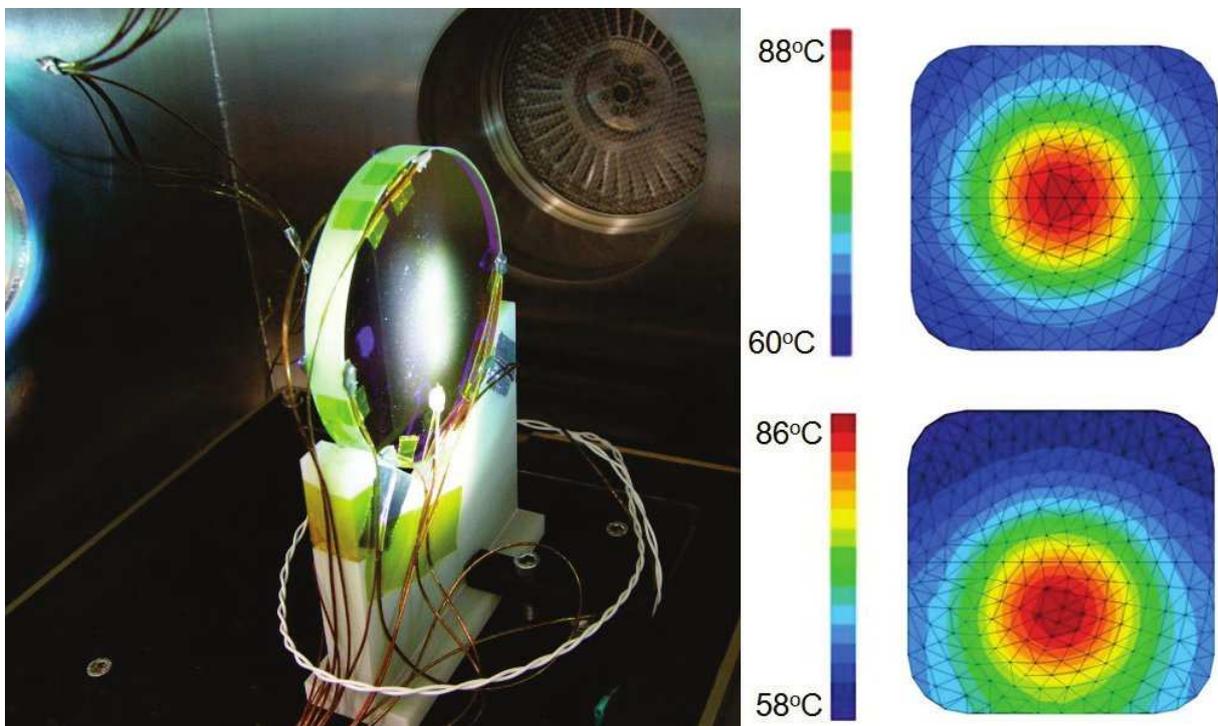


Proceedings of the  
**26<sup>th</sup> European  
Space Thermal Analysis  
Workshop**

ESA/ESTEC, Noordwijk, The Netherlands

20–21 November 2012



credits: RAL Space: Solar Orbiter SPICE instrument Primary Mirror thermal analysis

### **Abstract**

This document contains the minutes of the 26<sup>th</sup> European Space Thermal Analysis Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on 20–21 November 2012. 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](http://www.esa.int/TEC/Thermal_control) under 'Workshops'.

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## Programme Day 1

- 9:00 Registration
- 9:45 **Welcome and introduction**  
Harrie Rooijackers (ESA/ESTEC, The Netherlands)
- 10:00 **Thermal modeling of a non-uniform solar beam in ESATAN-TMS**  
Scott Morgan (EADS Astrium, United Kingdom)
- 10:30 **Presentation of eTherm 1.2**  
Thierry Basset & Patrick Connil & Jean-Paul Dudon (Thales Alenia Space, France)  
François Brunetti (Dorea, France)
- 11:00 Coffee break in the Foyer
- 11:30 **Advances in AblTan Ablative Tool development with application to system model analysis**  
Marco Giardino & Elena Campagnoli (Politecnico di Torino, Italy)  
Lorenzo Andrioli & Massimo Bertone (Thales Alenia Space, Italy)  
Gianni Pippia (SSE, Italy)
- 12:00 **A Thermal Analysis Pre-processor**  
Laurent Bauer (Astrium Space Transportation, France)
- 12:30 **Thermal Design and Analysis of the SPICE Primary Mirror**  
James Cornaby (Rutherford Appleton Laboratory, United Kingdom)
- 13:00 Lunch in the ESTEC Restaurant
- 14:00 **Thermal analysis of a piezo-actuated pointing mechanism**  
Paul Lardet (Sodern, France)
- 14:30 **SYSTEMA-THERMICA Demonstration — Part 1**  
Maxime Jolliet & Timothée Soriano (Astrium, France)
- 15:00 **SYSTEMA-THERMICA Demonstration — Part 2**  
Timothée Soriano & Maxime Jolliet (Astrium, France)
- 15:30 Coffee break in the Foyer
- 16:00 **ESATAN Thermal Modelling Suite — Product Developments**  
Henri Brouquet (ITP Engines UK Ltd, United Kingdom)
- 16:30 **ESATAN Thermal Modelling Suite — Thermal Modelling Process**  
Yannick Melameka (ITP Engines UK Ltd, United Kingdom)
- 17:00 **Thermal Concept Design Tool — Future developments and TCS Projects**  
Andrea Tosetto & Matteo Gorlani (Blue Engineering, Italy)  
Harrie Rooijackers (ESA/ESTEC, The Netherlands)
- 17:30 Social Gathering in the Wintergarden South
- 19:30 Dinner in *Iets Anders*

## Programme Day 2

- 9:00 **Innovative Analysis Methods for Improved Thermal Testing**  
Mélanie Doolaeghe & André Capitaine (Astrium Satellites, France)
- 9:30 **How SYSTEMA could provide valuable assistance in mission analyses and thermal worst cases determination**  
Nicolas Liquière (EPSILON, France)
- 10:00 **Rationalisation of Stabilisation Criteria for Thermal Balance Tests**  
Ettore Colizzi (ESA/ESTEC, The Netherlands)
- 10:30 **Solar Simulator Testing and Correlation of PHI Heat Rejecting Entrance Window (HREW) of Solar Orbiter**  
Enrico Friso & Stefano Debei (Università di Padova, Italy)  
Giovanni Taglioni & Chiara Ciccirelli (Selex Galileo S.p.A., Italy)  
Claudio Damasio (ESA/ESTEC, The Netherlands)
- 11:00 Coffee break in the Foyer
- 11:30 **Application of CADBench and ESATAN-TMS to the Advanced Closed Loop System**  
James Mulcahy (EADS Astrium Bremen, Germany)
- 12:00 **Mercury Planetary Orbiter Solar Array Thermal and Power Modelling**  
Martin Altenburg (Astrium GmbH, Germany)
- 12:30 **Dynamic Thermal Spacecraft Simulator based on nodal mathematical model**  
Anthony Mollier (Thales Alenia Space, France)  
François Brunetti (Dorea, France)
- 13:00 Closure
- 13:00 Lunch in the ESTEC Restaurant
- 14:00 TCDT Training provided by Blue Engineering

## Day 1

# Tuesday 20<sup>th</sup> November 2012

### 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 modeling of a non-uniform solar beam in ESATAN-TMS

S. Morgan (Astrium UK) described the design of thruster units on BepiColombo to withstand the high solar flux environment around Mercury, the test configuration at the University of Bern, and the method developed to model the non-uniform beam in the solar simulator. (See [appendix B](#))

B. Laine (ESA/ESTEC) asked how they had measured the flux in the solar simulator. S. Morgan replied that the flux had been measured by the test chamber group themselves. They had a device consisting of a 20x20 grid using measuring devices actually located in the chamber. B. Laine was interested in the details of the measurements, but S. Morgan said that the University of Bern had provided the data but he did not know how they had actually made the measurements.

J. Persson (ESA/ESTEC) noted that the figures showed a spatial distribution of flux. He wondered whether any consideration had been given to the temporal variation. S. Morgan said that they had not measured much temporal variation. There had been a small cycling over a very small amount of time. Over a two minute period they had seen a small cycle, but this had been taken into account for the steady state analysis by taking the average. They had not seen a measurable decrease in the beam during the test, so they were able to ignore any temporal variation.

B. Laine asked what temperature had been reached by the thruster units. S. Morgan said that the correlation had been successful, as expected, with the injection head, which was the critical component, staying within its temperature limits and not exceeding 75°C. Any higher and the fuel would vapourize before it reached the combustion chamber, which could lead to a so-called "vapour lock" that could stop the thruster from firing efficiently.

A. Franzoso (Carlo Gavazzi Space) asked about the order of magnitude of the thermal gradients along the different parts of the thruster. S. Morgan said that the largest gradient was from the tip of the nozzle at 250-300°C to 75°C at the bottom of the bracket. They had a 2-3°C accuracy on the thermocouples and they had had some difficulty with the correlation. The positions of the thermocouples were needed to millimetre precision. The injection head strap had spread the heat

well, so the temperature differences between the parts had been quite small.

J. Mulcahy (Astrium GmbH) asked whether the solar beam non-uniformity was important for the design of the nozzle during the mission or was it just an issue during test. S. Morgan said that it was only an issue with the test itself. They were not going to be modelling any non-uniformity in the solar mission, but in order to understand and correlate, to check that the thrusters were behaving as they expected them to, they had needed to look at this modelling technique for the test. The non-uniformity was only important during the different phases of the test where the orientation changed. They were not expecting to see any variations in solar flux during flight.

G. Jahn (Astrium GmbH) asked whether the non-uniformity of the beam was reproducible and whether this had been taken into account in the second test. S. Morgan said the beam was not reproducible, and that, indeed, the first measurement pattern they had received had been from a previous test. They had put this pattern into the model and the results just did not work, and for a long time they could not understand what was happening. In the end, they had asked the test chamber group to measure the beam again. They found that it was important to get a measurement exactly at the plane corresponding to the location of the tip of the nozzles. The previous measurement had been made a bit further forward, and because the beam was not a true parallel beam the distribution was different at different distances, and at different times it did vary. It was important to get a measurement just after the test, and in the right plane, in order to get the right distribution.

R. Briet (CNES) had noted that the results had been based on the direct solar flux, and wondered how they had prevented problems with reflections and indirect flux. S. Morgan explained that they had tried to reduce problems by creating a model of the chamber that was as close to the real chamber as possible. They had looked in the chamber to see how divergent the beam was and whether there were any unwanted reflections. R. Briet wondered whether they had needed to introduce any non-direct radiation terms to compensate for these reflections. S. Morgan said they had wrapped as much of the test sample as possible in MLI to avoid contamination from indirect radiation from other areas, and had not needed to add non-direct radiation terms in order to correlate the model. The chamber itself was very uniform, and it was quite a small chamber. They had not found any issues with variations over the chamber walls.

V. Baturkin (DLR) referred back to the slide with the grid fluxes, and wondered what had been used as the criteria for the correlation to say that they had been very good agreement. S. Morgan said that they had performed two analyses to determine the level of agreement. The first one was based on the total flux in the beam. In the second they had broken the beam down into small grid squares and had then looked at the flux in each of the small areas. He did not remember the exact details. The model gave very close agreement with the measured fluxes.

B. Laine commented that in energy terms the results appeared to agree, but the model should also take into account the 10% scattering of the flux values. Had they looked at the effect of the scattering on the distribution? S. Morgan answered that the scattering shown in the "rings" graph was due to the non-uniformity of the beam, where one ring could contain different hot and cold areas. The "grid" solution was better at taking these local variations into account. He didn't know about the level of uncertainty in the beam measurement.

J. Klement (Tesat-Spacecom GmbH) asked about the accuracy of the measurement of the flux. S. Morgan said that he would have to ask the University of Bern, because he did not know.

### 1.3 E-Therm New Release — Presentation of eTherm 1.2

In the absence of T. Basset (Thales Alenia Space), JP. Dudon (Thales Alenia Space) gave a brief history of the e-Therm tool, and an overview of the basic functionality. F. Brunetti (DOREA) then presented the orbitography session and the other thermal module features. (See [appendix C](#)) V. Baturkin (DLR) asked whether e-Therm was available on Windows XP or Windows 7. F. Brunetti replied that the software had been implemented on Windows 7 but had only been fully validated on Windows XP and so he recommended that people use e-Therm on Windows XP. He expected that the effort to port e-Therm to Windows 7 would not take very long, but they would still need to replay and validate more than 200 test cases on Windows 7.

E. Friso (Università di Padova) commented that the TMRT module related to the thermal network, and asked whether there were any plans to develop a module for reducing the geometric or radiative part. F. Brunetti said that he would like to propose a few ideas at the NESTA meeting. One idea would be to have a consortium to promote and develop such a tool. This was one reason why JP. Dudon had been involved, because some research had already been done on this part, and DOREA would be involved in this too. Some sort of geometrical or radiative reduction would be heavily used. TAS/Cannes used analysis software in dynamic spacecraft simulation for operations and in order to have good performance it was necessary to use a reduced model. TMRT was used for the nodal reduction of the TMM, but all of the geometry reduction was still done by hand, and this took time and really needed to be automated. In e-Therm it was possible to reduce the geometry, but it was very simple based on renaming the nodes. This meant you could keep the geometry for the reduced model and just replace the nodes from the detailed model with the reduced model.

P. Zevenbergen (Dutch Space) was interested to hear more about the use of 3D conductors. He understood that this was used to calculate conductors in all directions within a solid, and wondered what would be a typical application for this function. JP. Dudon said that it could be used for all complex 3D structures with surface or volume elements, such as mirror structures for example, some parts of mechanisms, thermal conductive parts between two elements where the conduction path was difficult to perform by hand or using a high level formula. In such a case they first used a 3D finite element meshing model, and calculated the conductive path in this mesh, and then used a reduction to compute a description at the lumped parameter level, say at the instrument level. P. Zevenbergen understood that the solid did not really exist in the thermal model, but was only really used to create conductor values. JP. Dudon confirmed that these "system level" couplings were used with the radiative couplings and the other couplings at the system level and were solved by the solver.

### 1.4 Advances in AblTan Ablative Tool development with application to system model analysis

M. Giardino (Politecnico di Torino) described the development and basic functionality of AblTan, a tool for calculating ablative shield behaviour which could then be used in ESATAN, and how AblTan had been applied to an analysis of parts of the IXV heat shields. (See [appendix D](#))

G. Jahn (Astrium GmbH) asked whether it had been possible to check the numerical results from the tool against actual experimental measurements of the ablative material. M. Giardino said that they had not been able to do this directly. They had some material data from their external partner,

Avio, but the vehicle had not yet flown. Once the IXV vehicle had flown, his dream was to be able to have real flight data which could be used to check the results.

G. Jahn supposed that they had some development or test data for the material itself that had been produced from wind tunnel measurements, for example. M. Giardino said that had not been possible to verify the numerical results because they had concerns about the interpretation of the material data received from Avio: there was no clear threshold for the degradation, and tiles appeared to degrade at much lower temperatures than expected.

G. Jahn wondered how the chemical reactions were represented in the model. M. Giardino said that it was a simplified model which used three Arrhenius reactions in order to get better results because a test had shown that there were three main reactions in the material.

## 1.5 A Thermal Analysis Pre-processor

L. Bauer (Astrium Space Transportation) described and demonstrated `Promether`, a geometric model builder and thermal analysis pre-processor which was able to automatically detect contiguous surfaces and volumes in order to generate enclosures and consistent surface and volume meshing, and to calculate the appropriate conductive couplings. (See [appendix E](#))

B. Laine (ESA/ESTEC) said that the presentation had been very impressive. He was interested to know who were the "happy users" that had been mentioned. L. Bauer said the users were the people from the thermal engineering department. He admitted that `Promether` did have a nice user interface. He felt it was important to point out that the modelling process had previously involved a lot of boring activities where the users had to work on Excel files, or edit things by hand using NotePad and so on. These boring activities were not completely over, because the scope of `Promether` today was not completely finished, it was far from being finished, but a big part of the process had now been automated where the boring and dangerous activities where it was easy to make a mistake had been replaced. There was still a lot of work to do on the load case definitions, and some cases where couplings could not be created based on the geometry, so there was still a long way to go.

S. de Palo (Thales Alenia Space) was interested to know which types of CAD format could be imported. L. Bauer said that they currently used `CATIA` to build the thermal DMU<sup>1</sup>, which was a CAD representation that was adapted to the thermal model. This thermal DMU was then extracted from `CATIA` and imported into `Promether`. He was not completely satisfied with this solution because whenever they changed the version of `CATIA` for example, they needed to recompile the tool, which was expensive. The tool was also too tightly linked to `CATIA`. He wanted to be able to have the same solution, but going through STEP AP214 or something like that, but still with the same process. The simplification should be done in a CAD tool, because that was the core business of the CAD tool to work with geometry, and then the bridge to `Promether` would be made via STEP.

P. Zevenbergen (Dutch Space) asked whether `Promether` also provided functionality to simplify the geometry, remove holes, bolts, etc. L. Bauer believed that it was not the responsibility of `Promether` to do this: the simplification of the geometry must be done in a CAD tool. Today, in this tool chain, users had to work with `CATIA`, and he knew that this was a big constraint. He wanted to provide the same kind of process, working with any kind of CAD tool thanks to the STEP bridge, but he felt that it was important that any simplification should be done in the CAD tool. This was the core business of the CAD tool.

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<sup>1</sup>Digital Mock-Up

P. Zevenbergen asked whether the `Promether` tool would be available to other parties. L. Bauer admitted that the development team was too small to be able to make significant progress with `Promether` as he could see that there were still years of work left to do. He was therefore interested in the possibility of collaboration with other people. In the short term it might be interesting to create a limited version of the tool which allowed simple model export so that the tool could be made available to others for evaluation.

S. Husnain (RST Aerospace) was interested to know whether surfaces had to be perfectly coplanar for the contact recognition to work. He said that sometimes there might be a small gap between surfaces, with some interface filler, and he was curious to know how the software would deal with such a case. L. Bauer said that the model needed to be as clean as possible. The default precision for contact detection was set to 10  $\mu\text{m}$ , but the user could change this precision in the interface if necessary. For cases where the geometrical or contact based coupling did not work, the user would have to switch back to manual couplings and define them by hand. The idea was that the geometry based engine would cover 80-90% of the user needs.

## 1.6 Thermal Design and Analysis of the SPICE Primary Mirror

J. Cornaby (RAL Space) described the challenges in designing a mirror for an instrument on Solar Orbiter which needed to reflect only a small proportion of the incident solar flux with the right wavelength into the main instrument, while allowing the rest of the spectrum and energy to be transmitted through and rejected into space. (See [appendix F](#))

J. Persson (ESA/ESTEC) commented that he had worked on the Cupola for the ISS, which also used Boron Carbide coatings, and that he remembered that there had been a lower temperature limit than the 88°C mentioned in the slides. J. Cornaby replied that they did not have a specific temperature limit in the current design, but they had not noticed any problems during testing. However, this was something that they would need to look at in the next phase of design.

S. de Palo (Thales Alenia Space) was interested in the thermoelastic analysis. The presentation had shown the need for quite a detailed model in order to have something which could be used for the thermoelastic analysis with ANSYS. He had understood that the thermal model had been built to have the same mesh as that used on the ANSYS side. J. Cornaby answered that the model had not been built to conform to the ANSYS mesh. The mechanical engineer had written a script that imported the temperatures and then related them to the mesh used within ANSYS. The thermal model did not use the same mesh as the ANSYS model. S. de Palo supposed that these dissimilar meshes were handled by running the MATLAB script mentioned. He wondered if they had thought about using the sort of pre-processors that the mechanical guys usually ran, such as PATRAN or HyperMesh, as these were able to perform some interpolation related to geometry. As far as he knew, ESATAN-TMS was also able to export geometry with coordinates, so it should be possible to have a map which would be imported into PATRAN or whatever. This could provide another way of providing temperature maps to ANSYS without having to write MATLAB scripts. J. Cornaby said that he did not know the details of the script and had left the conversion to the mechanical engineer.

P. Ferreira (Max Planck Institute) was curious about the flux table shown on the slide: how did they know that the fluxes were in these wavelength ranges? J. Cornaby admitted he did a lot of calculations in Excel: these ranges had not been calculated in ESATAN-TMS.

N. Karaismail (Turkish Aerospace) asked whether the predicted results had been compared against experimental data. J. Cornaby answered that that was what they were currently doing with the thermal testing. He had correlated the ohmic heating test with one of the models and they appeared

to be getting quite a good correlation. The big one would be the solar lamp test, which was ongoing. He hoped that they would have some nice correlations against the test data in the next couple of months.

## 1.7 Thermal analysis of a piezo-actuated pointing mechanism

P. Lardet (Sodern) described the development of a mounting system for the EarthCare LIDAR using pairs of piezo-actuators to give fine control over the two-axis pointing of the mirror assembly. He also described the challenges that needed to be overcome to ensure that differences in thermal gradients did not compromise the pointing requirements. (See [appendix G](#))

V. Baturkin (DLR) asked whether there had been any problems relating to the accuracy of the calculations, the size of the mesh used, etc. P. Lardet said that there had been sensitivity studies, especially on the mesh size, and especially because of the small perturbation in the response that had been seen and which did not make physical sense. He believed that they were really at the edge of the model precision when looking at such results. He admitted that the mesh resolution was an issue. The results shown in the presentation were the results of the middle part of the sensitivity study. This study had given the direction to follow for Phase C. The mesh was clearly one of the biggest issues in the study.

V. Baturkin asked whether there had been any investigations into the results achieved using different solvers. P. Lardet said that they had not tried to use any other solvers. They had looked at heat convergence solutions, and had checked the thermal balance convergence and other things. He felt that by using a small mesh and then verifying the convergence, the solver was not an issue for this set of conductors.

## 1.8 SYSTEMA-THERMICA Demonstration — Part 1

M. Jolliet (Astrium) described and demonstrated some of the new developments in the SYSTEMA framework, including enhanced mission, trajectory and kinematic handling, geometry import from CAD, model checking using user-supplied Python scripting, video generation, etc. (See [appendix H](#))

B. Laine (ESA/ESTEC) observed that there had been a comment towards the end about interfacing with other tools, but there had been no mention of the interface with STEP-TAS. M. Jolliet said that SYSTEMA did interface with STEP-TAS v6. This has not been mentioned explicitly in the presentation but he thought it had been included on one of the workflow slides.

S. de Palo (Thales Alenia Space) asked whether it was possible to model the presence of the Moon, and other effects due to both the Earth and the Moon. For example, when dealing with an orbit around the L2 position, was it possible to take into account the shadowing due to both the Moon and the Earth? M. Jolliet said that he had a case for a Lunar Lander model, developed by colleagues in Astrium Friedrichshafen. You could, of course, use the Moon: you could orbit around the Moon and use it in the trajectory, and you would be able to have the eclipse of the Moon on the satellite, but currently you could not have the Earth eclipse if you were on the Moon. The problem was that SYSTEMA had precision problems in the trajectory management so the smallest error in the position of the Earth, or the spacecraft relative to the Earth, resulted in a huge error for the eclipse. You may have the eclipse, but the time of the eclipse was not precise enough. They had discovered this during a power analysis case, where it had been very important to have an accurate time for the eclipse. What they had done was to allow the user to define their own

eclipses: the user could calculate the real eclipses of the Earth on the Moon and then inject them into the tool in order to have the eclipses that were needed. SYSTEMA was currently unable to calculate these eclipses with sufficient precision to offer this as a built-in feature.

A. Franzoso (Carlo Gavazzi Space) had seen that a complex geometry of an antenna had been imported from a CAD file into SYSTEMA, and wondered what happened to the mesh: was there a single node for every facet? Could the user manage the mesh in a simpler way? M. Jolliet said that when importing CAD models, there were two solutions. The first was to import the CAD model integrally into SYSTEMA shapes, and recreate the antenna for instance using SYSTEMA analytical shapes such as triangles, quadrangles, etc. but this could take some time. The second was to use the CAD model directly for the computation. In this case there would be one node per face on the CAD shape. It was not possible to submesh the CAD model because the SYSTEMA mesher was not able to cope with non-analytical shapes, such as the b-splines and other complex shapes defined in CATIA. It was possible to condense the different nodes in the model if the faces were too small and you didn't need such a fine mesh on the model. A. Franzoso asked whether the antenna had been imported as one node. M. Jolliet said that in CATIA it was possible to have a volume node defined by multiple faces but in SYSTEMA there was one node per face. He went to the SYSTEMA session to show that the antenna consisted of several meshed areas, each consisting of many individual facets, where each meshed area corresponded to a single node. He showed that in the CATIA model it was possible to have many faces per node, so for example, the five meshes on the antenna could be mapped to 5 nodes. He said this could be useful if really high precision was needed for irregular shaped meshes, the user could use the meshes directly, or could reduce the number of nodes in the mesh before importing.

## 1.9 SYSTEMA-THERMICA Demonstration — Part 2

T. Soriano (EADS Astrium) expanded on the previous presentation to describe and demonstrate new developments in THERMICA, including performance enhancement due to multi-threading and optimisation, ray tracing display, thermal mathematical model management and skeleton file generation, and post-processing. (See [appendix I](#))

F. Bodendieck (OHB) was concerned about the introduction of the new \$EDGES block, and asked whether there was a converter to convert the THERMISOL NWK file into a true ESATAN file for running under ESATAN. T. Soriano said that the user could select the output format from the conductive module. The options were to not create edges at all, to create them as classical thermal nodes, or to create them as edges. THERMICA offered these options because even if the edges were output as classical nodes, the temperature solver could not tell the difference between an edge and a classical node defined by the user. If the user wanted to know the flux going through shape 100 and 200, even though the flux went through an edge, if the user did not know the number of that edge and the couplings involved in that flux, the user would have to really search for this information. The fact that the solver had knowledge of the edges and the connections between the edges and the shapes, meant that when the user asked for the flux between shape 100 and shape 200, the solver would automatically compute that even though there were edges involved in the middle.

J. Mulcahy (Astrium GmbH) asked whether there were any plans to introduce 3D automatic conductance generation, as shown in other presentations. T. Soriano said that they were currently working on 3D conductor generation.

## 1.10 ESATAN Thermal Modelling Suite — Product Developments

H. Brouquet (ITP Engines UK) reminded everyone of the vision behind the consolidated tool suite, and how the recent releases had built on this vision to provide the performance, scalability and geometry modelling improvements needed for CAD model import and to address specific user requirements. He described the new features which would be available in ESATAN-TMS r5 to be released the following week, including an updated CADbench, improved conductor generation and pre- and post-processing, and support for planet surface modelling. He also gave details of the r6 release planned for the following summer, which would include solid modelling capabilities requested by Astrium Launchers. (See [appendix J](#))

C. Theroude (Astrium Satellites) asked whether there would be a STEP-TAS interface for the solids which would be introduced in r6. H. Brouquet said that he would need to check with ESA to see whether solids were also supported in STEP-TAS v6.

Further questions were deferred until after the following presentation.

## 1.11 ESATAN Thermal Modelling Suite — Thermal Modelling Process

Y. Melameka (ITP Engines UK) gave a live demonstration of the end-to-end modelling process, concentrating on the import and simplification of a CAD model via CADbench, and showing the typical reworking required to obtain a suitable thermal model, including new ways to generate simple primitive shells to replace areas of triangular facets left over from the CAD. (See [appendix K](#))

J. Mulcahy (Astrium GmbH) asked whether future versions of ESATAN-TMS would support multiple selection via the GUI. H. Brouquet (ITP Engines UK) said that there were plans for multiple selection. J. Mulcahy asked whether there would be support for undo and redo. H. Brouquet said undo and redo would not be available in r6.

## 1.12 Thermal Concept Design Tool — Future developments and TCS Projects

M. Gorlani (Blue Engineering) announced that TCDT had been ported to run on Windows 7 and Excel2010, and that this version would be available by the end of the year. He then described some of the new features that would be available in the first quarter of the following year as part of release 1.6.0, including the ability to chain orbital arcs, and improved flux calculations to take account of shadowing effects. He then presented the use of TCDT to generate and validate a simplified model of the EXOMARS EDM for coupling to the Proton Launcher. (See [appendix L](#))

F. Bodendieck (OHB) asked whether the Proton geometry export class would be available as part of the release, or whether it had been developed specifically for Thales-Alenia. M. Gorlani said that it was an internal development created by Blue engineering, which had been needed in order to perform the activity for Alenia. The TCDT supported the use of "add-in" modules, which meant that there was a sort of open door into which users could plug in their own functionality. The class was just a plug-in to the TCDT.

B. Laine (ESA/ESTEC) said that ESA had also been involved in a similar effort to convert models for a Proton coupled launch analysis, this time for TAS France. The first time was for Sentinel, and the second for the TAS-F part of Exomars. ESA therefore also had a converter from ESATAN-TMS

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to a Proton-like CSV format that could be imported into Excel, and were planning on adding this to `TASverter`. This would help other people avoid rework.

### 1.13 Workshop Feedback

In the few minutes before the social gathering at the end of the day, B. Laine (ESA/ESTEC) was interested to get some feedback from the participants about the workshop. He was very happy to see so many people, despite the current economic situation. He wanted to thank everyone for coming.

He wanted to have a quick show-of-hands survey about the participants to see how many people were here for the first, second, third, fifth, tenth and fifteenth times. A lot of people were attending for the first or second time, but it was clear that many people attended on a regular basis.

He said that from the following year, all ESA conferences had to demonstrate "financial equilibrium". The thermal workshop had always been free, and although it did not cost much, it was always a fight to keep the costs down. He wondered whether charging a small fee for future workshops would be an issue for any of the participants. S. Price (Astrium UK) said the workshop had always been free and relatively easy to get to, so it was easy to bring new engineers to present work. B. Laine said that it was clear that "free" meant that it was easier to get permission, and "not free" often involved a lot of administrative paperwork and approval. He hoped to be able to keep the workshop free, or low cost, or maybe even look for a sponsor.

B. Laine reminded everyone that the workshop had changed name. What should have been the 26<sup>th</sup> edition of the Thermal and ECLS workshop had become the European Space Thermal Analysis, or ESTA, Workshop. The new name brought it a bit closer to the related Network of Experts in Space Thermal Analysis, or NESTA. ESA usually took the opportunity of the workshop to schedule a meeting of NESTA.

B. Laine said that presentations on ECLS activities were still welcome, but the new name reflected an internal reorganisation within ESA and a lack of presentations on ECLS in recent years. It had been unclear whether to also add "Verification" to the title of the workshop, and whether to consider "Testing" or "Hardware" in the scope of the workshop. He wondered whether the workshop could become a more general European Thermal Workshop. He said that the presentations were high quality, and were certainly at a level that would be welcome at ICES. He stressed that this was the participants' workshop, and that everyone shaped it together based on the presentations that everyone provided.

B. Laine reminded everyone that, at the previous workshop, he had mentioned an activity to draft some guidelines on modelling and analysis. J. Etchells (ESA/ESTEC) and B. Bonnafous (ESA/ESTEC) had now produced a draft of the guidelines which was close to being ready, and which would be distributed to NESTA. He said that some printed copies would be made available the next day so that people could read them on the flight home. He would welcome any feedback and at any time: he did not want people to wait until next year's workshop! The idea was that these guidelines would form the basis for an ECSS handbook. The ECSS committee would be meeting soon to decide on next year's activities. These guidelines formed one proposal. He said it was important for people to push their ECSS representatives to get the guidelines included in the planning.

B. Laine had one final word: The social gathering was open, so enjoy the drink!



## Day 2

# Wednesday 21<sup>st</sup> November 2012

### 2.1 Innovative Analysis Methods for Improved Thermal Testing

M. Doolaeghe (Astrium) described the framework technology for linking DynaWorks with other tools to provide improved interaction, post-processing and correlation results during thermal testing. (See [appendix M](#))

J. Persson (ESA/ESTEC) noted that only temperature extrapolation would be used during the AlphaSat test<sup>1</sup> and that temporal extrapolation would be excluded. He felt that temporal extrapolation would have been useful. M. Doolaeghe agreed, but said that it had probably been excluded because that functionality was not yet fully mature. A. Capitaine (Astrium) confirmed that they had decided not to use it on AlphaSat.

G. Sieber (Jena-Optronik) commented that the first correlation usually depended on the knowledge of the model in setting up the initial parameters. He wondered whether it had been easy to get all of this information from the thermal engineers before setting up the system for test. He also wondered whether the fit attained had been towards the extremes of the expected range. He had found that coupled units sometimes caused problems during fitting and wondered how well they were handled by the tool. M. Doolaeghe said that they had obtained information from the thermal engineers before the test. She admitted that the tool tended to show one high and one low value and there was currently no way to control that. The expected physical variation was given as a range, as obtained from the thermal engineers, and the tool was supposed to optimize within the range.

### 2.2 How SYSTEMA could provide valuable assistance in mission analysis and thermal worst cases determination

N. Liquière (Epsilon) described the 3POD moving antenna system, which was articulated to give a range of azimuth and elevation angles and which was intended to provide longer connection times with individual ground stations. He explained how SYSTEMA had been used to discover worst cases for different configurations during different operational phases around the orbit. (See [appendix N](#))

V. Baturkin (DLR) noted that the presentation had shown a heat flux summary, but said that because the antenna was a large object, the flux density might be more important in order to avoid small points becoming overloaded. He wondered whether there was a need to orient the antenna

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<sup>1</sup>The AlphaSat thermal vacuum test would occur some time after the workshop.

based on temperature rather than flux considerations. N. Liquière said the antenna structure was made of aluminium and was therefore very conductive, and the engineers had not felt it would be a problem to define parameters based on flux values. V. Baturkin commented that due to consideration of the quality of the materials used in the design it was often necessary to understand the exact criteria used for the optimisation.

S. Price (Astrium UK) asked about the mass of the antenna unit. N. Liquière admitted that he didn't remember exactly but could find out. S. Price asked about the parametric cases. N. Liquière answered that they had only been interested in optimising based on the fluxes, and so they had selected the parameters based on geometry.

M. Gorlani (Blue Engineering) wanted to know more about the worst case determination. The presentation suggested that there had been a complete search across all values and that the worst case had been found by looking at the results manually. He wondered whether there had been any optimisation of the search. N. Liquière confirmed that there was no optimisation at the moment and that determining the worst cases relied on engineering experience. If there were any doubts, it was always possible to scan over all of the seasons to identify other potential cases. He said that the examples shown were the well-known cases. M. Gorlani summarised that the end was reached when the scan had been made of all of the parameters and that there was no optimisation. N. Liquière agreed that this was the case.

### **2.3 Rationalisation of Stabilisation Criteria for Thermal Balance Tests**

E. Colizzi (ESA/ESTEC) presented details of a theoretical approach that could be used to calculate a thermal time constant for any thermal network model and that this could therefore be used to determine whether a thermal test had reached stabilisation within given error bounds. (See [appendix O](#))

A. Capitaine (Astrium) asked whether it had been possible to test the theory on a full set of measurements during a real test. He was concerned that there would be difficulties due to local time constants for different equipment. Sometimes the higher time constants were due to components with high thermal inertia, such as tanks, and then the heat transfer coefficients would converge differently. E. Colizzi admitted that he had not had a chance to undertake a full verification during a test, but had been able to make an embryonic test of the method on SWARM and had found that the theory worked.

A. Capitaine said that with the experience of IAMITT they had seen that when the test was far from stabilisation they had needed to keep two exponential terms in order to have a good approximation of the final exponential. E. Colizzi said that if they had needed to track two exponentials then the numerical method suggested that the corresponding eigenvalues would decay to a single value representing the contribution of the two exponentials.

G. Sieber (Jena-Optronik) asked whether there was any intention to put this numerical method into practice on a real test. E. Colizzi said that he hoped to do so, but there was a question of finding resources. G. Sieber asked whether there was any way of predicting how the calculated pseudo time constant would behave compared to what was seen in a test. E. Colizzi said that the numerical method was intended to help with the rational use of time during a test, and that therefore he did not feel that the question was legitimate. The duration of the test was not related to the time constant, but depended on how far you started from the conditions required for the steady state of the equation. In marginal cases the difference between the pseudo time constant and the measured behaviour could give an indication of the truncation errors and confidence in the

level of stabilisation. However, how close the starting point was from the equation depended on the test setup, on how clean the transition between test phases was, etc.

G. Sieber said it would be interesting to see how long engineers and management felt a test needed to be compared to the pseudo time constant. E. Colizzi felt that it was possible to show that the time taken for a test was related to the experience of the engineers in charge. In general the stabilisation phase was usually considered to take between three and five time constants.

B. Laine (ESA/ESTEC) said that ESA had looked at verifying the mathematics involved and it all seemed to be correct. Now it was a case of checking it against real models under test. J. Etchells (ESA/ESTEC) was currently busy with the AlphaSat testing and was hoping to apply the method to the data obtained. One problem was the noise on the measurement: it was necessary to obtain a clean curve out of the measurement in order to apply the technique. He hoped to have something to present at a future workshop. E. Colizzi noted that the paper that he had presented at ICES described the effect of noise on the parameters calculated.

J. Candé (ESA/ESTEC) observed that thermal balance testing was a very boring process. He had tried, during tests many years ago, to derive data from `DynaWorks`, and then use a spline function to identify stabilisation criteria. He had tried to make a complicated derivation to calculate the stabilisation criteria instead of relying on temperatures, but had never been satisfied with the result. He felt that it was nice to be able to play with computers to see whether there were meaningful relationships between all sorts of parameters, but in the end it all came down to temperatures measured during the test. P. Poinas (ESA/ESTEC) said that he had been involved in some of the same tests, and most of the time, when you, as the thermal engineer, thought that you had reached steady state, industry had already decided to jump to the next test phase, based on the results.

E. Colizzi felt that the test criteria needed to show stabilisation rather than just reaching a temperature value. There were various numerical criteria that could be used to determine stabilisation, such as the time constant, etc. P. Poinas argued that the time constant was always changing as the test progressed, so there was a need to decide on the convergence of the time constant as well. E. Colizzi stated that the differentiation method gave a series of curves and it should be easy to see whether there were any false indicators.

## **2.4 Solar Simulator Testing and Correlation of PHI Heat Rejecting Entrance Window (HREW) of Solar Orbiter**

E. Friso (Università di Padova) presented the design of the heat rejecting window which used four coatings with wavelength dependent optical properties, how they had been modelled, and the experimental configuration required to test the model. (See [appendix P](#))

P. Ferreira (Max Planck Institute) had noticed that the test description did not include any measurement of the distribution of the flux in the solar simulator, or how the flux decayed with radius. He wondered whether this had not been required for the test. E. Friso answered that it had been necessary for the test. They had used a Gardon sensor on the Cartesian x,y frame in order to determine the uniformity over the beam radius. P. Ferreira commented that the presentation had contained a graph of flux against wavelength, and asked whether this had been measured at one point or across the whole beam, and therefore whether the irradiance had been measured at just one point, or at several. E. Friso repeated that they had used a Gardon sensor on a Cartesian x,y frame in order to measure at many points and calculate the flux distribution of the beam.

P. Ferreira was curious to know why the temperatures had gone up as shown on slide 17 plotting temperatures against time. E. Friso said that the temperatures appeared to go up because of the scale used for the graph. The graph showed more than one hour of measurement, but only the

last fifteen minutes of measurement were used as the boundary condition. In fact, the stability criterion of 3°C per hour had already been achieved, and then the measurement continued for one hour under stable conditions, and then the mean of the final fifteen minutes was used as the value for the boundary condition.

## 2.5 Application of CADbench and ESATAN-TMS to the Advanced Closed Loop System

J. Mulcahy (Astrium GmbH) described the Advanced Close Loop System rack for the Columbus Module, and the process of using CADbench to simplify CAD models for import into ESATAN-TMS. (See [appendix Q](#))

P. Zevenbergen (Dutch Space) asked at what phase of the project it had been decided to use CAD files for the geometry, and how the simplification process handled changes in the CAD files. J. Mulcahy said that they were currently working in a staggered PDR phase, so designs of some of the drawers in the rack had been finalized and some had not. They had started with the finalized models, and they expected to have minor changes in the future relating to the location of some of the components. As far as handling changes was concerned, they were typically using the same sorts of components in different places, so it was not a huge deal if these were modified, but simply a case of changing one and then copy/paste operations to handle the other locations. He said that changes to the cold plate design would be more difficult as such changes would involve much more rework.

P. Zevenbergen wondered whether the dressing down of the CAD model to remove holes, etc. could not be automated. J. Mulcahy answered that the process was not automated, the thermal engineer had to simplify the CAD import manually.

S. de Palo (Thales Alenia Space) wondered how the process handled FHTS models: the racks in Columbus all had cold plates which were attached to the Columbus fluid loops. J. Mulcahy admitted that they did not handle the fluid loops because some subcontractors would be looking at that part. The remit for the CADbench simplification work was to connect components to specific cold plates in order to create local thermal models with no obvious hot spots. These models would then be passed on to other people to connect them into the fluid loop models.

G. Sieber (Jena-Optronik) wondered whether it was possible to record CADbench operations in order to replay them on new CAD files. J. Mulcahy admitted that this sounded like a good idea, but didn't know how it would be possible to automate the simplification process. As each conversion was difficult, and different, he wondered how you could really automate it. Maybe it would be possible to simplify the removal of rounds and holes, but he did not know how.

## 2.6 Mercury Planetary Orbiter Solar Array Thermal and Power Modelling

M. Altenburg (Astrium GmbH) presented an outline of the complete BepiColombo spacecraft and its complex trajectory to reach Mercury. He described an analysis work-flow that took a detailed model of the Mercury Planetary Orbiter, created a reduced model which was used for calculating fluxes and GRs for the solar arrays, and which were then plugged into a simplified model using tables of data to calculate solar array power profiles. (See [appendix R](#))

P. Zevenbergen (Dutch Space) wanted to know whether he had understood correctly that the Python script called the solver directly, or did the method generate tables from the solver which

were then processed by the Python script? M. Altenburg clarified that the Python script called the solver. It opened the GMM in batch mode in order to calculate the fluxes, and then ran the TMM in batch, and then extracted the results for further processing.

## 2.7 Dynamic Thermal Spacecraft Simulator based on nodal mathematical model

In the absence of A. Mollier (Thales Alenia Space), D. Valentini (Thales Alenia Space) briefly described the background to the activity, and then F. Brunetti (DOREA) presented how various existing tools had been brought together to create a new dynamic spacecraft simulator.

(See [appendix S](#))

There were no questions.

## 2.8 Workshop Close

B. Laine (ESA/ESTEC) apologised for not introducing himself earlier as the head of the Analysis and Verification section that organised the workshop. He thanked everyone for coming, and said that it was a pleasure to see so many participants and especially presenters. He was happy to see that the tools were evolving quickly, that there was an improvement in performance, and that users were actually making use of the new functionalities. He wondered about having an on-line survey to find out what people really used and what new features they wanted. He emphasized that users should feel free to contact ESA at any time during the year, and not just wait for next year's workshop.

B. Laine reminded everyone about the Thermal Modelling Guidelines, there were still paper copies if people wanted to read on the plane, and that he hoped to have comments from industry which could be reviewed and incorporated in a reissue at the end of the year. He added a disclaimer that part of the document had been taken from an old copy of the ECSS standards from 2000 which had since been removed from the new ECSS as being informative rather than normative. The section marked with a green line was from the old ECSS. He hoped that the Guidelines would be accepted by ECSS next year so it was important for people to talk to their ECSS representatives.

B. Laine reminded everyone that they should still register for the Workshop if they had not already done so as it showed the level of interest and the value of the Workshop, and ensured people would receive links to the proceedings and the invitation to the next workshop.

H. Rooijackers (ESA/ESTEC) thanked everyone for coming, and the presenters for presenting, and brought the main part of the workshop to a close. He reminded people that there were still places available for the TCDT training course in the afternoon.

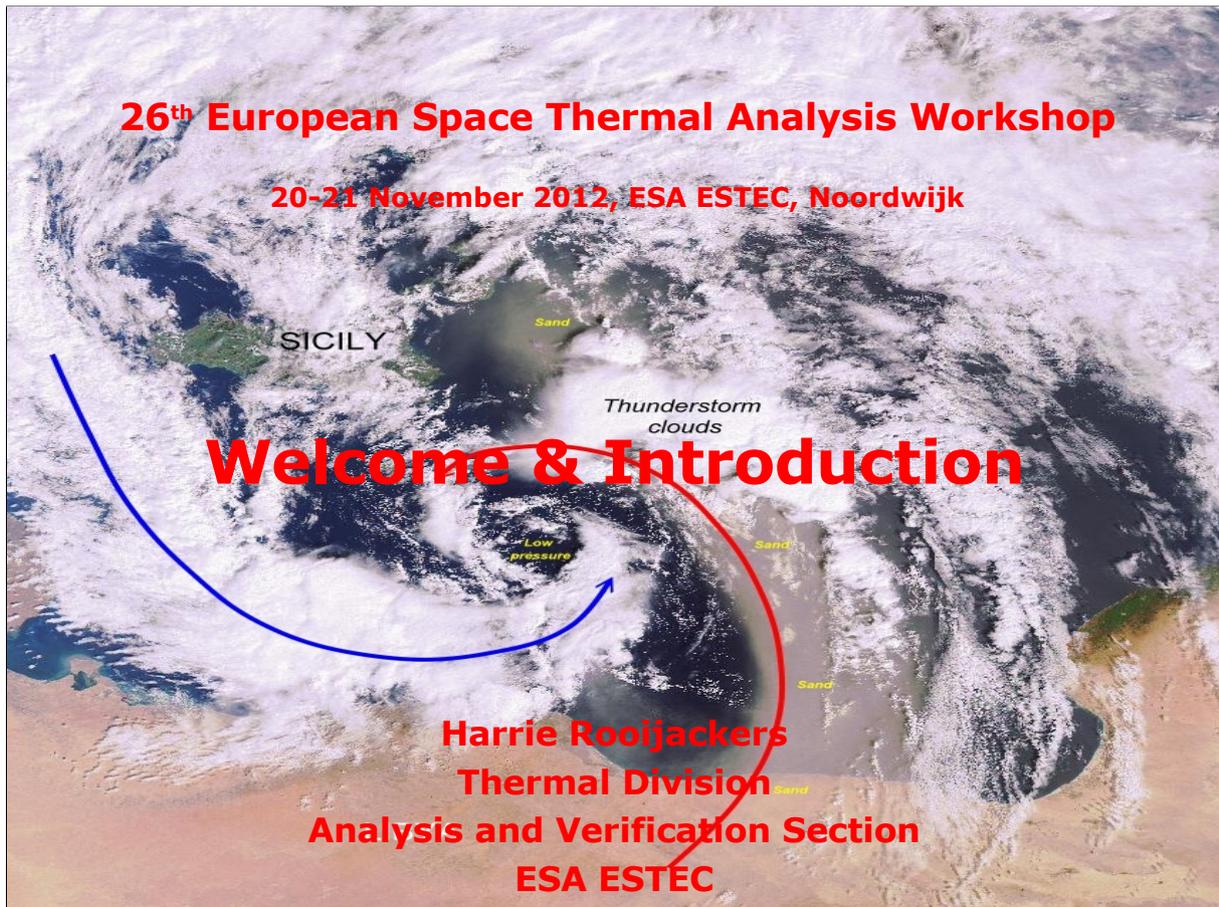


# Appendix A

## 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 engineering analysis tools and related methodologies
- To provide a forum for contact between end users and software developers
- To present developments on thermal engineering analysis tools and to solicit feedback
- To present new methodologies, standardisation activities, etc.

## 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

## Programme



- Two-day programme
- Presentations of 30 min, including 5 minutes for questions and discussions
- Cocktails today after the workshop in the Wintergarden South
- Dinner (optional) tonight in Noordwijk
- TCDT training session 2<sup>nd</sup> day after lunch

## Practical information



- **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 the Web.

## Practical information



- Lunch: 13:00 - 14:00
- Cocktail today at 17:30 in the Wintergarden South
- 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!

## Workshop diner



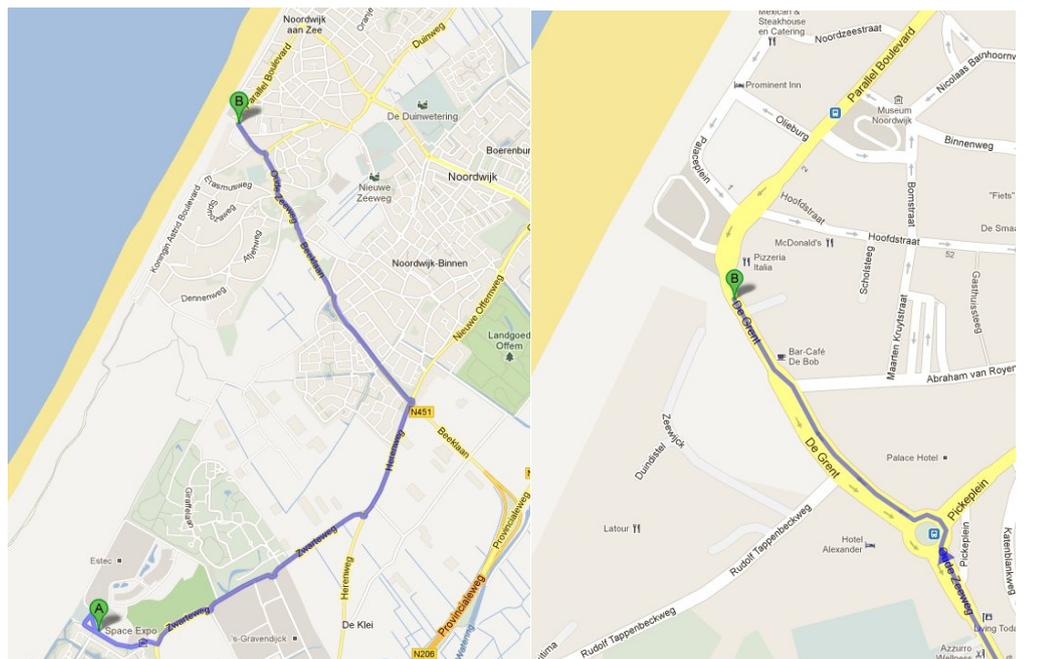
- in "Iets Anders", De Grent 30,  
2202 EL Noordwijk, ☎ +31(0)7136 11136
- fixed menu with choice of main course (fish, meat or vegetarian) for €34,50 p.p. incl. 1 drink  
*additional drinks are charged individually.*
- Restaurant booked today for 19:30
- Please arrange your own transport
- "Dutch" dinner == to be paid by yourself 😞
- If you would like to join, then 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

26th European Space Thermal Analysis Workshop

7/12

European Space Agency

## Restaurant "Iets Anders"



26th European Space Thermal Analysis Workshop

8/12

European Space Agency

**Menu** (€ 34,50 p.p. Including 1 drink) 

***Vegetarian Spinachsoup***  
or  
***Smoked wild Alaska salmon with classic garnish***  
or  
***Simmental beef carpaccio with Parmesan and Liquido d'Oro basil- flavoured ilve oil***  
~~~~~

***Cod fish fillet pan fried with a white wine tuffle sauced curry sauce***  
or  
***Iberico pork fillet slowly cooked, with a small cut of crispy belly bacon***  
or  
***Simmental beef with a red wine sauce***  
or  
***Fresh ribbon pasta with stir-fried basil, honey tomatoes and olives  
with buffalo Mozzarella***  
~~~~~

***Chocolate "salami" filled with tutti-frutti, nuts and rum-raisins ice cream***  
or  
***Selection of organic cheese***

European Space Agency

26th European Space Thermal Analysis Workshop 9/12

**ICES 2013** 

- The 43rd International Conference on Environmental Systems (ICES) will be held 14-18 July, 2013, Vail, Colorado, USA.
- Deadline for submitting abstracts: 1 November, 2012
- 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](http://www.aiaa.org/events/ices)

European Space Agency

26th European Space Thermal Analysis Workshop 10/12

## Workshop



18 very interesting presentations covering:

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

## Workshop



# Listen, Ask, Discuss

*most of all: **Enjoy***

## Appendix B

### Thermal modeling of a non-uniform solar beam in ESATAN-TMS

Scott Morgan  
(EADS Astrium, United Kingdom)

### **Abstract**

Due to the non-uniformities present in some test facility solar beams, a method has been developed to account for the variations in intensity experienced across a test object. This presentation discusses a few different methods that have been used to model this within ESATAN-TMS using the inbuilt transmissivity function, and the results obtained from the analysis.

