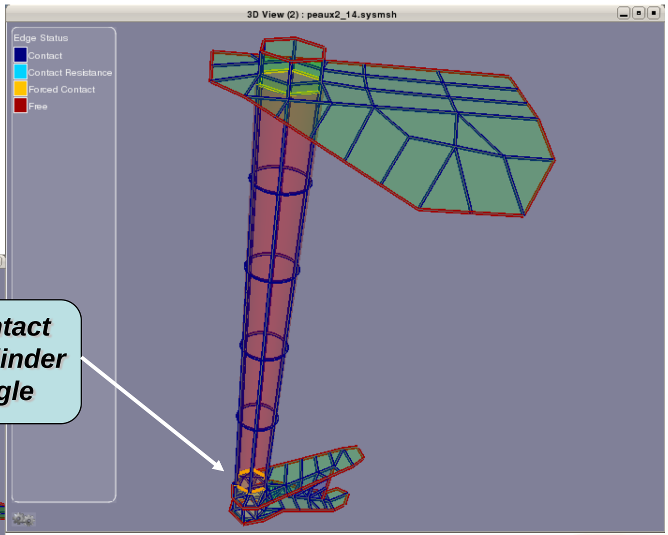
Edge Management

Visualization of Edges

- **Status**
  - Free Borders
  - Contacts
  - Contacts with Resistance
  - Forced Contacts





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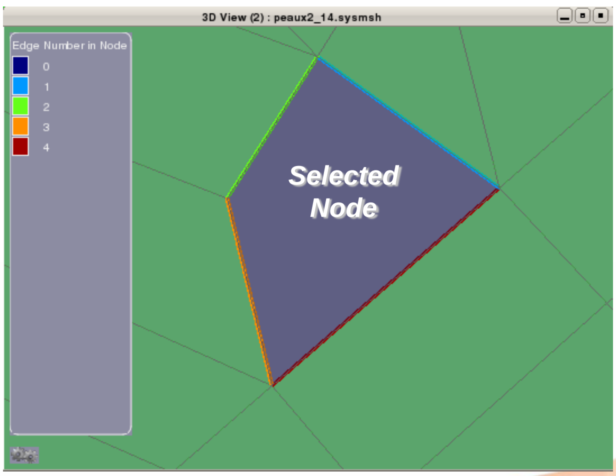
Edge Management

Visualization of Edges

- **Numbering**



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Edge Management

New Edge Data Block: Conclusions

- **The new Edges block is an answers to the user's needs**
  - It allows an easy computation of conductive flux
  - It does not increase the number of thermal nodes
  - The identification of edges becomes very simple
- **Plus a visual check**
  - The display of edge status (free, contact…)
  - The display of edge numbering within a thermal node
- **The EDGES block is a convenient alternative**
  - The classical Edge definition using classical thermal nodes is still supported and can be exported from the conductive module
  - A new simplified conductive method without edges may be used if accuracy on conductive flux is not required

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Simplified Conductive Method

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Simplified Conductive Module

Need for a simplified method

- The classical shape-to-shape approach was an easy-to-understand method leading to a simple expression of couplings directly related to the conductive heat transfer
- This topology of GL couplings is an approximation of the conductive effects but which may be sufficient if the temperature solution is quite closed to a linear profile
- The oldest geometrical approach had difficulties to handle complex shapes, condensation or non-conformances. The new shape-to-shape conductive coupling method shall handle them correctly in order to avoid the accumulation of approximations.

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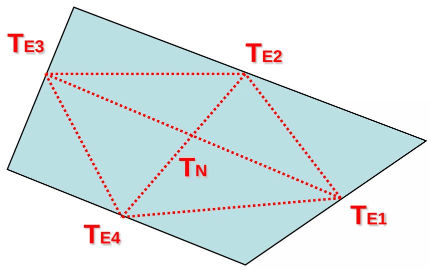
Simplified Conductive Module

Simplified RCN method (1/2)

- Based on the 2nd order RCN method, a simplified expression of the couplings is derived as follow:

Computation of RCN couplings



Expression of Conductive Flux to each Edge

$$\varphi_{Ei} = GL_{N,Ei}(T_N - T_{Ei}) + \sum_{Ej} GL_{Ei,Ej}(T_{Ej} - T_{Ei})$$

Simplification of Temperature Gradients

Assuming a linear temperature profile

$$T_{Ej} - T_{Ei} = \frac{\overrightarrow{E_i N}.\overrightarrow{E_i E_j}}{\left\|E_i N\right\|^2}(T_N - T_{Ei})$$

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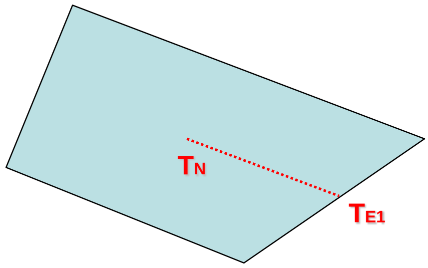
Simplified Conductive Module

Simplified RCN method (2/2)

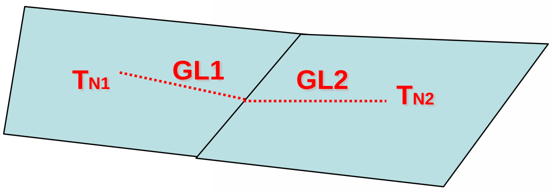
Expression of Conductive Flux to each Edge
Assuming a linear temperature profile

$$\varphi_{Ei} = \left(GL_{N,Ei} + \sum_{Ej} \frac{\overrightarrow{E_iN}.\overrightarrow{E_iE_j}}{\left\| E_iN \right\|^2} GL_{Ei,Ej} \right) (T_N - T_{Ei})$$

$$= GL^*_{N,Ei}(T_N - T_{Ei})$$



Association of Half Couplings



$$GL_{N1,N2} = \frac{1}{\frac{1}{GL1} + \frac{1}{GL2}}$$

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Simplified Conductive Module

Simplified RCN method: Conclusions

- Equivalent to known formulas in simple cases
  (rectangle, equilateral triangle)
- Hypothesis introduced: Linear Temperature Profile
- Consequences: The Simplified RCN method has the same limitations than all other shape-to-shape formulation but handles complex geometries, condensed nodes and non-conformant mesh
- The conductive flux is approximated and the temperature solution will be less accurate than with the complete RCN method
  But the choice is given to use a simplified expression of couplings

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Other Improvements
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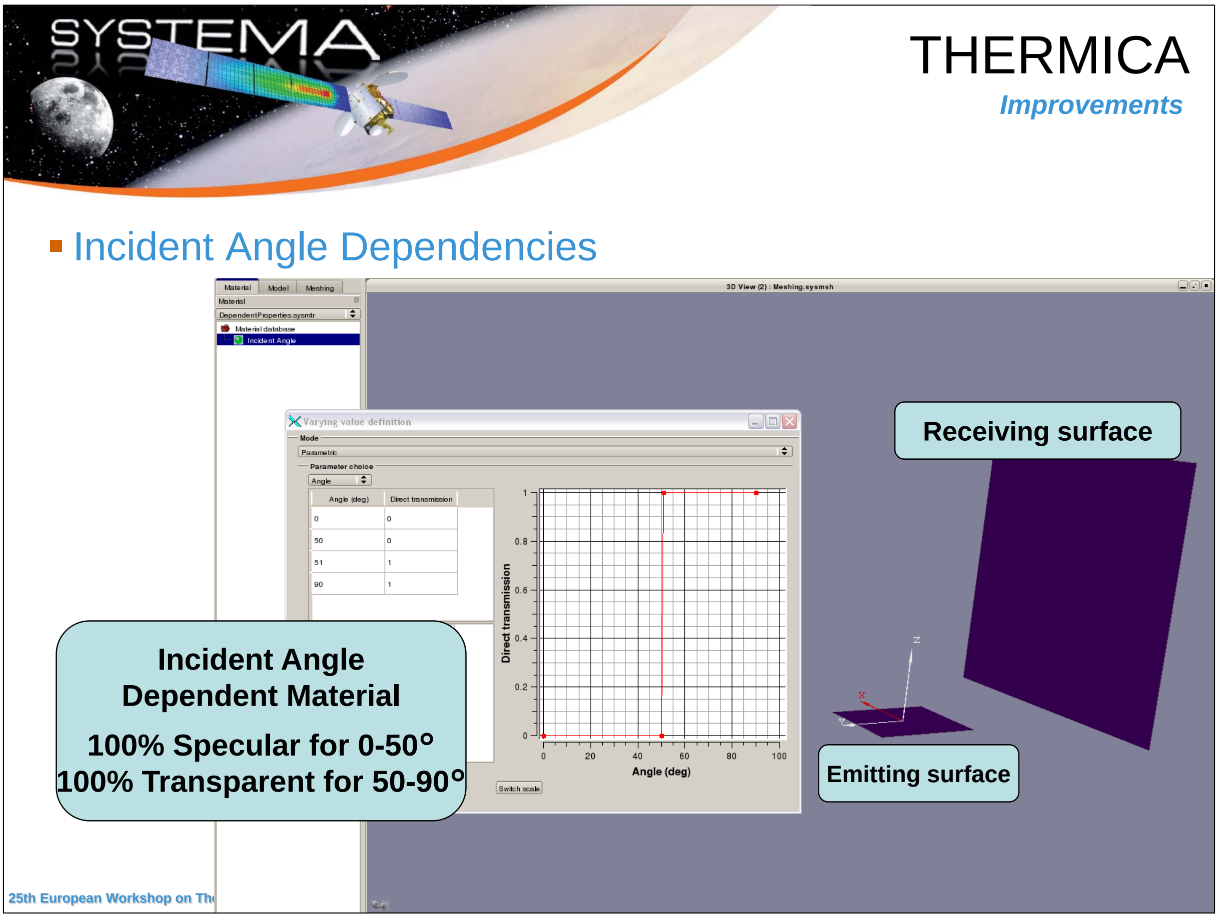
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Improvements
Incident Angle Dependencies
Varying value definition
Mode
Parametric
Parameter choice
Angle
Angle (deg)
Direct transmission
Angle (deg)
Switch scale
Receiving surface
Emitting surface
Incident Angle
Dependent Material
100% Specular for 0-50°
100% Transparent for 50-90°
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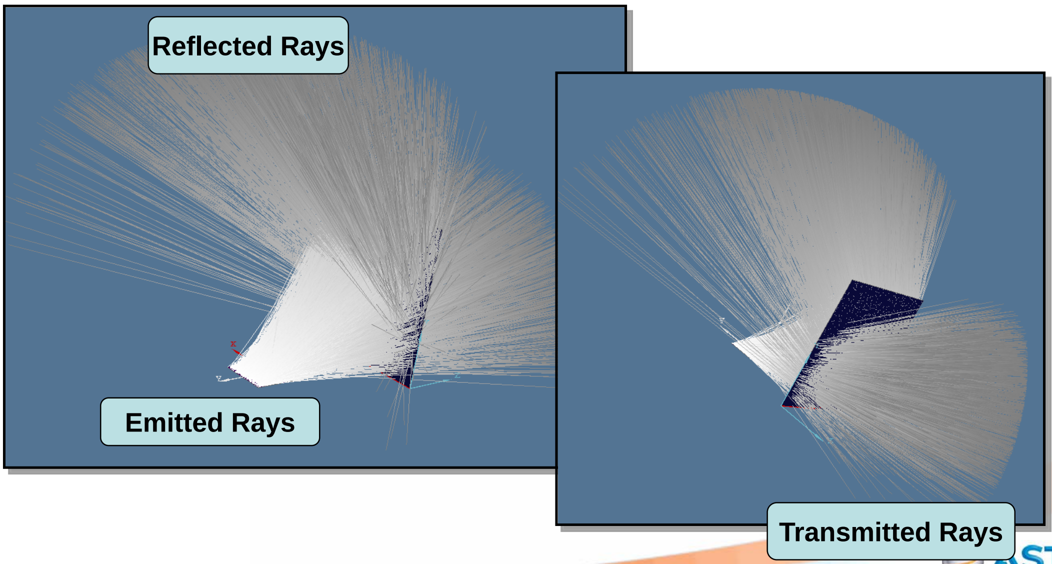
THERMICA
Improvements

▪ Incident Angle Dependencies



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Improvements

▪ Co-Planar Shapes Management

- Sometimes, it has been seen that geometrical models had overlaid shapes
  - ➢ The Ray-Tracing behavior is not predictable (which shape shall be impacted ???)
- The version 4.4 already tracks superposed shapes and return warnings
- Manual model corrections are often a time consuming task
- Now the 4.5 is able to correct some commonly found errors
- Errors that cannot be corrected are listed for further manual corrections

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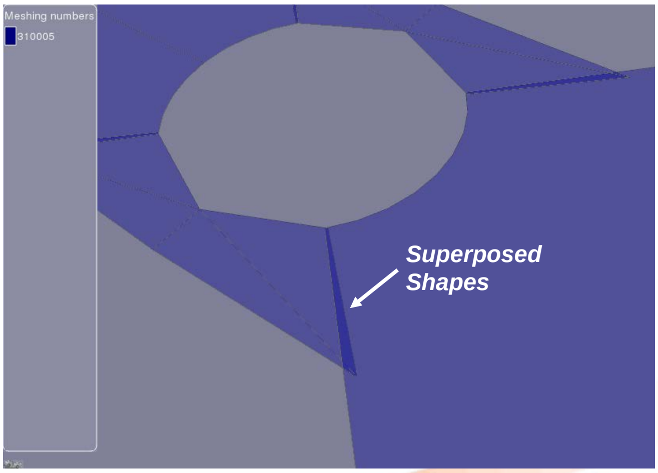
Improvements

Co-Planar Shapes Corrections

- **Inaccurate condensed node**

Corrections:

- Ray density preserved
- Re-computed node area



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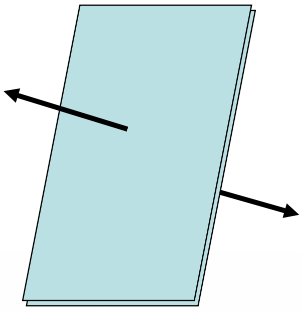
Improvements

Co-Planar Shapes Corrections

- **Distinct shape orientation**

Correction:

- The impact is considered to be on the shape being active on its impacted side



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THERMICA-THERMISOL v4.5.0

Conclusion

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v4.5.0
Conclusion

- Summary of evolutions in THERMICA-THERMISOL
  - Non-Grey Bodies
    Edge Management
    Simplified Conduction
    Incident Angle Dependencies
    Co-planar Shape Automatic corrections / Error Tracking
  - Material Parameterization of THERMICA outputs
    Double layer Bulk definition
    Transverse properties for shapes with distinct side nodes
  - Plus all the evolutions of the THERMICA framework - SYSTEMA

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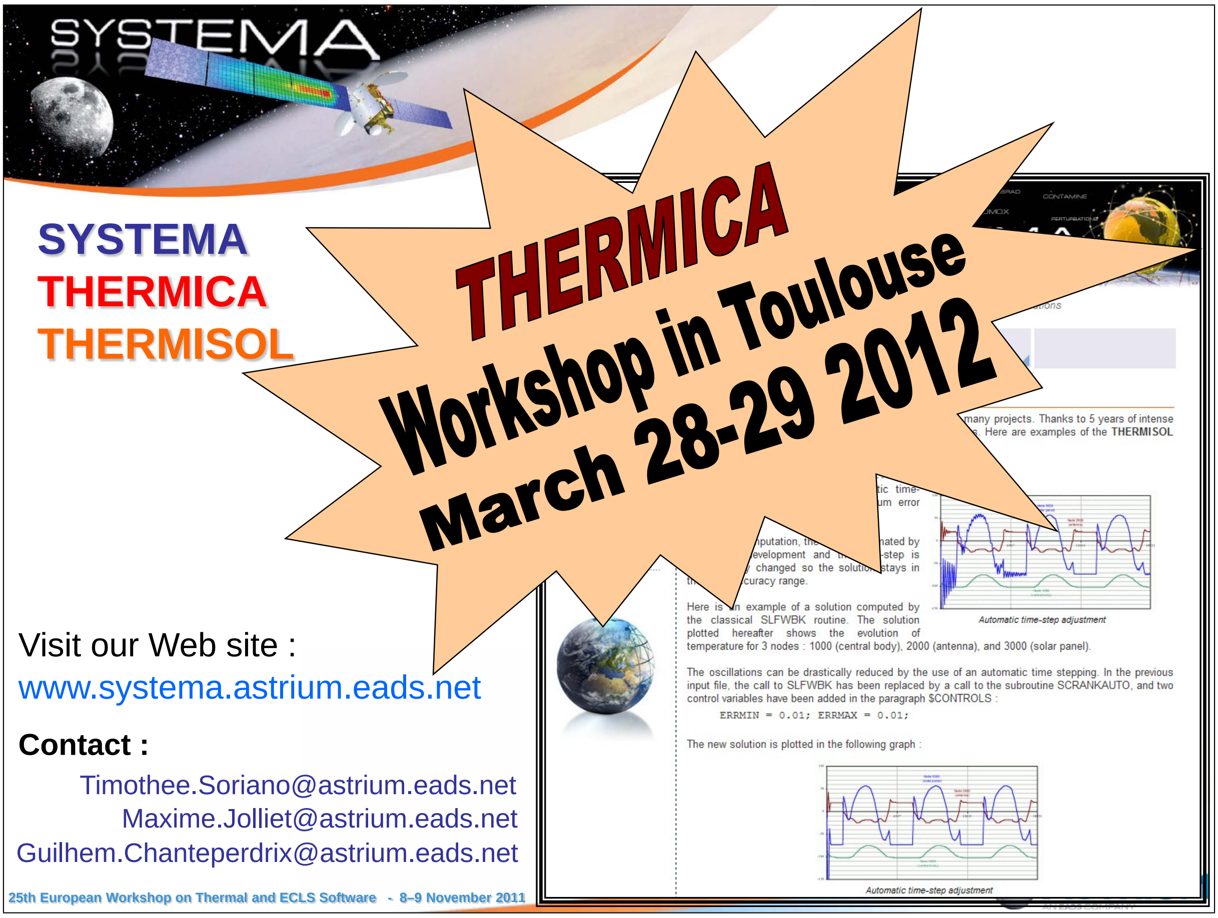
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March 28-29 2012
Visit our Web site :
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The oscillations can be drastically reduced by the use of an automatic time stepping. In the previous input file, the call to SLFWBK has been replaced by a call 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
Automatic time-step adjustment
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Appendix N

Spatial Infra-red Objective thermal analysis

Jean-Baptiste Meurisse Salem Belmana Remi Gazin
(Sodern, France)

Abstract

The aim of that thermal analysis is to calculate accurately the thermal gradient in all the lenses of a spatial infra-red objective facing a cryo-cooler. The issues of that work are to calculate the optical performances of the objective (stability, defocus ...) thanks to thermal predictions, to predict the appropriate flight adjustment shims and to accurately assess the heat flux radiated to the cryo-cooler so as to avoid overdimensioning. The difficulty of that analysis consists in taking into account the spectrally dependant thermo-optical properties of the lenses. Indeed, the functional bandwidth of that objective (around 10μm) being inside the "thermal bandwidth" ($\sim$[2μm;50μm] with a peak of luminance at 10μm) a strong semi-transparent effect had to be considered. A spectral calculation has been performed thanks to NX7.5 software and allows us to accurately calculate the flux radiated to the cryo-cooler. Its shows particularly the filtering (or semi-transparent) effect of the lenses on each other: the heat flux radiated by the internal lenses being way smaller than the one from the lens facing the cryo-cooler.

Spatial InfraRed Objective Thermal Analysis

8th and 9th november 2011

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R. Gazin (remi.gazin@sodern.fr)

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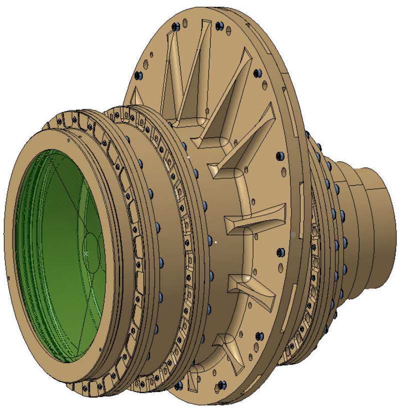
Equipment presentation

- **Equipment presentation**
  - **Infrared objective for space application (observation)**
    - High performances required
    - Accurate temperature gradient assessment required
  - **Fonctionnal bandwith inside [2µm;12µm]**
    - High transparency of the lenses inside this bandwith
    - Opacity/reflectivity above 12-20µm



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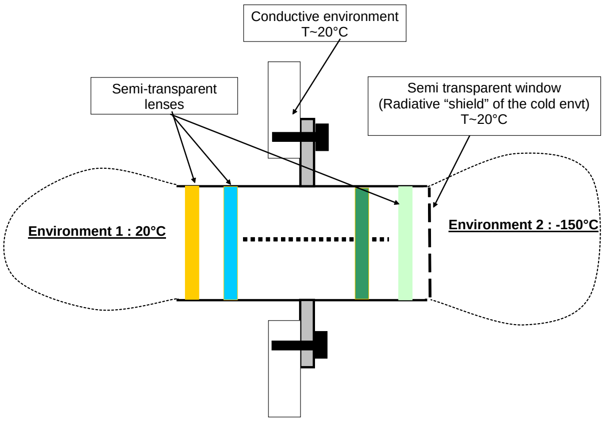
Technical challenges

- **Verification of the thermal gradients in a semi-tranparent and spectrally dependant environment**



- **Determination of in-flight focusing shim thickness by calculation only**
  - **Thermal gradient assessment thanks to NX7.5**
  - **Calculation of optical de-focus due to thermal gradient**
  - **Determination of the relevant shim**

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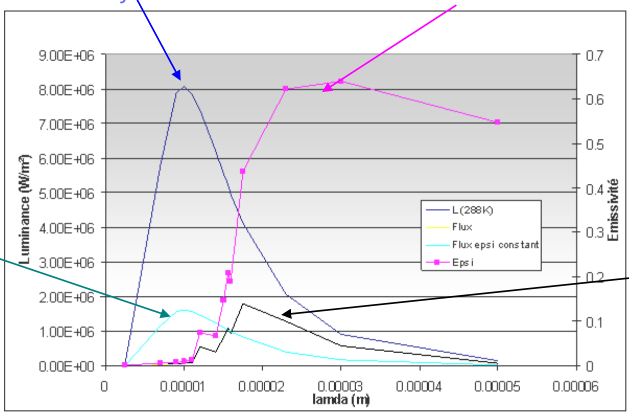
Spectral approach required (1/2)

- **Importance of the spectral aspects in the thermal exchanges:**
  - **Benchmark on the emittance of the window radiated to the lenses, when considering**
    - The actual spectral thermo-optical properties
    - The equivalent emissivity

spectral emissivity of a 5mm blade of Ge (~window and lense)

Luminance of black body at 20°C

Black body luminance multiplied by 0.2 (=ε eq for window).



Black body luminance multiplied by the spectral emissivity of the window

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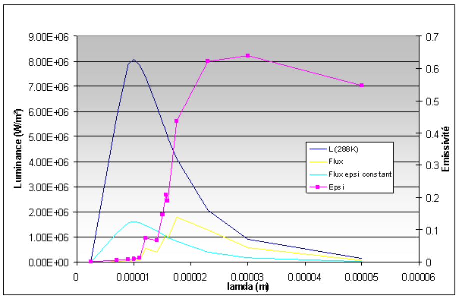
Spectral approach required (2/2)

- **The integral of the yellow and the light blue curves (i.e the energy [W] emitted by the window) are similar due to the equivalent emissivity definition**



- **The spectral fluxes are not centered on the same wavelength.**
  - **Lenses will absorb differently the two fluxes**
  - **In particular, the actual flux (yellow) will be more absorbed as it is centered on a high absorption wavelength ($\varepsilon_{window} \sim \varepsilon_{lense}$).**
- **The equivalent emissivity approach is too severe and does not allow the focus shim prediction**

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Choosen solution: NX7.5

- **Solving the spectrally dependent problem requires an adapted software that allows the semi-transparent resolution.**
- **NX7.5 has been choosen:**
  - **The spectral module is available since 2010**
  - **It is adapted to a fine meshing required to assess the lenses thermal gradient with good accuracy**
- **A validation campaign has been performed on the NX7.5 spectral module**
  - **Validation on a thin single window**
    - The maximum error on these cases is 4%
  - **Validation on a simplified (2 lenses) objective**

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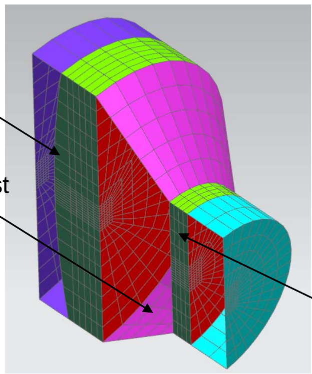
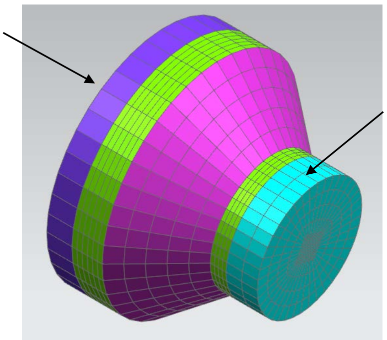
Spectral module validation (1/3)

- **Simplified 2 lenses objective**
  - **Aims at validating thermal couplings between two lenses**
  - **Allows for preliminary analysis of the cavity between the last lens and the window**
- **Model presentation**





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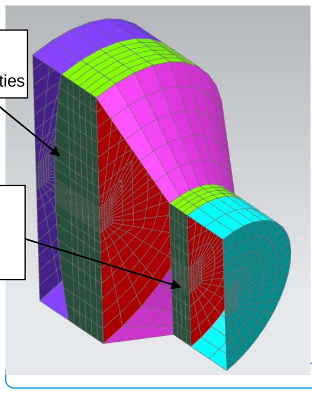
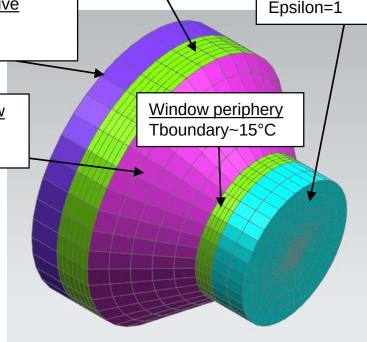
Spectral module validation (2/3)

- **Case 1: Nominal case boundary conditions**
  - **Last lens**
    - Boundary T° on its periphery : 20°C (radial conduction implemented)
    - Actual thermo-optical properties
  - **Window:**
    - Boundary T°~15°C
    - Actual thermo-optical properties without reflexion ($T=T_{réelle}+R_{réelle}$; $A=A_{réelle}$)
  - **Cavity lens-window:**
    - T~15°C
    - Epsilon=1
  - **Inside of the objective (representative of the other lenses)**
    - T=20°C
    - Epsilon=1





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Spectral module validation (3/3)

- **Validation cases**
  - **The monitored value is the heat flux emitted towards cold environment**
    - Cause for the radial gradient in the lenses
    - Cause for the decrease of the average temperature of the equipment

Computation case	Flux emitted to the cold envt (=$\Phi_{emitted} - \Phi_{absorbed}$)	
	Theoretical value	Calculated value
Case 1 – Nominal case (no reflective window)	24.2mW	24.5mW (error:1.5%)
Case 2 – Impact of the window's reflection Actual thermo-optical properties of the window	16.0mW 33% decrease of the flux emitted to the cold envt	15.9mW (error:1.0%)
Case 3 – Addition of a lense The inside objective has diffuse node and represent the additionnal lens	25.8mW	26.7mW (erreur:3.6%)

- **The spectral reflexion has a strong impact of the results**
- **The filtering of the lenses w.r.t the cold environment is important too**
- **The calculated error in these cases is below 4%**

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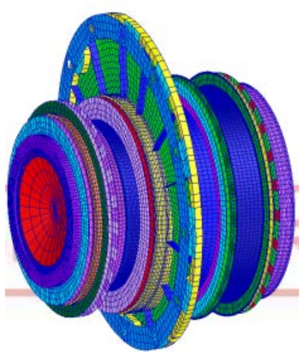
Preliminary results on the equipement

- **The thermal model of the equipment:**
  - **Meshing of the parts (lenses, mechanical structre, environments…)**
  - **Implementation of materials properties (thermo-optical properties, conductivity, heat capacity)**
  - **Boundary conditions implemented**
  - **Definition of the bandwidth for analysis and its discretisation, which depends on**
    - The temperature levels expected
    - The thermo-optical properties of the materials
    - The accuracy required



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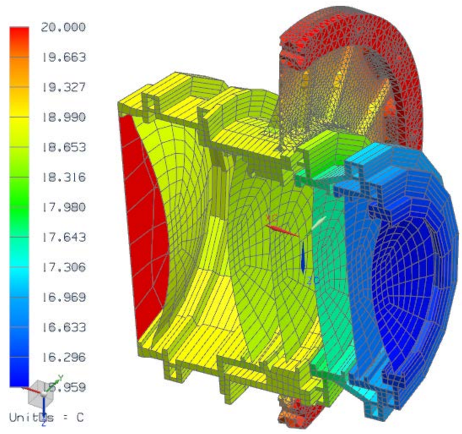
Preliminary results on the equipement

- **Preliminary results**

Half view of the model



➔Cold environment has strong impact on lenses.

➔Filtering effect is correclty taken into account

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Next steps

- **Consolidation of the results by sensitivity analysis**
  - **Hand calculation to be compared to computed values**
  - **Physical sensitivity**
    - Thermo-optical properties
    - Type of reflexion (diffuse / specular)
    - …
  - **Numerical sensitivity**
    - Number of emitted rays for the GR calculation
    - Discretisation of the spectral bandwidth
    - …
- **Finalize the thermal analysis:**
  - **Steady-state calculation**
    - Assessment of the thermal gradient in the lenses
    - Computation (CodeV optical software) of the associated optical performance
    - Prediction of the adapted shim to fit with location of focal plane
- **Transient calculation**
  - **Assessment of the thermal gradient stability due to environment variations**
  - **Computation (CodeV optical software) of the variation of focal plane location and the associated performances**

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Conclusion

- **The spectral dependent thermal aspects on our infra-red objective is the main issue of the analysis and of the design**
- **The problem is analyzed thanks to NX7.5 for which the appropriate module has been validated on simple cases**
- **The preliminary results are extremely encouraging as they are physically consistent and partially validated by hand calculation**
- **Sensitivity analysis has to be performed so as to:**
  - **Assess the optical performances in flight conditions**
  - **Compute the in-flight shim thickness**

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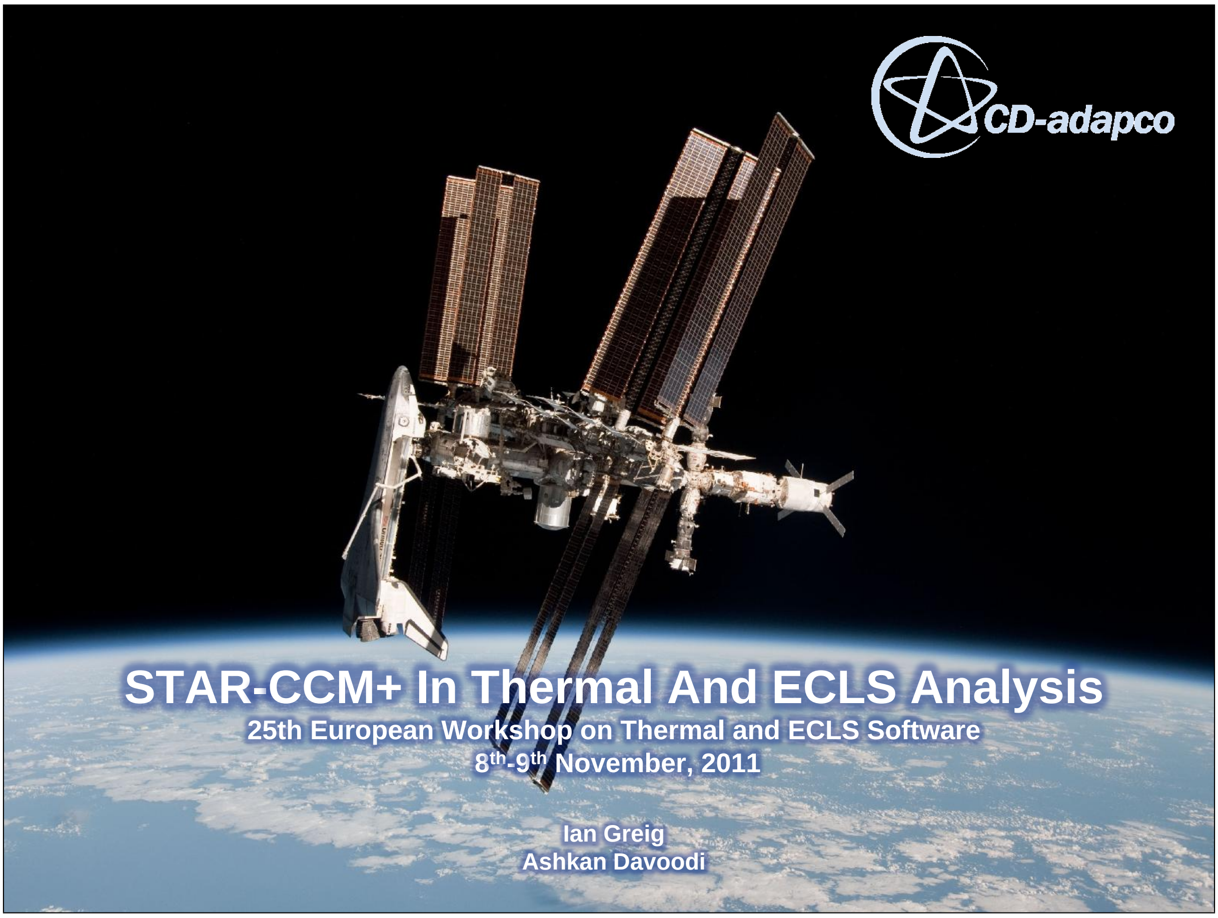
Appendix O

STAR-CCM+ for Complex CAE Design Problems

Ashkan Davoodi Ian Greig
(CD-adapco, United Kingdom)

Abstract

CD-adapco has a long history of working with the aerospace and space industry, tackling their toughest problems. CD-adapco'si new generation CAE software, STAR-CCM+, is used in industry every day to perform a full suite of fluid, thermal, mechanical and electro-magnetic analysis. STAR-CCM+ leverages modern software languages and architecture to take advantage of ever larger computing resources via a client-server architecture using JAVA and C++ respectively. STAR-CCM+ is based on the finite volume methodology, with additional capabilities to solve in the Lagrangian, particle framework and others. This presentation will provide an overview of some of the physics available within STAR-CCM+ to perform complex thermal and ECLS type analyses as well as supporting examples.



Agenda

1. Introduction to CD-adapco
2. What is STAR-CCM+?
3. Validation of Li-Ion Battery Electro-Thermo Model
4. Aircraft Cabin Comfort Modelling
5. Presentation Conclusion

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Introduction

- CD-adapco's state of the art multi-physics code STAR-CCM+ has found a wide range of applicability across the aerospace and space community
- STAR-CCM+ has been used across the space flight envelope and throughout spacecraft themselves, to simulate everything from re-entry to battery thermal management
- This presentation describes what STAR-CCM+ is, how it has been used, and it's capabilities, for thermal and ECLS analyses

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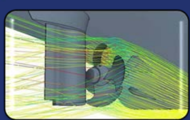
CD-adapco: *Engineering Success*

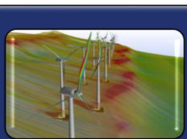
Our purpose is to ensure the customer's *success* through the use of engineering simulation

- Enable & inspire innovation
- Reduce engineering time & costs



We provide *successful* engineering simulation solutions

•Software products like STAR-CCM+ that are accurate, efficient, and easy to use
•Local dedicated support
•Engineering services: technology transfer, burst engineering resources, custom software tools



We are a growing and *successful* engineering simulation company

•17% growth in FY2010 global software sales
•>480 employees in ~25 offices
•>8000 users worldwide

Our independence breeds *engineering success*

•Largest independent CAE/CFD provider
•Heavily invest in employees
•Continuously invest in development of new technology

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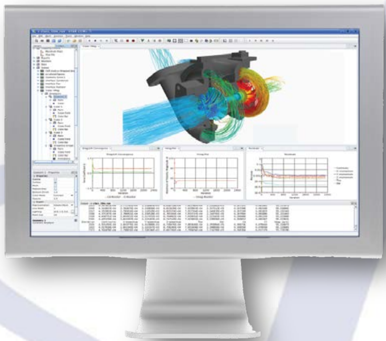
What is STAR-CCM+?

- Modern, fully parallel mutli-physics CAE software
- Client - Server architecture using JAVA - C++ respectively
- Complete process
  - CAD import/Generation
  - Meshing
  - Solving
  - Post Processing



- A comprehensive range of inclusive physics models and links to other packages of different dimensionality (1D, 2D, 3D)

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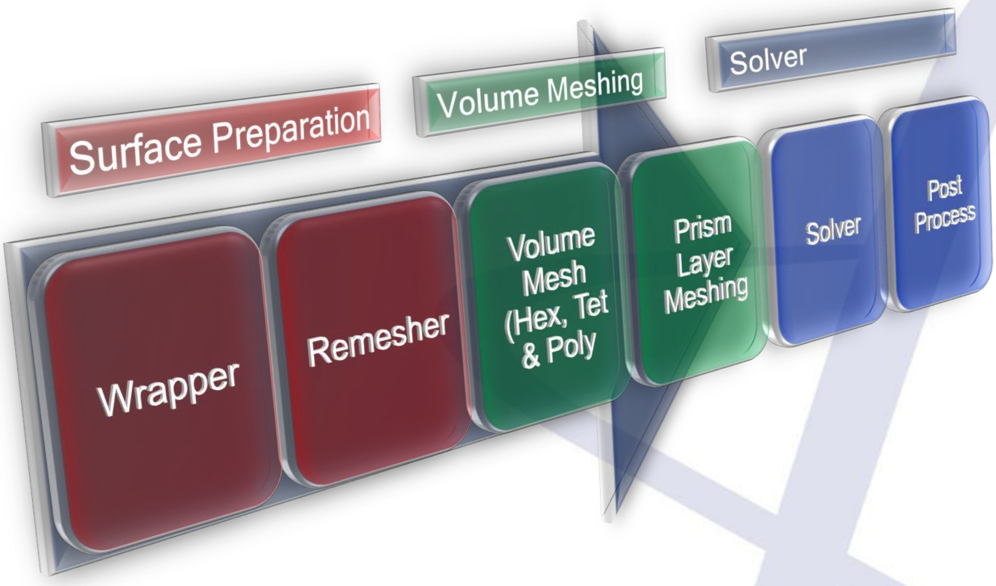
Mesh Generation in STAR-CCM+



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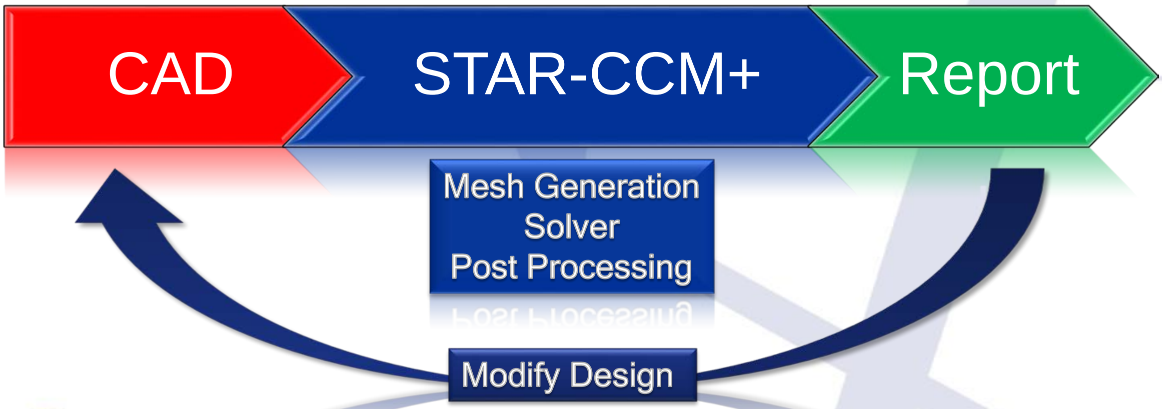
The STAR-CCM+ Advantage

- Meshing & post processing integrated with the solver in a single environment
  - Full CAE process scripted in a single code.
  - Full process can be run in batch or fully interactively.



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Validation of Li-Ion Battery Electro-Thermo Model

- This validation example*, from JAXA, compares temperatures calculated in two different ways with STAR-CCM+ with experimental cell temperatures on a COTS battery cell designed for space applications
- 2 different methods of simulation were used
  - Using Battery Design Studio to calculate the thermal heat sources and then performing a thermo-fluid analysis in STAR-CCM+
  - Using STAR-CCM+ Battery Design Module to calculate the coupled thermo-fluid and electro-chemical analysis

**Fundamental Study of Thermal Numerical Modeling of large Scale Li-Ion Battery for Space Application*, M. Kawase, H. Naito & K. Nishikawa, C5, ESPC 2011

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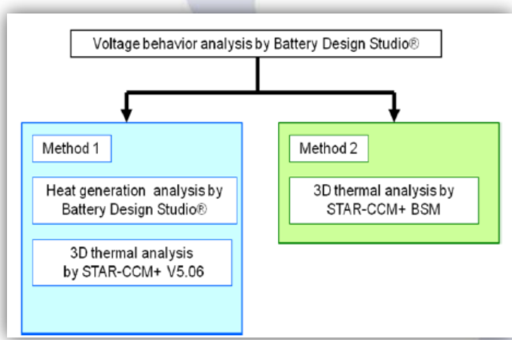
Analysis Methods

- Battery Design Studio® is used in both cases to characterise the battery cell as input for both of the thermal analyses
- Method 1 calculates thermal heat sources for STAR-CCM+
- Method 2 uses the cell characteristics as input and then performs a coupled thermo-electro-chemical analysis to determine heat generation and hence temperatures



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Geometry

- The analysis is conducted on an equivalent pouch cell of the elliptical, jellyroll cell below in both cases
- The elliptical cell geometry is used as geometry in STAR-CCM+ for calculating temperatures in Method 1
- The equivalent pouch cell geometry is used for Method 2 in STAR-CCM+

Model Cell
P/N : JMG100
Cell type : Elliptic cylinder
Cathode : $LiCoO_2$
Anode : Graphite
Nominal Capacity : 100Ah(Rated)
Nominal voltage : 3.7V
Weight : 2,800g
Dimensions (W x L x H) : 50mm x 130mm x 208mm
Energy density : 132Wh/kg , 273Wh/l

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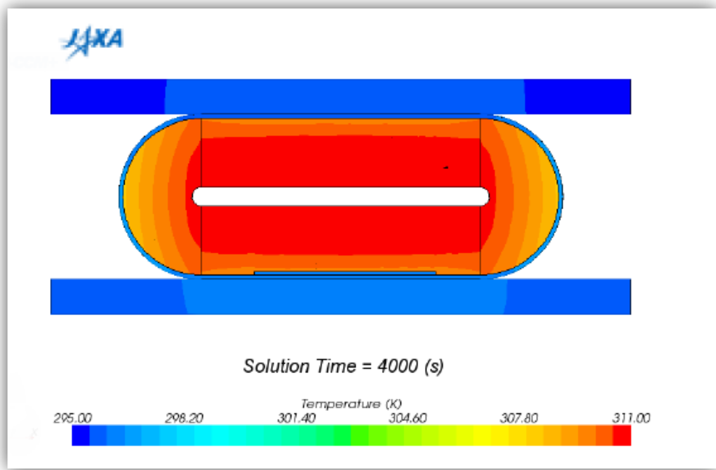
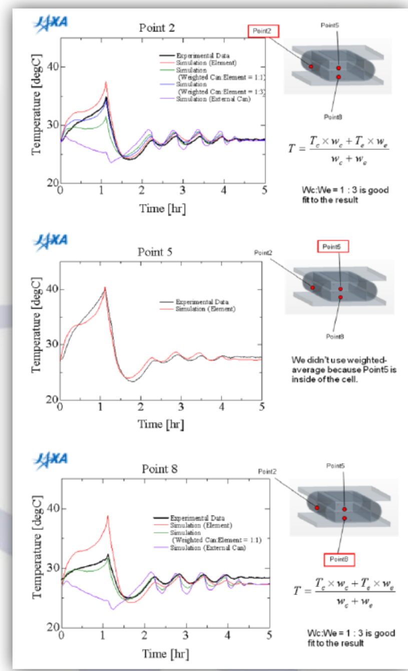
Method 1: Temperature Distribution in Jellyroll





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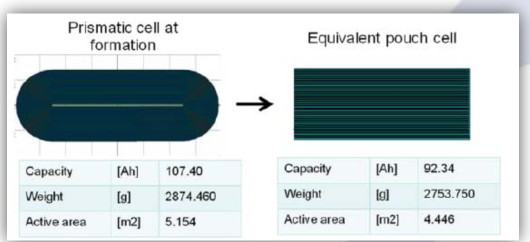
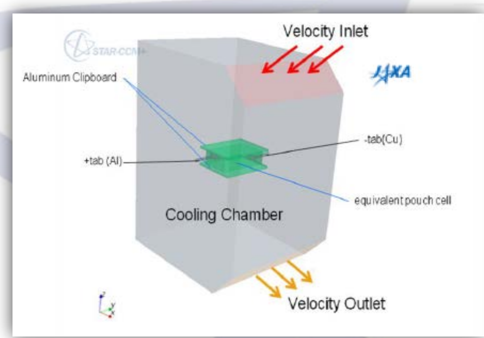
Method 2: Geometry

- For method 2, the elliptical cell is reduced to an equivalent pouch cell due to modelling requirements
- The analysis is conducted in an idealised cooling chamber with a velocity inlet, a pressure outlet and adiabatic walls, with the pouch cell, clipboards and air interfaced together





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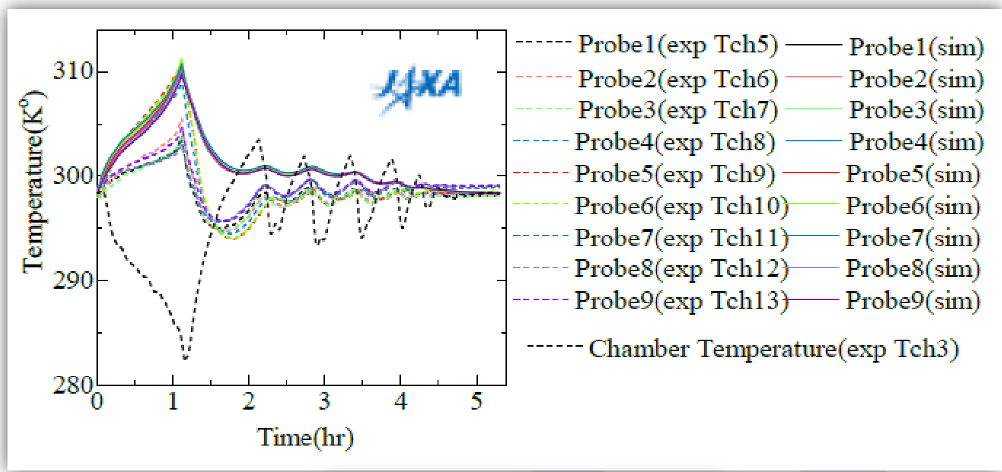
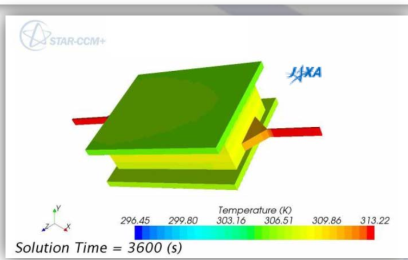
Method 2: Temp. Dist. In Equivalent Cell Pouch





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Validation Conclusion

- The experimental and simulation data match very well in both cases
- Discrepancies between the data are potentially down to incorrect boundary conditions, the equivalent pouch simplifications in the case of method 2 and the methods chosen for the cell characterisations
- STAR-CCM+ makes battery performance and lifetime analysis possible when thermal effects are an important consideration

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Aircraft Cabin Comfort Modelling

- An important consideration of human spaceflight is maintaining ideal working conditions for astronauts, and in the future commercial passengers, especially on long duration missions
- This process presentation* is an example of how STAR-CCM+ is currently being coupled to anatomical models to perform aircraft cabin comfort analysis

**Aircraft passenger cabin thermal comfort analysis by means of integrated mono dimensional-CFD approach*, P. Borrelli, A. Romano & D. Cannoletta, Alenia Aeronautica, STAR-European Conference 2011

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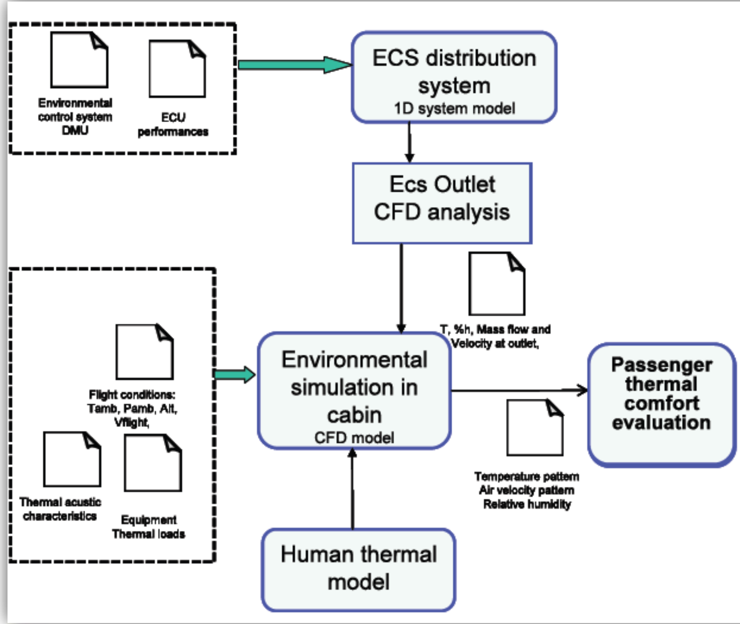
Process and Coupling Diagram



- Integrated 1D – CFD process view for the evaluation of thermal comfort in a passenger cabin environment
- Methodologies integration: taking the advantage of system-level and CFD methods to ensure that the simulation process is Fit For Purpose
- Parameters relevant for passenger thermal comfort:
  - outlets geometry, positioning and orientation (direct impinging air on the passengers);
  - ECS distribution system architecture (airflow splitting);
  - Thermo-acoustic configuration.