# Thermal modelling of a non-uniform solar beam in ESATAN-TMS

Astrium UK

Scott Morgan // 20/10/12

All the space you need



## Contents

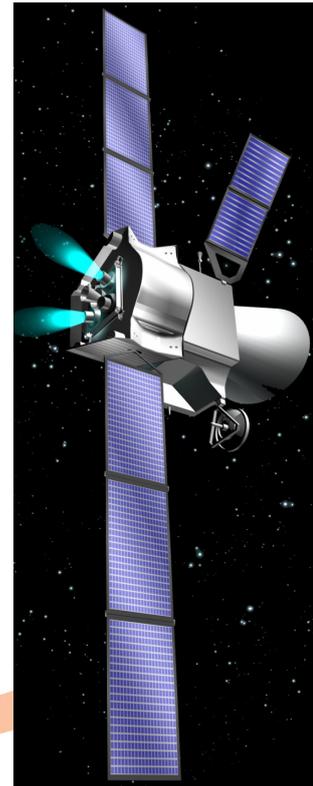
- Background
- The problem
- Solution 1
- Solution 2
- Results
- Conclusion

All the space you need



## Bepi Colombo

- Bepi Colombo is an ESA mission to Mercury, launching in 2015
- It is effectively 3 spacecraft stacked on top of each other
  - MTM – Mercury Transfer Module
    - Propulsion module, including attitude control thrusters and Xenon electric propulsion system
  - MPO – Mercury Planetary Orbiter
    - ESA science module, studying the Internal structure, Geology, Element composition and Polar ice.
  - MMO – Mercury Magnetospheric Orbiter
    - JAXA science Module, studying the Magnetic field of Mercury and the inner solar system

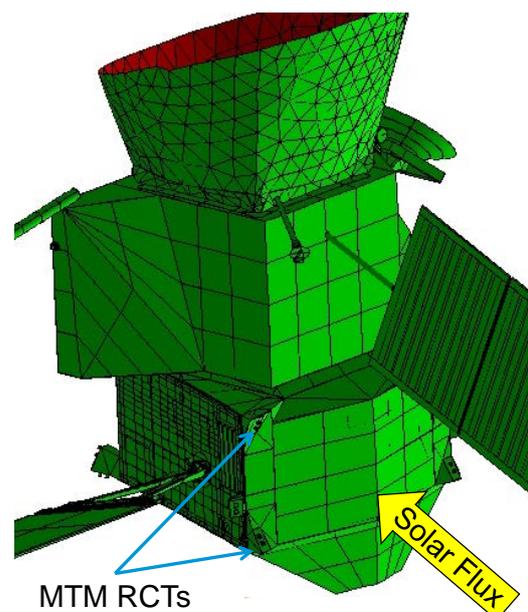


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## MTM RCTs

- The MTM attitude control system requires reaction control thrusters (RCTs) pointing towards the Sun
- Therefore the thruster nozzle is exposed to up to 11 Solar constants of flux in a steady state environment
- As a result, significant thermal design work has been necessary to control the temperature of the RCTs in this environment

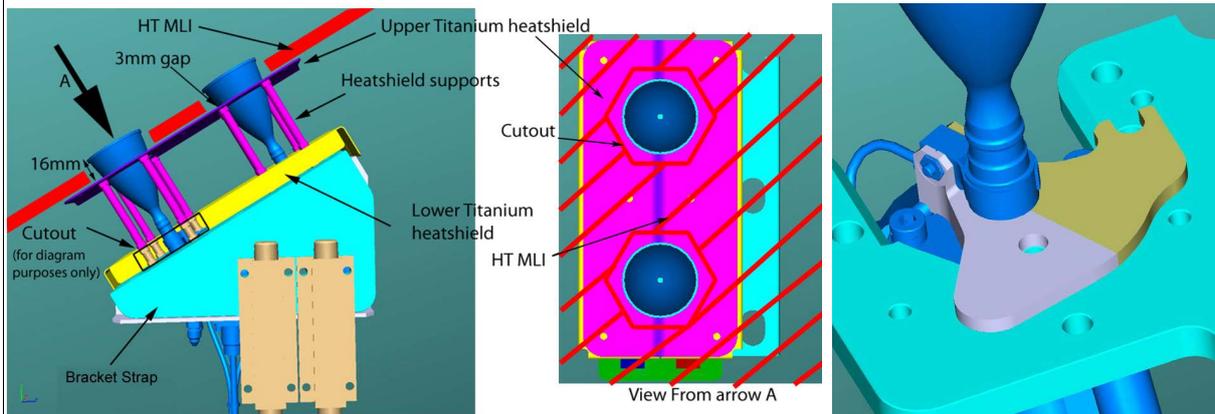


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Date - 4



## RCT Design Work



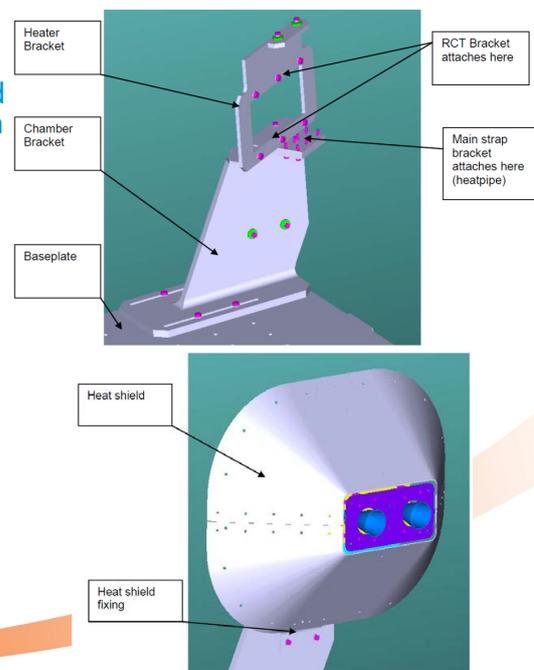
- The main thermal design strategy was to;
  - Reduce the amount of flux absorbed by the thruster
  - Remove as much heat as possible via a radiator mounted heatpipe

All the space you need



## RCT Test

- Once a design was found that was predicted to work, the entire setup needed to be tested in order to have confidence in the model.
- Therefore a solar simulation test was designed to test a thruster pair and its associated thermal hardware
- The heatpipe was replaced with a large Aluminium strut, that doubled as a support for the hardware
- Due to the flight MLI (made from Nextel) not being permitted in the chamber, an LAE MLI blanket was used instead
- This MLI was supported by a conical Titanium heatshield to account for the missing MLI support structure

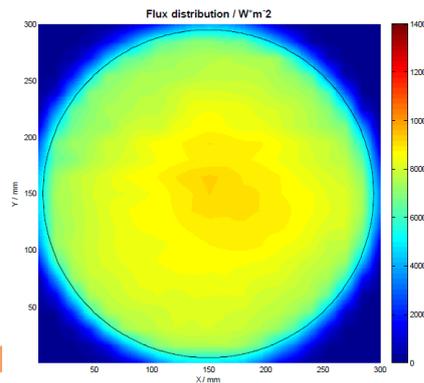


All the space you need



## The Problem

- The solar beam intensities from some chambers are not uniform
- This leads to modelling errors and uncertainties, which complicate and impede correlation activities
- Therefore a better method is needed to model solar simulation beams more accurately

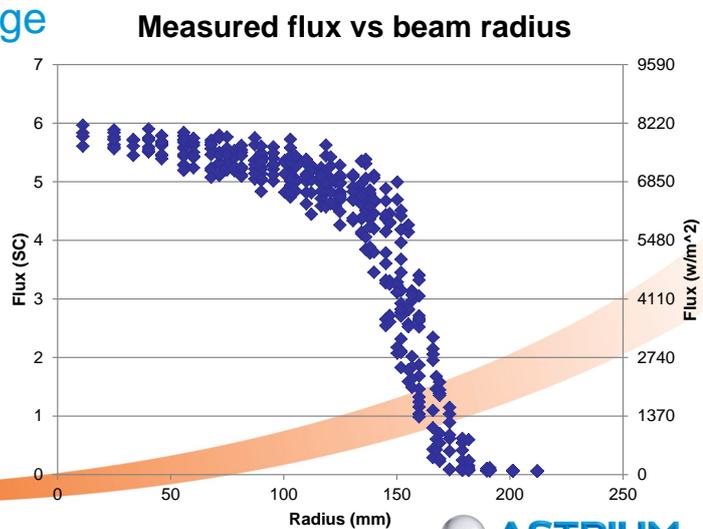


All the space you need



## The Problem

- The main non-uniformity in the beam of some solar simulators is a drop off from the centre of the beam to the edge
- Also the “edge” of the beam is usually not distinct, but decreases over a region of space

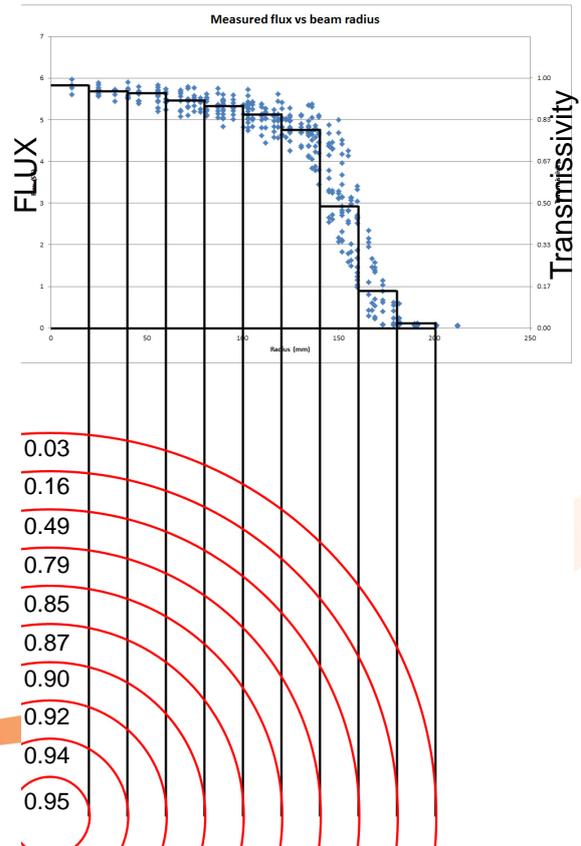


All the space you need



## Solution 1 - "Rings"

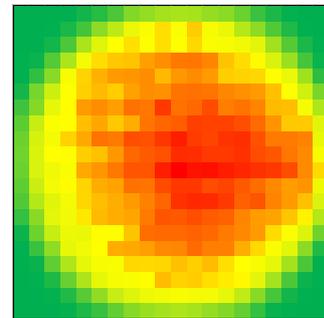
- A solution to this problem is to pass the uniform flux generated by ESATAN-TMS through concentric rings of variable transmissivity
- These rings decrease in transmissivity at larger radii from the centre, thus scaling the flux.



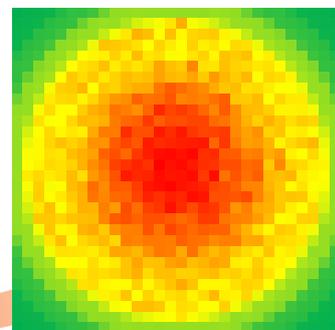
All the space you need

## Solution 1 – "Rings"

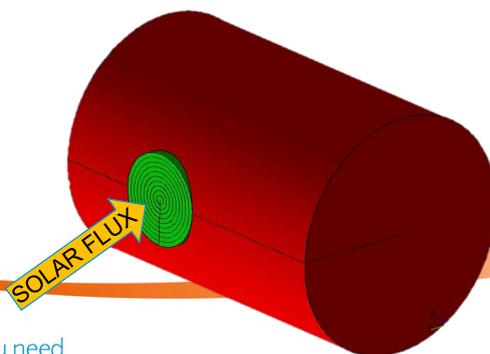
- Results for flux distribution is shown here, compared to original measured data
- Decrease in intensity at large radii is well modelled
- Good average agreement
- Fails to take into account local hotspots in beam



Measured solar flux from test



Simulated solar flux from model

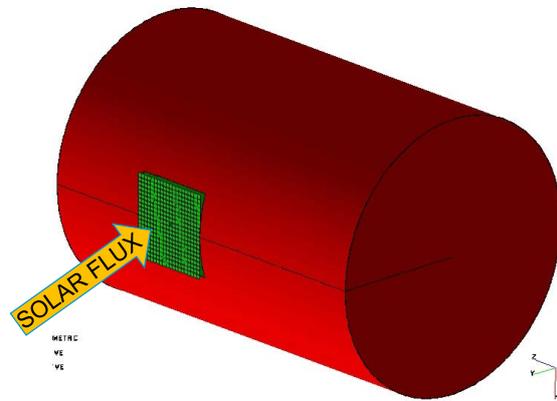


All the space you need



## Solution 2 - "Grid"

- Use a grid of variable transmissivity shells.
- This allows modelling of local hotspots
- Downside is that this method adds 100s of shells to a simulation

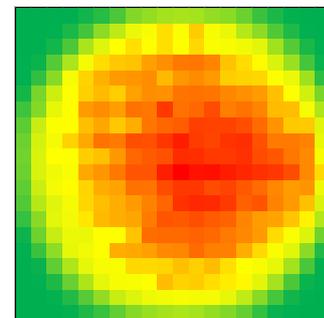


All the space you need

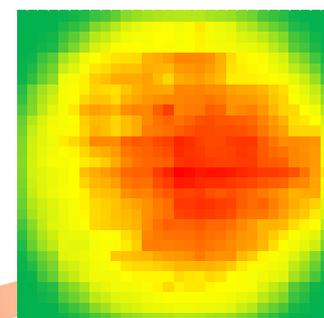


## Solution 2 – "Grid"

- Very good agreement between test data and simulated flux
- Local hotspots on the beam are accurately modelled



Measured solar flux from test



Simulated solar flux from model

All the space you need



## Results - Correlation

- The correlation results for the most important locations on the RCTs is shown in the table below. Note that the grid method was used for this correlation

Label	Test - Model temperature delta (°C)				
	TP01	TP02	TP03	TP04	TP05
TC3 - Injection head ring	-0.2	1.5	1.2	0.8	0.9
TC4 - Injection head	-0.9	-0.9	0.1	-1.3	0.8
TC6 - Valve Manifold	2.9	3.0	3.4	3.8	0.6
TC8 - Injection head ring (no IHS)	-3.1	-2.1	-1.7	-3.9	1.1
TC9 - Injection head (no IHS)	-2.7	-2.6	-0.4	-1.2	0.0
TC11 - IHS RH (near thermal strap bracket)	1.2	1.4	1.9	0.7	0.7
TC12 - Thermal Strap bracket (near IHS RH)	0.0	0.0	0.8	-0.8	0.7

- The results show a small deviation between test and model temperatures
- It also shows good agreement through different phases, which includes having the thruster at different orientations in the chamber
- This shows that the solar beam is well understood and well modelled

All the space you need



## Conclusion

- Two methods of modelling the variation of flux intensity of solar simulation beams has been presented
- The “ring” method
  - Takes into account the drop in intensity from the centre of the beam
  - Doesn't model local hotspots
  - Uses a small number of extra shells
- The “grid” method
  - Takes into account both the drop in intensity from the centre and the local hotspots
  - Uses a large number of extra shells
- Both methods increase the accuracy of solar simulation modelling and therefore improve the precision and correlation of thermal models
- The “grid” approach was used successfully in the correlation of the Bepi Colombo sun facing RCTs

All the space you need





# Appendix C

## Presentation of eTherm 1.2

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

François Brunetti  
(Dorea, France)

### Abstract

In Thales Alenia Space - Cannes, we have a long experience and expertise, in the thermal software development. Concerning this point, we work with external companies like DOREA. The subject concerns the presentation, the demonstration of a new thermal software in TAS Cannes (= e-Therm). This tool is funded entirely by Thales Alenia Space - Cannes and it should not have to be commercialised but freely distributed.

This presentation is an overview of e-Therm. Today this release includes pre-processing tools (CIGAL2 for the building of geometrical models - radiative and 2D-3D conductive ...). It includes also post-processing tools like CIGAL2 for plotting graphs or cartographies.

Then, we will talk about industrialization strategy especially based on using of our thermal software and on the integration of expert tools (2D-3D conductive module, Radiative module, Orbitography module, Solver module, Thermal model reduction tool, PTA is a tool dedicated for preliminary phases and very well adapted to the telecom program because it reuses automatically the recurrent part of spacecraft in the building of the model, friendly pre pro for telecom applications , CORAFIL , modelling / meshing) in order to improve and standardize the analysis process, in order to gain in cost and quality, for better also input/output traceability. In the soon future, we are going to integrate all the pre and post-processing modules developed initially for CORATHERM. These modules have been used on following programs : Apstar, Yamal, W6A, O3B, Iridium ...

In parallel of industrialization strategy, we develop a strategy of openness of e-Therm by distributing software free of charge to TAS-Toulouse for antenna applications and TAS-Turin for infrastructures and instruments and more generally to TAS-Group and a lot of companies.

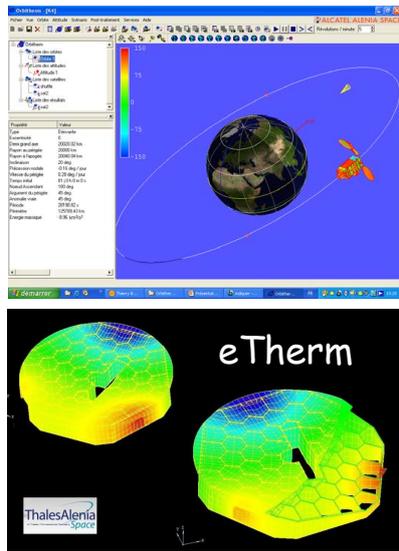
Finally, e-Therm is well interfaced with the market tools thanks to STEP-TAS : it is an exchange standard developed by ESA more or less ready for exchanging geometrical models but not ready for exchanging thermal model. It is why a direct interface has been developed between our solver and ESATAN using TMRT without no reduction process.

Moreover, it is possibly used e-Therm for concurrent design facilities, for thermal simulator for operation and customers, and planned to extend e-Therm to other fields in physics : using in the electronic board calculation, using for simulating ESD on geostationary satellite, based on plasma / satellite interaction modelling ...

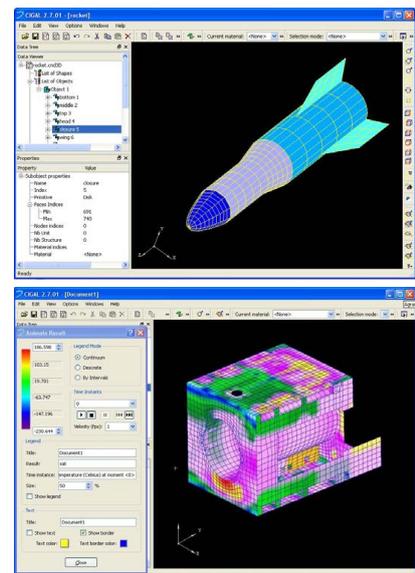


## 26<sup>th</sup> ESA workshop on Thermal Analysis

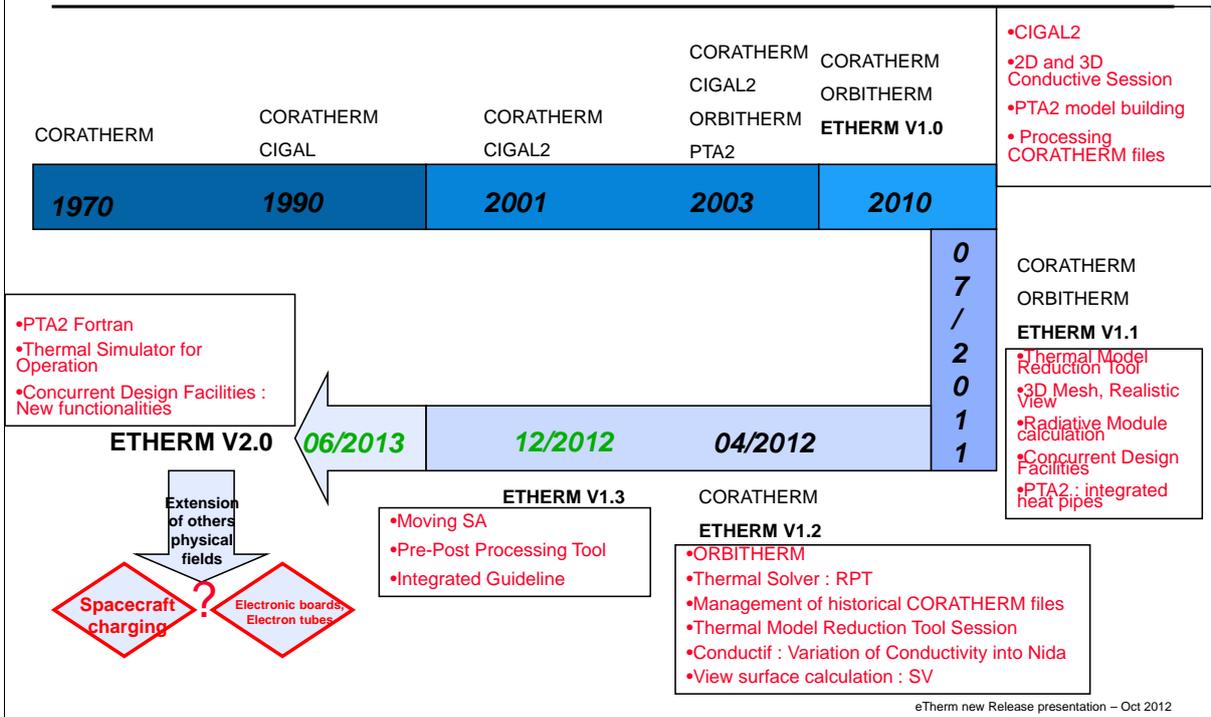
### Presentation of eTherm1.2



**THALES ALENIA SPACE  
CANNES**  
T. BASSET, P. CONNIL  
F. BRUNETTI (DOREA),  
JP. DUDON



## ETHERM : HISTORY, STRATEGY AND CONVERGENCE



eTherm new Release presentation – Oct 2012

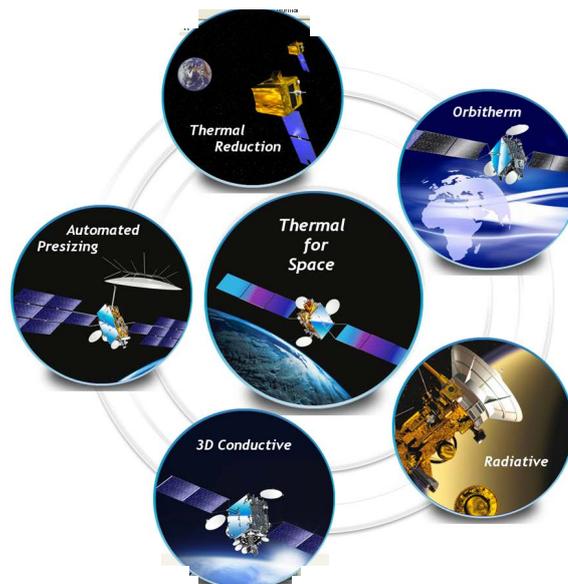
## eTherm v1.2 : 3 tools in 1

- Thermal for Space
- Dynamic Simulator for Space
- Concurrent design facilities



eTherm new Release presentation – Oct 2012

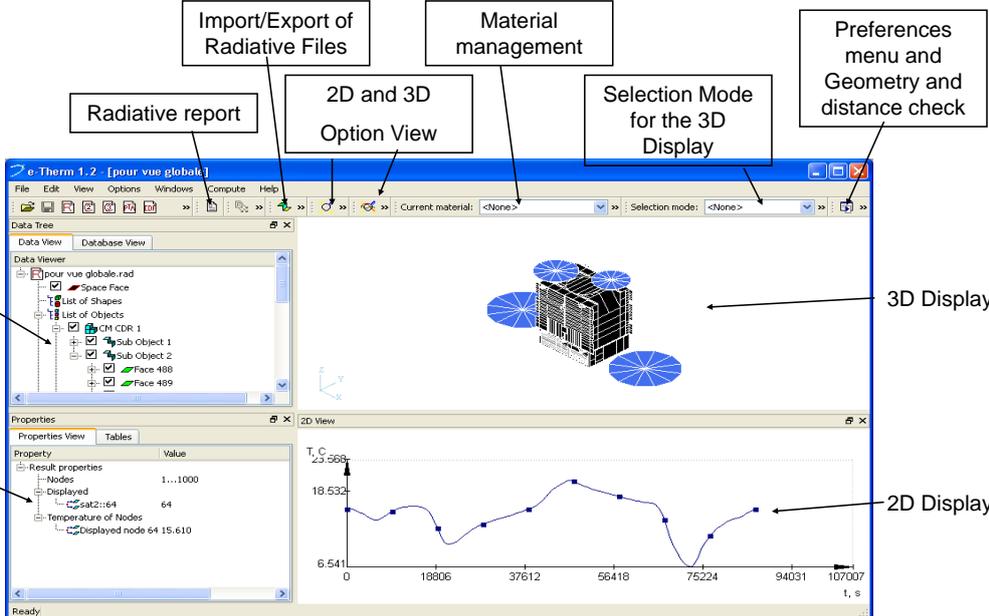
## « Thermal for Space » tool is composed of 5 modules



resentation – Oct 2012



## Radiative Session – GUI & Data Viewing



Import/Export of Radiative Files

Material management

Preferences menu and Geometry and distance check

Radiative report

2D and 3D Option View

Selection Mode for the 3D Display

Description of the architectural model

Description of the properties of the selected items

3D Display

2D Display

eTherm new Release presentation – Oct 2012

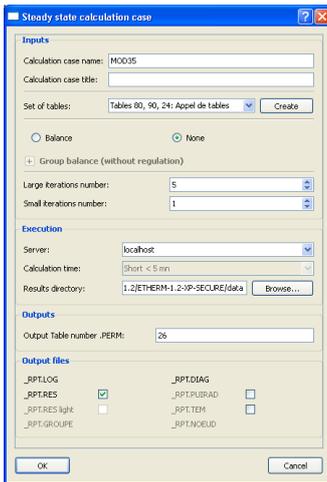


## Radiative Session - Database access

Launching of Calculation Case

Description of the database model (DAF)

Description of the properties of the selected items



Steady-State Calculation Case

Result File

eTherm new Release presentation – Oct 2012



## 2D Conductive Session – GUI & Data Viewing

---

**Import/Export of Conductive Files**

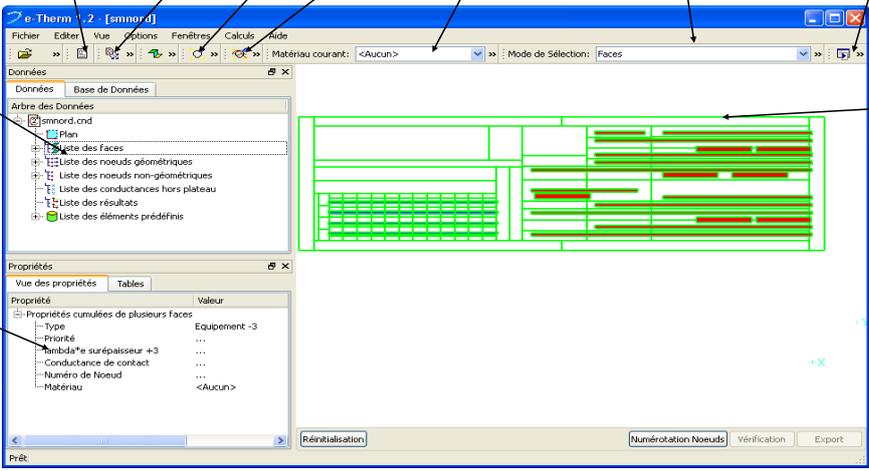
**Material management**

**Preferences menu and Geometry and distance check**

**Conductive report**

**2D and 3D Option View**

**Selection Mode for the 3D Display**



**2D Display**

Description of the architectural model

Description of the properties of the selected items

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## 3D Conductive Session - Data Viewing

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**Import/Export of Conductive Files**

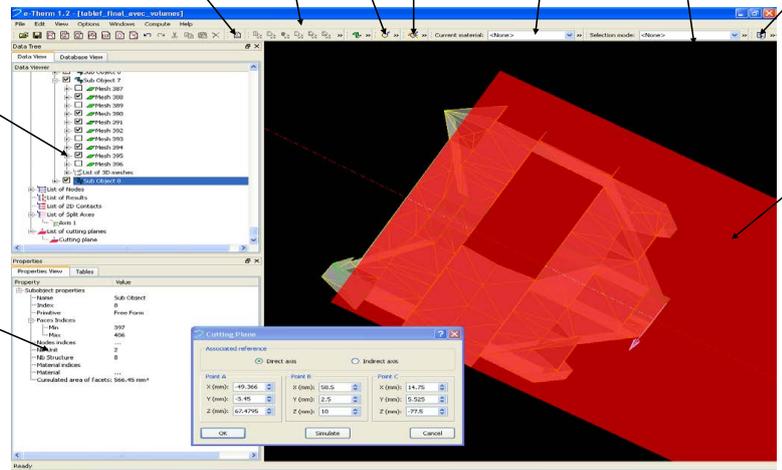
**Material handling**

**Preferences menu and Distance check**

**Conductive model report**

**2D and 3D Option View**

**Selection Mode for the 3D Display**



**3D Display**

Description of the architectural model

Description of the properties of the selected items

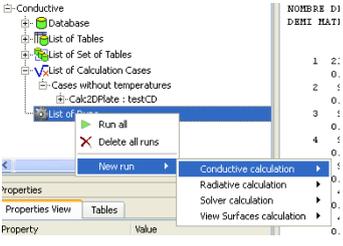
eTherm new Release presentation – Oct 2012



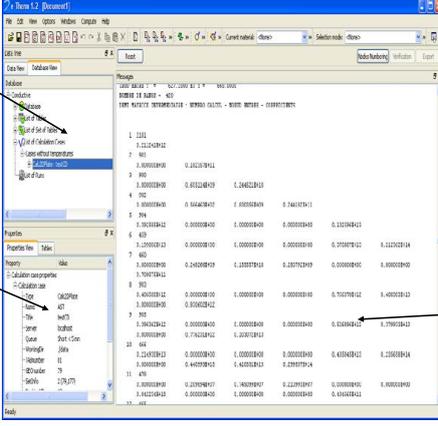
### Conductive Session - Database access

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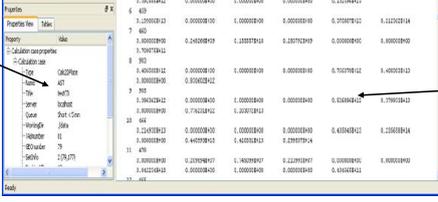
**Launching of Calculation Case**



**Description of the database model (DAF)**



**Description of the properties of the selected items**



**2D panels calculation case**

Inputs

Calculation case name: AST

Calculation case title: testCD

Set of tables: Tables 79, 177: My Set for PLAZD Create

Meshing on X: (mm) 10 on Y: (mm) 10

Meshing on Z: 2

Execution

Server: localhost

Calculation time: Short < 5 min

Results directory: I-2\ETHERM-1.2-XP-SECURE\data Browse...

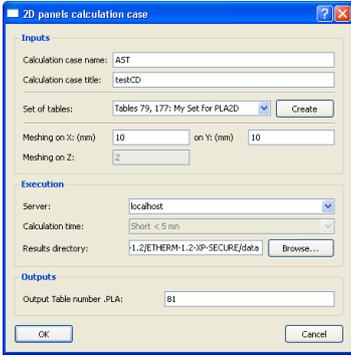
Outputs

Output Table number .PLA: 81

OK Cancel

**Conductive Calculation Case**

**Result File**



eTherm new Release presentation – Oct 2012



### Orbitography Session - Data View

---

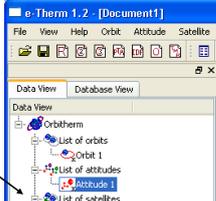
**Import Orbit, Attitude, satellite result Files**

**Print and Snapshot view**

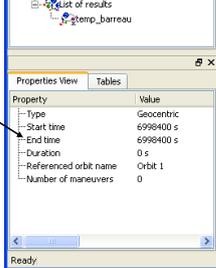
**Graphical action for the 3D Display**

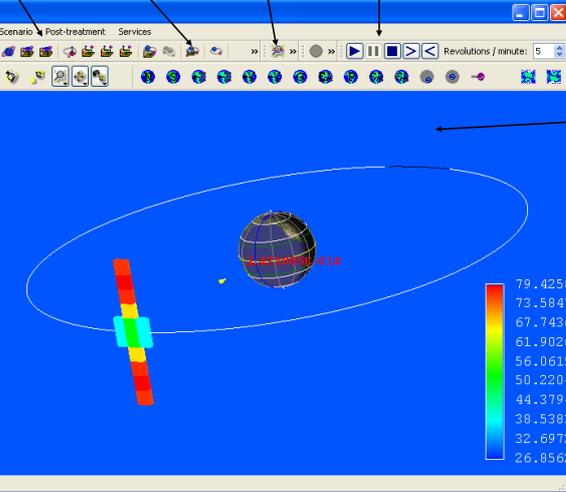
**Animation menu**

**Description of the architectural model**



**Description of the properties of the selected items**





**3D Display**

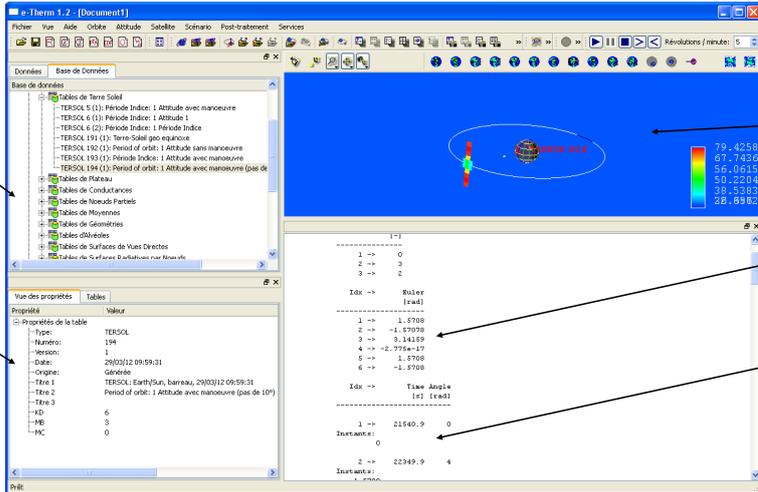
eTherm new Release presentation – Oct 2012



## Orbitography Session - Database View

Description of the DAF

Description of the TERSOL Table Structure



3D Display

Definition of the Orbit

Definition of the Maneuver

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## PTA Session and Application

**Goals and Interests**

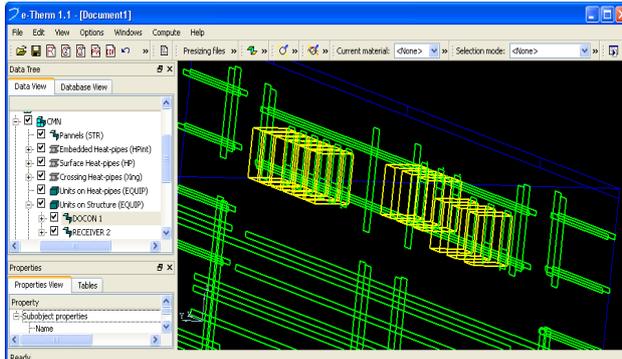
- To Generate a complete SPACEBUS S/C Model including
  - Generic P/F Parts issued from Data Base
  - Specific P/L Part created from CAD Data direct processing (North/South Panels)
- To Generate Preliminary conductive meshing of North/South Panels
- To include quickly and automatically a great number of each Unit or Heat Pipe reference with their specific thermal modeling
  - Data Base Management
- To Generate automatic numbering with complete consistency of
  - Radiative And Conductive Geometries and Associated Couplings
  - Inertia
  - Dissipation
- To propose an ergonomic and visual Graphical User Interface

**Outlooks**

- TMM delivery to be reduced to 3-4 weeks
  - User Guide and Support
  - P/L Units/Heat Pipes DataBase Completion and Management
- ATHENA-FIDUS
  - Generic P/F TMM update in progress
  - Specific P/L Units DataBase in progress

**Applications to CDR Model Building**

- AP7A (eTHERM V1.0)
  - 1<sup>st</sup> application on Telecom Program
  - Finalization/Validation of the Tool on full scale TMM
  - TMM delivered in 8 weeks
  - S/C TMM Correlation under nominal progress
- YAMAL 402 (eTHERM V1.1)
  - 1<sup>st</sup> application on Telecom Program for Embedded Heat Pipes Panels
  - Finalization/Validation of the Tool on full scale TMM
  - TMM delivered in 10 weeks
- EUT W6A (eTHERM V1.1)
  - TMM delivered in 6 weeks



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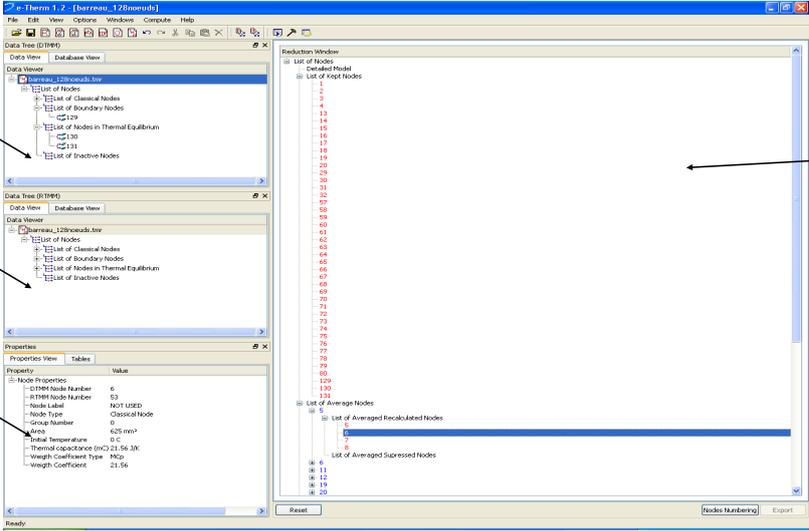
## Reduction Model Session - Data View

---

Description of the nodal detailed model

Description of the nodal reduced model

Description of the properties of the selected items



Definition of the reduction process

eTherm new Release presentation – Oct 2012



# TMRT

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- ❑ **Goals and Interest**
  - **To go from a Detailed TMM to a Reduced TMM**
    - Automatic Management of all the Exchanges and Power
    - Keeping the consistency of the thermophysics behavior
  - **To Enable iterative process to match to the Specified compromise**
    - Decreasing number of nodes and Exchanges
    - Keeping acceptable precision
  - **To work on both CORATHERM/ESATAN DTMM Formats**
    - Enable to convert TMM ESATAN <-> CORATHERM
- ❑ **Process**
  - **Principle :**
    - Use of the PLATEAU-EQUIVALE Method for Conductive exchanges and Capacitances (TAS-F Heritage)
    - Arithmetic Sum of Radiative Exchanges and Power
  - **Different Types of nodes**
    - Kept nodes : RTMM nodes
    - Re-Computed nodes : taken into account in the reduction and enabling to have complete Temperature Cartography by post-Process (initial TMM Cartography)
    - Eliminated nodes : taken into account in the reduction, but no possibility to retrieve Temperature after RTMM Process
  - **The gathering of the nodes are given in a Reduction Matrix**
    - Experience and Know-how to reach good compromise
- ❑ **Applications to S/C Model for Launcher Interface (from CDR Model)**
  - **AP7A : RTMM delivered in 9 weeks**
  - **YAMAL 402 : RTMM delivered in 10 weeks**
  - **EUT W6A: RTMM delivered in 6 weeks, Reduction from 3000 to 375 nodes, Precision : less than 2°C on Units, near 0°C mean discrepancy on the whole TMM**
  - **ATHENA-FIDUS : S/C Model for Launcher Interface : RTMM delivered in 4 weeks**
  - **O3B : Thermal Model for Operation Simulator : RTMM delivered in 3 weeks**

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□ Applications to S/C Model for Launcher Interface (from CDR Model) : W6A

node	descro	groupe	groupe name	mcp	nœuds calculés K/GR/GNR
					num. max: 400
286	SM/PCU_CONNECTOR	8 SMN Units		3.32E+03	246
287	SM/PCU_SUNLIGHT	8 SMN Units		9.69E+03	246
288	SM/PCU_CAPA	8 SMN Units		3.32E+03	246
289	SM/PCU_TMTC	8 SMN Units		3.70E+03	246
290	SM/PCU_BCR1_1	8 SMN Units		1.94E+03	246
291	SM/PCU_BDR1	8 SMN Units		4.27E+03	246
292	SM/PCU_BDR2	8 SMN Units		4.18E+03	246
293	SM/PCU_BDR3	8 SMN Units		4.18E+03	246
294	SM/PCU_BDR4	8 SMN Units		4.27E+03	246
295	SM/PCU_BCR1_2	8 SMN Units		1.94E+03	246
296	SM/GYRO+Z	9 SMS Units		3.38E+03	250
297	SM/GYRO-Z	9 SMS Units		3.38E+03	251
298	SM/SMU_2	9 SMS Units		2.00E+00	82
299	SM/PFDIU	9 SMS Units		1.73E+04	247
300	SM/SMU_1	9 SMS Units		2.00E+03	248
301	SM/RW -X-Z	10 RW		7.60E+03	249
302	SM/RW -X+Z	10 RW		7.60E+03	249
303	SM/RW +X-Z	10 RW		7.60E+03	249
304	SM/RW +X+Z	10 RW		7.60E+03	249

Group	Designation	Node	Localisation	N RTMM	T RTMM	T DTMM	DT
SM UNITS	PCU	246	INTERNAL	246	16.0	14.7	-1.3
	PFDIU	247	INTERNAL	247	23.4	24.9	1.5
	SMU	248	INTERNAL	248	22.9	23.1	0.2
	RW	249	INTERNAL	249	17.5	19.7	2.2
	GYRO+Z	250	INTERNAL	250	21.1	22.1	1.0
	GYRO-Z	251	INTERNAL	251	21.6	23.8	2.2

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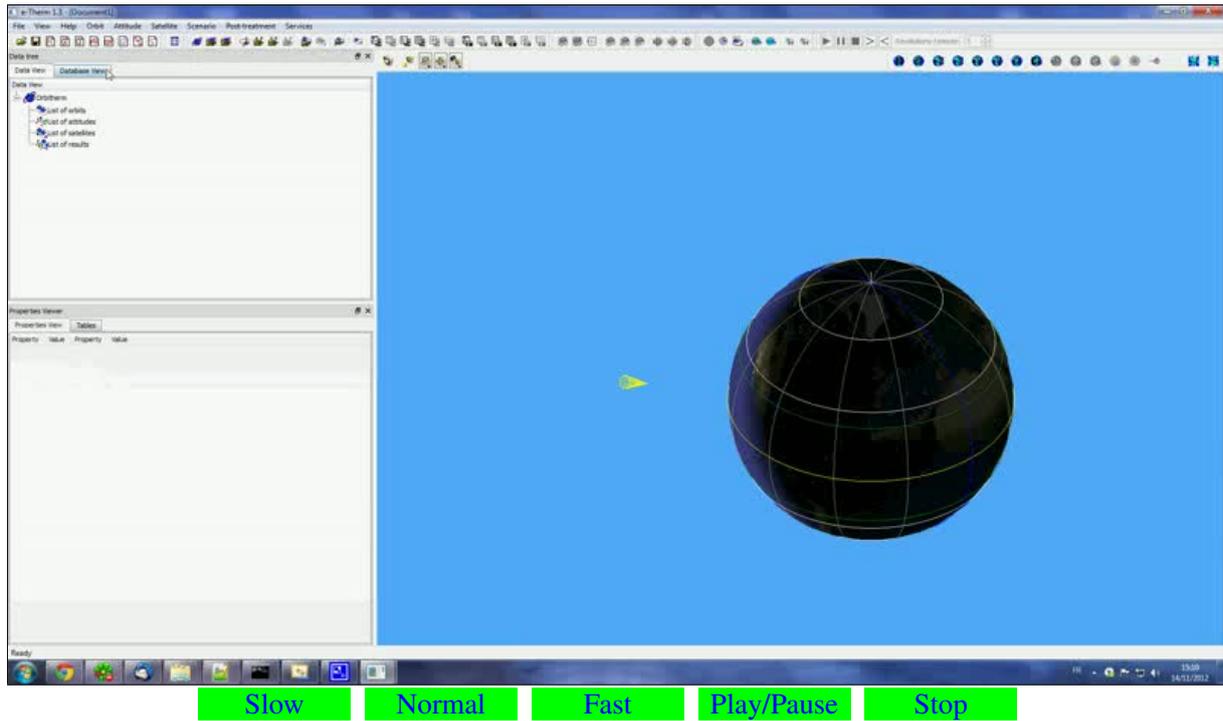
◆ eTherm 1.2 :

- Release available until September and it is a **FREE** software
- Availability :
  - ➔ Download from the website of DOREA
  - ➔ Supply install DVDROM
- Operative mode :
  - ➔ Launch the Setup (Windows XP with 3D graphical card – GeForce6600GT)
  - ➔ Supply the ethernet card number to [Thierry.basset@thalesaleniaspace.com](mailto:Thierry.basset@thalesaleniaspace.com)
  - ➔ Rename the file license in "license" and put this file in \\eTherm-1.2-XP\AlcateIResources directory

◆ Documentations

- User Manual
- EID : External Interface Document
- Guideline : training module, SVVP, Technical note

eTherm new Release presentation – Oct 2012





## Appendix D

### Advances in AblTan Ablative Tool development with application to system model analysis

Marco Giardino      Elena Campagnoli  
(Politecnico di Torino, Italy)

Lorenzo Andrioli      Massimo Bertone  
(Thales Alenia Space, Italy)

Gianni Pippia  
(SSE, Italy)

### **Abstract**

AblatTan is the ablative shield analysis tool, developed by ThalesAlenia Space — Italy and Politecnico di Torino, fully compatible with the ESATAN-TMS suite. The tool is currently undergoing first real application on system level analysis to assess the expected advantages of integrated approach analysis versus segregated/iterative method, for which ablative tool and system model TMM are run in a standalone fashion.

First results and discussion are presented together with the tool current development status.



## AblatAN Tool and Automatic Model Coupling

Marco Giardino (Politecnico di Torino, Italy)  
Elena Campagnoli (Politecnico di Torino, Italy)  
Lorenzo Andrioli (ThalesAlenia Space, Italy)  
Massimo Bertone (ThalesAlenia Space, Italy)  
Gianni Pippia (SSE, Italy)

26th European Workshop on Thermal and ECLS Software – ESTEC, 20-21 November 2012

## Index



- AblatAN tool
  - History and principles
  - Versions
  - IXV Program
  - P50 tile test: case and results – stand alone
  - P50 tile test: case and results – IXV TMM vehicle integrated
- Automatic Model Coupler
  - Problem definition
  - Implementation
  - Simple test case
- Conclusions & Future works

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## AblatTan history and principles



- Development started in 2011
- Simplified state of the art charring ablative material model directly in ESATAN
- Stand alone or system scale integrated simulations capability
- User friendly and reusable
- Minimize input parameters deck
- Options available for physics setting

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## AblatTan versions



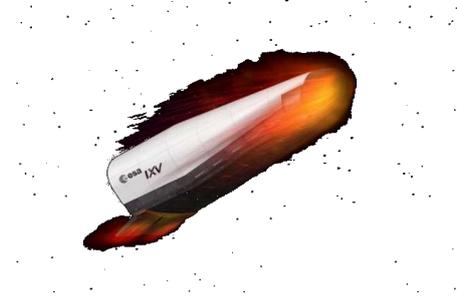
- 1.0.0 2011-11-08, base version, Apollo and EXOMARS simulations (presented at 25<sup>th</sup> European Workshop on Thermal and ECLS Software);
- 1.1.0 2012-05-09, new evaluation of pyrolysis heat sink term, quadratic evaluation of the all enthalpy values;
- 1.2.0 2012-06-12, bug fixed the corrective terms related to grid motion due to surface recession;
- 1.2.1 2012-06-15, added simplified geometry specification for radial geometries, TACOT test (<http://ablation2012.engineering.uky.edu/>); results anticipated at 6th European Ablation Working Group (June 2012); presented 42nd ICES, 15-19 July 2012;
- 1.2.2 2012-10-23, bug fix of a error in mass conservation evaluation for multi component material during surface recession;
- 1.2.3 2012-10-26, bug fix of the heat sink term related to material degradation;
- 1.2.4 2012-10-30, updated output format, time dependent external flow type (laminar or turbulent), updated the routine that read the input data to process more generic files;
- 1.2.5 2012-11-06, the tool now automatically check the solver type, and then set the correct properties update procedure, integrated IXV simulation;
- 1.3.0 expected for 2012-12, compatibility with the Automatic Model coupler Tool;
- 1.4.0 expected for 2013-04, thermochemical recession through thermochemical tables;

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## IXV Program



- Intermediate eXperimental Vehicle (IXV): autonomous European lifting and aerodynamically controlled re-entry system
- Design, development, manufacturing, and in-flight verification of thermal protection system (TPS) solutions among the mission objectives
- Amorim cork-based material P50 (provided by Avio) selected as IXV ablative TPS for its suitability for low aerothermal heat fluxes ( $<200 \text{ kW/m}^2$ )
- P50 composition: cork granulate + phenolic binder, enhancing ablation behavior (controlled endothermic decomposition kinetics), thermal insulating properties, mechanical elasticity

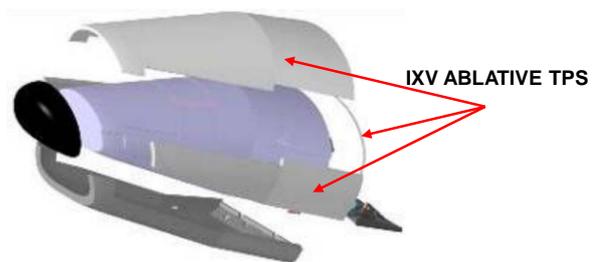


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## P50 stand alone test - input

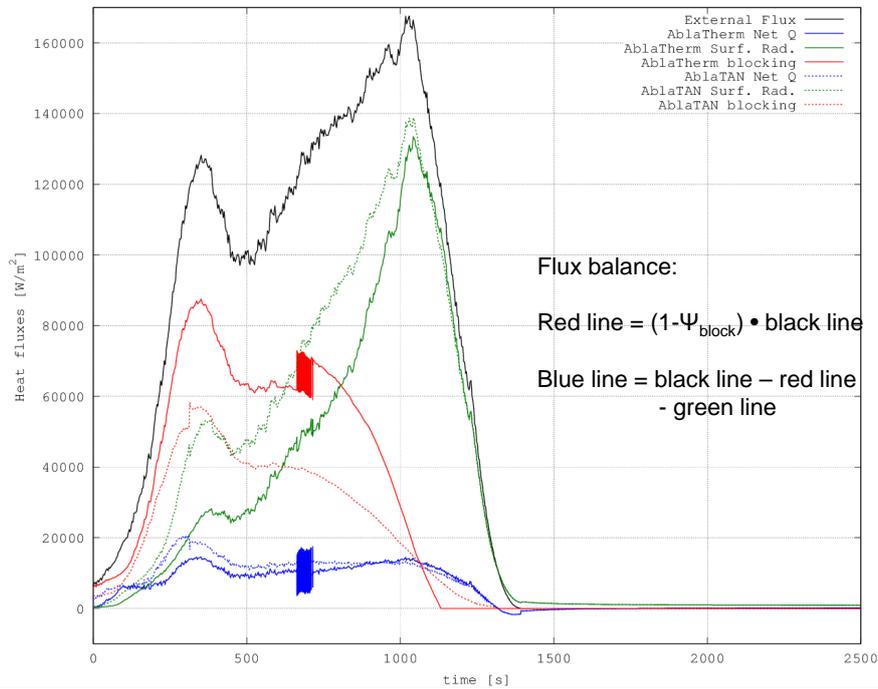


- Max IXV heat load trajectory
- Most stressed point of the surface
- Shield material: P50
- Shield thickness: 22 mm
- Back structure: 2 mm Al
- Adiabatic Internal surface
- Results compared with AblTherm tool (in-house software already validated through CMA / SAMCEF Amaryllis test cases)



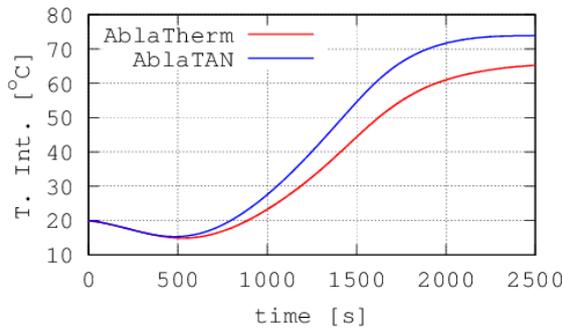
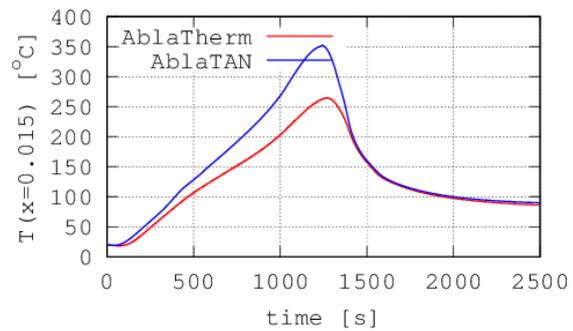
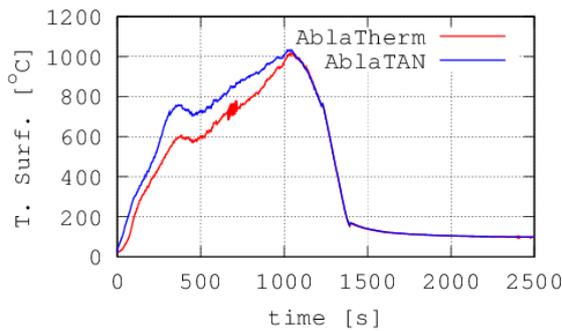
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## P50 stand alone test– heat fluxes



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## P50 stand alone test– Temperatures

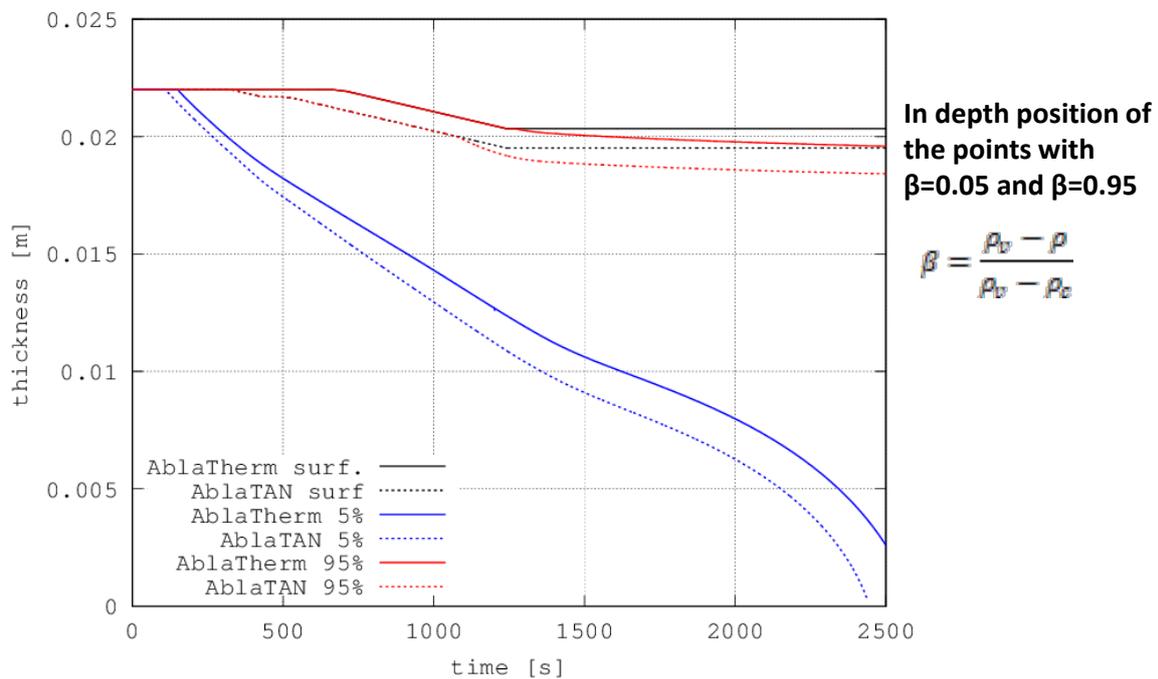


Code to code comparison,  
AblatTAN-AblatTherm:

- Max  $\Delta T_{\text{surf}}$  = 183 °C @ t = 312 s
- Max  $\Delta T_{\text{depth}}$  = 90 °C @ t = 1205 s
- Max  $\Delta T_{\text{int}}$  = 11.26 °C @ t = 1744.5 s

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## P50 stand alone test Degradation & recession



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## P50 stand alone test Results comparison



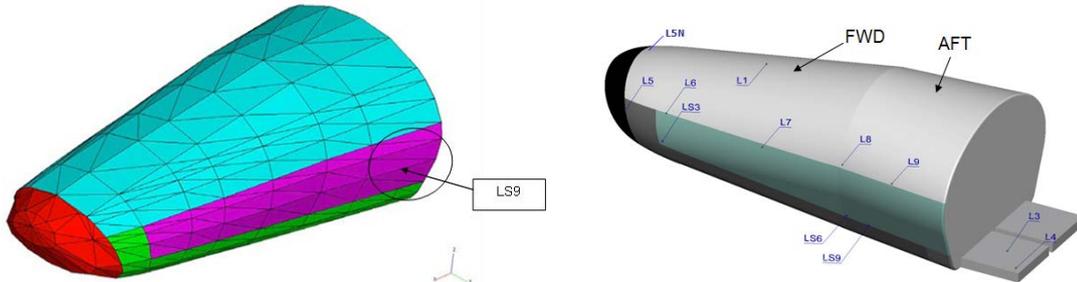
- Different surface temperatures due to wall enthalpy evaluation methods used in the blocking models
- AblatAN results (which relies on ESATAN solvers) show a higher stability (no oscillations in the results and a larger time step) and forecasts a deeper pyrolysis depth
- AblatAN provides higher temperature (caused by the lower blocking effect)
- Temperature differences at the end of the trajectory, structure to ablative interface : 8.6 °C

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## P50 IXV integrated test



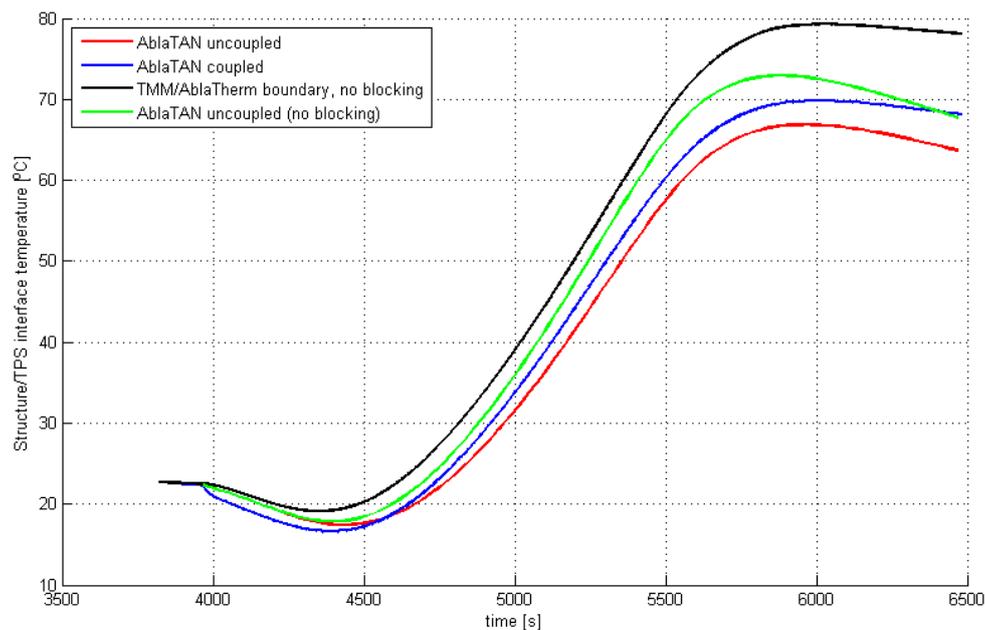
- P50 model integrated with IXV system TMM



- Only one tile simulated (at same stand alone test location) to:
  - Evaluate models integration response
  - Compare results coupled/uncoupled models to check possible mass/temperature savings
  - Preliminary computational cost evaluation

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## P50 IXV integrated test - Results



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## P50 IXV integrated test - Comments



- TMM/AblaTherm analysis performed with 2 iterations only (high computation / data management cost) is conservative
- TMM/AblaTherm analysis requires further iterations to full convergence
- TMM/AblaTAN coupled analysis has about 10 °C difference mainly due to coupling effects
- With only 1 tile no appreciable differences in run time between TMM and TMM + AblatAN

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## Automatic Model Coupler



### Problem:

- AblatAN is 1D tool
- TPS architecture uses different materials in different zones
- Need to model lateral contact zones with other materials
- 1D assumption not sufficient (different material properties and transverse temperature gradients)

### Solution → Automatic Model Coupler (AMC) tool

- AMC generates transverse thermal networks among a set of models
- AMC updates networks, accounting for geometry change (ablative surface recession) and properties variation (thermal conductivity)

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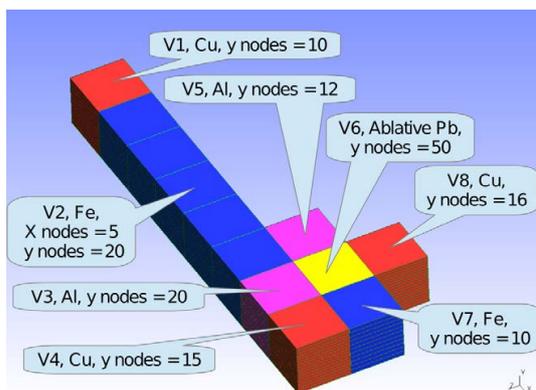
## Model coupler: implementation



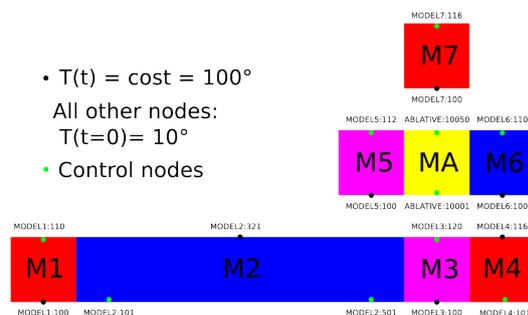
- All possible GLs between two sides' nodes generated via script (Matlab, bash shell script)
- GLs are activated/deactivated at runtime using the STATST subroutine
- Models ad hoc hierarchy is set to allow GL update, i.e.
  - Top model manages GLs update
  - Sub-models uses the target GLs
- Up to 4 couplings can be assigned each set of nodes

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## Simple coupling test case



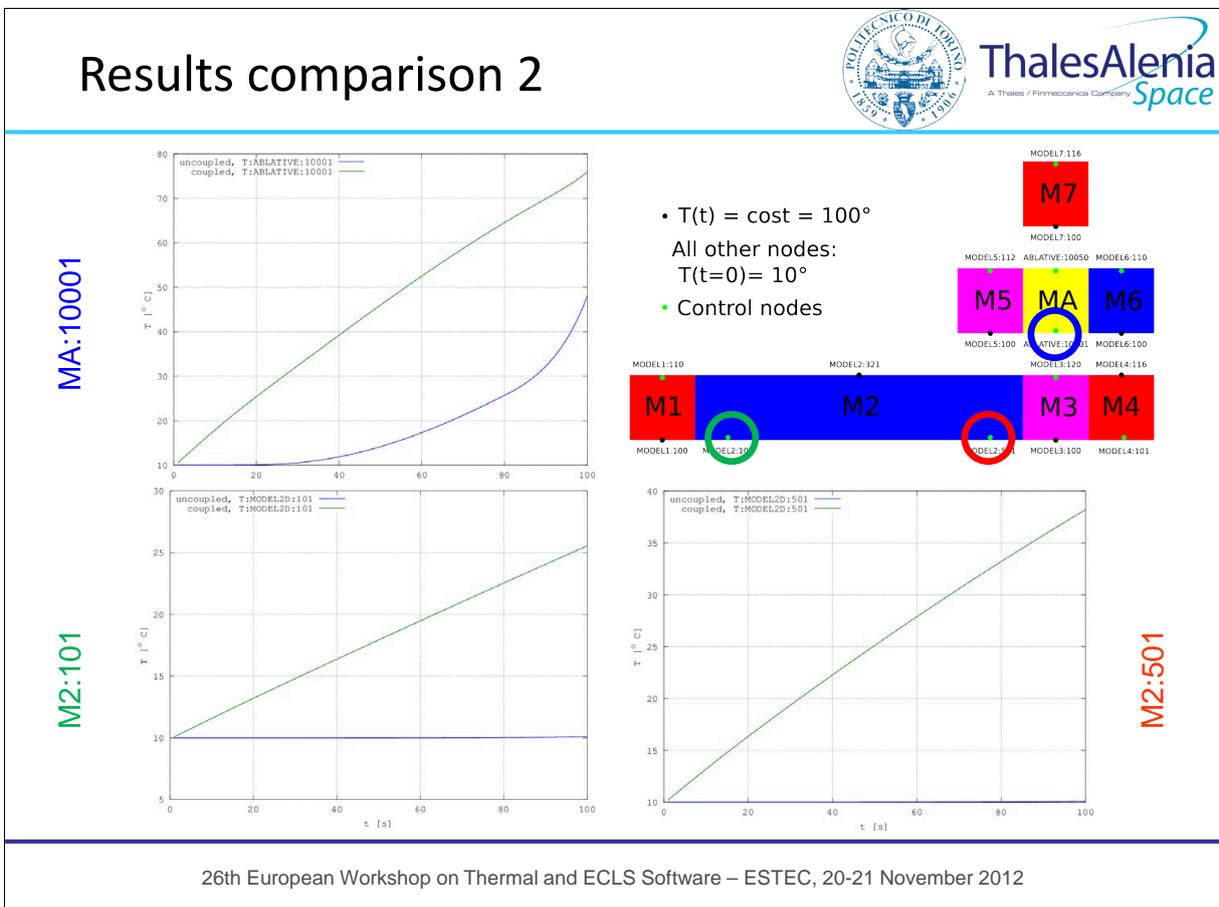
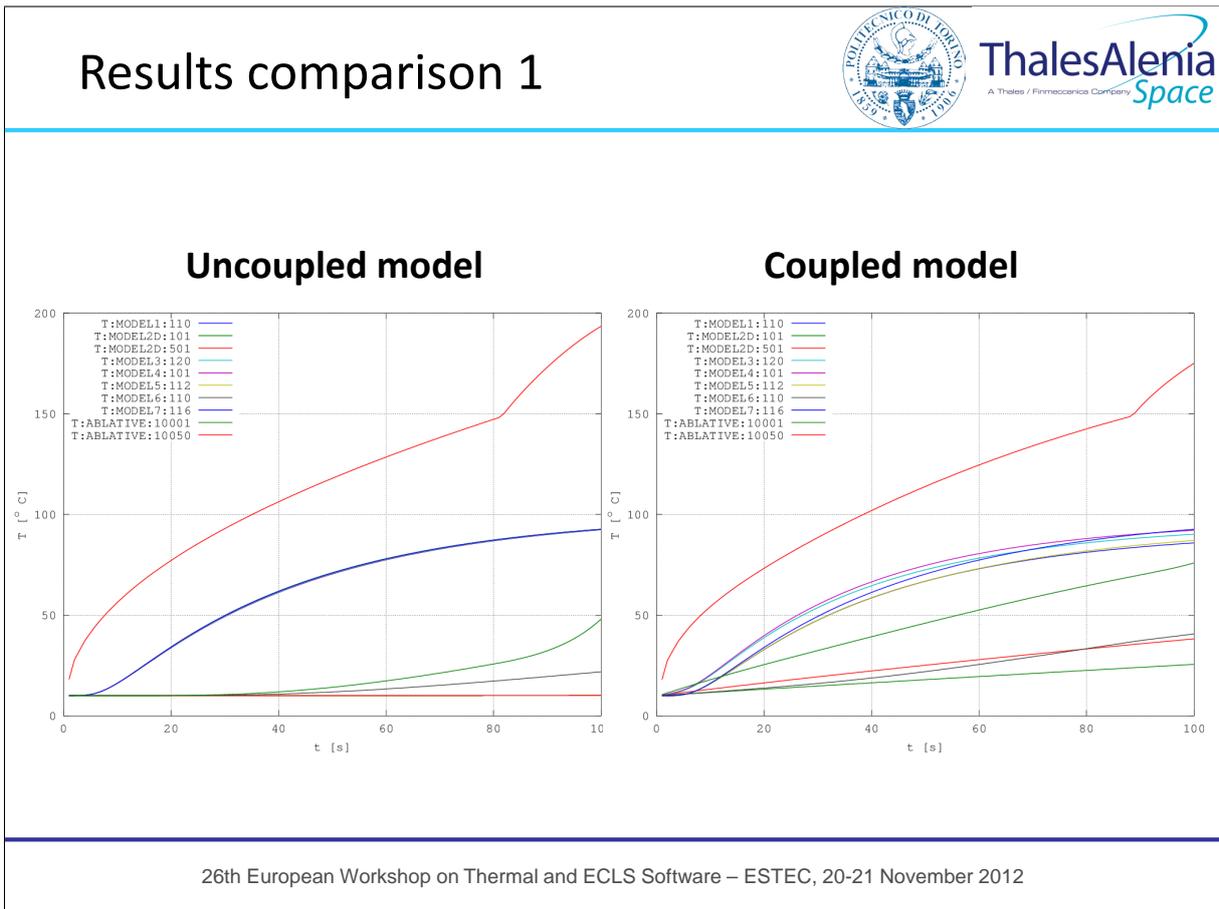
- $T(t) = \text{cost} = 100^\circ$
- All other nodes:  $T(t=0) = 10^\circ$
- Control nodes

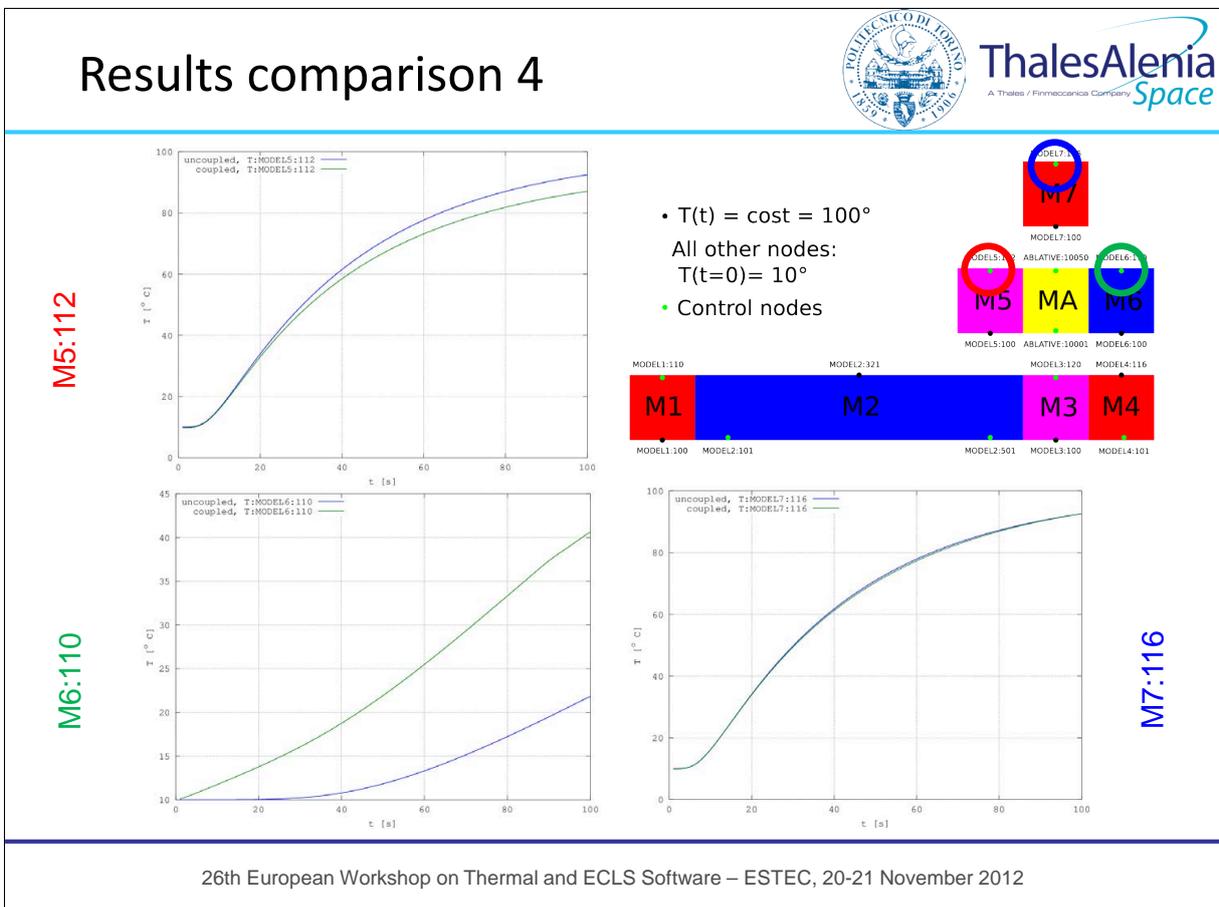
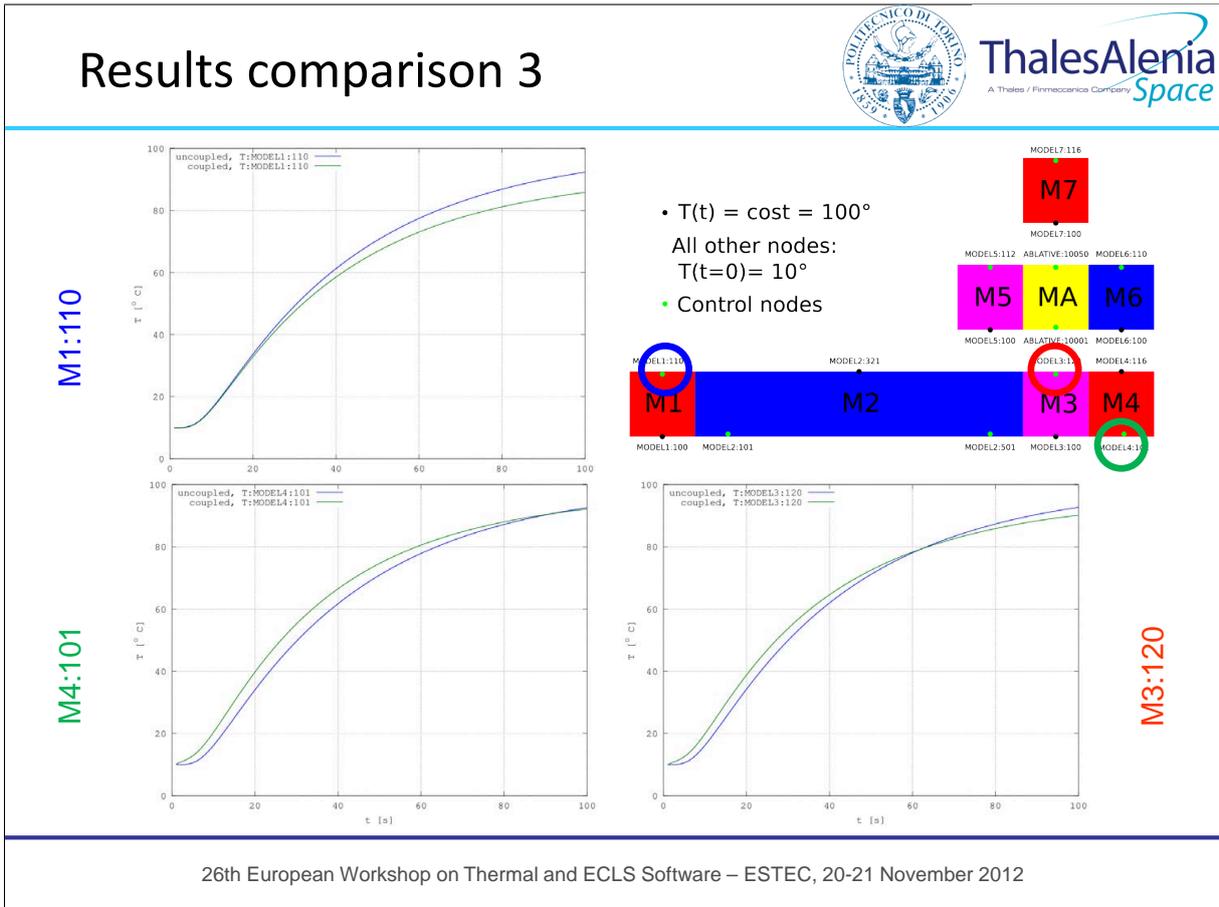


Blocks sections with boundary nodes and control nodes.

- Materials coupled: iron, aluminum, copper, lead (ablative behavior forced). 1D (M1, M3, M5, M6 and MA) and 2D (M2) models are used
- Black nodes are boundary nodes (fixed temperature). On the node ABLATIVE:10050 a fixed external heat flux is applied ( $100 \text{ kW/m}^2$ )
- Test geometry developed in order to check all the abilities of the tool

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## Conclusions & Future works



- Needs for transverse conduction implementation confirmed by first test cases
- Integration with AblTAN tool on going
- Future activities:
  - Complete IXV test run with full set of tiles implemented
  - Develop the thermo-chemical recession through thermo-chemical tables
  - Complete V&V with other FEM tools (i.e., MSC MARC)

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ANY QUESTIONS?

THANKS FOR YOUR ATTENTION.

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# Appendix E

## A Thermal Analysis Pre-processor

Laurent Bauer  
(Astrium Space Transportation, France)

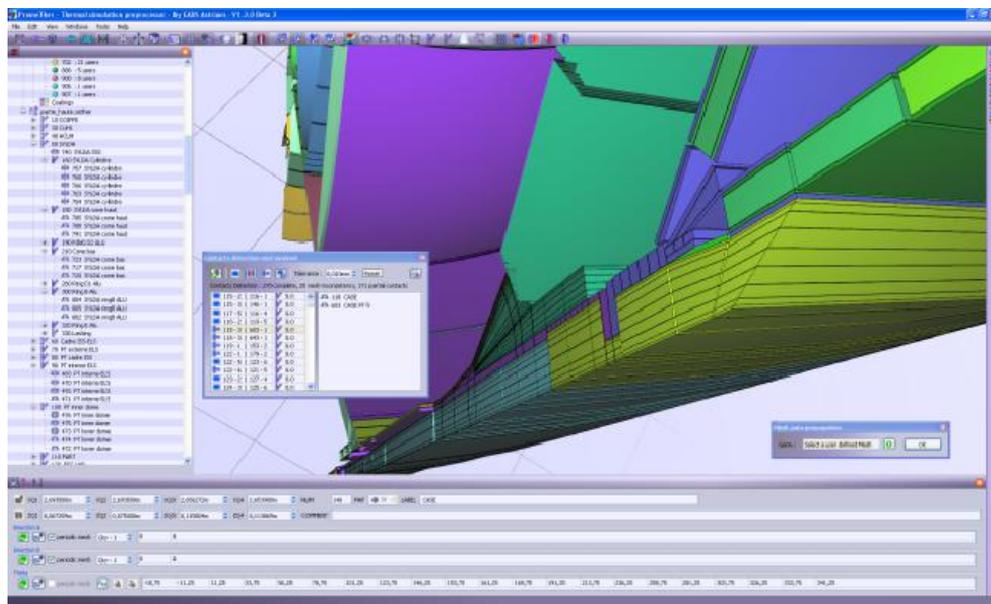
## Abstract

Promether is a thermal analysis pre-processor.

Its basic function is to create, from a 3D solid representation, the thermal models (conductive and radiative) that will be sent to the thermal solvers.

Promether has an internal contact recognition engine that allows an automated creation of the conductive couplings. The engine also supports extraction of surface models (cavities) to prepare the radiative model. By using Promether, both conductive and radiative models derive from a same and unique reference, ensuring consistency. The nodal model can be written in different file formats, enabling compatibility with different solvers.

Promether is a white-box software, thermal analysts oriented: the 3D graphical user interface continuously helps engineers to "see inside" their models. Using 3D metaphors to represent information (material, coatings ...), the visual feedback helps the users and increase models confidence and reliability. Numerous quality checks are also continuously performed in background.



## Promether

### A Thermal Analysis Pre-processor

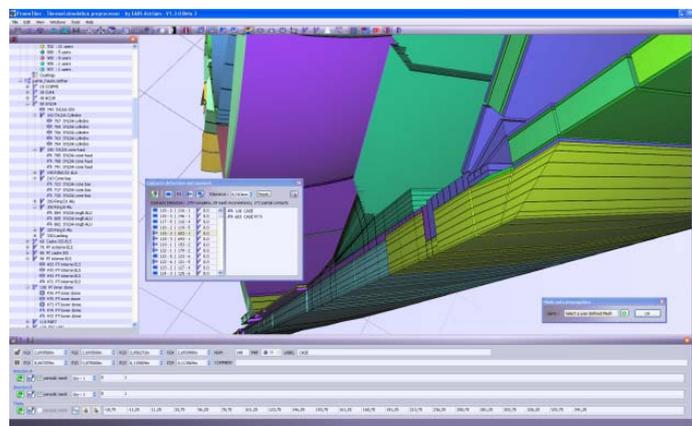
Laurent Bauer, Astrium Space Transportation

laurent.bauer//at//astrium.eads.net

**26th annual European Workshop on Thermal and ECLS Software**

**20 and 21 November 2012**

**ESTEC, Noordwijk, the Netherlands**



### Abstract

Promether is a thermal analysis pre-processor in charge of creating a conductive model and entries for radiative simulation. Both models are derived from one unique 3D volume model, thus ensuring consistency.

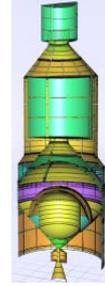
An internal contact recognition engine widely automates the creation of the conductive couplings. The engine also supports extraction of surface models (cavities) to prepare the radiative model. The nodal model can be written in different file formats, enabling compatibility with different solvers: Promether is solver-agnostic.

The application is thermal analysts oriented: the 3D graphical user interface continuously helps engineers to “see inside” their models. Using 3D metaphors to represent information (material, coatings...), the visual feedbacks helps the users and increase models confidence and reliability. Numerous quality checks are also continuously performed in background.

This software has been developed by Astrium Space Transportation in the frame of a self-funded improvement project, with a particular attention brought to Ariane 5 Middle Life Evolution studies. It is the result of a tight cooperation between the Methods & Tools department with the Thermal Engineering department.

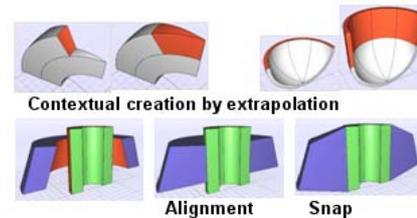
## Visualization and interaction

Promether is built upon an interactive 3D visualization engine supporting large assemblies. It seamlessly supports models with over 50 000 nodes on a standard desktop PC.



## Geometry construction

Promether has a volume modeller. It handles simple primitives like cone, sphere, cylinder or cube. Geometries are assembled in a tree. Many functions help the user to quickly define the geometry using contextual creation, extrapolation, aligning or snapping.



## Promether core: the contact engine

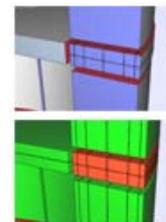
Promether's originality comes from an internal component called "contact engine". This invisible component continuously provides adjacency properties between faces and edges. Contacts will be used for many purposes. The geometric model quality can first be inspected by displaying neighbor geometries. Mesh subdivisions can be propagated to neighbors. A model of external surfaces can be extracted. Interface conductive couplings are also automatically identified.

Contacts might be planar, cylindrical, conical or spherical. The recognition engine handles positions, orientations and mesh definition. Identified contacts might be complete, partial or complete with different meshes.

## Mesh definition and propagation

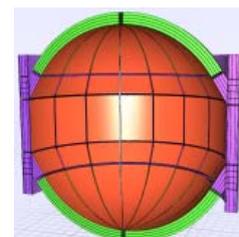
The volume model is refined using meshing functions defined by arithmetic, geometric or symmetric ratio. Once defined, a mesh can be propagated to neighbour geometries through faces in contact. This propagation is applied in all possible directions and recursively repeated.

Modifications of geometry and mesh are interactively updated providing constant visual feedback to the user.



## Cavities extraction: the surface model

A surface model is extracted from the volume model. A "seed algorithm" starts from an external face, and searches adjacent external faces. This leads to the extraction of topologically closed set of faces for well-formed models (complete contacts). For singular cases, cavities can also be user-defined. In both cases, quality controls run in background and signal broken rules like missing thermo-optical properties or forgotten cavities (external faces that not yet belong to any cavity).

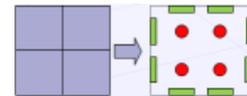


Together with thermo-optical properties, the surface model is exported to feed a radiative simulation.

## Conductive model creation

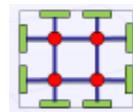
The conductive nodal model is directly computed from the volume model. It is composed of capacitive nodes and conductive couplings.

The nodes capacity, form factors – geometrical contribution to the conductance –, volumes and center of gravity are computed for each subdivision of the geometry. Additionally, arithmetic nodes with area and center of gravity are computed for each external facet.



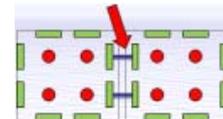
Conductive couplings are automatically generated between nodes that belong to the same geometry:

capacitive - capacitive and capacitive-arithmetic.

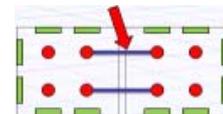


Interface couplings

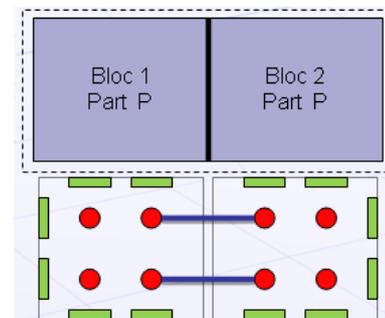
Once an interface resistivity is defined on a contact face, interface couplings are automatically computed between fronting facets.



If a zero resistivity is applied, couplings are generated between fronting capacitive nodes. Corresponding arithmetic nodes are removed.



In addition, coupling generation takes into account a part concept. A part is an assembly of geometric primitives. It must be considered as a real life part: a homogeneous bloc of matter. For part internal interfaces, Promether directly chooses capacitive-capacitive couplings and removes arithmetic nodes.



To sum up, user's task is reduced to interface resistivity definition. The rest of the geometry-based conductive model is computed automatically.

## Modifications and updates

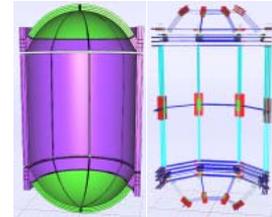
The nodal model is continuously updated and available whenever needed.

Since both radiative and conductive models derive from the same reference, modifications that preserve the model definition will update both radiative and conductive model and ensure consistency. This might be especially important for nodes numbering consistency.

## The Thermal Mathematical Model

The thermal mathematical model is described in memory. Writing this information in a specific format is a simple implementation task. It makes this pre-processor potentially compatible with any kind of thermal solver. Promether is solver-agnostic.

The thermal mathematical model is continuously updated and can be 3D visualized at any time. This increases the confidence in the software and obviously the models reliability.



## A user oriented and thermal analyst oriented software

The software is developed according to modern software standards. A special attention was paid on user ergonomics and interaction design:

- 100% Undo-redo capabilities
- Interactive visualization
- Real time updates
- Continuous quality checks
- Visual feedbacks: colorizing by material, thermo-optical properties, red lights for broken quality rules...

In general, interaction has been developed to ease user's activities and maximize automation. Users get rid of boring and error prone tasks and refocuses on thermal engineering: fine-tune a more representative model or try, test and design more technical solutions. This feature finally increases the interest of engineers for daily works.

# PromeTher

Thermal Pre-processor

Laurent Bauer - 20th Nov. 2012  
TA34 - Process Methods & Tools

All the space you need

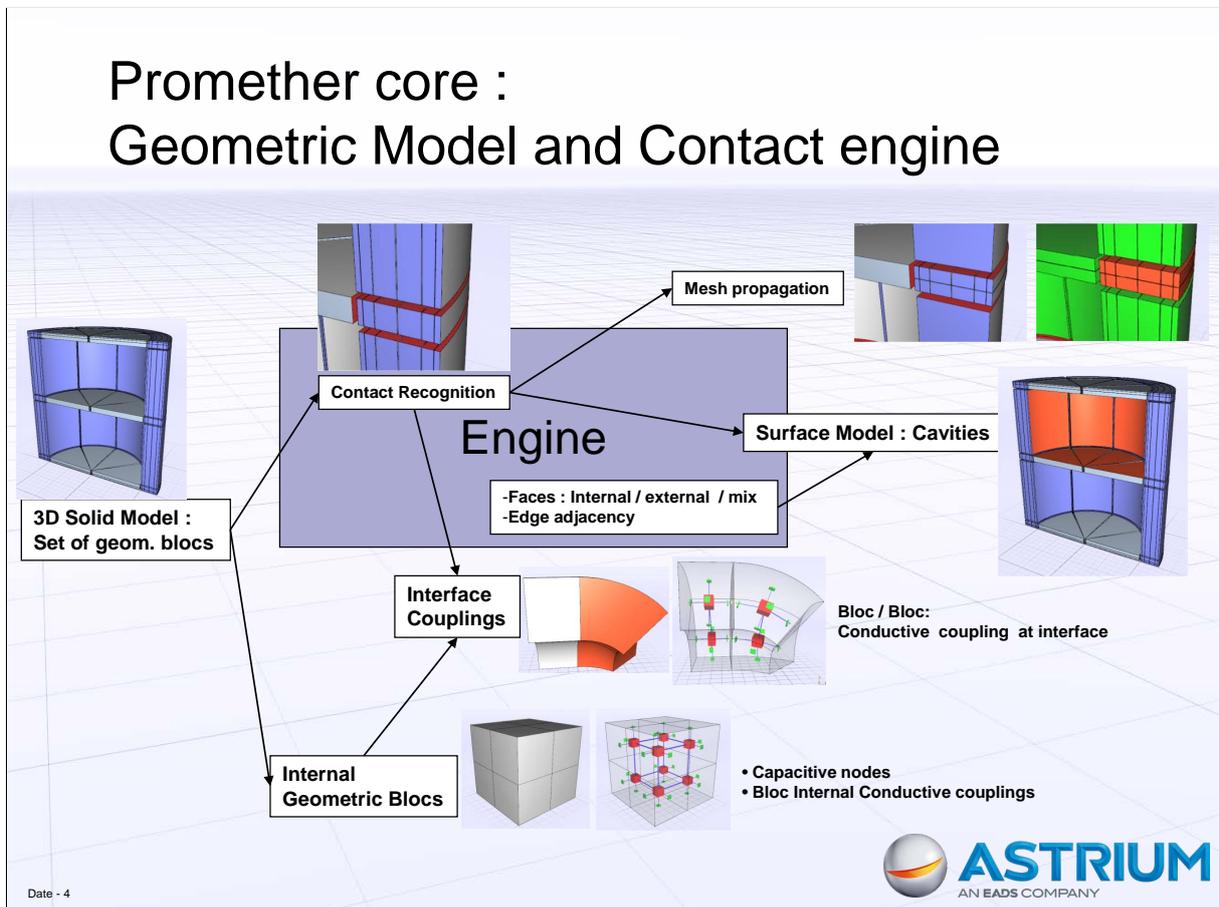
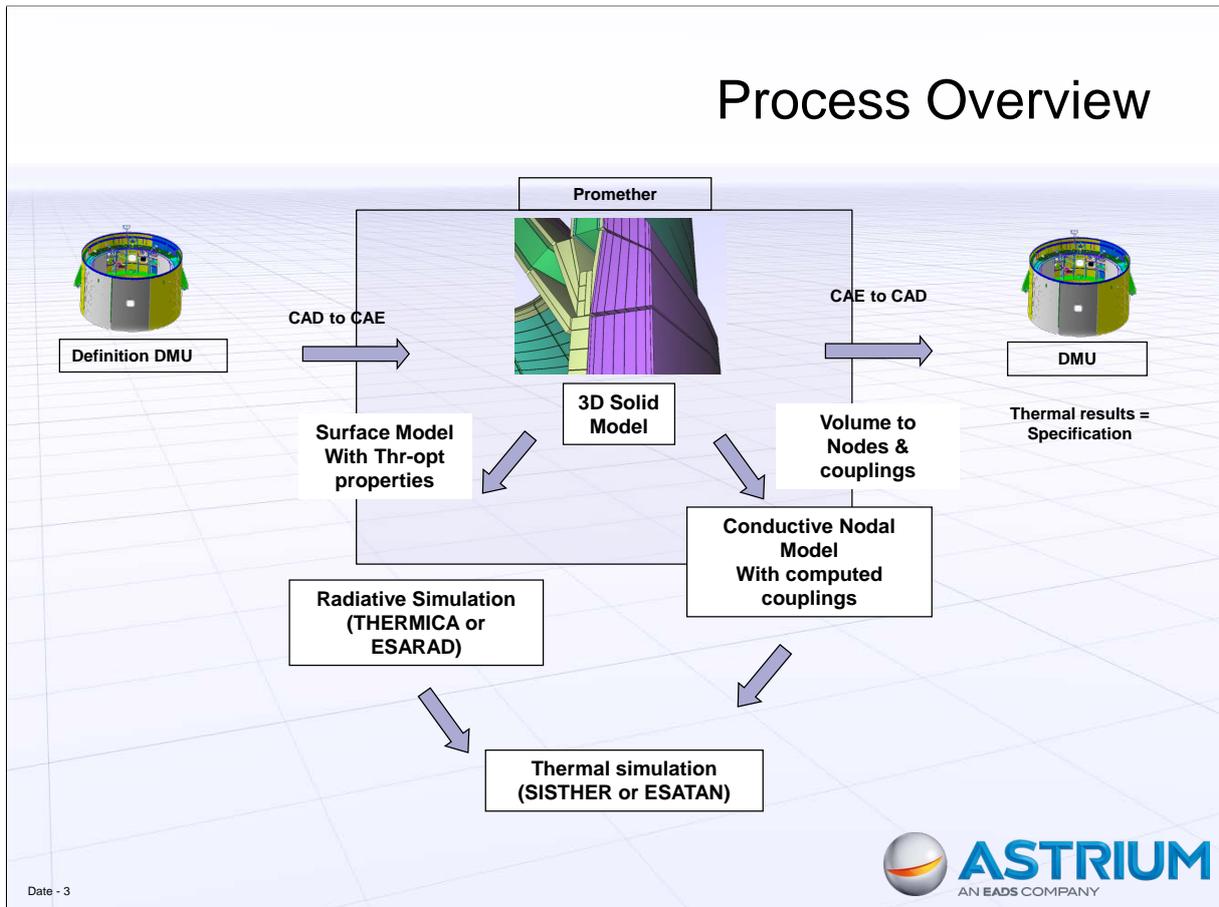


## Content

- Global process with Promether
- Promether core : 3D model & contact engine
- Conductive nodal model
- Entries for radiative model
- Overview of other tool features
- Futures

Date - 2



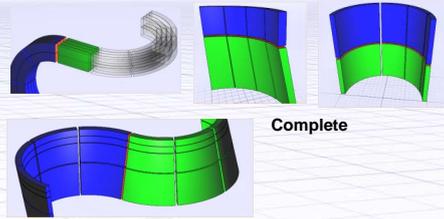


## Contact engine features:

Works in background

Recognition between :

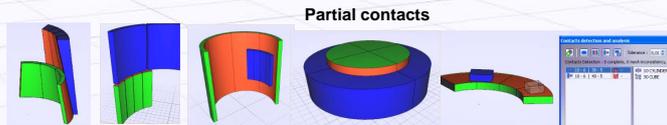
- Different types of Geometrical Blocs
- With different position and orientation
- Different geometric definition
- Different meshes



Entity	Type	Material	Mesh	Color	State
1	Surface	Steel	10mm	Blue	OK
2	Surface	Alu	10mm	Green	OK
3	Surface	Steel	10mm	Blue	OK
4	Surface	Alu	10mm	Green	OK
5	Surface	Steel	10mm	Blue	OK
6	Surface	Alu	10mm	Green	OK
7	Surface	Steel	10mm	Blue	OK
8	Surface	Alu	10mm	Green	OK
9	Surface	Steel	10mm	Blue	OK
10	Surface	Alu	10mm	Green	OK
11	Surface	Steel	10mm	Blue	OK
12	Surface	Alu	10mm	Green	OK
13	Surface	Steel	10mm	Blue	OK
14	Surface	Alu	10mm	Green	OK
15	Surface	Steel	10mm	Blue	OK
16	Surface	Alu	10mm	Green	OK
17	Surface	Steel	10mm	Blue	OK
18	Surface	Alu	10mm	Green	OK
19	Surface	Steel	10mm	Blue	OK
20	Surface	Alu	10mm	Green	OK
21	Surface	Steel	10mm	Blue	OK
22	Surface	Alu	10mm	Green	OK
23	Surface	Steel	10mm	Blue	OK
24	Surface	Alu	10mm	Green	OK
25	Surface	Steel	10mm	Blue	OK
26	Surface	Alu	10mm	Green	OK
27	Surface	Steel	10mm	Blue	OK
28	Surface	Alu	10mm	Green	OK
29	Surface	Steel	10mm	Blue	OK
30	Surface	Alu	10mm	Green	OK
31	Surface	Steel	10mm	Blue	OK
32	Surface	Alu	10mm	Green	OK
33	Surface	Steel	10mm	Blue	OK
34	Surface	Alu	10mm	Green	OK
35	Surface	Steel	10mm	Blue	OK
36	Surface	Alu	10mm	Green	OK
37	Surface	Steel	10mm	Blue	OK
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94	Surface	Alu	10mm	Green	OK
95	Surface	Steel	10mm	Blue	OK
96	Surface	Alu	10mm	Green	OK
97	Surface	Steel	10mm	Blue	OK
98	Surface	Alu	10mm	Green	OK
99	Surface	Steel	10mm	Blue	OK
100	Surface	Alu	10mm	Green	OK

Contacts Types :

- Complete
- Partial
- Complete with different meshes
- No over-detection

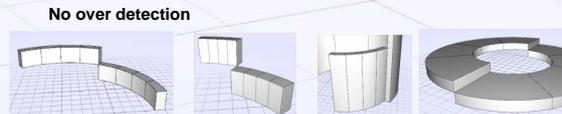


Test Suite :

- 213 unary test cases

Default Precision

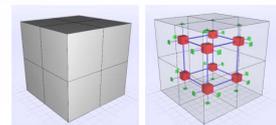
- 1E-05 m.
- Customizable



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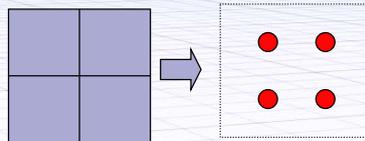


## Conductive Nodal Model Geometrical Bloc : Internal

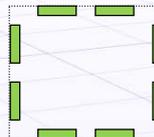


Full automatic generation of :

● Capacitive Nodes

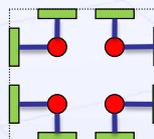
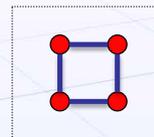


■ Arithmetic nodes on external faces



— Couplings : Blocs Internal :

- capacitive / capacitive
- capacitive / arithmetic



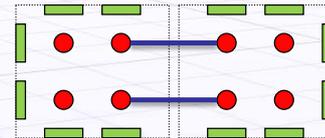
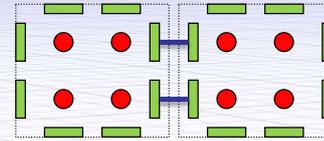
Date - 6



## Conductive Nodal Model Bloc – Bloc Interface

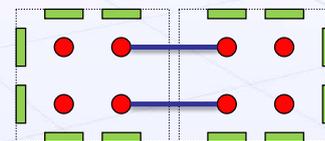
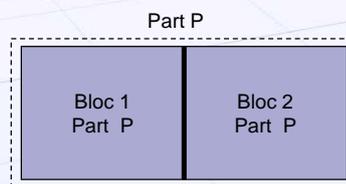
### Couplings : Blocs External

- arithmetic / arithmetic
  - User defines interface R/GL
  - Engines creates couplings between fronting arithmetic nodes
- If  $RI=0$  (User Defined)
  - No arithmetic node generation
  - Capa/Capa Coupling creation



### Bloc External, Part Internal

- Automatically  $RI=0$

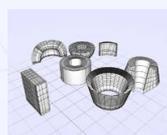
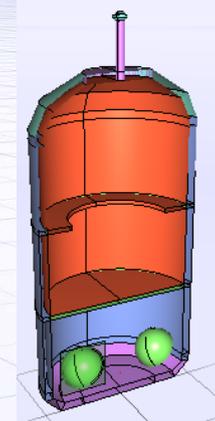


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## Cavities : Surface Model + thermo-optical properties

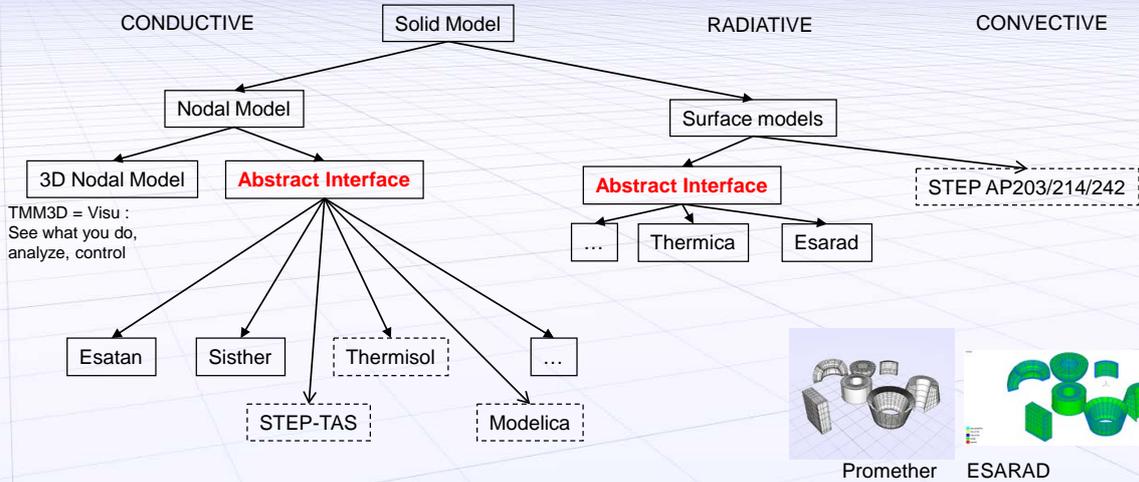
- Automated creation
  - "Seed" (propagation from ~) algorithm
- Manual creation :
  - Selection by face
  - Assemble cavities
  - Activate/ Inactivate
- Quality : Checks / Warnings
- Thr-Optical Properties :
  - emissivity, absorptivity
  - From pointed coating object
- Export
  - Esarad
  - Pegase: bridge to Thermica V3
  - Thermica V4 is planned



Date - 8



# Promether architecture Multi-format, Multi-solver

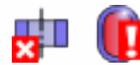


Models derived from a single and shared reference  
 Ensure consistency between Models (node numbering)  
 Export in the desired format => Solver interchangeability



Date - 9

## Other features : Model quality / Generalized checks



### RULES

- $R_{min} < R_{max}$
- Cones vertices defined in the trigonometric orientation
- Unique Identifier is Unique !
- Cannot export Cavity without coatings

### WARNINGS

Warning, the cavity contains faces without coating

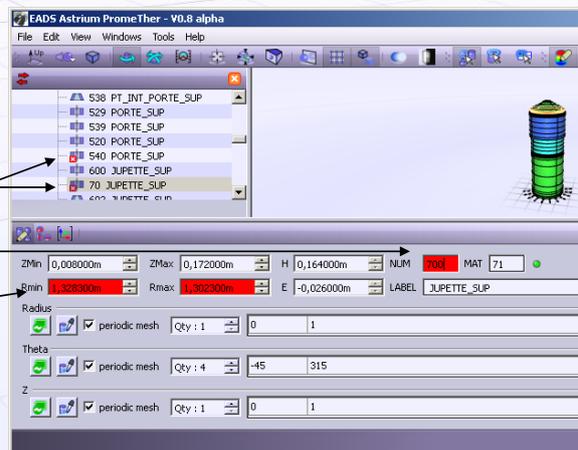
### Visual feedbacks

- Visual identification of Inconsistent objects
  - In 3D
  - In Data Tree
  - In object editor

Inconsistent objects are identified in the tree

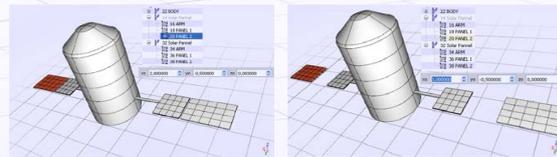
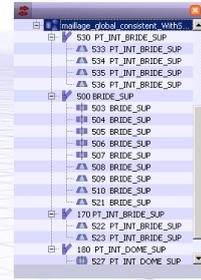
Num already exists

Inconsistent values :  $R_{min} > R_{max}$



## Other features

- **Assembly Tree**
  - Assembly
    - Part
      - Geometric bloc*
      - Nodes*
  - Instances
    - Modify once
    - Propagate where used
- **Import Export :**
  - assembly of files/models
- **Work in progress:**
  - User defined conductive couplings
  - Non geometrical nodes



Date - 11



## Demo

- Large Model support
- Geometric Model creation :
  - Using “contextual modeling” features
  - Assembly tree
- Mesh
  - Definition
  - Propagation
- Conductive Nodal Model Creation
  - User defined interface resistivity : 0 and Not 0
  - Part internal interfaces (matter continuity)
- Cavity creation
  - Automated, manual
  - Quality checks

12



## Promether future

- We continue
- We believe that the future is in collaboration
  - See “open innovation”
- Co-development ?
  - Co-funding, R&D project
  - Private, academics, consortium...
- Open to discussion, proposition
- Contact : laurent.bauer // at // [astrium.eads.net](mailto:laurent.bauer@astrium.eads.net)

Date - 13





# Appendix F

## Thermal Design and Analysis of the SPICE Primary Mirror

James Cornaby  
(Rutherford Appleton Laboratory, United Kingdom)

### **Abstract**

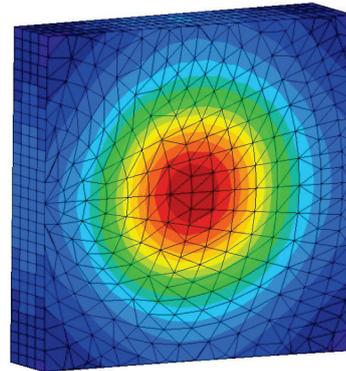
The Spectral Imaging of the Coronal Environment (SPICE) is a payload on-board ESA's Solar Orbiter satellite. The instrument is a high resolution imaging spectrometer operating at ultraviolet wavelengths. The Rutherford Appleton Laboratory is responsible for the design and build of this instrument. Current design status for SPICE represents that at preliminary design review (PDR).

The primary mirror is a component on-board SPICE that is used to reflect EUV light to the detector assembly via a diffraction grating. The mirror is constructed from fused silica and has a boron carbide coating on the sun facing side. One of the key challenges of the SPICE instrument is for the primary mirror to manage the high heat load and resulting thermal deformations at perihelion (0.284AU). For this reason, the primary mirror has been designed to maximise the amount of EUV light (used for science observations) that is reflected whilst trying to minimise absorption in the remaining part of the spectrum. A detailed geometrical mathematical model (GMM) and thermal mathematical model has been created for this component using ESATAN-TMS. The GMM has utilised a CAD converter to ensure an accurate representation of the geometry of the mirror. The TMM has employed equations to model the spectral absorption through the silica medium of the mirror. The model is being used to provide inputs to the thermo-elastic deformation analysis of the mirror.