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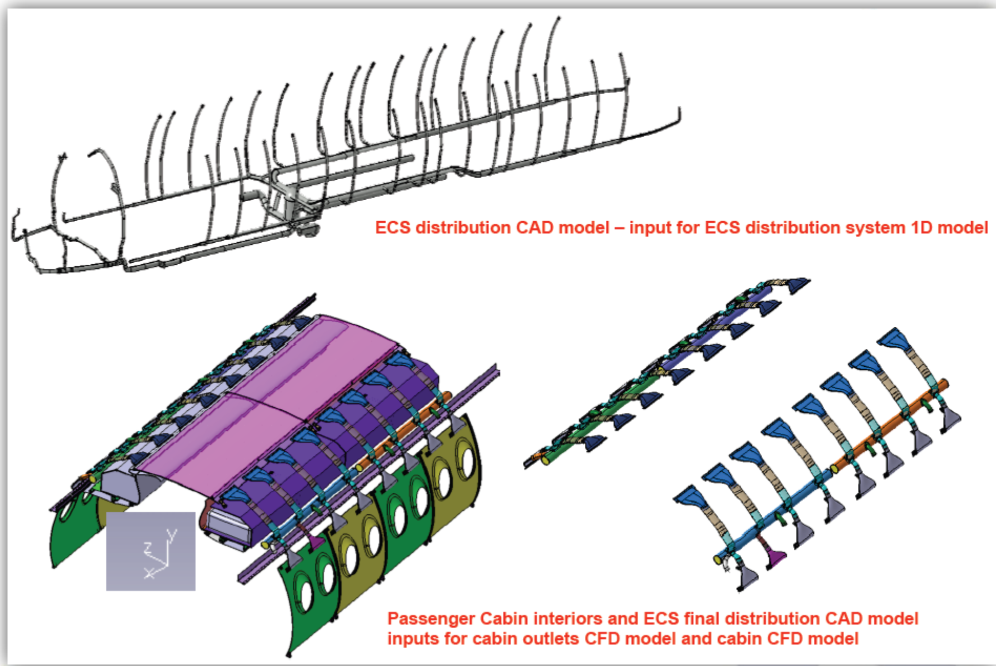
ECS and CFD Geometry Input



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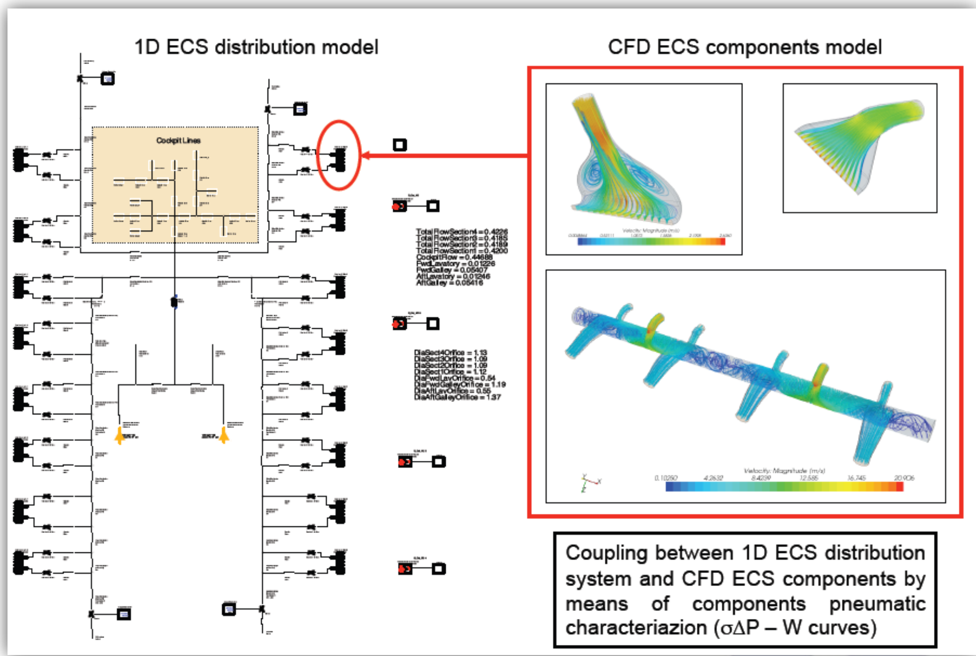
ECS Components Coupling



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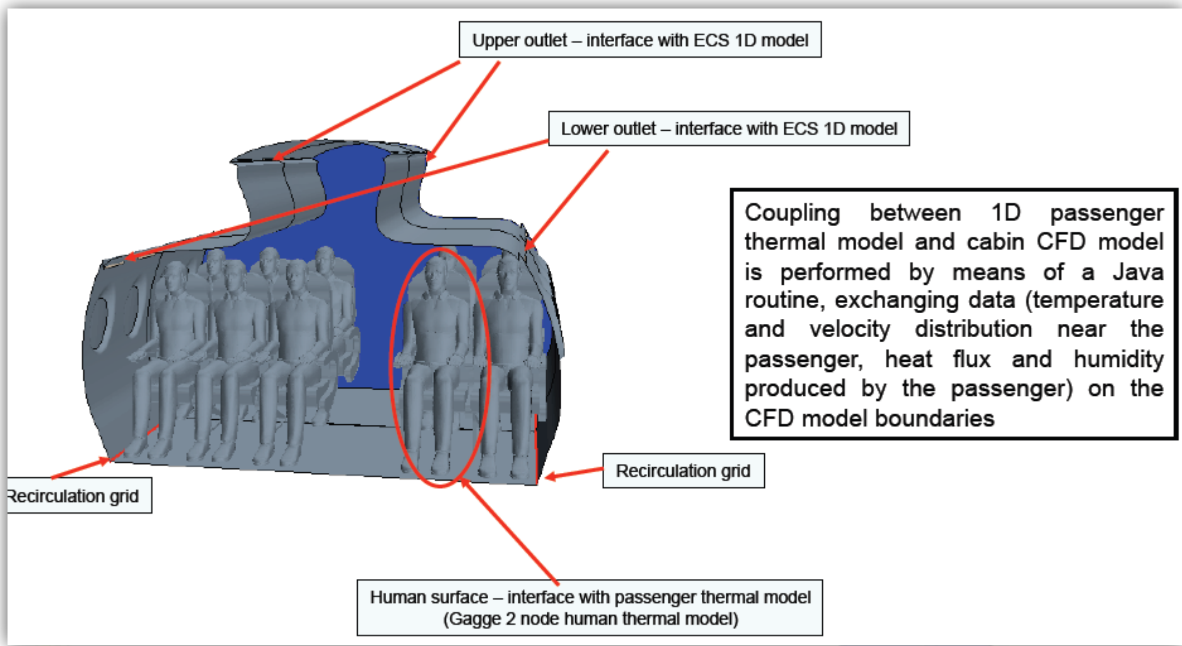
CFD Cabin Model



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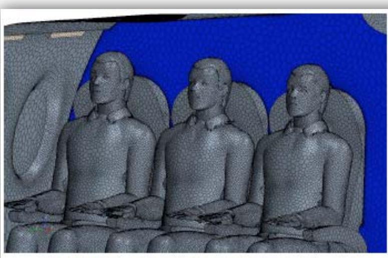
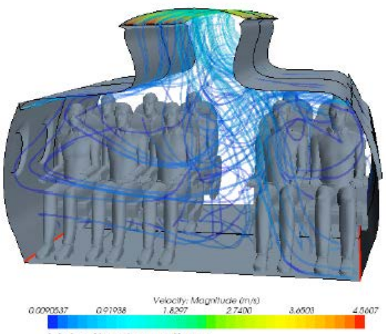
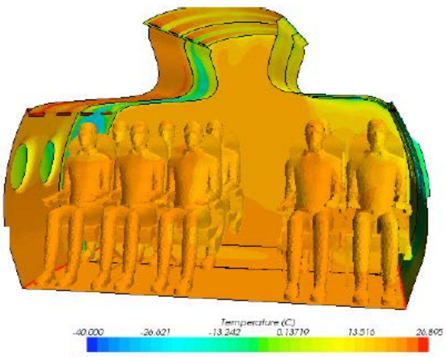
Coupled Fluid-Anatomical Model Results



Mesh model (approx 10^7 cells)



Velocity streamlines



Temperature pattern

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Conclusion

- Models such as these can include solar radiation effects, conjugate heat transfer and other important factors such as internal heat sources, electrical or mechanical
- Coupling with external codes of any dimensionality is made possible via STAR-CCM+'s JAVA macro faculties
- In the near future, STAR-CCM+ will come with it's own socket based coupling API so that users can program a coupling between STAR-CCM+ and potentially any other program

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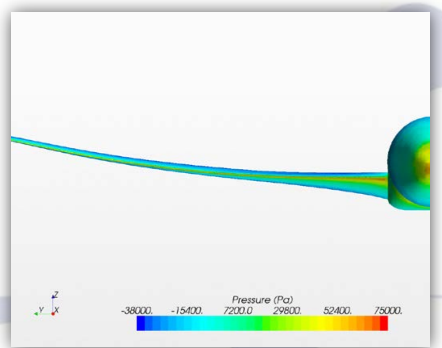
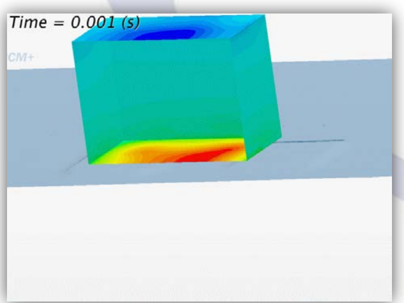
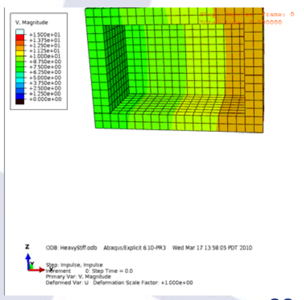
Advanced Simulation Capabilities

- Dynamic Fluid Body Interaction
- Particle dynamics
- Multiphase
- Fluid-Structure Interaction
- Electro-statics/Electro-magnetics
- Aeroacoustics
- Combustion
- Battery Modelling
- And More!







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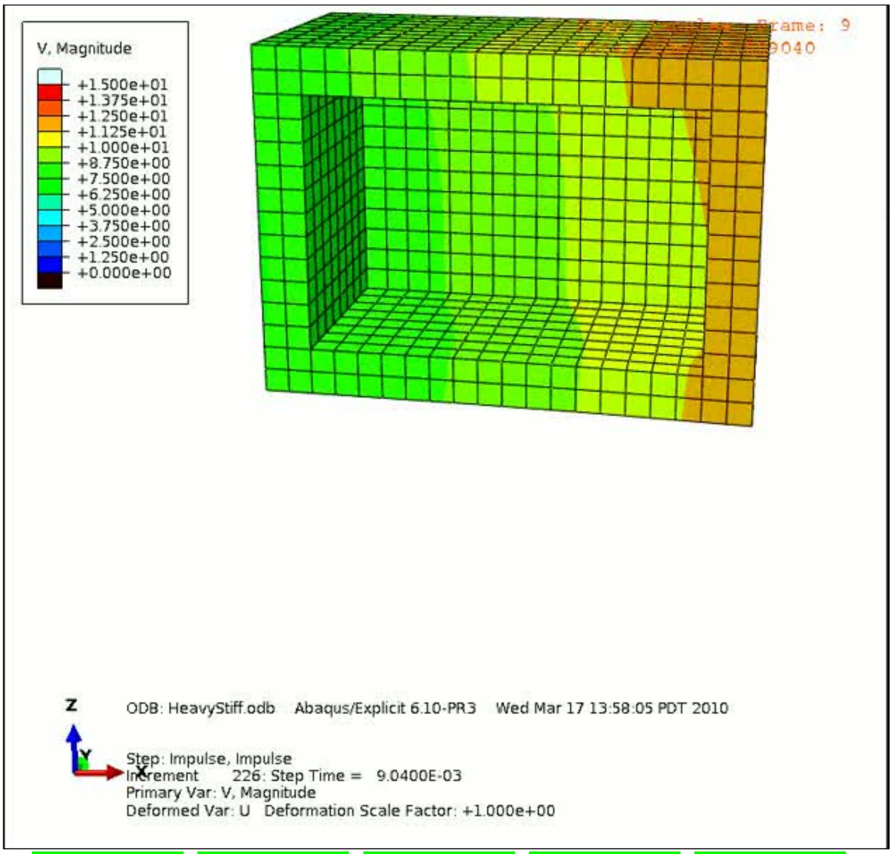

Slow Normal Fast Play/Pause Stop

Presentation Conclusion…

- STAR-CCM+ has found a wide user base in the missile, aerospace and space flight community for many applications
- The combination of advance physics and ease of use makes even the most challenging analysis manageable and possible within a reasonable timeframe
- CD-adapco's experts are always at hand to answer difficult questions and to expand the capabilities of the software to simulate the latest challenges

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…And a Request!

- CD-adapco is continually updated, improving and validating STAR-CCM+ against industrial benchmark cases, using industrial strength models the compare well with experiment/other data
- If there is such a case that you feel we should use to benchmark ourselves in this field, then please let us know!

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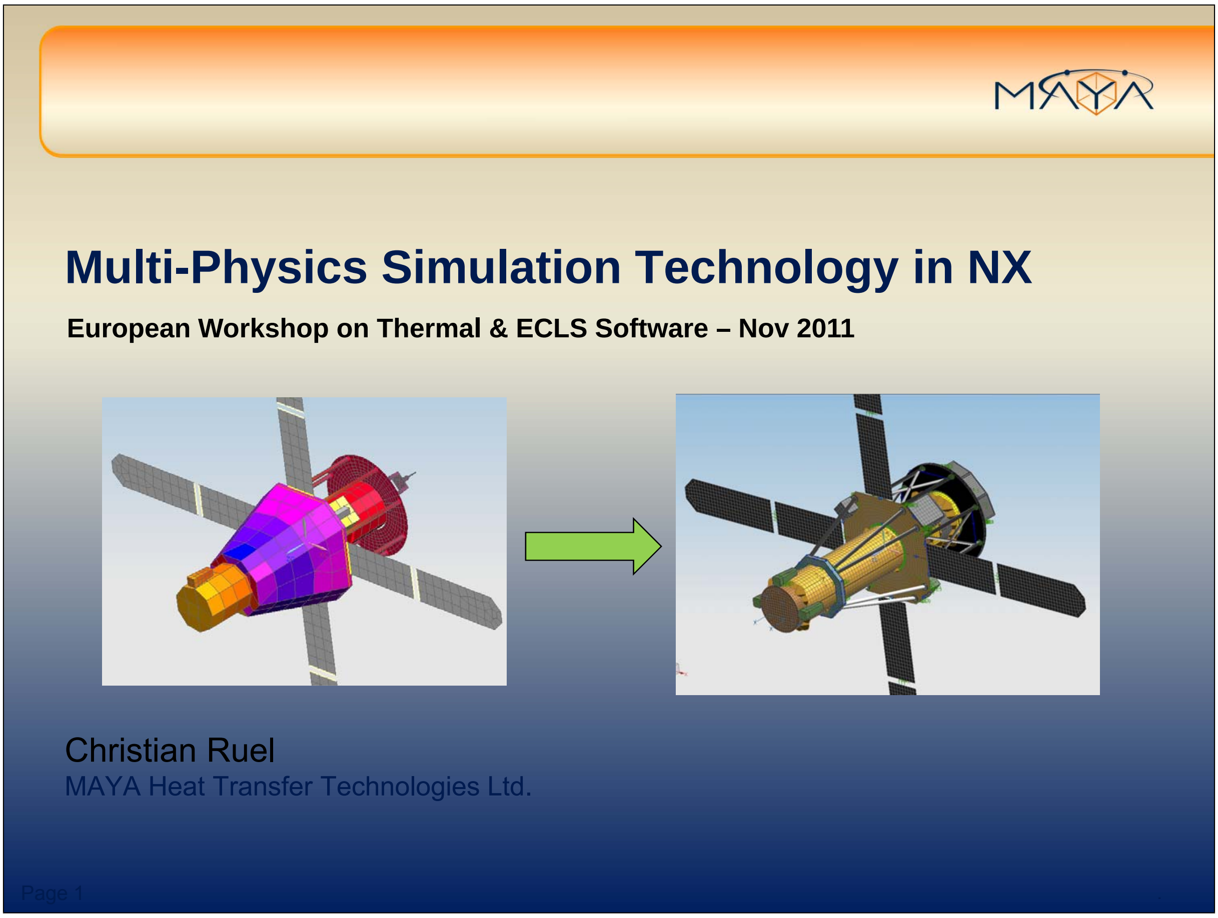
Appendix P

Multi-Physics Simulation Technology in NX

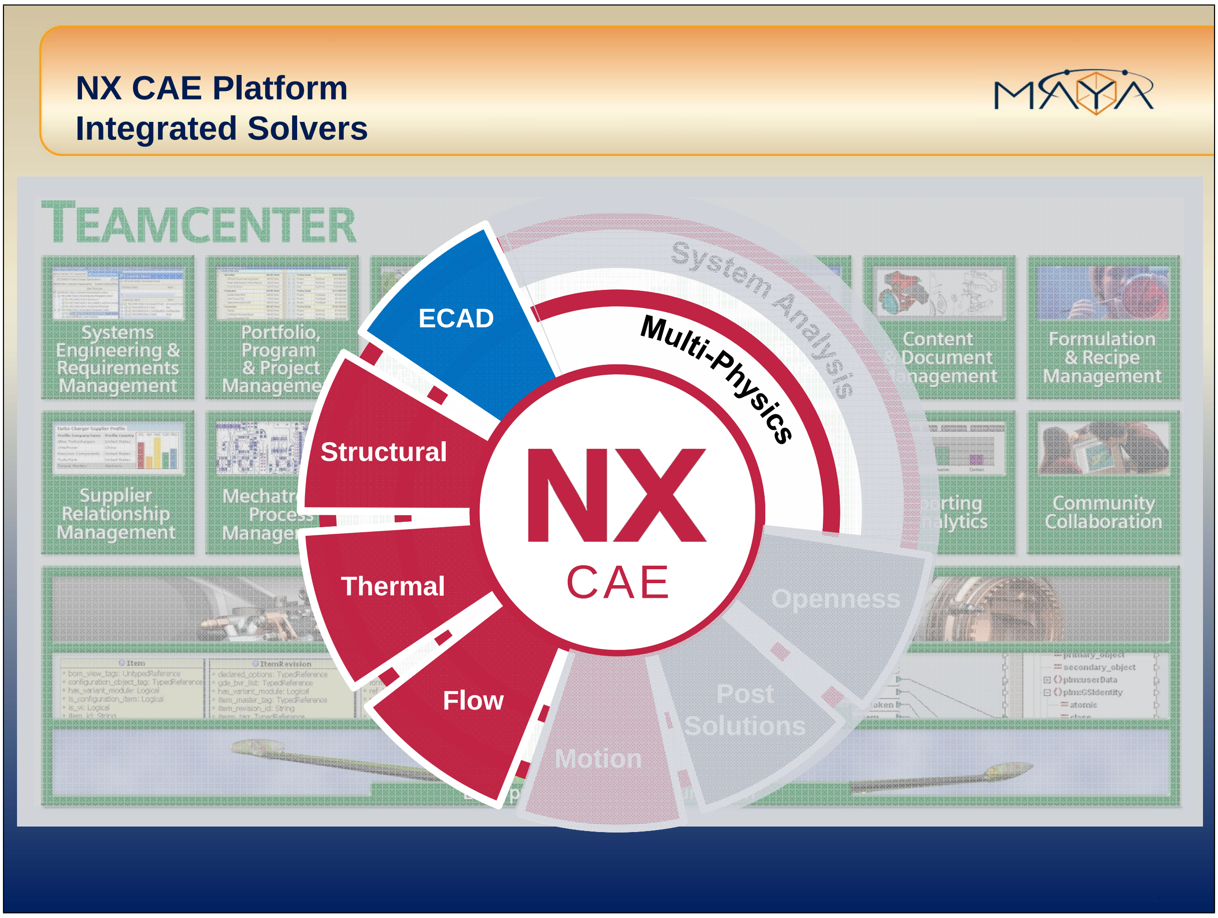
Christian Ruel
(Maya Htt, Canada)

Abstract

As engineers increasingly rely on simulation models within the framework of a collaborative environment, demands for effective solution systems that bridge the gap between multi-disciplinary fields such as thermal, flow, structural and electrical fields are becoming more and more frequent. To solve numerically these complex and coupled fields simultaneously, a comprehensive matrix that includes all the terms in all physical fields should be resolved. However, it is not only extremely difficult and challenging computationally, but also infeasible as typically different physical fields have different behavior that requires different meshing to be modeled correctly. MAYA has developed and maintained concurrent solve of thermal and flow fields which has helped solve efficiently and accurately coupled thermal and flow applications. To enable thermal and structural interaction, MAYA has developed various tools for mapping thermal results to structural models and, more recently, developed a multi-physics application that allows sequential coupling of NX Thermal and NX Nastran allowing the simulation of thermally induced large deformations on a structure and, in turn, their effects on the way heat transfer takes place.


MAYA
Multi-Physics Simulation Technology in NX
European Workshop on Thermal & ECLS Software – Nov 2011
Christian Ruel
MAYA Heat Transfer Technologies Ltd.
Page 1


NX Simulation
Unmatched breadth and depth of integrated CAE solutions
MAYA
Advanced Meshing
Linear Structures
Thermal
Flow
Motion and Controls
Assembly Management
Multi-CAD Geometry Editing
Nonlinear Structures
Electronics Systems Cooling
FE Correlation and Update
Durability
Knowledge Automation
Multi-Solver Support
Nastran
Ansys
Abaqus
LS-Dyna
Recurdyn
Adams
Response Dynamics
Space Systems Thermal
Laminate Composites
Optimization
Integrated Data Management


NX CAE Platform
Integrated Solvers
TEAMCENTER
Systems Engineering & Requirements Management
Portfolio, Program & Project Manageme
Supplier Relationship Management
Content & Document Management
Formulation & Recipe Management
Community Collaboration
ECAD
Structural
Thermal
Flow
Motion
Post Solutions
Openness
Multi-Physics
System Analysis
NX
CAE

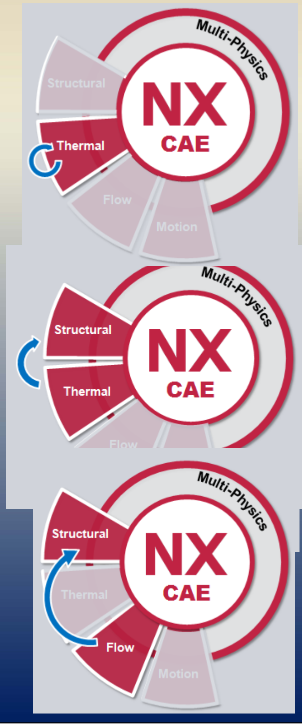

Thermal / Flow Solutions
NX SPACE SYSTEMS THERMAL
NX ELECTRONIC SYSTEMS COOLING
NX ADVANCED FLOW
NX ADVANCED THERMAL
NX FLOW
NX THERMAL

Coupled Physics Modeling

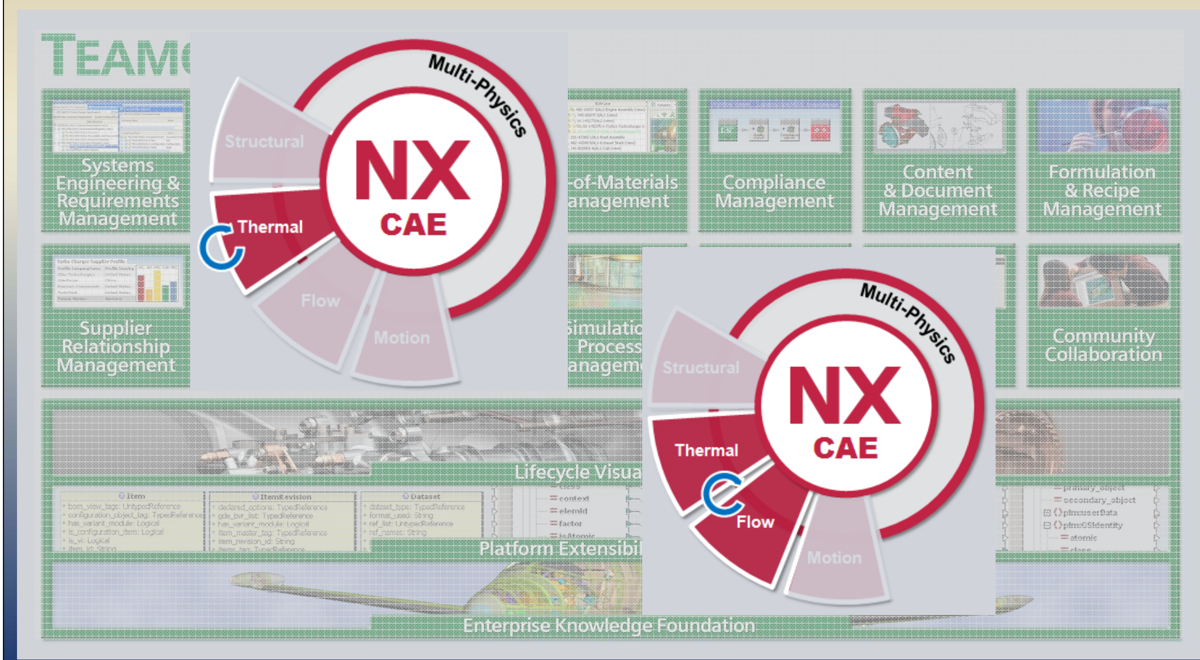
Thermal-Fluid
- NX Thermal incorporates a fully-coupled 1D fluid network solution
- NX Thermal and NX Flow are fully coupled
- Supports dissimilar thermal/fluid mesh at convecting surfaces

Thermal-Structural
- NX Thermal temperature results can be mapped onto dissimilarly-meshed structural model, as thermal pre-loads or spatially varying temperature load
- Bidirectional coupling between NX thermal and NX Nastran: effects of temperatures on the structure and, vice versa, of displacements on the thermal solution

Fluid-Structural
- NX Flow can map temperature and pressure results onto dissimilarly-meshed structural model
- One-way fluid-structural: pressure results from NX Flow used by NX Nastran to compute stresses, deformations



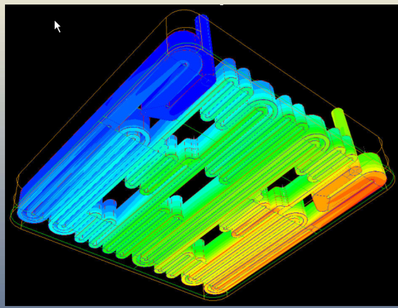
NX CAE Platform
Integrated Thermal-Fluid Solvers



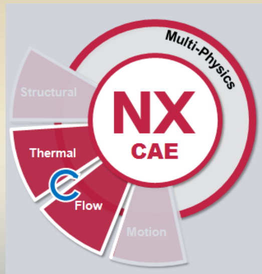
Thermal to 1D-Flow Coupling

Thermal and 1D Flow models are fully coupled

- Forced and natural convection
- Flow and convection resistances are based on known correlations
- Handles all types of conjugate heat transfer
- Mesh can be fully disjoint at the fluid/solid boundaries

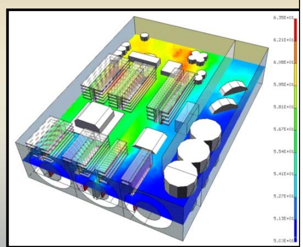


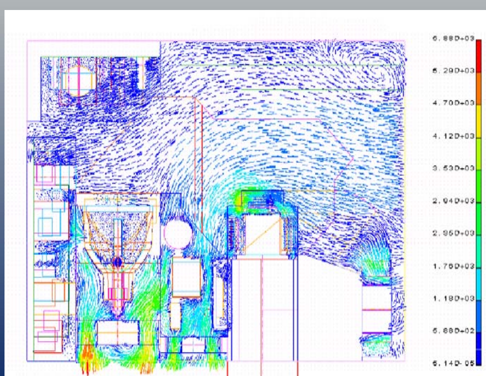
Thermal to CFD Coupling

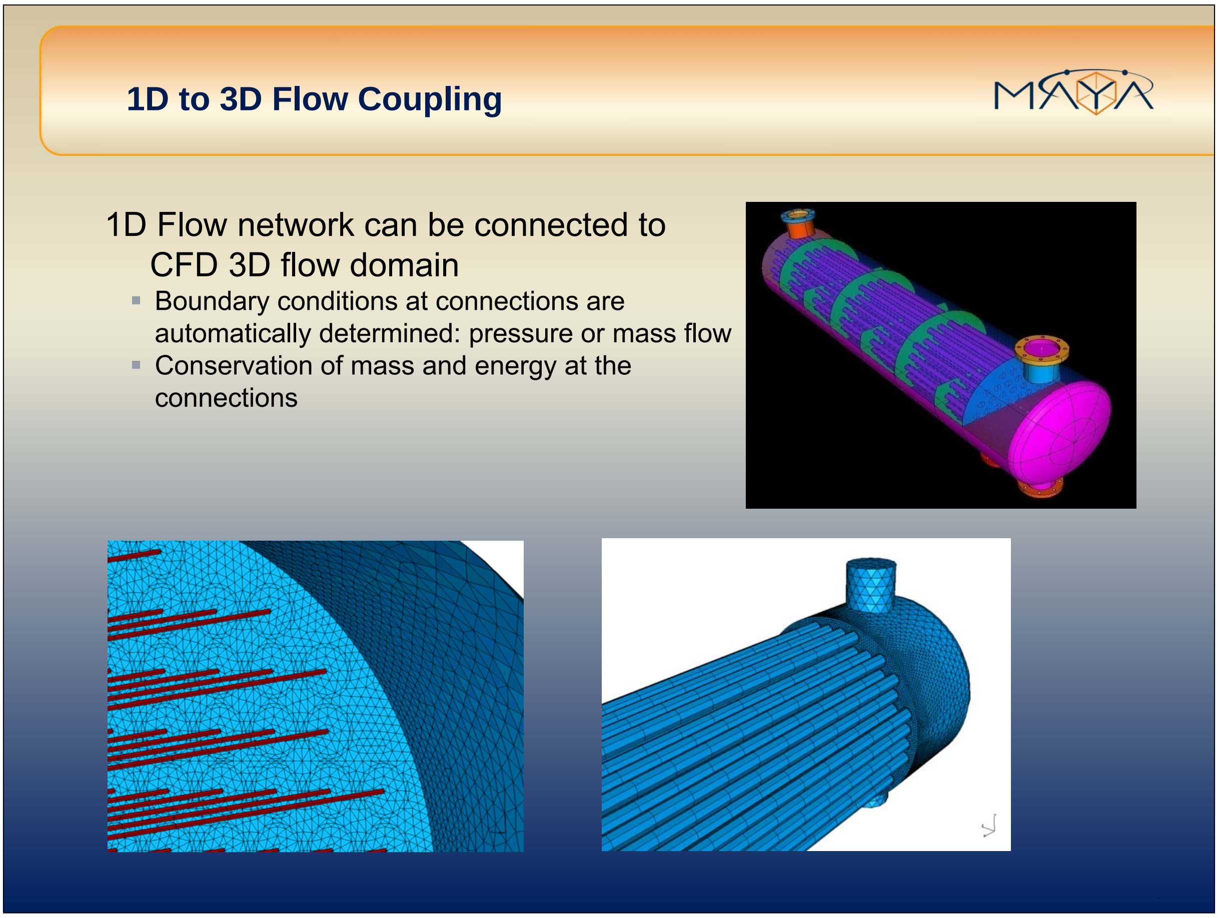


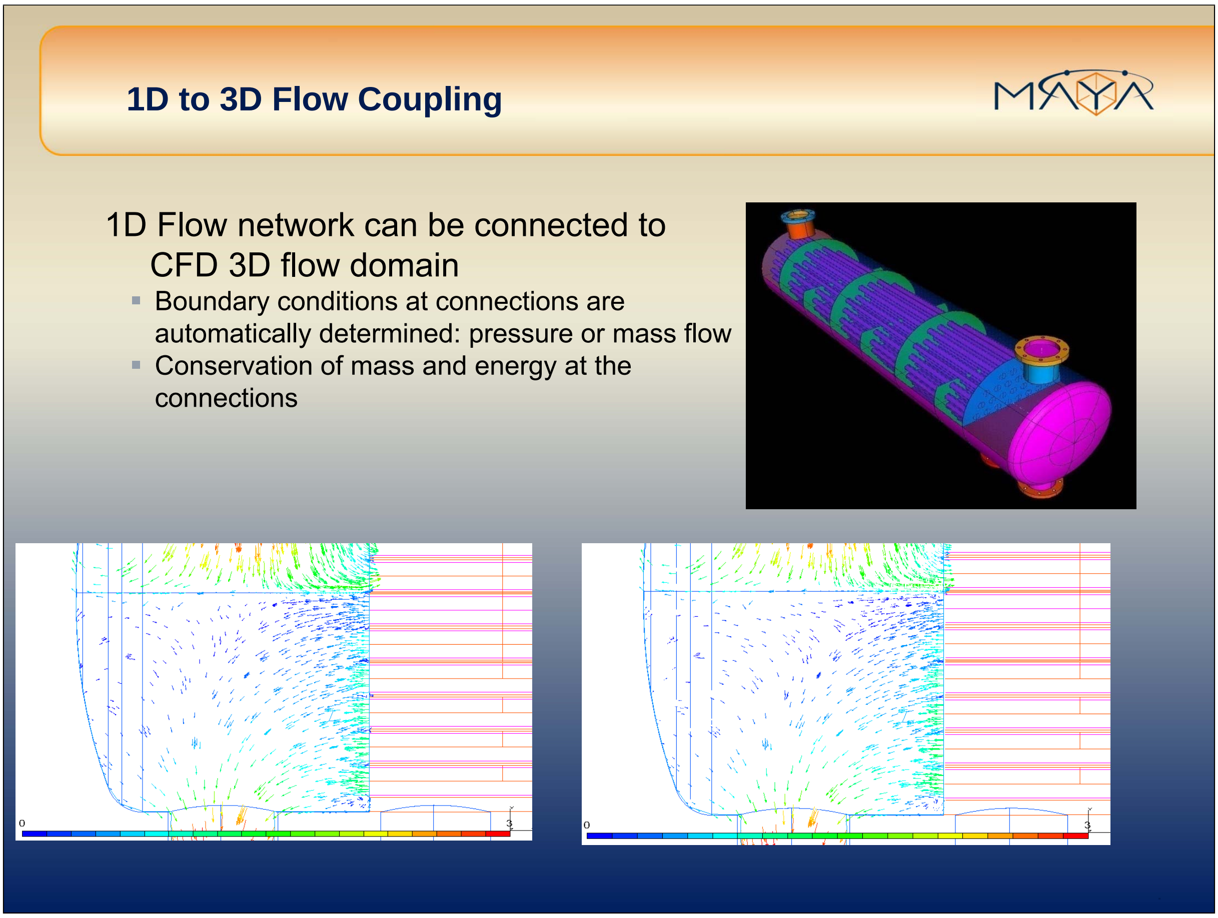
NX Thermal and NX Flow can be fully coupled

- Two separate solvers running concurrently
- Boundary condition exchange frequency can be controlled.
- Meshes can be fully disjoint at fluid/solid interface.
- Handles all types of conjugate heat transfer problems.





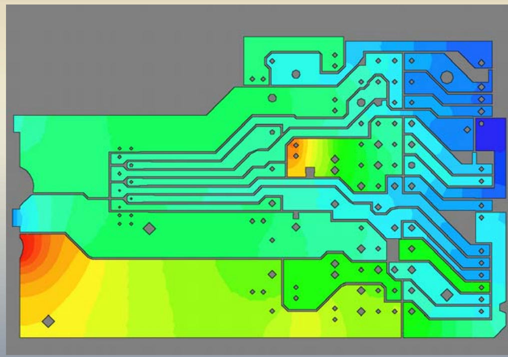

1D to 3D Flow Coupling
MAYA
1D Flow network can be connected to CFD 3D flow domain
Boundary conditions at connections are automatically determined: pressure or mass flow
Conservation of mass and energy at the connections


1D to 3D Flow Coupling
MAYA
1D Flow network can be connected to CFD 3D flow domain
Boundary conditions at connections are automatically determined: pressure or mass flow
Conservation of mass and energy at the connections

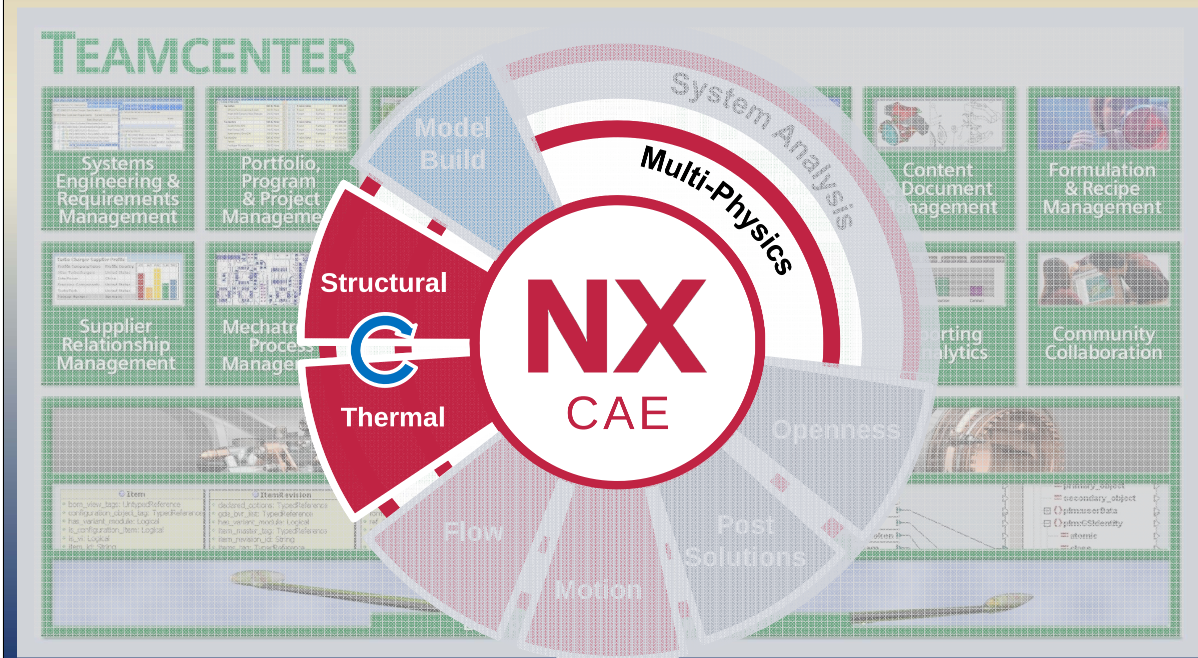
Electrical-Thermal Coupling

Joule Heating

- Electrical network solved based on material electrical resistivity and voltage and current boundary conditions
- Resulting ohmic losses are automatically applied to thermal network



NX CAE Platform
Integrated Thermal-Structural Solvers

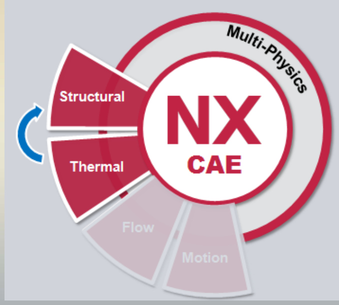


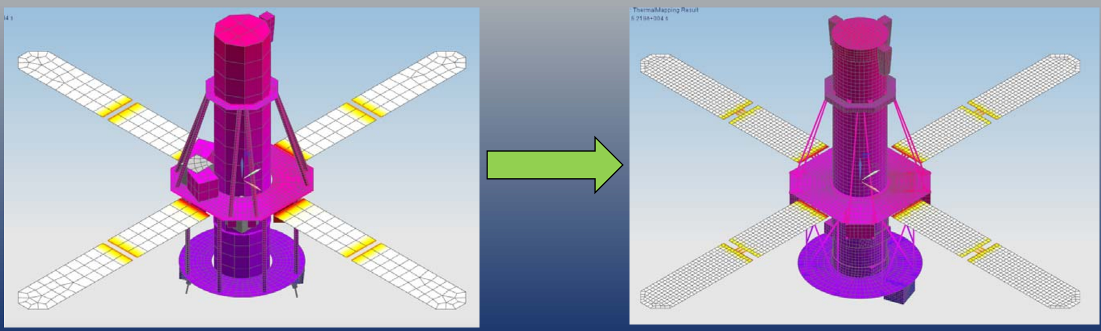
Thermo-Structural Mapping

Temperature results from an NX Thermal model can be mapped onto a structural model

- Models can have different meshes
- User can guide and control the mapping process through target sets and mapping zones.

Geometric proximity is used to find the nearest thermal element for every structural node

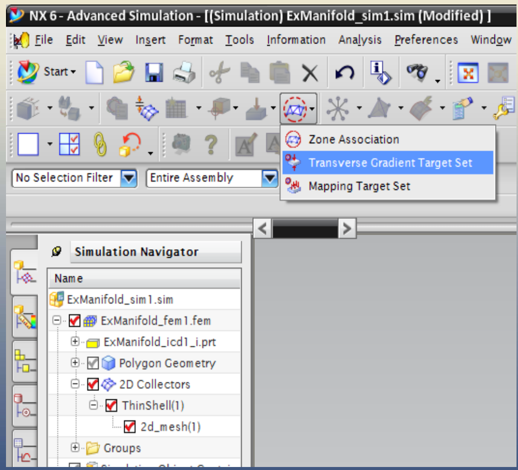


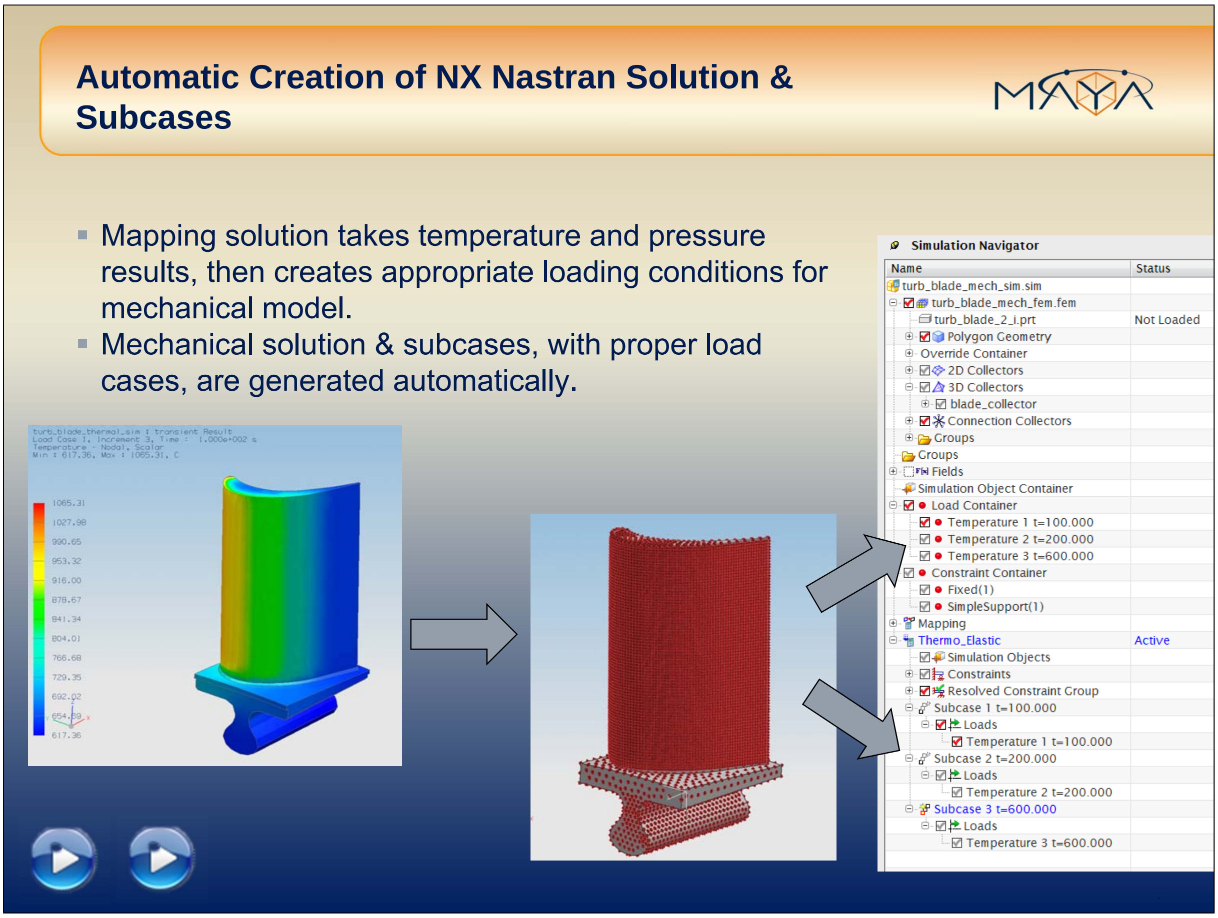


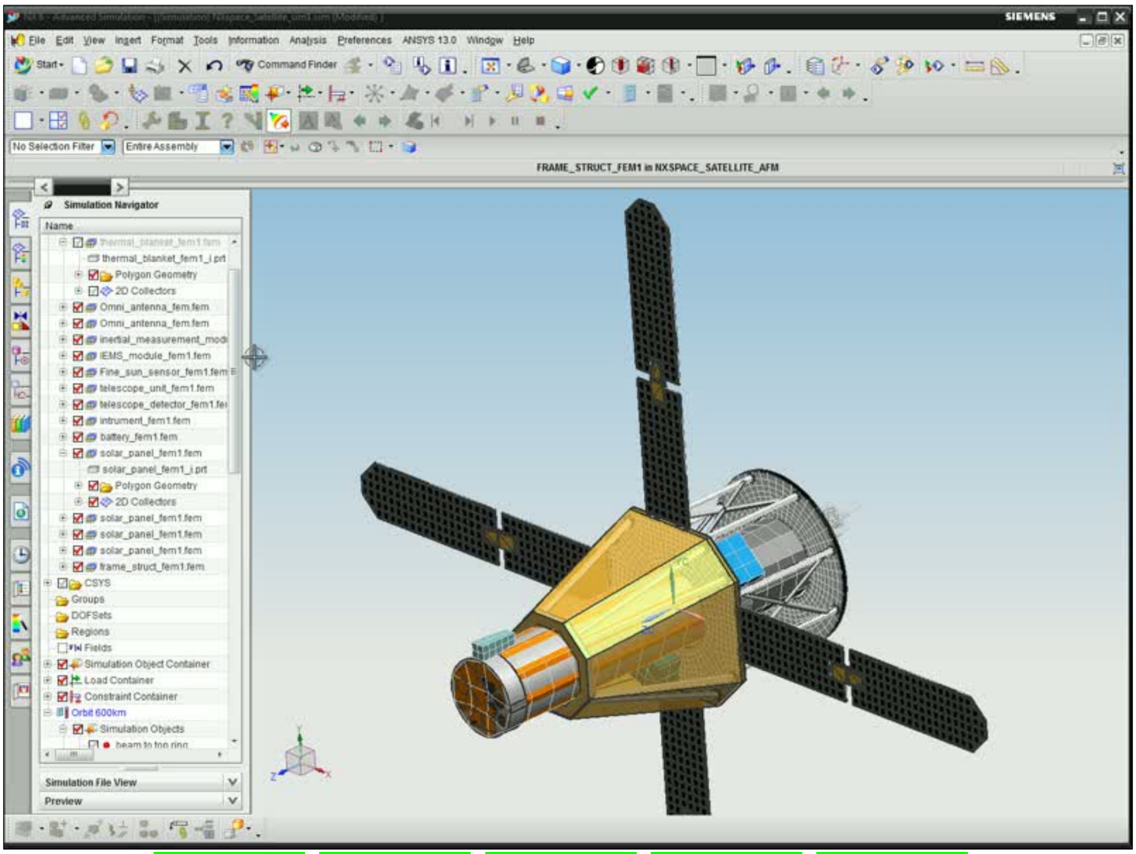
Temperature Mapping Control

User defined constraints can be used to better control the mapping process

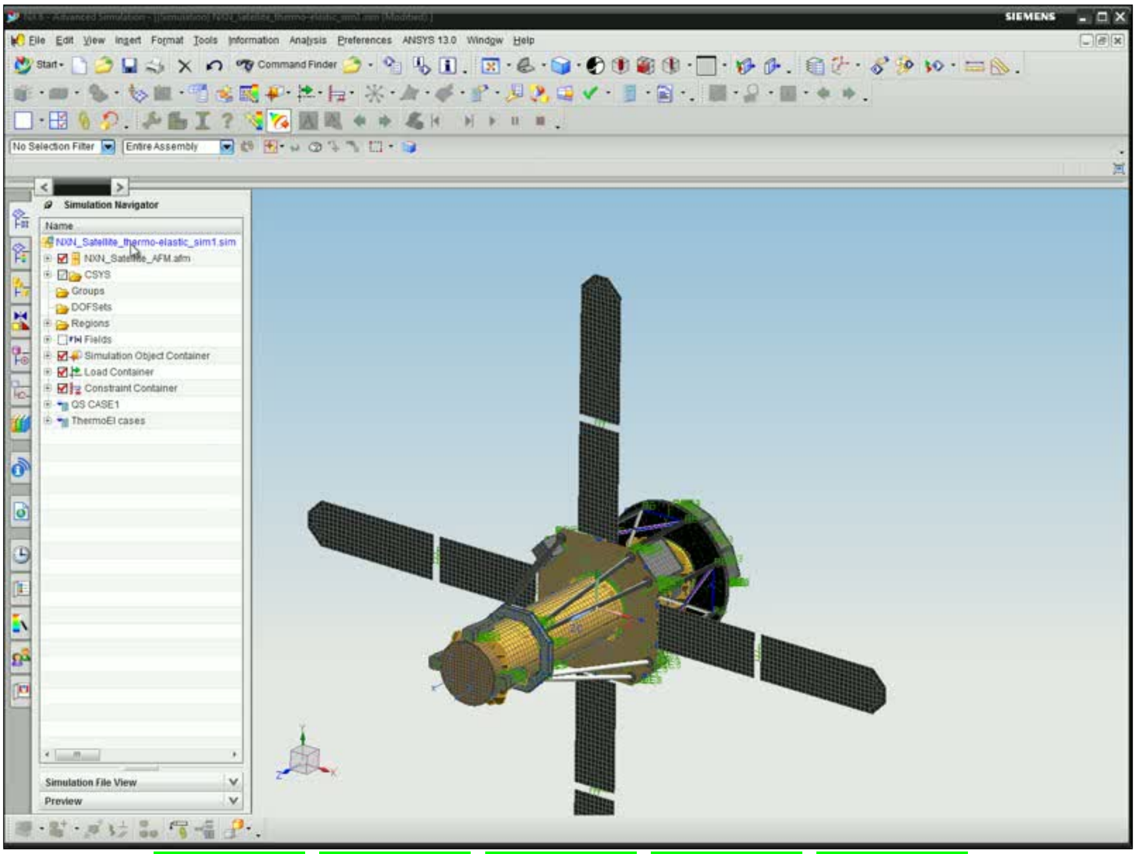
- Zone association forces the mapping between specific sets of elements
- Transverse gradient sets identifies element pairs between which a transverse gradient should be calculated
- Exclude element sets specify thermal elements to ignore during mapping, e.g. for multi-layer insulation (MLI)



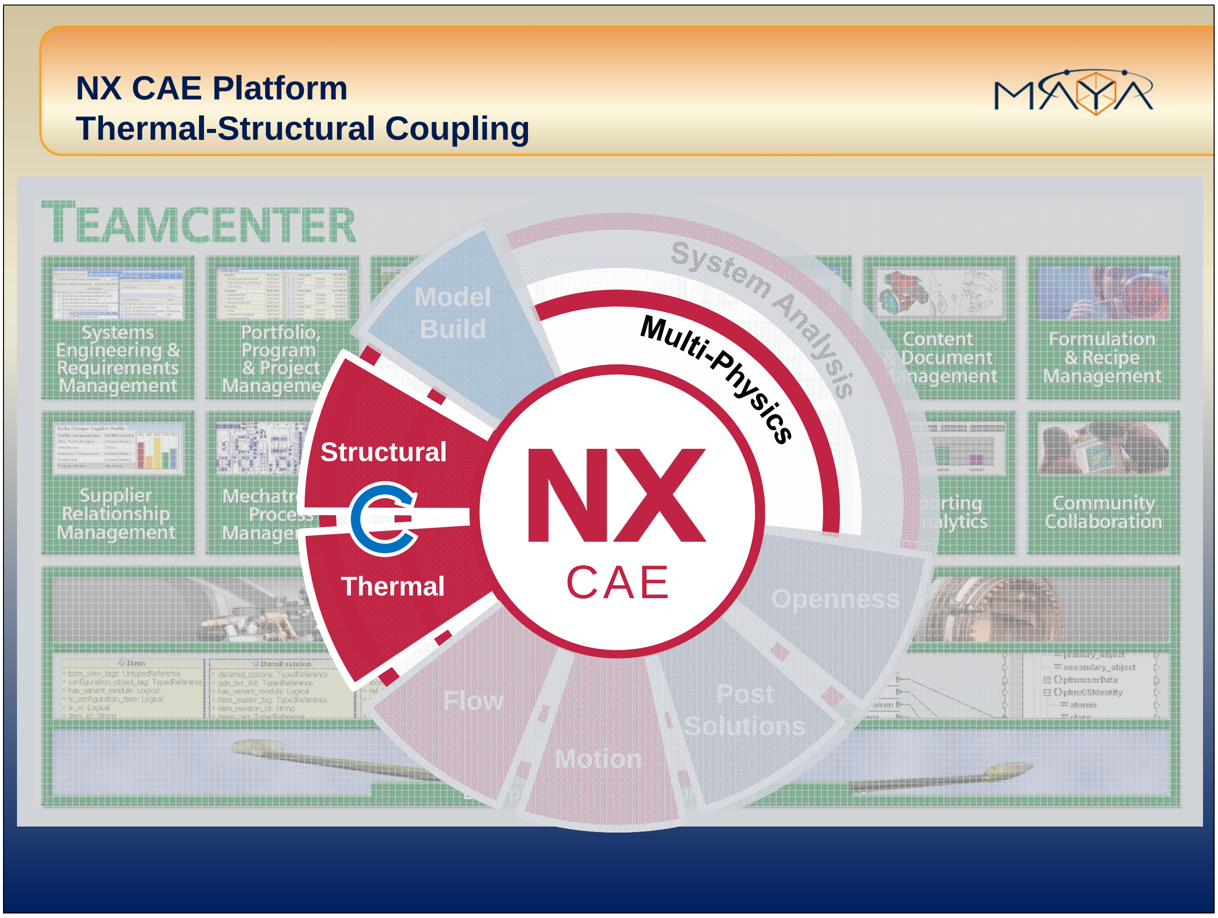




Slow | Normal | Fast | Play/Pause | Stop



Slow Normal Fast Play/Pause Stop



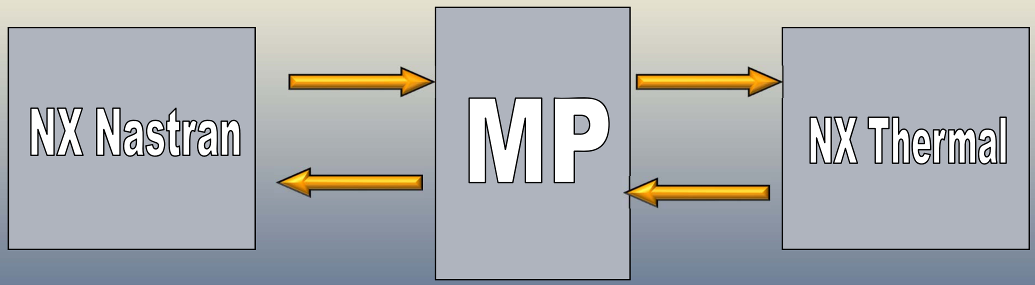
Thermal-Structural Coupling

- Bidirectional coupling between thermal and structural solutions
- Based on NX Advanced Thermal and NX Nastran Solution 101 (linear statics including linear contact)
- Two-way couplings, offers capability to analyze a variety of cases:
  - Thermal loads on structural model
  - Varying gap conductance on thermal model
  - Contact pressures
  - Changes to radiation enclosures
- Steady-steady, or transient-steady (quasi-static) problems to be supported

Thermal-Structural Coupling

NX Multi-physics (MP) Application

- MP is designed as a middleware which connects NX Thermal and NX NASTRAN



Thermal-Mechanical Coupling

Solution Data Passed between Solvers

- Solution data is passed from solvers to MP, MP maps the data onto the target solver's mesh
- Solution data from NX Nastran
  - Nodal displacements
  - Gap distances
  - Contact pressures
- Solution data from NX Thermal
  - Temperatures
  - Temperature gradients through shells
- MP manages the solve, monitors 'coupled' convergence and coupled iterations. Information passed to solvers includes:
  - Begin, end time intervals
  - Case labels for Nastran
  - Output options

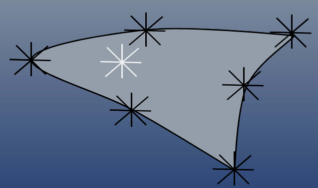
MP Mapping - Supporting Different Meshes

MP gets information about the solver meshes in the mesh setup stage

- Meshes are sent through API's from the solver
- Validation
- Similarity check (proximity)
- Identity check (same mesh?)

Mapping associations performed during solve time

- Associate a node on the target mesh to an element in the source mesh
- Provides data structure for quick interpolation of solution data



Convergence Monitoring
MP vs. Solver Responsibilities

Loose Coupling (transient only):

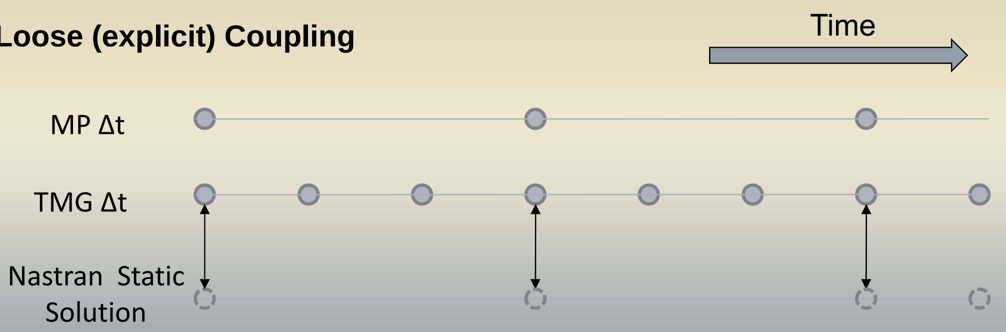
- No coupled convergence check, only one exchange of data per coupling time step

Tight Coupling:

- Solvers are responsible to compute their individual solutions to the convergence criteria specified in their input decks
- Solvers report their convergence status to MP at the end of each solve they do. MP input file has setting to determine subsequent action (CONTINUE or STOP)
- "Coupled" convergence is monitored by MP, checking either a
  - maximum norm convergence criteria, max(|Δx|)/ mean{|x|}; or
  - "L^2" criteria, $||\Delta x||_2 / ||x||_2$
- Maximum number of coupled solve iterations per time step also respected

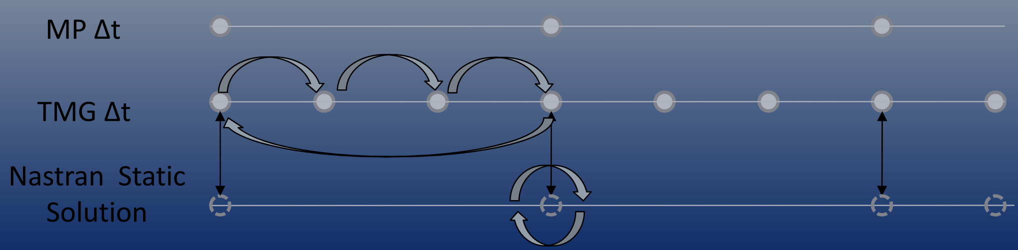
Transient Thermal/Quasi-static Mechanical

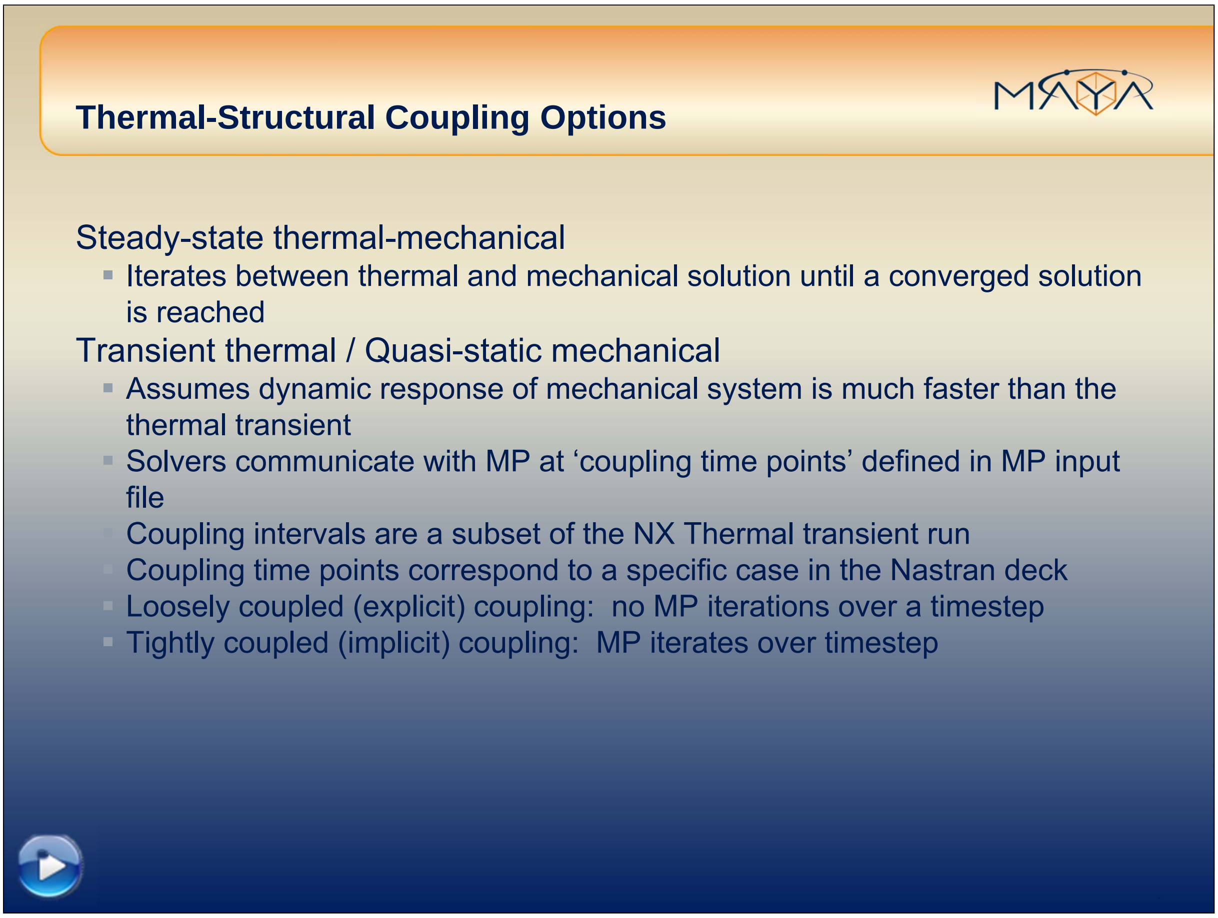
Loose (explicit) Coupling

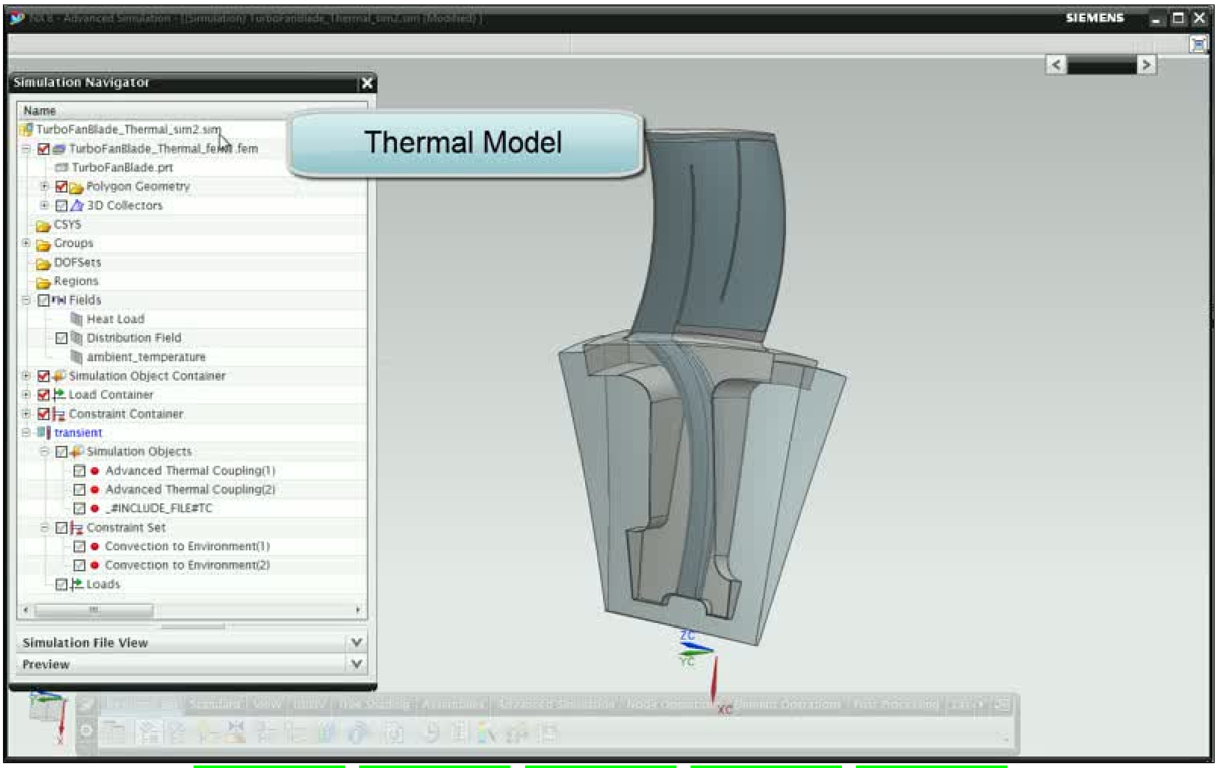


Tight (implicit) coupling

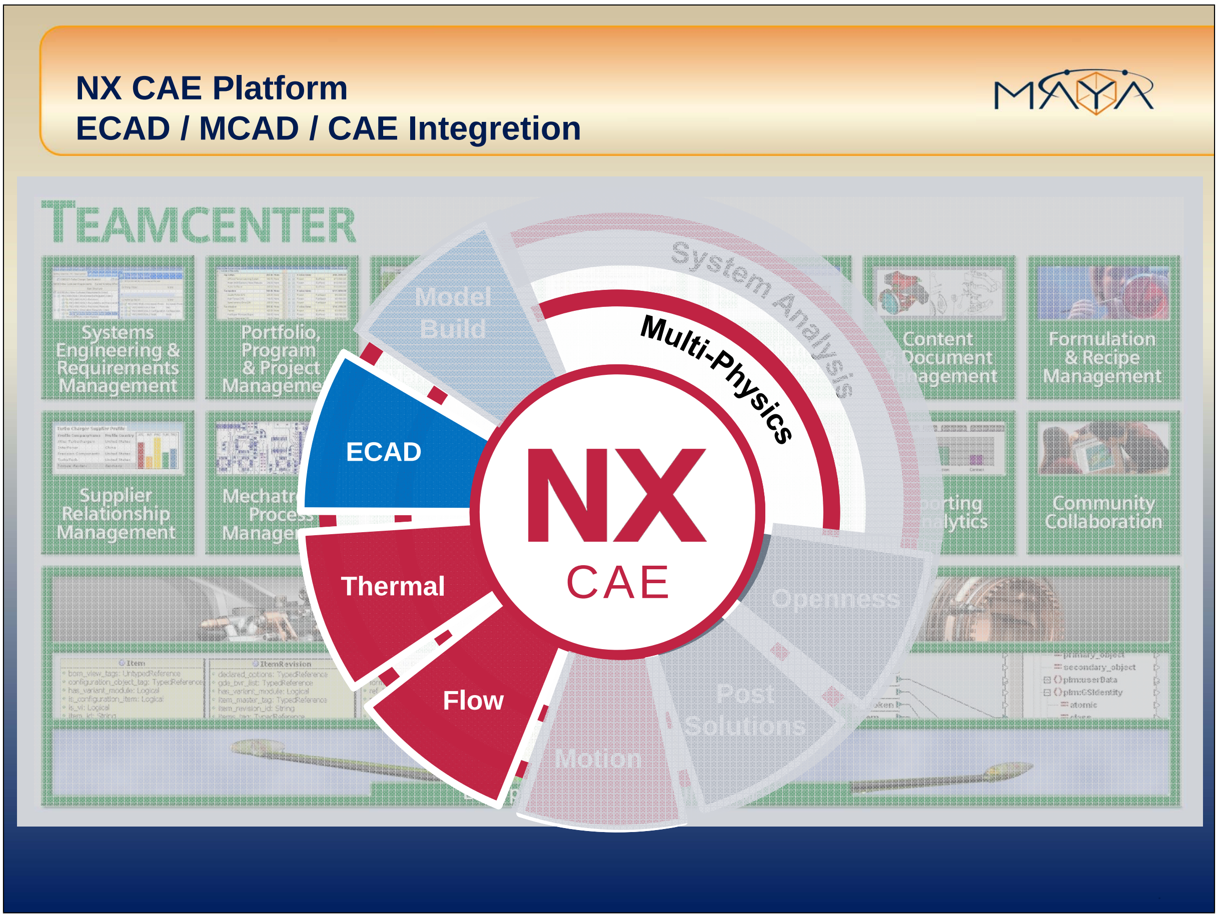
- Solvers need to support implicit coupling modes

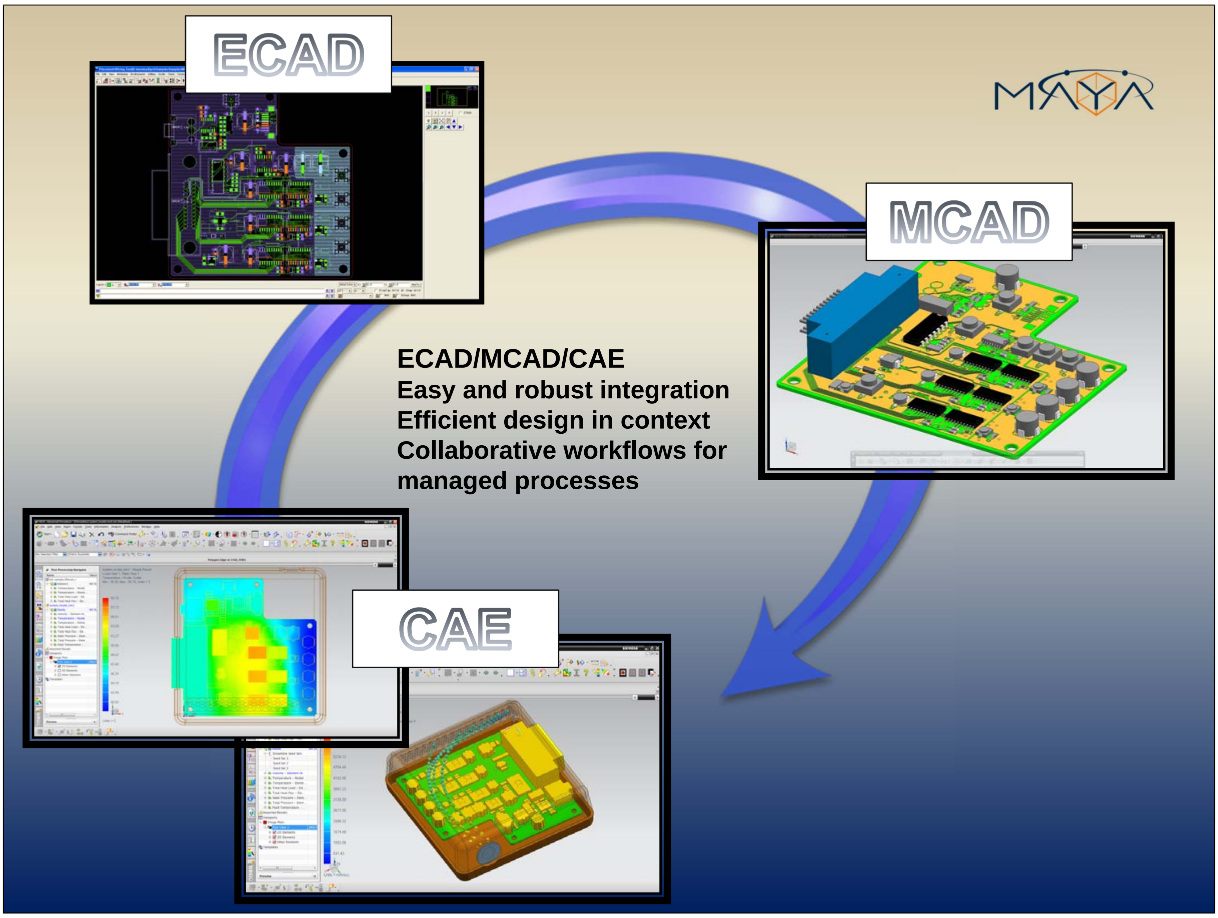


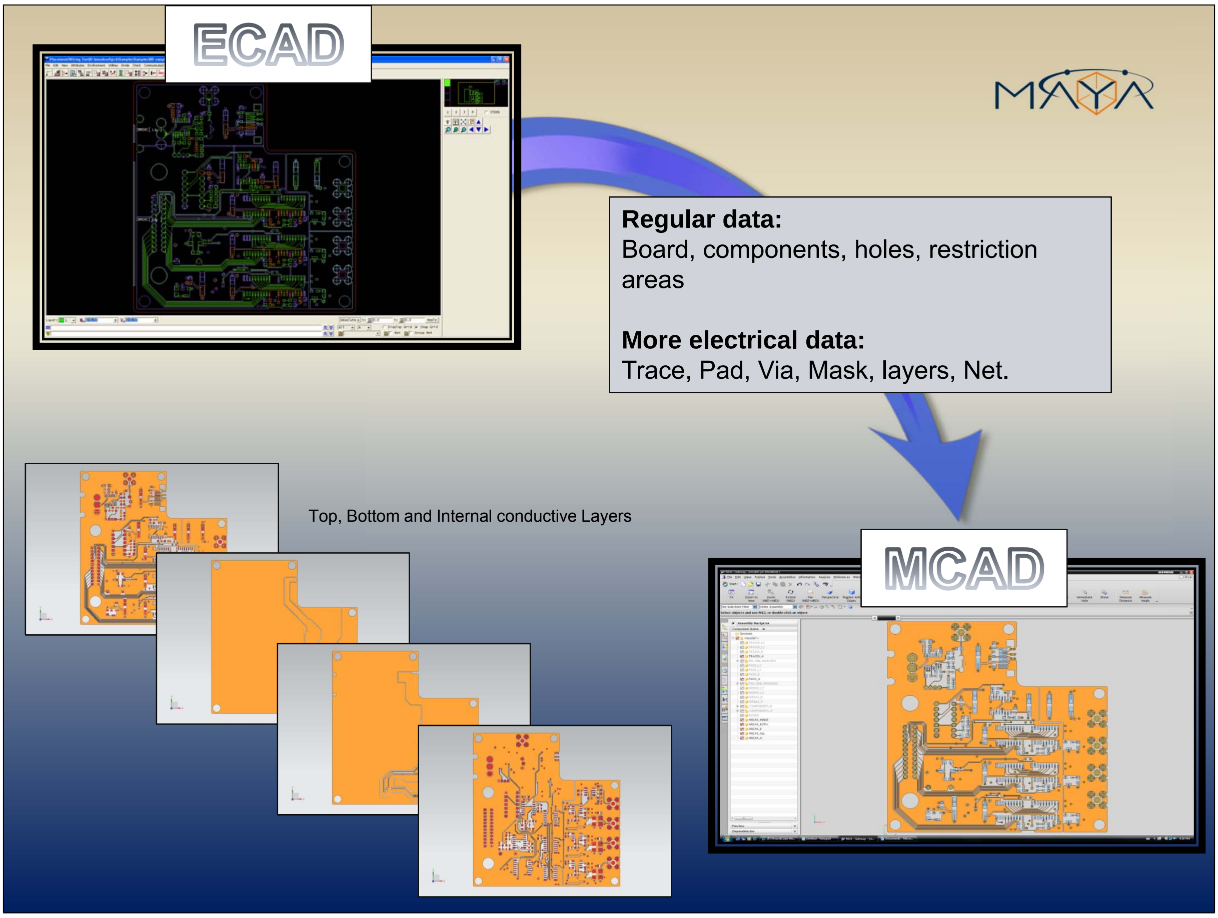


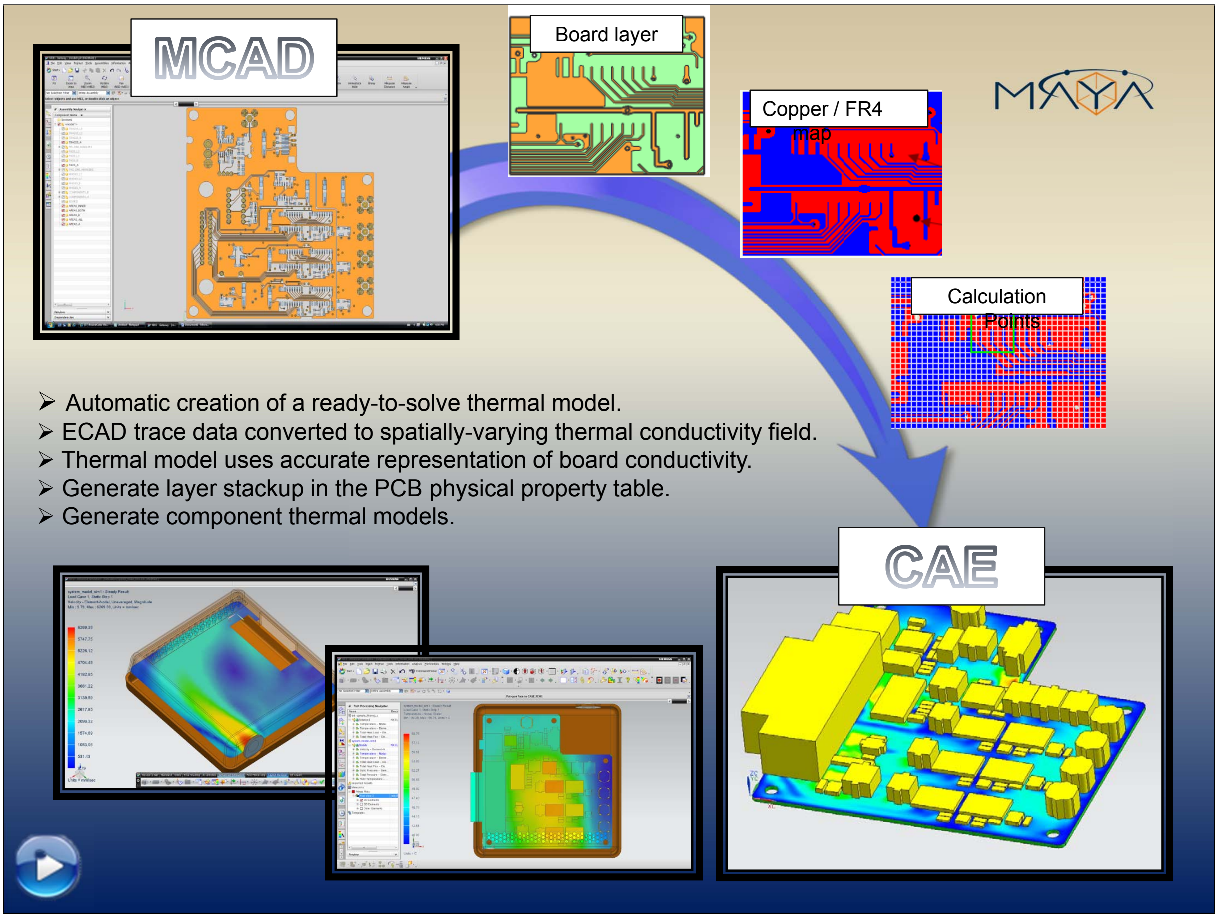


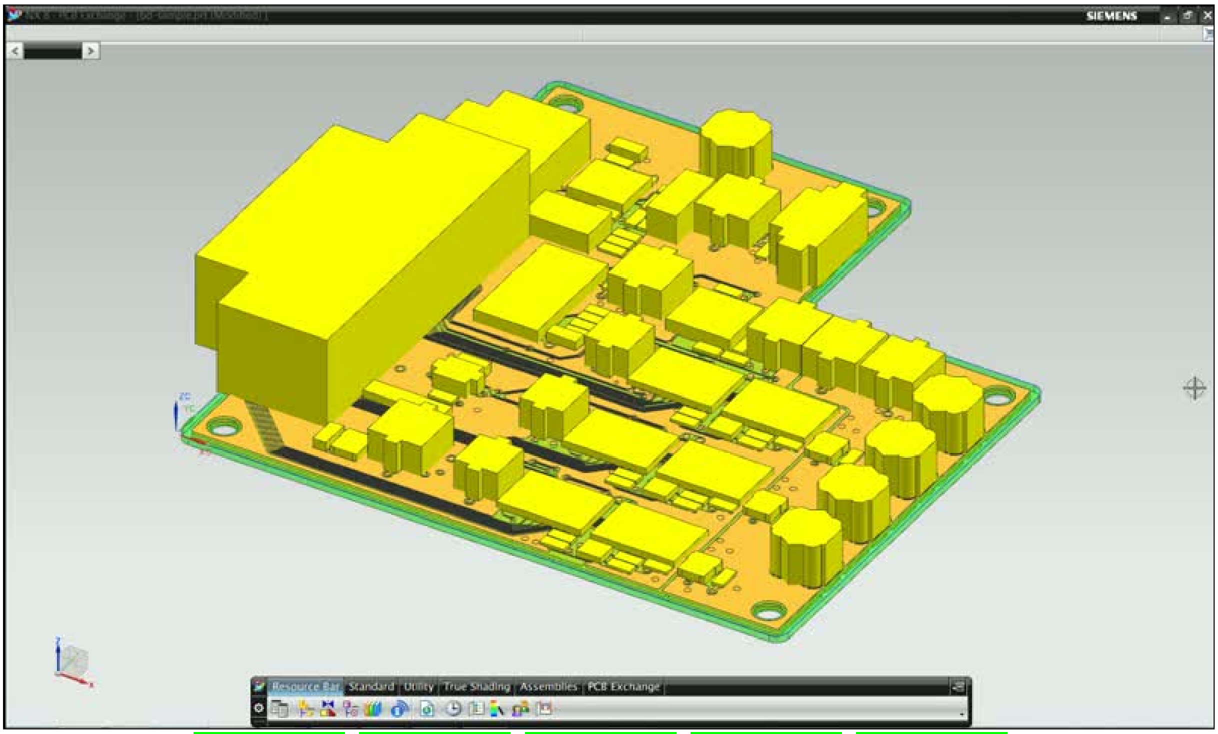
Slow Normal Fast Play/Pause Stop


NX CAE Platform
ECAD / MCAD / CAE Integretion
TEAMCENTER
Systems Engineering & Requirements Management
Portfolio, Program & Project Manageme
Content & Document Management
Formulation & Recipe Management
Supplier Relationship Management
Community Collaboration
Model Build
System Analysis
Multi-Physics
ECAD
Thermal
Flow
Motion
Post Solutions
Openness
NX
CAE

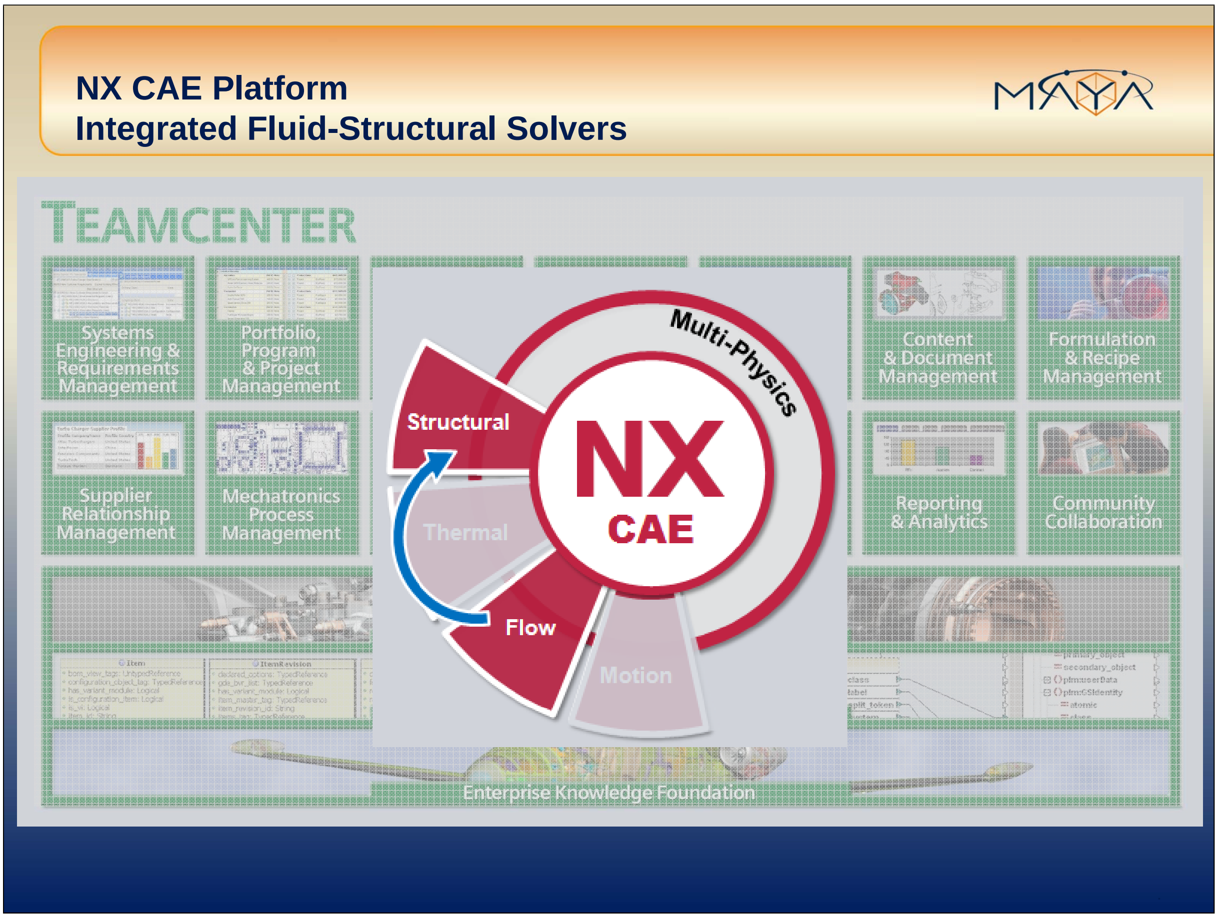

ECAD
MCAD
CAE
ECAD/MCAD/CAE
Easy and robust integration
Efficient design in context
Collaborative workflows for managed processes


ECAD
MAYA
Regular data:
Board, components, holes, restriction areas
More electrical data:
Trace, Pad, Via, Mask, layers, Net.
Top, Bottom and Internal conductive Layers
MCAD

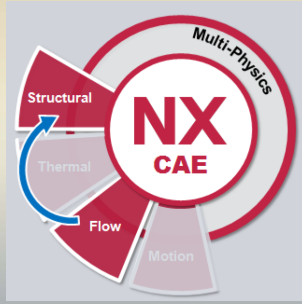

MCAD
Board layer
Copper / FR4 map
MAYA
Calculation Points
➢ Automatic creation of a ready-to-solve thermal model.
➢ ECAD trace data converted to spatially-varying thermal conductivity field.
➢ Thermal model uses accurate representation of board conductivity.
➢ Generate layer stackup in the PCB physical property table.
➢ Generate component thermal models.
CAE



Slow Normal Fast Play/Pause Stop



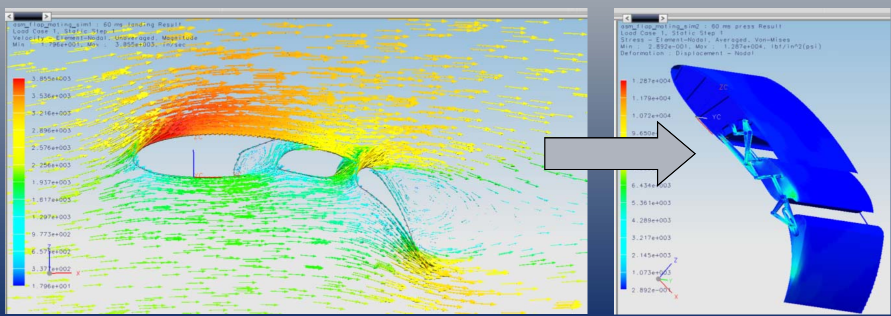
Fluid – Structure Mapping



Structural Solvers Supported

- NX Nastran
- MSC.Nastran
- ANSYS
- ABAQUS
- LS-Dyna

Fully dissimilar and disjoint flow and structural model supported



Thank You

christian.ruel@mayahtt.com

Appendix Q

Thermal Correlation of BepiColombo MOSIF 10 Solar Constants Simulation Test

Savino De Palo Tiziano Malosti
(ThalesAlenia Space, Italy)

Gianluca Filiddani
(Sofiter System Eng., Italy)

Abstract

BepiColombo is the first European mission directed so close to the Sun and will provide the greatest advance in understanding Mercury. It is an international cooperation coordinated by the European Space Agency (ESA) with the participation of the Japan Aerospace Exploration Agency (JAXA).
The mission is composed of four spacecraft, the most important of which are the Mercury Planetary Orbiter (MPO), which will map and study the planet surface and interior from a low orbit, and the Mercury Magnetospheric Orbiter (MMO), whose main goal is to investigate the magnetosphere of the planet closer to the Sun.
One of the most complex and demanding activities related to the BepiColombo thermal control concerns the design of the MOSIF, the solar shield which will protect the Japanese module (MMO) during the journey from the Earth to Mercury. BepiColombo will be exposed to an ever increasing solar heat flux along the whole cruise: up to ten times higher, once orbiting around Mercury, than when launched from the Earth.
A Thermal Balance Test (TBT) of MOSIF was held in ESA/ESTEC in November 2010. This presentation compares two different methods for correlating the test data with the TMM analysis results.
The first part is focused on a brief description of the activities related to the correlation of MOSIF TMM; this work has been carried out by applying the rules specified by a TAS-I internal procedure. The second part reports the process followed to achieve the same correlation level in a different way, which consists in implementing a stochastic approach by means of iSight™. Eventually, advantages and disadvantages in using these two different methods are highlighted.