# SPICE Primary Mirror Thermal Modelling

James Cornaby  
Thermal Engineer



26<sup>th</sup> European Space Thermal Analysis Workshop, 20<sup>th</sup> -21<sup>st</sup> November

## Agenda



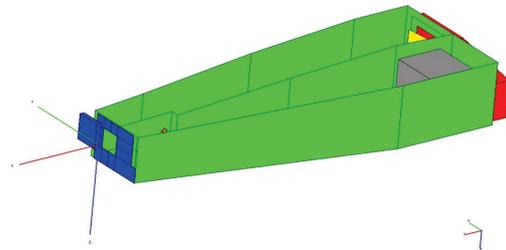
- SPICE overview
- Primary mirror overview
- Introduction
- Modelling challenges
- Geometrical Modelling
- Conductive heat transfer
- Thermo-optical properties
- Radiative attenuation
- Thermal predictions
- Summary of results
- Conclusions
- Questions



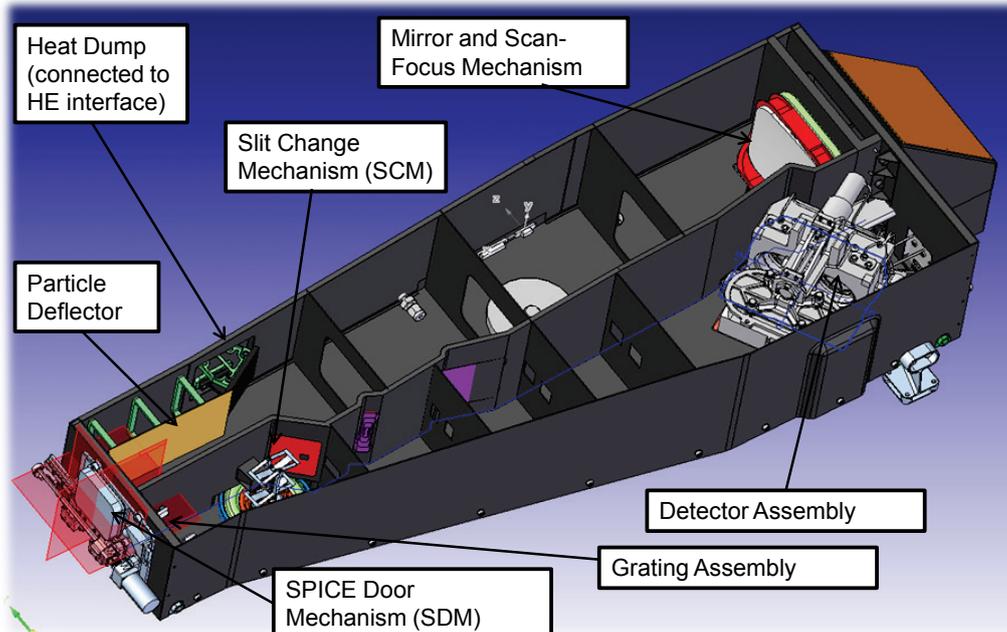
## SPICE Overview

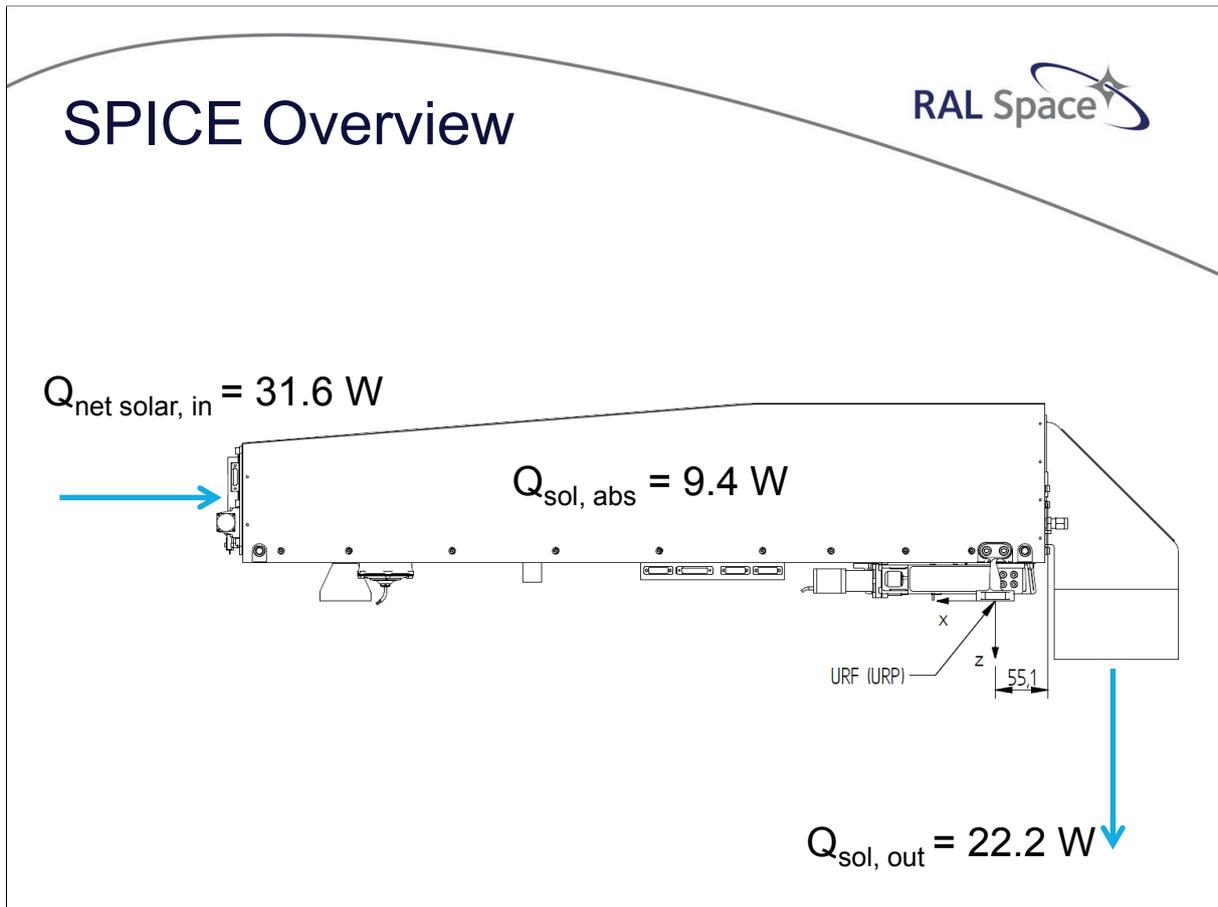


- Spectral imaging of the coronal environment (SPICE)
- High resolution spectrometer, recording EUV spectra and spectral lines from the Sun's atmosphere
- Payload on-board ESA's Solar Orbiter satellite
- Key science:
  - Solar wind
  - Coronal mass ejections
  - Solar dynamo



## SPICE Overview





## Primary Mirror Overview

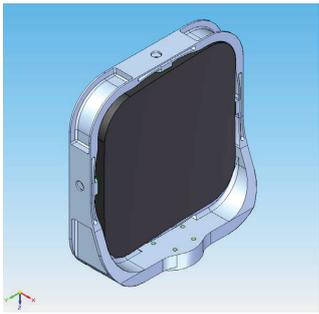
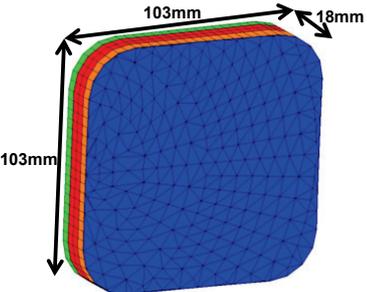


- Reflects EUV solar radiation (used for science observations), transmits unwanted solar energy which is then rejected to space

*Construction:*

- Fused **silica** substrate with **boron carbide** ( $\text{B}_4\text{C}$ ) coating\* on **parabolic** front face

- Critical component on SPICE instrument
- Low thermal conductivity (1.5 W/mK)
- Mounted with titanium mount
- Focus adjusted using scan focus mechanism (SFM)

\* Boron carbide coating data produced by the Max-Planck-Institut für Sonnensystemforschung (MPS)

# Introduction



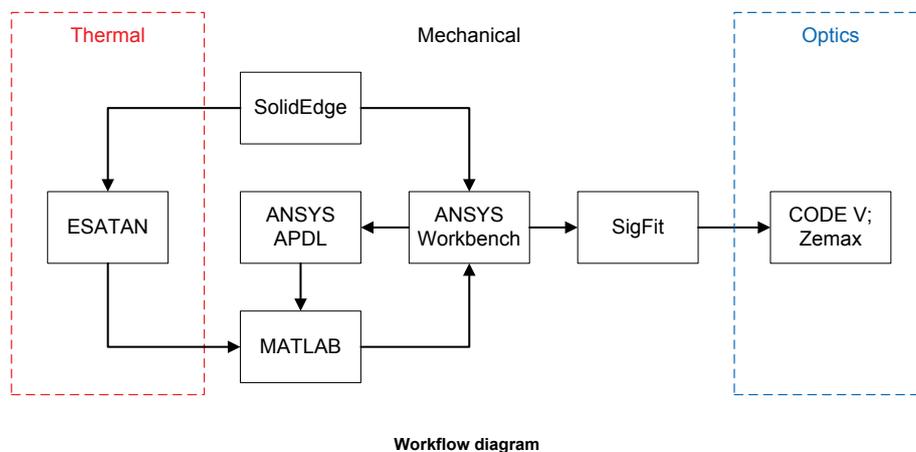
## Aim:

- Create an accurate thermal model of the SPICE primary mirror to provide inputs for the thermo-elastic analysis
  - Thermal deformation of optical surface

## Design drivers:

- Manage high heat load at perihelion ( $\sim 31$  W incident at 0.284 AU)
  - Minimise temperature gradients and differential thermal expansion
- Modelling using ESATAN-TMS R4

# Introduction

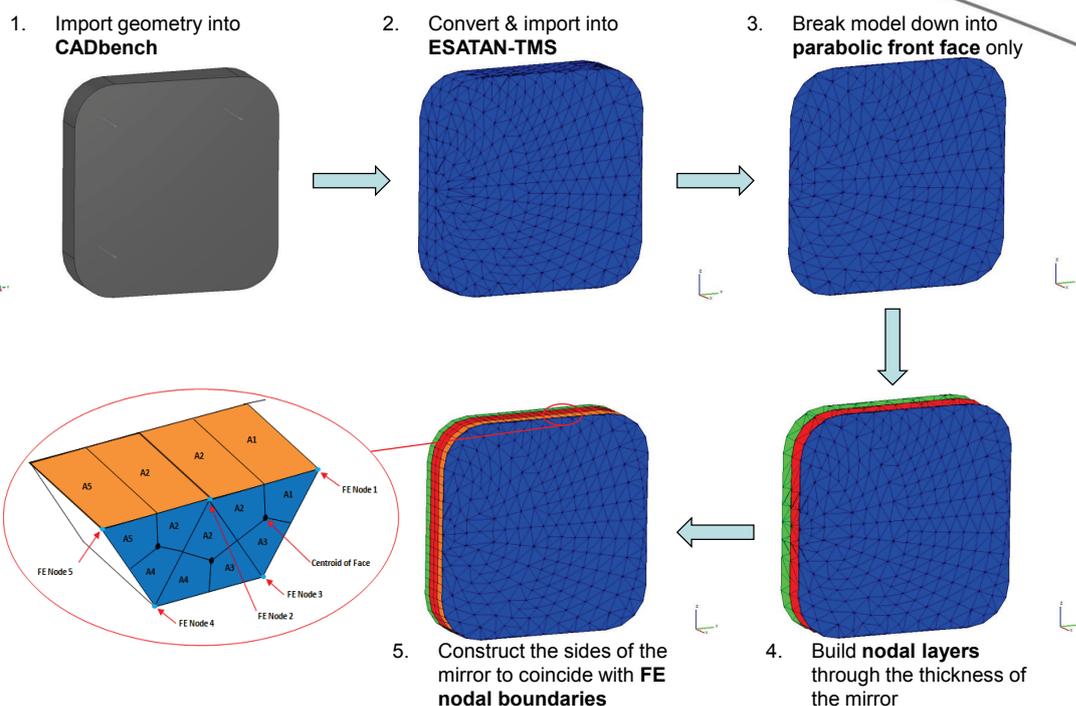


## Modelling Challenges



- Difficult geometry (parabolic front face)
- Wavelength-dependent thermo-optical properties:
  - Solar properties
  - Infrared properties
- Attenuation of solar load through silica medium:
  - Wavelength-dependence
  - Feature not available in ESATAN
- Transfer of data to ANSYS for thermo-elastic modelling
  - Efficient and accurate process

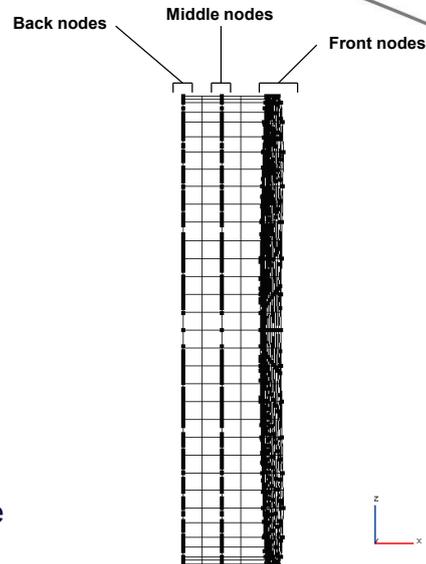
## Geometrical Modelling



# Conductive Heat Transfer



- Mirror broken down into 3 layers of finite element (FE) nodes through the thickness
  - *Front nodes* (269 nodes)
  - *Middle nodes* (269 nodes)
  - *Back nodes* (269 nodes)
- Thickness of each set of nodes set appropriately
- Conductive links across each layer of nodes generated by ESATAN-TMS using FE analysis
- Conductive links between layers input into the model using lumped parameter analysis



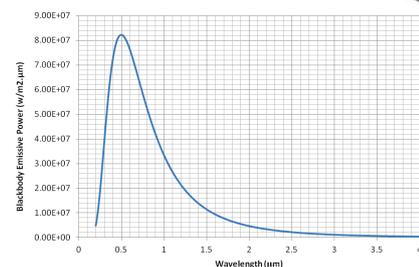
# Thermo-optical Properties



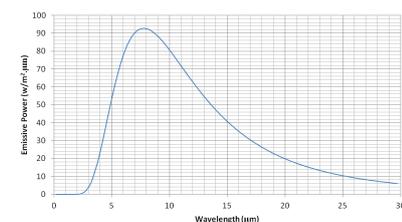
- Wavelength-dependent solar and IR properties:
  - $B_4C$  coating\*
  - Silica
- Simulated using weighted average values (not ESATAN function):

$$X_{\theta} \approx \frac{\int_0^{\infty} X_{\theta}(\theta, T) E_{\theta, b}(\theta, T) d\theta}{\int_0^{\infty} E_{\theta, b}(\theta, T) d\theta}$$

- Calculated values used within ESATAN-TMS:
  - Transmissivity ( $B_4C$ ) = ~ 0.8
  - Reflectivity ( $B_4C$ ) = ~ 0.1
  - Absorptivity ( $B_4C$ ) = ~ 0.1
  - Emissivity (silica) = ~ 0.97



Planck blackbody emissive power for the Sun (5770K)



Planck blackbody emissive power for an object at 100°C (approx. Temperature of the mirror)

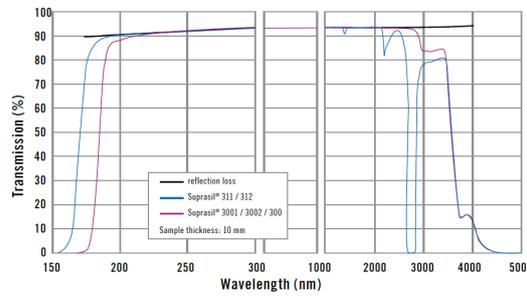
\* Boron carbide coating data produced by the Max-Planck-Institut für Sonnensystemforschung (MPS)



# Radiative Attenuation

*Theory:*

- High internal transmissivity (95-98%) between 0.2μm - 2.0μm
  - 94% (29.1 W) of the incident solar energy is distributed in this spectral band
- The internal transmissivity decreases between 2.0μm - 5.0μm
  - 5.5% (1.7 W) of the incident solar energy
- At wavelengths greater than 5.0μm the silica is essentially opaque
  - 0.5% (0.2 W) of the incident solar energy



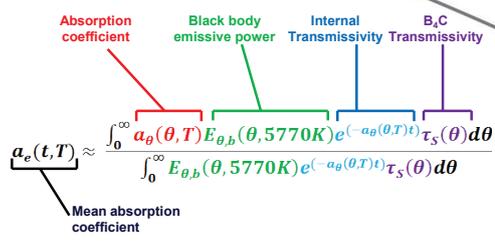
External transmissivity for Heraeus Suprasil silica



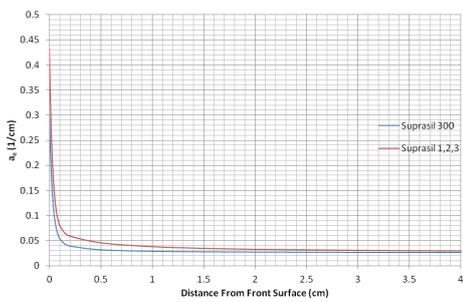
# Radiative Attenuation

*Theory:*

- Solar radiation is attenuated through the silica medium according to linear absorption coefficients,  $a_\theta$ 
  - Wavelength-dependent property
- Beer-lambert law used to calculate internal transmissivity:
 
$$\tau_l(\theta, T) = \exp(-a_\theta(\theta, T)t)$$
- Mean absorption coefficient,  $a_e$ , calculated using a weighted average that varies through the thickness of the silica medium
 
$$\tau_e(\theta, T) = \exp(-a_e(\theta, T)t)$$



Mean absorption coefficient



Mean absorption coefficient through the thickness of the mirror

# Radiative Attenuation



## Modelling:

- TMM splits the mirror thickness into 28 segments
  - Constant  $a_e$  through each segment
  - 17 segments for first 1mm
- Nodal absorption attributed as follows:
  - Front nodes → **Boron carbide absorbed + internal absorption (0-1mm)**
  - Middle nodes → **Internal absorption (1-10mm)**
  - Back nodes → **Internal absorption (10-18mm)**

# Radiative Attenuation

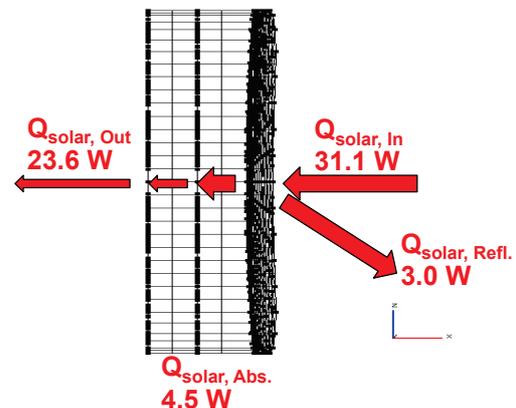


## Modelling:

- Total solar absorption (4.5 W) broken down as follows:
  - Front nodes = 3.1 W
  - Middle nodes = 0.8 W
  - Back nodes = 0.6 W

Mirror Segment	Solar Absorbed (W)		
	0.2 $\mu$ m - 2.0 $\mu$ m	2.0 $\mu$ m - 5.0 $\mu$ m	>5.0 $\mu$ m
10nm B4C layer	2.80	0.00	0.00
0-1mm	0.08	0.09	0.15
1-10mm	0.57	0.18	0.01
10-18mm	0.52	0.07	0.00

Absorbed solar loads through the mirror

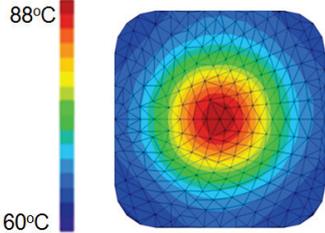


# RAL Space

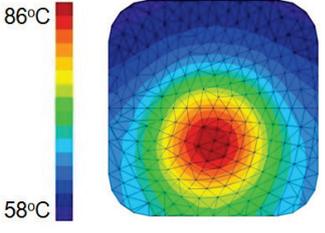
## Thermal Predictions

*At perihelion (on-axis pointing):*

- Solar footprint:
  - ~70mm x 70mm square centred on mirror
  - Differential solar flux across footprint
- Temperature predictions:
  - Peak temperature = **88°C**
  - Max gradient through thickness = **7°C**
  - Max gradient across nodal layers = **24°C**



Perihelion temperature plot  
On-axis



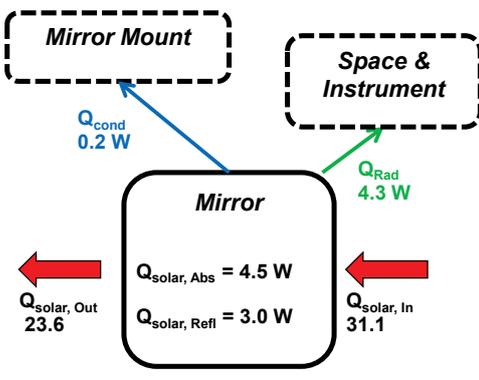
Perihelion temperature plot  
Off-axis +0.95° rotation about y-axis

# RAL Space

## Summary of Results

- High peak temperatures and gradients at perihelion:
  - Large solar absorbed load
  - **Low thermal conductivity** of the silica
  - Differential solar flux across footprint

→ **BUT silica has a very low CTE so can cope with these gradients**
- Radiation is the dominant mode of heat transfer for the mirror
  - **Low conductance** from mirror to mount (undesirable feature)
  - **High emissivity** (desirable feature)

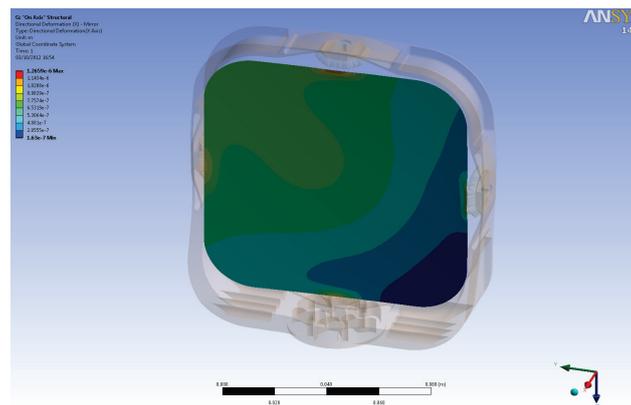


Mirror energy balance

## Summary of Results



- Mounting configuration has little impact on thermal gradients
- Mirror surface deformation: curvature  $\sim 0.2 \mu\text{m}$ 
  - Focus adjusted using  $\sim 100 \mu\text{m}$  linear motion of the SFM
    - Within the  $\pm 0.5\text{mm}$  allowable linear focus adjustment of the SFM

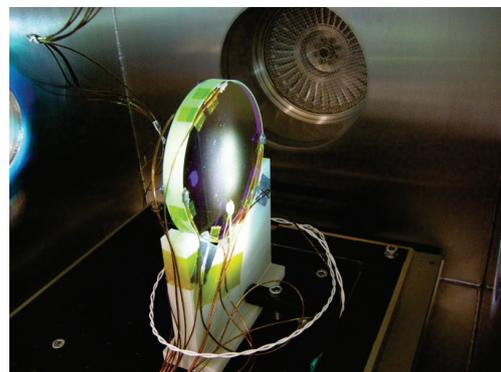


Mirror thermal deformations (ANSYS)

## Conclusions



- Detailed thermal model of the primary mirror created
- Model provides temperature and nodal coordinate data for thermo-elastic analysis of mirror
- Predictions show large thermal gradients exist in the mirror
  - Focus adjustments calculated
- Analysis is on-going:
  - Anti-reflection coatings
  - Boron carbide coverage



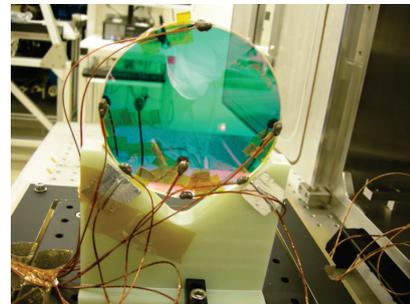
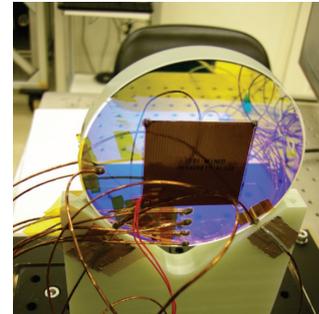
## Conclusions



- Thermal testing is on-going
  - Ohmic heating test
  - Solar lamp test

### *ESATAN modelling:*

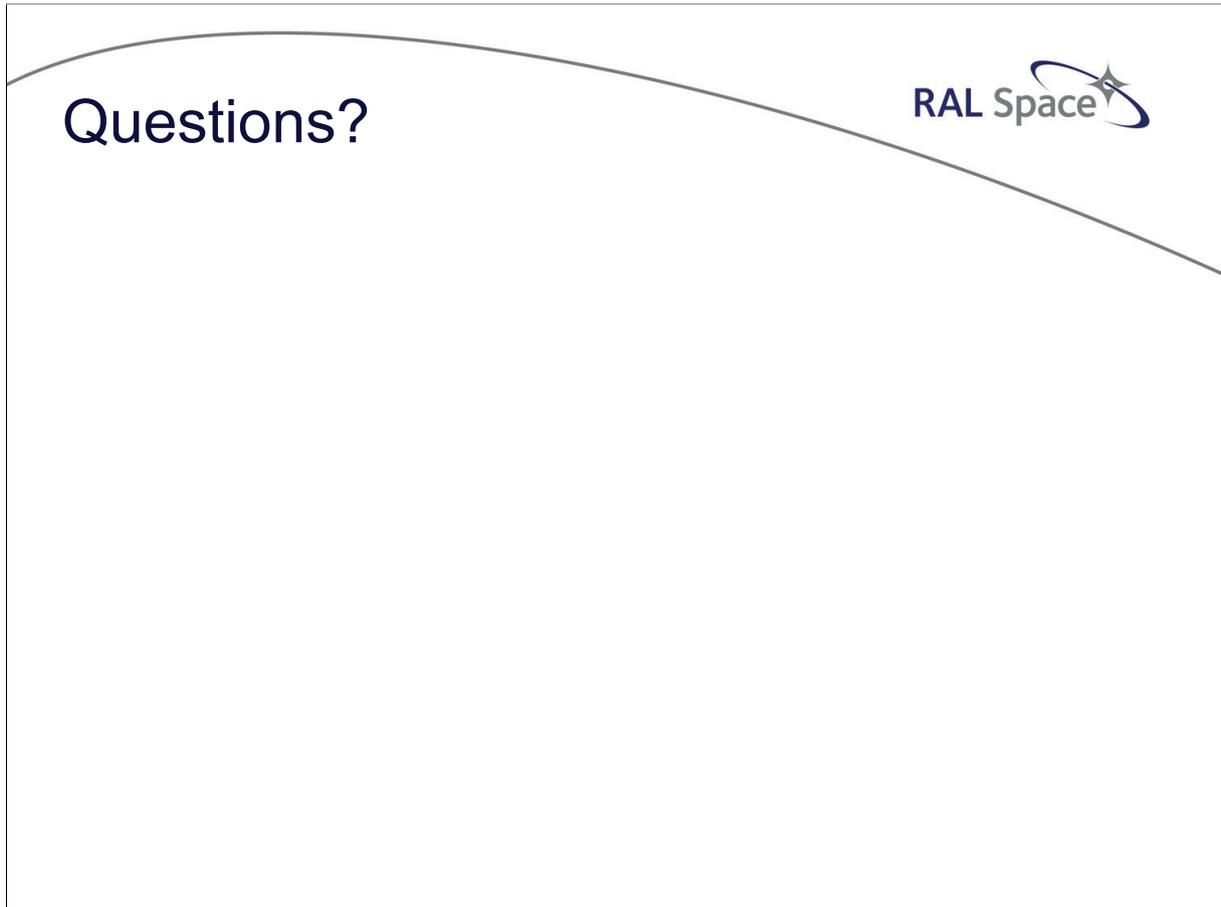
- First year using the software
- Generally impressed with the software, areas for improvement:
  - FE nodal areas and node numbers
  - Wavelength-dependent thermo-optical property explanations/examples



## Acknowledgements



- This work was funded by ESA contract number: **SOL.S.ASTR.CON.00070**
- I would like to acknowledge the Max-Planck-Institut für Sonnensystemforschung (MPS) for data relating to the boron carbide coating



## Appendix G

### Thermal analysis of a piezo-actuated pointing mechanism

Paul Lardet  
(Sodern, France)

### **Abstract**

For the pointing of the Earthcare satellite lidar, Sodern designed a piezo-actuator tip-tilt mechanism. Each four piezo-actuator of this mechanism are equipped with two strain gages mounted in a Wheatstone bridge to precisely regulate pointing.

The behaviour of this regulation strongly depends on the thermal state of the actuators: temperature differences between actuators or gages lead to angular deviation of the mirror, and must be controlled. In particular, thermal studies were realised on two life stages of the mechanism.

During electronic system start-up, the thermal variation leads to temporary gradients delaying the availability of mirror pointing, and therefore must be minimized. Studies showed that the main factor influencing these gradients is the conduction in the system structure. The difficulty of this identification consisted in separating the influences of various parts, as the mechanism is very intricate and the required precision very fine ( 5mK gradients).

During operating mode, thermal variations at base plate induce gradients between the actuators. The time response of the system has been indentified in order to evaluate the spectral range of variation that must be taken into account. After that, the coefficient of influence of the base-plate temperature on the pointing performances has been determined. For that purpose, a new approach using a comparison between step response and frequency response has been developed, in order to consider small amplitude spectral thermal solicitations.

# Thermal study of a piezo-actuated mechanism

P. LARDET – European Space Thermal Analysis Workshop – Nov. 20th 2012

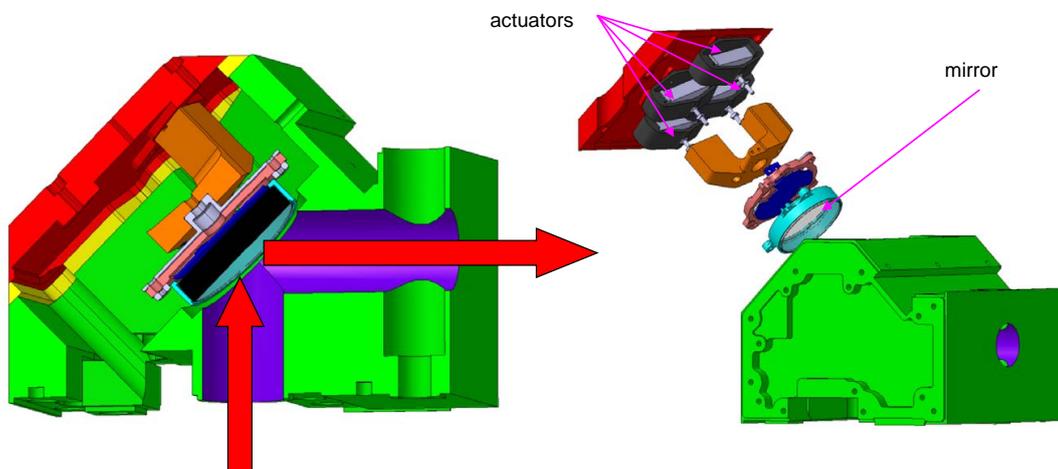


*Innovation based  
on Experience*



## Mechanism presentation

- **Equipment: pointing mechanism of the EarthCARE LIDAR**
- **A mirror points the LIDAR laser beam**
- **The mirror is actuated by four piezo-actuators, each equipped with two strain gages mounted in a Wheatstone bridge**



**SODERN**

## Actuators schematic

- For each axis, 2 actuators working in push-pull

Mirror

Actuators

Flexible joint

SODERN – 2012/11/20

European Space Thermal Analysis Workshop

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**SODERN**

## Actuators schematic

- For each axis, 2 actuators working in push-pull

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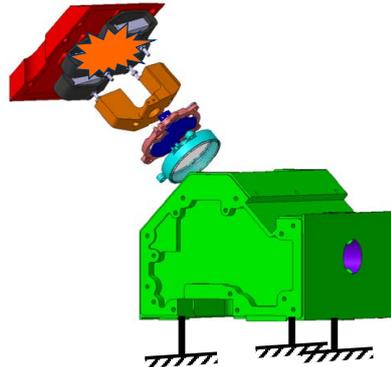
European Space Thermal Analysis Workshop

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## Thermal issues

- High pointing precision is required ( $\sim 0.1\%$  of 3mrad)
- Pointing precision strongly depends on thermal state of actuators: Temperature differences between actuators disturbs pointing
- Two lifecycle phases are studied



Electronic activation

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European Space Thermal Analysis Workshop

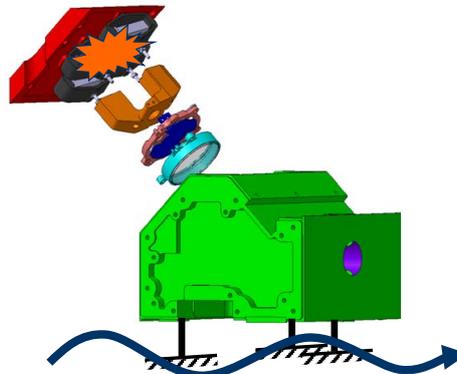
SODERN

P. 5



## Thermal issues

- High pointing precision is required ( $\sim 0.1\%$  of 3mrad)
- Pointing precision strongly depends on thermal state of actuators: Temperature differences between actuators disturbs pointing
- Two lifecycle phases are studied



Thermal perturbation at base plate

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European Space Thermal Analysis Workshop

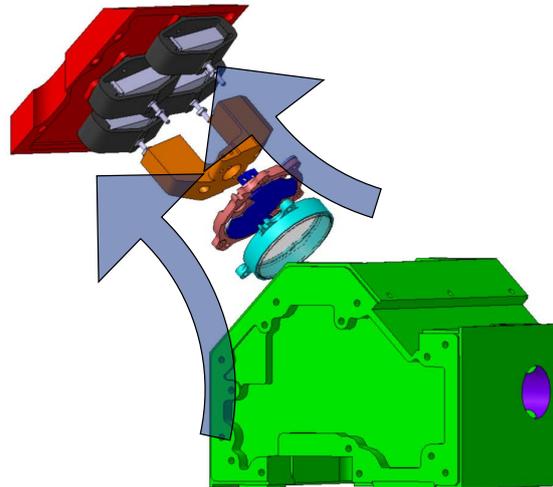
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P. 6



## Main Thermal influencing factors

- Potential items influencing the actuators thermal state
- Geometrical dissymmetry of thermal diffusion



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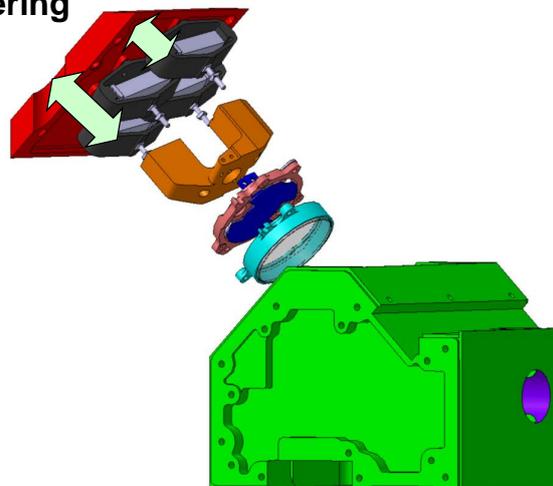
European Space Thermal Analysis Workshop

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## Main Thermal influencing factors

- Potential items influencing the actuators thermal state
- Geometrical dissymmetry of thermal diffusion
- Contact thermal resistance scattering



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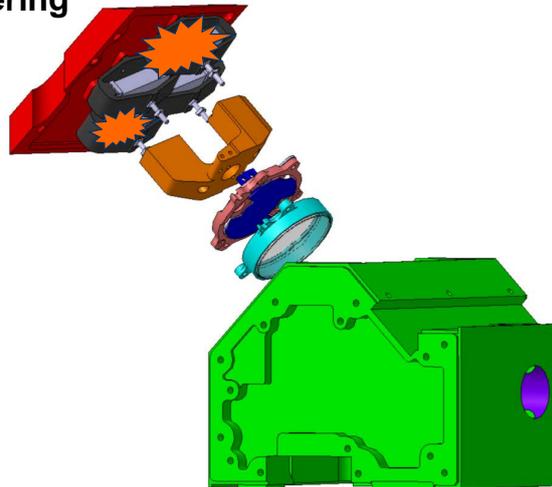
European Space Thermal Analysis Workshop

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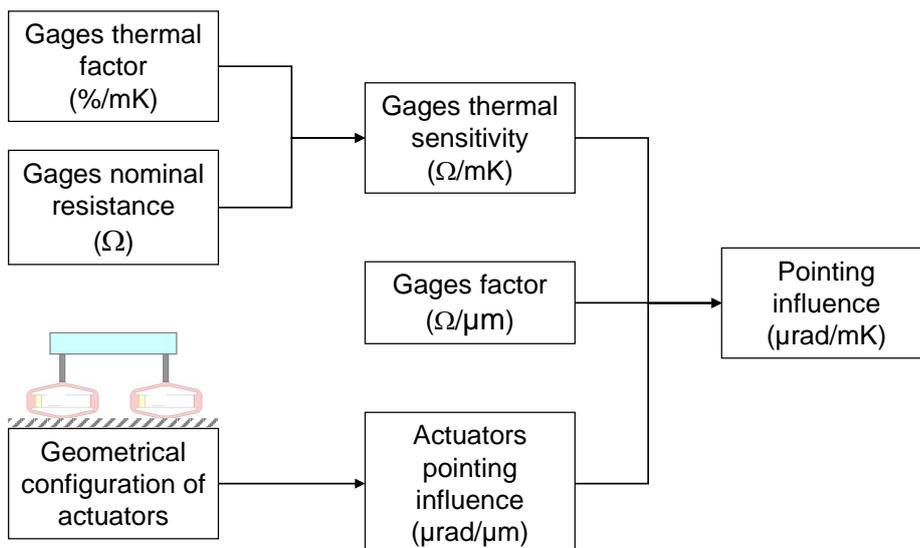
## Main Thermal influencing factors

- Potential items influencing the actuators thermal state
  - Geometrical dissymmetry of thermal diffusion
  - Contact thermal resistance scattering
  - Gage thermal power scattering
- Because a compensing system is present, only temperature difference *variation* is important  
 → Scattering is not an issue in this study, because it is constant over time. The problem is purely diffusive



## Influence factor of temperature on pointing

- On each axis:





## Technical challenges

- **Main difficulties of the studies:**
- **Electronic start:**
  - Quick stabilization of *temperature difference* between actuators is needed to get early equipment availability
  - Actuator stabilization is not important, but *symmetry between them* is !
- **Thermal perturbation at base plate**
  - Thermal specification includes random variation (0.05mHz-10mHz) and drift (above 90min up to lifetime) of base plate temperature
  - Phase B do not allow to dig further detailed random calculations
  - And long term transitory calculations are not achievable
  - Time constant calculation is the key
- **For both cases**
  - Small temperature differences (~5mK per push-pull) are expected
  - High precision results are needed

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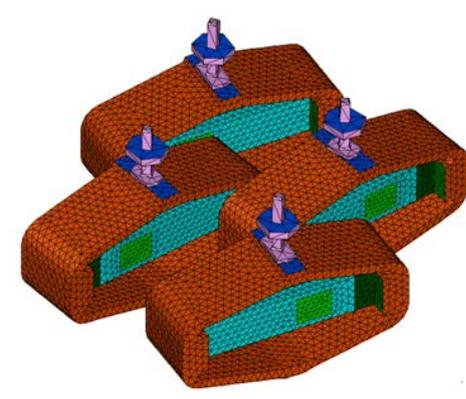
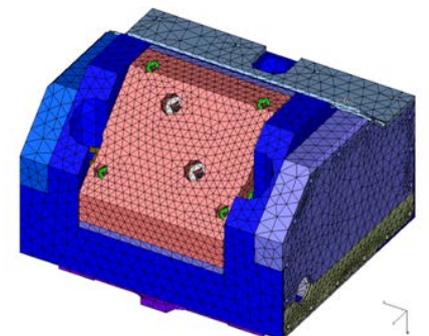
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## Model used for calculations

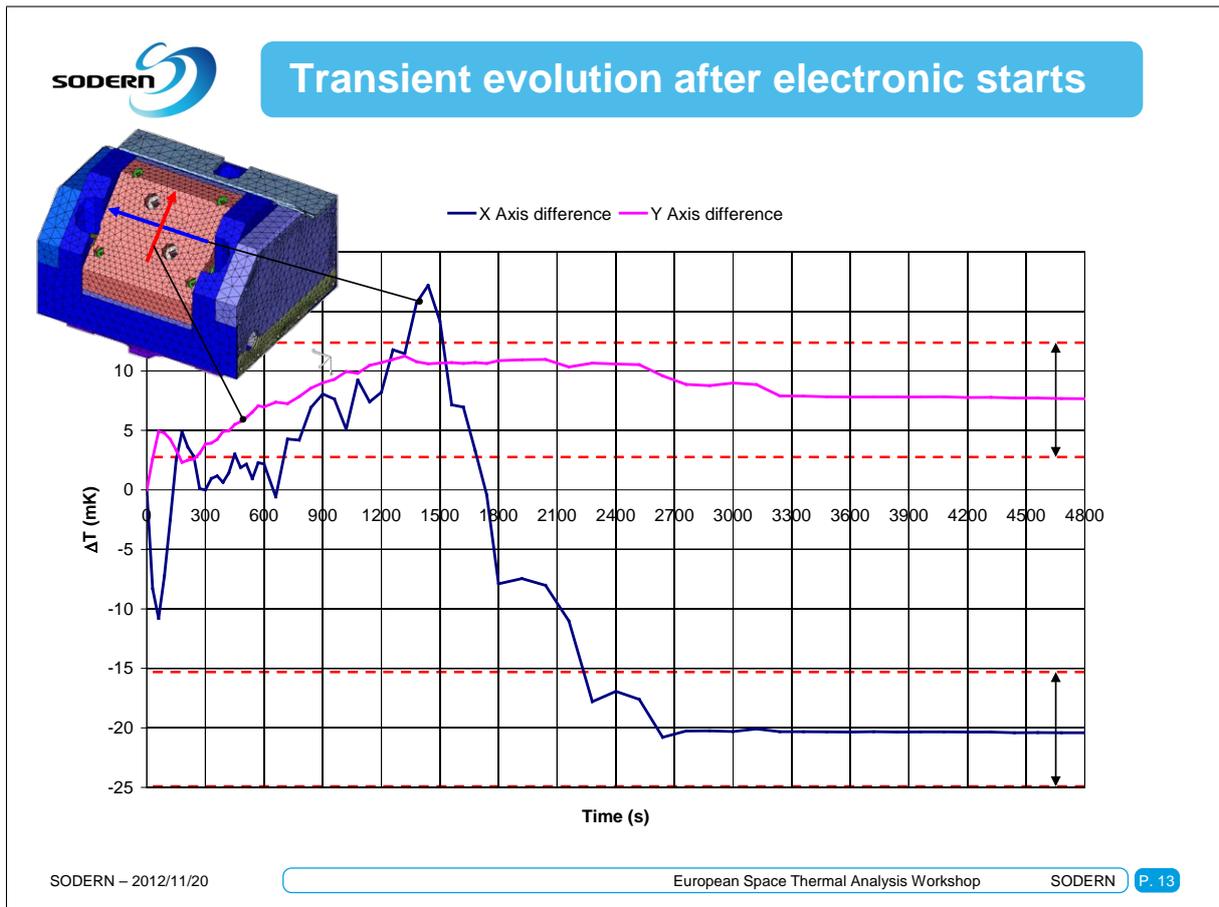
- **NX I-DEAS/TMG 6 modelling**
- **Special attention on actuators**



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**SODERN** **Analysis of transient results**

- The big differences between X and Y Axis asks for temperature field analysis
- Late stabilization is not caused by global dissymmetry

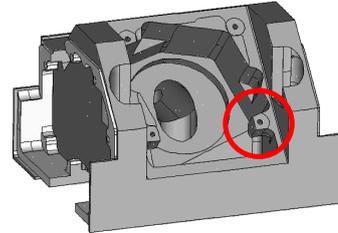
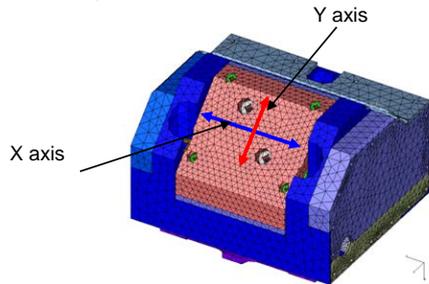
X axis Y axis

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## Analysis of transient results

- The big differences between X and Y Axis asks for temperature field analysis



- Late stabilization is not caused by global dissymmetry
- Late stabilization is caused by very local dissymmetry

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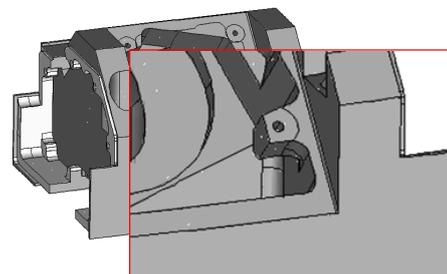
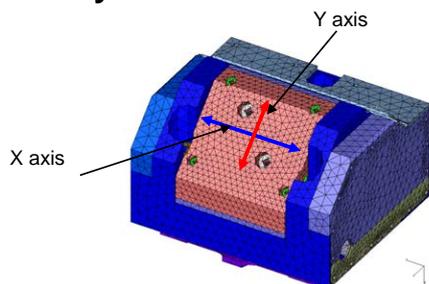
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## Analysis of transient results

- The big differences between X and Y Axis asks for temperature field analysis



- Late stabilization is not caused by global dissymmetry
- Late stabilization is caused by very local dissymmetry
- Design recommendations for phase C: As low as possible geometrical dissymmetry on equipment casing

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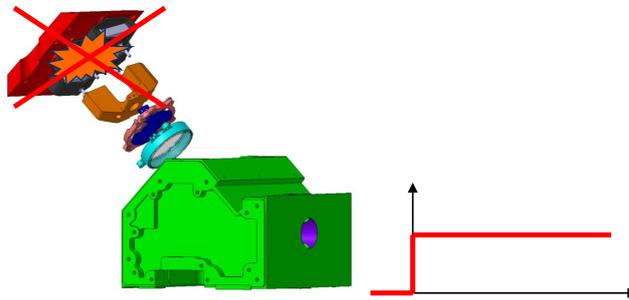
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## Thermal perturbation study

- Influence of radiation proved to be positive on gradients
  - Calculation w/o radiation, system is linear
- As system is linear, BC influences can be separated
  - Calculation w/o any electronic dissipation
- Response to a step is greater than to a sine
  - Calculation: 10°C temperature step at base plate, output of variation of temperature differences between actuators



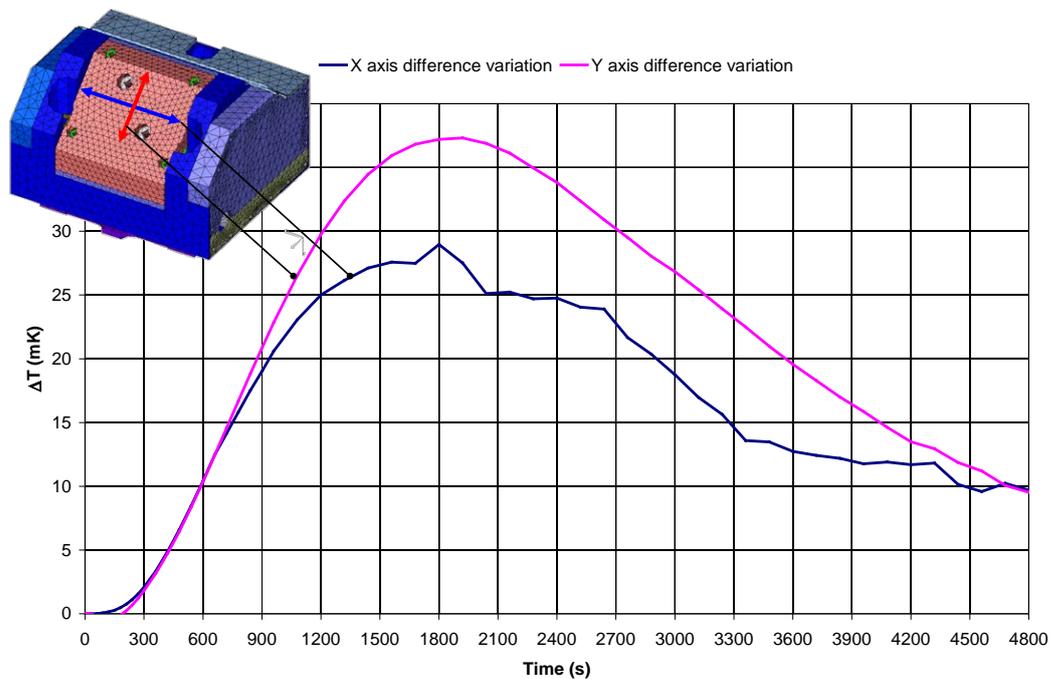
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## Time response to a step perturbation



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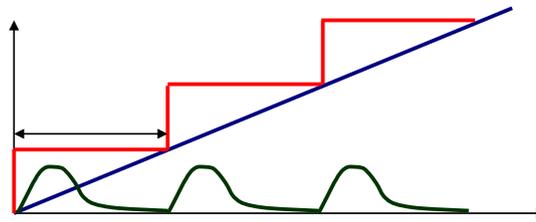
European Space Thermal Analysis Workshop

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## Analysis of stability results

- Time constant  $\tau$  of actuators response is about 1800s
- Response coefficient of actuators temperature difference is less than  $35/10=3.5\text{mK}/^\circ\text{C}$
- For random perturbations, RMS values of pointing thermal stability ( $\mu\text{rad}^2$ ) can be calculated with this upper bound value
- For drift perturbation, base-plate variation is over-estimated by steps of length  $10\tau$
- Drift on this period is used to calculate the corresponding maximum pointing deviation



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## Synthesis and coming next

- Answer to various issues with very few calculations
- Use of simple step response to estimate response to random perturbation
- Use of middle term time constant to estimate response to very long term perturbations
- For Phase C, frequency analysis could be performed:
  - calculation of harmonic response for different frequencies
  - With this transfer function, calculation of the RMS thermal pointing stability
  - Increase of calculation precision

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SODERN

P. 20



## The end

- **Thank you for your attention**
- **Any questions ?**



# Appendix H

## SYSTEMA-THERMICA Demonstration Part 1

Maxime Joliet      Timothée Soriano  
(Astrium, France)

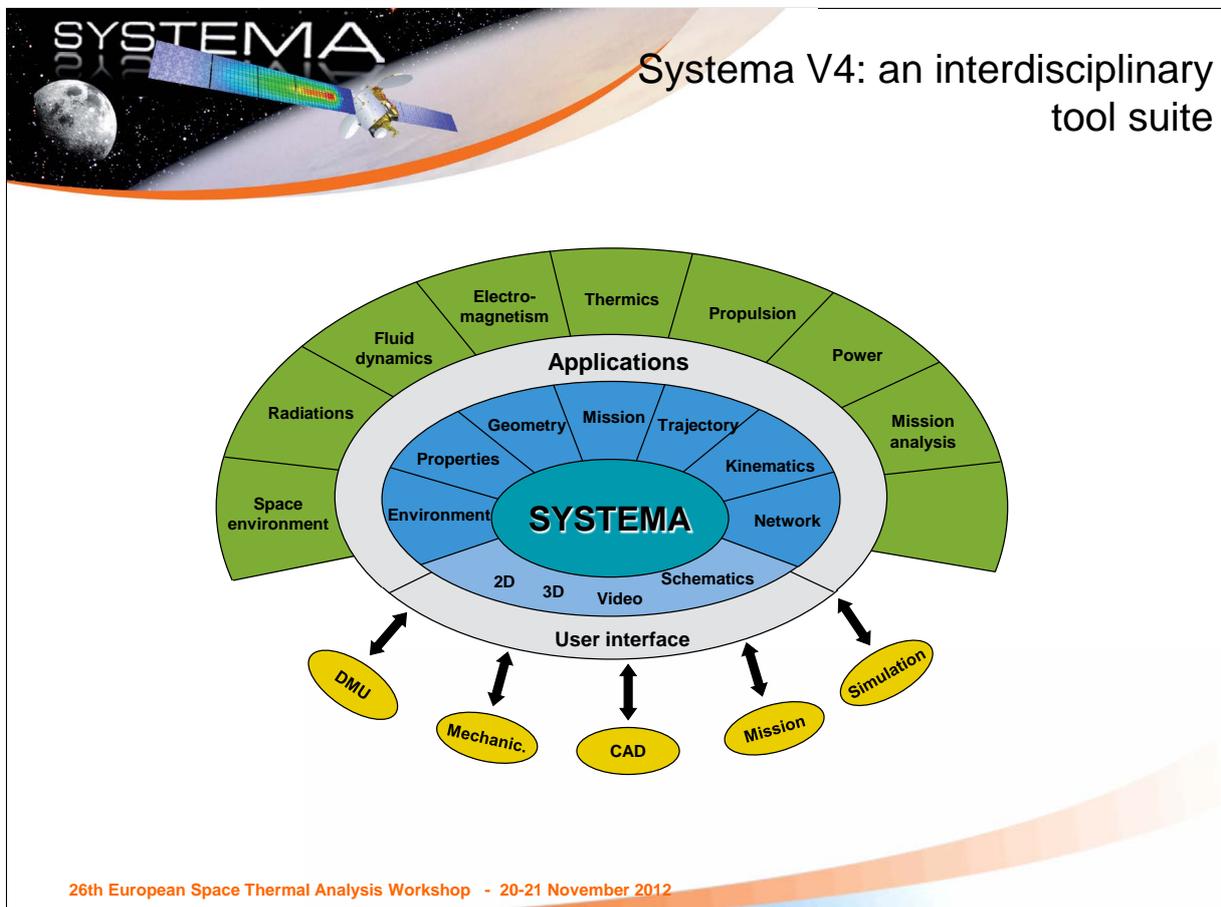
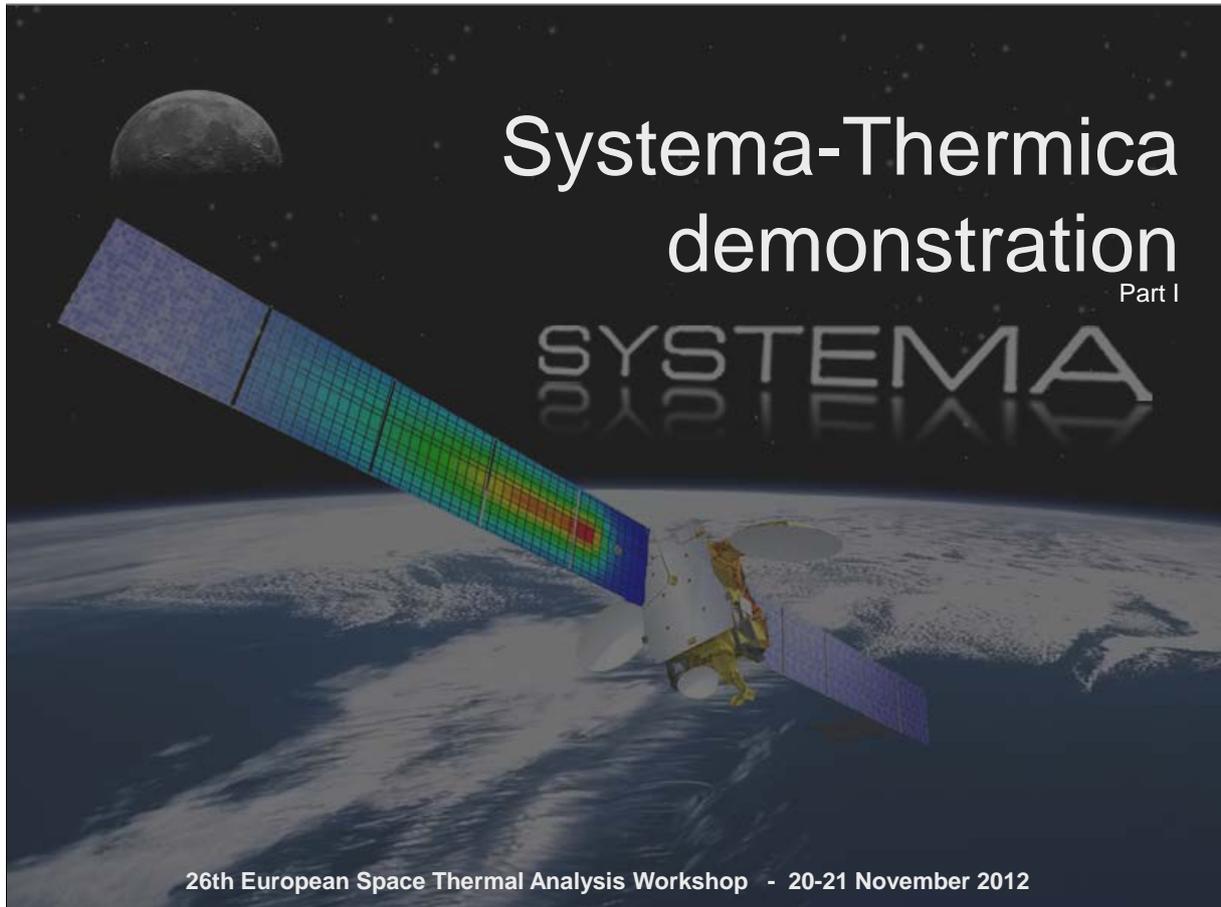
### Abstract

The SYSTEMA v4 project started in the mid 2000's and has successfully achieved its first goal: propose a new multi-physics software suite beyond on the v3 capabilities, in which new developments and evolutions becomes possible. Since the 2010's many new features and optimizations have been added and others are currently in development so to ease the process of thermal simulations from early phases to CDR, chamber test and in-orbit correlations.

Each year, the newly developed functionalities have been presented. This year's presentation is dedicated to an end-to-end use case covering the entire process from geometrical pre-processing to results post-processing, showing how the new SYSTEMA functionalities can ease thermal engineers work.

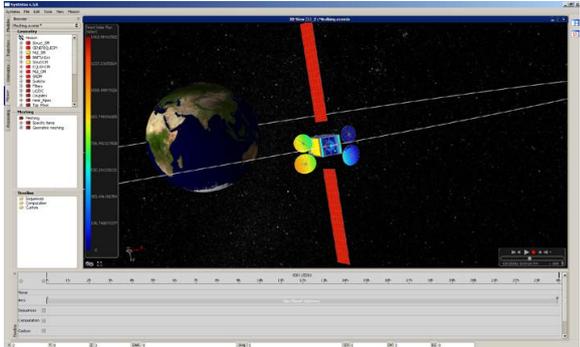
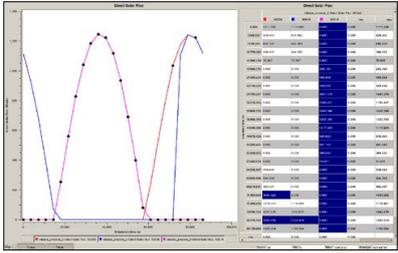
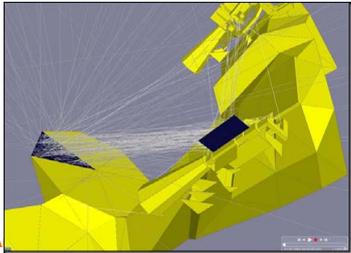
In particular, this first part covers:

- Geometry Management and Pre-processing
  - CAD geometry insertion and management
  - Import of Nastran model
  - Execution of Python script
  - Reverse orientation of multi-selection
  - Interactive geometry transformations
  
- Mission Settings and Management
  - Real Solar system management
  - Import of custom trajectories
  - Kinematics tree creation
  - Import of custom transformations
  - Mission's time-line and events management

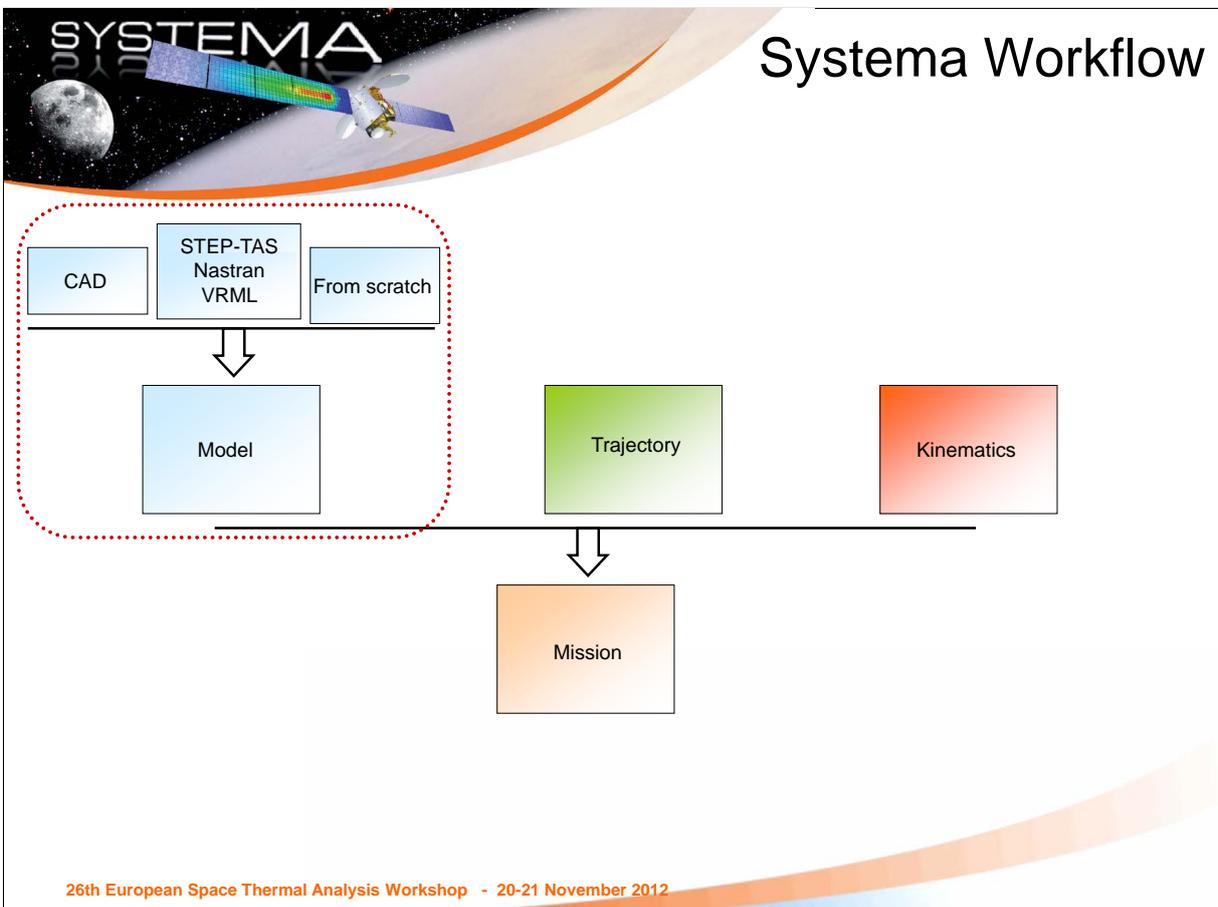


## Systema v4.5.1 – current status

- Python scripting
- Timeline is available in both the Trajectory & Mission module
- Curve & table view for post-processing
- Ray display

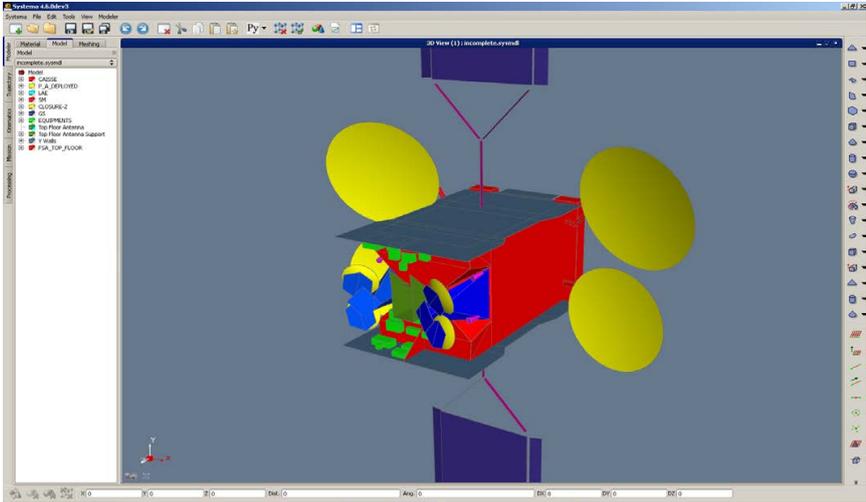
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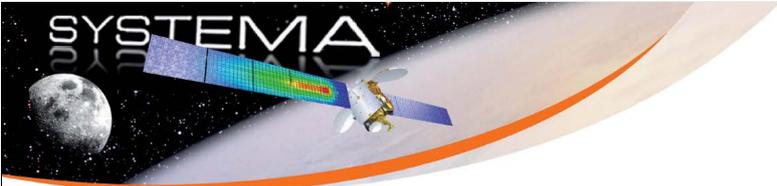
# Demonstration

- Loading of the reference model



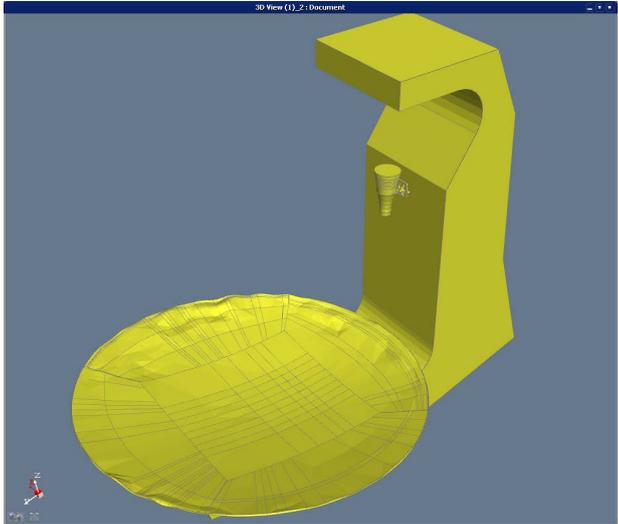
- We will work on a typical Telecom satellite

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# STEP-AP203

- Systema manages STEP files in import

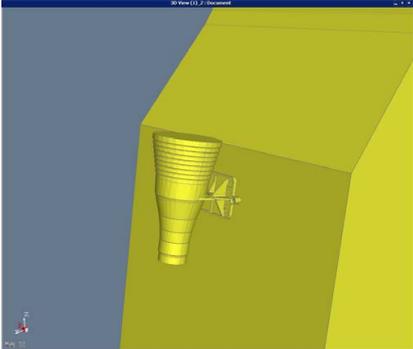
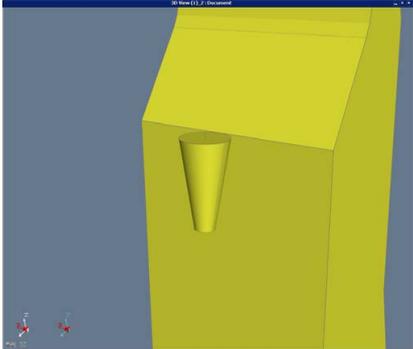


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## STEP-AP203



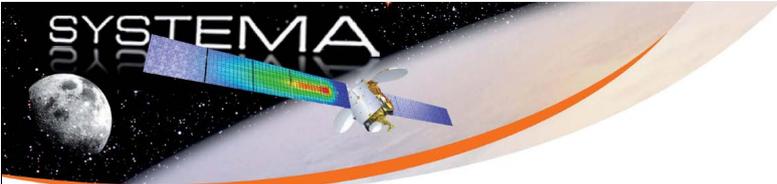
- Simplifications can be done directly in the framework


→


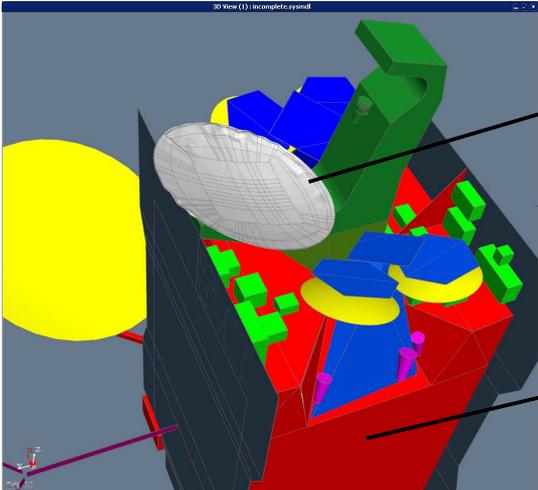
- Computation can be made directly on the STEP
- Or the STEP can be converted into Systema's model

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## STEP-AP203



- Mixing of models from different sources



Imported from CAD

Systema's native shapes

- Adaptation using transformations

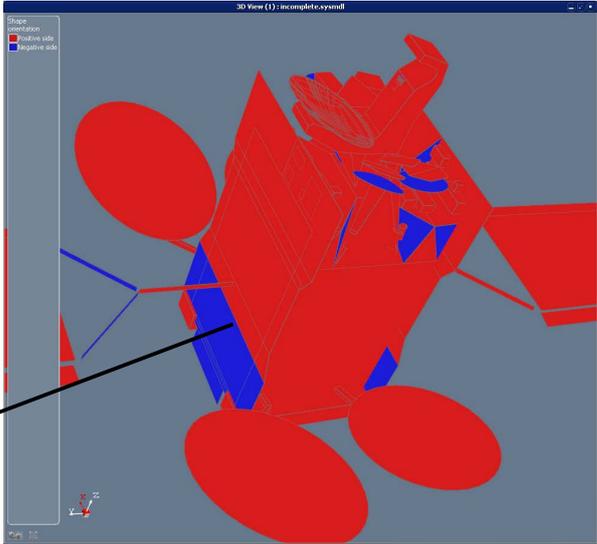
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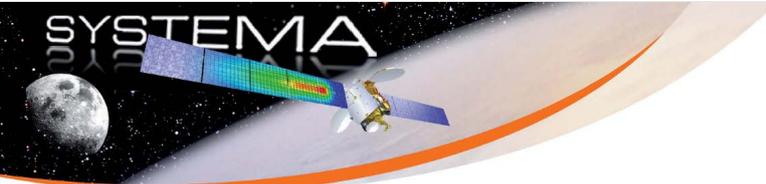
## Model checking

- Shape orientations are easy to check out and modify using the 3D

Shape orientation discrepancies



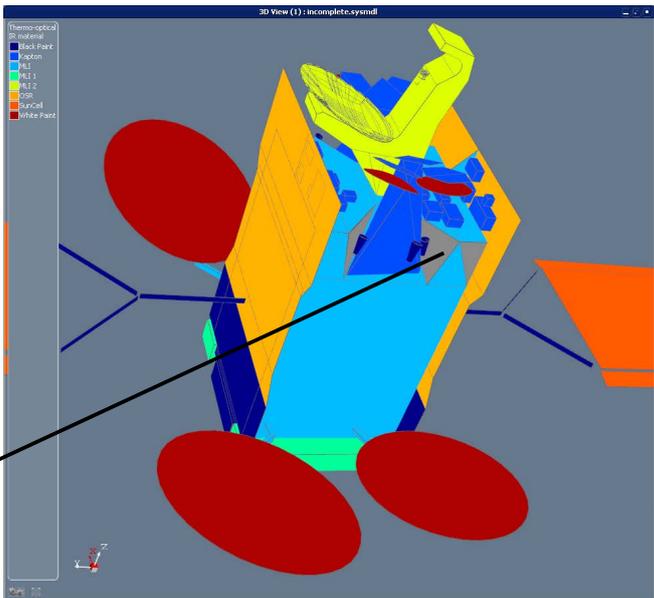
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## Model checking

- As shape orientations, the different materials can be displayed
  - Materials & physical properties can be set in the browser view

No material is defined



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## Model checking

- Complex checking using Python
- I want to verify that my node numbering is within my specifications

*Text file*

GS: [7500-8800]  
 Reflectors: [5000-5700]  
 Feeds: [500000-540000]

Returns and displays the out-of-spec meshes

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## Systema Workflow

CAD

STEP-TAS  
Nastran  
VRML

From scratch

Model

Analytical

Positions table

Trajectory

Kinematics

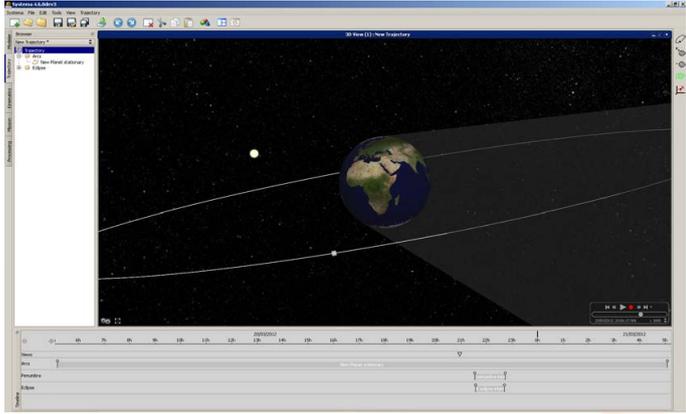
Mission

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# Trajectory



- Systema allows the user to easily define its trajectory
- Sun-synchronous, geo-stationary & general keplerians orbits are available



- Display of eclipses

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# Systema Workflow



CAD    STEP-TAS  
Nastran  
VRML    From scratch

↓

Model

Analytical    Positions table

↓

Trajectory

S/C attitude    Mobile elements attitude

↓

Kinematics

↓

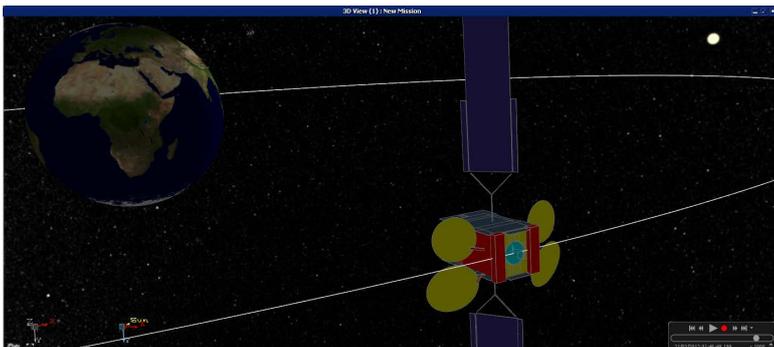
Mission

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# Kinematics



- Definition of the S/C attitude
- Definition of the orientation of the GS

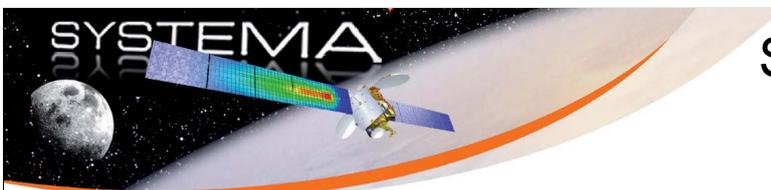


*Correct orientation of the S/C and its solar arrays*

- Pointing laws to planets, sun, velocity vector ; linear rotations ; attitudes defined by tabulated data are available

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# Systema Workflow



```

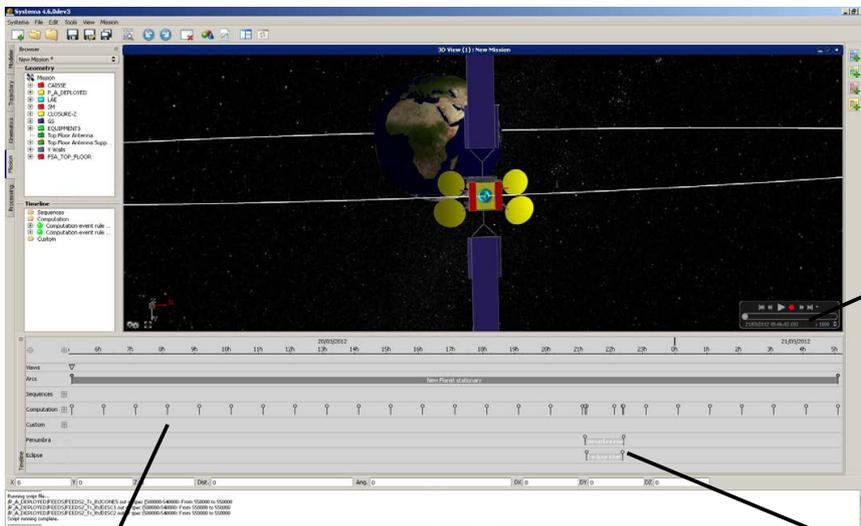
    graph TD
      subgraph Inputs
        I1[CAD]
        I2[STEP-TAS  
Nastran  
VRML]
        I3[From scratch]
        I4[Analytical]
        I5[Positions table]
        I6[S/C attitude]
        I7[Mobile elements attitude]
      end
      subgraph Processing
        M[Model]
        T[Trajectory]
        K[Kinematics]
      end
      subgraph MissionPhase [Mission]
        CP[Computation points]
        MI[Mission]
        O3D[3D]
        OTherm[Thermica]
        OLog[Log files]
      end
      I1 --> M
      I2 --> M
      I3 --> M
      I4 --> T
      I5 --> T
      I6 --> K
      I7 --> K
      M --> MI
      T --> MI
      K --> MI
      CP --> MI
      MI --> O3D
      MI --> OTherm
      MI --> OLog
  
```

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## Mission



- The mission scenario can be set up within seconds



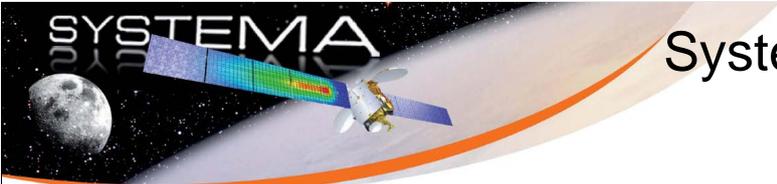
Real-time visualization

Computation points

Eclipse interval

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## Systema Framework... In a nutshell



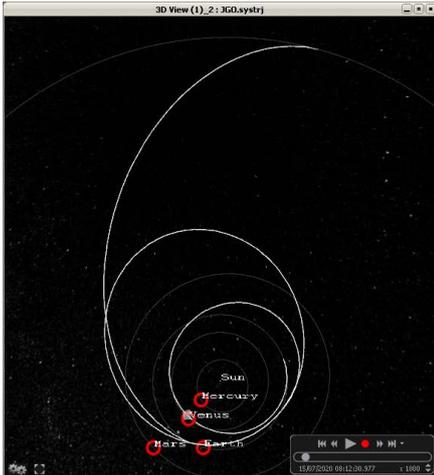
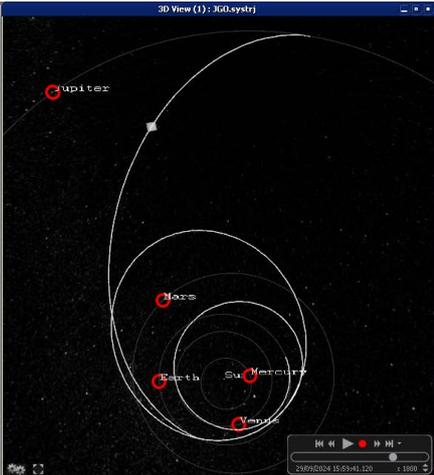
- Easy interfacing
  - With CAD
  - With NASTRAN
  - With AOCS tools
  - Using Python
- Gives integral access to the data
  - In 3D
  - With the time line
  - Using Python
  - As textual information
- A powerful mission creation
  - Can be created with a snap of the fingers
  - Complete trajectory & kinematics management

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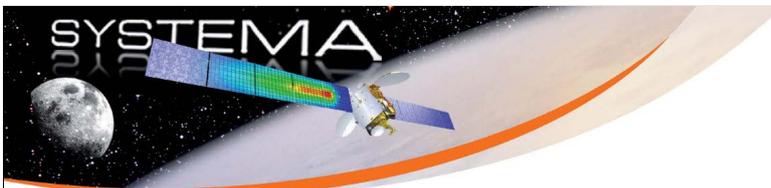
## Additional slide Trajectory

- For complex trajectories, possibility to use tabulated data
- Full & real-size solar system

*Jupiter Ganymede Orbiter example trajectory – Venus flyby (left) – Jupiter approach (right)*

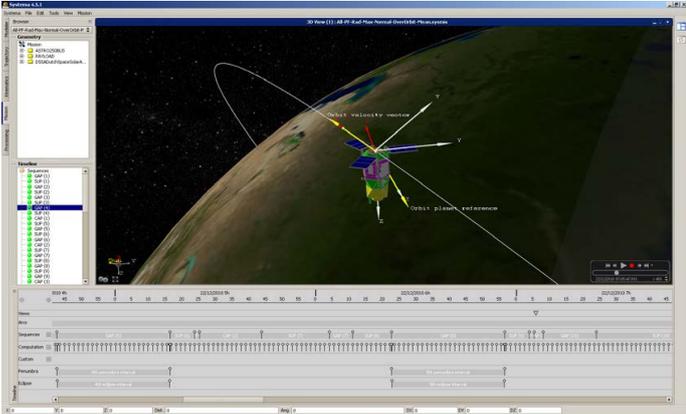
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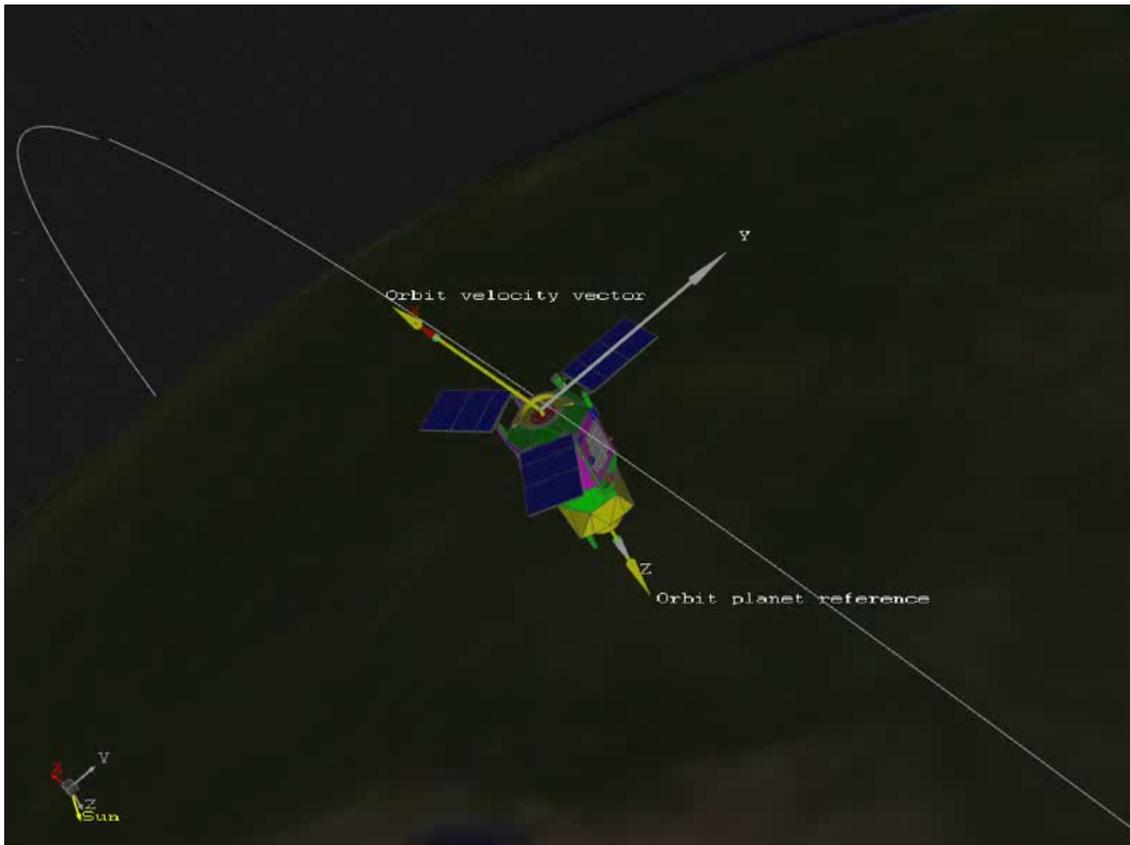
## Additional slide Sequences

- To create complex mission plan
- Typically, for an EO satellite
  - Acquisition period
  - Charging (Solar arrays pointing the Sun)
  - Waiting (Earth pointing)

[Cf video](#)



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Slow Normal Fast Play/Pause Stop



**SYSTEMA**  
**THERMICA**  
**THERMISOL**

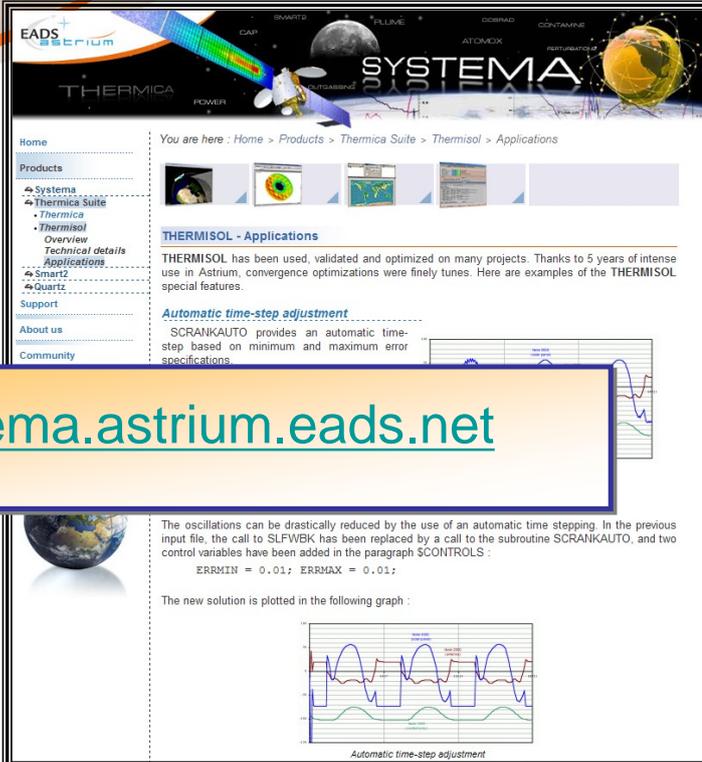
Visit our Web site :

[www.systema.astrium.eads.net](http://www.systema.astrium.eads.net)

Contact :

timothee.soriano@astrium.eads.net  
maxime.jolliet@astrium.eads.net  
anne.millet@astrium.eads.net

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**SYSTEMA**  
**THERMICA**  
**THERMISOL**

**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 tuned. Here are examples of the THERMISOL special features.

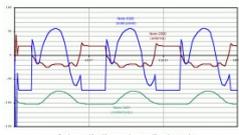
**Automatic time-step adjustment**

SCRANKAUTO provides an automatic time-step based on minimum and maximum error specifications

ERRMIN = 0.01; ERRMAX = 0.01;

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 :

The new solution is plotted in the following graph :



Automatic time-step adjustment



# Appendix I

## SYSTEMA-THERMICA Demonstration Part 2

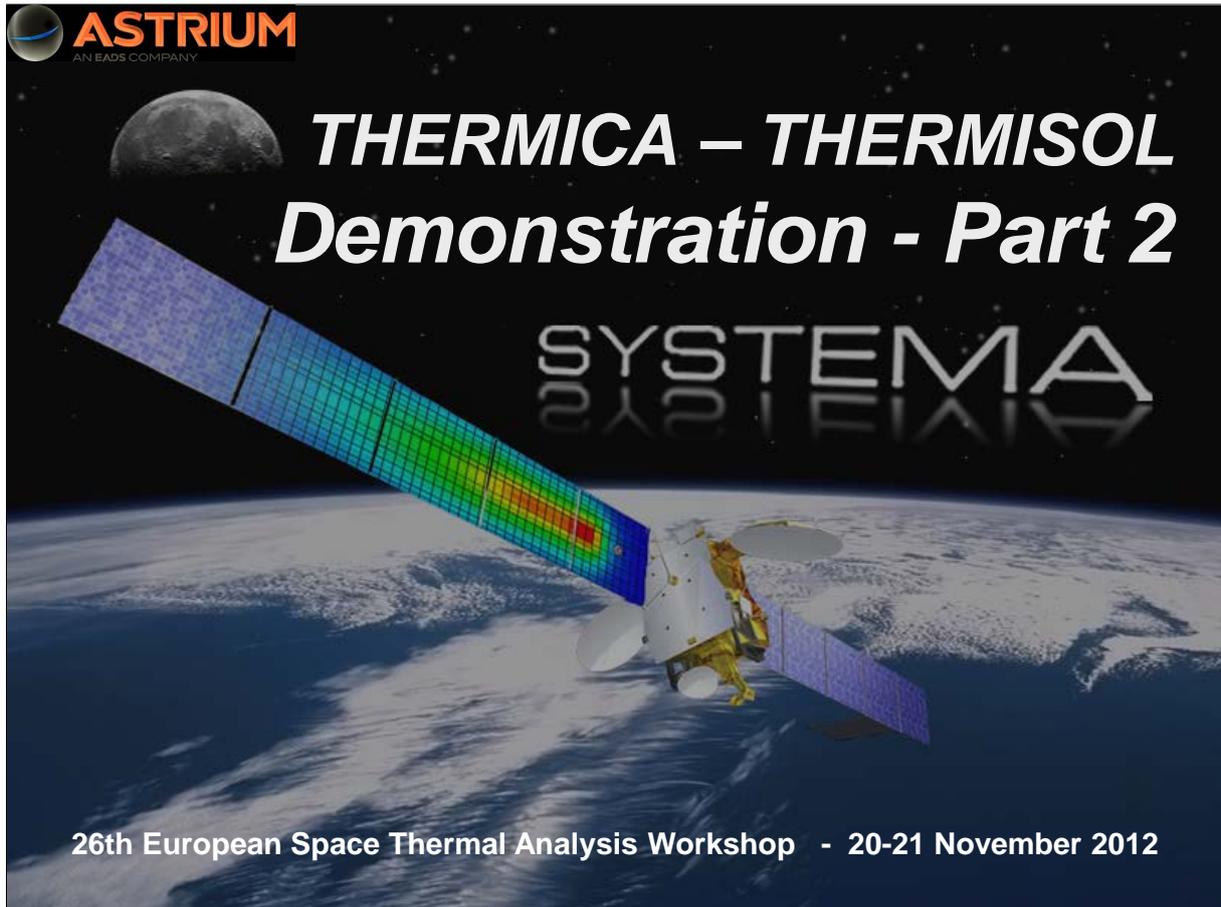
Timothée Soriano      Maxime Jolliet  
(Astrium, France)

### **Abstract**

Following the previous part of this SYSTEMA-THERMICA demonstration, this second part focuses on the simulations and results handling.

In particular, this second part covers:

- THERMICA analysis
  - Multi-threading and Ray-Tracing acceleration
  - Accuracy and modelling error handling
  - THERMICA processes and options
- THERMISOL analysis
  - Skeleton management
  - Temperature computation
  - Post-Processing toolbox
- SYSTEMA post-processing
  - 3D results mapping and video recording
  - Advanced dynamic curve, table views and csv export
  - Ray visualization

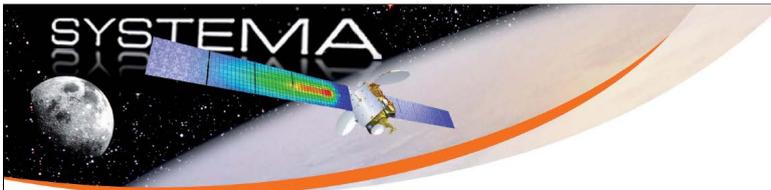


## Demonstration

Part 2

- **SYSTEMA: Process**
  - Global View of full process, links, inputs and outputs
  - Access to processes options

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## Demonstration

*Part 2*

- **SYSTEMA: Process**
  - Selective Module's executions

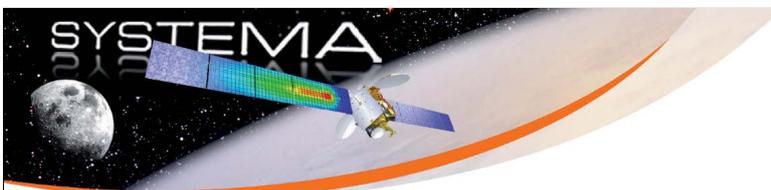
**Process run**

Select which processes you want to run :

Process	Status
<input type="checkbox"/> Mission	No execution required
<input type="checkbox"/> Nodal_Descri...	No execution required
<input type="checkbox"/> Conduction	No execution required
<input type="checkbox"/> Radiation	No execution required
<input type="checkbox"/> Solar_Flux	No execution required
<input type="checkbox"/> Planet_Fluxes	No execution required
<input checked="" type="checkbox"/> Skeleton	Execution required : run parameters have been updated
<input checked="" type="checkbox"/> Solver	Execution required : a previous process is executed

Overwritten files Cancel Run

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## Demonstration

*Part 2*

- **Process Outputs**
  - LOG: Execution summary report
  - NWK: Network files dedicated to the temperature solver
  - H5: HDF5 results, rays...
  - ...

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## Demonstration Part 2

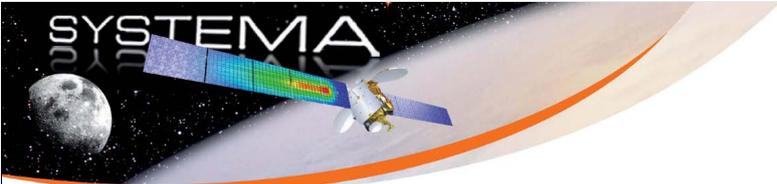
- THERMICA: Nodal Description
  - Parametric Material Outputs

```

$MODEL Mission
# Material Properties
$LOCALS
$REALS
# MLI
EPS_MLI = 0.710;
ALP_MLI = 0.520;
# Black_Paint
EPS_Black_Paint = 0.900;
ALP_Black_Paint = 0.950;
# White_Paint
EPS_White_Paint = 0.810;
ALP_White_Paint = 0.250;
# MLI_1
EPS_MLI_1 = 0.800;
ALP_MLI_1 = 0.590;
# SunCell
EPS_SunCell = 0.820;
ALP_SunCell = 0.740;
# Kapton
EPS_Kapton = 0.850;
ALP_Kapton = 0.850;
# MLI_2
EPS_MLI_2 = 0.900;
ALP_MLI_2 = 0.950;
# OSR_1
COND_OSR_1 = 1.64;
DENS_OSR_1 = 2530.00;
CP_OSR_1 = 821.00;
# OSR
EPS_OSR = 0.810;
ALP_OSR = 0.059;

```

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## Demonstration Part 2

- THERMICA: Nodal Description
  - Sub-Model management
  - Use of specific Items

```

$CONDUCTORS
# Surface Contact: Surface Contact (1)
GL( Equipments:1 , 400 ) = 1.898E+000;
GL( Equipments:2 , 300 ) = 5.695E+000;
GL( Equipments:3 , 300 ) = 2.989E+000;
GL( Equipments:4 , 400 ) = 2.347E+000;

$INITIAL
# Capacitance Overloads :
# Capacitance Overload (1)
C:Equipments:1 = 3500
# Capacitance Overload (2)
C:Equipments:2 = 2600
# Capacitance Overload (3)
C:Equipments:3 = 1850
# Capacitance Overload (4)
C:Equipments:4 = 2485

# Internal Dissipations :
# Internal Dissipation (1)
QI:Equipments:1 = 20
# Internal Dissipation (2)
QI:Equipments:2 = 30
# Internal Dissipation (3)
QI:Equipments:3 = 35
# Internal Dissipation (4)
QI:Equipments:4 = 48

```

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## Demonstration

*Part 2*

- **THERMICA: Conduction**
  - Nwk: Edge definitions, Coupling structure

```

$EDGES
E = 100000|E1, A = 6.6657E-001 * 5.0000E-003;
E = 100000|E2, 100500|E8, A = 3.0010E-001 * 5.0000E-003;
E = 100000|E3, 100002|E4, A = 1.0557E+000 * 5.0000E-003;
E = 100000|E4, 100100|E4, A = 9.6667E-001 * 5.0000E-003;
E = 100000|E5, A = 1.0557E+000 * 5.0000E-003;

$CONDUCTORS
# Couplings from node 100002
GL(100002, 100002|E1) = 2.747E-002 * COND_OSR_1;
GL(100002, 100002|E2) = 3.276E-002 * COND_OSR_1;
GL(100002, 100002|E3) = 2.747E-002 * COND_OSR_1;
GL(100002, 100002|E4) = 3.276E-002 * COND_OSR_1;
GL(100002|E1, 100002|E2) = -1.468E-005 * COND_OSR_1;
GL(100002|E1, 100002|E3) = -9.144E-003 * COND_OSR_1;
GL(100002|E1, 100002|E4) = -1.468E-005 * COND_OSR_1;
GL(100002|E2, 100002|E3) = -1.468E-005 * COND_OSR_1;
GL(100002|E2, 100002|E4) = -1.090E-002 * COND_OSR_1;
GL(100002|E3, 100002|E4) = -1.468E-005 * COND_OSR_1;

```

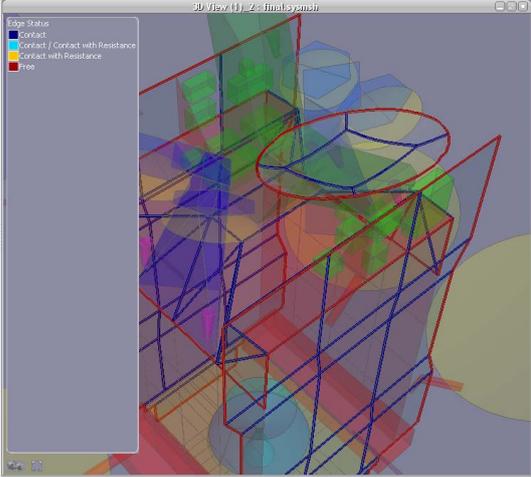
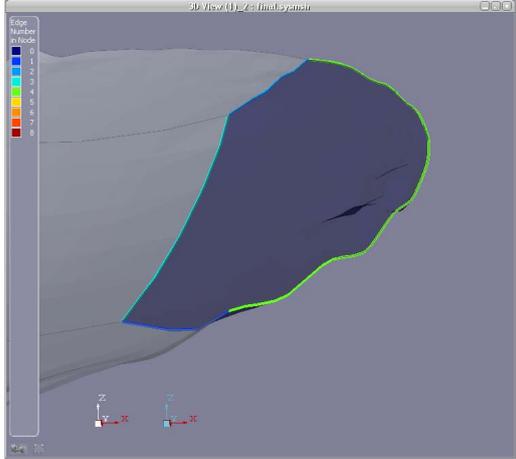
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## Demonstration

*Part 2*

- **THERMICA: Conduction**
  - Visualization of Edges and their properties in 3D model

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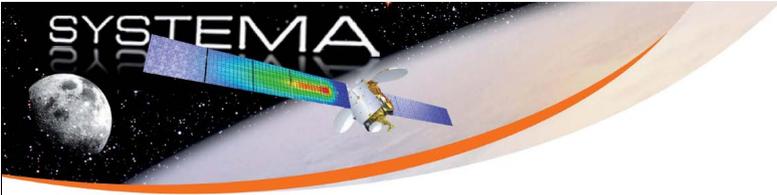




## Demonstration Part 2

- **THERMICA: Radiation**
  - Multi-threaded Application
    - Number of active threads : 4 ( / 4 available)
  - Smart *Copy* or *Skip* of orbital position computations
    - orbital position 15/40 - *copying position 14*

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## Demonstration Part 2

- **THERMICA: Radiation**
  - Superposition Management

Log:

```
* WARNING *
Superposition within node: Node 80500 (0.772363 %)
(area of node adjusted to: 2.59412)
```

Nwk:

```
$INITIAL
# Corrections of area due to overlapping (1 nodes concerned)
A80500 = 2.594E+000
```

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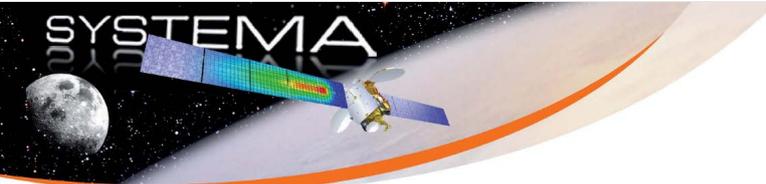
## Demonstration Part 2

- **THERMICA: Radiation**
  - Error Estimation:
 

IR Gebhart Factor Budget :

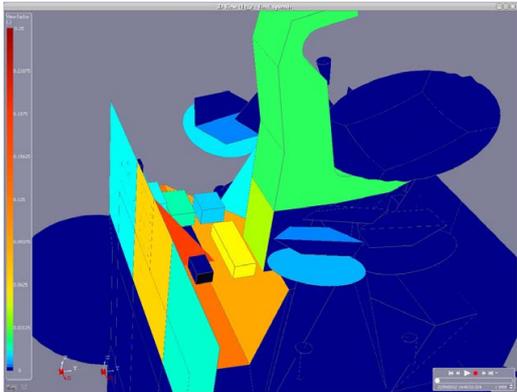
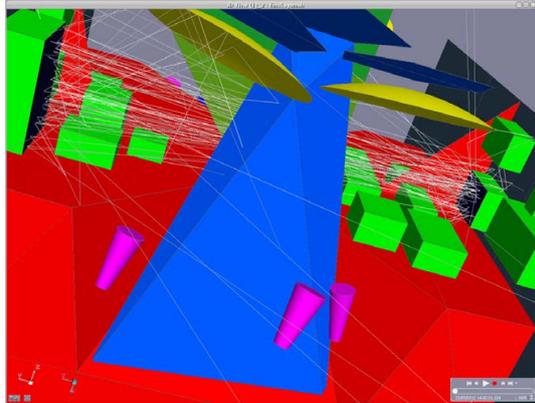
Emission Node	Rays Emitted	REF sum	Error
80500	9982	0.9847	1.53 %
10300	10000	1.01	1.04 %
<b>Number of nodes with less than 1 % of error:</b>		237	( 99.2 %)
  - Other Tables:
    - Inactive Impingements
    - Low Space Couplings

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## Demonstration Part 2

- **THERMICA: Radiation**
  - 3D Mapping and Ray-Visualization
 

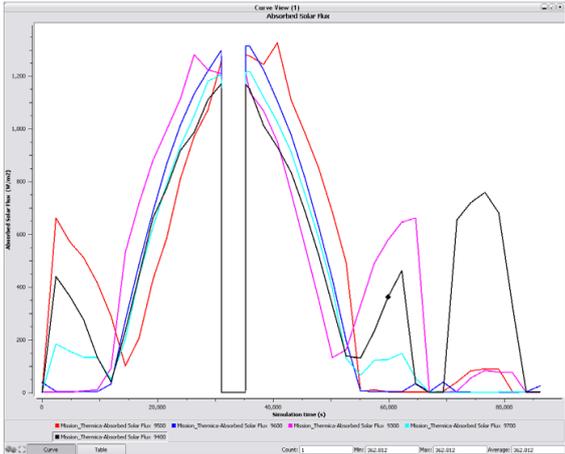



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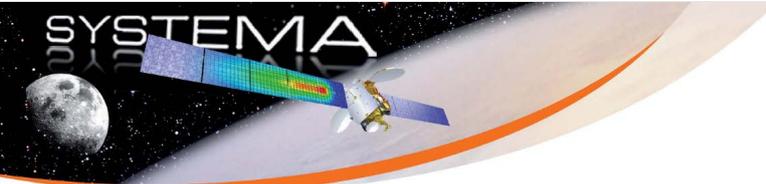


## Demonstration Part 2

- **THERMICA:** External fluxes
  - Curve View - *export to jpeg file*



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## Demonstration Part 2

- **THERMICA:** External fluxes
  - Table View *export to csv file*

Simulation time (s)	Mission_Thermica-Absorbed Solar Flux (W/m2)						
	9500	9300	9400	Equipments:1	Equipments:2	Equipments:3	
0.000	3.456	0.252	1.523	18.887	46.381	0.000	
2393.349	663.527	1.406	441.267	34.260	61.973	2.509	
4786.707	572.344	1.465	365.927	26.885	52.016	1.445	
7180.065	512.774	5.834	276.892	24.483	45.988	1.487	
9573.422	416.758	10.489	134.185	95.320	157.206	0.599	
11966.772	291.150	92.336	39.747	268.305	280.495	4.591	
14360.129	101.070	531.729	233.260	331.153	349.033	21.511	
16753.487	206.394	718.539	444.488	387.513	396.647	115.092	
19146.845	427.868	879.450	661.067	437.973	451.307	209.255	
21540.194	584.737	996.458	777.036	451.611	496.007	295.593	
23933.552	810.496	1114.860	918.803	36.962	513.519	248.030	
26326.909	973.451	1282.398	987.976	43.024	531.947	15.200	
28720.259	1073.433	1225.079	1112.713	288.314	471.572	2.175	
30976.085	1256.569	1210.838	1171.558	60.514	381.043	1.959	
31103.595	0.000	0.000	0.000	0.000	0.000	0.000	
33506.974	0.000	0.000	0.000	0.000	0.000	0.000	
35151.710	0.000	0.000	0.000	0.000	0.000	0.000	
35279.211	1282.837	1209.336	1170.195	7.811	11.475	10.937	
35900.332	1277.707	1140.020	1150.447	1.768	38.899	19.859	
38293.681	1245.267	1070.027	1014.321	3.540	20.729	114.874	
40687.039	1327.142	951.810	932.317	3.160	26.701	494.283	
43080.396	1109.863	757.944	834.619	17.855	8.991	493.740	

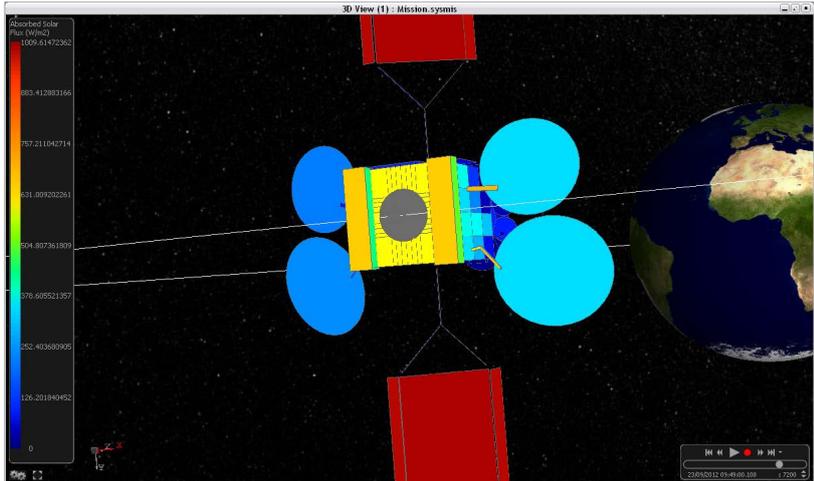
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## Demonstration

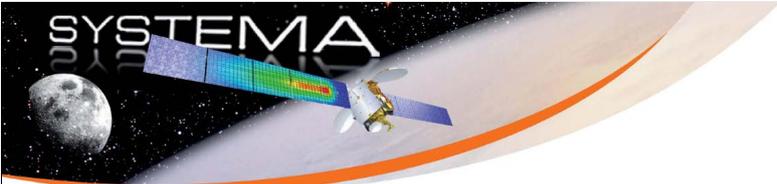
Part 2

- **THERMICA:** External fluxes
  - 3D and 4D Animated Results - export to jpeg / mpeg file



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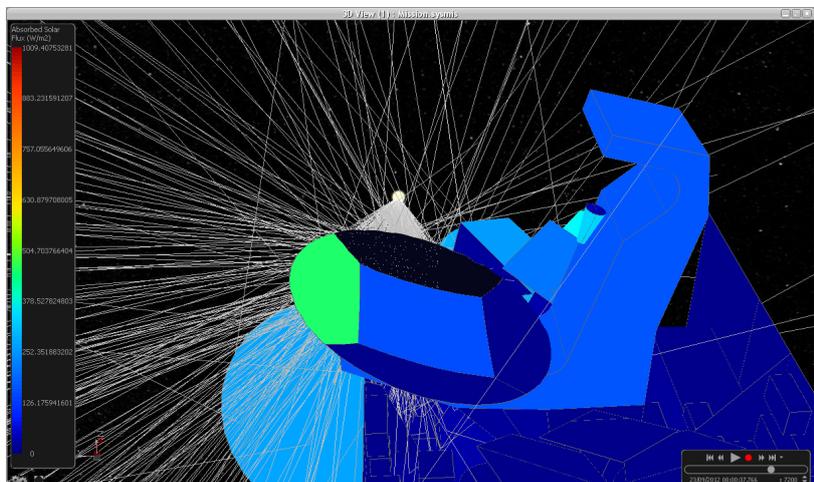




## Demonstration

Part 2

- **THERMICA:** External fluxes
  - Ray Display



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## Demonstration

Part 2

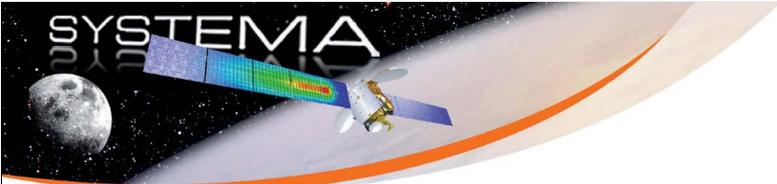
- THERMISOL: Skeleton
  - Easy Data collection

```
#USE "Mission.nod.nwk"
#USE "Mission.gl.nwk"
#USE "Mission.gr.nwk"
#USE "Mission.fp.nwk"
#USE "Mission.fs.nwk"

$INFOS
$MODEL #READ-MODELNAME "Mission.nod.nwk"
$LOCALS
$NODES
[...]
```

Skeleton File

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## Demonstration

Part 2

- THERMISOL: Solver
  - Pre-Processor: Model Verification & Error Checking

```
*****
WARNING  Undeclared Symbols found !!!
*****
- WVAR   has been found 1 times in file Model.dck at lines 21430
*****
```

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# Demonstration

*Part 2*

- **THERMISOL: Solver**
  - Pre-Processor: Model Verification & Error Checking

```

Sizes:
- Number of Models : 2
- Number of Thermal Nodes : 245
- Number of Thermal Edges : 249
- Number of GL : 1075
- Number of GR : 6050
- Number of GRWLB : 0
- Number of GF : 0
- Number of Electric Nodes : 0
- Number of Electric Components : 0
Model 'Mission':
- Number of Events : 0
- Number of Thermal Nodes : 230
- Number of Electric Nodes : 0
--> Warning : Thermal Node 5800 has no connection
--> Warning : Thermal Node 5900 has no connection
--> Warning : Thermal Node 6000 has no connection
--> Warning : Thermal Node 6100 has no connection
--> Warning : Thermal Node 6200 has no connection

- List of unused symbols :
-- GVAR (real)
-- ECLFLG (real array)
Model 'Mission:Equipments':
- Number of Events : 0
- Number of Thermal Nodes : 15
- Number of Electric Nodes : 0
    
```

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# Demonstration

*Part 2*

- **THERMISOL: Solver**
  - Execution Summary Report

Transient run : Crank-Nicholson										
Time Variables			Implicit Convergence			Time Discretisation Error				
% TIME	TIMEN	DTIMEU	LOOPCT	RELXCC	NRLXCC	ENBALT	ERRT	NERRMAX	DT OPT	
1 ----->	0.00000 %	0	172.32	27	-3.88E-05	4000 ( Mission)	7.42E-05	5.60E-01	3500 ( Mission)	40.528
1 ----->	2.00000 %	1723.2	172.32	19	6.52E-05	4700 ( Mission)	1.03E-04	4.79E-03	4600 ( Mission)	198.254
1 ----->	4.00000 %	3446.4	172.32	19	5.66E-05	4100 ( Mission)	9.09E-05	4.15E-03	4500 ( Mission)	207.931
1 ----->	6.00000 %	5169.6	172.32	50	-9.68E-05	4100 ( Mission)	1.10E-04	3.14E-01	3600 ( Mission)	49.137
1 ----->	8.00000 %	6892.8	172.32	16	6.54E-05	4700 ( Mission)	1.60E-04	3.36E-04	4900 ( Mission)	480.609
1 ----->	10.00000 %	8616	172.32	94	9.54E-05	900 ( Mission)	8.66E-05	9.29E-04	4900 ( Mission)	342.382
1 ----->	12.00000 %	10339.2	172.32	17	5.98E-05	4100 ( Mission)	1.19E-04	3.19E-03	4500 ( Mission)	226.927
1 ----->	14.00000 %	12062.4	172.32	21	-3.84E-05	4700 ( Mission)	6.38E-05	1.16E-01	4600 ( Mission)	68.504
1 ----->	16.00000 %	13785.6	172.32	17	-6.17E-05	4700 ( Mission)	9.67E-05	1.25E-03	3 ( Equipments)	310.252
1 ----->	18.00000 %	15508.8	172.32	15	9.05E-05	4100 ( Mission)	8.94E-04	3.42E-03	4400 ( Mission)	221.766
1 ----->	20.00000 %	17232	172.32	17	-6.11E-05	4100 ( Mission)	9.27E-05	1.87E-02	4600 ( Mission)	125.918
1 ----->	22.00000 %	18955.2	172.32	16	8.45E-05	4700 ( Mission)	3.95E-04	5.71E-04	5 ( Equipments)	402.662
1 ----->	24.00000 %	20678.4	172.32	17	-7.59E-05	4100 ( Mission)	2.57E-04	1.22E-03	4900 ( Mission)	312.861
1 ----->	26.00000 %	22401.6	172.32	20	-8.81E-05	4100 ( Mission)	1.18E-04	1.26E-02	3600 ( Mission)	143.713

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# Demonstration

Part 2

- THERMISOL: Solver
- Results Report

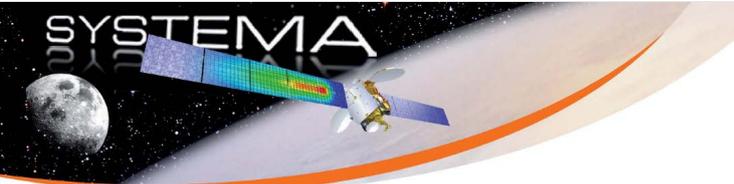
```
PRNDTB ' ', 'L,C,T,QS,QA,QE,QI,QR' in model Mission (TIMEN = 0)

MODULE SCRANK
TIMEN = 0 (TIMEND = 86160)
DTIMBU = 172.32 (DTIMBI = 172.32)
LOOPCT = 28 (NLOOP = 1000)
ENBALT = 8.6136e-005 (INBALT = 1000)
RELKCC = -9.9363e-005 (RELKCA = 0.0001) at node 3800 in model
```

	MODEL	NODE	L	C	T	QS	QA	QE	QI	QR
Mission	100	D	Model/CAISSE/CLOSURE+X	0.000000	-119.521760	2.3623	0.069309	0.061389	0	0
Mission	101	D	Model/CAISSE/CLOSURE+X	0.000000	-126.563782	0.070773	0.15781	0.10553	0	0
Mission	102	D	Model/CAISSE/CLOSURE+X	0.000000	-122.770370	0.019602	0.23355	0.10069	0	0
Mission	103	D	Model/CAISSE/CLOSURE+X	0.000000	-129.265758	5.172e-008	0.2043	0.081003	0	0
Mission	104	D	Model/CAISSE/CLOSURE+X	0.000000	-141.402654	0.51721	0.06508	0.095743	0	0
Mission	105	D	Model/CAISSE/CLOSURE+X	0.000000	-129.394738	0.94562	0.20897	0.1329	0	0
Mission	106	D	Model/CAISSE/CLOSURE+X	0.000000	-128.378253	0.001628	0.2866	0.09078	0	0
Mission	107	D	Model/CAISSE/CLOSURE+X	0.000000	-134.960308	0	0.20401	0.10888	0	0
Mission	108	D	Model/CAISSE/CLOSURE+X	0.000000	-124.218373	3.6141	0.045	0.058222	0	0
Mission	109	D	Model/CAISSE/CLOSURE+X	0.000000	-133.540969	3.2304e-006	0.20547	0.084845	0	0
Mission	110	D	Model/CAISSE/CLOSURE+X	0.000000	-127.410547	0	0.25728	0.13741	0	0

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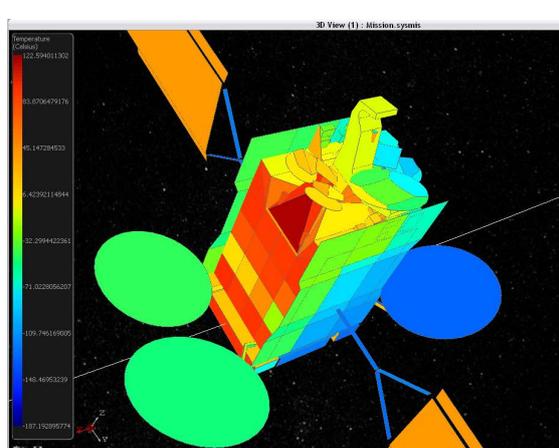


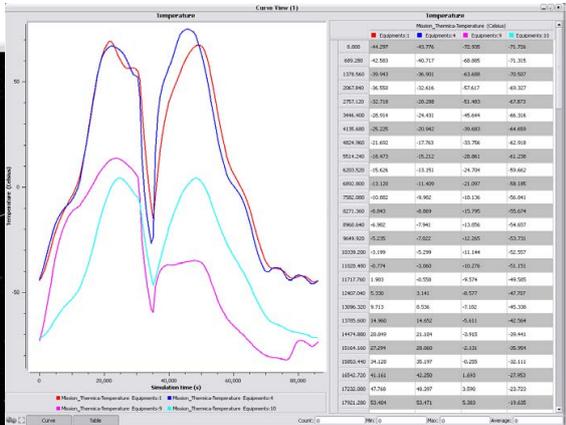


# Demonstration

Part 2

- THERMISOL: Solver
- SYSTEMA Display: Curve, Table, 3D, 4D





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# Demonstration

*Part 2*

- **Conclusions**
  - Easy and Visual Process management
  - Fast Process executions
  - Exhaustive Log files with Errors checking and handling
  - Powerful results display in SYSTEMA
- We are eager to collect users feedback to keep up with the improvement of the tool

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## SYSTEMA THERMICA THERMISOL

Visit our Web site :

[www.systema.astrium.eads.net](http://www.systema.astrium.eads.net)

**SYSTEMA THERMICA 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 tuned. Here are examples of the THERMISOL special features.