THERMAL CORRELATION OF BEPICOLOMBO MOSIF 10 SOLAR CONSTANTS SIMULATION TEST

Written by: *Tiziano Malosti, Gianluca Filiddani*

Presented by: *Savino De Palo*

BS- Infrastructure and Transportation

25th European Workshop on Thermal & ECLS S/W, 8-9 Nov. 2011

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INTRODUCTION

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- MOSIF ⇨ BepiColombo solar shield which shades the MMO (the Japanese orbital module) during the cruise mission phase

- Two different approaches for the correlation of MOSIF TMM with 10 solar constants Thermal Balance Test (TBT) held in ESA/ESTEC in November 2010 :

  1. Standard / classical method
  2. Optimization / DoE approach using iSight™

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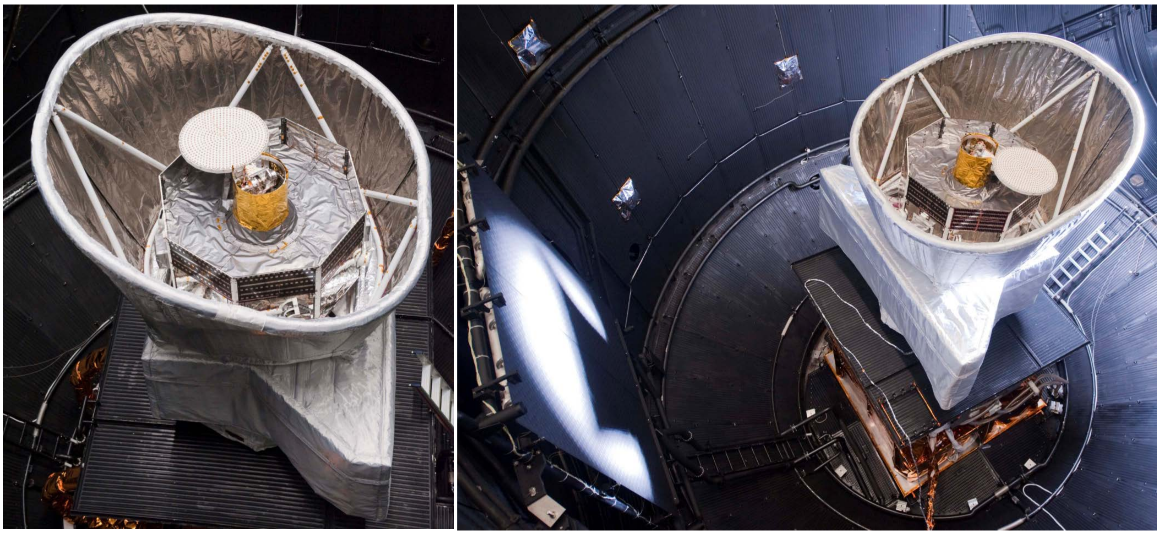
MOSIF TEST ARTICLE INTO ESTEC LARGE SPACE SIMULATOR (LSS)



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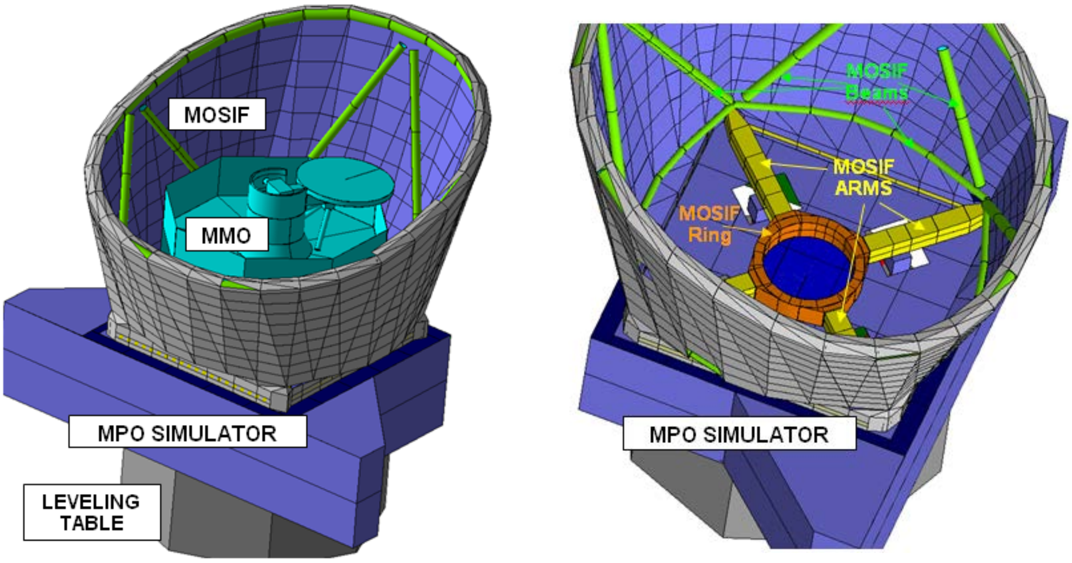
ESARAD GMM OF MOSIF TEST ARTICLE



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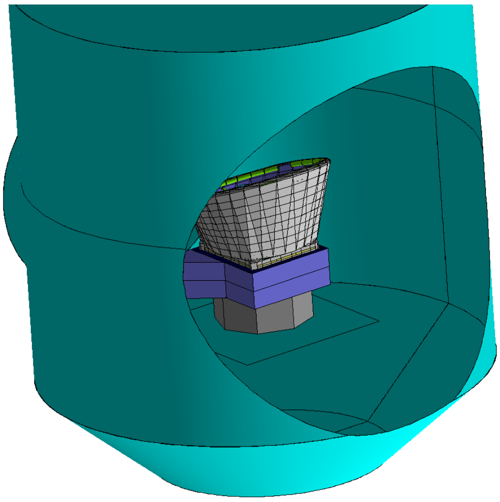
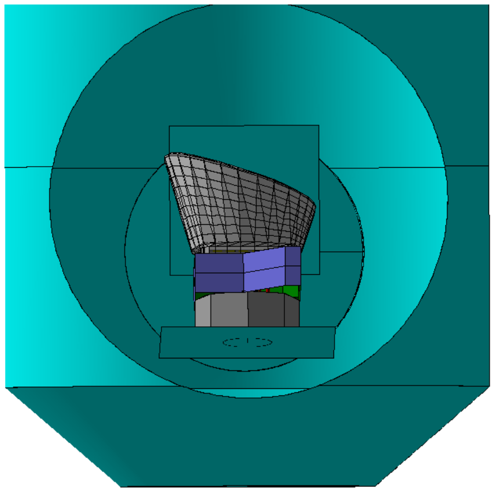
MOSIF TEST ARTICLE INTO LSS – ESARAD MODEL



NOMINAL POSITION



SURVIVAL POSITION

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STANDARD CORRELATION

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STANDARD CORRELATION MAIN RESULTS

1. GMM Replacement
   - Original MOSIF Sunshade GMM provided by manufacturer did not reproduce the concavity on +Y side (see next chart) of the test item
   - Original GMM replaced with a new one derived from CATIA model, meshed with HyperMesh tool and exported to ESATAN-TMS via NASTRAN .bdf import capability
2. MLI parameters refinement
   - MLI thermo-physical parameters (equivalent emissivities used in radiative conductor calculation) were updated to obtain a proper simulation of MLI performances

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STANDARD CORRELATION

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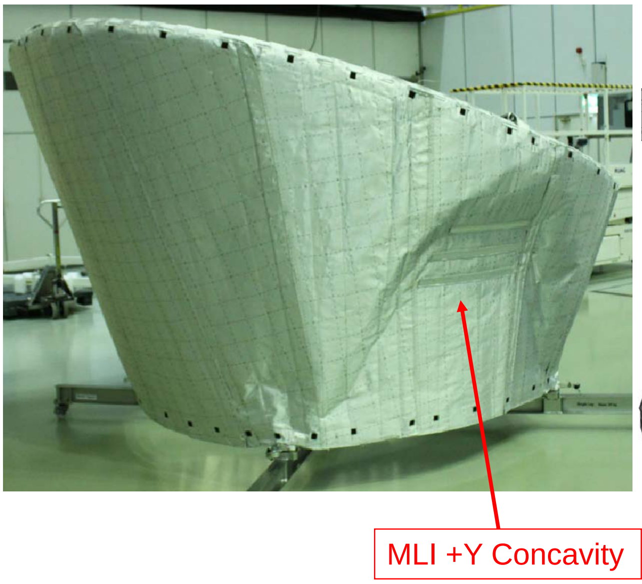
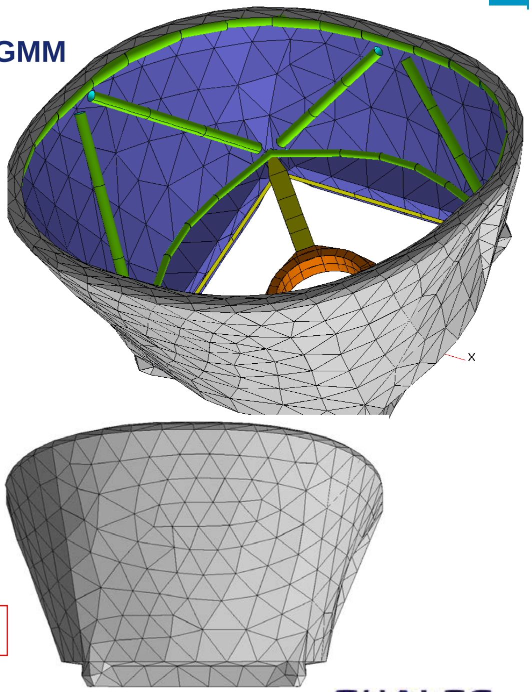
MOSIF SUNSHADE +Y CONCAVITY & NEW GMM





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STANDARD CORRELATION

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- MOSIF Sunshade TMM was correlated with TBT results, obtaining **fully acceptable values of Delta-T and standard deviation (σ) for all cases** as showed by table in the following slide

- **The correlated values of MLI** thermo-physical parameters are reported in the table here below

Thermo-Physical Parameter	Test article items	Old Value	Updated value
Equivalent emissivity in the radiative conductor	External 1st layer (Nextel) → MLI ext 2nd layer	*0.140*	**0.140**
Equivalent emissivity in the radiative conductor	MLI ext 2nd layer → MLI inner layer Titanium **(APPLIED IN THE +X HGA CONCAVITY)**	*0.019*	**0.023**
Equivalent emissivity in the radiative conductor	MLI ext 2nd layer → MLI inner layer Titanium **(APPLIED IN THE MLI GAP)**	*0.019*	**0.024**
Equivalent emissivity in the radiative conductor	MLI ext 2nd layer → MLI inner layer Titanium **(ALL THE OTHER SUNSHADE ZONES)**	*0.019*	**0.019**

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STANDARD CORRELATION

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MOSIF SUNSHADE MLI	Phase 3 - Cold calibration			Phase 4 - Hot Final Cruise			Phase 6 - Survival Sun from +X			Phase 7 - Intermediate Cruise			Phase 8 - Initial Cruise		
	Post Correlation results	TEST DATA 02/12/2010 18.51.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 04/12/2010 13.07.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 05/12/2010 14.46.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 07/12/2010 10.42.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 08/12/2010 16.21.00	Δ T (Test-Analysis)
+Y UPPER (Outer Ti layer)	-148.0	-138.6	9.4	44.7	79.1	34.4	-79.8	-52.6	27.2	-24.7	-0.7	24.0	-82.4	-61.2	21.2
+Y UPPER (Ti layer behind nextel)	-176.2	-133.2	43.0	268.7	313.6	44.9	-8.8	-16.3	-7.5	146.1	180.4	34.4	37.9	68.0	30.1
+Y MEDIUM (Outer Ti layer)	-131.3	-135.3	-4.0	48.7	77.2	28.5	-60.8	-14.6	46.2	-20.1	-0.2	19.9	-75.3	-60.0	15.3
+Y MEDIUM (Ti layer behind nextel)	-173.2	-132.6	40.6	272.3	303.0	30.7	32.8	118.1	85.3	148.9	172.5	23.6	40.0	61.5	21.5
+Y LOWER (Outer Ti layer)	-112.6	-125.4	-12.8	56.3	98.3	42.0	-49.9	6.9	56.8	-12.2	15.1	27.2	-64.7	-49.5	15.2
+Y LOWER (Ti layer behind nextel)	-168.8	-127.8	41.0	274.1	332.8	58.7	27.6	147.4	119.8	150.3	193.3	43.0	41.2	76.1	34.9
+Y+X UPPER (Outer Ti layer)	-148.1	-148.3	-0.3	-3.5	17.6	21.1	43.9	92.2	48.3	-60.3	-36.2	24.1	-105.1	-81.5	23.6
+Y+X UPPER (Ti layer behind nextel)	-176.1	-150.1	26.0	172.5	166.2	-6.3	264.7	283.2	18.5	71.9	65.2	-6.7	-16.6	-26.9	-10.3
+Y+X MEDIUM (Outer Ti layer)	-130.2	-143.8	-13.6	2.5	22.7	20.2	47.9	110.7	62.8	-53.2	-29.5	23.7	-94.7	-74.6	20.1
+Y+X MEDIUM (Ti layer behind nextel)	-172.8	-150.7	22.1	174.6	173.6	-1.0	269.8	346.8	77.0	73.5	78.1	4.6	-15.3	-16.0	-0.7
+Y+X LOWER (Outer Ti layer)	-106.3	-138.2	-31.9	4.4	6.2	1.8	56.1	118.4	62.3	-46.4	-39.5	6.9	-80.3	-78.1	2.2
+Y+X LOWER (Ti layer behind nextel)	-166.7	-147.1	19.6	161.5	56.6	-104.9	271.1	344.9	73.8	63.5	-4.3	-67.9	-22.3	-63.3	-41.1
-Y UPPER (Outer Ti layer)	-125.2	-134.0	-8.8	-93.8	-85.0	8.8	-52.5	-28.7	23.8	-111.3	-109.7	1.5	-119.3	-123.7	-4.4
-Y UPPER (Ti layer behind nextel)	-171.7	-150.5	21.2	-141.4	-115.9	25.5	39.7	40.9	1.2	-157.8	-133.6	24.2	-166.5	-143.4	23.1
-Y LOWER (Outer Ti layer)	-110.8	-122.7	-11.9	-83.1	-83.2	-0.1	-47.5	-18.1	29.4	-98.5	-103.7	-5.2	-105.1	-114.3	-9.2
-Y LOWER (Ti layer behind nextel)	-168.2	-142.8	25.4	-141.6	-114.1	27.5	34.6	80.1	45.5	-156.2	-129.1	27.1	-163.6	-136.9	26.7
MOSIF SUNSHADE MLI AVERAGE DELTA T	*10.3*			*14.5*			*48.2*			*12.8*			*10.5*		
MOSIF SUNSHADE MLI STD DEVIATION	*22.8*			*36.7*			*32.7*			*25.7*			*19.7*		

Post Test Predictions vs TBT

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STANDARD CORRELATION

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MOSIF SUNSHADE MLI	Phase 3 - Cold calibration			Phase 4 - Hot Final Cruise			Phase 6 - Survival Sun from +X			Phase 7 - Intermediate Cruise			Phase 8 - Initial Cruise		
	Post Correlation results	TEST DATA 02/12/2010 18.51.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 04/12/2010 13.07.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 05/12/2010 14.46.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 07/12/2010 10.42.00	Δ T (Test-Analysis)	Post Correlation results	TEST DATA 08/12/2010 16.21.00	Δ T (Test-Analysis)
+Y UPPER (Outer Ti layer)	-152.7	-138.6	14.1	81.3	79.1	-2.2	-59.4	-52.6	6.8	2.6	-0.7	-3.3	-64.5	-61.2	3.3
+Y UPPER (Ti layer behind nextel)	-174.5	-133.2	41.3	294.4	313.6	19.2	-9.6	-16.3	-6.7	165.9	180.4	14.5	52.6	68.0	15.4
+Y MEDIUM (Outer Ti layer)	-145.0	-135.3	9.7	84.3	77.2	-7.1	-13.5	-14.6	-1.1	5.4	-0.2	-5.6	-61.4	-60.0	1.4
+Y MEDIUM (Ti layer behind nextel)	-172.3	-132.6	39.7	297.3	303.0	5.7	110.9	118.1	7.2	168.2	172.5	4.3	54.3	61.5	7.2
+Y LOWER (Outer Ti layer)	-119.3	-125.4	-6.1	92.3	98.3	6.0	1.8	6.9	5.1	13.4	15.1	1.7	-50.8	-49.5	1.3
+Y LOWER (Ti layer behind nextel)	-163.7	-127.8	35.9	302.6	332.8	30.2	134.3	147.4	13.1	172.4	193.3	20.9	57.6	76.1	18.5
+Y+X UPPER (Outer Ti layer)	-153.1	-148.3	4.8	12.1	17.6	5.5	86.6	92.2	5.6	-49.5	-36.2	13.2	-99.7	-81.5	18.2
+Y+X UPPER (Ti layer behind nextel)	-174.5	-150.1	24.4	169.6	166.2	-3.4	301.4	283.2	-18.2	69.6	65.2	-4.5	-18.2	-26.9	-8.7
+Y+X MEDIUM (Outer Ti layer)	-143.2	-143.8	-0.6	28.4	22.7	-5.7	100.6	110.7	10.1	-36.3	-29.5	6.8	-88.7	-74.6	14.1
+Y+X MEDIUM (Ti layer behind nextel)	-170.5	-150.7	19.8	177.8	173.6	-4.2	303.4	346.8	43.4	76.0	78.1	2.1	-13.3	-16.0	-2.7
+Y+X LOWER (Outer Ti layer)	-122.6	-138.2	-15.6	-10.8	6.2	17.0	111.7	118.4	6.8	-60.7	-39.5	21.2	-95.3	-78.1	17.2
+Y+X LOWER (Ti layer behind nextel)	-163.0	-147.1	15.9	87.9	56.6	-31.3	314.0	344.9	31.0	7.2	-4.3	-11.5	-62.5	-63.3	-0.8
-Y UPPER (Outer Ti layer)	-129.0	-134.0	-5.0	-83.8	-85.0	-1.2	-29.0	-28.7	0.3	-107.6	-109.7	-2.1	-120.2	-123.7	-3.6
-Y UPPER (Ti layer behind nextel)	-167.3	-150.5	16.8	-126.4	-115.9	10.5	53.0	40.9	-12.1	-147.5	-133.6	14.0	-159.6	-143.4	16.2
-Y LOWER (Outer Ti layer)	-111.8	-122.7	-10.9	-78.8	-83.2	-4.4	-27.3	-18.1	9.2	-97.0	-103.7	-6.7	-105.3	-114.3	-9.0
-Y LOWER (Ti layer behind nextel)	-160.7	-142.8	17.9	-129.7	-114.1	15.6	60.6	80.1	19.5	-146.5	-129.1	17.4	-155.1	-136.9	18.2
MOSIF SUNSHADE MLI AVERAGE DELTA T	*12.6*			*3.1*			*7.5*			*5.1*			*6.6*		
MOSIF SUNSHADE MLI STD DEVIATION	*17.5*			*14.1*			*15.1*			*10.5*			*10.1*		

Standard Correlation Results vs TBT

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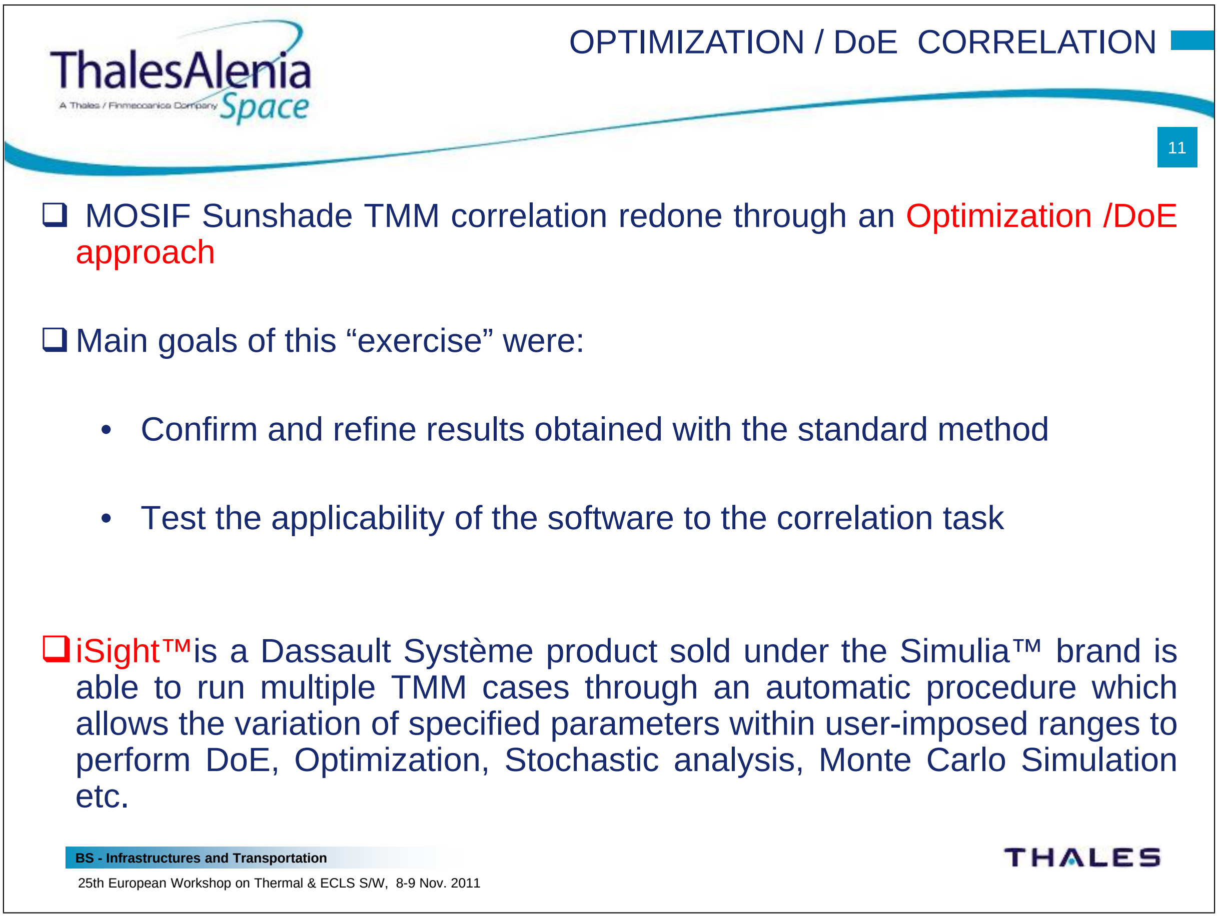
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OPTIMIZATION / DoE CORRELATION
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❑ MOSIF Sunshade TMM correlation redone through an Optimization /DoE approach
❑ Main goals of this "exercise" were:
• Confirm and refine results obtained with the standard method
• Test the applicability of the software to the correlation task
❑ iSight™ is a Dassault Système product sold under the Simulia™ brand is able to run multiple TMM cases through an automatic procedure which allows the variation of specified parameters within user-imposed ranges to perform DoE, Optimization, Stochastic analysis, Monte Carlo Simulation etc.
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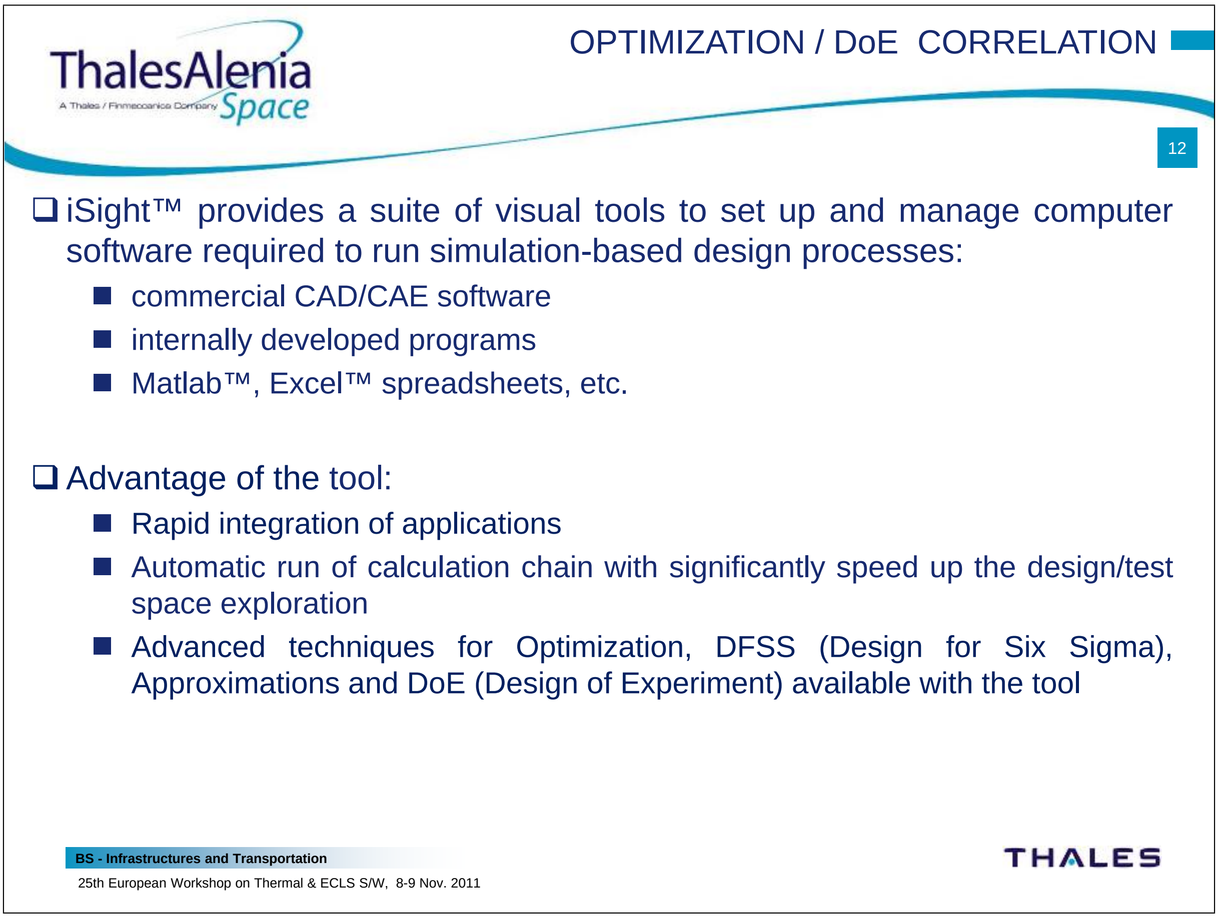
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OPTIMIZATION / DoE CORRELATION
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❑ iSight™ provides a suite of visual tools to set up and manage computer software required to run simulation-based design processes:
■ commercial CAD/CAE software
■ internally developed programs
■ Matlab™, Excel™ spreadsheets, etc.
❑ Advantage of the tool:
■ Rapid integration of applications
■ Automatic run of calculation chain with significantly speed up the design/test space exploration
■ Advanced techniques for Optimization, DFSS (Design for Six Sigma), Approximations and DoE (Design of Experiment) available with the tool
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OPTIMIZATION / DoE CORRELATION

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- Selection of significant parameters for the Optimization / DoE took advantage of the experience gained from the standard correlation: correct physical understanding of the TMM response to the changes of all the most significant thermal parameters

- 3 equivalent IR emissivities were selected for this scope

Thermo-Physical Parameter	Test article items	Parameter Name
Equivalent emissivity in the radiative conductor	External 1^{st} layer (Nextel) → MLI ext 2^{nd} layer	MOSIF_EPS_12
Equivalent emissivity in the radiative conductor	MLI ext 2^{nd} layer → MLI inner layer Titanium	MOSIF_SS_EPS
Equivalent emissivity in the radiative conductor	MLI on GAP position	MOSIF_GAP_EPS

- Optimization/DoE goal: minimization of the temperature differences between TMM and TBT

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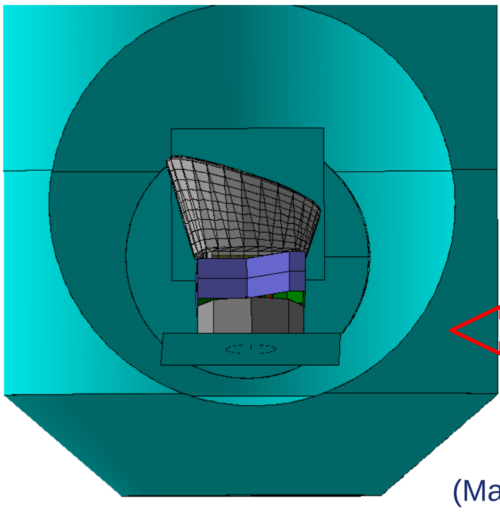
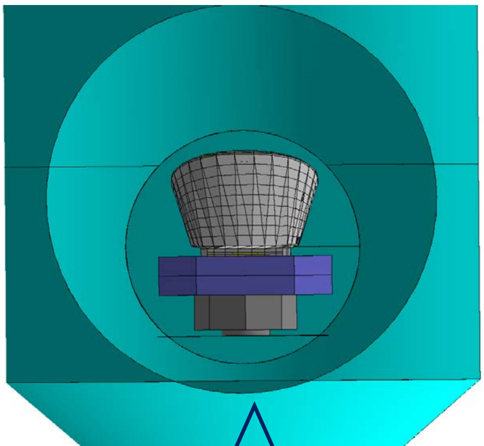
OPTIMIZATION / DoE CORRELATION

TARGETS of Correlation:
Delta temperatures Test – Analysis, calculated with an **Excel Spreadsheet**





TEST CASES:
Phase 4 – *Hot Final Cruise*
Phase 6 – *Survival*

(Maximum) Solar Heat Flux =13000 W/m²

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OPTIMIZATION / DoE CORRELATION

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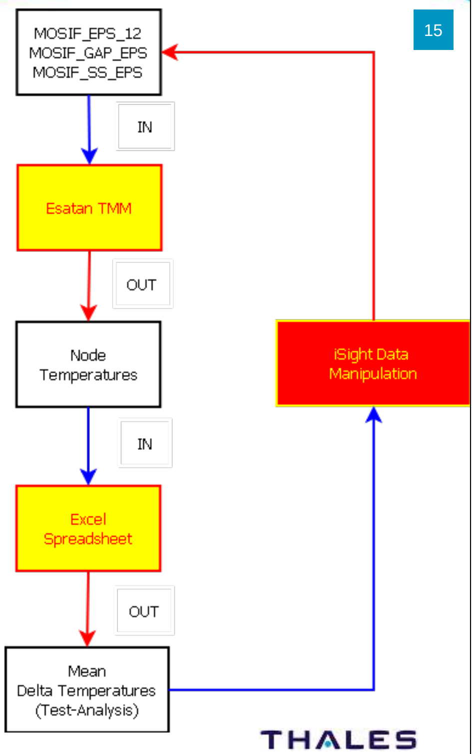
Integrated iSight™ model consists of several "elements" that automatically performed following operations:

- TMM execution (ESATAN)
- TMM results manipulation for Delta-T, between test and analysis results, calculation (Excel)
- Evaluation of new simulation parameters' values (DoE / Optimization Algorithm)



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OPTIMIZATION / DoE CORRELATION

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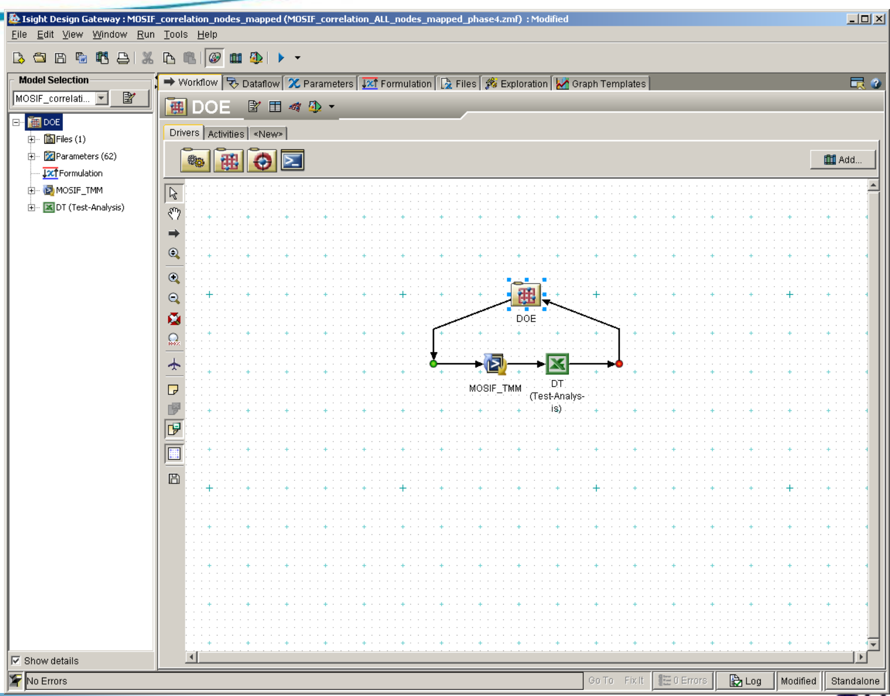

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OPTIMIZATION / DoE CORRELATION

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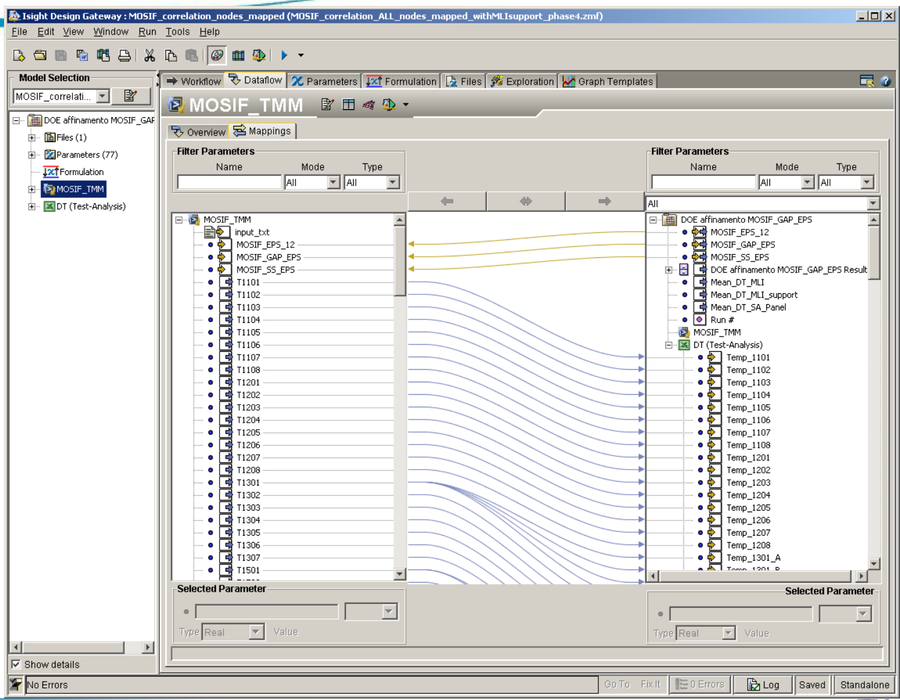

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OPTIMIZATION / DoE CORRELATION

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- At the beginning 5 DoE (Latin Hypercube -20 levels) were performed, starting with
  - MOSIF_EPS_12 starting range 0.01-0.9
  - MOSIF_GAP_EPS and MOSIF_SS_EPS starting range 0.01-0.1

- The first set of DoE are in line with the standard correlation results especially for MOSIF_EPS_12 and MOSIF_SS_EPS (see table below).

	Correlated Values (Standard Correlation)	DoE Results
MOSIF_EPS_12	0.14	0.123
MOSIF_GAP_EPS	0.024	0.015
MOSIF_SS_EPS	0.019	0.018

- Refinement of DoE results were carried out with an Optimization (Downhill Simplex method) run for Phase 4 (Hot Final Cruise)

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OPTIMIZATION / DoE CORRELATION

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❑ Optimization results for Phase 4 – Hot Final Cruise

	Optimization Results (Phase 4)	Correlated Values (Standard Correlation)
MOSIF_EPS_12	0.1259	0.14
MOSIF_GAP_EPS	0.0258	0.024
MOSIF_SS_EPS	0.0186	0.019

Phase 4	Mean ΔT	Standard Deviation	Mean ΔT (Standard Correlation – Phase 4)	Standard Deviation (Standard Correlation – Phase 4)
MOSIF Beam	**1.88**	4.79	3.0	4.9
MOSIF Lower Ring	3.61	2.85	3.6	2.9
MOSIF Upper Ring	**3.44**	5.61	4.3	5.4
MOSIF Arms	7.76	8.57	7.1	8.7
MOSIF I/F Ring	40.5	1.33	39.8	1.4
MOSIF Internal Panels	5.40	3.80	4.6	3.9
MOSIF S/A Panels	1.98	3.69	1.0	3.6
MOSIF Sunshade MLI	**0.056**	13.79	3.1	14.1
MOSIF MLI Support	**1.89**	13.51	3.1	14.4

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OPTIMIZATION / DoE CORRELATION

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❑ Phase 4 Optimization results was validated against Phase 6 (Survival) test data

Phase 6	Mean ΔT	Standard Deviation	Mean ΔT (Standard Correlation – Phase 6)	Standard Deviation (Standard Correlation – Phase 6)
MOSIF Beam	**3.01**	6.81	4.0	7.0
MOSIF Lower Ring	**1.88**	3.82	3.0	4.3
MOSIF Upper Ring	**1.04**	5.47	1.8	5.6
MOSIF Arms	9.00	8.23	8.4	8.4
MOSIF I/F Ring	39.92	2.14	39.4	2.2
MOSIF Internal Panels	4.63	5.08	4.0	5.2
MOSIF S/A Panels	0.97	4.68	0.1	4.9
MOSIF Sunshade MLI	**4.30**	14.58	7.5	15.1
MOSIF MLI Support	**1.80**	17.39	2.7	17.9

❑ Better results (lower Delta-T w.r.t. standard correlation) are obtained also for Phase 6

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OPTIMIZATION / DoE CORRELATION

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- Starting from DoE results, another Optimization was performed over Phase 6 data, with a decreasing of MOSIF_EPS_12 but also an increasing of Solar Array (SA) panel Delta-T.

- Results of Phase 4 optimization are preferred since minimize the most important MMO Solar Array panels Delta-T

	Standard Correlation (Phase 4)	Standard Correlation (Phase 6)	Optimization Phase 4 Results	Optimization Phase 6 Results
MOSIF_EPS_12	0.14	0.14	0.1259	**0.1200**
MOSIF_GAP_EPS	0.024	0.024	0.0258	0.0269
MOSIF_SS_EPS	0.019	0.019	0.0186	0.0211
Mean_DT_MLI	3.1	7.5	0.056	0.731
Mean_DT_MLI_support	3.1	2.7	1.89	0.541
Mean_DT_SA_panel	1.0	0.1	1.98	**3.725**

Selected Values

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CONCLUSIONS

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Optimization/DoE advantages w.r.t. Standard approach:

- Computes the actual emissivity values that minimize the target of correlation (ΔT and Standard Deviations) ⇨ *MOSIF_EPS_12* decreasing example

- Time saving: integrated iSight model build-up and run took about 7 working days instead of several weeks needed for the standard correlation method.

but…

- Results obtained with Optimization/DoE analyses must be critically assessed

- Always verify that the optimal **solution** is **numerically correct and also realistic**

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Thanks for your attention
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Appendix R

Lessons Learned on Modelling of Cryogenic Systems

Moritz Branco
(ESA/ESTEC, The Netherlands)

Abstract

The use of ESATAN-TMS as a thermal modeling tool for systems in the cryogenic domain (< 120 K), gives rise to specific issues on model convergence and the results analysis. This presentation's purpose is to present some of the issues found and solutions considered while working on a model for a compact cryostat with a full cryogenic chain from 300 K to 2 K.

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Lessons Learned on Modelling of Cryogenic Systems with ESATAN-TMS

25th European Workshop on Thermal and ECLS Software

Moritz Branco

ESTEC, Noordwijk, The Netherlands

8-9/11/2011

European Space Agency

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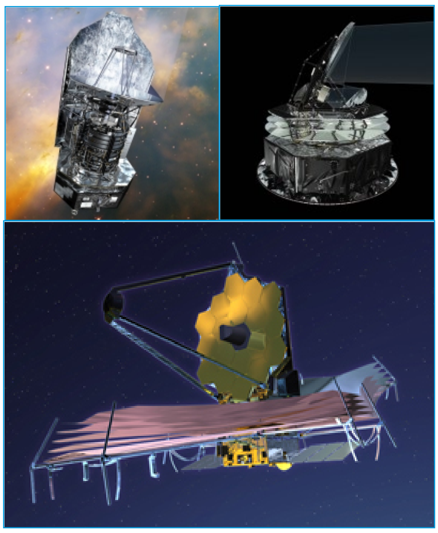
Lessons Learned on Cryogenics Modelling
Contents

1. Context:
   The XMS Cryo-Chain

2. Problems Encountered /
   Solutions Proposed

3. Results Analysis:
   Specific Issues



Lessons Learned on Modeling of Cryogenic Systems with ESATAN-TMS | Moritz Branco | 14/04/2011 | Noordwijk | Pag. 2

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Lessons Learned on Cryogenics Modelling The XMS Cryo-Chain

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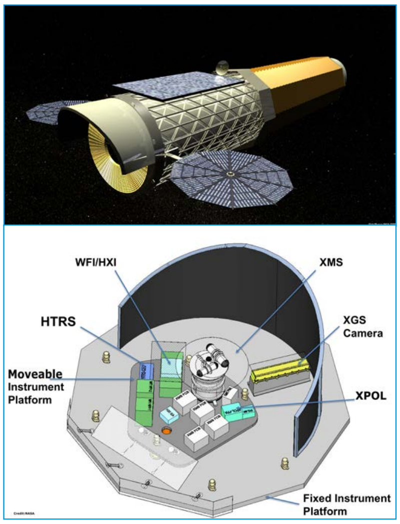
Brief Description:

- X-ray microcalorimeter spectrometer (XMS)
- Instrument aboard ATHENA, previously called IXO
- Requires cooling down to 50 mK with 1 μW cooling power available
- No liquid cryogens (5-10 years life)



Depictions of IXO, whole and XIM

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Lessons Learned on Cryogenics Modelling The XMS Cryo-Chain

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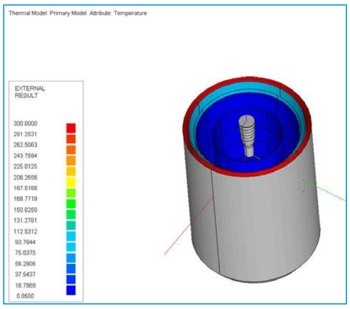
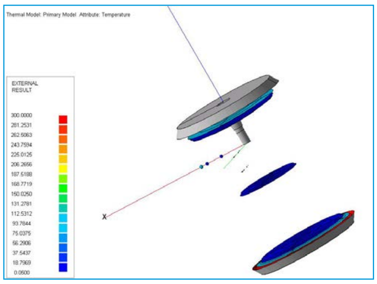
The ESATAN-TMS model:

- Russian Doll type configuration (different T stages, 100 K, 15 K, 2K..)
- Performance Data from available cryo coolers
- Data on MLI, harness, mechanical supports

from previous studies and missions

- Detailed analysis of the optical baffle
- Study on flexible thermal links
- Modelling of interdependent behaviour of cryocoolers





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Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

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Problem: TABS = 0.0

- In the model.d file the node block defines all nodes with a T=0.0, no matter the TABS considered.
- Solver crashes

```
$NODES
  D100 = 'Filter50m', T = 0.0,
   C = 1.963495E-008 * Cp_Kapton * Dens_Kapton,
   A = 0.001963, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0125000, FY = 1.53076E-018, FZ = 0.530020;
  D1000 = 'Filter1K', T = 0.0,
   C = 3.926991E-008 * Cp_Kapton * Dens_Kapton,
   A = 0.003927, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0125000, FY = 1.53076E-018, FZ = 0.610020;
  D2000 = 'Filter15K', T = 0.0,
   C = 5.473353E-009 * Cp_AlAl * Dens_AlAl,
   A = 0.000547, ALP = 0.460000, EPS = 0.020000,
   FX = -0.00466667, FY = 5.71483E-019, FZ = 0.695020;
  D2005 = 'Filter15K', T = 0.0,
   C = 1.642006E-008 * Cp_AlAl * Dens_AlAl,
   A = 0.001642, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0140000, FY = 1.71445E-018, FZ = 0.695020;
  D2010 = 'Filter15K', T = 0.0,
   C = 2.736676E-008 * Cp_AlAl * Dens_AlAl,
   A = 0.002737, ALP = 0.460000, EPS = 0.020000,
   FX = -0.0233333, FY = 2.85741E-018, FZ = 0.695020;
```

Solutions proposed:

- Setting an initial temperature boundary condition to all nodes: not flexible and didn't work.
- Setting an initialization routine in the template file with SETNDR. Worked.

```
$INITIAL
C set initial temperatures
CALL SETNDR(‘ ‘,’ T ’,10.0D0, CURRENT)
```

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Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

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Problem: MLI modelling

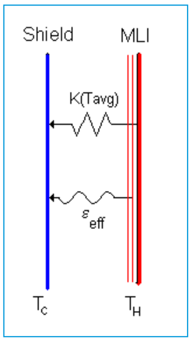
- MLI is modelled as having an effective emissivity and a temperature dependent pseudo-conductivity

	$q = (a\,(T_H + T_C)/2 + b)\,(T_H - T_C) + \varepsilon\,\sigma\,((T_H^4 - T_C^4)$		
	a	b	ε
10-layer MLI	8.720E-06	2.353E-05	0.00395
20-layer MLI	4.360E-06	1.177E-05	0.0019725

Table 4-18. Thermal performance of "Herschel" type MLI [RD5]

Solution found:

- Additional shell added, and a conductor depending on average T (T_{MLI} and T_{SHELL}) is entered between each face
- Not flexible:
  - nodal breakdown analysis
  - geometry study
- Possible request feature: Temperature dependent through-conductance in a shell



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Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

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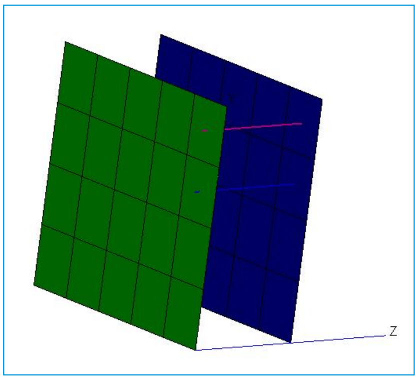

$MLIcond(T)=aT+b \quad T=Th/2+Tc/2$

$GL(MLI_i, shell_i)=MLIcond(TMLI_i/2+Tshell_i/2)$

- Possible request feature: Temperature dependent through-conductance in a shell

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Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

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Problem: High GL's for small ΔT's

- Highly conductive thermal links (10^0 W/K) for small temperature differences (10^{-1} K) are typical in cryogenic systems (e.g. copper straps).

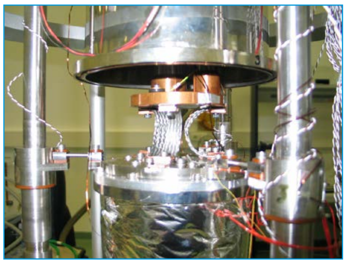
- Numerical instabilities:

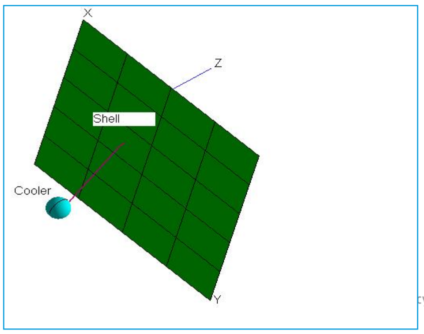
Solver not solving or

Diffusive node (shell node) with a very high relative heat inbalance

Solution found:

- Using SOLVFM / in cases transient
- Applying a damping factor 0.1-0.5
- Initial Temperatures boundary setting to start with a very low ΔT





Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

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Cooler Modelling

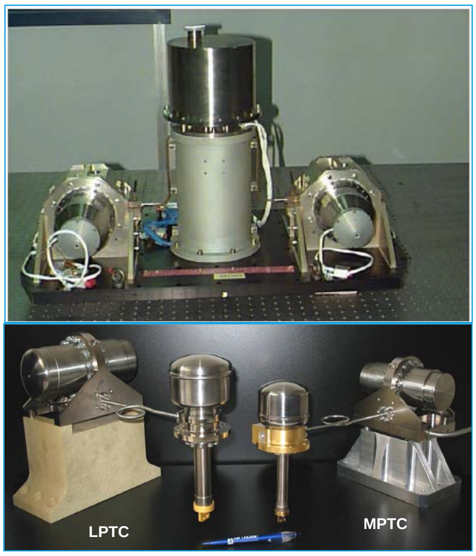
- First Approach: Boundary nodes, T constant

- Diffusive nodes with an balanced QI, given by the cooler performance data.

- Boundary node with T changing every iteration,

  T given by the cooler performance data.

- A damping scheme had to be applied.