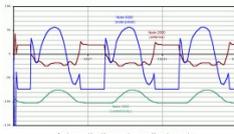
**Automatic time-step adjustment**

SCRANKAUTO provides an automatic time-step based on minimum and maximum error specifications.

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*

Contact :

timothee.soriano@astrium.eads.net  
maxime.jolliet@astrium.eads.net  
anne.millet@astrium.eads.net

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## Appendix J

### ESATAN Thermal Modelling Suite Product Developments

Henri Brouquet  
(ITP Engines UK Ltd, United Kingdom)

### **Abstract**

ESATAN-TMS provides a powerful and integrated thermal modelling environment. Last year saw a major evolution of the product's analysis capability with the introduction of the functionality to perform a combined finite element / lumped parameter analysis. Developments this year have continued on improving the modelling process, focusing on reducing the overall modelling time. This presentation outlines the developments going into the new release of the product.



26<sup>th</sup> European Thermal & ECLS Software Workshop  
ESA/Estec, Noordwijk, the Netherlands

# ESATAN Thermal Modelling Suite

## Product Status

Author: Henri Brouquet  
Date: 20<sup>th</sup> November 2012

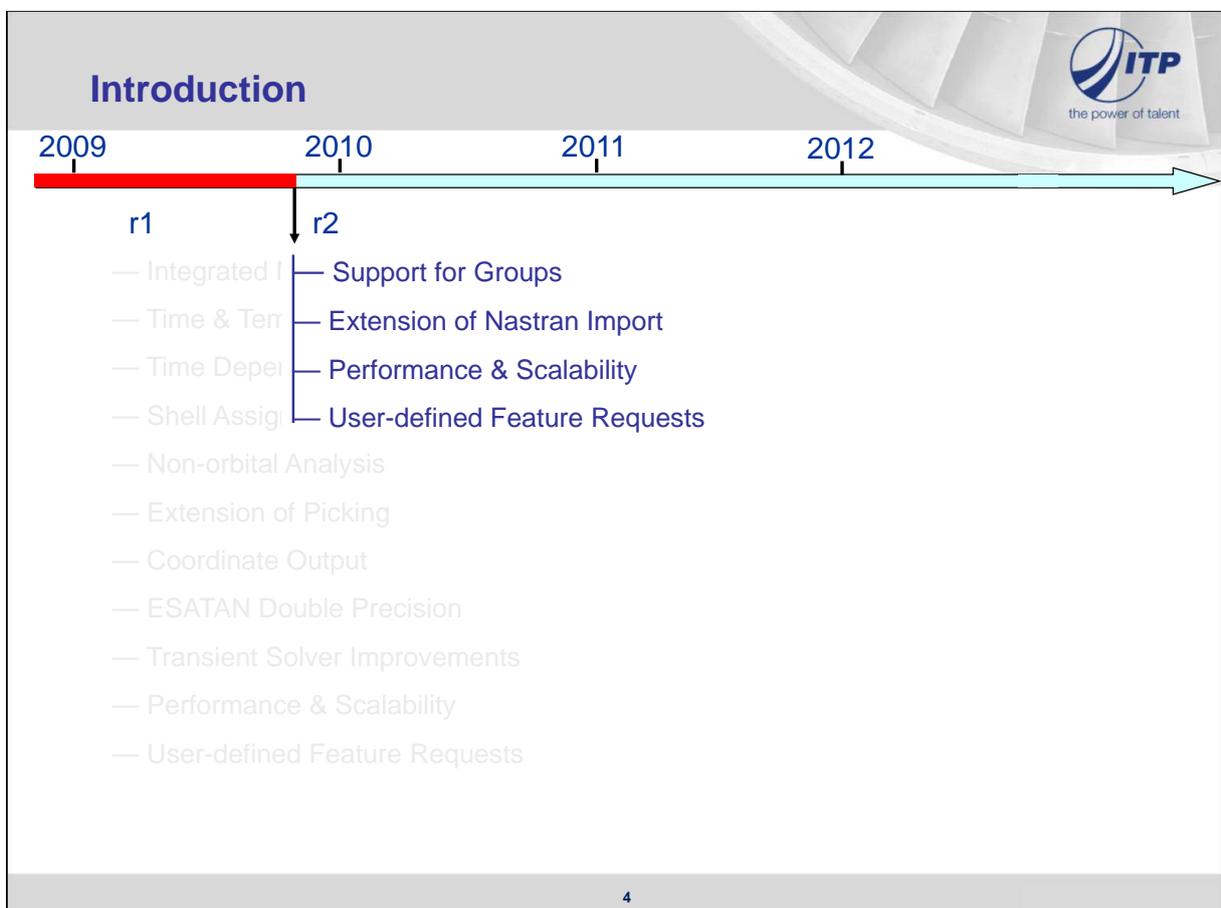
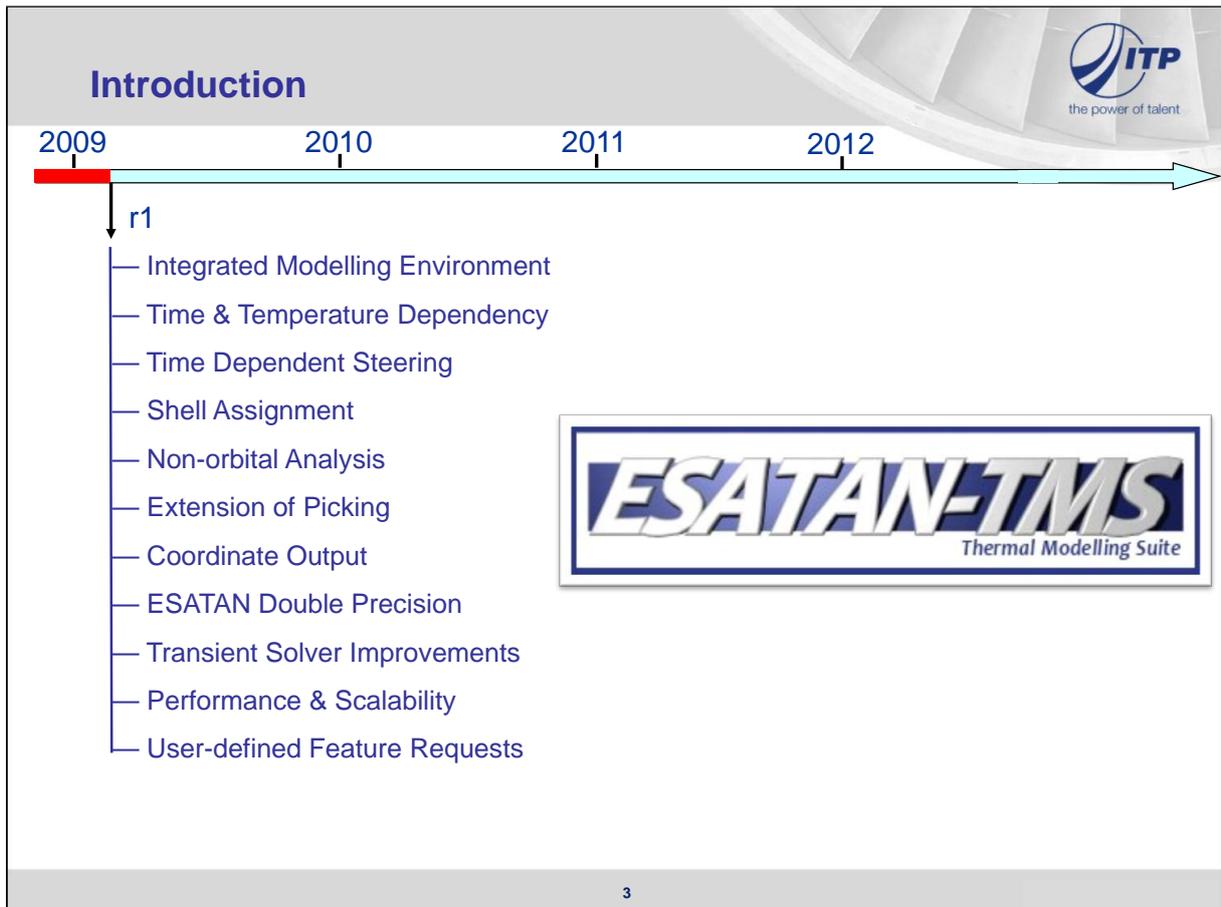


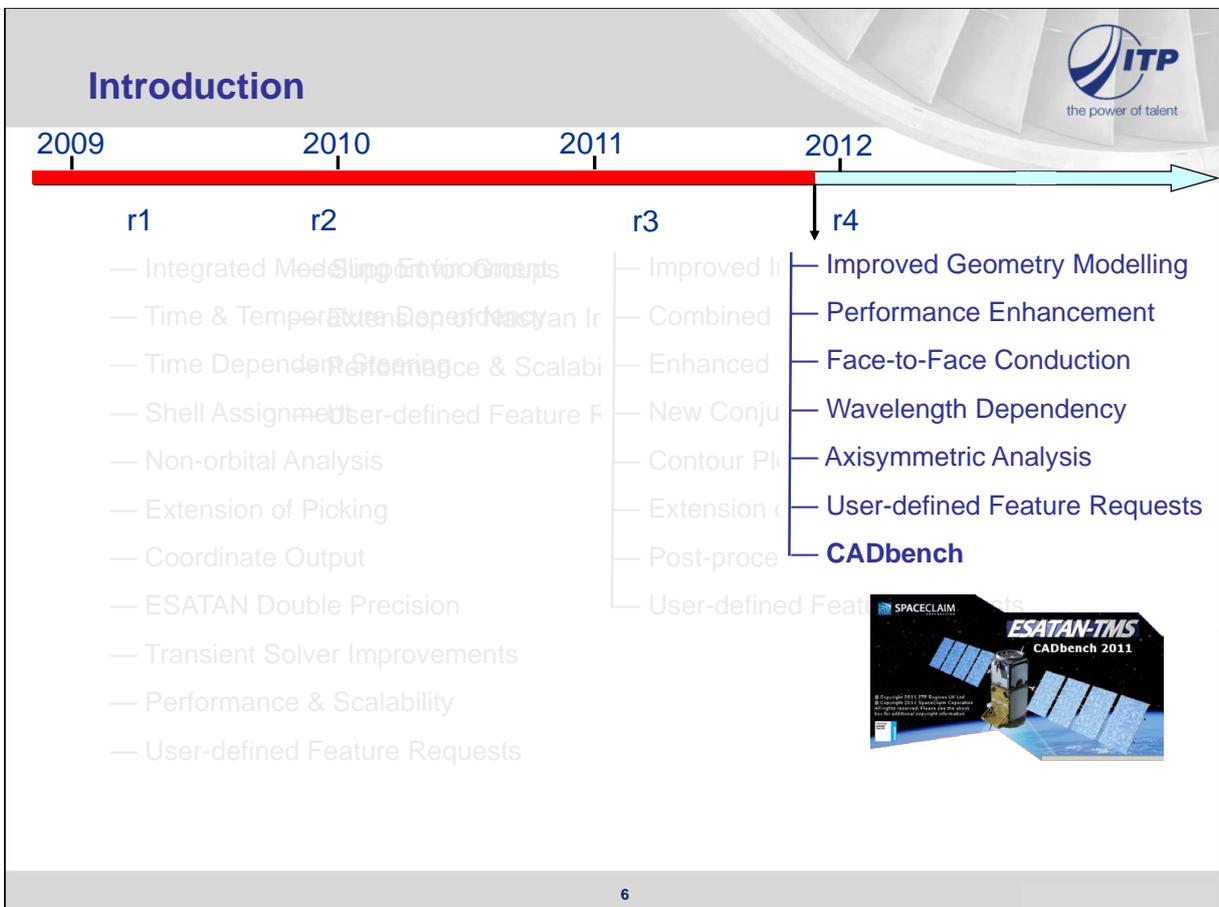
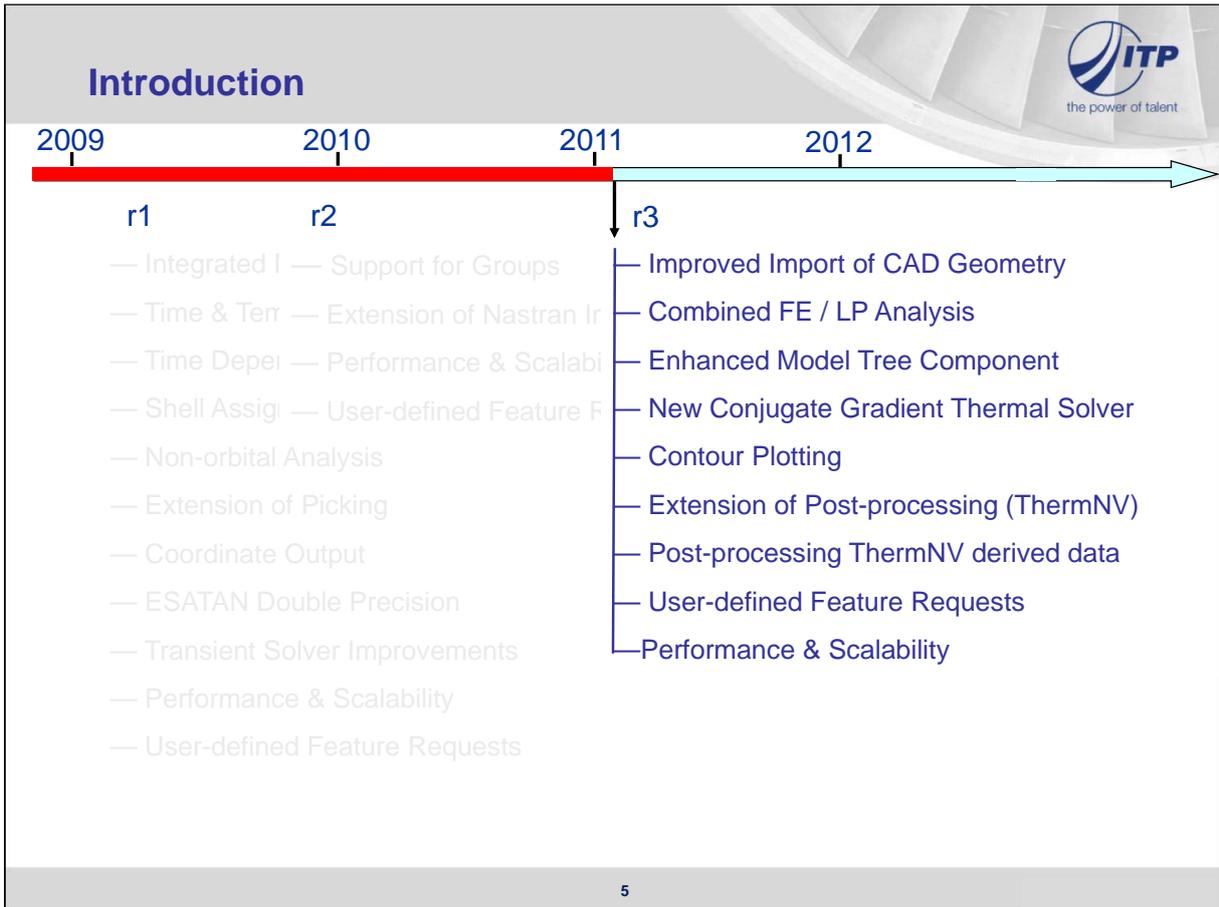
### Introduction



- 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







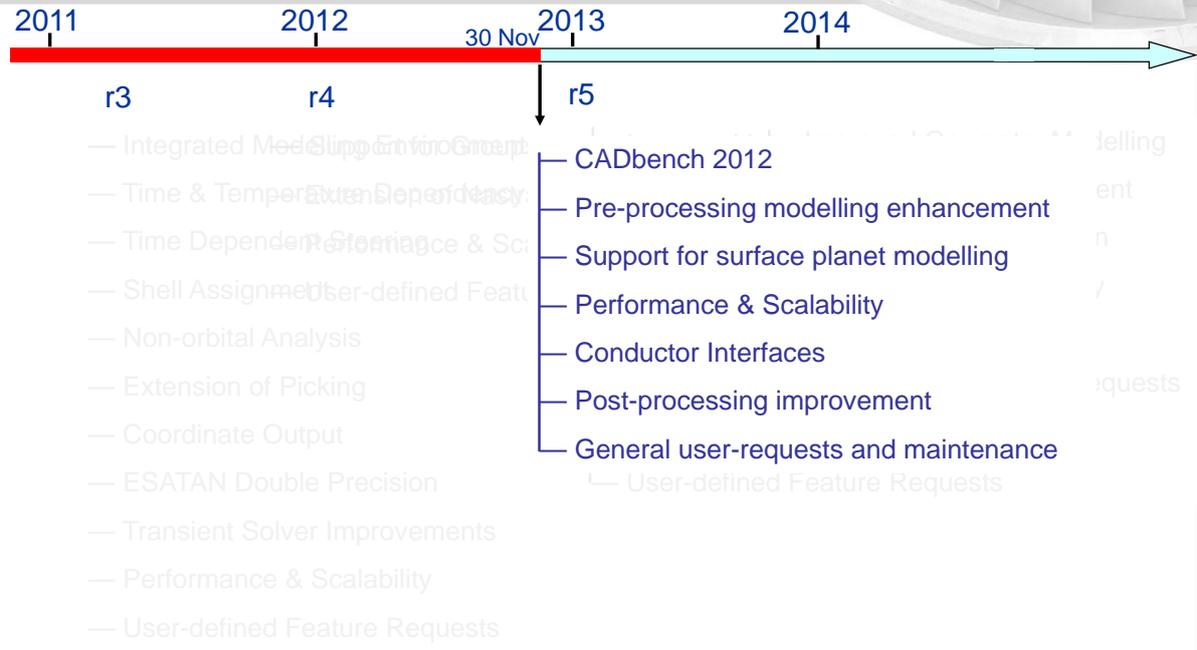
## Agenda

- New features in ESATAN-TMS r5
- Conclusion
- Beyond ESATAN-TMS r5
- Live Demo
- Coming Events

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## ESATAN-TMS r5



2011	2012	30 Nov 2013	2014
r3	r4	r5	
<ul style="list-style-type: none"> <li>— Integrated Model Support for Compact</li> <li>— Time &amp; Temperature Dependence</li> <li>— Time Dependent Powering &amp; Sizing</li> <li>— Shell Assignment</li> <li>— Non-orbital Analysis</li> <li>— Extension of Picking</li> <li>— Coordinate Output</li> <li>— ESATAN Double Precision</li> <li>— Transient Solver Improvements</li> <li>— Performance &amp; Scalability</li> <li>— User-defined Feature Requests</li> </ul>	<ul style="list-style-type: none"> <li>— CADbench 2012</li> <li>— Pre-processing modelling enhancement</li> <li>— Support for surface planet modelling</li> <li>— Performance &amp; Scalability</li> <li>— Conductor Interfaces</li> <li>— Post-processing improvement</li> <li>— General user-requests and maintenance                             <ul style="list-style-type: none"> <li>— User-defined Feature Requests</li> </ul> </li> </ul>		

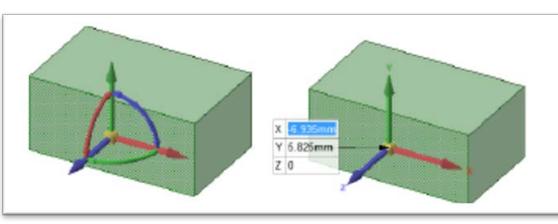
8



## CADbench 2012

- CADbench has been updated in line with SpaceClaim 2012
- Support for 32-bit and 64-bit platforms
- Improved capabilities to repair and prepare CAD model
  - new FixCurve ribbon
  - Extended midsurface capabilities
- Increased Move functionalities
  - X,Y,Z & Radial move
- Significant performance improvement



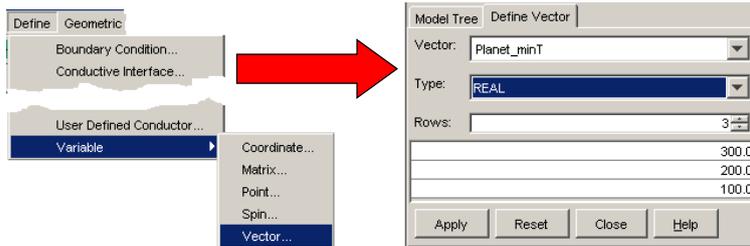


9



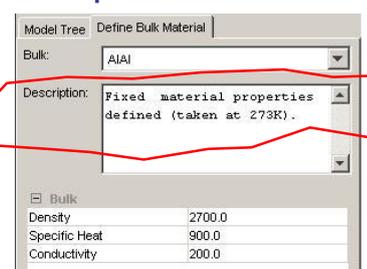
## Modelling enhancement

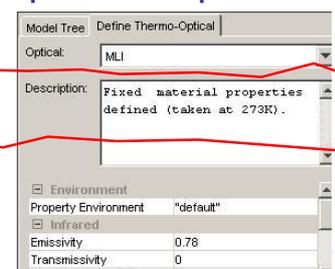
- Define Vector User Interface



e.g. Definition of Radiative Case True Anomaly and Planet Temperature map

- Description for Material & Optical Properties





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## Recursive Shell Properties extension



- Redesigned user interface
  - Vertical properties table format
  - Visibility & selection of shells
  - Consistent with Define dialog
- Global editing of mesh properties mesh density & mesh spacing
- All shell property attributes now available

Model Tree Recursive Shell Properties

Select Shells:

- shell38
- shell39
- shell4
- shell40
- shell41
- shell42

Mesh

- Faces along Direction 1
- Faces along Direction 2
- Faces along Direction 3
- Faces along Direction 4
- Ratio in Direction 1
- Ratio in Direction 2
- Ratio in Direction 3
- Ratio in Direction 4
- Analysis Type

Side 1

- Label
- Activity
- Radiative Criticality
- Submodel name
- Base Node Number
- Node Increment
- Optical Coating
- Colour

Side 2

- Label
- Activity
- Radiative Criticality
- Submodel name
- Base Node Number

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## Picking table extension



- Picking now extended to pick Shell and Point data
  - Controlled by Pick Mode
  - Point data includes Thermal Nodes
  - Result of current plot presented, e.g. Temperature
  - Average Face value given for FE Faces

Picking Mode:

Face

- Face
- Shell
- Point
- Direction
- Distance

Item	Attribute	Attribute Value	Node	Face	Coordinate	Optical Coating	Bulk Material	Emissivity ( $\epsilon$ )	Absorptivity ( $\alpha$ )
Shell						SolarCells["default"]	AIAI	.840	.750
Face	Temperature	39.3313 nodal avg	N/A	221		SolarCells["default"]	AIAI	.840	.750
Point	Temperature	38.9962	9015		[1.75263, 0.0, 0.0]				

Pick Shell, Face or Point data

Temperature of Face or Point

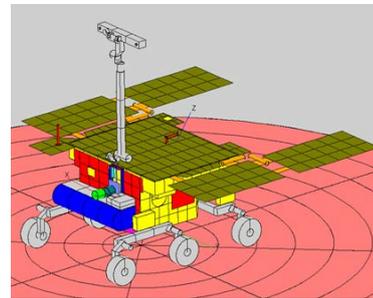
- Control of table columns provided
- Any attribute can be presented
- Order of columns can be controlled

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## Planet surface support



- Requirements
  - Simulate a model on the Planet surface and take into account heat fluxes with respect to the Planet / Sun position throughout the day
  - Model an array of solar connectors, focusing the solar rays to a single focus point
  
- Extension to the Radiative Case / Assembly definition
  - New option “Planet Surface”
  - Multiple Pointing directions
  - Pointing to the “bisecting angle”



Courtesy of Astrium UK

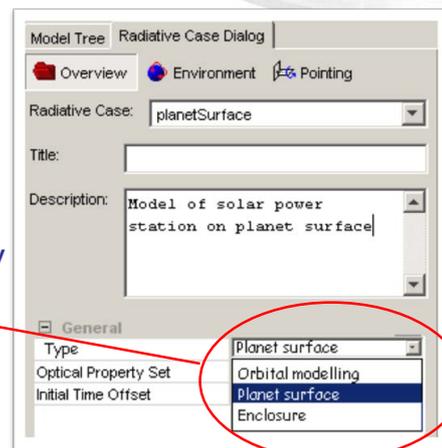
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## Planet surface support



### Planet Surface Radiative Case

- Model on the planet surface
- Include heat fluxes
  - Position on planet surface
  - Sun position throughout the day
- Select Radiative Case Type
  
- Enclosure option is the Ground Case where heat fluxes are not included



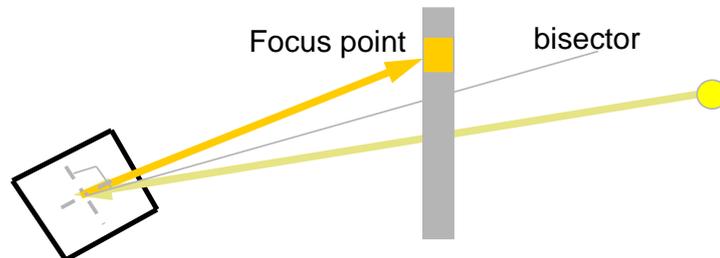
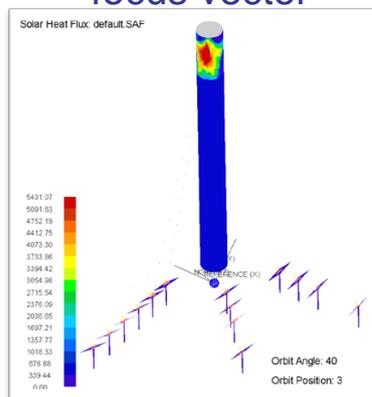
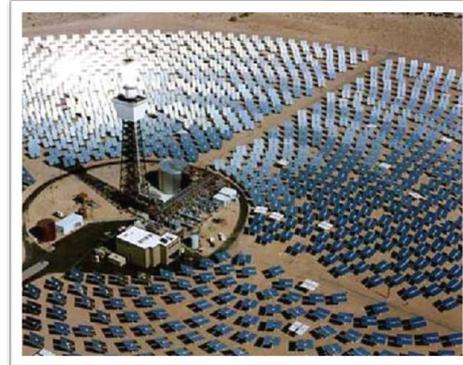
14

## Heliostat Application



### Modelling a solar power station

- Each assembly defines its own focus point
- Point to the bisecting angle between the Sun vector & focus vector

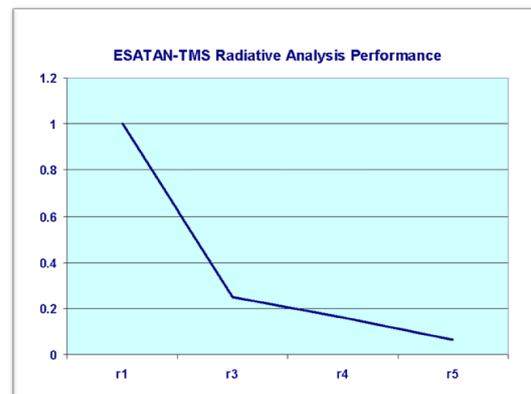


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## Performance & Scalability



- Our vision is to provide a complete and effective thermal modelling environment
  - Models are becoming larger & more detailed
  - Ability to perform a hybrid LP / FE solution
  - Integration with CAD / FEM
  - Performance is critical
- On-going activity to improve performance & scalability
  - Replacing / rewriting of components
  - Optimisation of code
  - Development of new methods

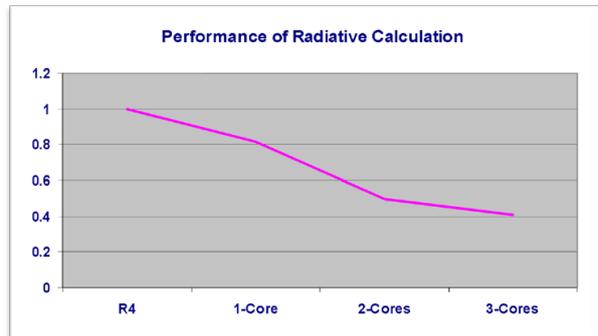


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## ESATAN-TMS Radiative Performance



- Radiative performance is critical as model size grows
- Another approach to performance is making use of **multiple cores** on a machine
- Extended Radiative to allow processing on multiple cores
- Environment variable “OMP\_NUM\_THREADS” to control number of cores used

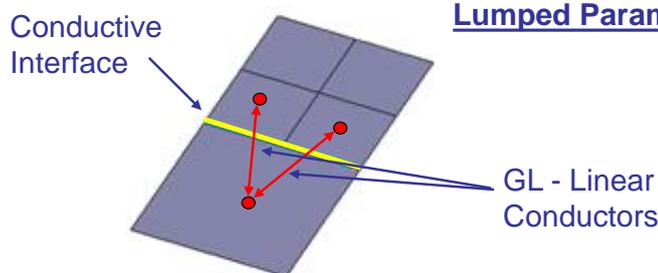


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## Conductive Interfaces



- What is a Conductive Interface (CI)?
  - Defines the interface between shells



### Lumped Parameter Shells



Courtesy of Astrium Launchers

- Defines the conduction path

**Capability now extended to handle curved interfaces**

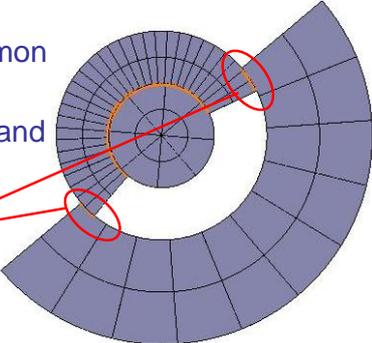
18

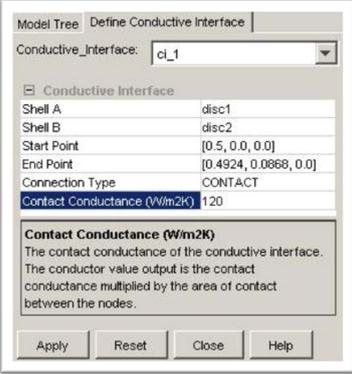


## Conductive Interfaces

- Process for defining a CI
  - A CI is defined between 2 Shells, with a common Start Point & End Point.
  - Interfaces between LP Shells or between LP and FE Shells.

Two curved interfaces identified between the same two Shells





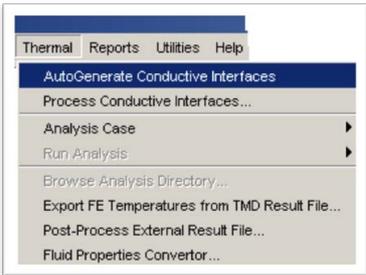
- Equation of edge used to detect the interface
  - No requirement on congruency of the mesh
- For interfaces between **FE Shells**
  - Meshed using linear Quads & Tris
  - Interface assumed if the **mesh is congruent**.
  - CI can be defined to “break” the mesh, e.g. to add a contact resistance

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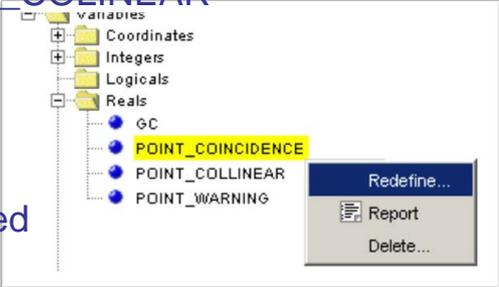
## Conductive Interfaces

- Automatic Conductor Generation
  - Algorithm uses the model tolerances **POINT\_COINCIDENT & POINT\_COLINEAR**
    - Real Variables
    - Default to 1.0E-4m
    - User definable
  - AutoGenerate CI option extended for Curved Interface





Process Conductive Interfaces



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## Conductive Interfaces



- Manage CI through the Process CI dialog
- Visualisation displays the interfaces for **displayed shells**
- CI selection through the Visualisation or the dialog

Conductive-Interface	Shell A	Shell B	Start Point	End Point	Connect Type	Contact Conductance
ci_1	disc1	disc2	[0.5, 0.0, 0.0]	[0.4924, 0.08682, 0.0]	CONTACT	120.0
ci_2	disc1	disc2	[-0.483, 0.1294, 0.0]	[-0.5, 0.0, 0.0]	CONTACT	120.0
ci_3	disc2	disc3	[0.25, 0.0, 0.0]	[-0.2266, -0.1057, 0.0]	CONTACT	120.0

Apply Change to Selection

Shell A:  Start Point:  Connect Type:

Shell B:  End Point:  Contact Conductance(W/m2K):

- Connect Type
  - **Not Processed**, Not Connected, Contact & Fused

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## ESATAN-TMS Thermal Performance



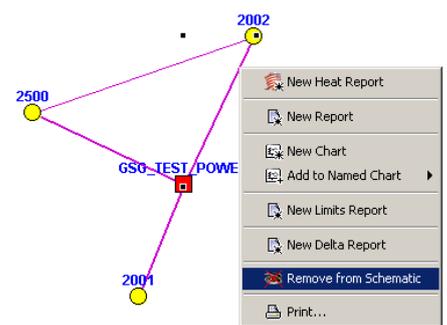
- Improvements to thermal solvers over previous years
- Focus on fluid solvers
  - Performance improvements mapped to fluid solvers FGENSS & FGENFI
  - >3x improvement seen for fluid models containing a large thermal network.
  - FGENFI default changed to quasi-transient
    - QTRSOL = 'Yes'
    - Hydraulic steady state (P & M)
    - Transient thermal solution (T)
- Identified & removed loop constraints (in ≈800 routines)

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## Post-Processing Improvements

- Post-processing of results using ThermNV
- ThermNV improvements for ESATAN-TMS r5
  - Control of display of Conductors displayed



**New Conductors Tab**

**Right-click Menu**



**Display List**

Display	Description	Path
<input checked="" type="checkbox"/>	GL(9097,9107)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3521,9095)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3522,3541)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(9055,9095)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(9053,9125)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3512,5001)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3531,3544)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3520,9069)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3543,9073)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(9059,9060)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(9033,9125)	GSG_TEST_POWER
<input checked="" type="checkbox"/>	GR(3507,5000)	GSG_TEST_POWER

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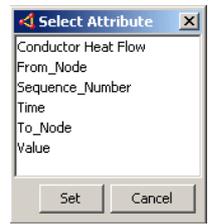


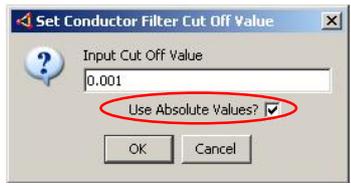
## Post-Processing Improvements

- Conductor Filter cut-off value
  - Another way of controlling the display
  - Don't display conductor below the cut-off value



**Useful for directional dependent quantities**



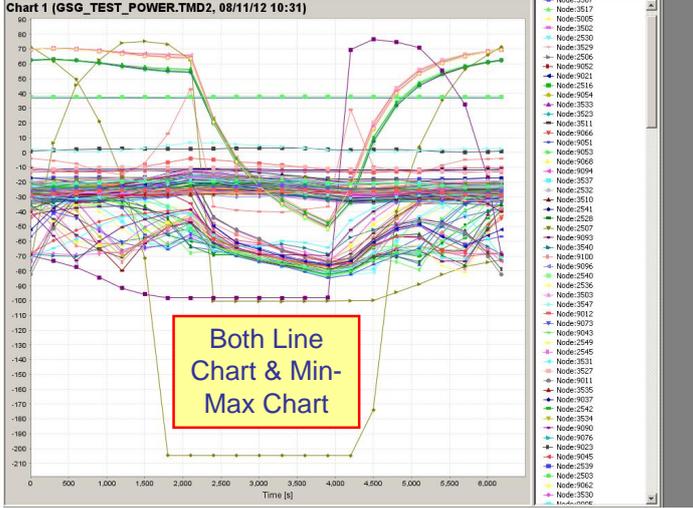


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## Post-Processing Improvements

– Improvements to the Chart Legend



- Legend now a scrollable list
- New toolbar icon 
- Separate graphic in batch report

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## General user-requests & Maintenance

- All products are now supported on 64-bit platforms
- PRNCVS has been extended to output 100,000 columns
- ThermNV grouping facility significantly improved
- Shell Attributes in ESATAN-TMS Workbench have been updated
- Bug Fixing

Analysis Type	Lumped Parameter
Side 1	
Label	ome_optibenc
Activity	Active
Radiative Criticality	Inactive
Submodel name	Radiative
Base Node Number	Conductive
Node Increment	Active
Optical Coating	optical
Colour	YELLOW

■	Non Geometric
■	Radiative
■	Conductive
■	Active
■	Inactive

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## Conclusion



### ESATAN-TMS r5 release date 30 Nov 2012

- Continued focus on overall modelling process
- Major developments,
  - CADbench 2012
  - Modelling enhancement
  - Curved Conductive Interfaces support
  - Multi-core support for radiative calculation
  - Support for surface planet modelling
  - Post-Processing improvement

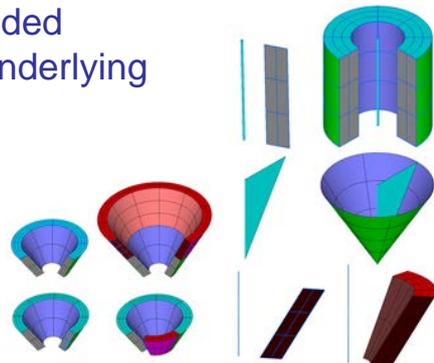
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## Beyond ESATAN-TMS r5

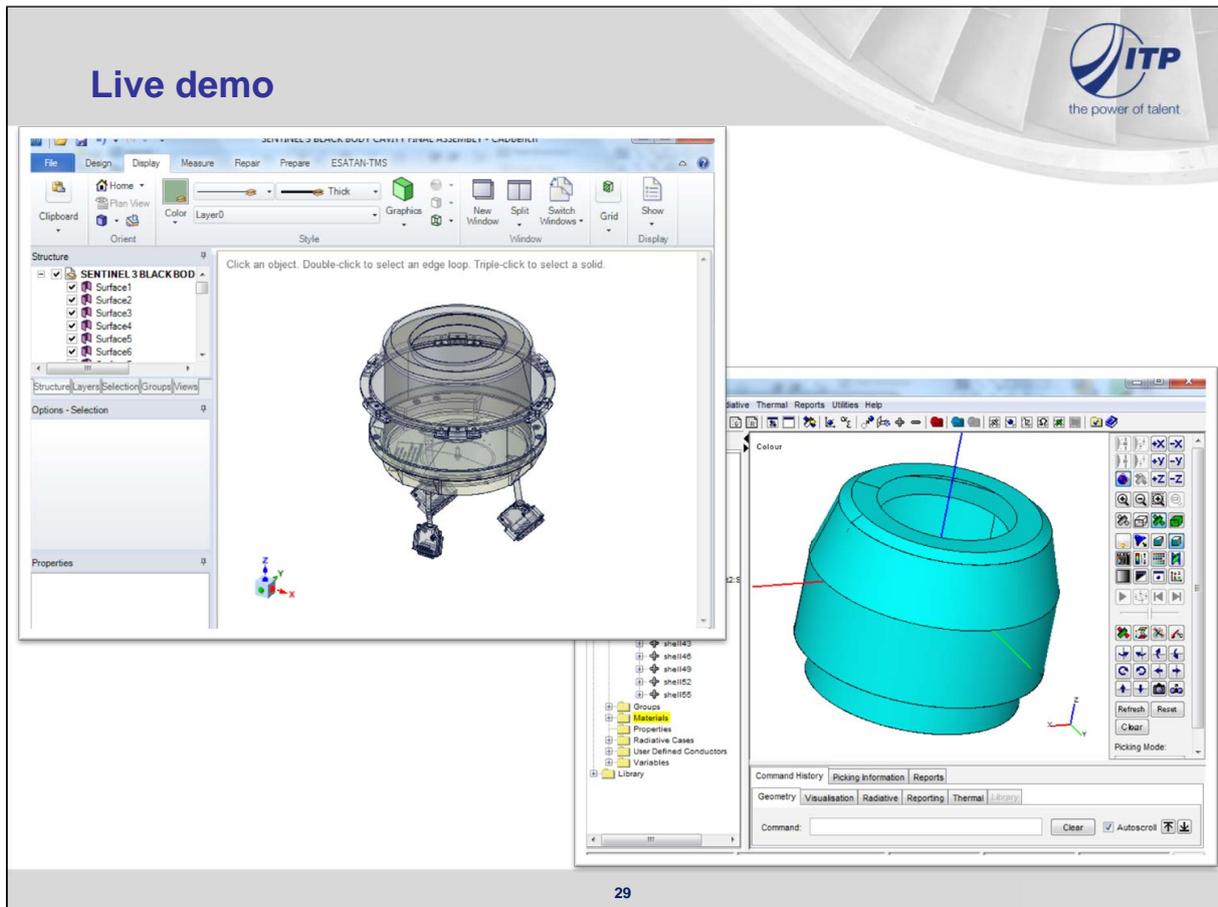


### ESATAN-TMS r6 Planned For 2013

- Development underway to extend support for modelling solid geometry
  - ESA Contract CCN7 “Thermal Software Development for 3D Analysis”
  - Immediate requirement coming from Astrium Launchers
  - Major development, which has included significant change to the products underlying architecture
  - Rewrite of visualisation component



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**Coming Events**

- ESATAN-TMS r5 release 30 Nov 2012
- Webinar
  - 23 Nov 2012: CADbench overview (*already fully booked*)
  - 07 Dec 2012: CADbench overview
  - 18 Dec 2012: ESATAN-TMS r5
- ESATAN-TMS Training Course
  - 26-29 Nov 2012 – Advanced Course
  - Feb 2013 – Beginner Course
  - March 2013 – Advanced Course
- ESATAN-TMS r6 release Mid 2013

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# Appendix K

## ESATAN Thermal Modelling Suite Thermal Modelling Process

Yannick Melameka  
(ITP Engines UK Ltd, United Kingdom)

### **Abstract**

To emphasize the strength and flexibility of ESATAN-TMS a demonstration of the complete thermal modelling process shall be given. The latest version of ESATAN-TMS shall be used, with particular emphasis on the new features in the release.

See [previous presentation](#).

# Appendix L

## Thermal Concept Design Tool Future developments and TCS Projects

Andrea Tosetto      Matteo Gorlani  
(Blue Engineering, Italy)

Harrie Rooijackers  
(ESA/ESTEC, The Netherlands)

### **Abstract**

The TCDT is in the 6th 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 1.5.1, already developed and delivered to the European Thermal Community can be used on Office 2010 systems.

The new version 1.6.0 is foreseen for the first quarter of next year with some improvements:

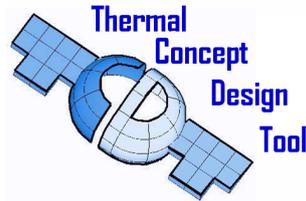
- Flux calculation for TCDT model,
- Orbits Chains Definition

The engineers can easily use TCDT models of older versions thanks to the automatic converter provided by the 1.6.0 version.

During the 6th year of distribution some TCS projects has been developed with the use of TCDT, a short description will be provided during the presentation.

# Thermal Concept Design Tool

## Future developments and TCS Projects



**Andrea Tosetto**

**Matteo Gorlani**

Blue Engineering, Torino, Italy

**Harrie Rooijackers**

European Space Agency, Noordwijk, The Netherlands

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## Overview

- **Background**
- **Version 1.5.1 Improvements**
- **Version 1.6.0 Improvements**
- **Maintenance Activity**
- **Modeling with TCDT**

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## Background

### 6° YEAR OF DISTRIBUTION & MAINTENANCE STARTED APRIL 2012

- 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 1.5.1 will be available before the end of 2012
- TCDT version 1.6.0 will be available on the first quarter of 2013

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## TCDT 1.5.1 Improvements

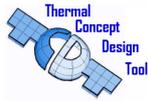
The new 1.5.1 version will be compatible with Excel 2010 and Windows 7.

TCDT Geometric Nodes							
Node ID's				Geometric Properties			
Side1	Side2	Label	Type	Dim1	Dim2	Dim3	

Compatibility test on Windows server 2008 is under evaluation at ESA

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# TCDT 1.6.0 Improvements

- Orbit Arcs Definition
- Chained Orbits
- Simplified Fluxes calculator for geometric model
- Version Converter Updated to 1.6.0

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# TCDT Improvements (1/8)

## Mission Definition : Orbit Arcs

TCDT Mission:			
Orbit Name :	Orbit1	Orbit2	Chain1
<b>Sun/Planet Parameters :</b>			
Planet radius (km)	6371	6371	Chain
Planet-Sun distance (10 <sup>6</sup> km)	149.6	149.6	Orbit1
Planet temperature (K)	288	288	1
Albedo factor (<1)	0.3	0.3	TRUE
Gravitational acceleration (m/s <sup>2</sup> )	9.80655	9.80655	Orbit2
Solar declination (deg)	0	0	1
Sun radius (km)	696000	696000	TRUE
Sun temperature (K)	5770	5770	
Sun gc (m/s <sup>2</sup> )	274	274	
<b>Thermal Environment</b>			
Solar constant override flag	Overriden	Overriden	
override value (W/m <sup>2</sup> )	1360	1360	
<b>Orbital Parameters :</b>			
Orbit Centre	PLANET_CENTRED	PLANET_CENTRED	
Inclination (deg)	0	0	
Argument of periaipsis (deg)	0	0	
Altitude of periaipsis (km)	800	800	
Altitude of apoapsis (km)	800	5600	
Ascending node(deg)	0	180	
TOPIC epoch :	12:00:00 AM	12:00:00 AM	
<b>Calculation Parameters</b>			
Nr. of orbital positions	8	8	
Include eclipse entry/exit positions	No	No	
Offset (deg)	0.5	0.5	
Initial True Anomaly	0	0	
Final True Anomaly	180	180	

The TCDT 1.6.0 will include:

- The definition of the final true anomaly
- Orbit Arc management

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# TCDT Improvements (2/8)

## Mission Definition : Orbit Arcs

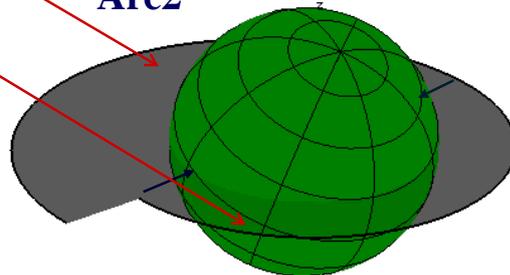
Calculation Parameters			
Nr. of orbital positions	8	8	
Include eclipse entry/exit positions	No	No	
Offset (deg)	0.5	0.5	
Initial True Anomaly	0	0	
Final True Anomaly	180	180	

Arc1

Arc2

Arcs are defined using the Final true anomaly.

By changing the other orbital parameters and using the Orbit Viewer is possible to link the orbit arc each other.



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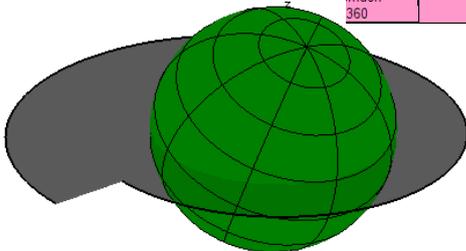
# TCDT Improvements (3/8)

## Mission Definition : Chained Arcs

Orbit2	Chain1
371	Chain
49.6	Orbit1
888	1
0.3	TRUE
10655	Orbit2
0	1
6000	TRUE
770	
274	
ridden	
360	

The mission timeline is defined in the mission sheet like previous version.

It is possible to define the sequence of arcs and for each arc the number of cycles and the final point result usage as in esarad.



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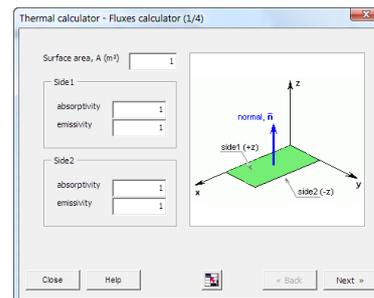


## TCDT Improvements (4/8)

### Fluxes Calculator for Model

TCDT 1.6.0 will include a simplified adsorbed fluxes calculator for the Geometric model surfaces.

The feature is based on the analytic fluxes calculator of THECAL. Solar, Albedo and Planet IR fluxes are evaluated



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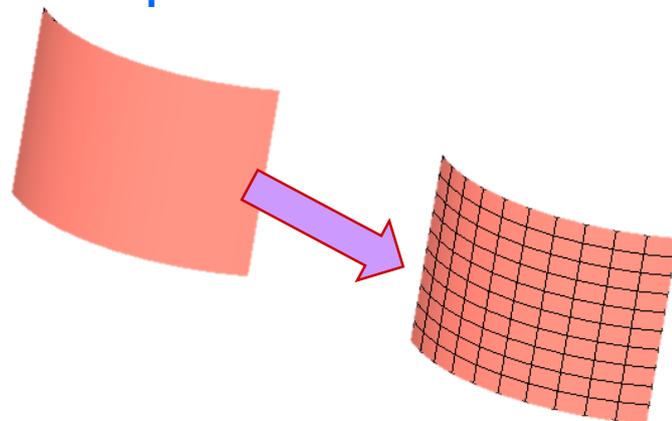


## TCDT Improvements (5/8)

### Fluxes Calculator for Model

Each curved surface is divided in flat surface that approximate the original shape.