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Lessons Learned on Cryogenics Modelling Problems Encountered / Solutions

esa

Cooler Modelling

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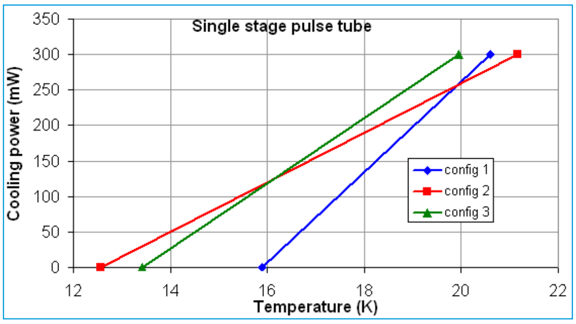

$Qcool = FLUXGL(Tcooler, Tnode)$

$T_{i+1} = \text{Performance Curve}(Qcool)$

$Tcooler = Tcooler + DAMPF * (T_{i+1} - T_i)$

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Lessons Learned on Cryogenics Modelling
Problems Encountered / Solutions

Cooler Modelling

Problem:

- Cooler temperature was calculated using FLUXGL
- Temperatures result in NaN
- At first iteration, when calling $VARIABLES1, GL's aren't yet calculated

Qcool = FLUXGL (Tcooler, Tnode)

T_{i+1} = Performance Curve (Qcool)

Tcooler = Tcooler + DAMPF * (T_{i+1}-T_i)

Solution found:

- To manually calculate the GL between cooler and shell node

Qcool = CNDFN1(Tcooler, Tnode, KThermalStrap, 1)*(Tcooler-Tnode)

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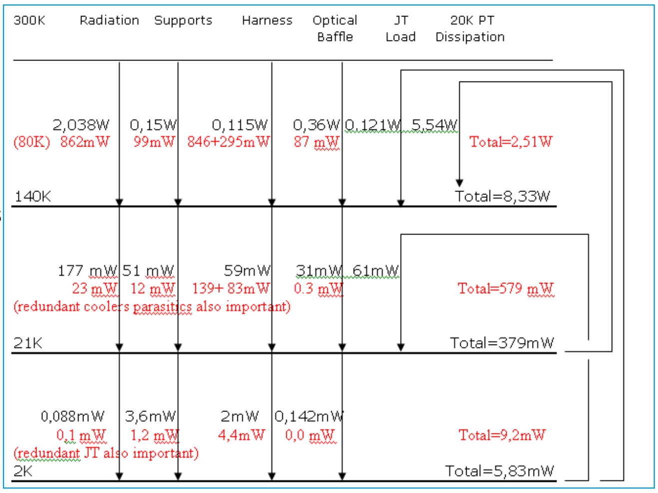
Lessons Learned on Cryogenics Modelling
Results Analysis

Results Analysis

- Heat flows are the most important quantity
- Importance of different contributions a general heatflow
- Accuracy of heatflow results is critical, since it could drive the whole system



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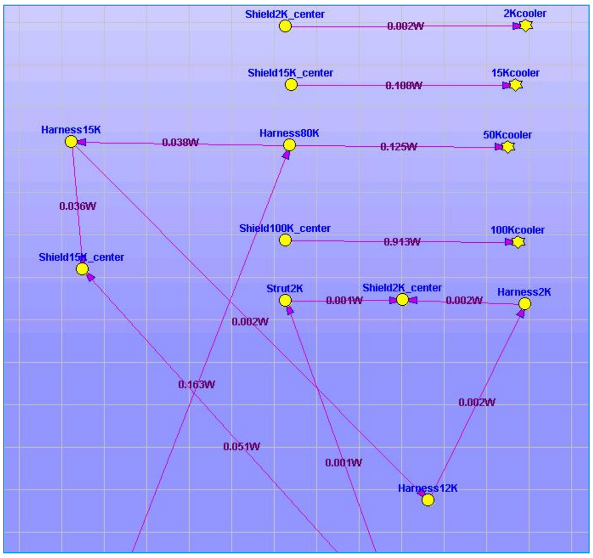
Lessons Learned on Cryogenics Modelling Results Analysis

Results Analysis

Importance of heat flow accuracy

- Cryogenic models are very sensitive to very small heatflow variations
- At 20 K, every mW counts!
- At 2 K, one mW can drive the whole cryostat configuration



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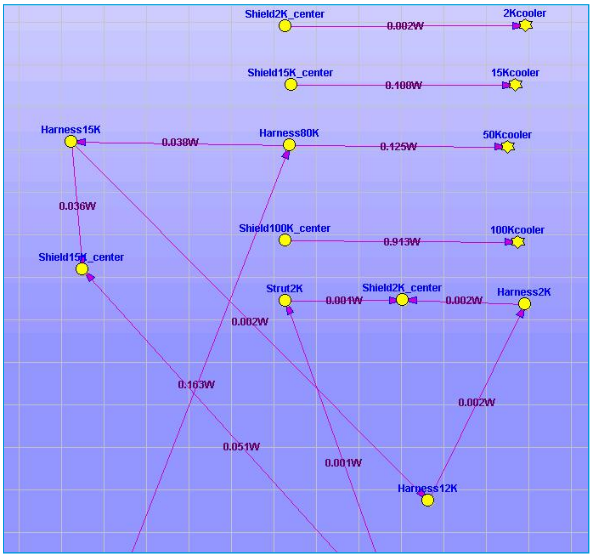
Lessons Learned on Cryogenics Modelling Results Analysis

Results Analysis

Critical Factors:

- Numerical uncertainties
- Modelling parameters sensitivity
- Low accuracy of results – high engineering margins
- More importance given to empirical knowledge from previous cases



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Lessons Learned on Cryogenics Modelling Conclusions

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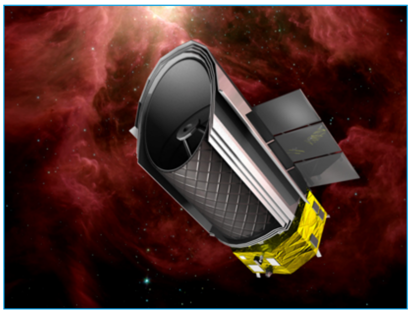
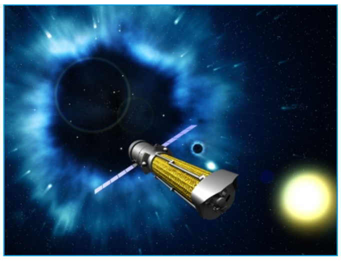
Conclusions

- Specific Issues were tackled
- System level cooler modelling
- Important factors in cryogenic model results analysis
- Empirical knowledge still most valuable





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THANK YOU

Moritz Branco,
Work undergone at TEC-MT
moritz.branco@esa.int

UNIÃO EUROPEIA
Fundo Social Europeu
Ciência.Inovação 2010 Programa Operacional Ciência e Inovação 2010
Governo da República Portuguesa

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Appendix S

Model reduction of Sentinel 1

Daniel Kintea
(ESA/ESTEC, The Netherlands)

Abstract

This presentation is intended to give a brief overview on the thermal model reduction using the Thermal Model Reduction Tool on the Sentinel-I satellite. It also shows the capabilities and restrictions of the reduction method and the tool.

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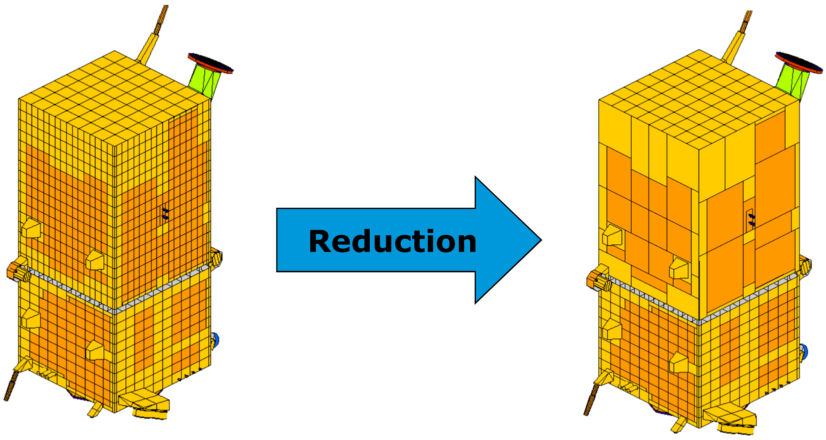
Model reduction of the Sentinel-I using the TMRT



Daniel Kintea
Stagiaire at ESA/ESTEC
Student of the TU Darmstadt

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1. Introduction
2. Reduction
3. Results
4. Conclusion

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Introduction

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Model reduction …

… reduces computation time

… ideally keeps the input-output behavior of the detailed model

TMRT*…

… stands for **T**hermal **M**odel **R**eduction **T**ool

… is developed under GSTP contract by Astrium, Thales Alenia Space and Dorea

This presentation …

… gives an overview of the usage of the TMRT applied to a real orbital case of the Sentinel-I**

… shows the potential of the model reduction

… shows the restrictions of the reduction

*) previously presented at this Workshop in 2010 [Mathieu Bernard (EADS Astrium, France), Thierry Basset (Thales Alenia Space, France), James Etchells (ESA/ESTEC, The Netherlands): TMRT]

**) Component of EU & ESA's Global Monitoring for Environment and Security Programme (GMES), Thales Alenia Space is Satellite prime contractor, EADS Astrium GmbH is the instrument responsible.

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Reduction

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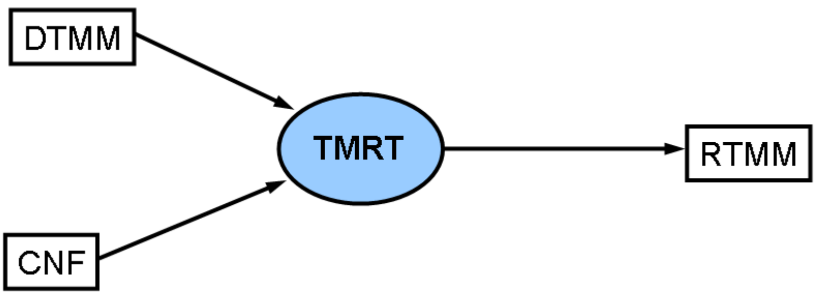
DTMM: Detailed thermal mathematical model
RTMM: Reduced thermal mathematical model
CNF: Condensed node file
DGMM: Detailed geometrical mathematical model
RGMM: Reduced geometrical mathematical model
GR: Radiative conductor



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Reduction

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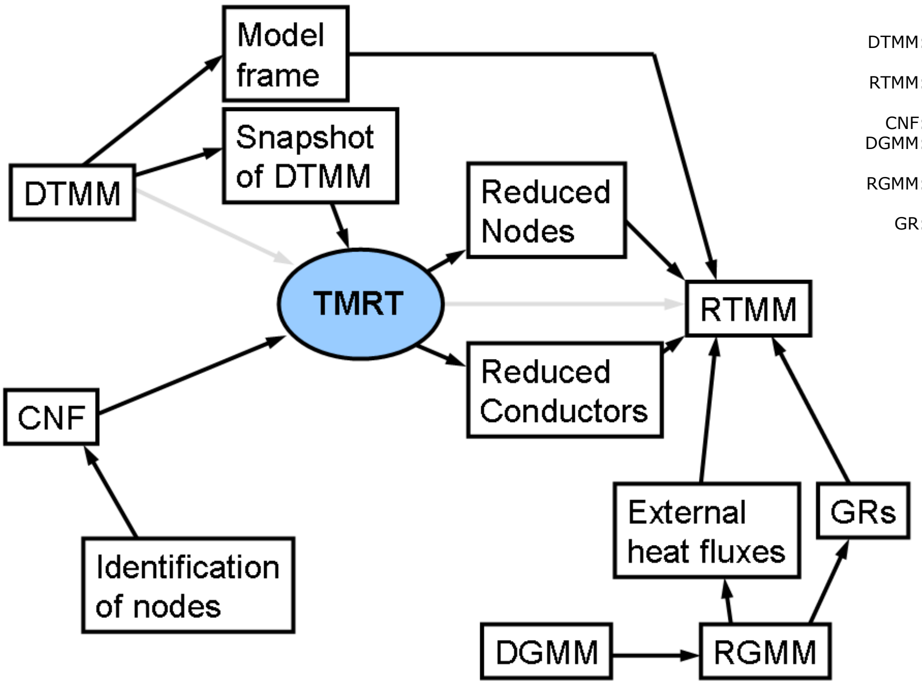

DTMM: Detailed thermal mathematical model
RTMM: Reduced thermal mathematical model
CNF: Condensed node file
DGMM: Detailed geometrical mathematical model
RGMM: Reduced geometrical mathematical model
GR: Radiative conductor

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The stowed model

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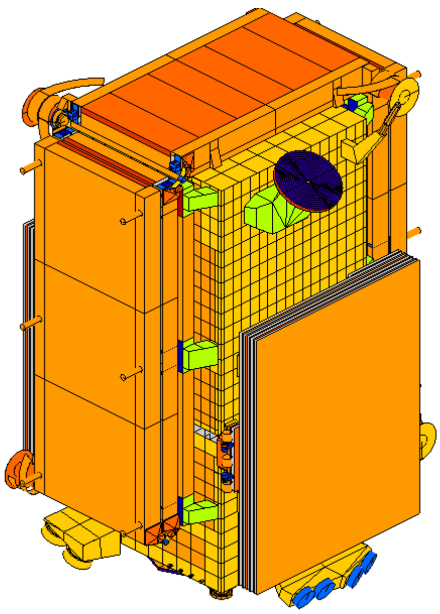

Model is courtesy of Thales Alenia Space

LEOP CASE H11:

- Solar inputs 1420 W/m2 (WS)
- Sun-synchronous orbit
- Mission phase: LEOP Contingency
- Pitch rate -0.0608°/s
- Configuration: STOWED

Requirements for RTMM:

- $\Delta T_{Equipment} < 3$ K
- $\Delta T_{Structure} < 5$ K
- $\Delta T_{MLI} < 10$ K
- $\Delta P_{Heater} < 5$ %

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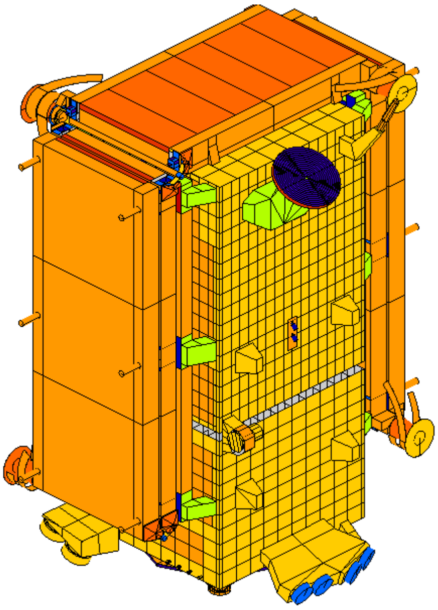
The stowed model



Model is courtesy of Thales Alenia Space

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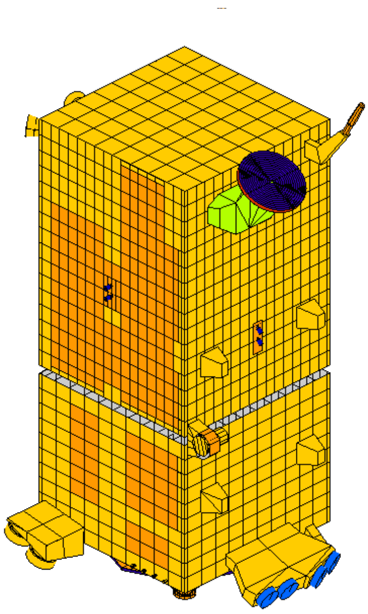
The stowed model



Model is courtesy of Thales Alenia Space

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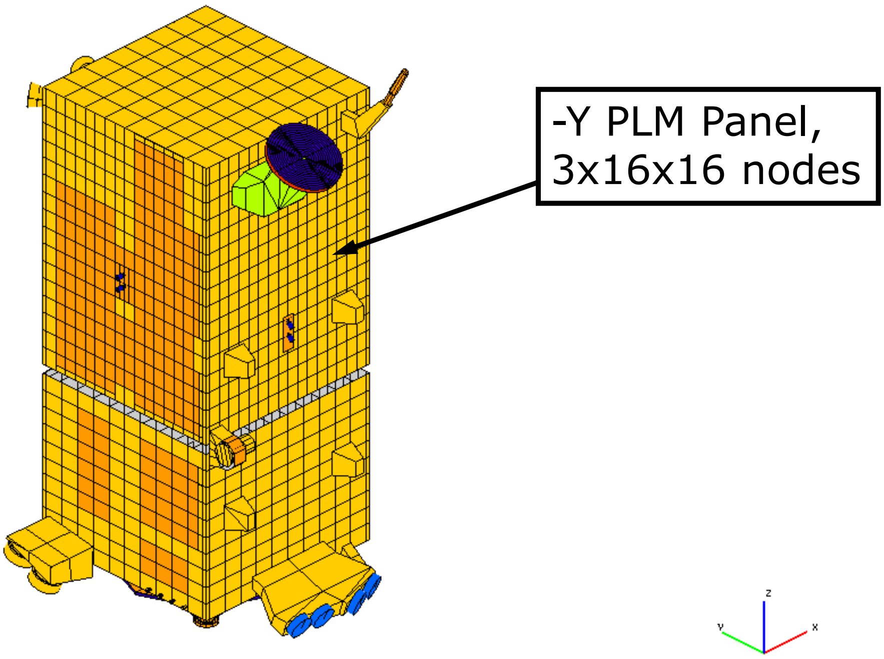
Reduction of the –Y PLM Panel



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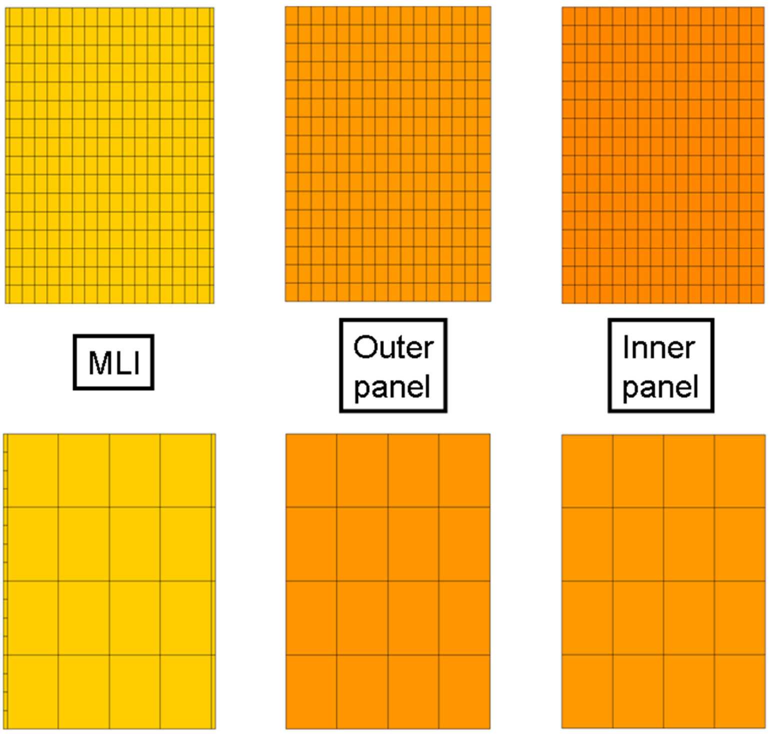
Reduction of the –Y PLM Panel



DTMM 532 shells 768 nodes

⇒ ***93.8 % of the nodes condensed***

⇒ ***90.2 % of the shells condensed***

RTMM 52 shells 48 nodes

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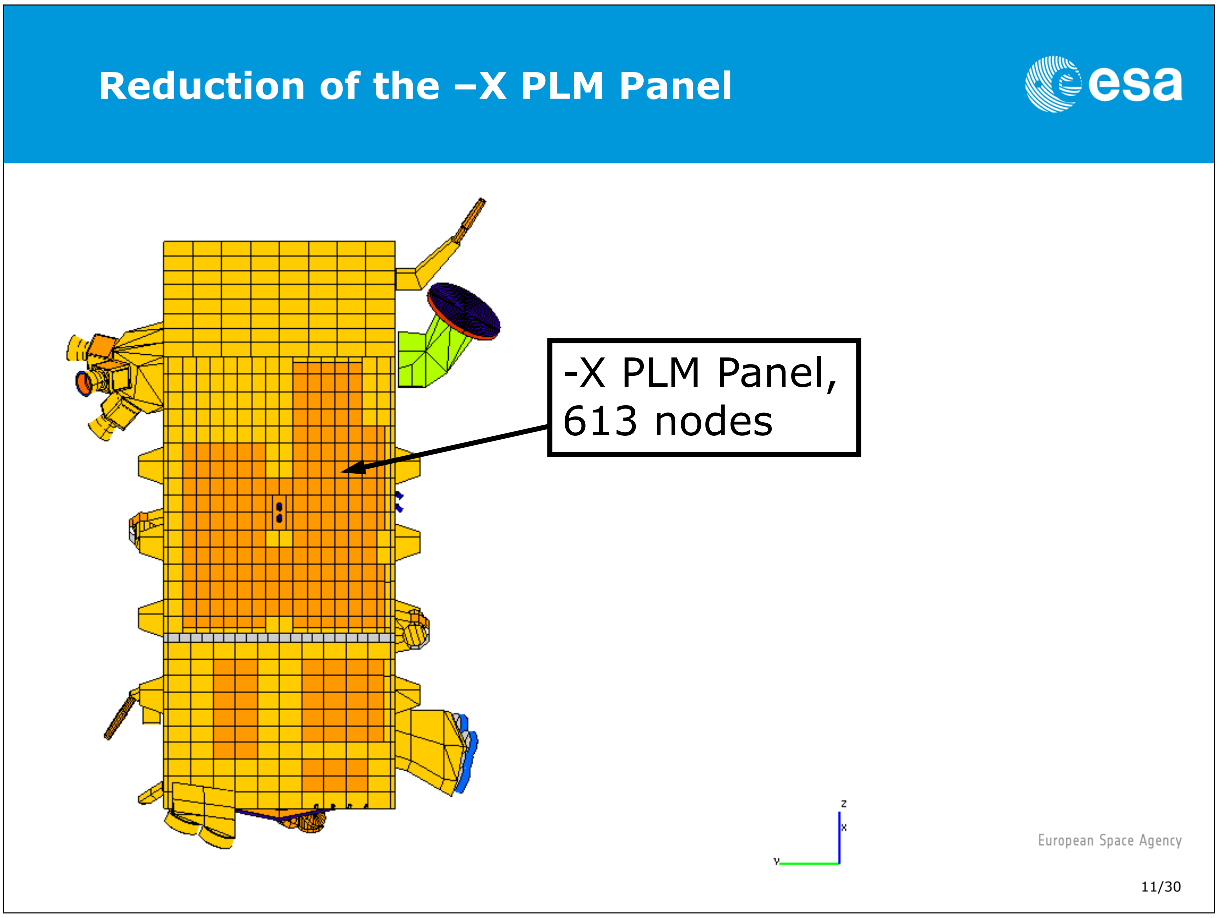
10/22


Reduction of the –X PLM Panel
esa
-X PLM Panel,
613 nodes
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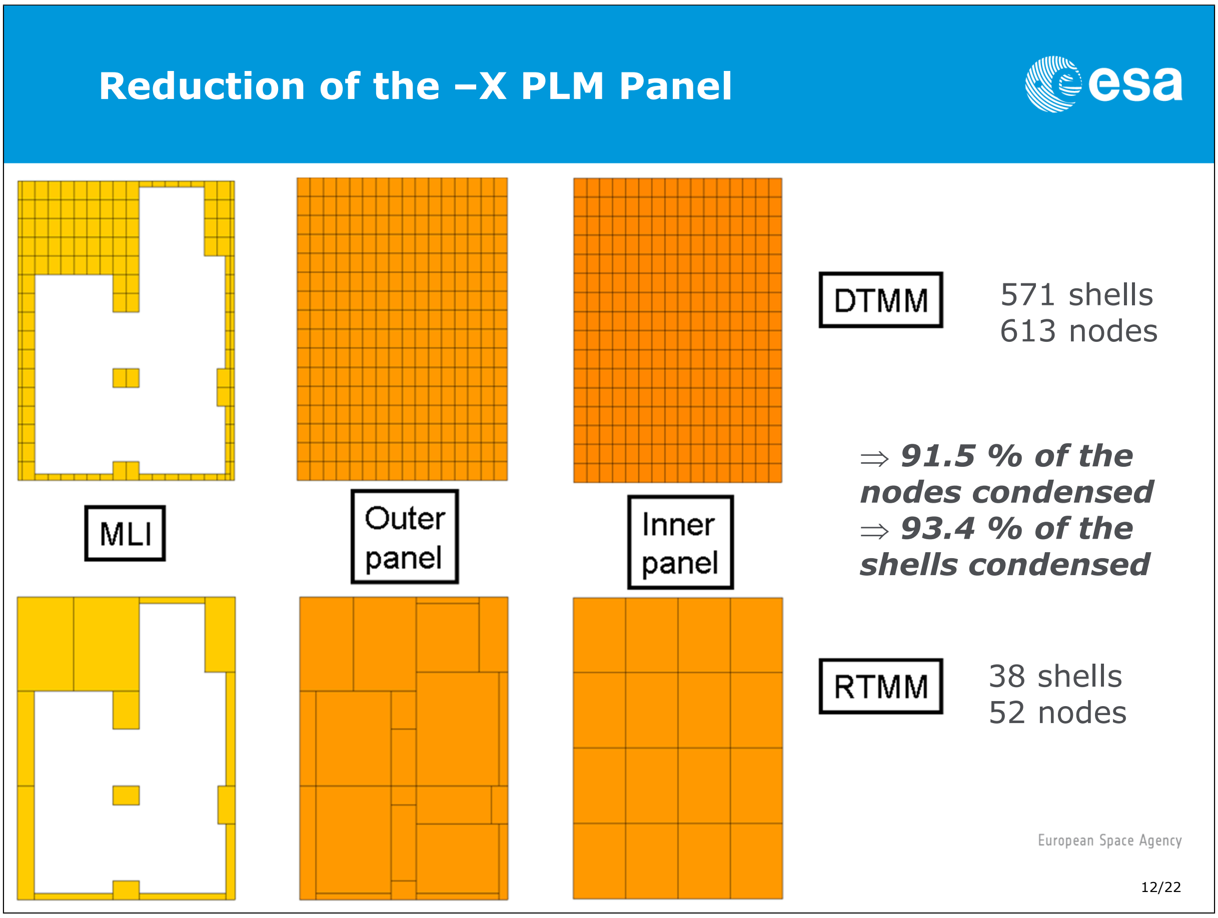
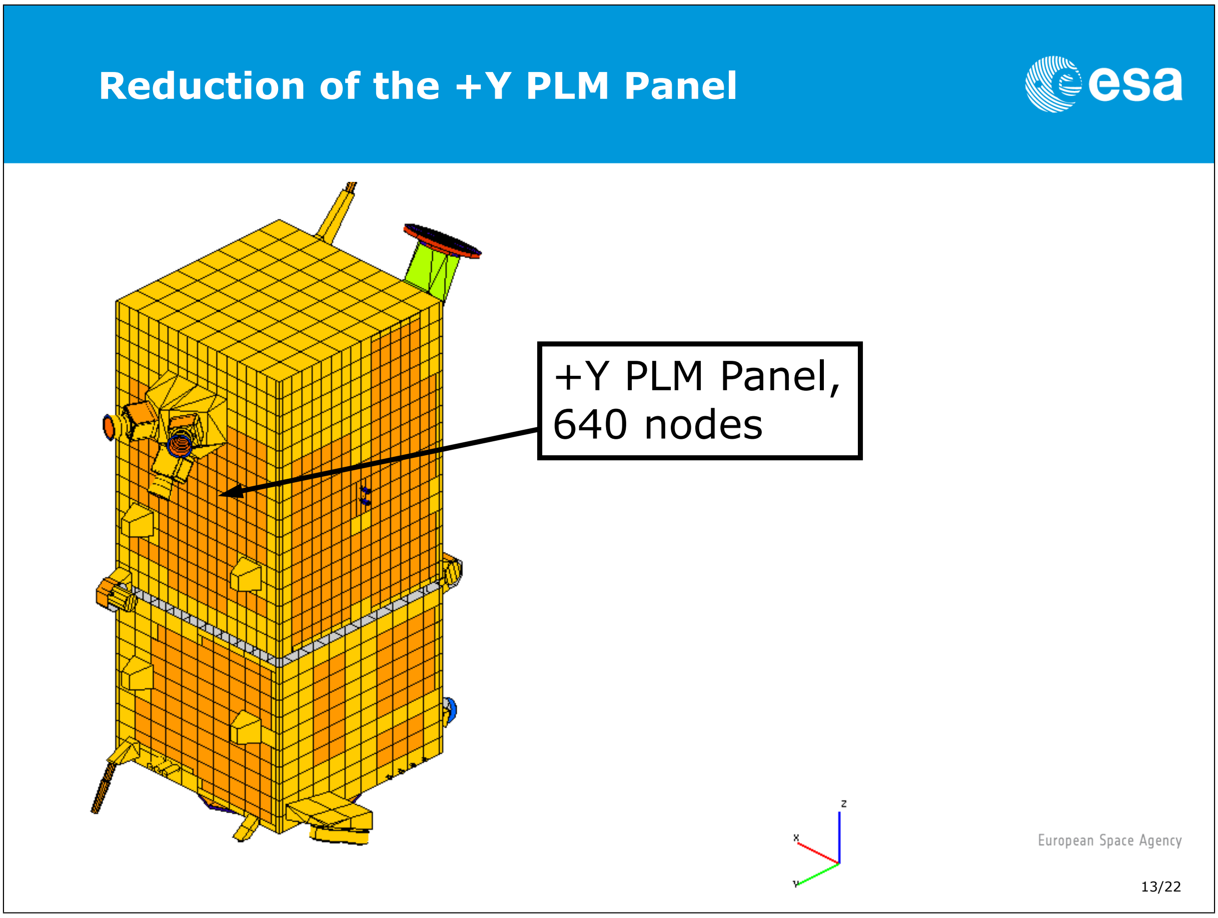
11/30


Reduction of the –X PLM Panel
esa
MLI
Outer panel
Inner panel
DTMM
571 shells
613 nodes
⇒ 91.5 % of the nodes condensed
⇒ 93.4 % of the shells condensed
RTMM
38 shells
52 nodes
European Space Agency
12/22


Reduction of the +Y PLM Panel
esa
+Y PLM Panel,
640 nodes
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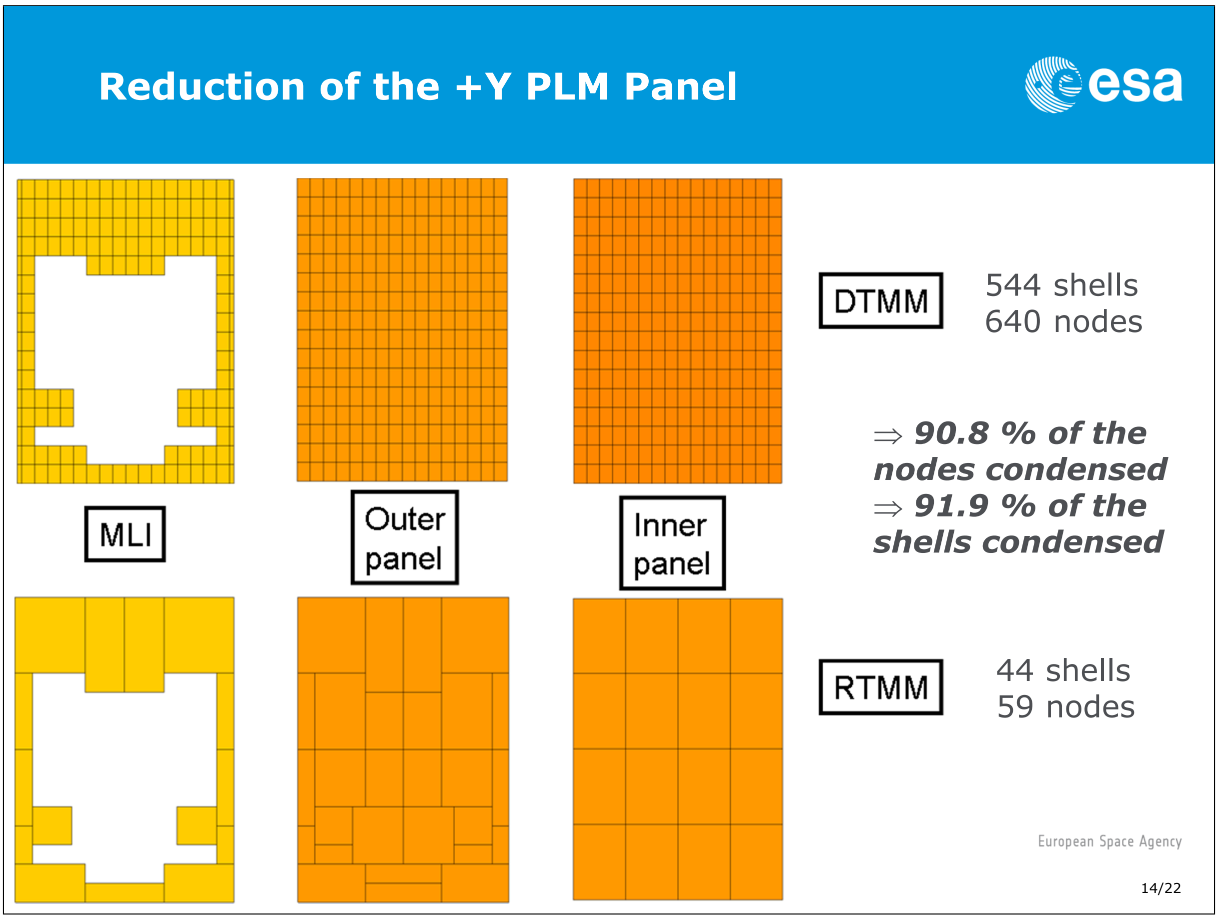
Reduction of the +Y PLM Panel
esa
MLI
Outer panel
Inner panel
DTMM
544 shells
640 nodes
⇒ 90.8 % of the nodes condensed
⇒ 91.9 % of the shells condensed
RTMM
44 shells
59 nodes
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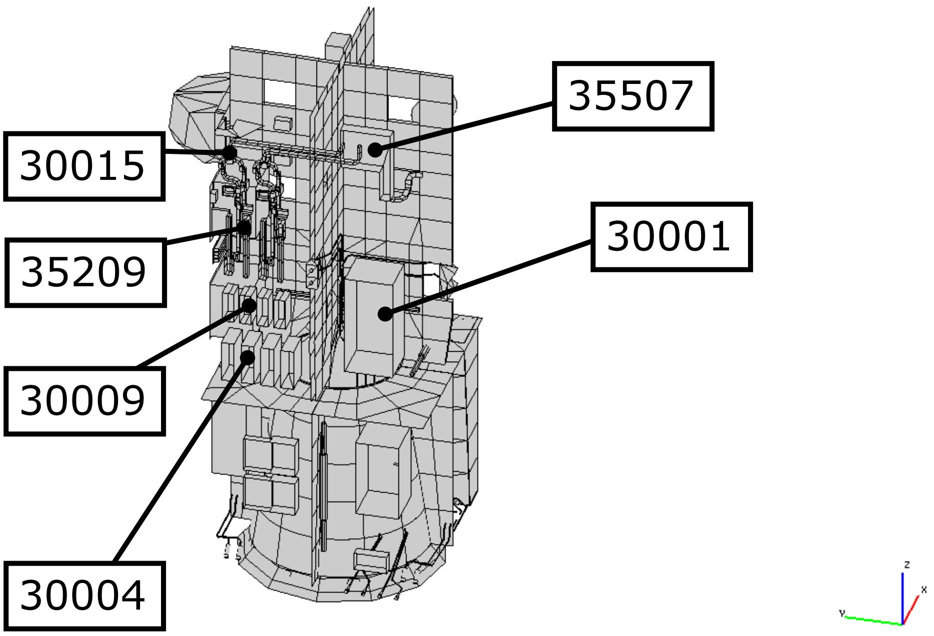
Reference Nodes on –X Panel



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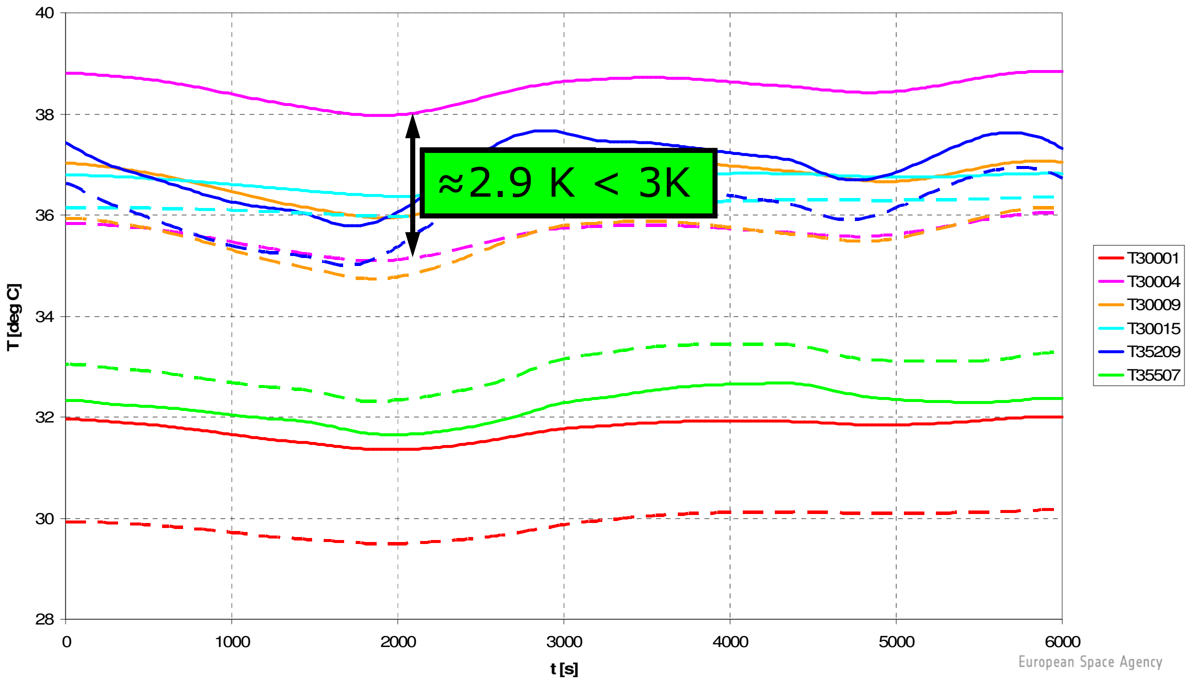
Equipment node temperatures on –X Panel



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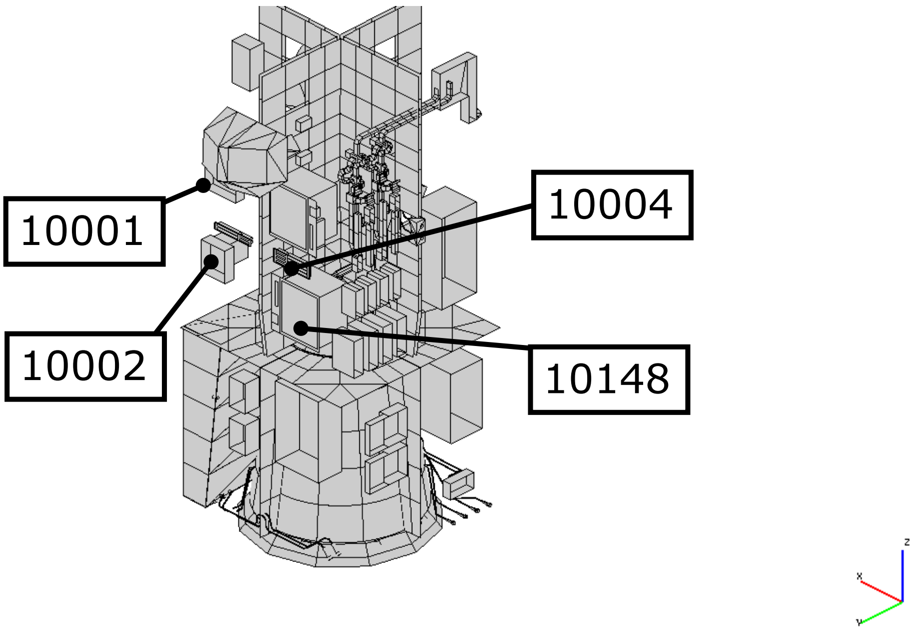
Reference Nodes on +Y Panel



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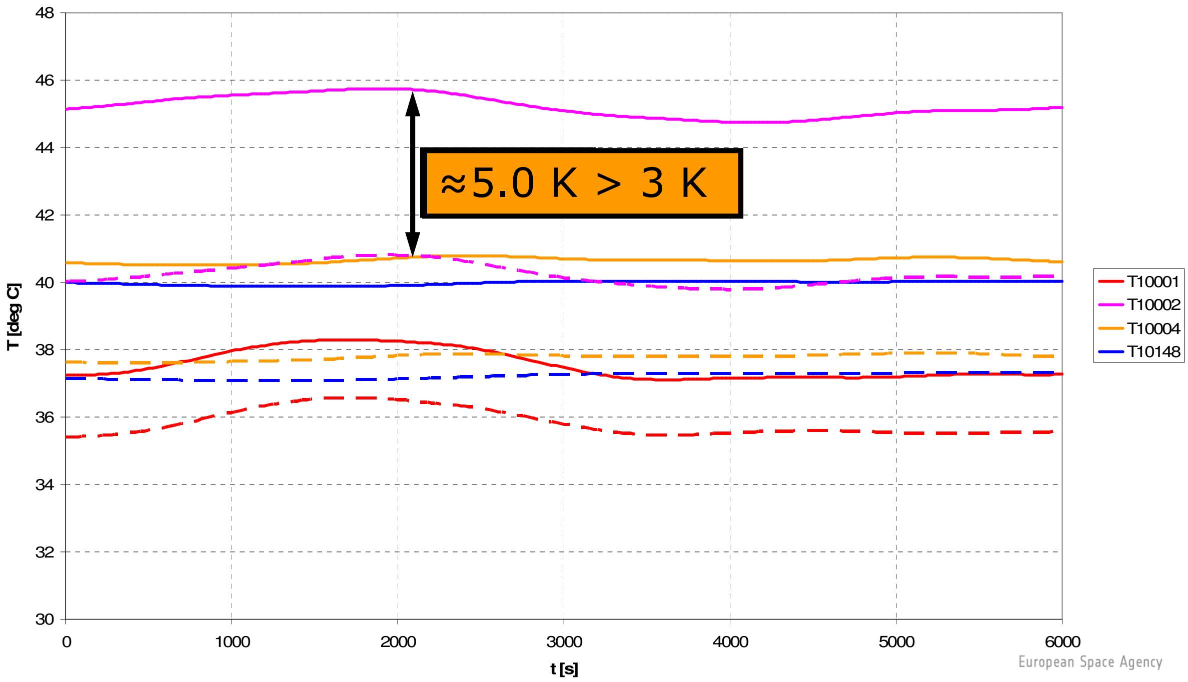
Equipment node temperatures on +Y Panel



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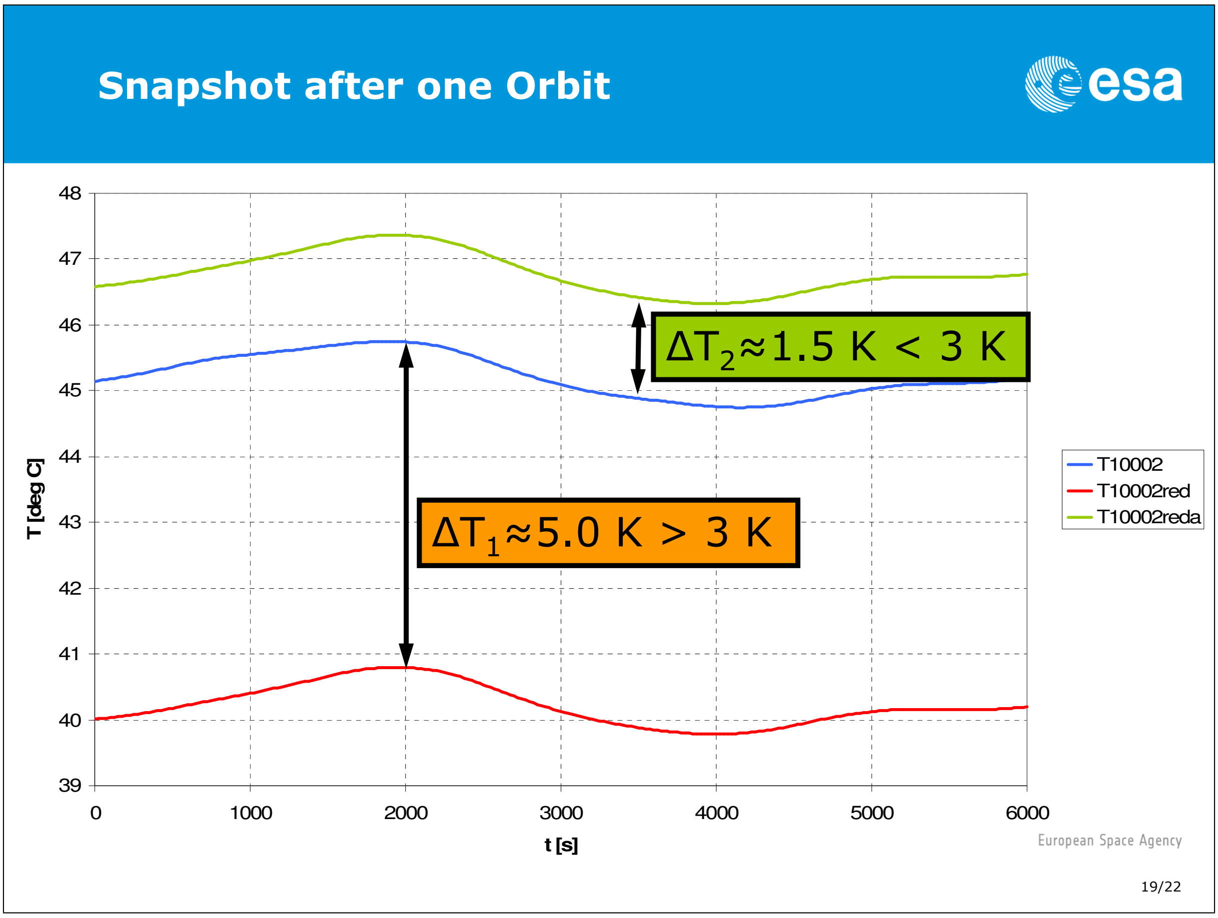
Snapshot after one Orbit
esa
48
47
46
45
44
43
42
41
40
39
T [deg C]
0
1000
2000
3000
4000
5000
6000
t [s]
ΔT2≈1.5 K < 3 K
ΔT1≈5.0 K > 3 K
T10002
T10002red
T10002reda
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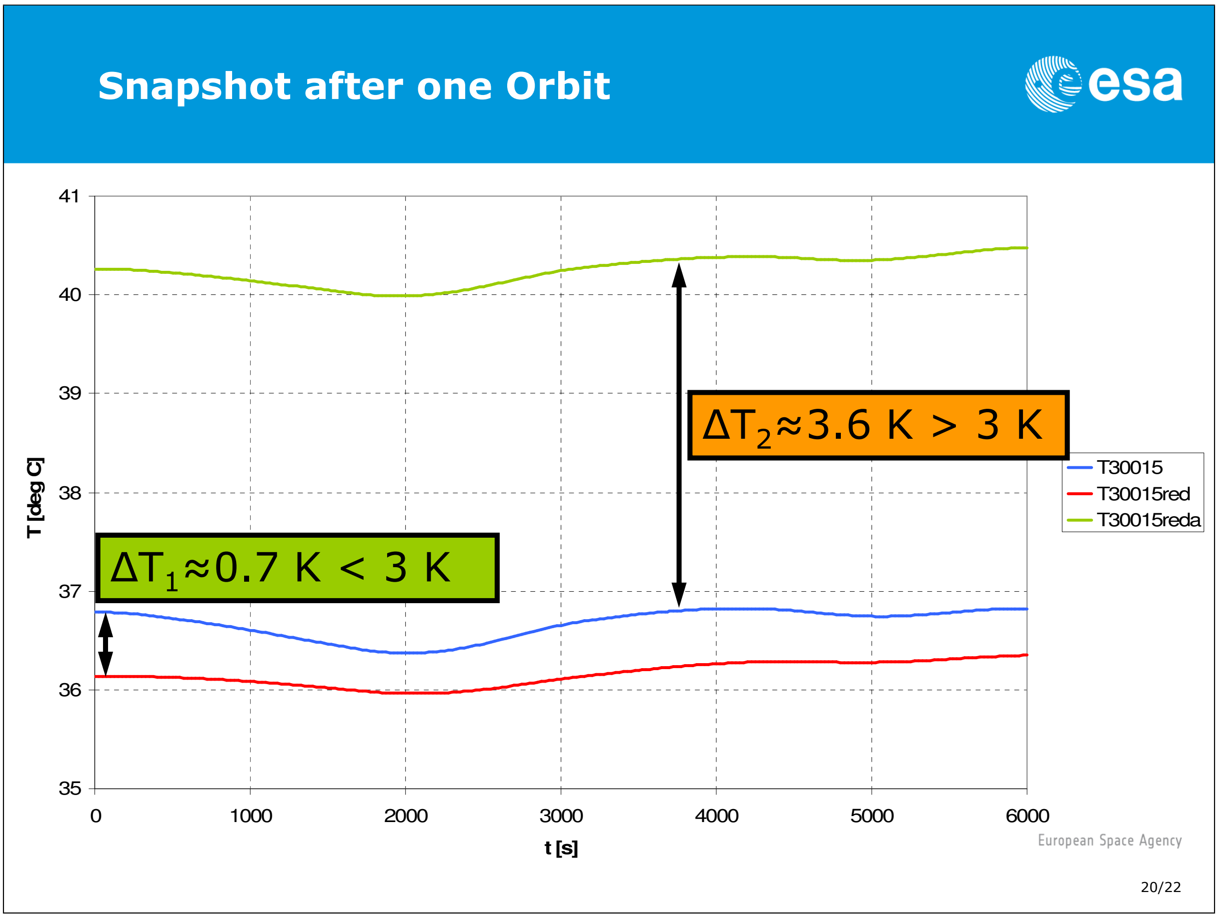
19/22


Snapshot after one Orbit
esa
41
40
39
38
37
36
35
T [deg C]
0
1000
2000
3000
4000
5000
6000
t [s]
ΔT2≈3.6 K > 3 K
ΔT1≈0.7 K < 3 K
T30015
T30015red
T30015reda
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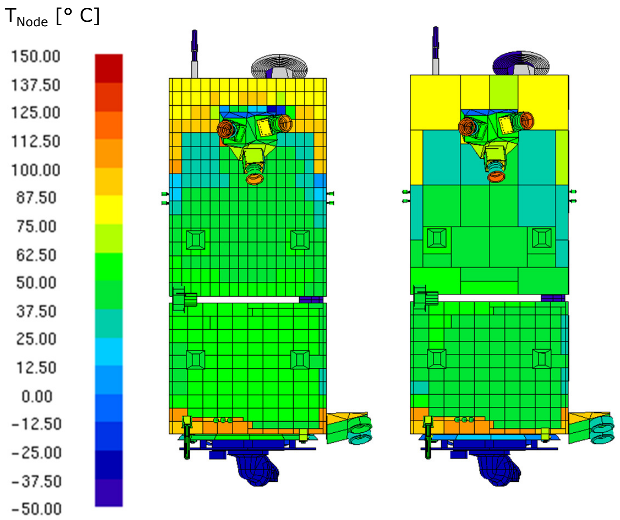
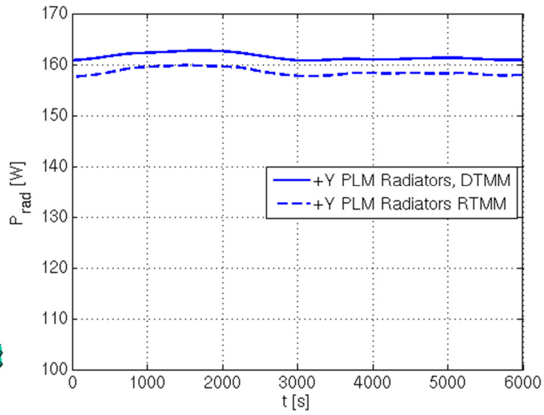
20/22

Heat flux from radiators on +Y Panel





$$\left.\begin{aligned} W_{rad,DTMM} &= 968.9\ \text{kJ} \\ W_{rad,RTMM} &= 951.2\ \text{kJ} \end{aligned}\right\} \quad 1.8\ \%\ \text{deviation}$$

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Conclusion

90 % reduction of the panels:

- ⇒ Equipment nodes within the requirements
- ⇒ Most of the reduced structural parts are within the requirements; Min/Max-values deviate more than 5 K
- ⇒ Deviations of heat flux to deep space is negligible low
- ⇒ Heater power deviates more than 5 % from the detailed model
- ⇒ Time- or temperature dependencies cannot be handled by the TMRT
  - ⇒ But can be handled manually

- ⇒ *TMRT has a great potential for strong reductions*
- ⇒ *In many cases the reduction is much more than just applying the TMRT on the DTMM*
  - ⇒ *Effort of reduction can be decreased if the DTMM was designed to be reduced*

...any Questions?