For each flat shape the THECAL function is evaluated taking into account the surface orientation according to the selected mission.



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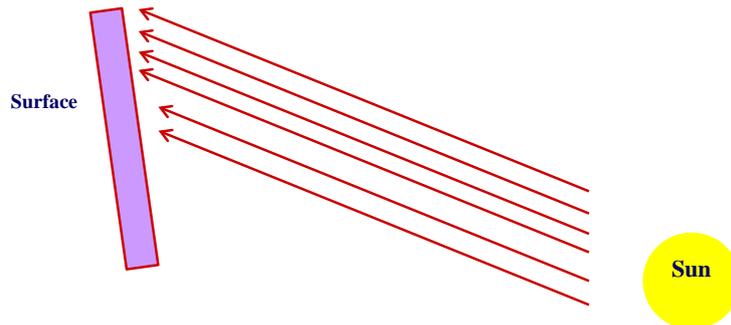


## TCDT Improvements (6/8)

### Fluxes Calculator for Model

A Montecarlo Ray Tracing method is developed to evaluate the reduction factor to be applied on the calculated flux coming from sun or planet due to the shadowing effect of the other surfaces.

From each shape a user defined number of parallel rays are thrown toward the direction of the center of the target (Sun or planet)



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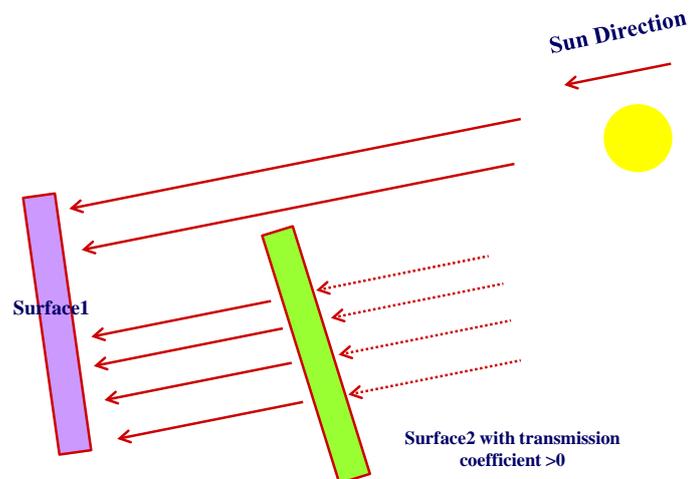


## TCDT Improvements (7/8)

### Fluxes Calculator for Model

Each ray is "charged" with energy and if, during its path, it encounters a surface its energy value is reduced according the transmission coefficient.

By calculating the sum of this energy is possible to evaluate the shadows coefficient, for the flux on one surface.



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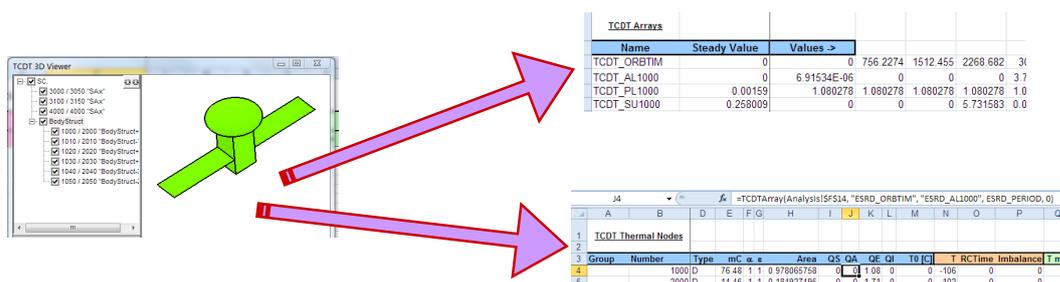


## TCDT Improvements (8/8)

### Fluxes Calculator for Model

Fluxes are calculated for each surface selected by the user (or all the surfaces), and for each orbit point defined in the selected mission.

Results are stored in the arrays sheet and linked to the QS,QA,QE nodes properties.



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esa



## Modeling with the TCDT (1 / 9)

### Exomars EDM RTMM for PROTON launcher

- Activity:
  - reducing the 4000 nodes Exomars EDM Detailed Model, to a 150 Nodes Reduced Model composed by flat surfaces.
  - RGMM and RTMM exported in PROTON specific format.
- The TCDT is used to:
  - import the geometry from an ESARAD geometry file
  - manage the results
  - export PROTON model with "Proton Geometry Export" User class
- BLUE Performed the activity for ThalesAleniaSpace Turin

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esa

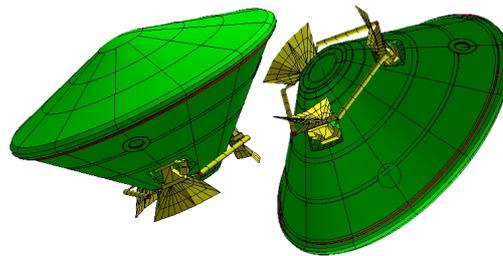




## Modeling with the TCDT (2 / 9)

### Work Flow:

Subdividing the detailed GMM into main components to be compatible with TCDT characteristics



- Meshing of surfaces is reset to 1 node per surface
- Each sub component is exported in different g Files

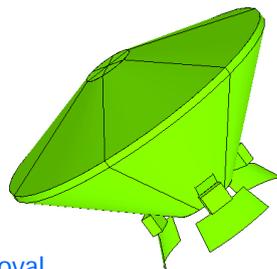
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## Modeling with the TCDT (3 / 9)

### Work Flow:

Importing GMM's (g files) in TCDT for further simplifications to meet reduction requirements



- Surface check and removal
- Meshing of surfaces to guarantee adequate geometrical representation for RGMM



ESARAD thermo-optical properties are automatically applied to new RGMM surfaces

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## Modeling with the TCDT (4 / 9)

### Work Flow:

Creating the TMM in the TCDT

Group	Number	Label	Area	QS	QA	QE	Q
20000	ESRD FS_Disk_MLI_Ext	0.122269	0	0	0	0	0
20001	ESRD FS_Cone_MLI_Ext	0.777941	0	0	0	0	0
20002	ESRD FS_Cone_MLI_Ext	0.777941	0	0	0	0	0
20003	ESRD FS_Cone_MLI_Ext	0.777941	0	0	0	0	0
20004	ESRD FS_Cone_MLI_Ext	0.777941	0	0	0	0	0
20005	ESRD FS_Cone_MLI_Ext	7.78E-01	0	0	0	0	0
20006	ESRD FS_Cone_MLI_Ext	7.78E-01	0	0	0	0	0
20050	FS_Disk_Struct	0	0	0	0	0	0

Label	First Node	Second Node	Value
Doubler Plate	22204	22200	4.00E+00
FS_MLIExt-Struct	20000	20050	1.04E-02
FS_MLIExt-Struct	20001	20051	6.11E-02
FS_MLIExt-Struct	20002	20052	6.11E-02

- ESATAN analyses
- Management and post-process results
- export PROTON model with “Proton Geometry Export” User class



Process managed with the TCDT

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## Modeling with the TCDT (5 / 9)

### Focus: Temperature Management

The target temperatures derived from the DTMM are calculated taking into account the temperature and the capacity of the DTMM nodes that was collapsed into single RTMM nodes.

The allowed maximum temperature difference between the DTMM and the RTMM was:

- 5 C for internal units and tanks
- 10 C for internal structures and lander antennas
- 15 C for structures

The target temperature and the requirements are introduced in the TCDT temperature requirements for TNodes.

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## Modeling with the TCDT (6 / 9)

### Focus: Results Management

By setting the temperature requirements in the TCDT is possible to check immediately after loading the results from the ESATAN analysis

QE	QI	T0 [C]	T	RCTime	Imbalance	T min	T max
0	0	-45.7	-162.7359	0	0	-96	4
0	0	-172.367	-164.512	0	0	-222	-122
0	0	-172.05	-164.7743	0	0	-222	-122
0	0	-170.583	-162.0358	0	0	-221	-121
0	0	-170.5	-161.2335	0	0	-221	-121
0	0	-169.25	-164.1375	0	0	-219	-119
0	0	-170.383	-163.5279	0	0	-220	-120

T outside the requirements have different colors

#### Achieved maximum temperature difference after 10 iterations

- $\Delta T < 3.6$  C for internal units and tanks
- $\Delta T < 8$  C for internal structures and antenna
- $\Delta T < 14.4$  C for external structure
- Main MLI surfaces has  $\Delta T < 19$  C

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## Modeling with the TCDT (7/ 9)

### Focus: PROTON Geometry Export

The PROTON geometric data model requirements are:

- Surfaces are made of quadrangles or triangles
- Double active sides are made with 2 surfaces separated by a small gap and properly oriented
- Each surface is defined by points
- The reference frame for all the points is the S/C frame.

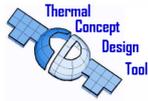
#### The PROTON geometric data model is composed by

- points data
- Surfaces data (group of points that define the orientation of the surface)
- Area of the surface
- Surface thermal node
- Emissivity and Assorptivity

The PROTON thermal data model includes nodes, internal conductors dissipation, etc, and it is easily managed by copy paste operation from TCDT excel sheets.

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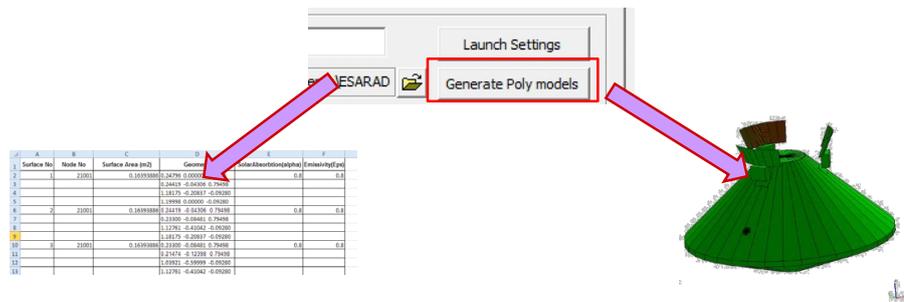




## Modeling with the TCDT (8/ 9)

### Focus: PROTON Geometry Export

A BLUE User add-in is implemented in order to generate the data required for PROTON and a flat surfaces ESARAD geometric model used for correlation and geometry check:



Exporting a table file with nodes data and other required

By using the same points data a flat surface ESARAD model is generated

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## Modeling with the TCDT (9/ 9)

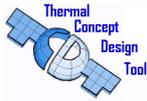
### Conclusions

The TCDT feature used for this work are:

- Import ESARAD Models
- Management of GMM from TCDT GUI or Excel sheets with immediate check of correctness.
- Faster check of results validity
- Easy Implementing of new exporting features

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## TCDT Team

### DISTRIBUTION & MAINTENANCE

BLUE ENGINEERING S.R.L.

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**Andrea Tosetto** - Software Development

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**Support**

[tcdtsw@blue-group.it](mailto:tcdtsw@blue-group.it)

Blue Group - Engineering & Design

WEB: <http://www.blue-group.it>

ESA - ESTEC

**Benoit Laine** - Head of Thermal Analysis and Verification Section

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**Dr. Harrie Rooijackers** - Project Manager

[harrie.rooijackers@esa.int](mailto:harrie.rooijackers@esa.int)

ESTEC-D/TEC-MTV

WEB: <http://www.esa.int>

**WEB: [www.blue-group.it/TCDT](http://www.blue-group.it/TCDT)**  
**EMAIL: [tcdtsw@blue-group.it](mailto:tcdtsw@blue-group.it)**

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## Appendix M

### Innovative Analysis Methods for Improved Thermal Testing

Mélanie Doolaeghe      André Capitaine  
(Astrium Satellites, France)

### Abstract

*An R&D study by ESA, led by ASTRIUM in cooperation with INTESPACE, LKE (CZ), ETS and Global Vision Systems.*

Thermal testing is part of the verification process needed on a space system. Located on the critical path of the spacecraft project, thermal testing is a complex, demanding, long and expensive task. Thermal test complexity associated to the constraints in term of cost and schedule requires efficient dedicated tools for data handling, monitoring and exploitation, in real time and after the test. Improving analyses methods and tools used to ease thermal testing is in the centre of the cost and schedule reduction problematic.

The proposed presentation deals with the activity performed in the frame of ESA R&D project Innovative Analysis Methods for Improved thermal Testing (IAMITT).

In phase one, a critical analysis of current industrial practises among all industrial space thermal companies led to identify potential improvements and select those to implement into the different modules prototyped in phase 2.

The replay of Lisa PathFinder thermal test showed the efficiency and the limitations of the different IAMITT modules:

- 3D displays gather relevant information contained in the thermal test database and dynamically link them to GMM thermal model, CAD model and pictures visualisation. The possibility of real-time visualizing all the test data available aims at increasing the spacecraft safety, facilitating the thermal team understanding, and enhancing its efficiency.
- Spatial extrapolation allows estimating the temperatures of non instrumented nodes or disabled thermal sensor in function of the temperature of instrumented ones during steady-state phase as soon as all dissipations and heater status are available.
- Temporal extrapolation predicts steady-state stabilisation, leading to a better efficiency of the test monitoring, and may lead to the shortening of test phases.
- Dynaworks database is also interfaced with a dedicated tool (TMUT) to perform model correlation by regenerating predictions with measured environment conditions but also real-time model updating using genetic algorithms.

The presentation will be concluded with some validations on a previous commercial telecommunication spacecraft but also with a short description (perhaps even the first views for this application) of the validation which is on-going on ALPHASAT in the frame of ESA R&D EVATHERM.

# Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

26<sup>th</sup> European Space Thermal Analysis Workshop

M. Doolaeghe – A. Capitaine - EADS Astrium  
22.11.12

All the space you need



## Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

### Agenda

- **IAMITT project**
  - Motivation and study logic
  - Design and validation (Lisa PathFinder, TLC S/C)
- **IAMITT modules**
  - 3D display
  - Spatial Extrapolation
  - Thermal Model updating (test conditions and model parameters)
  - Thermal Test Database
  - Temporal Extrapolation
- **Operational use on TLC S/C**
  - Update of predictions
  - Highlight of non conformances
- **Alphasat / EVATHERM R&D**
  - Objectives
  - First views – 3D display, Spatial Extrapolation
- **Future IAMITT developments**
  - Existing, new functionalities and connected topics
  - Industrialization

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22/11/2012 2



**Innovative Analysis Methods for Improved Thermal Testing (IAMITT)**

## IAMITT project

### Motivation and Study logic

- Thermal testing issues
  - Measurements
    - Management of hundreds of TCs and TMs
    - TCs localisation identification not immediate
    - Difficulty to access to some area temperatures
    - Different acquisition sources
    - Only curves
  - Length of the test
    - Long thermal tests
    - No quick status of thermal balances convergence
  - Thermal model correlation
    - No status of model correlation at the end of the test
    - Difficulties to get dissipation after test end
    - Long post test process after test for correlation
- IAMITT project
  - ESA R&D
  - Multinational cooperation
  - 2 phases
  - => Significant reduction of cost and time

**Analysis of current industry practice, Identification of inefficiencies and potential analysis methods and tools improvements**

**Design of innovative analysis methods, Implementation & Verification, Validation**

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**Innovative Analysis Methods for Improved Thermal Testing (IAMITT)**

## IAMITT project - Phase 1

### Critical analysis and Conceptual Design - Improvements identification

#### Critical analysis

- Space companies  
CNES, Dutch Space, TAS Turin, STFC RAL, Astrium ST
- Thermal test facilities  
Intespace, ETS, CSL, IABG, Thales Alenia Space Cannes
- Wide scope of space systems  
Telecommunication, observation and scientific satellites  
Space equipments, Instruments  
Launchers, ATV
- Topics related to all disciplines  
Thermal analysis and architecture  
Assembly, Integration and Testing  
Product assurance
- Main bottlenecks, gaps

#### Conceptual design

- Feasibility  
Definition of improvements  
Feasibility assessment (thermal & SW)
- Trade-off
  - Price / performance / constraints
  - Selection of 5 improvement modules  
*3D display (3D)*  
*Spatial Extrapolation (SE)*  
*Thermal Model Updating Tool (TMUT)*  
*Temporal Extrapolation (TE)*  
*Thermal Test Database (TTD)*
  - R&D thermal issues
  - Stand-alone SW modules
  - Based on Dynaworks COTS

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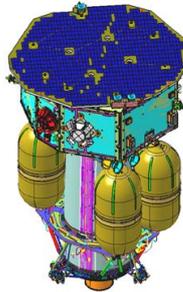
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# IAMITT project - Phase 2

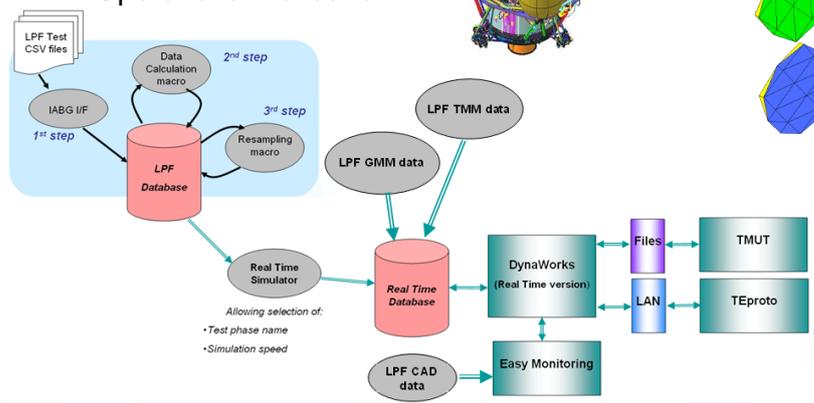
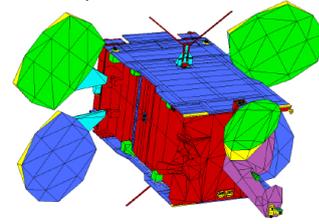
## Development, Verification and Validation - Modular organization

### Validation

- Candidates (≈ 8500 nodes)
  - Lisa Pathfinder
    - 3 steps validation
    - Not fully successful
- Operational Validation



- Telecom Spacecraft
  - Complements



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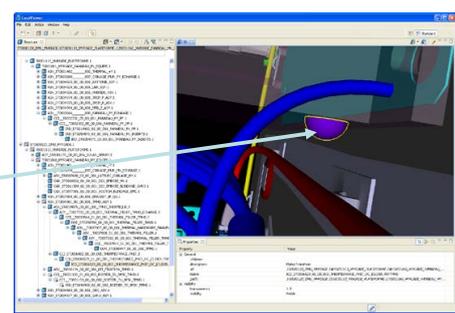
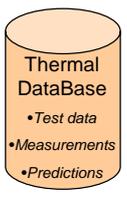
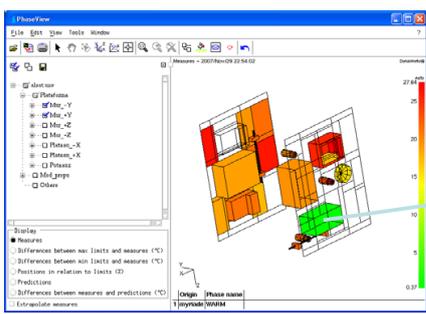
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# IAMITT modules - 3D display

## Thermal / CAD models and test data



### GMM 3D display (DynaWorks)

- Thermal data associated to nodes
  - Measured / Predicted temperatures
  - Measured / Predicted dissipations
  - Measured / Predicted heating powers
  - Differences

### CAD 3D display (EasyMonitoring)

- Full CATIA native model
- Specimen definition & thermal sensors
- Link towards pictures

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## IAMITT modules - Spatial Extrapolation

Access to whole temperature map

**Measured T° only**

**Whole thermal map**

- Non measured area
- Physical understanding

**Sink temperatures on instrumented nodes**

**Linearized thermal equation**

Conductive couplings:  $RT^4 + LT = P$      $AT = P + Q$

Radiative couplings:  $Q = 3RTI^4$     Heating power

Dissipation:  $P = -QI - QR + C \frac{dT}{dt}$     Transient term

**Return to Temperatures**

measured T°

$$T_k = W_{kl} T_l + X_{kk} (P_k + Q_k)$$

$$W_{kl} = -A_{kk}^{-1} \cdot A_{kl} \quad \text{and} \quad X_{kk} = A_{kk}^{-1}$$

**Issue: no access to transient term for non instrumented nodes (4 methods tested)**

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**Innovative Analysis Methods for Improved Thermal Testing (IAMITT)**

## IAMITT modules - Spatial Extrapolation

Access to whole temperature map

- Validation with telecom model**
  - Theoretical case SE{predicted\_data}
    - Theory :  $T_e = T_p$
    - Validation criteria:  $|T_p - T_e| < 0.1^\circ \text{C}$
    - Experiment:  $|T_p - T_e| < 0.07^\circ \text{C}$

=> A new thermal tool prediction?
  - Real case SE{measured\_data}
    - Simulation of 23 invalid TC (randomly chosen)
    - Comparison between measurement and extrapolation

=> Error lower than  $5^\circ \text{C}$  for most of the TC, depending on

    - Thermal model quality extrapolation is better if prediction is good
    - Powers inputs
    - Measurement accuracy

3D display:  $T_p - T_e$

0.07° C

5° C

Range	Number
$\Delta < 1$	6
$1 < \Delta < 3$	7
$3 < \Delta < 5$	7
$5 < \Delta < 6.5$	3

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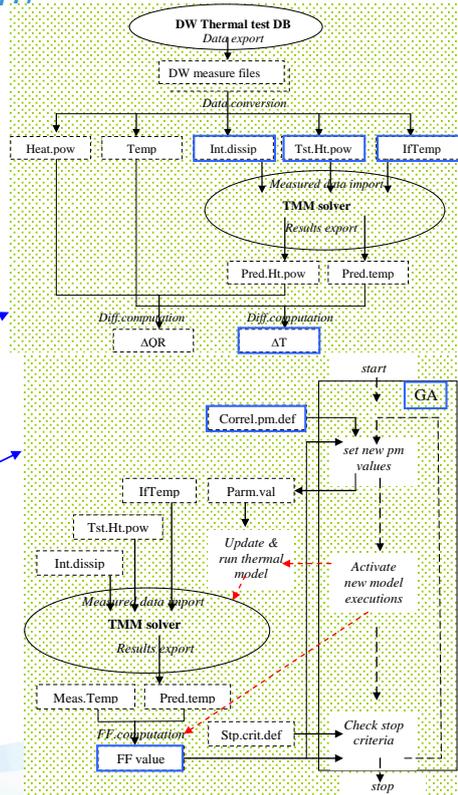
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# IAMITT modules – Thermal Model Updating Tool Near Real Time Correlation

- **Logics and assumptions**
  - Steady-state conditions
  - Several cases management
  - Fitness Function FF (# Tmes-Tpred)
- **TCU (Test Conditions Updating)**
  - Real-time prediction update
  - Useful for test management
- **MPU (Model Parameters Updating)**
  - Preliminary identification of uncertain parameters with physical possible variation range
  - Automatic iteration with Genetic Algorithm to decrease the FF
- **Results**
  - Replay of TC S/C correlation

=> **0.5° C** avg. improvement WRT best known manual solution



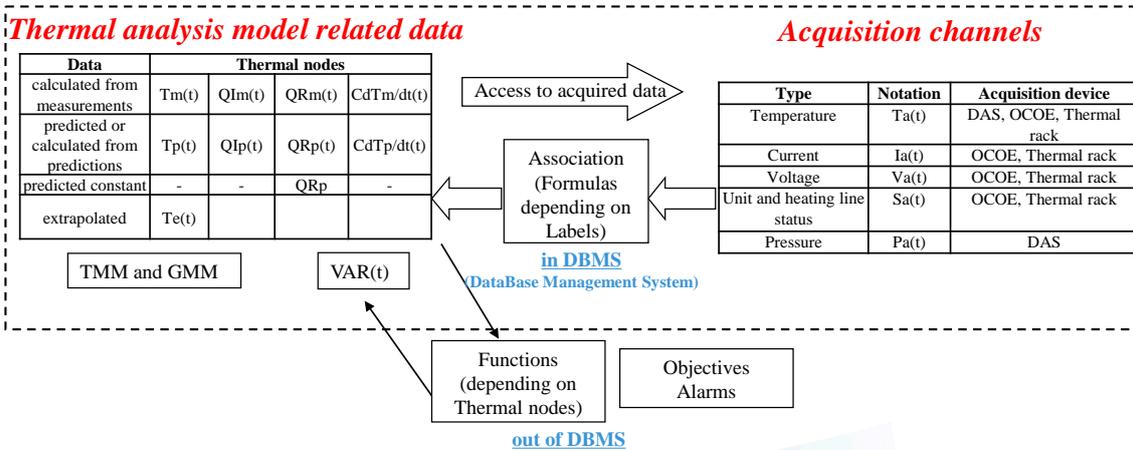
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# IAMITT modules - Thermal Test Database One Single Database

- Access to all thermal test predictions and measurements data
- Needed by IAMITT modules : 3D, SE, TE, TMUT



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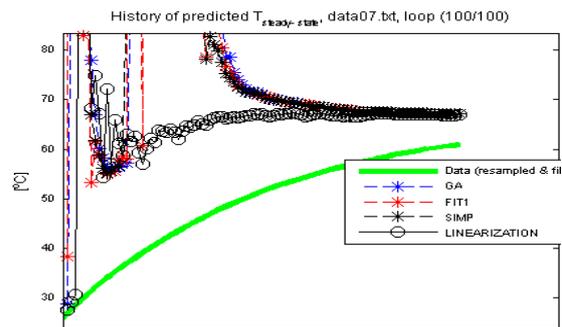
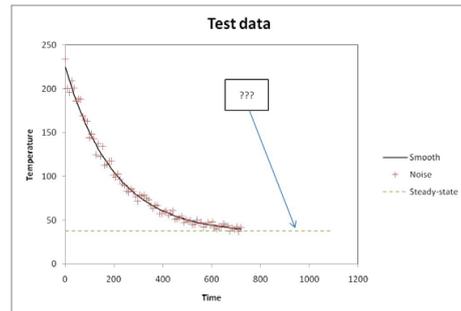
# IAMITT modules - Temporal Extrapolation

Shortening thermal balance phases

- Prediction of steady-state temperature
- Temperature curve modelled by a sum of exponential functions

$$T(t) = T_{\infty} + \sum_{j=1}^p \alpha_j e^{-\beta_j t}$$

- Combination of 2 methods
  - M1 - Linearization (LIN)
  - M2 - Optimization of exponential coefficients
- Results (test replay)
  - Saving ≈ 50% of phase length for 80% of 300 tested curves
  - TE quality and time depending on
    - Deviation from steady state conditions
    - Evaluation frequency



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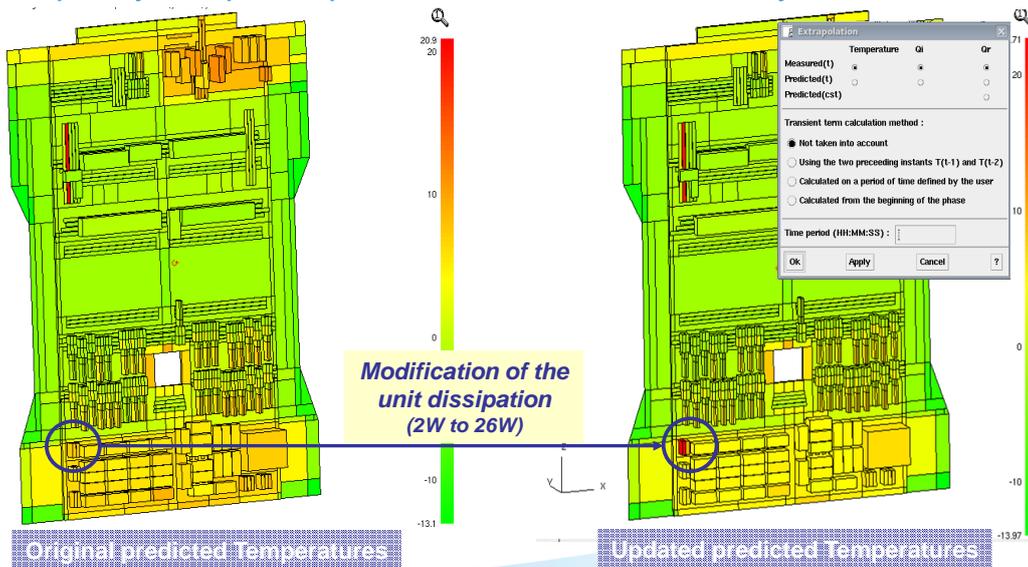


Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

# IAMITT applications – Use on TLC spacecraft

First industrial uses

- Capacity to update predictions in real time in Dynaworks



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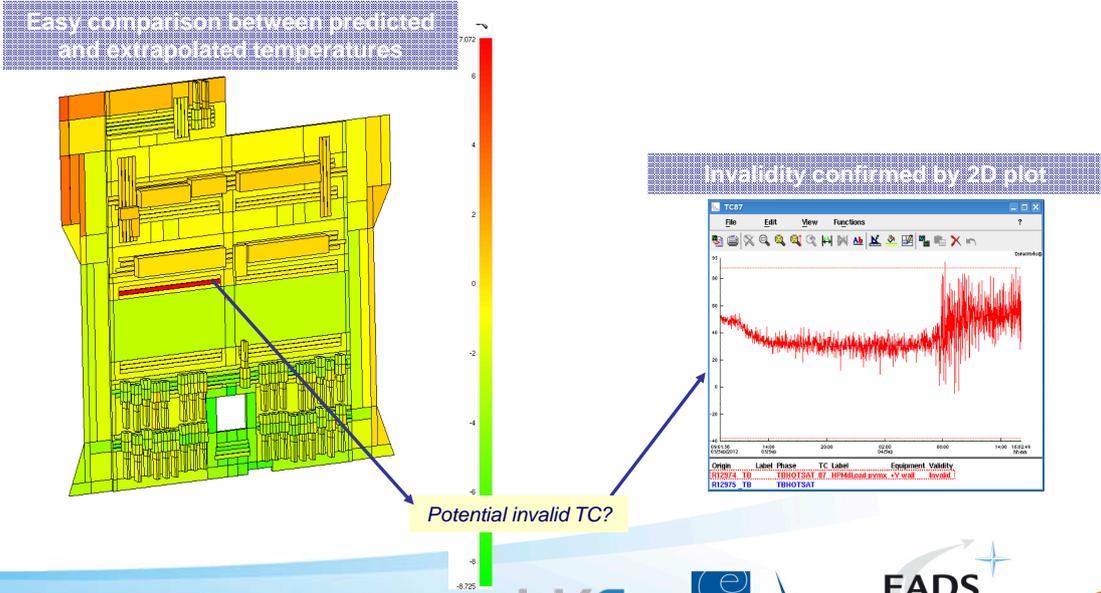


Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

# IAMITT applications – Use on TLC spacecraft

First industrial uses

- Highlight of non conformances (ex : invalid TC)



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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

# IAMITT applications - ALPHASAT / EVATHERM

Objectives

- Use of IAMITT modules during Alphasat Tvac
  - 3D display (GMM view)
  - Spatial Extrapolation  
Access to propulsion line temperature estimation
  - Thermal model updating in real time  
4-core laptop allows to perform more than 10 000 steady-state runs per day with this 15500 node model
- Dissipations computation  
Introduced in DW DB
- Use in parallel to operational system  
Helper tools
- Not tested for Alphasat
  - Temporal Extrapolation
  - CAD interfaces

15.500 thermal nodes  
1000 acquisition channels  
10 days longest phase  
74 days



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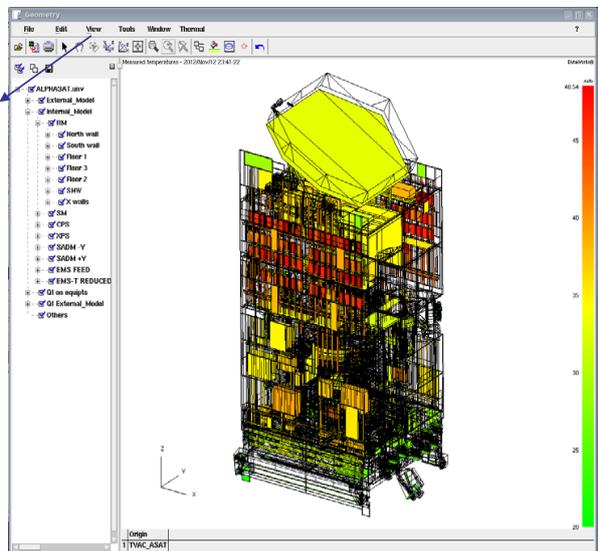
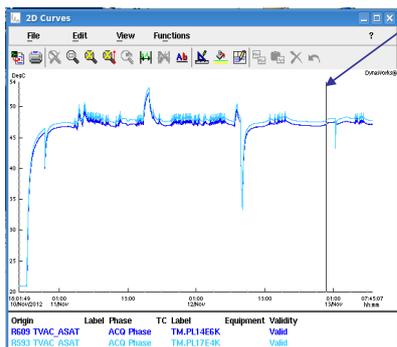
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# IAMITT applications - ALPHASAT / EVATHERM

On-going – First views

- 3D display module

Replay a phase with the 3D module as well as 2D plots



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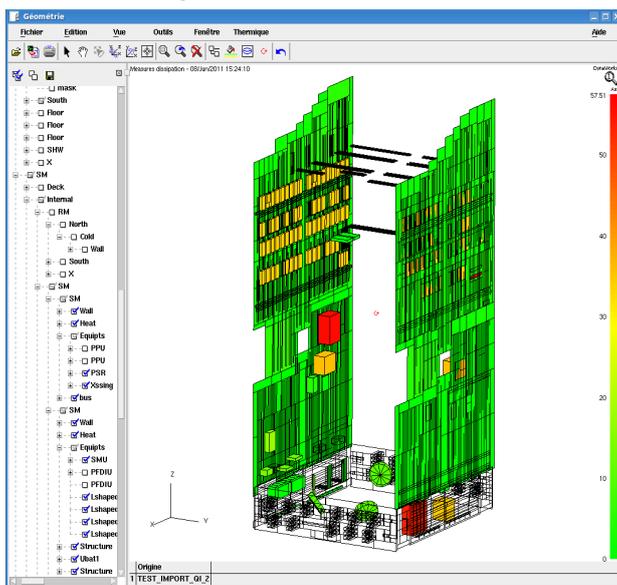


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# IAMITT applications - ALPHASAT / EVATHERM

On-going – First views

- 3D extrapolation



*Final results and conclusions will be presented in the next months*

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*Innovative Analysis Methods for Improved Thermal Testing (IAMITT)*

## Future IAMITT developments

- Existing functionalities optimization
  - STEP-TAS, CAD, pictures,...
  - Spatial Extrapolation methodology optimisation (performances)
- New real time functionalities development
  - TC validity evaluation
  - Spatial Extrapolation for transient phases
  - Transient cases for TMUT
  - LKE development on Temporal Extrapolation to be optimised
  - Quick thermal solver in Dynaworks
  - Set of thermal tools
    - Real-time Thermo elastic calculation (Wave Front Errors)
    - Line of Sight or Image quality estimation
    - Estimation of duty cycles
    - Fluxes calculation
- Connected topics
  - Dissipations and heating powers computation
  - Interfaces (data, software, test devices)
  - Telemonitoring
- Industrialization within version Dynaworks V7 of the more mature IAMITT functionalities  
3D display (GMM), Spatial Extrapolation, Thermal Test Database

*... And many other potential ideas after EVATHERM*



*Innovative Analysis Methods for Improved Thermal Testing (IAMITT)*

Thanks to ESA for their support

Thank you for your attention

Any questions?





## Appendix N

How SYSTEMA could provide valuable assistance in mission analyses and thermal worst cases determination

Nicolas Liquière  
(EPSILON, France)

### **Abstract**

Thermal design activities require a full understanding of the studied space system's mission. Standard missions are efficiently assisted thanks to the qualitative approach, especially to determine the worst external heat flow loading. For more complex missions, the qualitative approach remains vital but should be supported by a quantitative approach. This presentation is focused on demonstrate the capabilities provided by SYSTEMA v4.5 to automate the determination of the worst external heat flow loading. Based on a mobile antenna mechanism, it is shown how the mission's characteristics are handled into SYSTEMA in order to determinate parameters values leading to maximize or minimize external heat flow at the antenna subsystem level.



bridge the thermal gap

## A tool to assist sizing cases determination

How SYSTEMA could provide valuable assistance in mission analyses and thermal worst cases determination



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### Context

#### → Worst external heat flow loading determination

- qualitative approach
- quantitative approach

#### → A tool that assists

- Provides accurate results
- Easy to develop
- Easy to reuse
- Easy to upgrade

Source: CNES, March 2003 (Pierre Carril)

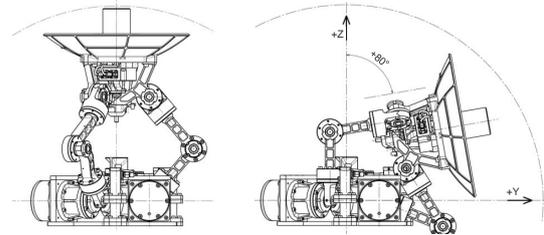
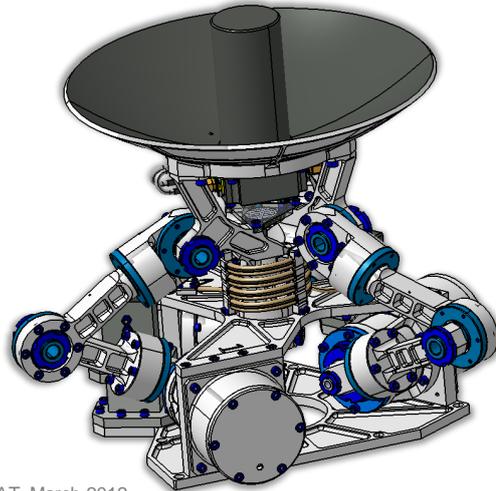


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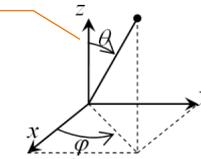
# 3POD project

→ An innovative mobile antenna mechanism (COMAT/CNES)



ZENITH: [0°, +80°]

AZIMUTH: [0°, +360°]



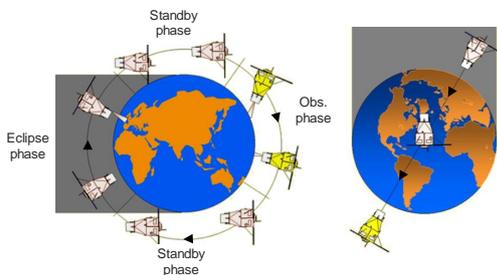
Crédit: COMAT, March 2012



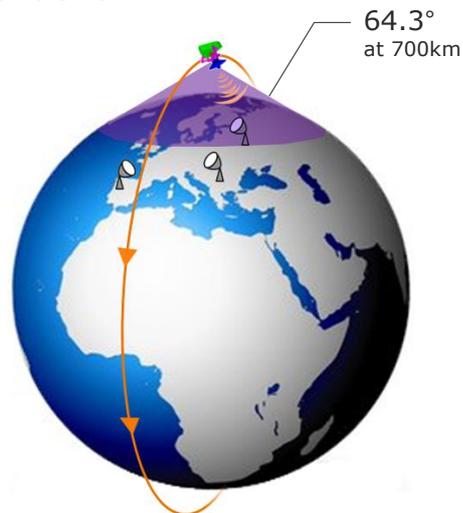
# Qualitative approach

→ **Antenna:** During the observation phase, the heat flow loading is multi-parameter-dependent.

- The season
- The mission

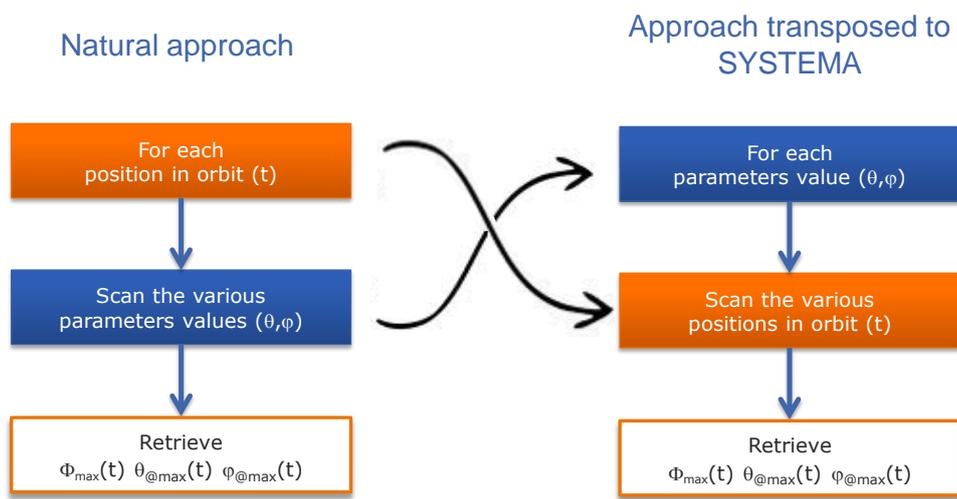


Sun-synchronous 700km  
Ascending node at 22h30



## Quantitative approach

→ Scan the different possibilities



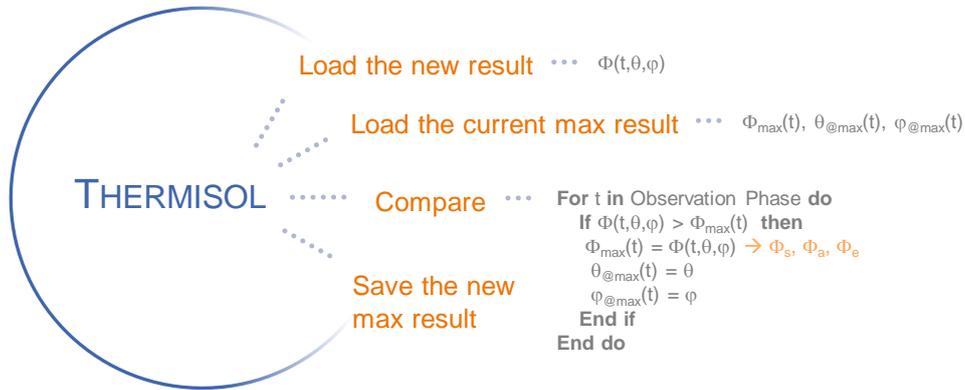
## Tool process

→ SYSTEM AND MISSION DEFINITION



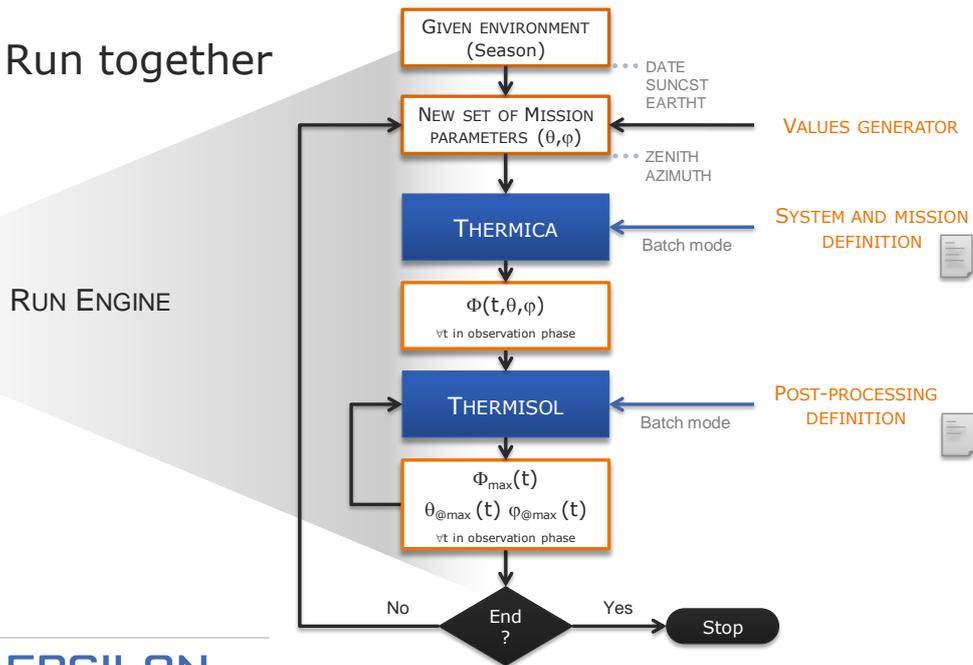
# Tool process

## → POST-PROCESSING DEFINITION



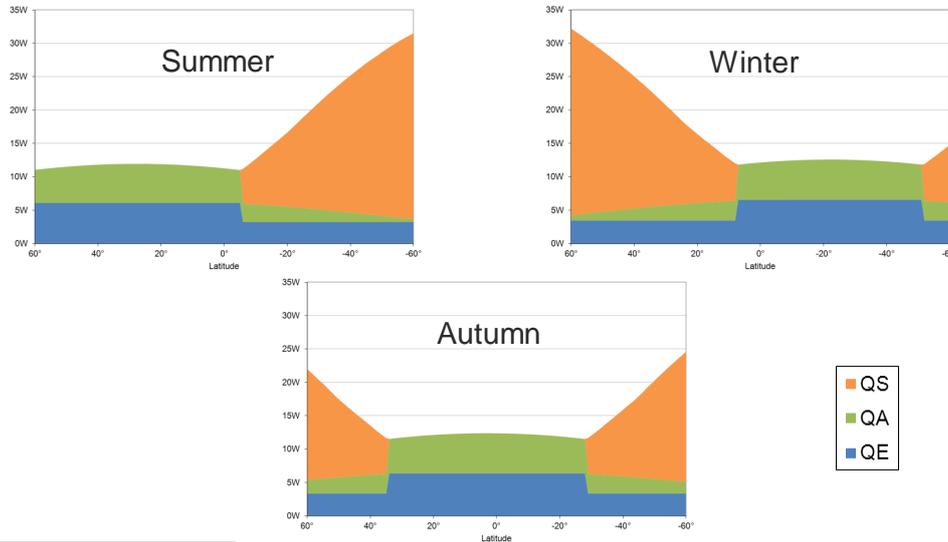
# Tool process

## → Run together



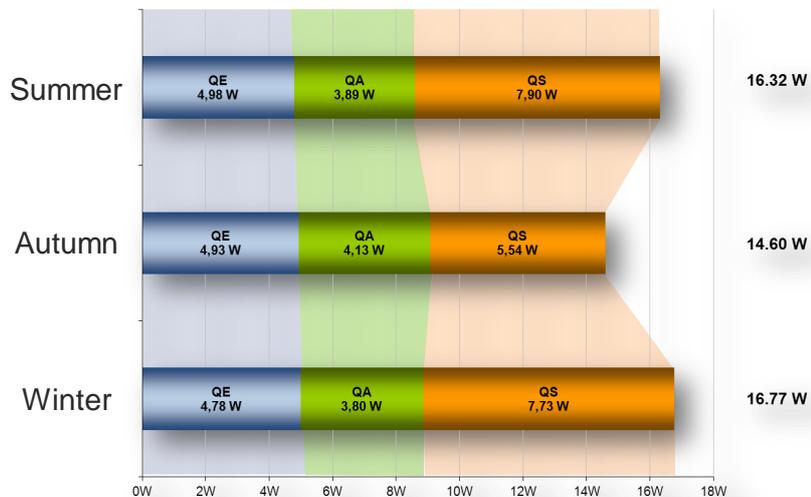
# Results

## → Maximum absorbed heat flux profiles



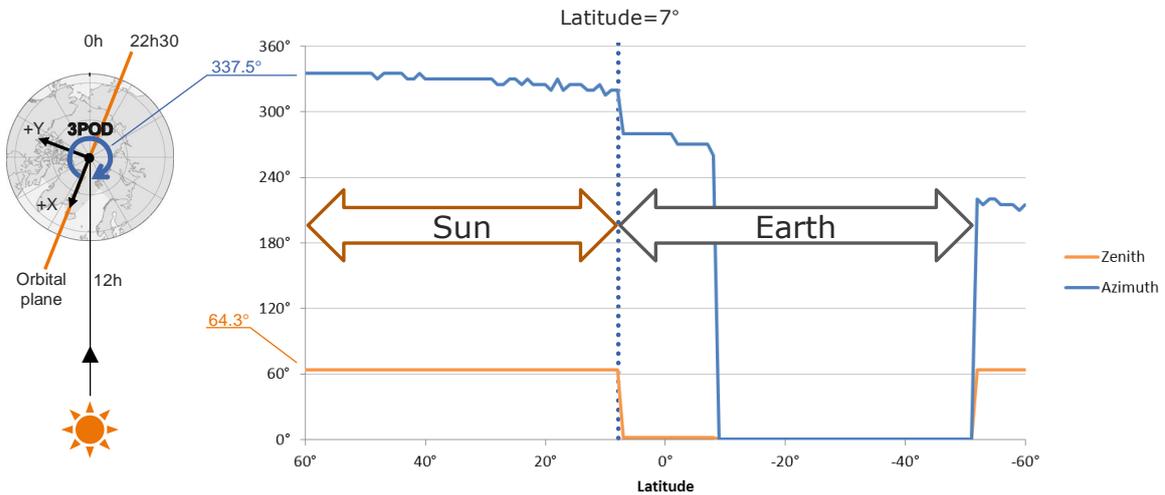
# Results

## → Average max. absorbed heat flux



# Results

## → Mission parameters (Winter solstice)



A tool to assist sizing cases determination

A worst external heat flow on a mobile antenna mechanism



Slow

Normal

Fast

Play/Pause

Stop

## Conclusion

→ Based on SYSTEMA applications, the solution:

- Gives **accurate results**: geometry, mission, heat fluxes
- Requires **little programming**:
  - Geometry & mission      **.....>** Ensured by SYSTEMA
  - Heat flow computation    **.....>** Ensured by THERMICA
  - Post-Processing            **.....>** FORTRAN using THERMISOL
  - Run Engine                 **.....>** Few lines of script code, using SYSTEMA batch mode
- Easy to **adapt** and **reuse**

→ Improvement : Values generator

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**bridge** the **thermal** gap

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<http://www.epsilon-alcen.com>

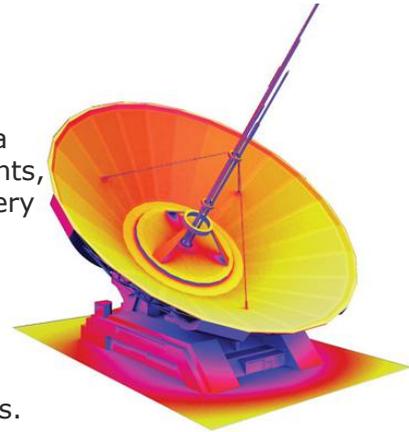
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## Corporate

EPSILON is the only private European research company that specializes in thermics. It works with major European players in aeronautics, the space industry, on-board systems, building, energy and health.

EPSILON thermal engineers' expertise and know-how and their ability to continuously break new ground enables them to master all the thermal phenomena required for designing and building basic components, subsystems and entire systems often working in very severe environments... and to keep them in good running order.

EPSILON is the operator and a member of the FAHRENHEIT, innovation platform, whose specific characteristic is to mutualize knowledge in thermics.



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## Activities

EPSILON proposes its expertise in the following domains:

- *thermal, electronic, hydraulic and mechanical modeling and simulation for components, housings or systems;*
- *system integration;*
- *predictive reliability;*
- *developing software;*
- *characterizing materials;*
- *performance tests.*

The EPSILON in-house laboratory includes:

- *means of measuring temperatures;*
- *small and medium scale testing resources, more particularly for quantifying parameters that are essential for thermal model inputs;*
- *measuring methods and resources for validating thermal models;*
- *specific methods and resources related to the activities and requirements in the programs carried out by the Research Department.*



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## Appendix O

### Rationalisation of Stabilisation Criteria for Thermal Balance Tests

Ettore Colizzi  
(ESA/ESTEC, The Netherlands)

### **Abstract**

When a space vehicle or its lower level elements are subjected to thermal testing, it is recurrently found that concepts such as "thermal equilibrium" and "thermal stability" are addressed lacking necessary rigor. Therefore, the quality of the results of possibly expensive Thermal Balance Tests may be diminished, if not jeopardized.

The set of concepts developed and presented are meant to allow thermal specialists to deal with stabilisation aspects of thermal balance tests on a rational ground. Moving from the theory of thermal transient analyses carried-out by means of lumped-parameter network mathematical models and using Linear Algebra, the behaviour of a network close to stabilisation is studied. The novel concepts of "instantaneous" time constant and network "terminal" time constants are introduced. The latter, in particular, is shown to be a powerful means sufficient to describe the whole network nearly-stable behaviour.

Methods to determine the terminal time constant of complex networks are illustrated, and crucial conclusions of practical interest are drawn on the ability to keep by simple means under strict control the errors arising from the truncation of stabilisation transients.