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Appendix T

Validation of a Method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model

Lars Hagemann
(EADS Astrium - Space Transportation, Germany)

Abstract

The thermal behavior of the cryogenic upper stage of the Ariane 5 launcher is simulated on system level with an overall thermal mathematical model (TMM) in ESATAN.
The stage mainly consists of the tanks which are surrounded by sub-systems and further structure. Cavities between the components are vented with inert gas. During ground phase, convection in the cavities plays a major role in the thermal budget of the stage. This convection is mostly predominated by buoyancy forces, because of large temperature gradients appearing in the vicinity of the cryogenic tanks. The flow regime is typically in transition or full turbulent regime.
To simulate the flow in the cavity computation fluid dynamics (CFD) simulation is used. The heat flows are transferred to the TMM by calculating the thermal conductor values from the results of the CFD simulation.

In this presentation the validation of this method is explained. A test setup representing a simplified typical upper stage configuration was developed and realized. In order to achieve the requested flow similarity, two temperature controlled walls were part of this test cavity: one cooled with liquid nitrogen, the other one heated with a water conditioned heat exchanger. Temperature measurements attached to other walls of the cavity as well as gas temperature measurements were used for validation of the CFD simulation.
The test setup was modeled with the CFD code Ansys/FLUENT. Good agreement between test and CFD simulation was achieved. The steady state solutions of these fluid dynamic calculations are used to determine heat transfer coefficients, which are introduced into the related ESATAN model. The wall heat transfer coefficients are calculated on an area-weighted basis of wall heat fluxes and refer to mean gas temperatures within the cavity in the same way as implemented in the ESATAN code.
A simplified system level model of the test setup was established in ESATAN, where the heat transfer coefficients from the results of the CFD simulation were implemented.
Little differences in the resulting temperatures between CFD and TMM show the validity of this engineering method.

25th European Workshop on Thermal and ECLS Software
ESA/ESTEC, Noordwijk, The Netherlands, 8 – 9 Nov 2011

Validation of a Method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model

Lars Hagemann

16/11/2011

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1. Introduction
2. Test setup
   → From BMA-Cavity to Test setup
   → Test Procedure
   → Results from Test
3. CFD analysis with Ansys/FLUENT
   → Simulation Model
   → Convergence Criterias
   → Results from CFD Analysis
4. Simulation in ESATAN
   → Simulation Model
   → Results from ESATAN
5. Conclusion

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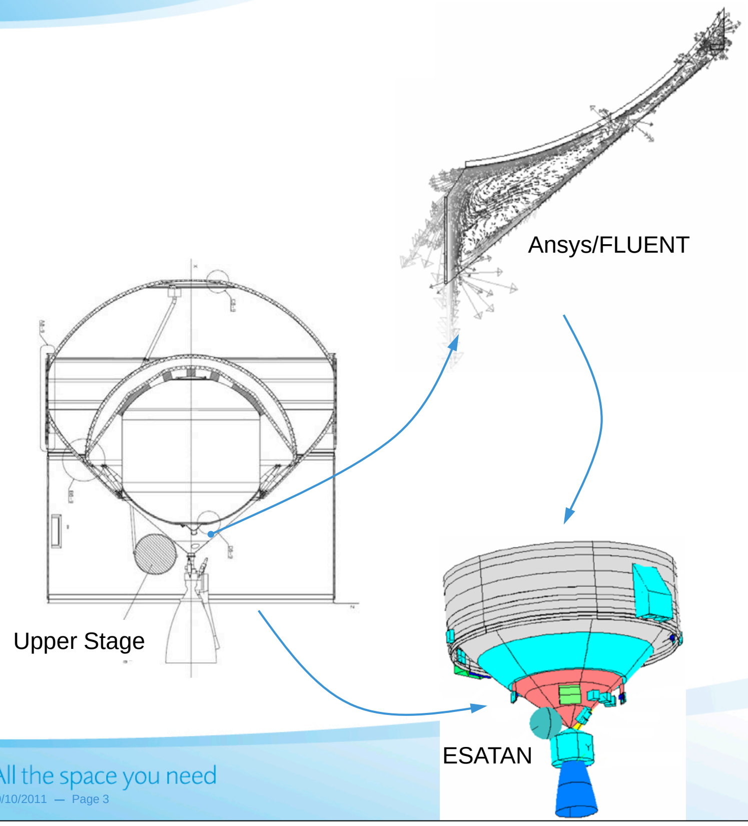
Introduction



- Simulation of upper stage on system level with a thermal mathematical model (TMM) in ESATAN
- Mostly turbulent flow in cavities, due to high temperature gradients in the vincinity of cryogenic tanks
- Computational Fluid dynamics simulation of the flow in Ansys/FLUENT. Delivering heat flows, temperatures and heat transfer coefficients
- Implementation of heat transfer coefficients into the TMM via linear thermal conductor values

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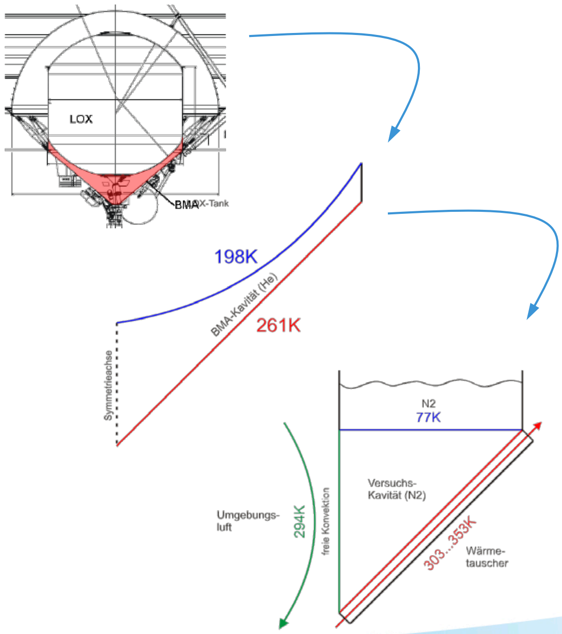
Test Setup

From BMA-Cavity to Test Setup



- Estimation of the flow regime inside the BMA-Cavity
  - → Venting gas Helium
  - → Characteristic length 1.8 m
  - → Rayleigh-Number $Ra=1.06 \cdot 10^9$
  - → Turbulent flow regime
- Estimation of the required temperature gradient inside the test setup
  - → Venting gas Nitrogen
  - → Characteristic length 0.707 m
  - → Required minimum Rayleigh-Number $Ra=1.06 \cdot 10^9$
  - → With a Nitrogen cooled (77K) wall on the top side of the cavity the minimum temperature on heated wall is 303K to reach a turbulent flow regime.

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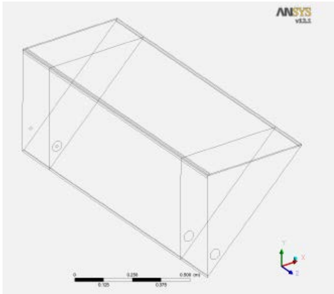
Test Setup

Test configuration and procedure

- Configuration of the cavity
  - → Three compartments for decoupling the measuring section from impact of the noninsulated walls at the beginning and end of the cavity.
- Convection Test Procedure
  - → The test cavity is vented with a small Nitrogen mass flow rate. Due to the hot and cold wall a natural convection flow develops and produces an temperature distribution on the vertical wall. Together with the gas temperature this data is recorded.



- Positions of thermocouples on vertical wall for recording the temperature distribution:

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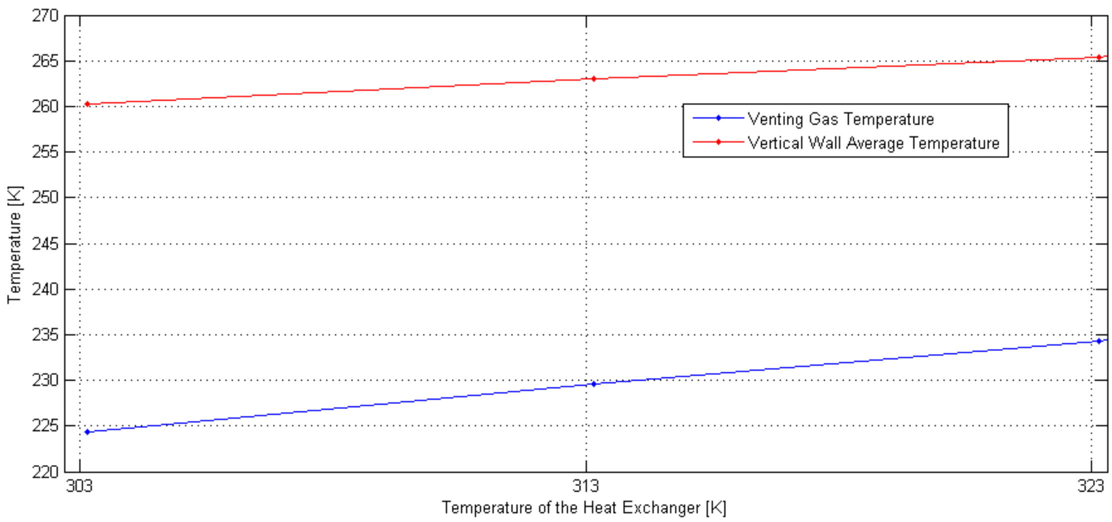
Test Setup

Results from convection test



- By varying the temperatur of the hot wall the evolution of the resulting temperatures is evaluated

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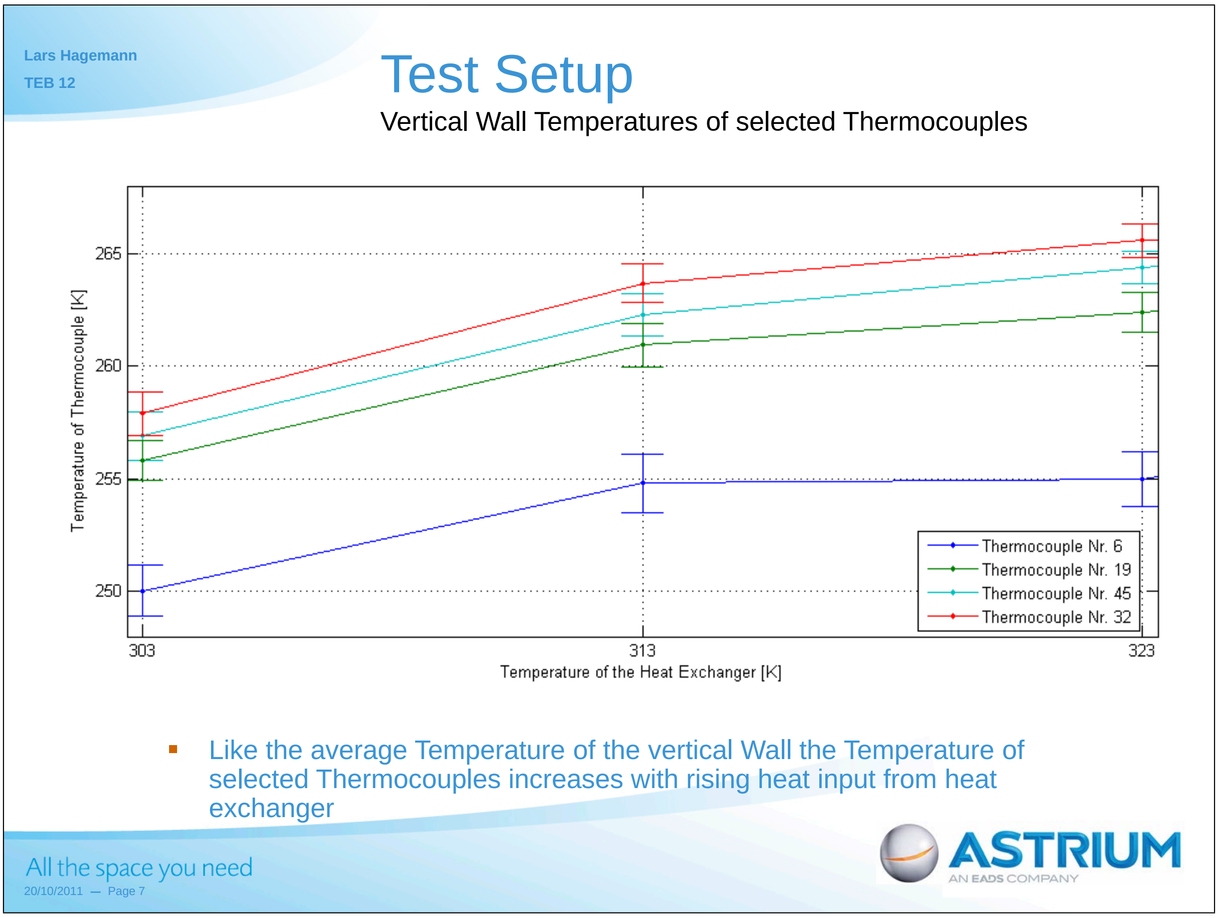
Lars Hagemann
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Test Setup
Vertical Wall Temperatures of selected Thermocouples
Temperature of Thermocouple [K]
265
260
255
250
303
313
323
Temperature of the Heat Exchanger [K]
Thermocouple Nr. 6
Thermocouple Nr. 19
Thermocouple Nr. 45
Thermocouple Nr. 32
Like the average Temperature of the vertical Wall the Temperature of selected Thermocouples increases with rising heat input from heat exchanger
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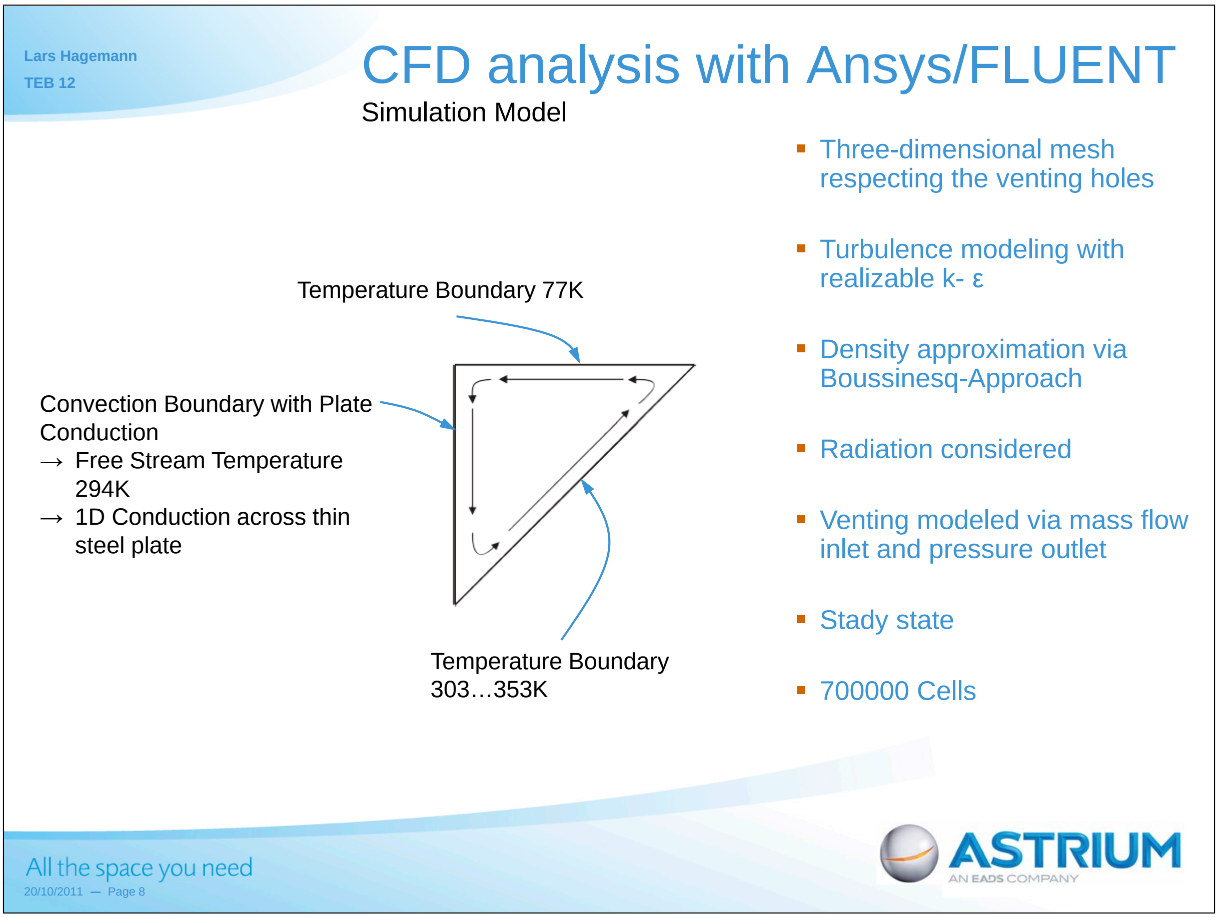
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CFD analysis with Ansys/FLUENT
Simulation Model
Temperature Boundary 77K
Convection Boundary with Plate Conduction
→ Free Stream Temperature 294K
→ 1D Conduction across thin steel plate
Temperature Boundary 303…353K
Three-dimensional mesh respecting the venting holes
Turbulence modeling with realizable k- ε
Density approximation via Boussinesq-Approach
Radiation considered
Venting modeled via mass flow inlet and pressure outlet
Stady state
700000 Cells
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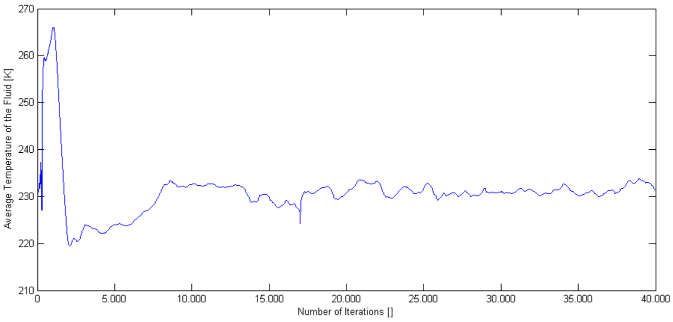
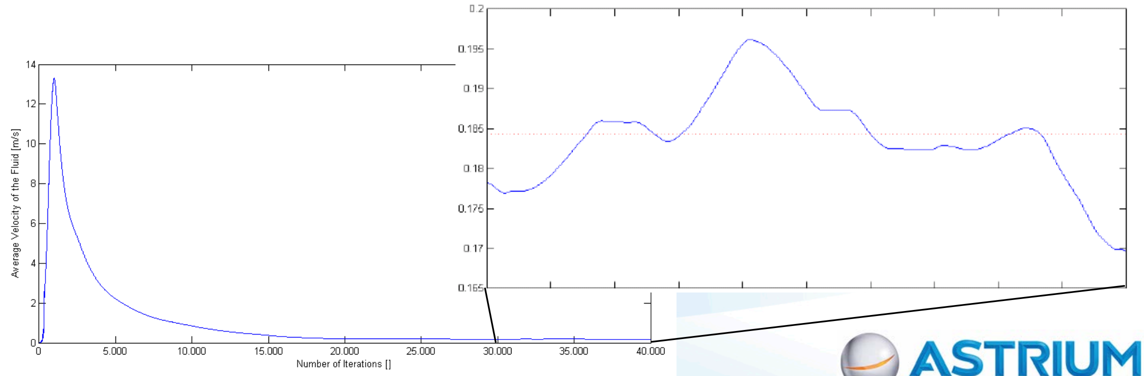
CFD analysis with Ansys/FLUENT

Indicators for Convergence

- The residuals in a CFD simulation with a bouyancy driven flow are not significant. Therefore other indicators for convergence are used:
  - → Total heat flux across the model
  - → Average speed of the fluid
  - → Average temperature of the fluid





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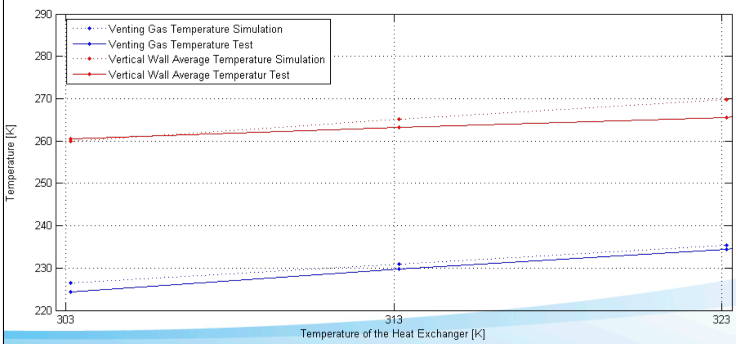
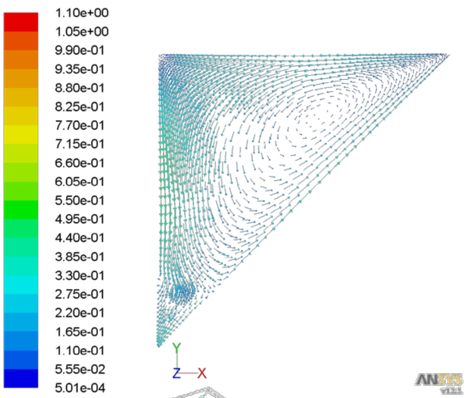
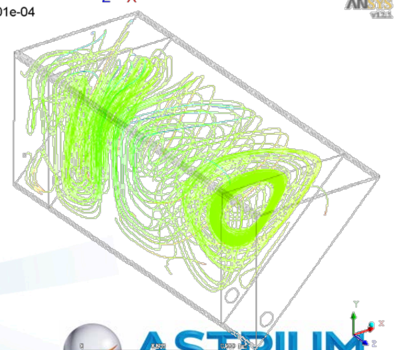
CFD analysis with Ansys/FLUENT

Results from CFD simulation

- Good agreement between test and simulation for heat exchanger temperatures between 303K and 323K
- Mainly circulating flow inside the cavity
- Divergence in upper temperature level. Fluid flow is unstable due to higher energy level inside the cavity







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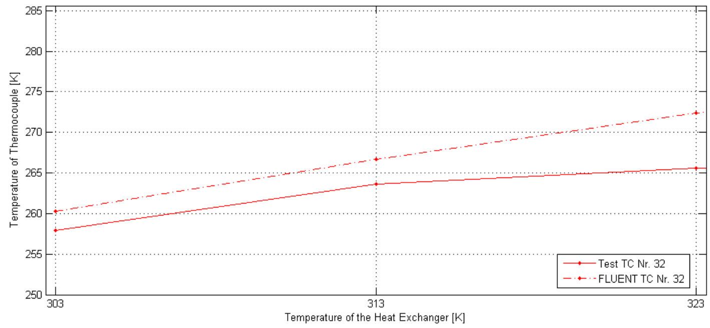
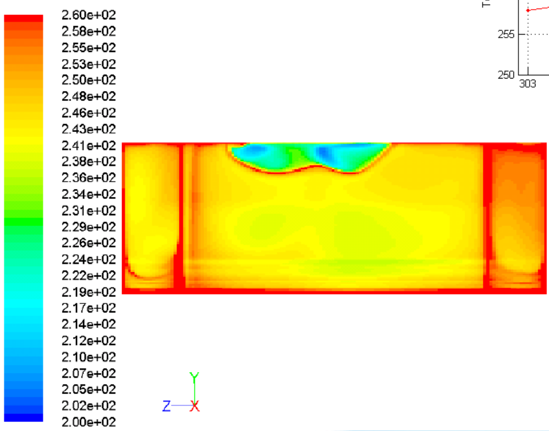
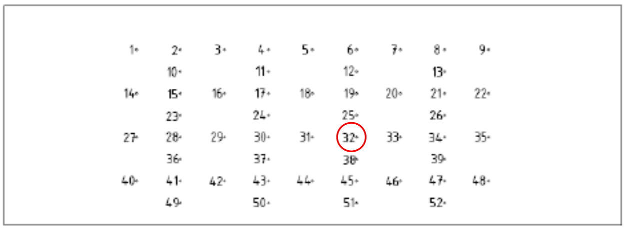
CFD analysis with Ansys/FLUENT

Results from CFD simulation

- Divergence in upper temperature level occurs. similar to average temperatures.
- High gradients in temperatures at some areas







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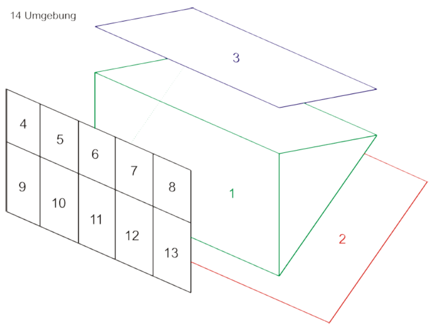
Simulation in ESATAN

Simulation Model

- Modeling the test cavity with 14 thermal nodes
- One gaseous node representing the fluid in the middle section
- Subdevision of vertical wall for temperature distribution
- Linear conductors representing the convection between walls and fluid

$$GL_{i,j} = \alpha \cdot A = \frac{\dot{Q}}{T_j - T_i}$$

- Due to no significant impact the venting and the heat transfer via the walls at beginning and end are neglected



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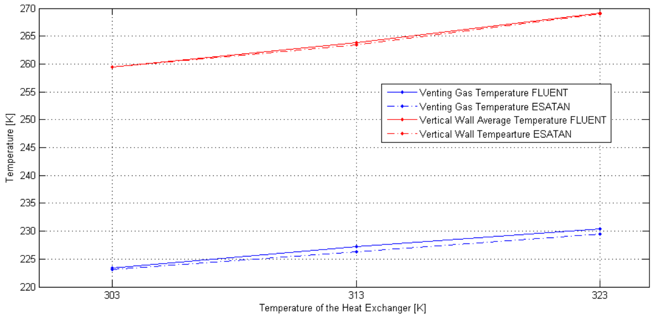
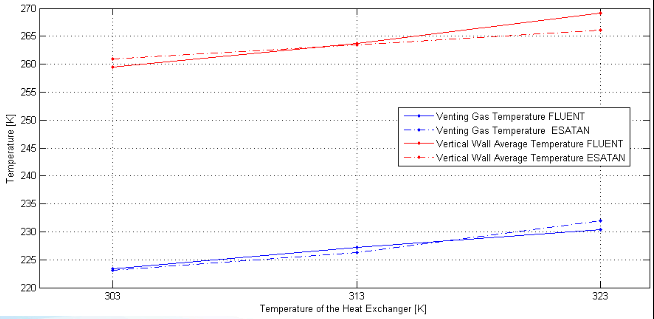
Simulation in ESATAN

Results

- Comparison CFD and test results
  - → Little differences between CFD and test results
  - → Good agreement of linear conductors representing the convection



- Linear Conductors valid over a wide domain (see lower diagram)
  - → Linear conductor values of the heat exchanger temperature 313K is used to calculate the other cases with higher or lower temperature



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Conclusion

- Validity of the method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model is affirmed
- Good agreement between test results and CFD results
- Good overall agreement between CFD results and Lumped Parameter TMM

- Future outlook
  - → Further studies on flow instabilities
  - → Extension to multiple gaseous nodes and implemeting of Heat transfer between gaseous nodes in TMM

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Questions ?
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Appendix U

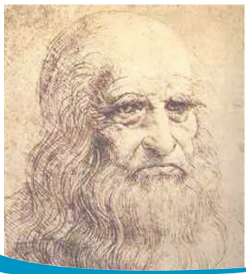
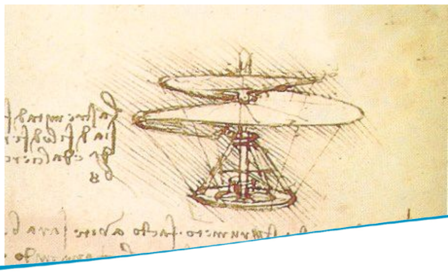
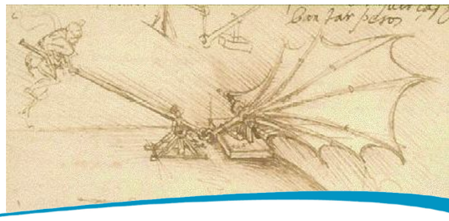
Evaluation of stochastic & statistic methods for spacecraft thermal analysis

Jean-Paul Dudon
(Thales Alenia Space, France)

Hélène-Marie Pasquier
(CNES, France)

Abstract

The design and analysis of thermal control system are particularly important during the development of a space project. These projects are characterized by a small number of specialists in thermal processes and consolidation of the concept often imposed by customers.
Anyway for years this context has been challenged by the need to continuously improve the overall thermal analysis and design process. There is in particular a growing trend to avoid over-design. In this sense, the duration and costs are reduced and the concept, in general, is more flexible with regard to changes that it may undergo throughout a project.
In this new area, the evaluation of new methodologies is seen as useful and necessary for the development of thermal control in space projects. The management problem of inaccuracies of the parameters, which is largely presented and considered in several other domains, arises with increasing insistence.
Therefore, it is interesting to evaluate the feasibility of advanced approaches such as stochastic, heuristic or metamodeling to improve development process in terms of consolidation of thermal control.
This study aims to evaluate the feasibility and methodology of various of above mentioned approaches for sensitivity/uncertainty analysis and for correlation of thermal models with regard to the thermal balance test on the "real satellite."
OPTIMUS tool has been chosen since it proposes a large panel of methods for sensitivity and optimisation.
The aim is to compare various of these methods between themselves and with the traditional method currently used by Thales Alenia Space thermal engineers. The comparison is based on efficiency on results, such as reduced gap between measurement and calculation for correlation exercise or impact on margin for sensitivity analysis. Impact on the duration of analyses and compatibility with industrial process in place are also considered as output of this project.

Evaluation of stochastic & statistical methods for spacecraft thermal analysis

Jean-Paul Dudon, *Thales Alenia Space*, Cannes
Hélène Pasquier, *CNES*, Toulouse

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Summary

Page

- Introduction / context
- Direct simulation and meta-modeling methods assessed
- Application # 1 : Model correlation
- Application # 2 : Sensitivity/uncertainty analysis
- Conclusion

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Context & objectives

Context

- For few years it has been shown that stochastic approach can improve spacecraft thermal analysis activity (FSASTA study in 2004 ,…)
- R&T TAS–CNES for the present study on new stochastic & statistical approach

Objective of this study

- Confirm profit and applicability of stochastics for internal use
- Evaluating new methods to reduce cost of the approach on two test cases : correlation and sensitivity/uncertainty analysis for which SM was revealed as promising but heavy time consuming
- To reduce cost the idea is to evaluate the feasibility of using predictive approaches based on meta-modeling techniques versus direct simulation approach

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SM : Stochastic Methods MCS : Monte Carlo Simulation, DOE : Design of Experiment , RSM : Response Surface Model, EGO : Efficient Global Optimisation

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Summary

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- Introduction / context
- Direct simulation and meta-modeling methods assessed
  - Methods
  - OPTIMUS tool
- Application # 1 : Model correlation
- Application # 2 : Sensitivity/uncertainty analysis
- Conclusion

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Meta-modeling approach

Page

Definition :

Meta-modeling is a statistical technique to approximate the response of an analysis code. These statistical approximations or metamodels are built and used to replace time-consuming numerical analysis calculation in order to facilitate activities such as optimization/calibration, exploration of design, multi-discipline simulation.

Meta-modeling may use deterministic or stochastic approaches. It includes techniques such as design of experiments (DOE), Response surface models (RSM)

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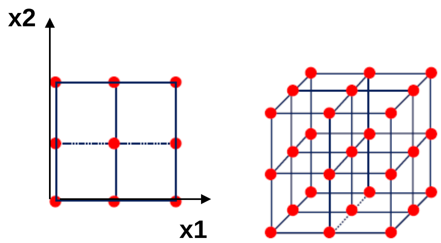
Meta-modeling approach

Page

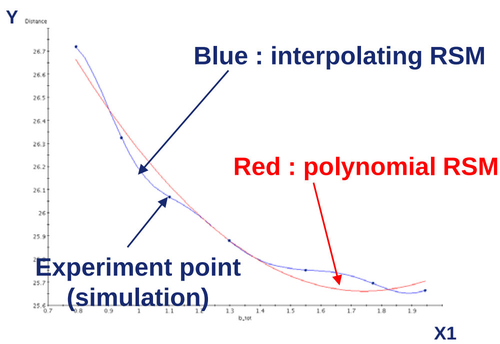
- Design of Experiment (DOE) : DOE is a powerful tool aiming at sampling design space with limited computed experiments
  - Wide panel of recent DOE available in OPTIMUS (orthogonal, random, …)



3^2 and 3^3 Ful Factorial DOE

- Response Surface Model (RSM) : RSM is built from a reduced sampling (DOE typically) to simulate analytically the model response
  - Wide panel of RSM available in OPTIMUS : least square (deterministic), Interpolating (Kriging, stochastic),

$$f(x_1, x_2, \ldots x_n) = \mu + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} \sum_{j=i}^{n} b_{i,j} x_i x_j$$



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- f = response of the meta-model to variations of xi variables

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Meta-modeling approach

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Meta-modeling approach has been tested for both exercices :

- For sensitivity/uncertainty analysis
  - DOE allow to reduce number of factors within a limited number of simulation
  - RSM lead to a « low cost » sampling for uncertainty propagation
- For correlation
  - Correlation is optimisation ➔ Minimisation of observation / model distance
  - 1- DOEs are used to build the highest fidelity RSM as possible
  - 2- RSM is then used to simulate analytically the model response
  - 3- Optimisation methods are run on RSM in order to save CPU
  - WARNING : RSM has to be validated before optimisation in order to get efficient AND reliable results

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SM : Stochastic Methods MCS : Monte Carlo Simulation, DOE : Design of Experiment ,
RSM : Response Surface Model, EGO : Efficient Global Optimisation

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Direct simulation approach

Page

More commonly used approaches using direct simulation have been also assessed for comparison:

- Direct MCS for sensitivity/uncertainty analysis
  - Reference method but costly sampling (1 experiment = 1 simulation)
  - More efficient with Latin Hypercube (LH) DOE for sampling
- Random Search and Evolutionary algorithm for correlation
  - Random Search with LH : Equivalent method in PANAMA (Blue), STORM, ..
    - Global optimum search but can be unreasonably time consuming
  - Self-Adaptive Evolution method (SAE) : Evolutionary algorithm quite close to genetic algorithm
    - Convergence usually more rapid when a two step optimisation process : 1- Global SAE for 5-6 iterations and 2- gradient like local optimisation

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SM : Stochastic Methods MCS : Monte Carlo Simulation, DOE : Design of Experiment ,
RSM : Response Surface Model, EGO : Efficient Global Optimisation

Hybrid optimisation method : EGO

EGO : Hybrid method between RSM and simulation for optimisation

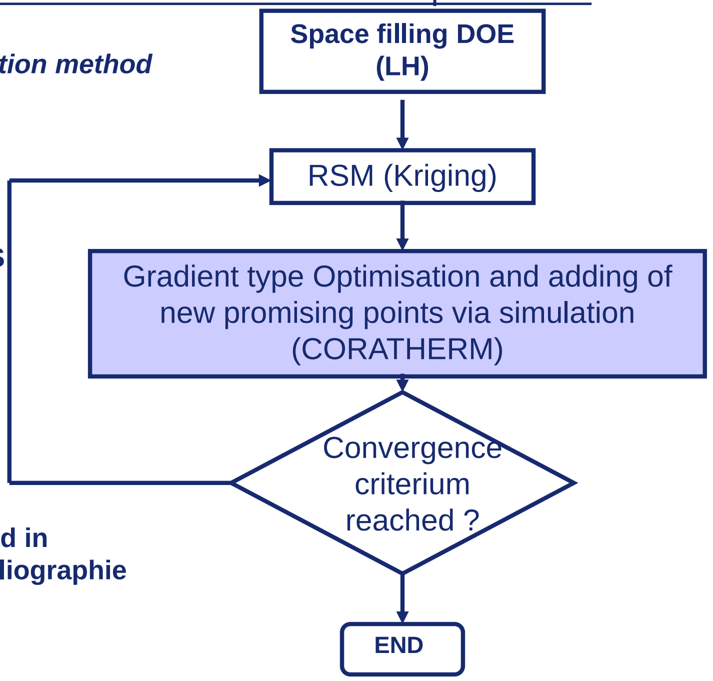
EGO : *Efficient Global Optimization method*

Major interests :

-Low cost

-Self validation of RSM

-Fully implemented in OPTIMUS



EGO widely plebiscited in specialized recent bibliographie (1997-2010)

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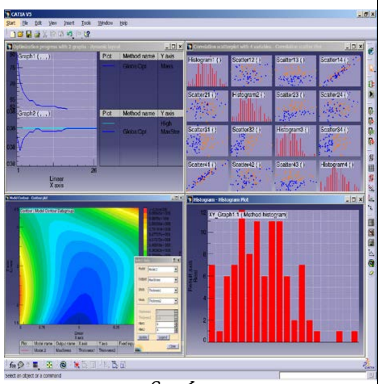
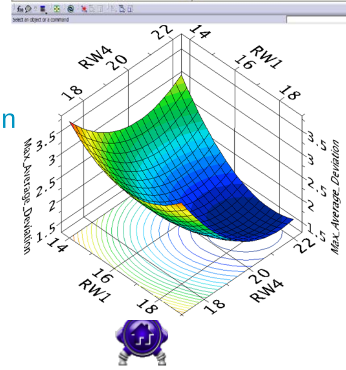
About selected tool : OPTIMUS

OPTIMUS (LMS Noesis) assessment

- Large panel of stochastic and statistical methods (DOE, RSM, MCS, …)
- Powerful and user friendly dedicated **pre and post processing**
- **Highly automated process for computation integration** Easy with CORATHERM and ESATAN codes
- Strong interest of **parallel run capability**
  - Significant saving of computation time
  - Higher added value with free license code (Coratherm in TAS for example)





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Summary

- Introduction / context
- Stochastic and meta-modeling methods assessed
- Application # 1 : Model correlation
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Correlation exercice

Selected approach

- **No interest for "all stochastic" :**
  - Too much factors and not enough information on input distribution
  - Too much impact on industrial process (step by step),
- **Decision to use a step by step process and gathering most or all of them in a unique workflow**
  - By using OPTIMUS for steps for which its methods are the best adapted and keep other steps for traditional process (modeling error, material change,…)
  - For a limited number of parameters per optimisation (< 20 for the moment)

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Correlation exercice

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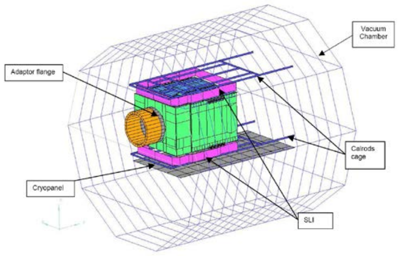

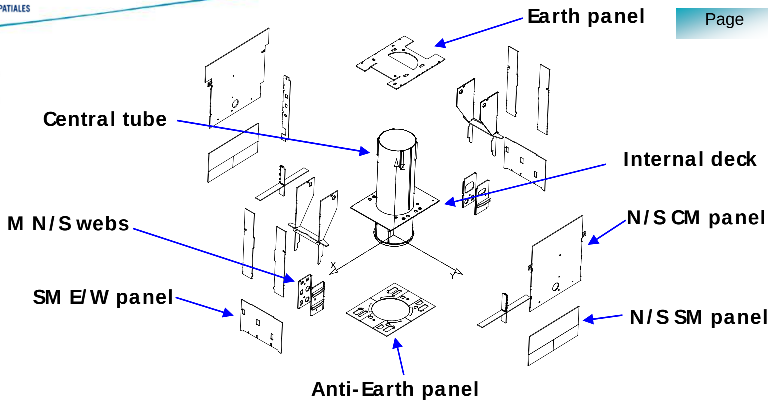

Application #1 : Correlation exercise on a *SATCOM*

4 steps selected for model test correlation from traditional approach :

Step 1 : Reaction wheels dissipation evolution in E2 (SM)

Step 4 : Update of unit payload dissipations (crossing CM)

Step 7: Update of Ka TWT- Heat Pipe coupling (CM)

Step 8 (added) : Update of conductivity of CM North & South panels

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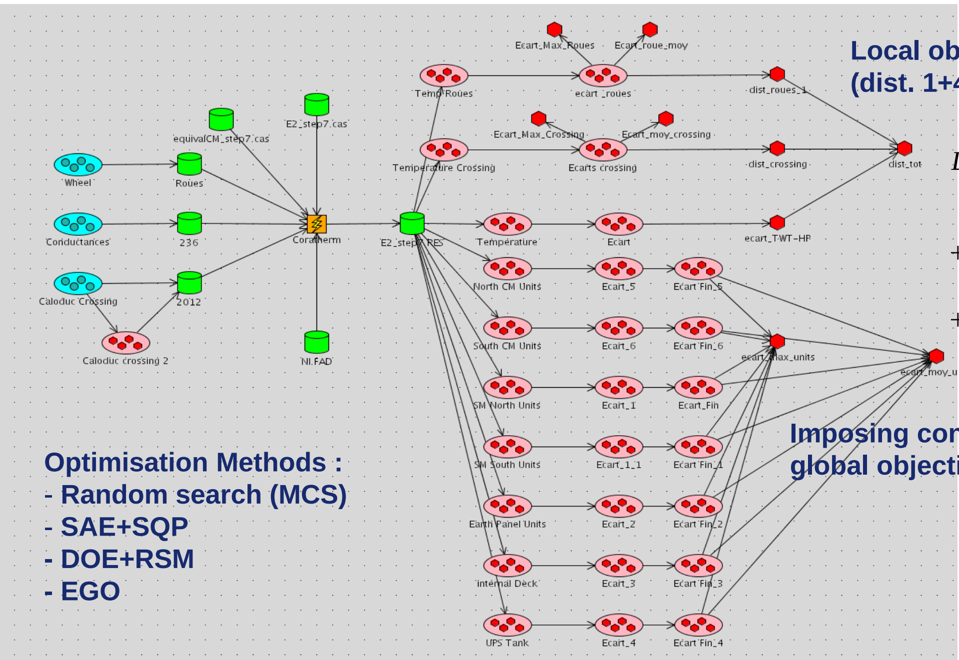
Correlation exercice

OPTIMUS Workflow for updating steps 1, 4 & 7 at a time (cas E2)



Local objective function (dist. 1+4+7)

$$Dist = \sqrt{\sum_{i=1,Crossing}^{13} (\Delta T_i)^2} + \sqrt{\sum_{i=1,Wheels}^{4} (\Delta T_i)^2} + |\Delta T_{3376}|$$

Correlation exercice

OPTIMUS correlation approach : Exemple of relevant results

Best tested solution : EGO with constraint imposed on outputs
➔Lowest local distance model/observation
➔Global criteria totally respected
➔Lowest time

steps 1,4 & 7 (full drive conf)	temperature deviations > 5°C	mean deviation on all obs units (110 nodes)	local deviation on critical nodes	total time
Traditional	8	0.1	13.3	2 days
OPTIMUS (EGO)	0	0.05	3.02	5 hours

Key results of SATCOM correlation with OPTIMUS (EGO) and comparison with traditional method on steps 1, 4 & 7

➔ OPTIMUS use was proven to improve the correlation results and the analysis run time using stochastic & meta modeling methods

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Correlation exercice : Conclusions

- About Global Process
  - The stochastic methodology revealed as very interesting when locally applied within a “step by step” process,
  - Interest to group several steps in one, by imposing specific constraints besides the local objective was demonstrated
  - Use of OPTIMUS tool is flexible and allow to choose different calculation methods
  - Theoretical competences needed are minimised (compared with the possible advantages)
- About Methodology
  - EGO > SAE+SQP > SAE only > Random Search
  - EGO is the best compromise duration / efficiency / reliability and it is easy to use
  - DOE and Polynomial RSM can save lot of time on case by case basis,
    - but since they are not fully implemented in OPTIMUS the validation phase of the RSM is iterative and can limit the gain
    - Number of required simulation for polynomial RSM building increase rapidly with number of parameters

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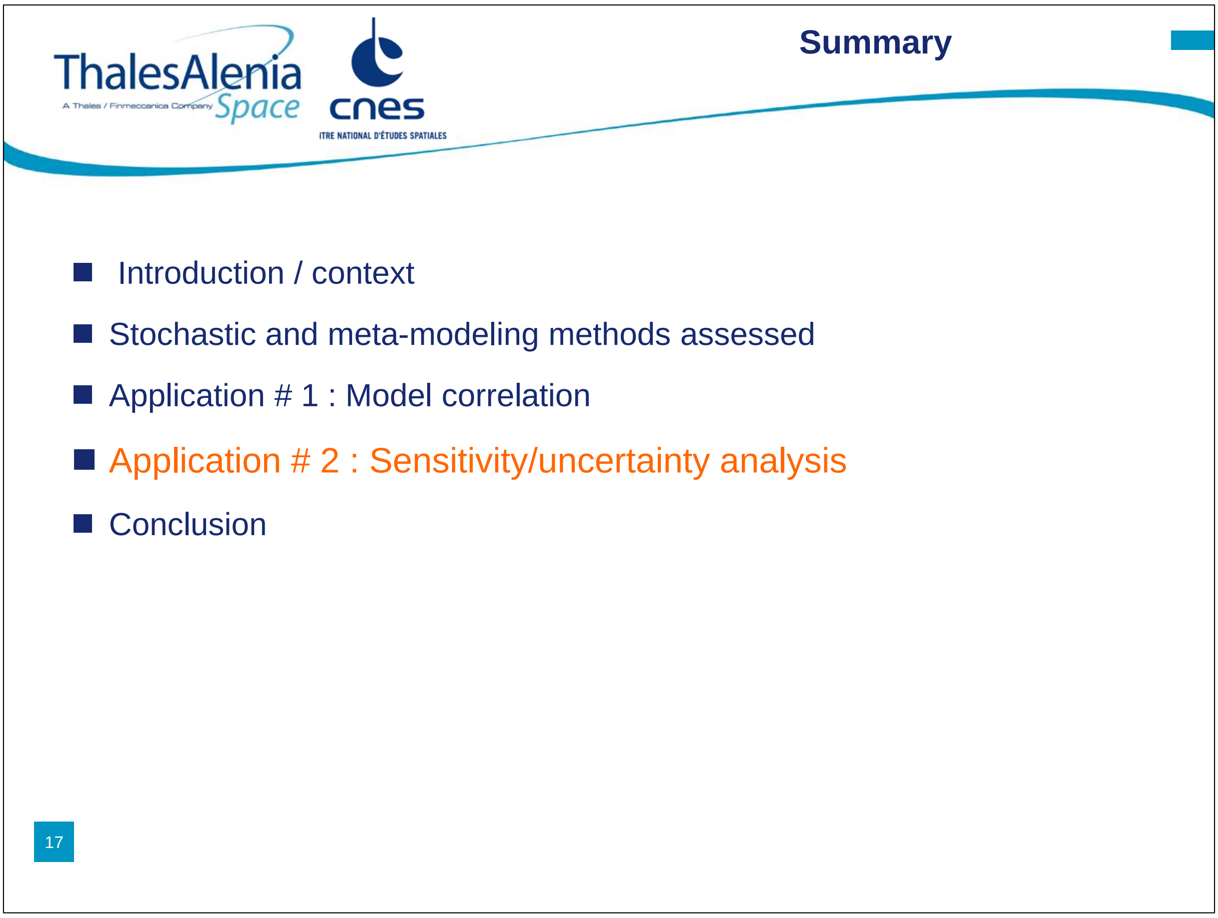
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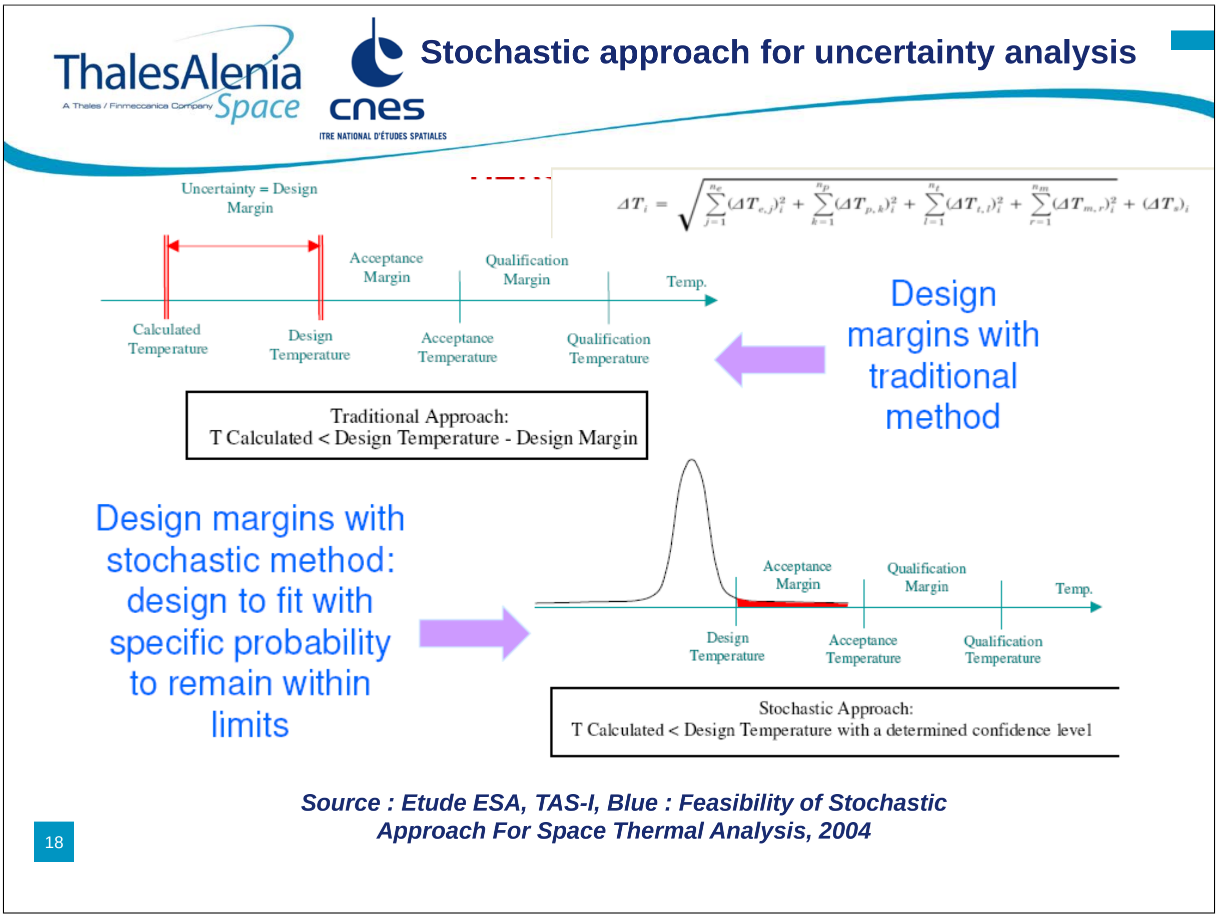
Stochastic approach for uncertainty analysis
$\Delta T_i = \sqrt{\sum_{j=1}^{n_e}(\Delta T_{e,j})_i^2 + \sum_{k=1}^{n_p}(\Delta T_{p,k})_i^2 + \sum_{l=1}^{n_t}(\Delta T_{t,l})_i^2 + \sum_{r=1}^{n_m}(\Delta T_{m,r})_i^2 + (\Delta T_s)_i}$
Uncertainty = Design Margin
Acceptance Margin
Qualification Margin
Temp.
Calculated Temperature
Design Temperature
Acceptance Temperature
Qualification Temperature
Traditional Approach:
T Calculated < Design Temperature - Design Margin
Design margins with traditional method
Design margins with stochastic method: design to fit with specific probability to remain within limits
Acceptance Margin
Qualification Margin
Temp.
Design Temperature
Acceptance Temperature
Qualification Temperature
Stochastic Approach:
T Calculated < Design Temperature with a determined confidence level
Source : Etude ESA, TAS-I, Blue : Feasibility of Stochastic Approach For Space Thermal Analysis, 2004
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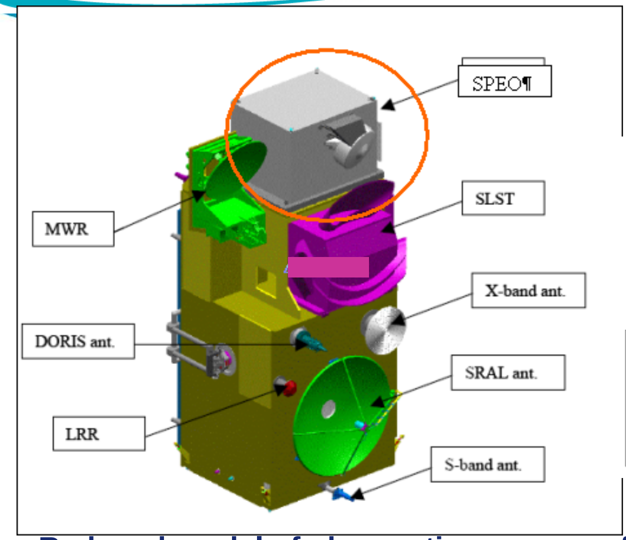
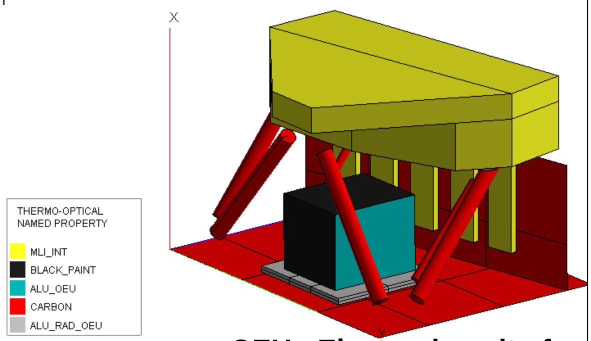
Stochastic approach for uncertainty analysis

The model





OEU : Electronic unit of observation instrument

Reduced model of observation spacecraft :

- **ESATAN, ESARAD (radiative) , CORATHERM (conductive)**
- **280 nodes**
- **Sensitivity/uncertainty on OEU unit**

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Stochastic approach for uncertainty analysis

Objectives

Compare effects of concurrent inaccuracies and confidence level (*stochastic approach*) versus cumulative inaccuracies and margin (*deterministic approach*)

1- Calculate the $T_{max\ OEU}$ corresponding to various X percentile (μ+3σ, μ+2σ, median), i-e the $T_{max\ OEU}$ obtained by X % of total runs

2 - Compare it to $T_{Max\ design}$ and to design margin (10°C) taken in the deterministic approach

$Tmax_{design}$ = 40 °C
T_{calcul} (Nominal case) = 30°C
Margin (deterministic approach) = 10°C

Temperature LIMITS	OPERATIONAL						
	Min			Max			Min
Element designation	Q	A	D	D	A	Q	Start up
OEU	-30	-20	-10	+40	+50	+60	-30

NB : We add to $T_{max\ stochastic}$ a 3°C margin for systematic error not taken into account in probabilistic process (modeling error, …)

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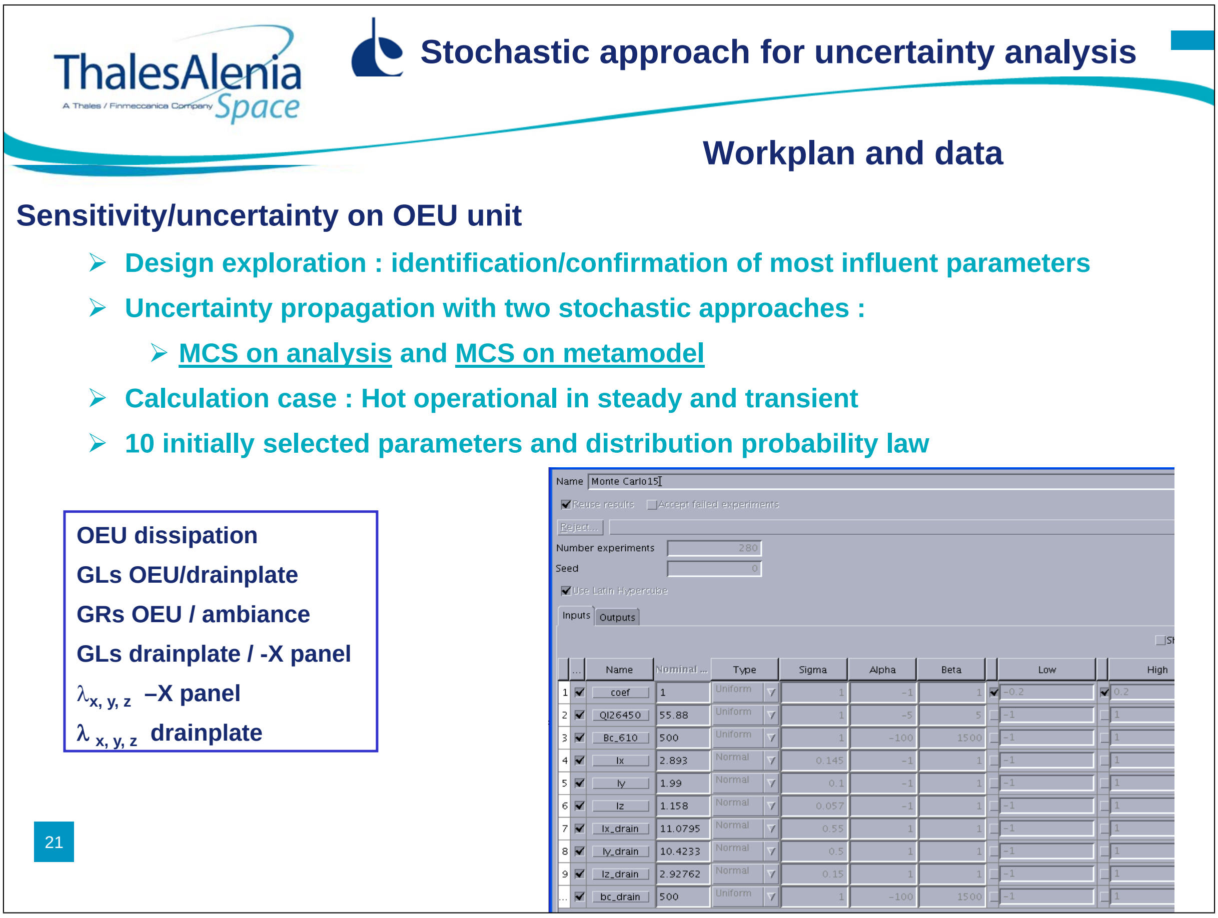
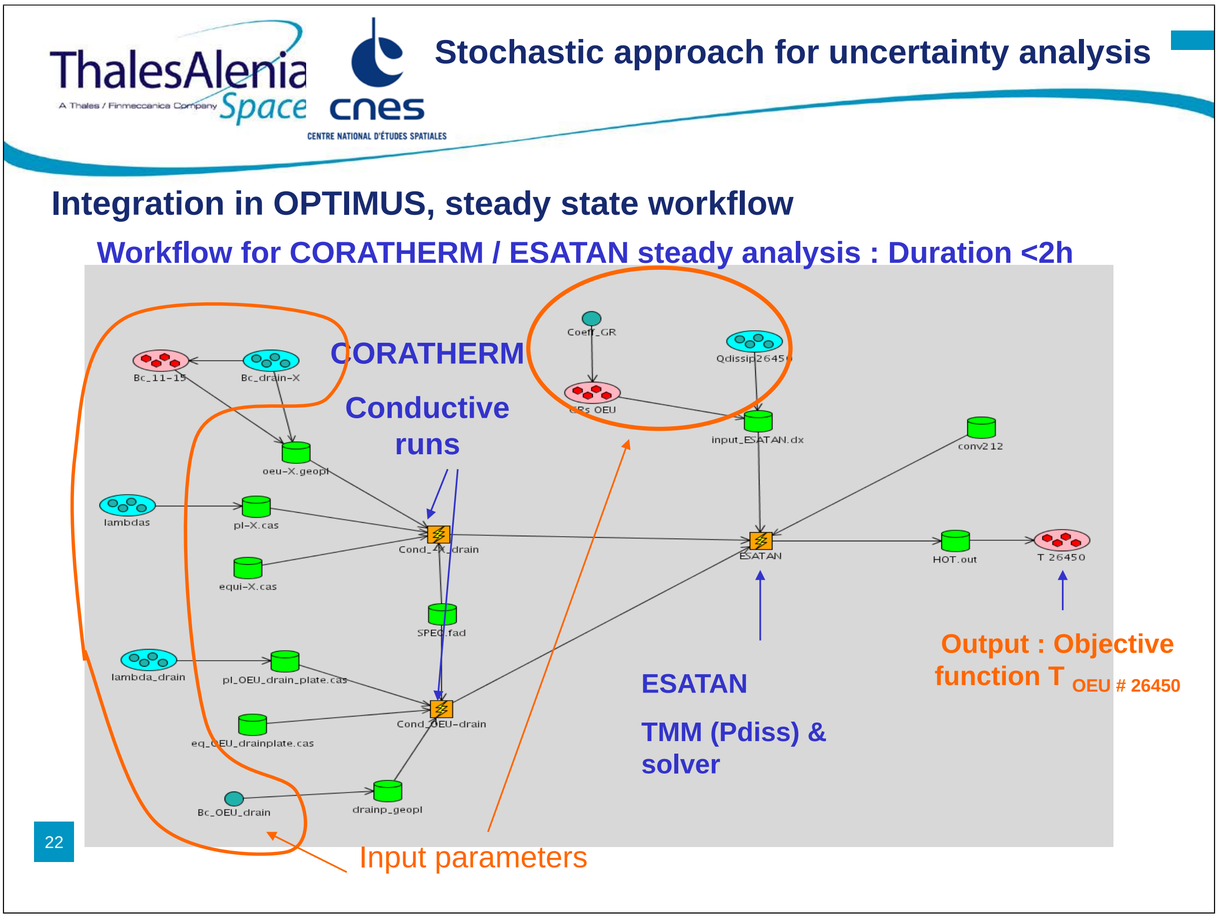


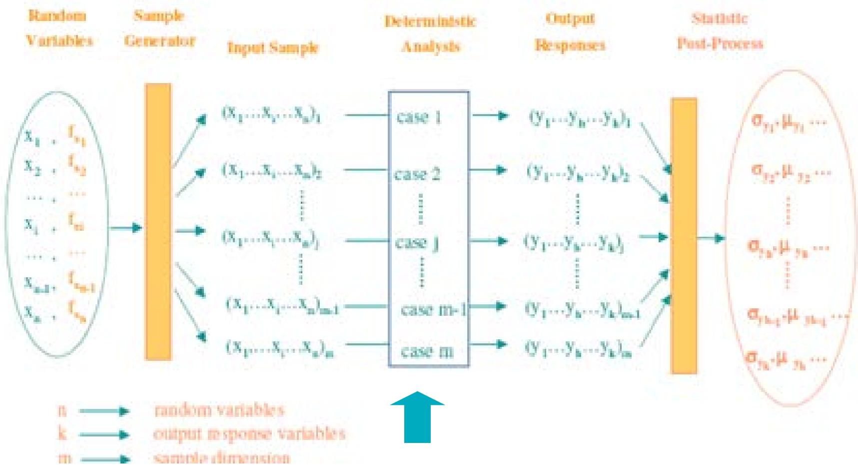
	...	Name	Nominal ...	Type	Sigma	Alpha	Beta		Low		High
1	✔	coef	1	Uniform	1	-1	1	✔	-0.2	✔	0.2
2	✔	QI26450	55.88	Uniform	1	-5	5		-1		1
3	✔	Bc_610	500	Uniform	1	-100	1500		-1		1
4	✔	lx	2.893	Normal	0.145	-1	1		-1		1
5	✔	ly	1.99	Normal	0.1	-1	1		-1		1
6	✔	lz	1.158	Normal	0.057	-1	1		-1		1
7	✔	lx_drain	11.0795	Normal	0.55	1	1		-1		1
8	✔	ly_drain	10.4233	Normal	0.5	1	1		-1		1
9	✔	lz_drain	2.92762	Normal	0.15	1	1		-1		1
...	✔	bc_drain	500	Uniform	1	-100	1500		-1		1



Stochastic approach for uncertainty analysis

Simulation and metamodeling approach

Orthogonal DOE (Placket Burman) allow to reduce number of input factors (4 vs 10) in a limited time



RSM (quadratic polynomial) instead of analysis code allow to save most of analysis time

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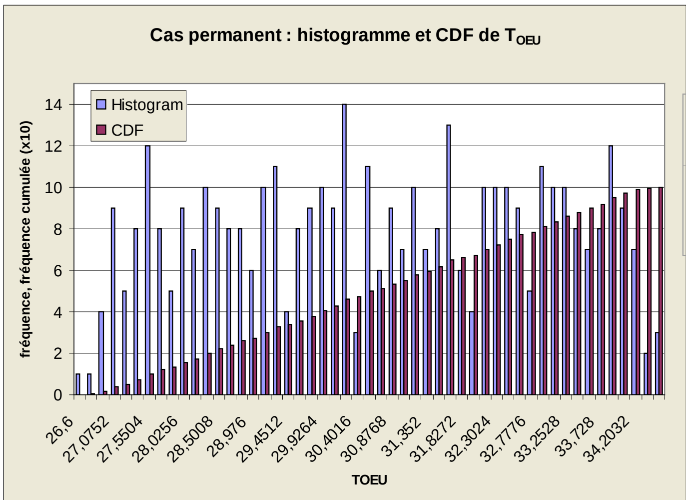
Stochastic approach for uncertainty analysis

Results with MCS on simulation (400 runs, 9 hours CPU)

CDF calculation and percentiles at 50% (median) , 97.7% ($\mu+2\sigma$) et 99.85% ($\mu+3\sigma$)



	P99.85	P97.7	P50
OEU Temp (C) 400 runs	37.5	37.1	33.6

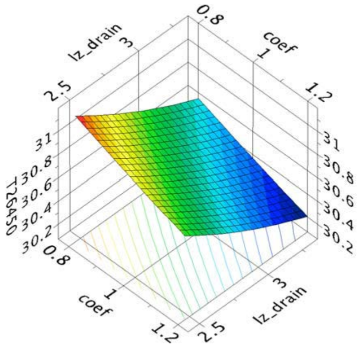
Vs T_{marged} TAS = $T_{max\ design}$ =40 °C

➔ The margin was overestimated with deterministic approach

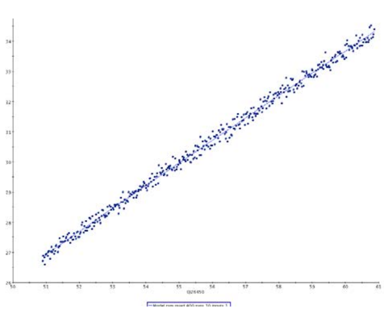
24 **Histogram and CDF of T_{OEU} (Excel)**

Stochastic approach for uncertainty analysis

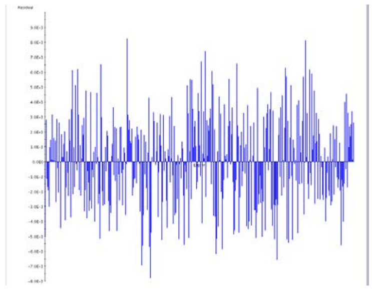
MCS on metamodel : RSM validation and meaning (2/2)



3D view of RSM



2D plot : RSM vs simulation



Error RSM/simulation

MCS on Metamodel Vs MCS on Simulation : comparison

Identical statistical results !!

	P99.85	P97.7	P50	CPU time
T0EU on simulation	37.5	36.9	33.6	9h
TOEU on RSM	37.5	36.9	33.6	25 mn

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Stochastic approach for uncertainty analysis

- **Conclusions (1/2)**
  - In the chosen test case the stochastic method pointed out that design margin taken was overestimated
  - ➔ Successful effect of competitive inaccuracies instead of cumulative ones
  - SM allow to evaluate the probability to stay below a design limit temperature starting from dispersion laws associated to input variables
  - ➔ In this case we obtain a probability of 99.85% to stay below 37.5°C for OEU whereas traditional margin philosophy give Tmax = 40°C
  - About OPTIMUS : High level of integration of various computation codes and great interest for easy parallelisation of computation

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Stochastic approach for uncertainty analysis

- **Conclusions (2/2)**
  - Strength and user-friendliness of reference method : MCS with Latin hypercube DOE
    - But it can be too much time consumer when used through direct simulation code
  - Meta-modeling technique (Design of Experiment & Response surface) allow to save great part of calculation time vs reference MCS method
    - !! Require validation of metamodel
  - Whatever the approach (simulation or metamodel) stochastic method is useful to size thermal design when it's marginal, but it's still questionable if an optimized less conservative design is always achieved through this method.
    - The distribution law of the design parameters variation around their nominal values could affect the method. Even if it was not an issue here.

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Summary

- Introduction / context
- Stochastic and meta-modeling methods assessed
- Application # 1 : Model correlation
- Application # 2 : Sensitivity/uncertainty analysis
- Conclusion

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Global conclusion

- Stochastic and statistical methods are globally useful for improving thermal engineering activity
  - Deeper design exploration, powerful optimisation methods
- Meta-modeling methods are successful to save significant part of analysis time
- But a particular attention shall be paid to the validation of the metamodel before any use of it for optimisation, sampling, …
- OPTIMUS was revealed well adapted to our needs
  - Large panel of design exploration & optimisation methods, powerful pre-post processing, user friendly GUI, easy integration of various applications (CORATHERM, ESATAN, THERMICA, …)

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Thank you for your attention,

Any question ?

Appendix V

The ESATAN-TMS Finite Element Analysis Method

User Experiences

Gunnar Sieber Stefan Kasper
(Jena-Optronik GmbH, Germany)

Abstract

Based on a current space application analysis case, first-hand experiences of using the ESATAN-TMS Finite Element (FE) analysis method are presented. The steps from geometric model creation to post-processing of results are shown. Differences with respect to the traditional Lumped Parameter (LP) analysis method are highlighted and specific aspects related to the new FE analysis approach are discussed. Also suggestions for further improvement of this modeling approach are made.

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The ESATAN-TMS Finite Element Analysis Method: User Experiences

G. Sieber & S. Kasper, 09.11.2011

space for success

The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 1

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Introduction

The finite element analysis method offers new possibilities for thermal modeling and analysis with ESATAN-TMS

Motivation to use FE method in thermal analysis:

- need for data exchange with structural analysis, optical analysis, and mechanical designers → in most analysis fields, FE models are commonly used
- automated model generation (geometry) via CAD import is desirable

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The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 2

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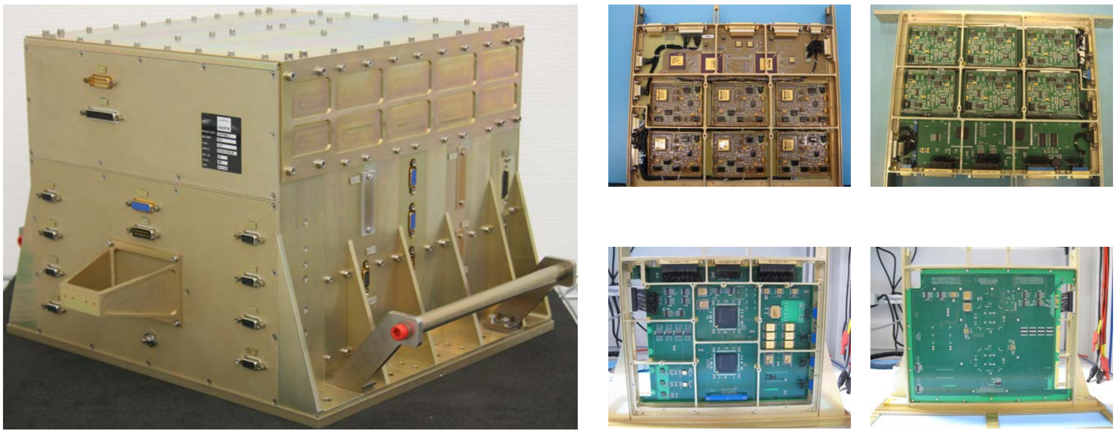
Simulation Case: Electronics Box for Sentinel-2 (VCU)



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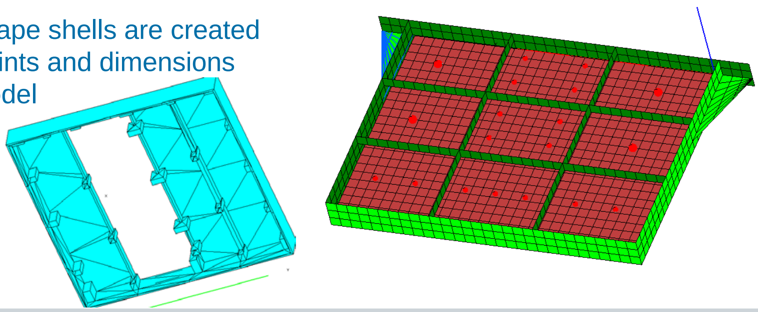
Model Creation (1/2)

CAD Import using ESATAN-TMS CADConverter 1.0

- “simple shapes” converted to triangles → too many individual shells
- CAD 3D solids vs. ESATAN-TMS 2D shells
- converted geometry is used only as basis for model creation
- individual simple shape shells are created using coordinate points and dimensions of the converted model



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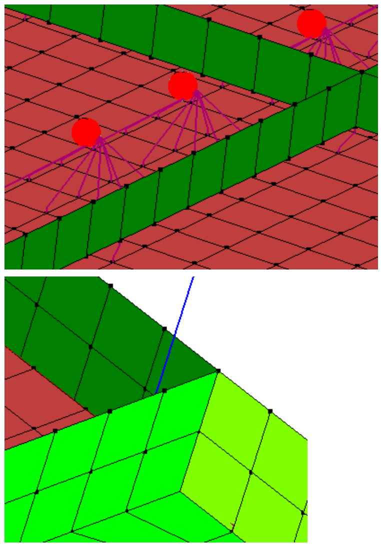
Model Creation (2/2)

- use of fixed mesh size (e.g. 10 mm) allows automatic conductance generation at shell interfaces (fused interfaces)
- fully automated node numbering
- fused connections of shells can be avoided by introducing spatial gaps between shells
- definition of contact conductance only possible between shell edges: for T-shaped connections, separate shells at either side of the T-shaped connection must be defined



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The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 5

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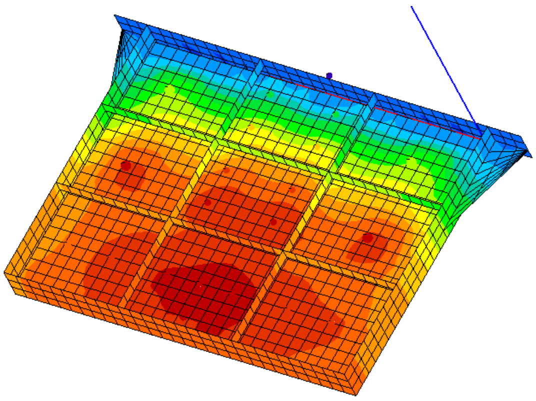
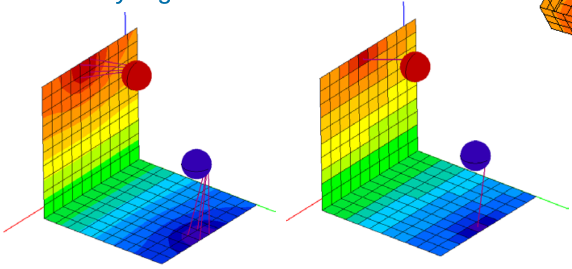
Post-Processing (1/2)

- ESATAN-TMS Workbench: for FE models, a more realistic visualization can be obtained via colored temperature maps compared to the classical LP method
- ThermNV: handling/performance problems due to very high number of nodes





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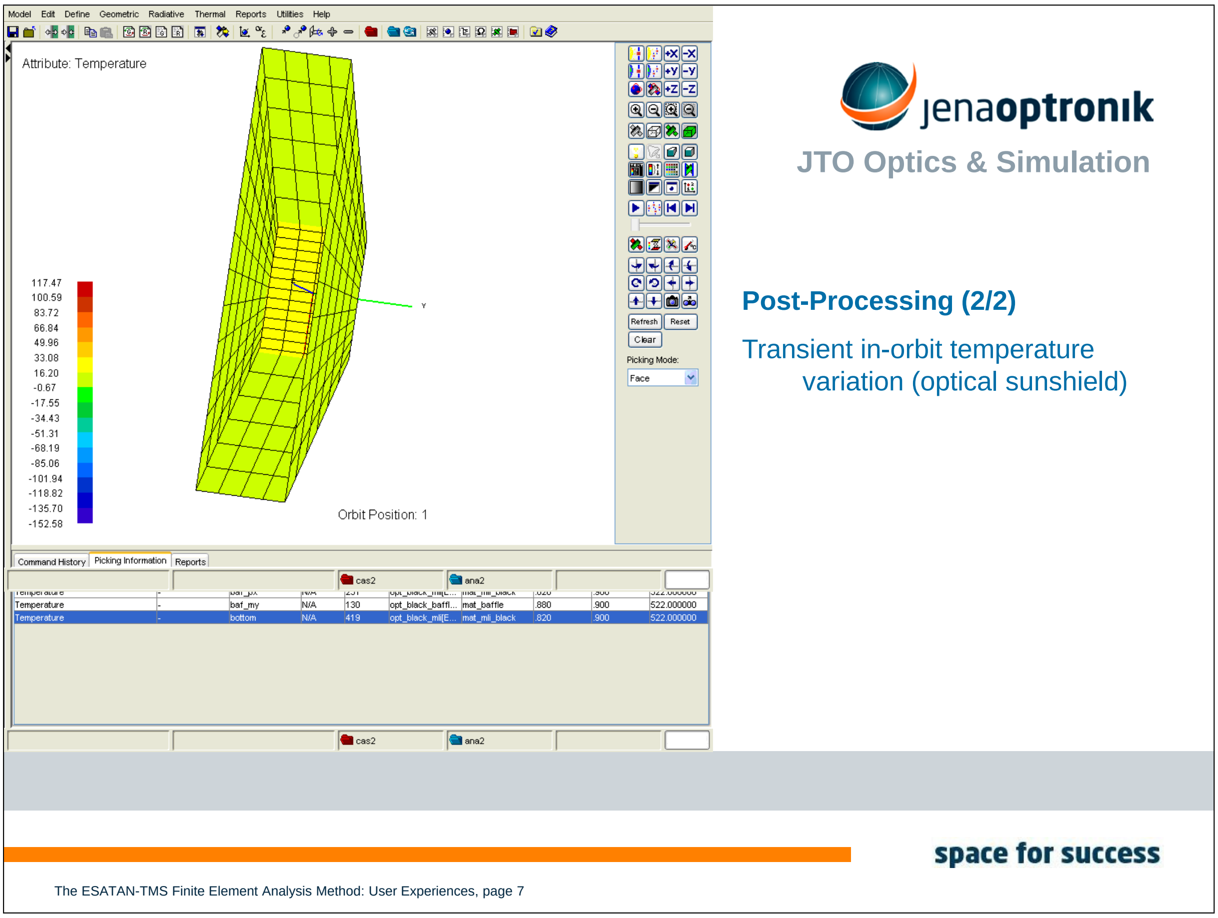
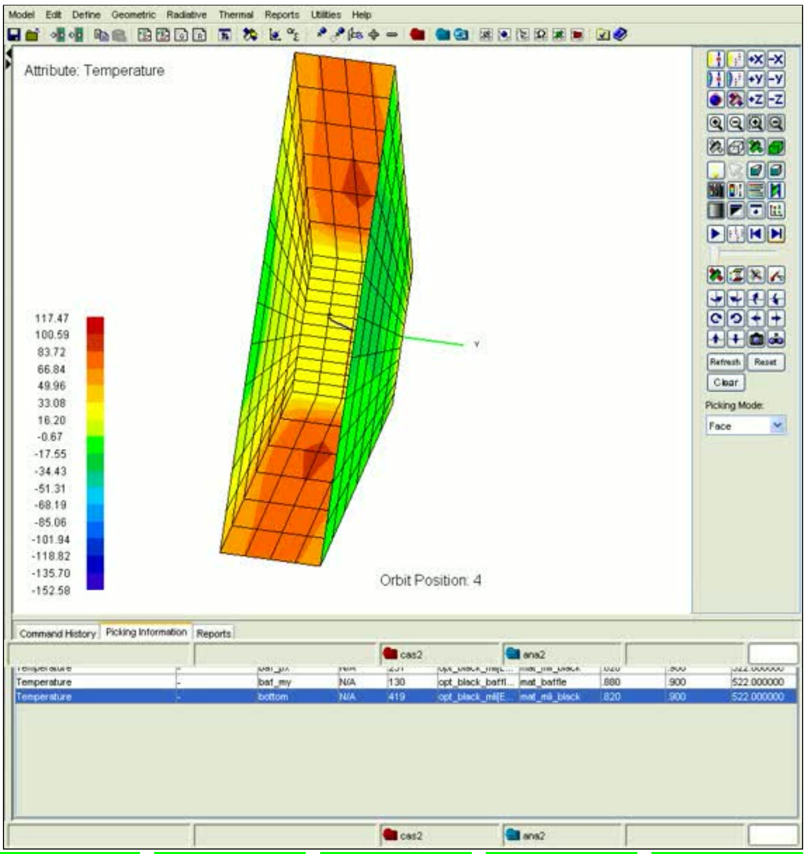
The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 6





Slow Normal Fast Play/Pause Stop

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Open Issues related to FE modeling

- CAD Import (3D solids → 2D shells), smart recognition of simple shapes, minimize number of individual shells
- Conductive interfaces: proper treatment of all interfaces (T-shaped connections, adjacent shells with different meshing, and cylindrical/circular interfaces)
- Post-processing of large models in ThermNV

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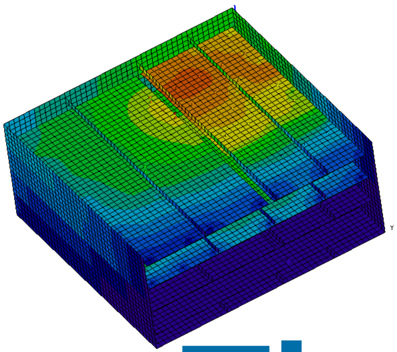
The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 8



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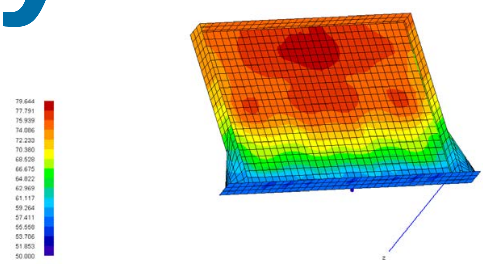
Thank you



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The ESATAN-TMS Finite Element Analysis Method: User Experiences, page 9

Appendix W

Thermal Concept Design Tool
5th Year

Matteo Gorlani Andrea Tosetto
(Blue Engineering, Italy)

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

The TCDT is in the 5th year of distribution and maintenance. During this period the tool has evolved both according to the improvements required by the users and the enhancements included in the development plan in the frame of the maintenance contract. The TCDT version 1.5.0, developed within this year, will be ready for the delivery to the European Thermal Community. This last version implements the following new functionalities required by the users and ESA:

- ESARAD Import
- ESATAN Import
- Geometric Assembly Merge
- Improved post processing

The engineers can easily use TCDT models of older versions thanks to the automatic converter provided by the 1.5.0 version.

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 1.5.0 Improvements**
- **Maintenance Activity**
- **Modeling with TCDT**

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Sheet 2

Background

5° YEAR OF DISTRIBUTION & MAINTENANCE STARTED APRIL 2011

- 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 1.5.0 will be available before the end of 2011

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TCDT 1.5.0 Improvements

- Import Geometric Model from ESARAD
- Import Thermal Model from ESATAN
- Merge a meshed assembly
- Improved 3D Viewer Post processor
- Version Converter Updated to 1.5.0

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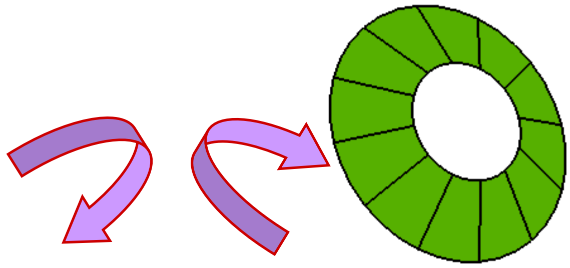
Thermal Concept Design Tool

TCDT Improvements (1/10)

ESARAD Geometry Import

ESARAD erg files can be imported and translated into TCDT geometric model data.

```
SHELL   AFT2_CON;
AFT2_CON = SHELL_CONE
              (label=" AFT_CONE ",
               point1=[   -1.139395,     0.0,    0.0000],
               point2=[    0.000000,      0.0,    0.0000],
               point3=[    0.0000,  2.238600,   0.000000],
               point5=[   -0.61552,  0.00,   0.000000],
               nodes1 = 12 ,
               side2="INACTIVE",
               nbase1 = 36200,
               ndelta1 = 5,
               opt1=ALENIA_NODE2_MDPS_BOL);
```



BEGIN		AFT2_CON	90	0	90	-1.139395	0	0							
36200	0		0	0	0	0	0	0	Cone	63.024971	0	90	0.523875	1.139395	0
36215	1		0	0	0	0	0	0	Cone	63.024971	90	180	0.523875	1.139395	0
36230	2		0	0	0	0	0	0	Cone	63.024971	180	270	0.523875	1.139395	0
36245	3		0	0	0	0	0	0	Cone	63.024971	270	360	0.523875	1.139395	0

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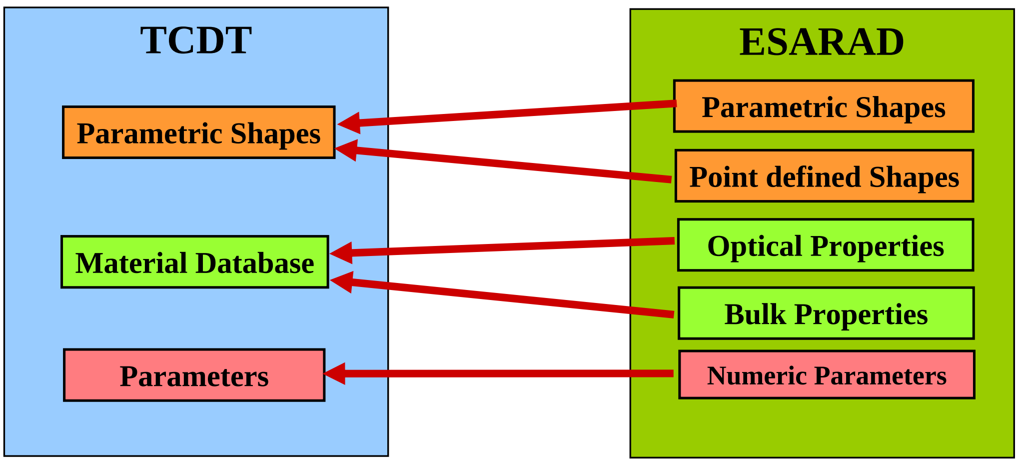
esa blue engineering

Thermal Concept Design Tool

TCDT Improvements (2/10)

ESARAD Geometry Import



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Sheet 6

esa blue engineering

TCDT Improvements (3/10)

ESARAD Geometry Import

Rotation and translation transformation computed each time that an operation is requested into the ESARAD file.

A final Transformation Matrix is converted back to Translation vector and Rotation angles.

The matrix to euler angles routine is Gimbal Lock free.

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TCDT Improvements (4/10)

ESATAN Model Import

```
D10080=    'Stiffener,angle +x+y+z', C=125.,                T=0.0;
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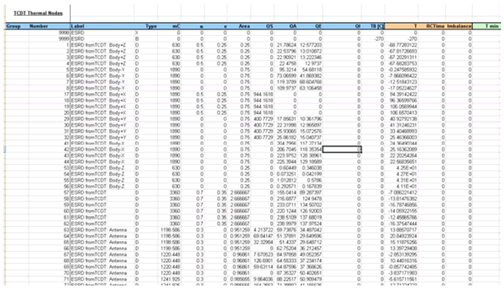

ESATAN Models can be imported

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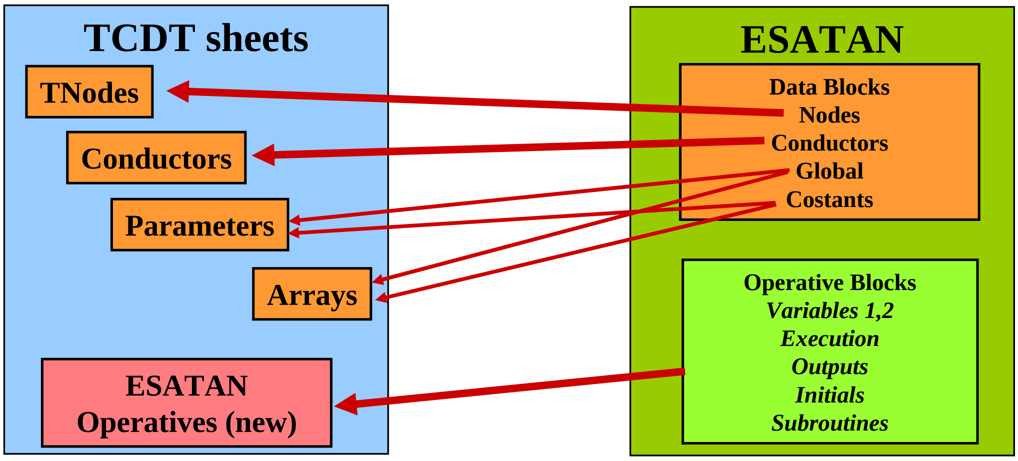
TCDT Improvements (5/10)

ESATAN Model Import



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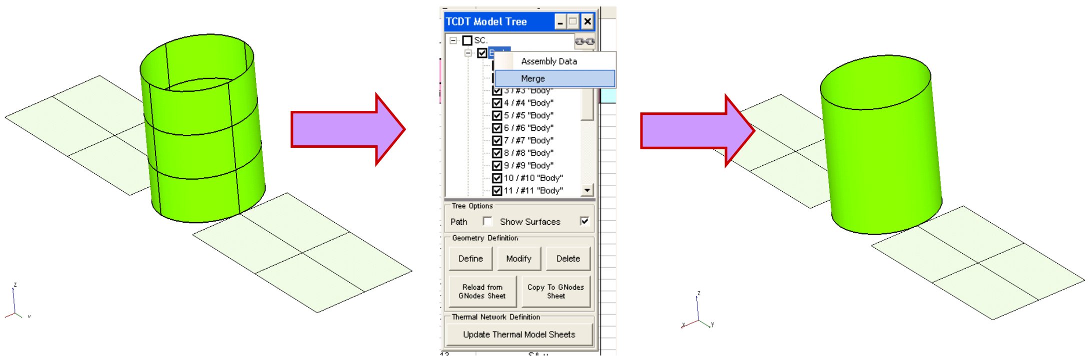
TCDT Improvements (6/10)

Merge

TCDT creates one surface for each element of the mesh definition. This operation now can be undone with the merge functionality.



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TCDT Improvements (7/10)

Merge

The Merge algorithm defines a shell of the same type of the shells contained into the original assembly with the proper dimensions.

Property	Weigth Factor
Thickness	Volume
Height	Area
Optical Properties	Area
Bulk Properties	
Density	Volume or Area
Thermal Capacity	Volume or Area
Normal K	Area/Thick. Or Area
Planar K	Thickness Or geom.

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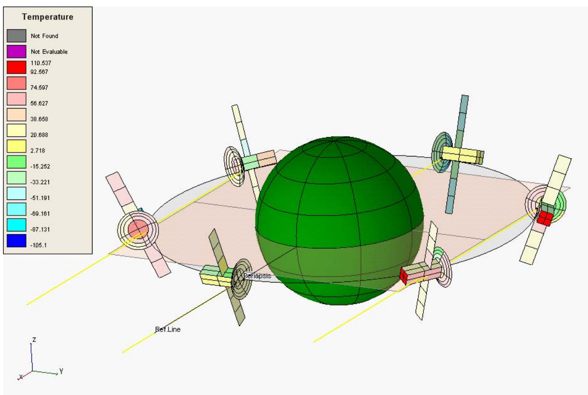
TCDT Improvements (8/10)

Improved Post Process

The improved post processor can show the temperatures and fluxes values by couloring the shapes of the geometric model, also when the viewer displays the mission.



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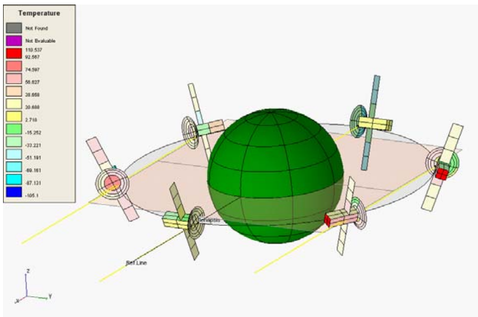
TCDT Improvements (9/10)

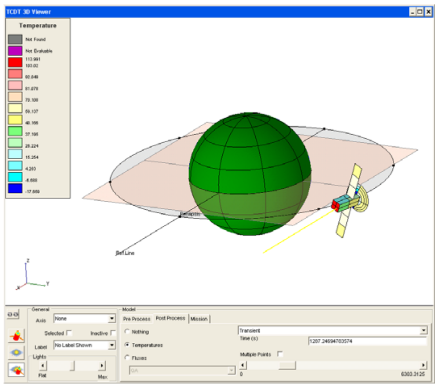
Improved Post Process

Two type of views are possible:



Multiple Points View

Time Dependent View



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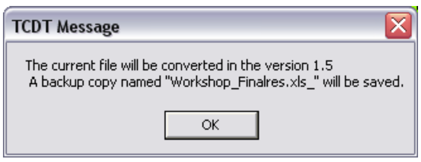
TCDT Improvements (10/10)

Version Converter

Performs the necessary operations to update an old model file (created with version 1.3.x,1.4.0) to the new template, maintaining all the data present in the model.



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TCDT Maintenance Activity (1/2)

The 3D Control is updated to have a behaviour more understandable.

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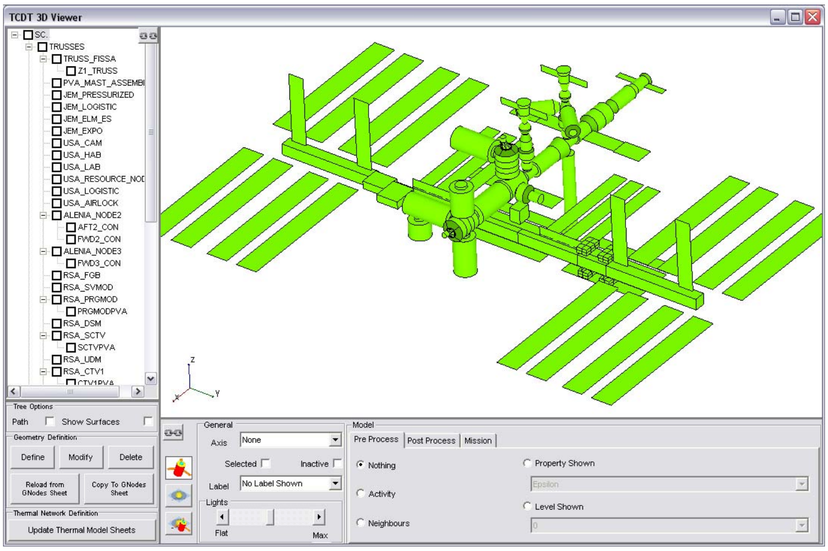
Importing ESARAD Geometry with the TCDT (1/2)

ISS (400 nodes)



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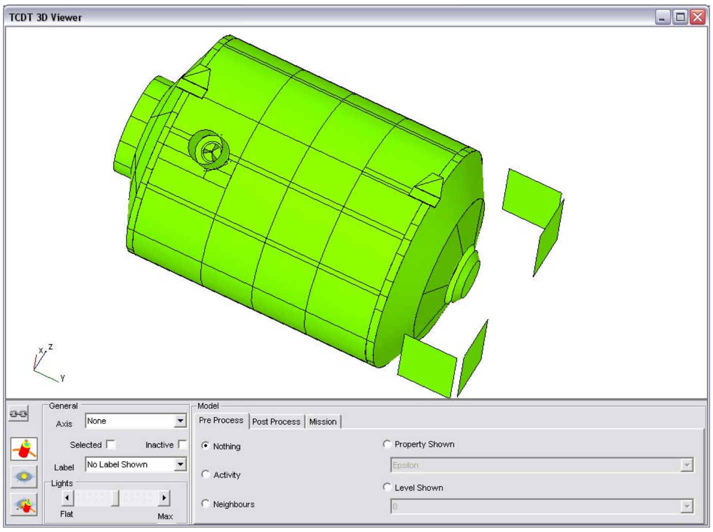
Importing ESARAD Geometry with the TCDT (2/2)

Columbus Reduced Model (400 Nodes)



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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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TCDT Team

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EMAIL: tcdtsw@blue-group.it

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Appendix X

Thermal Model Verification Guidelines
Draft Proposal

TEC-MTV
(ESA/ESTEC, The Netherlands)

Abstract

The use of computational analysis to support the development of S/C Thermal Control Systems (TCSs) is ubiquitous in modern industry. Thermal Models (TMs) are used during all phases of the S/C development and to support a large array of activities ranging from conceptual design right through to final in-flight predictions. Indeed, in some cases, thermal analysis is the only way that certain TCS requirements can be verified as physical tests are either too expensive or unrealisable. Because of this dependence upon computational analysis it is vital that there is a consistent approach to TM Verification and Validation (V&V). Ultimately such a V&V approach should improve the credibility of the predictions made using TMs.

The theme of V&V is well known in the context of quality assurance and systems engineering (including software systems). There has also been some work in other domains such as Computational Fluid Dynamics (CFD) and structural mechanics to develop processes for V&V of simulation models. In this particular context the following formal definitions usually apply:

- Verification is the process of determining that a computational model accurately represents the underlying mathematical model and its solution
- Validation is the process of determining the degree to which a computational model is an accurate representation of the real world from the perspective of the intended uses of the model

More informally the following questions, analogous with systems engineering, are often used:

- Verification "did we solve the equations correctly?"
- Validation "did we solve the correct equations?"

Whilst these definitions may be over simplistic they do allow the basic concepts of thermal model V&V to be communicated in just two short sentences.

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DOCUMENT

Thermal Model Verification Guidelines

DRAFT VERSION

Your suggestions & comments are welcome.

Prepared by	**TEC-MTV**
Reference	**TEC-MTV/2011/3562/ln**
Issue	**DRAFT**
Revision	**00**
Date of Issue	**24/10/2011**
Status	**Draft**
Document Type	**OTHER**
Distribution	

European Space Agency
Agence spatiale européenne

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APPROVAL

Title	
Issue DRAFT	**Revision** 00
Author	**Date** 24/10/2011
Approved by	**Date**

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue DRAFT	**Revision** 00		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

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1 INTRODUCTION

1.1 Context

The use of computational analysis to support the development of S/C Thermal Control Systems (TCSs) is ubiquitous in modern industry. Thermal Models (TMs) are used during all phases of the S/C development and to support a large array of activities ranging from conceptual design right through to final in-flight predictions. Indeed, in some cases, thermal analysis is the only way that certain TCS requirements can be verified as physical tests are either too expensive or unrealisable. Because of this dependence upon computational analysis it is vital that there is a consistent approach to TM Verification and Validation (V&V). Ultimately such a V&V approach should improve the credibility of the predictions made using TMs.

The theme of V&V is well known in the context of quality assurance and systems engineering (including software systems). There has also been some work in other domains such as Computational Fluid Dynamics (CFD) and structural mechanics to develop processes for V&V of simulation models. In this particular context the following formal definitions usually apply:

- Verification is the process of determining that a computational model accurately represents the underlying mathematical model and its solution
- Validation is the process of determining the degree to which a computational model is an accurate representation of the real world from the perspective of the intended uses of the model

More informally the following questions, analogous with systems engineering, are often used:

- Verification "did we solve the equations correctly?"
- Validation "did we solve the correct equations?"

Whilst these definitions may be over simplistic they do allow the basic concepts of thermal model V&V to be communicated in just two short sentences.

1.2 Scope

The scope of the proposed document is limited to verification and the topic of validation will only be briefly touched upon. This is because the topic of validation is intrinsically linked to the topic of testing. Moreover, in a classical V&V process for computational models the task of verification comes before validation. It thus seems natural to address first verification, and to obtain feedback from users, before moving on to the topic of validation.

The intended users of the document are any persons, working in the domain of space systems, who use thermal analysis as part of their work. These users could be in industry, in agencies such as ESA or CNES, or in academia. Moreover, the guidelines should be applicable to users working on products at every level of the S/C product tree – that is to say at system level, sub-system level, unit level etc. The scope of the document (at least in early versions) will, however, be limited to "classical" S/C thermal analysis. This means that certain specialised topics will not be covered directly. Examples of these specialised topics might be re-entry systems, simulation of fluid loops and CFD for conjugate heat transfer.

Models are built at different levels (detailed dedicated model at unit/subsystem level) and have to be reduced for delivery and assembly to build the system level model. Tight planning leads to more and more automatization and few time-consuming analytical checks are performed. It is therefore crucial to define relevant checks and verification steps to ensure the validity of the model reduction, format change if any, delivery and correct assembly. This is necessary to validate the results obtained, and optimize the system tests and their correlation which are usually on a very critical path for planning.

Guidelines for those methodologies are necessary to ensure quality and acceptability of the approach at all levels (between companies and with agencies).

It is proposed that the style of the document should be practical in nature and the guidelines should be amenable to direct implementation by the users. The rationale for this is that most of the existing documents that address model V&V focus more on philosophy and processes than upon practical guidelines. Therefore, users who have an interest at this conceptual level already have a number of relevant sources to draw upon. The aim of producing "practical guidelines" is challenging, however, such a document has the best chance of being used.

1.3 Glossary

CDR	Critical Design Review
CFD	Computational Fluid Dynamics
CNES	French National Space Agency
COTS	Commercial Off-The-Shelf
CSG	ratio of nodal capacitance to sum of conductances
ESA	European Space Agency
FE	Finite Element
FEM	Finite Element Model
GMM	Geometric Mathematical Model
PDR	Preliminary Design Review
S/C	Space Craft
TCS	Thermal Control System
TM	Thermal Model
TMM	Thermal Mathematical Model
V&V	Verification & Validation

2 ADMINISTRATION OF THERMAL MODELS

2.1 Conventions

2.1.1 Language

2.1.2 Units

2.1.3 Coordinate System

2.2 Standardisation

2.2.1 Naming Conventions

2.2.2 Common Symbols

2.3 Configuration Control

2.3.1 Guidelines

Guideline 1: All thermal models should be placed under configuration control. The configuration control environment shall support the following features:

- Tracking of model changes with informative remarks
- Comparison (differencing) between distinct version of the model in the repository
- Tagging of model releases at critical milestones (e.g. PDR, CDR)

Guideline 2: Results of all production runs should be traceable to a specific version of the model inside the configuration control repository.

Guideline 3: The TMM & GMM couples shall be consistently tracked in the configuration control environment

Most thermal models of spacecraft are under some form of version control. However, this is often textual headers at the top of analysis files and manual incrementing of version numbers in file names.

There are many COTS and OS configuration control environments available (e.g. subversion, Mercurial), particularly for software development. These environments can be directly applied to thermal model configuration control, especially for ASCII formats. Moreover, many binary formats for documentation are also supported (e.g. .doc, .pdf). The use of such configuration control tools should not be a burden and will actually improve the efficiency and productivity of the analysts. Moreover, the maintainability of models over a number of years is vastly improved via the use formal version control.

2.4 Style

2.4.1 Comments

Guideline 4: Comments shall be in the English language for all models produced under ESA contract.

Guideline 5: Comments shall not be used to alter model topology, boundary conditions or procedural behaviour. Such conditions shall be implemented via user logic or alternative skeleton files etc.

Guideline 6: All user variables in a model shall be commented. The comments shall include:

- A short description of the data stored with the variable and intended purpose of the variable

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- Identification of units where the variable relates to a physical quantity
- Justification of major thermal assumptions should be commented where it improves understanding of the model
- Readability of flow control structures (if …else … / select … case) & loop structures may also benefit from an adequate commenting of their purpose.

In 2.4.1, the use of comments in this way reduces the readability and maintainability of models. Such conditions are easy to overlook and shall be avoided. An illustrative example is shown in ESATAN syntax in snippet below.

```
# JRME 2011-10-12, Antenna hold-down conductors. Comment out these # conductors
for deployed cases

GL(1021, 3678) = 0.56;

GL(1022, 3686) = 0.56;
```

3 THERMAL MODEL CHECKS AND NUMERICAL VERIFICATION

3.1 Introduction

This section aims to cover the topic of thermal model checks and numerical verification, or, using the informal definitions introduced in TBD, "did we solve the equations correctly?"

It should be noted that typically the verification of computational models is split into ***code*** verification and ***calculation*** verification. Throughout the following discussion it is assumed that the code verification is carried out by the software vendors. Therefore, as users of the thermal analysis tools we need only concern ourselves with calculation verification.

3.2 Guidelines

3.2.1 Topology Checks

Many problems with thermal models can be attributed to ill-defined node/conductor topology in the model. As a minimum the following guidelines should be adhered to.

Guideline 7: Isolated nodes should be justified

Guideline 8: Conductively isolated groups of nodes should be justified

Guideline 9: Parallel conductors should be justified

Guideline 10: Negative or null conductors should be justified

Guideline 11: Negative or null nodal thermal capacities should be justified

3.2.2 Steady State Convergence

The adequate convergence of steady state analyses is a critical factor in ensuring the credibility of the model predictions. Unfortunately, and especially for large models, the computational time required to achieve adequate convergence can be significant. The temptation is thus to relax the convergence requirements in order to reduce computation time.

Guideline 12: The sensitivity of relevant model outputs to convergence criteria should be evaluated and appropriate limits agreed upon for the model. The following criteria shall be evaluated:

- Primary convergence criteria for iterative solutions (e.g. RELXCA/INBNDM in ESATAN)
- Energy balance (e.g. INBALA/INBALR in ESATAN)

Guideline 13: Steady state production runs should be converged in the sense that all criteria listed in 3.2.2 are within the limits agreed with the customer.

In the guidelines above it is proposed that the term ***relevant outputs*** may be temperatures, heat flows, heater powers or any other pertinent model variables. Essentially, in a well converged model, the results that the user is interested in should be independent of any further tightening of the convergence criteria.
In reality the actual value of the convergence criteria will be highly model dependent and therefore hard numerical guidelines cannot easily be established. For example, the appropriate convergence criteria for a telecommunications platform model and a cryogenic instrument may be entirely different.

3.2.3 Transient Analysis

The use of transient thermal analysis to produce flight temperature predictions for the spacecraft is standard. However, the transient analysis, in the way it is used by thermal engineers, is also quite different from the types of analysis carried out in other computational domains. For example, a low-earth orbit may have a period of 100 minutes. Therefore, the model must be run for several orbits in order to reach a quasi-stabilised condition. This calls for long transient analyses adding to the computational demands. Once again, therefore, the thermal engineer must balance the computational effort against the accuracy of the model predictions.
The following guidelines aim to improve the credibility of transient analysis predictions by ensuring the convergence and stability of the solution process.

Guideline 14: For transient runs using explicit solvers the time step should be smaller than the CSG limit

Guideline 15: For transient runs using non-explicit solvers the time step should be smaller than half the shortest time constant in the model

Guideline 16: The sensitivity of model outputs to transient solver criteria should be evaluated and appropriate limits agreed upon for the model. The following criteria should be evaluated:

- Primary convergence criteria for iterative solutions (e.g. RELXCA/INBNDM in ESATAN)
- Transient time step

Similarly to steady state analysis, the term ***relevant outputs*** may be temperatures, heat flows, heater powers or any other pertinent model variables.
3.2.3 regarding the CSG limit is necessary to ensure the stability of explicit solvers. Whilst this is a well known requirement from the theory of transient solvers, the use of explicit solvers is not common for space thermal analysis. Therefore 3.2.3 and 3.2.3 are more important when using implicit and Crank–Nicolson type solvers. There is an intrinsic inter-relation between these two parameters and a balance shall be sought such that the truncation and convergence errors are minimised. Ideally the model outputs shall be independent of the transient solver criteria although, in practice, the objective will be to reduce these errors to acceptable levels.
Where the smallest time constants in the model are very short then it may be advantageous to use arithmetic nodes for the lowest capacity elements in the model in order to increase the time step. Alternatively, in some tools, the use of local sub-stepping is possible, whereby the items with small thermal capacities use a smaller time step than the rest of the model.
Beyond numerical convergence of the solution, there are also other points to consider regarding transient analysis.

Guideline 17: The transient time step should be chosen such that the effects of imposed loads and boundary conditions are adequately resolved.

Guideline 18: The time range over which model results are observed should be driven by the model dynamic behaviour (either induced by the environment variations or by the thermal control operation) or the simulated mission sequence.

Guideline 19: The cyclic convergence should be assessed between successive time ranges and based upon criteria agreed with the customer that may address temperature differences and heating budget stability.

For example, if the model is subject to a short pulse of imposed heat input, the time step should be small enough to resolve the resulting temperature changes in the model. It happens also that the time step choice may be driven by the active thermal control itself (e.g. PID controller working at higher frequency) or by the results acquisition rate required to justify the meeting of a requirement (e.g. stability over a short period of time).

Moreover, regarding cyclic solution routines, where the heater cyclic period is of the same order as the orbit (or repeats analysis period) then assessment of the heater duty and budgets can become difficult.

3.2.4 Finite Element Models

The introduction of finite element methods into the thermal analyst's toolbox will lead to some specific additional requirements. These requirements are quite generic for all finite element models across application domains. The actual safe limits used for topology check can probably be less restrictive for thermal models compared with, say, structural models i.e. we can probably use worse elements in thermal models. Nonetheless the following guidelines should be adhered to ensure the quality of finite element meshes.

Guideline 20: The geometrical adequacy of finite elements should be checked to be within the limits defined in TODO. The following criteria should be checked: warp, skew, interior angle, aspect ratio [ref]

Guideline 21: Duplicate or overlapping elements should be justified

Guideline 22: Duplicate finite element nodes should be justified

Guideline 23: The topological connectivity of finite element meshes should be checked using the following utilities:

- Free edges (for 2D and 3D elements)
- Free faces (for 3D elements)

3.2.5 Radiative Computations

Discussion TODO

Guideline 24: For models containing surfaces with non-zero specularity, an appropriate method should be used. Examples of appropriate methods are: MCRT

Guideline 25: For MCRT computations, the sensitivity of relevant model outputs to input parameters of the ray-tracing algorithm should be evaluated and appropriate limits agreed upon for the model:

- The sensitivity analysis should consider both radiative couplings and heat fluxes
- The sensitivity analysis should consider measures of statistical convergence such as line accuracy, reciprocity and variation of random number seeds
- The sensitivity analysis should consider end-to-end results from the thermal solution (e.g. temperature, heat flows etc.) due to ray-tracing parameters.

Guideline 26: The sensitivity of relevant model outputs to the filtering of radiative couplings should be evaluated and appropriate limits agreed upon for the model:

- The sensitivity analysis should consider end-to-end results from the thermal solution (e.g. temperature, heat flows etc.) due to ray-tracing parameters.

Guideline 27: For a given face, the REFs to inactive surfaces shall make up less than TODO of the total REFs from that face.

Guideline 28: The sensitivity of relevant model outputs to the number of orbital positions shall be evaluated and appropriate limits agreed upon for the model.

3.3 Additional Guidelines

More points to be added TODO

Guideline 29: Tabulated data shall take make provision for "end-conditions." Extrapolation outside of table bounds shall not be occur during the solution routine

4 GUIDELINES FOR CODING AND USER LOGIC

4.1 Introduction

If the thermal model and the structural FE model of a given spacecraft were to be compared, one of the most obvious differences would be the amount of procedural code, or user logic, to be found in the thermal model. This user logic, typically written in a language such as FORTRAN, is available in most of the thermal analysis tools for space applications (at least in ESATAN, THERMISOL and SINDA) and provides almost limitless flexibility to the user. This flexibility is tremendously valuable for many applications such as handling non-standard cases, modelling specific thermal control hardware or for customised reporting and data processing. However, along with this flexibility comes a certain amount of risk. There is always potential for programming errors to be introduced into user logic and even the most advanced pre-processor or syntax checker cannot guard against all of these errors.

Generally speaking the users of thermal analysis tools take a pragmatic approach to writing user logic – if the logic seems to have the desired thermodynamic effect on the model then it is probably OK. This is an entirely understandable view given that the users probably have very little formal training in software engineering (maybe an undergraduate course or two). However, the code that is written is often quite complex and represents a very significant amount of work. Moreover, the life time of the generated models can be many years (the full S/C development plus possible operational usage) and during this period it is likely that several users will work on, modify or even just read the code. Therefore the introduction of some coding guidelines is a key factor in improving the quality and maintainability of thermal models.

The following guidelines are a mixture of some standard FORTRAN-like coding conventions (many of which can be found online) and some thermal modelling specific points. The guidelines are strongly driven by the input formats of the standard tools for space thermal analysis in Europe notably the ESATAN syntax, however, they may also generally applicable to other tools such as user subroutines in TMG or NASTRAN.

4.2 Guidelines

4.2.1 Minimising the Number of Warning Messages

As a general rule the user should try to minimise the number of warnings generated by the analysis tool. This may seem like an obvious statement, however, experience shows that many models generate a lot of warning messages; often for trivial syntactical inconsistencies. The problem is that, whilst these warnings may not adversely affect the analysis results, they can mask other more significant warnings which the user should take note of.
In order to reduce the number of warning messages, the following guidelines should be adhered to.

> Guideline 30: Each auxiliary variable with scope limited to a single operations block should be declared at the start of that operation block

Very often the user wishes to create an auxiliary variable within an operations block. Often this variable is only used within the scope of that block, for example; a common example of this would be counter variables used in a do-loop. If these variables are not declared then the tool may generate warning messages in the log file.

To reduce the number of these warning messages all auxiliary variables should be declared at the top of the operations block in which they are used. Note that in FORTRAN 77 it is required that all variables are declared at the beginning of a subroutine. In ESATAN all operations block as are mapped to subroutines by the pre-processor and therefore variables should be declared at the top of the operations block.

Guideline 31: Only flow control structures that pass through the pre-processor without generating warnings should be used

The use of flow control structures such as do-loops in operations blocks is widespread, however, it is observed that associated warning messages are often produced. This is because the pre-processor expects only FORTRAN-77 style loops of the form:

```
      DO 100, ICOUNT 1, 10

         ……

100   CONTINUE
```

Often, however, FORTRAN-90 style loops are used of the form:

```
      DO ICOUNT 1, 10

         ……

      END DO
```

These loops will create warnings, although they may pass through the compiler and execute correctly.
To reduce the number of warning messages the user should ensure that all do-loops are of the FORTRAN-77 style and are terminates by a separate continue. Alternatively, if this entails too much effort, other flow control structures such as REPEAT, UNTIL or WHILE, ENDWHILE may be considered.

4.2.2 Coding Style

Guideline 32: The use of tab characters to generate whitespace in user generated code shall be avoided. Spaces should be used in place of tabs.

To improve portability of the user generated code, both across platforms and between tool chains, it is recommend to use spaces, rather than tabs, to implement whitespace.
The use of tabs to generate whitespace can mean that the formatting of the file is not preserved when moving between platforms or tool chains (e.g. text editors). This affects the readability of the user generated code, especially if a mix of tabs and spaces have been used. In some cases the use of tab characters can also lead to syntax errors during the pre-processing of the model.

Guideline 33: The body of flow control structures should be indented.

The use of indentation in programming languages is an important concept which helps to convey the program flow and structure. Whilst indentation is not formally required in most programming languages (with notable exceptions such as Python) it is strongly recommended to improve the readability of the code. In particular the use of indentation helps to clearly and quickly identify flow control structures such as loops and conditions.

Just like in any other computer program, the use of indentation in thermal models can only help to improve the readability maintainability of the user generated code. The size of the indent is not essential, however, the use of a consistent indent level throughout the code is recommended.
The use of spaces is recommended to implement indentation rather than tab characters.

Guideline 34: Use subroutines and functions to logically structure user generated code.

Guideline 35: Keep subroutines and functions short

Good programming practice dictates that code should be split up into logical sections in functions or subroutines. If all the code is gathered in one main program or subroutine then it is difficult to have a full overview of what that code does on a single computer screen. The user must therefore scroll up and down the code leading to disorientation and potential loss of context.
As a general rule the code is clearer to understand if related things are kept close together. For example, one rule of thumb is that the contents of any flow control structure, function or subroutine should fit within one computer screen. To achieve this the user is forced to move large or repeated blocks of code to subroutines or functions. Moreover, if subroutines and functions are kept short then the declaration of variables at, the top of the subroutine, will be close to the location where they are used. This again helps with the readability and maintainability of the code.

NOTE 1. There are of course many examples of subroutines which are very long, e.g. auto-generated solar fluxes. This is not a problem because they are auto-generated and the user need not traverse them regularly.

4.2.3 Variable Naming

Compared with more modern programming languages older version of FORTRAN were restrictive in terms of the permitted naming for variables, for example they were limited to 6 characters. More recently this limitation has been relaxed in the analysis tools and variable names of up to TODO characters are permitted. The user should therefore take advantage of this increased variable name length in order to improve the readability and maintainability of the code.

Guideline 36: The user should aim to make variable names clearly readable

Guideline 37: Variable names should be in the English language for all models produced under ESA contract

The readability of user produced code is improved if the variable names can be clearly identified. In the past common practice was to use all uppercase variable naming, often limited to only 6 characters. Better readability can be achieved using, for example, mixed case naming of the form:

```
INTEGER*loadCase = 1;            # [-] 1 for hot case

                                 #     2 for cold case



REAL*detectDissip = 60.0D-3;     # [W] Detector dissipation
```

The exact naming convention used is not as important as giving thought to this issue and maintaining consistency throughout the model.

Guideline 38: A variable name should give an indication of the physical quantity stored within it.

The readability of user produced code is improved vastly if the naming of variables or user constants gives an indication of the physical quantity is represents. For example, a some examples using one such convention ar shown below:

```
REAL*thkPanel = 0.45D0;        # [m] Thickness of panel

REAL*kAl6061 = 185.0D0;        # [W/mK] Conductivity of Aluminium 6061

INTEGER*numBolts = 5;          # [-] Number of bolts around flange

REAL*condBolt = 0.05;          # [W/K] Total conductance of bolted

                               #       interface including washers
```

Such a naming convention helps to improve the readability of the code and, moreover, increases the chance of detecting human errors of the form:

```
GL(300, 305) = condBolt + numBolts;
```

which are evidently dimensionally incorrect upon first inspection of the code.
It should be noted that the actual naming convention used is not as important as maintaining consistency throughout the model and across variables.

4.2.4 Access to Solver Internal Variables

Guideline 39: Internal variables and arrays of the solver should not be directly accessed or set by the user.

In tools such as ESATAN the internal data structure is often a series of arrays which can be indexed to obtain model entities. These data structures are, however, internal to the tool and do not form part of the public interface of the software. It is therefore risky to use these variables because they could change at any time, for example due to restructuring of the code by the developer.
Moreover, whilst use of these arrays may provide convenient shorthand, it relies upon a knowledge of the internal data structures which is often not available in the user documentation. Therefore for less experienced users the code is difficult to interpret complex to maintain over time.
An example of the use of internal variables to set the temperature of all nodes of a model except the last 2, which are in this case the inactive (99998) and space (99999) nodes, is shown below.

```
      DO, 100, ICOUNT 1, FLG(1)- 2

         T(ICOUNT) = 20.0D0

100   CONTINUE
```

This is convenient for syntax for experienced users, however, it relies on knowledge of the FLG array contents and the fact that there is a array of temperatures internally. A better solution which could be implemented (although not the only one) would be to use an ESATAN public routine, for example:

```
      CALL SETNDR('#1-99997', 'T', 20.0D0, CURRENT)
```

5 TRANSFER OF THERMAL MODELS

5.1 Introduction

The transfer of thermal models between parties is a task that occurs many times during the course of a typical space project. For example, models of equipment or subsystems are regularly provided by sub-contractors to customers for integration into a higher level model. Prime contractors also regularly provide system level models to customers (e.g. ESA) or reduced models to launch authorities for coupled analysis. Unfortunately, every time a model transfer occurs there is the potential for problems to arise.

Some examples of the kind of problems that can occur when exchanging models between parties are given in the following (non-exhaustive) list:

- Corruption, or even loss, of electronic data
- Incomplete or incorrect deliveries meaning that the model cannot be executed (e.g. missing files)
- Incomplete or inadequate documentation describing the model and how to execute it
- Portability problems such as the use of different operating systems (e.g. MS Windows, Linux, HP)
- Problems associated with supporting tools required to execute an analysis (e.g. proprietary, obsolete or in-house tools etc.)

The following guidelines aim to establish best practice for the transfer of thermal models between parties.

5.2 Guidelines

5.2.1 Required Analysis Files and Reference Results

The fundamental items in any model delivery are the analysis files themselves; usually both geometrical models and thermal models are included. For a formal delivery, associated with a project milestone, there are also typically a number of scenarios which are delivered relating to worst cases, different operation models, different configurations (e.g. stowed, deployed) etc.

In order to make the transfer of thermal models as seamless there is a minimum set of deliverable model files which are necessary.

> Guideline 40: A formal model transfer should contain all the necessary components to execute a complete analysis run.

When a thermal model is transferred between parties, the recipient should be able to directly execute a complete analysis run and obtain results. In order for this to be possible it is essential that the delivery contains all of the necessary components to execute an end-to-end analysis. Here the term components may refer to:

- All of the ***analysis files*** together with associated include files and global files
- Any ***external libraries*** or routines required to run the model. For example externally linked FORTRAN routines for material properties or results processing
- Any ***supporting tools*** such as run scripts, or EXCEL based tools, which are used to execute the analysis chain. For example tools used to: extract radiative couplings or fluxes, set up analysis cases, create results directories, or carry out other pre- and post-processing

Guideline 41: A formal model transfer should contain, for each analysis case provided, a set of reference results to be used for verification of the delivery. Reference results should be in raw data files in the same format as produced by the analysis process.

Guideline 42: The execution of the analysis cases provided should yield identical results to those provided with the delivery

Assuming that a complete set of analysis files is provided in-line with , the recipient should be able to directly execute the model and obtain results. The results can then be compared to those provided in the delivery. The purpose of this comparison is to ensure that the delivered files were not corrupted in any way, and that the recipient's tool-chain is capable of producing results consistent with the supplier's.
In principle the recipient's results should be numerically identical to the reference results, although some differences may be expected due to different computing architectures (32 or 64 bit) or different versions of the analysis software. For example, enhancements or bug fixes in the analysis software may lead to numerical differences. Generally speaking, however, these kind of numerical differences should be several orders of magnitude (TODO) lower than the uncertainty applied to the analysis predictions.

5.2.2 Documentation

The formal transfer of thermal models should be accompanied by supporting documentation that allows the recipient to install and use the models on their computing system. This may be a standalone document, a read-me file, or it may form part of the thermal model description document (see ECSS []). Nonetheless it is an essential part of any model delivery.

Guideline 43: The documentation provided with a formal model transfer should contain full end-to-end instructions on how to install and run the delivered analysis cases. This should also include:

- Description and usage of any software utilities, in addition to the thermal analysis tools, required to run the analysis cases
- Description of any manual steps that are required to run the analysis cases

Guideline 44: The documentation provided with a formal model transfer should contain the following administrative information:

- Versions of all thermal analysis software used to produce reference results
- Versions of all thermal models in the supplier's configuration control environment
- Computational architecture and platform used by the supplier and used to generate the reference results

The provision of the information described in the previous guidelines is essential in order for the recipient to be able to execute the model with minimum effort. Moreover it is important to establish a traceable workflow from the model files to the reference results. This is especially important when the long lifetime of space projects, and the number of people who may work on a given project, is considered.

In addition to the formal documentation discussed in the guidelines above there are, from experience, many other more subtle points that can cause difficulties during model transfer. Whilst these points are difficult to formalise in guidelines, several such issues are listed in the bullet points below:

- Most thermal model transfers use an electronic archive of some sort (e.g. zip or tar). It should be noted that this can have unforeseen consequences such as loss of model directory structure and loss of symbolic links used to organise model files.

- Often the thermal models delivered contain some sort of hard-codes file paths which can cause problems on the recipients file system. If the models need to be unpacked in a specific directory structure, or if certain file paths are required, then this should be flagged in the delivery documentation

5.2.3 *Portability of Thermal Models*

In order to improve the portability of thermal models between computing platforms (e.g. between Windows and Linux) the following guidelines are proposed:

Guideline 45: Limit file and directory names to the characters A-Z, a-z, 0-9, full stop, hyphen, and underscore.

Guideline 46: Do not use full stop in directory names.

When software utilities, additional to the thermal analysis tools, are required to execute a full analysis run, then consideration should be given to the portability of the tools. For example if the extraction of external heat fluxes, and processing for input to the TMM, is carried out using a Visual Basic program then it will be difficult to execute the complete workflow on a Linux system. The same concern is applicable to in-house tools which cannot be distributed.

Guideline 47: Supporting software utilities should be portable across computing platforms.

Guideline 48: Supporting software utilities should not be based on proprietary software which cannot be included in a thermal model delivery

6 GUIDELINES FOR MODEL CONVERSION

6.1 Introduction

6.2 Guidelines

TODO

- System subroutines, e.g. Thermostats on/off variable inversed
- Defaults orbit parameters can be different – small g
- Arithmetic nodes – SINDA/ESATAN
- Double side inactive shells (blocker, invis.)
- Variable naming length (SINDA limit)
- Realistic test cases that actually test logic – e.g. heaters
- Units
- Nodal quantities

7 CRITICAL FEATURES, PITFALLS & TIPS IN THERMAL MODELLING

NOTE 1. This prototype chapter is to offer an alternative or complementary way of presenting verification items by addressing them directly in users' reference frame, i.e. the model input file structure.

7.1 Thermal mathematical models (TMM)

This chapter lists the critical features that need to be questioned as one performs a thermal model assessment. It parallel addresses the most common pitfalls and provides a number of good-practice considerations that ESTEC would like to foster in order to ease the exchange process of thermal models within the community.

This discussion should be regarded as a top-level verification guideline and is not intended to supersede any of the different user manuals provided by thermal software editors.

Most common thermal network analysers (such as ESATAN, SINDA or THERMISOL for instance) share, with some nuances, a similar card-structured syntax, as far as their input files are concerned. That's the reason why it has been deemed appropriate in practice to sort the different discussed items according to the ESATAN-like card they belong to.

7.1.1 $MODEL

This section is appropriate to gather configuration information (Cf. paragraph 2.3.1).

2.3.1 All thermal models should be placed under configuration control. The configuration control environment shall support the following features:

2.3.1 Results of all production runs should be traceable to a specific version of the model inside the configuration control repository.

2.3.1 The TMM & GMM couples shall be consistently tracked in the configuration control environment

7.1.2 $LOCALS

Run speed-up opportunity

TODO

Standardization opportunity (Cf. paragraph 4.2.3)

4.2.3 The user should aim to make variable names clearly readable

4.2.3 Variable names should be in the English language for all models produced under ESA contract

4.2.3 A variable name should give an indication of the physical quantity stored within it.

Parameterization

7.1.3 $NODES

3.2.1 Isolated nodes should be justified

3.2.1 Negative or null nodal thermal capacities should be justified

Number of nodes

A proper thermal lumped network should conform to certain basic rules as far as spatial discretization is concerned.
For instance, the **isothermal assumption** that basically governs the thermal nodal breakdown shall be assessed with respect to the targeted accuracy and to the needed observables that shall justify the thermal design performances.

Temperature requirements generally apply to specific locations called **temperature reference points** (TRP). It is quite important to properly render those points in the thermal model breakdown in order to allow a straightforward comparison. There are other usual requirements (gradients, gradients stability, heating power …) that may require **local refinements** of the nodal breakdown to allow a proper assessment.

Automatic network generation routines show great interest, in terms of initial effort to get a thermal network namely, but sometimes provide so deeply involved and numerically intricate models that they may simply prohibit any further thermal analysis. A thermal model should allow to still comprehend the **physical phenomena** at stake (e.g. intuitive couplings, flux evolution). Marginally, the huge number of nodes generated may become also out-of-range for network analysers and post-processing tools capabilities.
Directly linked to the way the model is discretized, there is a real interest, numerically speaking, for the most common transient solution routines to avoid a great dispersion of the couplings values (typically a factor 1000 between maximum and minimum conductive couplings). Same recommendation stands for thermal capacities. This may otherwise disturb numerical convergence and drastically slow down the run completion.

Numbering philosophy

In the perspective of collaborative effort, specific numbering conventions might be used to ease sub-models reconciliation and integration inside the top-level model. The use of some functions or routines (e.g. heat flux functions) may be drastically facilitated if a methodical numbering is adopted.

Sink temperatures

Handle with care. TODO

Fluid modelling

TODO

Clear and explicit labelling required

TODO

Arithmetic nodes

TODO

Sub-models

TODO

7.1.4 $CONDUCTORS

Conductive couplings

3.2.1 Conductively isolated groups of nodes should be justified

3.2.1 Parallel conductors should be justified

3.2.1 Negative or null conductors should be justified

Automatic conductor generation (warnings)
Care for parameterization capabilities

Radiative couplings

2.3.1 The TMM & GMM couples shall be consistently tracked in the configuration control environment

Fluidic couplings

TODO

7.1.5 $CONSTANTS

2.4.1 All user variables in a model shall be commented. The comments shall include:

4.2.3 The user should aim to make variable names clearly readable

4.2.3 Variable names should be in the English language for all models produced under ESA contract

4.2.3 A variable name should give an indication of the physical quantity stored within it.

7.1.6 $CONTROL

Convergence criterion

Cf. paragraph 3.2.2 & 3.2.3.

3.2.2 The sensitivity of relevant model outputs to convergence criteria should be evaluated and appropriate limits agreed upon for the model. The following criteria shall be evaluated:

3.2.2 Steady state production runs should be converged in the sense that all criteria listed in 3.2.2 are within the limits agreed with the customer.

3.2.3 For transient runs using explicit solvers the time step should be smaller than the CSG limit

3.2.3 For transient runs using non-explicit solvers the time step should be smaller than half the shortest time constant in the model

3.2.3 The sensitivity of model outputs to transient solver criteria should be evaluated and appropriate limits agreed upon for the model. The following criteria should be evaluated:

3.2.3 The transient time step should be chosen such that the effects of imposed loads and boundary conditions are adequately resolved.

3.2.3 The time range over which model results are observed should be driven by the model dynamic behaviour (either induced by the environment variations or by the thermal control operation) or the simulated mission sequence.

3.2.3 The cyclic convergence should be assessed between successive time ranges and based upon criteria agreed with the customer that may address temperature differences and heating budget stability.

7.1.7 $ARRAYS

3.3 Tabulated data shall take make provision for "end-conditions." Extrapolation outside of table bounds shall not be occur during the solution routine

Temperature dependent items

According to the system sensitivity to this topic and in particular when dealing with cryogenic temperatures, the temperature dependence of materials properties (e.g. thermal conductivity or capacitance) shall be properly addressed.
A few thermal hardware products require an explicit expression of their key parameter in function of temperature (e.g. louvers opening angle, Peltier device cooling efficiency).

Time dependent items

- Mission timeline
  - Phases sequence (e.g. electronics dissipation)
  - Eclipse flag
  - Aerothermal flux
  - Altitude (marginally)
- External fluxes
  - Solar radiation
  - Albedo
  - Infrared radiation
- Interfaces
  - Sink temperatures
  - Interface fluxes

Mission control

- Mode selection
- Supply voltage

7.1.8 $SUBROUTINES

Cf. paragraph 4.2

4.2.2 The use of tab characters to generate whitespace in user generated code shall be avoided. Spaces should be used in place of tabs.

4.2.2 The body of flow control structures should be indented.

4.2.2 Use subroutines and functions to logically structure user generated code.

4.2.2 Keep subroutines and functions short

4.2.4 Internal variables and arrays of the solver should not be directly accessed or set by the user.

7.1.9 $INITIAL

2.4.1 Comments shall not be used to alter model topology, boundary conditions or procedural behaviour. Such conditions shall be implemented via user logic or alternative skeleton files etc.

4.2.1 Each auxiliary variable with scope limited to a single operations block should be declared at the start of that operation block

4.2.1 Only flow control structures that pass through the pre-processor without generating warnings should be used

7.1.10 $VARIABLES1

2.4.1 Comments shall not be used to alter model topology, boundary conditions or procedural behaviour. Such conditions shall be implemented via user logic or alternative skeleton files etc.

7.1.11 $VARIABLES2

2.4.1 Comments shall not be used to alter model topology, boundary conditions or procedural behaviour. Such conditions shall be implemented via user logic or alternative skeleton files etc.

7.1.12 $EXECUTION

2.4.1 Comments shall not be used to alter model topology, boundary conditions or procedural behaviour. Such conditions shall be implemented via user logic or alternative skeleton files etc.

Appropriate routine

Starting point

- Steady-state routine
  - Requires mean conditions
- Initialization file
  - Risk of loss of status constants

Model consistency check

TODO

7.1.13 $OUTPUTS

Heat flux

Curves

Tables

- Gradients
- Min/ave/max

7.2 Radiative models

Cf. paragraph 3.2.5.

3.2.5 For models containing surfaces with non-zero specularity, an appropriate method should be used. Examples of appropriate methods are: MCRT

3.2.5 For MCRT computations, the sensitivity of relevant model outputs to input parameters of the ray-tracing algorithm should be evaluated and appropriate limits agreed upon for the model:

3.2.5 The sensitivity of relevant model outputs to the filtering of radiative couplings should be evaluated and appropriate limits agreed upon for the model:

3.2.5 For a given face, the REFs to inactive surfaces shall make up less than TODO of the total REFs from that face.

3.2.5 The sensitivity of relevant model outputs to the number of orbital positions shall be evaluated and appropriate limits agreed upon for the model.

Accuracy assessment

- Appropriate sized surfaces vs. number of rays
- Statistical error estimate
- Filtering of REFs
  - Percentage of lost energy
  - Not with space
- Special care when opticals are present
  - Analytical surfaces

Thermo-optical properties

- Robustness
  - Sources to be identified
  - Parameterised
- Main concerns
  - Low emissivity or absorptivity => increase the number of rays
  - Transmissivity
  - Wavelength dependence
  - Incidence angle dependence
    - UV/IR specularity
    - Non-lambertian coatings
  - Ageing factors
    - UV
    - Atomic oxygen
    - Radiation
  - Electrical conductivity

7.3 Conductive models

Physical properties

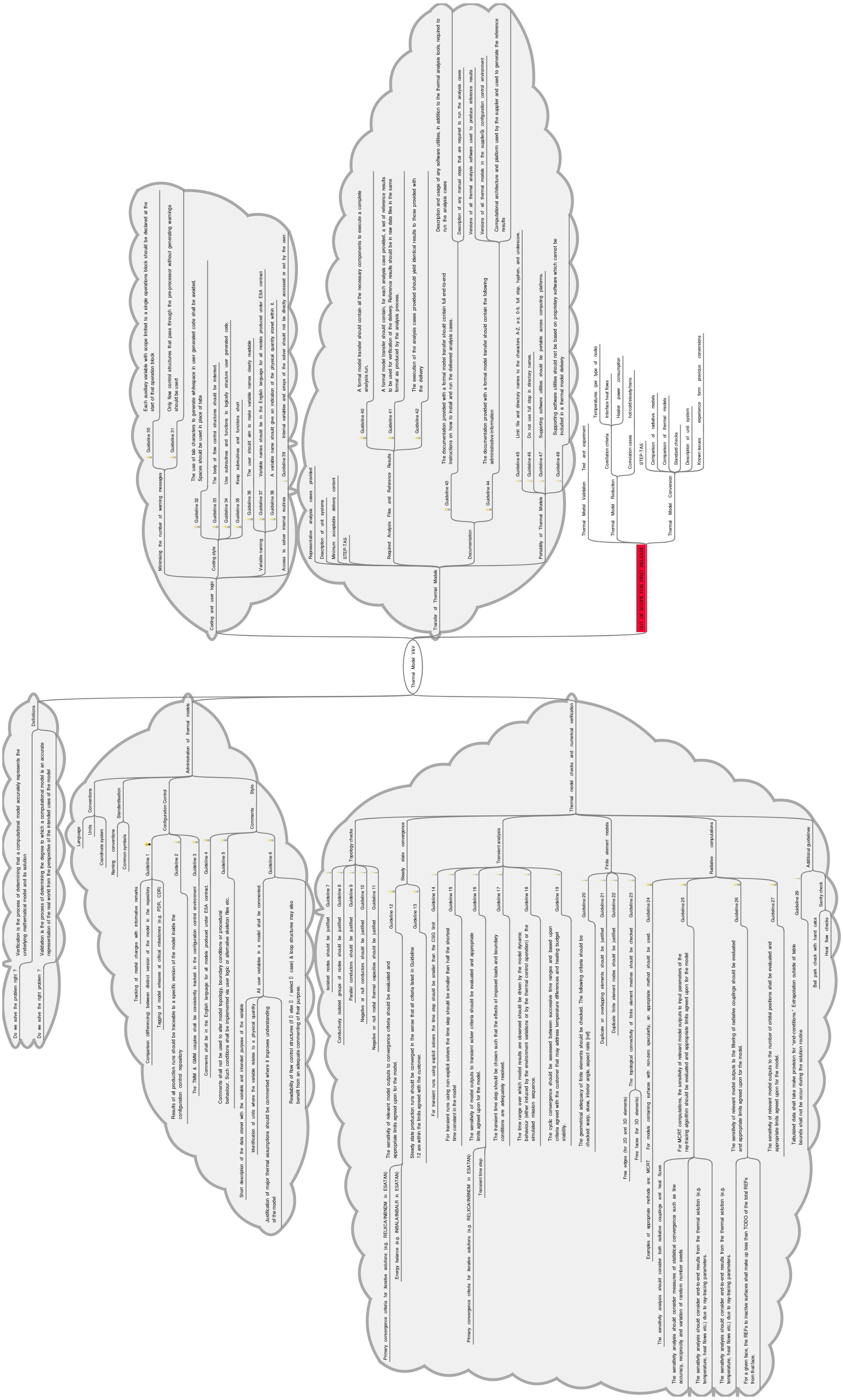
- Thermal conductivity
- Thermal Capacity

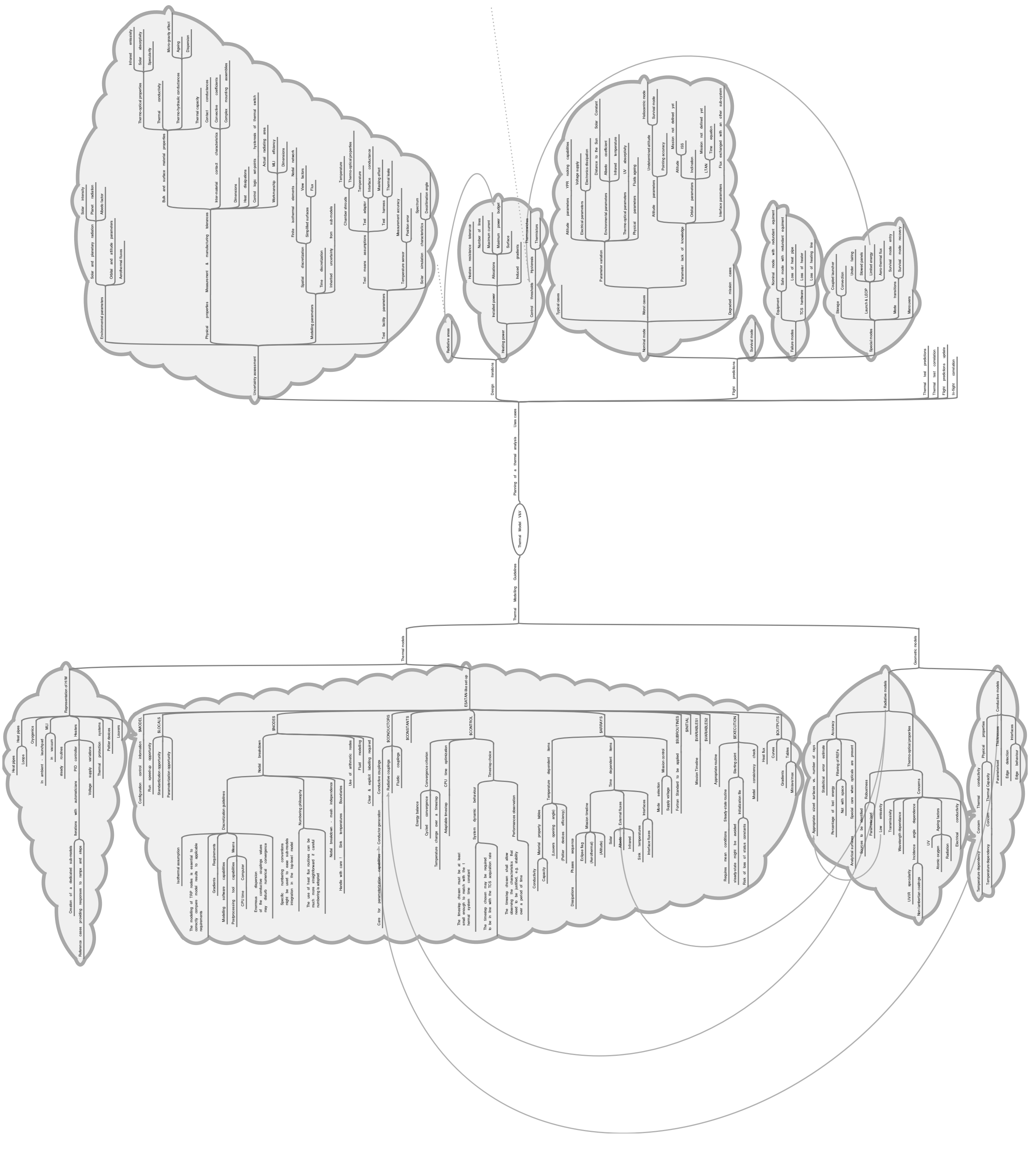
Thicknesses

- Parameterised

Interfaces

- Edge detection
- Edge behaviour


Thermal Model V&V
Coding and user logic
Transfer of Thermal Models
OUT OF SCOPE FOR FIRST RELEASE
Definitions
Administration of thermal models
Thermal model checks and numerical verification



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