# *Rationalisation of Stabilisation Criteria for Thermal Balance Tests*

**E. Colizzi – Ettore.Colizzi@esa.int**  
**European Space Thermal Analysis Workshop,**  
**ESA/ESTEC, Noordwijk, 20-21/11/2012**

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## **Introduction – Background Overview**



**Well known steps typically involved in thermal design and verification of Spacecraft, Subsystems, Sub-Assemblies, Equipment (etc.) include:**

- Establishment of a TMM (Thermal Mathematical Model)
- Preliminary utilisation of that TMM for design purposes
- Validation (fine tuning) of TMM by means of correlation with a [Thermal Balance Test](#), for which test predictions are produced
- Production of on-orbit thermal predictions

E. Colizzi , ESA/ESTEC - Stabilisation Criteria Rationalisation – 26<sup>th</sup> Space T.A. Workshop – Noordwijk 20-21/11/2012 – Slide 2  
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## Introduction – *Background Overview*



**Thermal Balance Tests**, irrespective of the dimensions and complexity of the test article involved are recurrently judged

- Too long, by Project Managers and AIT Managers
- Too short and with too few test phases, by Thermal Analysts and Thermal Engineers

**While, on the other hand it is indisputable that:**

- Costs are normally relatively high and very steeply increasing with duration are indisputable
- A variety of approaches and standards dealing with “*Stabilisation Criteria*” are in use, not always easy to defend, whereas they have obvious effects on Thermal Test duration

**Therefore:**

- *A solid and rational approach to trade-off test duration (and costs) against accuracy of results is more than just desirable.*

## Introduction – *Preliminary Considerations*



**By common sense, an ideal Thermal Stabilisation Criterion:**

- *Should be solely based on engineering considerations about “affordable truncation errors” (i.e.: conscious acceptance of differences between actual instantaneous temperature measurements vs their true asymptotic values)*

**Moreover, for practical reasons:**

- *It should involve only measurable quantities (temperatures, time)*
- *It should have simple and straightforward formulation, verifiable in real time during test execution (even by half-asleep engineers)*

## Introduction – Preliminary Considerations

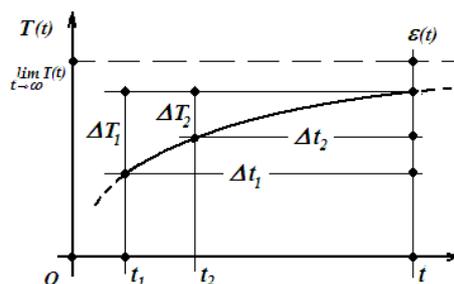


### Trivial starting point: single diffusive node linear thermal network:

- Temperature evolution governed by known Equation type:  $T(t) = a + be^{-t/\tau}$

- Consequent Equation of truncation error can be easily be determined, without involving the unknown parameters  $a$  and  $b$ , as:

$$\varepsilon(t) = \frac{|\Delta T_1|}{e^{\Delta t_1/\tau} - 1} = \frac{|\Delta T_2|}{e^{\Delta t_2/\tau} - 1}$$



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## Introduction – Preliminary Considerations



### Noticeable facts, once the thermal time constant " $\tau$ " of the network is known:

1. Truncation error can be determined (precisely, in this case) by mere reliance on observable (measurable or predictable) parameters (temperature and time)
2. Given an acceptable truncation error  $\varepsilon$  a (virtually) arbitrary choice can be made among consistent couples of  $\Delta T$ 's and  $\Delta t$ 's to verify – at a given time – that truncation error is matched (or not exceeded).

Remarkably, virtually identical considerations apply when a generic non-linear thermal network (of whatever number of nodes and conductors) is dealt with. In particular:

- A process will be illustrated to extend these basic concepts, by means of identifying one single network-specific parameter (the "Terminal Time Constant") capable to synthesize the network response
- The need for a relatively modest computational efforts will be shown to quantify the Terminal Time Constant of networks of whatever complexity.

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## Introduction – *Development Overview*



### Line of thinking to attain the anticipated results:

- Acknowledge that the thermal transient of any system eventually approximate the behaviour of linear system
- Adopt an operative definition of a time-dependent pseudo time-constant to establish the legitimacy of the linear approximation
- Capitalise on the Physical fact that eventually all temperatures evolve along exponential curves characterised by **the same (terminal) time constant**
- Investigate ways to determine the value of the terminal time constant (the only non-measurable quantity encountered within this context)
- Illustrate the outcome of Linear Algebra utilisation: the maximum (negative) Eigenvalue method
- Propose the Discrete Derivation method based on the novel definition of “Instantaneous Time Constant”
- Extend the concept of truncation error control to complex networks, as a means to preserve compliance to the postulated best common sense approach
- Suggest rationalised approach to stabilisation criteria for practical application

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## Introduction – *Development Overview*



### Further considerations:

- Assessment of the effect of stabilisation criteria on test duration
- Warnings about the concept of “local time constant”

#### Note:

*Expansion and deepening of the subject presented, including legitimacy of approximations, are among the matters dealt with in my previous paper:*

*“Thermal Balance Testing: A Rigorous Theoretical Approach to Stabilisation Criteria Based on Operative Re-Definition of Thermal Time Constant” (AIAA Publication 2012-3405, 42<sup>nd</sup> ICES, S. Diego, CA – July 2012) Copyright © 2012 by Ettore Colizzi - ESA/ESTEC.*

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## Considerations about Nearly-Stable Network Behaviour



- Irrelevance of knowledge about network thermal evolution history
- Modest amplitude of temperature changes allows linearisation of the description of the network behaviour and **legitimizes reliance of linear algebra**

**Note:** *this encompasses any sources of non-linearity (e.g.: material property dependence on temperature) , and not only the most obvious radiation exchange mechanism*

- Capitalising from the time constant property of truly linear networks:

$$\tau = -\frac{dT_1}{dt} \bigg/ \frac{d^2T_1}{dt^2} = -\frac{d^n T_1}{dt^n} \bigg/ \frac{d^{n+1} T_1}{dt^{n+1}} = \text{constant}$$

by analogy, a “pseudo time constant”, function of time, can be generically defined as an ad-hoc analytical tool to “gauge” the network actual proximity to linear behaviour:

$$\tau^*(t) = -\frac{dT_1}{dt} \bigg/ \frac{d^2T_1}{dt^2}$$

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## The Eigen-vector Method – Algebra



**Briefly recalling from linear algebra:** the N equation of energy balance at each of the N nodes:

$$c_n \frac{dT_n}{dt} = p_n - \sum_{q=1}^N K_{n,q} (T_n - T_q) - \sum_{b=1}^{N_b} H_{n,b} (T_n - \theta_b)$$

are resolved by means of Eigen-vector and Eigen value method. I.e: by resolving the set of simultaneous equations (in vector form below):

$$\frac{d}{dt} \vec{T} = [A] \vec{T} + \vec{F} \quad (\text{Complete Equation})$$

$$[A] \vec{U} = \lambda \vec{U} \quad (\text{Eigen-value and Eigen-vector Generator})$$

$$0 = [A] \vec{V} + \vec{F} \quad (\text{Auxiliary Equation for Particular Integral Determination})$$

and imposing initial conditions. The latter operation allows then to determine the values of the N coefficients  $b_k$  and the complete final solution (vector and scalar form, respectively):

$$\vec{T}(t) = \vec{V} + \sum_{k=1}^N b_k \vec{U}_k e^{\lambda_k t} \quad T_n(t) = v_n + \sum_{k=1}^N b_k u_{k,n} e^{\lambda_k t}$$

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## The Eigen-vector Method – Existence of the Terminal Time Constant



Linear algebra allows to demonstrate that:

- All network nodal temperature profiles are a linear combination of the same family of (decaying) exponential functions

Therefore, after sufficiently long time:

- Only one (most persistent) exponential will prevail on all the other as a descriptor of the evolution of all nodes thermal behaviour

As such:

- All residual transient profiles will be characterised by the same **terminal time constant**  $\tau_\infty$  associated to the (**unknown**) Eigen-value  $\lambda_m$  characterised by minimum absolute value, with:

$$\tau_\infty = -\frac{1}{\lambda_m}$$

- The equation of the nodal temperature will approximately be (as for the one-diffusive node network case):

$$T_n(t) \approx v_n + b_n u_{m,n} e^{\lambda_m t} = v_n + \beta_n e^{-t/\tau_\infty}$$

## The Eigen-vector Method – Terminal Time Constant Calculation



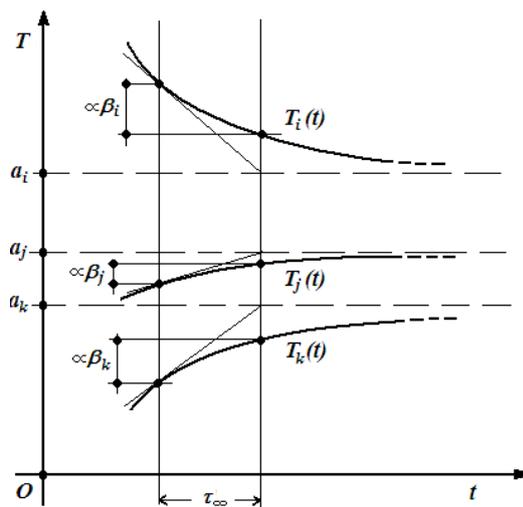
Further effects of the existence of a terminal time constant:

- the rate of change of all temperatures and components of the (terminal) Eigenvector  $\vec{U}_m$  satisfy the equalities:

$$\frac{dT_i(t)}{dt} \bigg/ \frac{dT_j(t)}{dt} \approx \frac{T_i(t) - T_i(t-\eta)}{T_j(t) - T_j(t-\eta)} \approx \frac{\beta_i}{\beta_j} = \frac{u_{m,i}}{u_{m,j}}$$

- Once the (terminal) Eigen-vector is known, the semi-arbitrary choice of  $\eta$  allow to attain the explicit expression:

$$\lim_{t \rightarrow \infty} \frac{\sum_{s=1}^N [T_s(t) - T_s(t-\eta)] c_s}{\sum_{s=1}^N [T_s(t) - T_s(t-\eta)] \sum_{b=1}^{N_k} H_{s,b}} = \tau_\infty$$



Asymptotic Behaviour of Temperatures Under Terminal Time-Constant Regime

## The Eigen-vector Method – Implementation



### The How to make use of these findings?

1. Establish a value for  $\eta$  such that expected temperature differences surpass (with margins) the numerical accuracy of the test predictions about to be carried-out
2. Implement an automated process in the TMM for test article external radiative conductor linearisation
3. Implement automatic algorithm in the TMM network solver carrying-out the summations over the entire set of diffusive nodes of the network (numerator) and double summation over diffusive node and boundary nodes (denominator)
4. Produce test predictions for the transient leading to stabilisation: the output will include by default  $\tau_{\infty}(t)$
5. Check convergence of  $\tau_{\infty}(t)$  to an asymptotic value
6. Adopt  $\tau_{\infty}(t)$  (asymptotic value) for transient truncation control strategy
7. Make use of the temperature measurements taken during the test (and without any need of the TMM) to confirm, if necessary, the terminal time constant value theoretically determined

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## Discrete Differentiation Method - Principle



- Principle: direct application of the definition of  $\tau^*(t)$  :

$$\tau^*(t) = -\frac{dT_1}{dt} \bigg/ \frac{d^2T_1}{dt^2}$$

by numerical differentiation process carried-out by the TMM network solver during the Thermal Balance test prediction runs, on the temperature profile of any diffusive node

**Example of numerical differentiation algorithm** for equally spaced time intervals:

$$\tau^*(t) = -\frac{dT(t)}{dt} \bigg/ \frac{d^2T(t)}{dt^2} \approx -\left(\frac{T_3 - T_1}{2\Delta t}\right) \bigg/ \left(\frac{T_3 + T_1 - 2T_2}{\Delta t^2}\right) = -\frac{\Delta t}{2} \frac{T_3 - T_1}{T_3 + T_1 - 2T_2}$$

**Warning:** meaningful results will be conditional to the satisfaction of the minimum conditions safeguarding against numerical differentiation error, i.e.:

$$\Delta t > 8\tau \left( \frac{\delta T}{|\Delta T|} \right) \bigg/ \left( \frac{\delta \tau}{\tau} \right)$$

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## Discrete Differentiation – Implementation



The method is node-specific, therefore:

- It does not need to be applied to the whole population of diffusive nodes (ideally any-one of the diffusive nodes would have to be sufficient to provide meaningful results!)

As a **reasonable compromise**:

- Use of a small population of pilot nodes of various typology scattered over the test article is recommended

Expected results, and **demonstration of process consistency** will be obtained by observing:

- Convergence of  $\tau^*(t)$  to an asymptotic value, for each of the nodes
- Strong trend to coincidence of all the asymptotes of all pilot nodes to the same numerical (time) value, i.e.: *the network terminal time-constant*  $\tau_\infty(t)$

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## Stabilisation Criteria – Truncation Error Control



**Main implication of the ability to determine network  $\tau_\infty$  :**

- Ability to transfer to any networks of whatever complexity the considerations made about the single diffusive node network (ideally, by simply replacing  $\tau$  by  $\tau_\infty$ )
- Assurance that in a large network for each diffusive node  $j$ , future deviations of its temperature from its asymptotic value will be such to satisfy the inequality:

$$\varepsilon_j(t) < \frac{|\Delta T_j|}{e^{\frac{t}{\tau_\infty}} - 1} = \varepsilon_{j,MAX}$$

*I.e.: If an upper limit is imposed to the maximum temperature drifts observed during a TB test over a relatively recent past (measured in terminal time constant units) the maximum expected deviation from their asymptotes will be constrained within a known quantity.*

**Note:** This matches the goals of simple formulation and utilisation of directly measured parameters only

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## Truncation Error Control: Practical Considerations



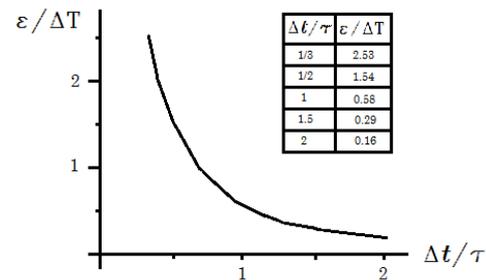
- Interest in shortening the observation time, to avoid unnecessarily prolong the test

*On the other hand:*

- Observed temperature differentials, well in excess of the accuracy of temperature measurements are desirable

*Therefore, in conclusion*

- **Systematic utilisation of the illustrated rational approach is highly recommended**
- **Adaptation to specific cases should be traded-off within the offered degree of freedom**



*Granted asymptote proximity  
as a function of observation time*

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## Truncation Error Control: Effect on Test Duration



### Further relationships assisting the selection of Stabilisation Criterion:

- **Minimum observation time** for a given affordable truncation error

$$\Delta t > \tau_{\infty} \ln \left( 1 + \frac{|\Delta T|}{\varepsilon_{j,MAX}} \right)$$

**Limiting factor:** *minimum value  $|\Delta T|$  of reliable temperature differential measurements over time*

- **Duration of Steady State test phases** as a function of allowed truncation error

$$D(\varepsilon_{j,MAX}^{(2)}) = D(\varepsilon_{j,MAX}^{(1)}) - \tau_{\infty} \ln \frac{\varepsilon_{j,MAX}^{(2)}}{\varepsilon_{j,MAX}^{(1)}}$$

**Note:** *only duration increment/decrement attributable to different truncation error can be quantified, since possibly lengthy transients between thermally distant levels are obviously test-specific.*

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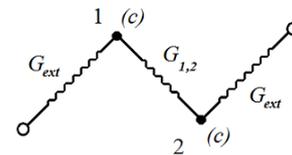
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## Eigenvalues and Local Time Constants



### A word of warning:

- Network Eigenvalues (and associated time constants) are characteristic of the entire diffusive node network
- "Local" time constants associated to the N diffusive node taken one by one depend on network parameters too



### But:

*No actual direct relationship exists between magnitude of local time constants, network Eigenvalues and network terminal Time constant*

$$G_{1,2} \gg G_{ext}$$

$$\tau_1^{(Local)} = \tau_2^{(Local)} \sim \frac{C}{G_{1,2}} \ll \frac{C}{G_{ext}} = \tau_{\infty}$$

Only weak relationships hold, such as:

$$\sum_{i=1}^N \frac{1}{\tau_i^{(Local)}} = \sum_{k=1}^N \frac{1}{\tau_k} \quad \min_{1 \leq i \leq N} \{\tau_i^{(Local)}\} \leq 2\tau_k \leq 2\tau_{\infty}$$

**Local vs terminal time constant paradox**

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**Thanks for your attention!**

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## Appendix P

### Solar Simulator Testing and Correlation of PHI Heat Rejecting Entrance Window (HREW) of Solar Orbiter

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(Università di Padova, Italy)

Giovanni Taglioni      Chiara Ciccirelli  
(Selex Galileo S.p.A., Italy)

Claudio Damasio  
(ESA/ESTEC, The Netherlands)

### **Abstract**

The ESA mission Solar Orbiter will provide a look at the Sun closer than ever before. Among other instruments is the Polarimetric and Helioseismic Imager (PHI) lead by the Max Planck Institute for Solar System Research (MPS). PHI instrument will observe the Sun through the Heat Rejecting Entrance Window (HREW) which is an optical filter that has to be placed at the entrance of the instrument acting as a filter rejecting all the radiation coming from the Sun with the exception of a very narrow spectral band around 613.3nm where it is provided a 80% transmission.

A Thermal Balance Test of HREW filter and mounting frame has been held in December 2011 using the Solar Simulator facility of CISAS University of Padova to validate the values of the thermal parameters adopted for the thermal modeling of the HREW window in operative conditions. This paper describes the solar simulator test campaign and the thermal modeling performed in order to compare numerical and experimental results. A thermal mathematical model of the test-bed with all the thermal and mechanical interfaces has been added to the filter model in order to compare the experimental data with the results of the numerical models. Thermal model correlation allow to validate the HREW filter thermal mathematical model providing more reliable prediction of thermal behavior of rejecting window during Solar Orbiter mission.



## Solar Simulator Testing and Correlation of PHI Heat Rejecting Entrance Window (HREW) of Solar Orbiter

Enrico Friso, Stefano Debei - CISAS "G.Colombo" University of Padova, Italy

Giovanni Taglioni, Chiara Ciccirelli - Selex Galileo S.p.A., Italy

Claudio Damasio - ESA/ESTEC, The Netherlands

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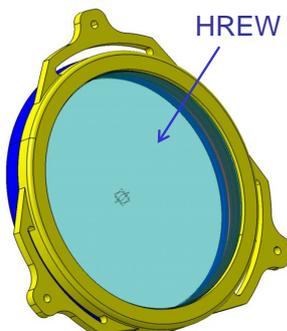
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## Introduction



The ESA mission Solar orbiter will investigate the Sun closer than ever before. Among other instruments is the **Polarimetric and Helioseismic Imager (PHI)** lead by the Max Planck Institute for Solar System Research (MPS) that will observe the Sun through the **Heat Rejection Entrance Window (HREW)** which is an optical filter that has to be placed at the entrance of the instrument.



A **Thermal Balance Test** of HREW filter and its mounting frame has been held in December 2011 using the **Solar Simulator** facility of CISAS "G.Colombo" University of Padova in order to validate the values of thermal parameters adopted for the thermal modeling of HREW filter

Thermal model **correlation** allow to validate the TMM of the HREW filter providing more reliable prediction of thermal behavior of rejecting window during Solar Orbiter mission

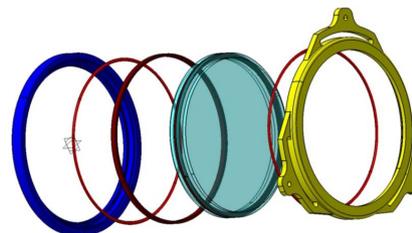
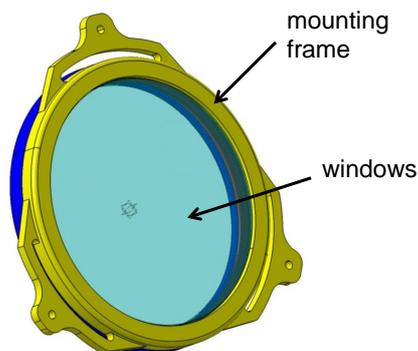
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### Overview

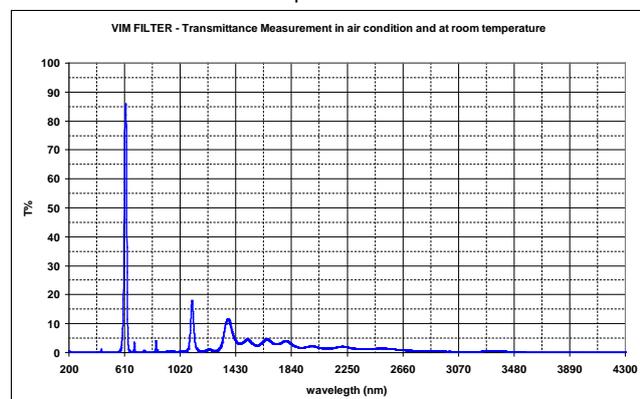
- Description of the HREW filter
- Test lay-out: Solar Simulator and TBT set-up
- TBT test campaign and results
- Modelling the HREW and TBT set-up
- HREW Thermal Model correlation
- Conclusions

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HREW filter exploded view

The Heat Rejection Entrance Window is an optical component that has to be placed at the entrance of PHI instrument acting as a filter rejecting the radiation in the range from 200nm to 5000nm with the exception of a very narrow band at 617,3nm where the transmission is more than the 80%.



HREW spectral performance

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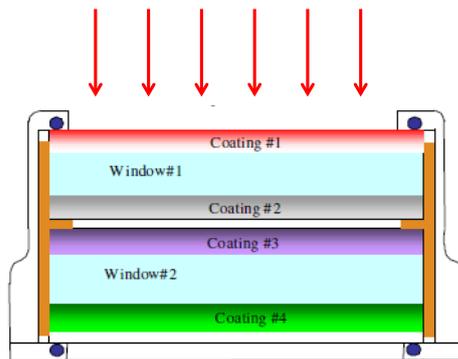


### Description of HREW filter



The filter is composed by two quartz windows (diameter = 160 mm, thickness = 10mm) separated by a 3mm gap.

The optical performances are provided by 4 coatings on windows



The optical performances are provided by 4 coatings:

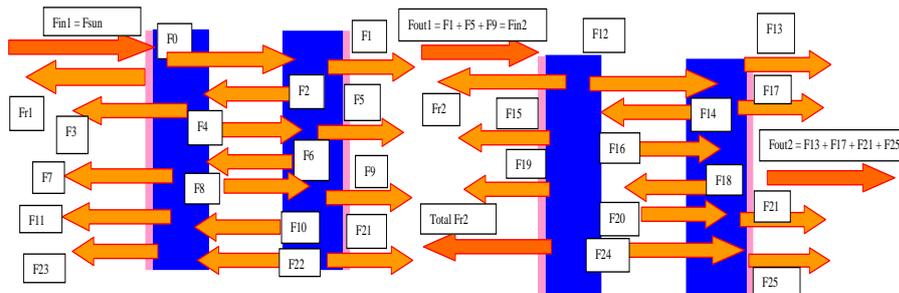
- **Coating #1:** UV Mirror to reflect the UV radiation down to 200 nm
- **Coating #2:** High-Pass Dichroic to define the cut on the band pass
- **Coating #3:** Low-Pass Dichroic to define the cut off on the band pass
- **Coating #4:** IR Shield to reflect the IR radiation up to 4300 nm



### Thermal Model of HREW filter



How to model in ESATAN-TMS wavelength dependant optical surface ?



$$\alpha_i^{rel} = \frac{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda) \cdot A_i^{coating}(\lambda)}{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda)}; \quad \rho_i^{rel} = \frac{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda) \cdot R_i^{coating}(\lambda)}{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda)}; \quad \tau_i^{rel} = \frac{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda) \cdot T_i^{coating}(\lambda)}{\sum_{\lambda=250nm}^{\lambda=2500nm} F_i(\lambda)}$$

$A_i^{coating}(\lambda)$  absorptivity

$R_i^{coating}(\lambda)$  reflectivity

$T_i^{coating}(\lambda)$  transmittance

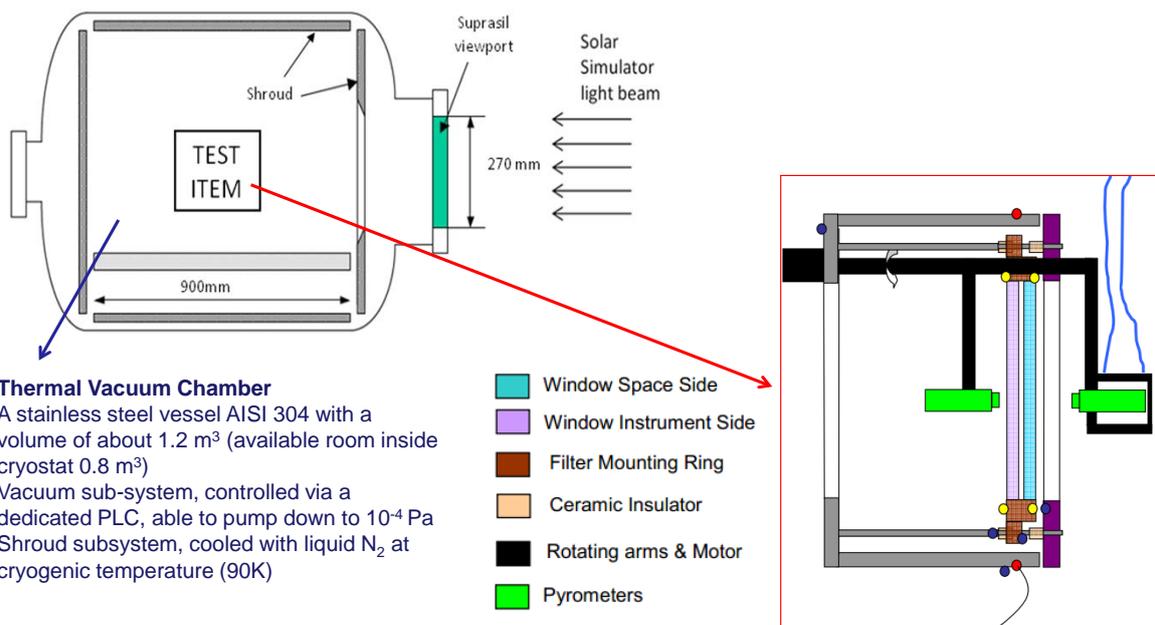
$F_i(\lambda)$  Flux to the coating taking into account the multiple reflections (ASTM-E90 solar spectrum model)

For each single coating, the parameters in this case have been calculated considering the sum of all fluxes at each single wavelength, including fluxes coming from multiple reflections and averaging the thermo-optical properties to the Solar Spectrum (C.Damasio, ESA & Selex Galileo)

### Overview

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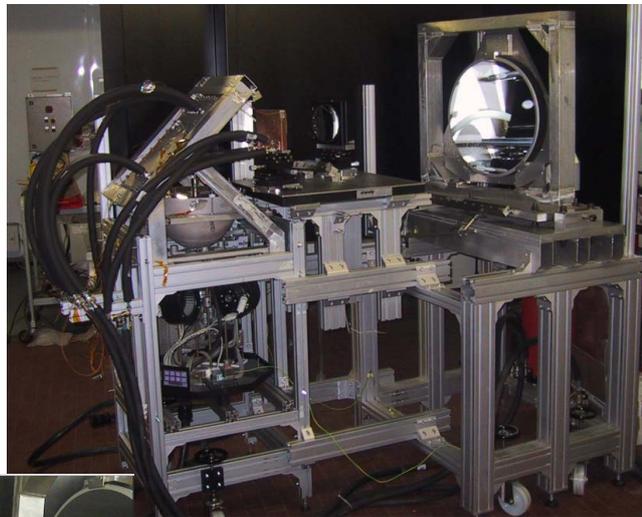


**CISAS - Solar Simulator**

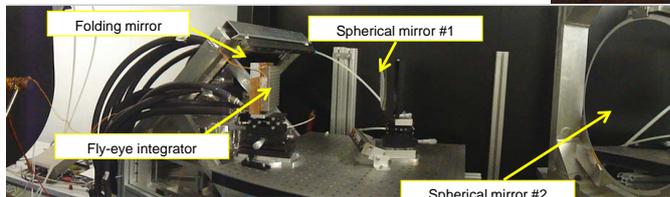


Placed externally to the TVC, it produces a nearly-collimated (divergence < 30') steady beam with a homogeneous flux distribution (uniformity better than 10%) across an aperture of 300 mm diameter and allows to obtain an irradiance up to 6-7 SC.

The light beam is generated by a 10kW Xenon lamp placed in the focus of an ellipsoid mirror. The optical path is based on a series of multiple reflections onto thermally controlled mirrors to produce a collimated beam towards the TVC



CISAS - Solar Simulator lay-out



CISAS - Solar Simulator Optical bench

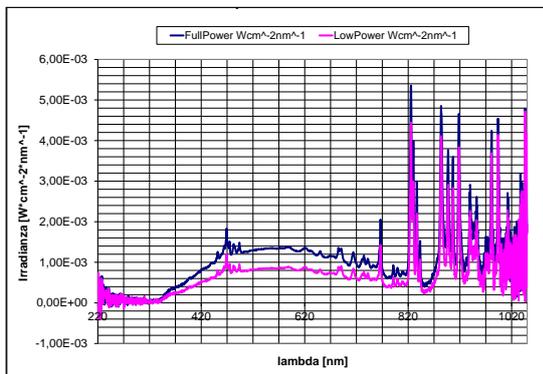


**CISAS - Solar Simulator**

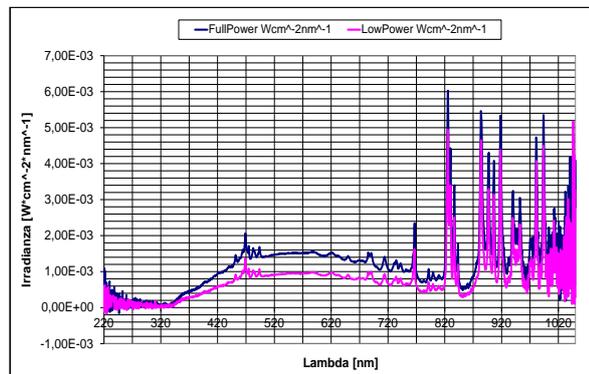


Once aligned and correctly positioned with respect to the thermal vacuum chamber, the solar simulator has been characterized using a spectrometer (both outside and inside the thermal vacuum chamber) and a water cooled Gardon heat flux sensor

The maximum irradiance is of about 9-10 kW/m<sup>2</sup>



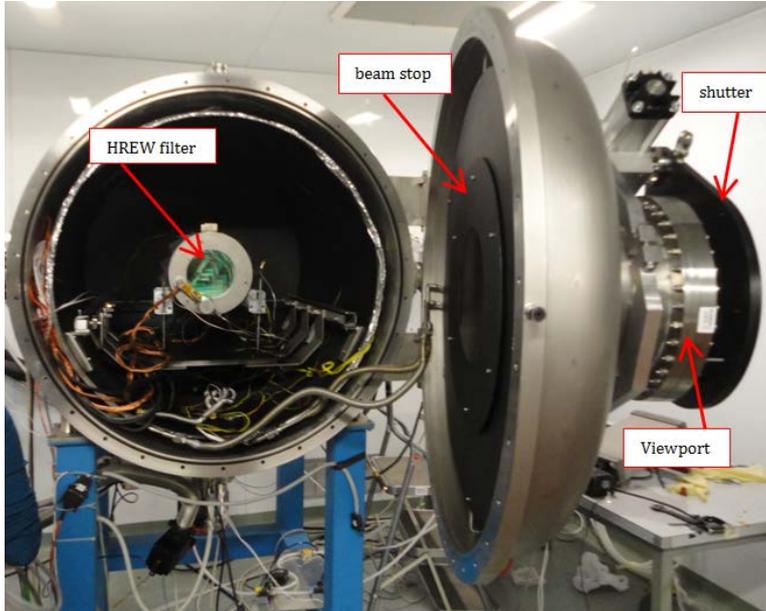
SS spectrum Inside Viewport : maximum and lowered power



SS spectrum Outside Viewport : maximum and lowered power



### HREW Thermal Balance Test set-up



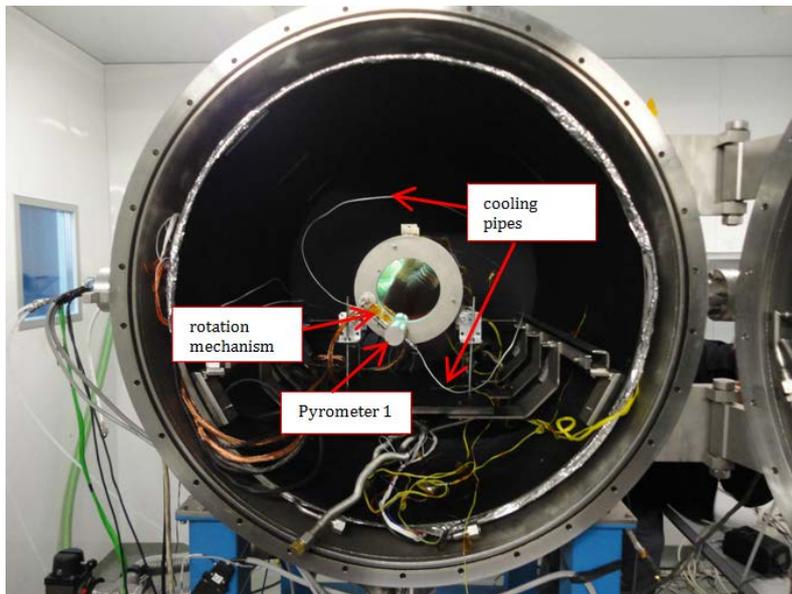
HREW filter inside TVC, diaphragm, viewport and external shutter

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### HREW Thermal Balance Test set-up

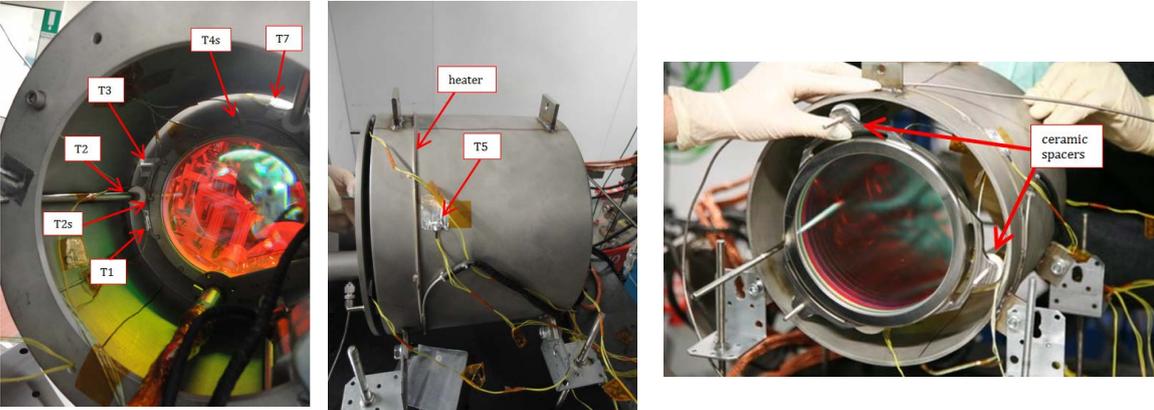


HREW filter inside TVC

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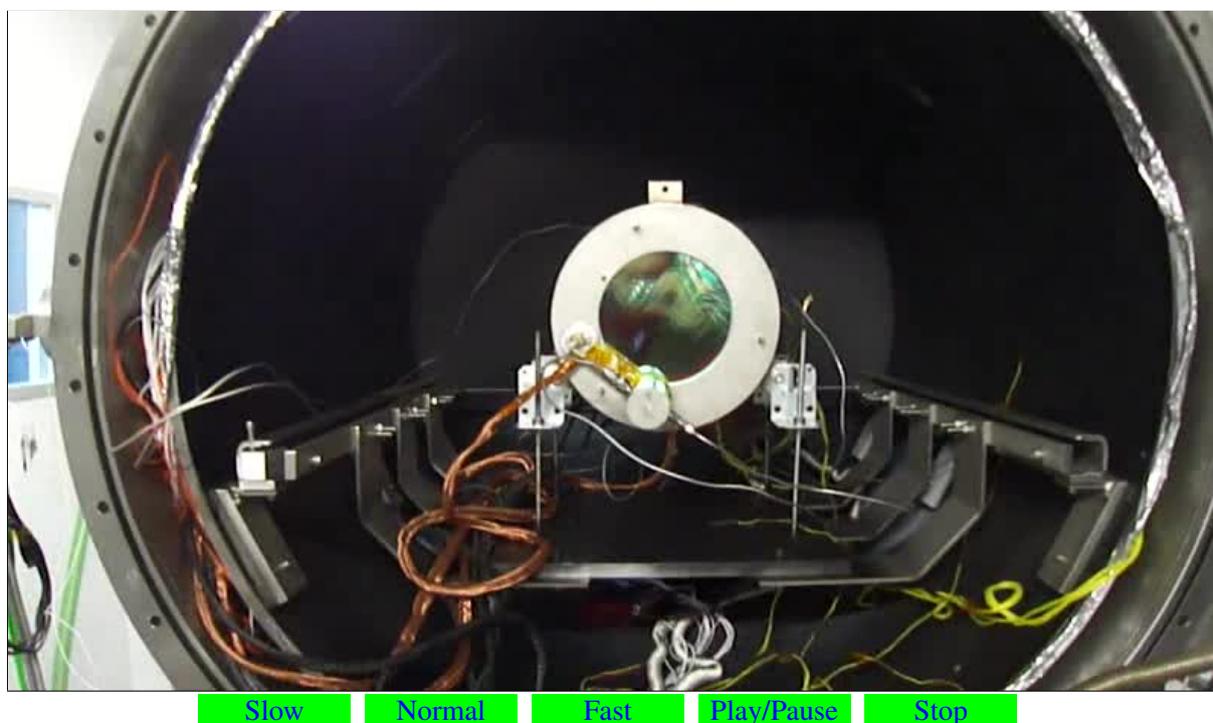
**CISAS** G. COLOMBO **HREW Thermal Balance Test set-up** **SELEX GALILEO** A Proximate Company



HREW filter test set-up

⇒ VIDEO of pyrometers moving mechanism

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## Solar Simulator Testing and Correlation of HREW filter

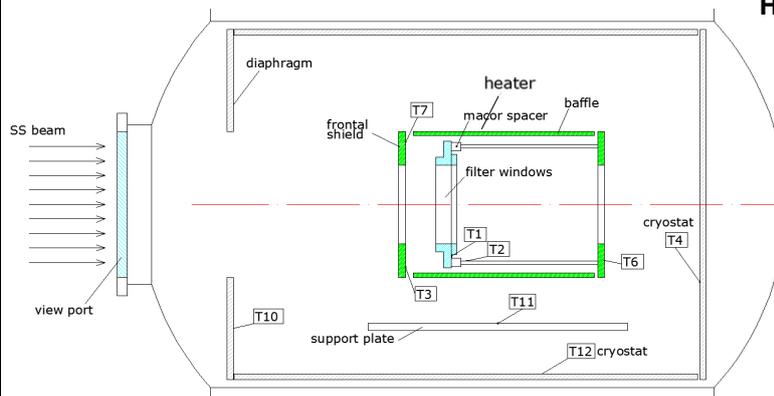


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## TBT campaign and results



### HREW Test campaign: test levels

Four Steady State conditions have been reproduced :

- **A:** SS @ maximum power, heater off
- **B:** SS @ maximum power, heater on
- **C:** SS @ lowered power, heater off
- **D:** SS @ lowered power, heater on

The steady state condition has been considered achieved when the rate of change of the temperature sensors was  $\leq 3^\circ\text{C/h}$

SS case	ref. #	SS Lamp	heater	Description
A	1	I = I <sub>max</sub>	OFF	1st measure with pyrometers
	2			2nd measure with pyrometers
B	3	I = I <sub>max</sub>	ON	1st measure with pyrometers
	4			2nd measure with pyrometers
C	5	I < I <sub>max</sub>	OFF	1st measure with pyrometers
	6			2nd measure with pyrometers
D	7	I < I <sub>max</sub>	ON	1st measure with pyrometers
	8			2nd measure with pyrometers

For each case (A to D):

- Solar simulator switched ON
- wait for thermal stability at set-up sensors
- shutter closed (SS beam blinded)
- pyrometer mechanism ON and temperature acquired on HREW (coating #1 and #4)
- shutter opened and wait for steady state condition. Repeat HREW measurement

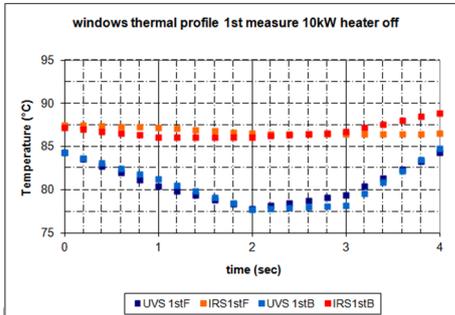


Fig. 4-1: Pyrometers measurement of HREW. Measure #1: SS max power, Heater Off

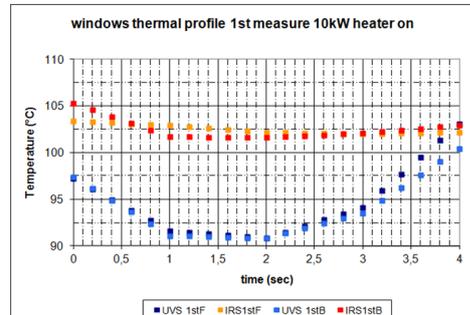


Fig. 4-3: Pyrometers measurement of HREW. Measure #3: SS max power, Heater ON

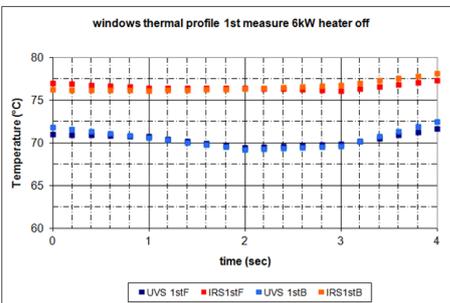


Fig. 4-5: Pyrometers measurement of HREW. Measure #5: SS low power, Heater OFF

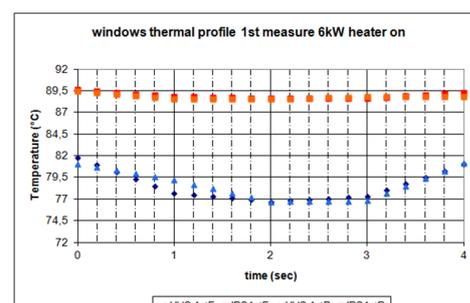


Fig. 4-7: Pyrometers measurement of HREW. Measure #7: SS low power, Heater ON

Example: case A

Shutter closed.  
HREW windows temperature  
acquired by pyrometers

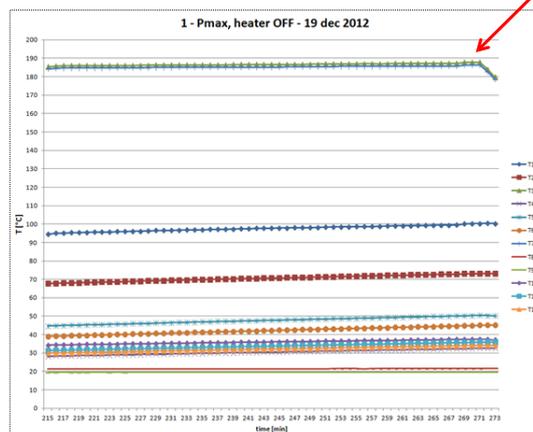


Figure 7: Lamp power = 10kW, I = I<sub>max</sub>, heater OFF (tests of 19-dec-2011). 1st measure with pyrometers (#1)  
The graph plots Pt100 temperatures 1 hour foregoing the pyrometer measurement

# 1	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12
Tmean	99.6	72.7	187.1	32.2	50.0	44.6	185.6	21.5	19.6	37.2	35.5	33.8
Tmin	99.0	72.3	184.0	31.8	49.4	44.0	182.7	21.5	19.5	37.0	35.0	33.4
Tmax	100.4	73.2	187.9	32.6	50.4	45.1	186.3	21.5	19.6	37.5	35.9	34.1

Table 2: Pt100 temperature (see Fig.5, Fig. 6) computed on the set of data 10min foregoing the pyrometer measure



Solar Simulator Testing and Correlation of HREW filter



Overview

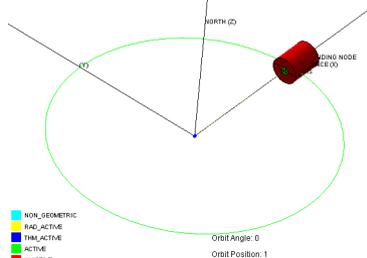
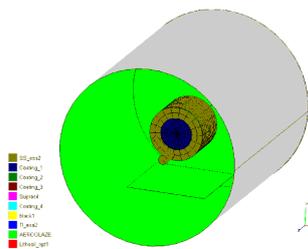
- Description of the HREW filter
- HREW Test lay-out: Solar Simulator and TBT set-up
- TBT test campaign and results
- Modelling the HREW and TBT set-up
- HREW Thermal Model correlation
- Conclusions



Modelling the HREW and TBT set-up

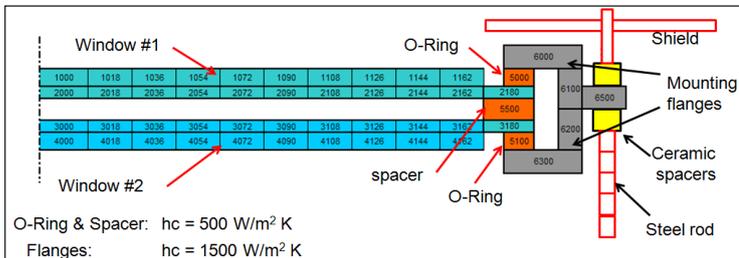
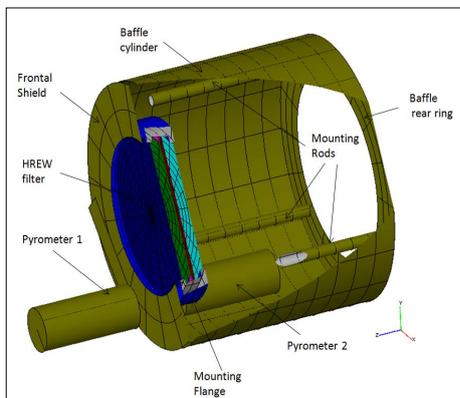


Thermo-optical Properties



Sun centered orbit of the HREW testing in order to reproduce the light beam irradiance of the solar simulator facility

radiative case	q SS [W/m <sup>2</sup> ]
Q5000	5000
Q10000	10000



O-Ring & Spacer: hc = 500 W/m<sup>2</sup> K  
Flanges: hc = 1500 W/m<sup>2</sup> K

The alpha and thermo-optical properties in the UV range have been re-calculated taking into account the SS lamp spectrum

Item	$a_i$ rel	$t_i$ rel	$r_i$ rel	ToT Rel
W1 -1	0,57%	81,95%	17,48%	100%
W1 -2	0,07%	73,88%	26,04%	100%
W2 -1	0,01%	43,83%	56,16%	100%
W2 -2	3,85%	10,32%	85,83%	100%



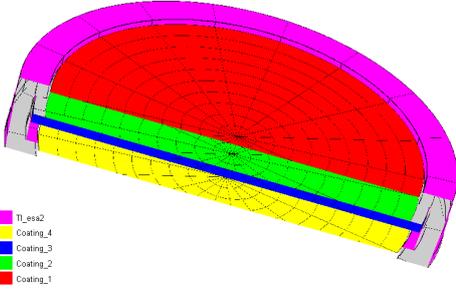
## Modelling the HREW and TBT set-up



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### Thermo-optical properties of HREW test model

Name	Thermal Finish	$\epsilon_h$	$\rho_h^d$	$\tau_h$	$\alpha_s$	$\rho_s^d$	$\tau_s$	$\rho_h^s$	$\rho_s^s$
Window 1-1	UV shield (Coating_1)	0.86	0.000 (*)	0.0	0.0057	0.0	0.1748	0.140 (*)	0.8195
Window 1-2	High pass (Coating_2)	0.82	0.000 (*)	0.0	0.0007	0.0	0.2605	0.180 (*)	0.7388
Window 2-3	Low pass (Coating_3)	0.82	0.000 (*)	0.0	0.0001	0.0	0.5616	0.180 (*)	0.4383
Window 2-4	IR shield (Coating_4)	0.06	0.000 (*)	0.0	0.0385	0.0	0.8583	0.940 (*)	0.1032
Window 1-2 (edge)	Suprasil	0.90	0.0	0.0	0.05	0.0	0.5	0.1	0.45
Window 2-3 (edge)	Suprasil	0.90	0.0	0.0	0.05	0.0	0.5	0.1	0.45
Mounting flange Space side	Titanium (TI_esa2)	0.20	0.80	0.0	0.53	0.47	0.0	0.0	0.0
Mounting flange Instr. side	Titanium (TI_esa2)	0.20	0.80	0.0	0.53	0.47	0.0	0.0	0.0
Baffle cylinder	Stainless Steel (SS_esa2)	0.27	0.73	0.0	0.48	0.52	0.0	0.0	0.0



(\*) All specular reflectivity in the IR range as baseline

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26<sup>th</sup> European Space Thermal Analysis Workshop – ESA/ESTEC 21 November 2012



## HREW thermal model correlation

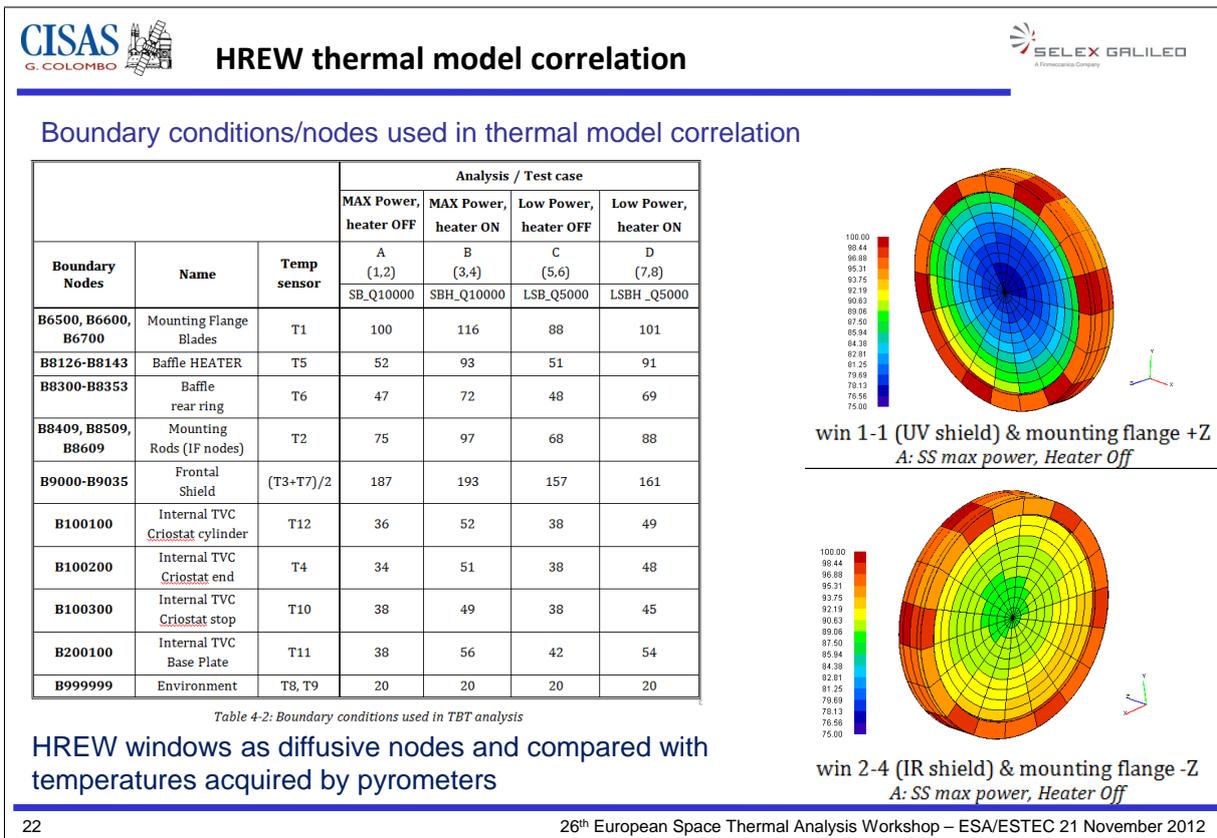


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### Overview

- Description of the HREW filter
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26<sup>th</sup> European Space Thermal Analysis Workshop – ESA/ESTEC 21 November 2012





## HREW thermal model correlation



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A comparison between the temperature range of HREW window obtained during test campaign and the results of thermal model are summarized in Table

A	model [°C]		test [°C]		ΔT [°C]		test [°C]		ΔT [°C]	
	SB_Q10000		A - measure #1		# 1		A - measure #2		# 2	
	periphery (*)	center (**)	periphery	center	periphery	center	periphery	center	periphery	center
UV shield (ext.)	87	78	84	78	3	<1	86	80	1	-2
IR shield (ext.)	92	89	87	86	5	3	91	90	1	-1
B	model [°C]		test [°C]		ΔT [°C]		test [°C]		ΔT [°C]	
	SBH_Q10000		B - measure #3		# 3		B - measure #4		# 4	
	periphery (*)	center (**)	periphery	center	periphery	center	periphery	center	periphery	center
UV shield (ext.)	100	90	99	91	1	-1	98	91	2	-1
IR shield (ext.)	106	102	105	102	1	<1	-	-	-	-
C	model [°C]		test [°C]		ΔT [°C]		test [°C]		ΔT [°C]	
	LSB_Q5000		C - measure #5		# 5		C - measure #6		# 6	
	periphery (*)	center (**)	periphery	center	periphery	center	periphery	center	periphery	center
UV shield (ext.)	75	68	72	69	3	-1	76	70	-1	-2
IR shield (ext.)	79	76	77	76	2	<1	80	79	-2	-3
D	model [°C]		test [°C]		ΔT [°C]		test [°C]		ΔT [°C]	
	LSBH_Q5000		D - measure #7		# 7		D - measure #8		# 8	
	periphery (*)	center (**)	periphery	center	periphery	center	periphery	center	periphery	center
UV shield (ext.)	85	77	82	77	3	<1	82	77	3	<1
IR shield (ext.)	91	87	91	90	<1	-3	91	90	<1	-3

ΔT between experimental and numerical results is ≤ 3°C

Temperature range: periphery-center of the window:  
 (\*) mean value of periphery rings nodes of the window  
 (\*\*) mean value of center nodes of the window



## Solar Simulator Testing and Correlation of HREW filter



### Conclusions

- HREW filter has been tested using a Solar Simulator facility giving an experimental insight of the filter thermal behavior
- Thermal Model of the filter has been correlated to experimental results and the assumptions made on thermal properties has been validated
- The updated HREW model provided more reliable prediction of thermal behaviour of rejecting windows during Solar Orbiter mission
- Wavelength dependant properties implementation on ESATAN-TMS would be a great advantage for modelling this kind of devices



# THANK YOU

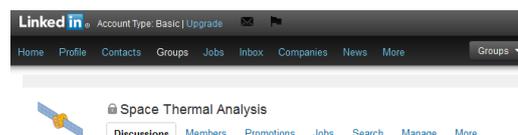
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## Appendix Q

### Application of CADBench and ESATAN-TMS to the Advanced Closed Loop System

James Mulcahy  
(EADS Astrium Bremen, Germany)

### **Abstract**

A recent addition to the ESATAN-TMS software is the CADBench tool for transferring a variety of CAD formats directly into the esatan geometry format. This presentation assesses the initial experience of this tool applied to the Advanced Closed Loop System (ACLS). The ACLS project requires the creation of a thermal geometry with a large number of components in a short time frame and as such is considered a good test for the capabilities of the new CADBench tool. This presentation will discuss the advantages, challenges and lessons learned in the initial application of this software tool in the frame of the ACLS project.

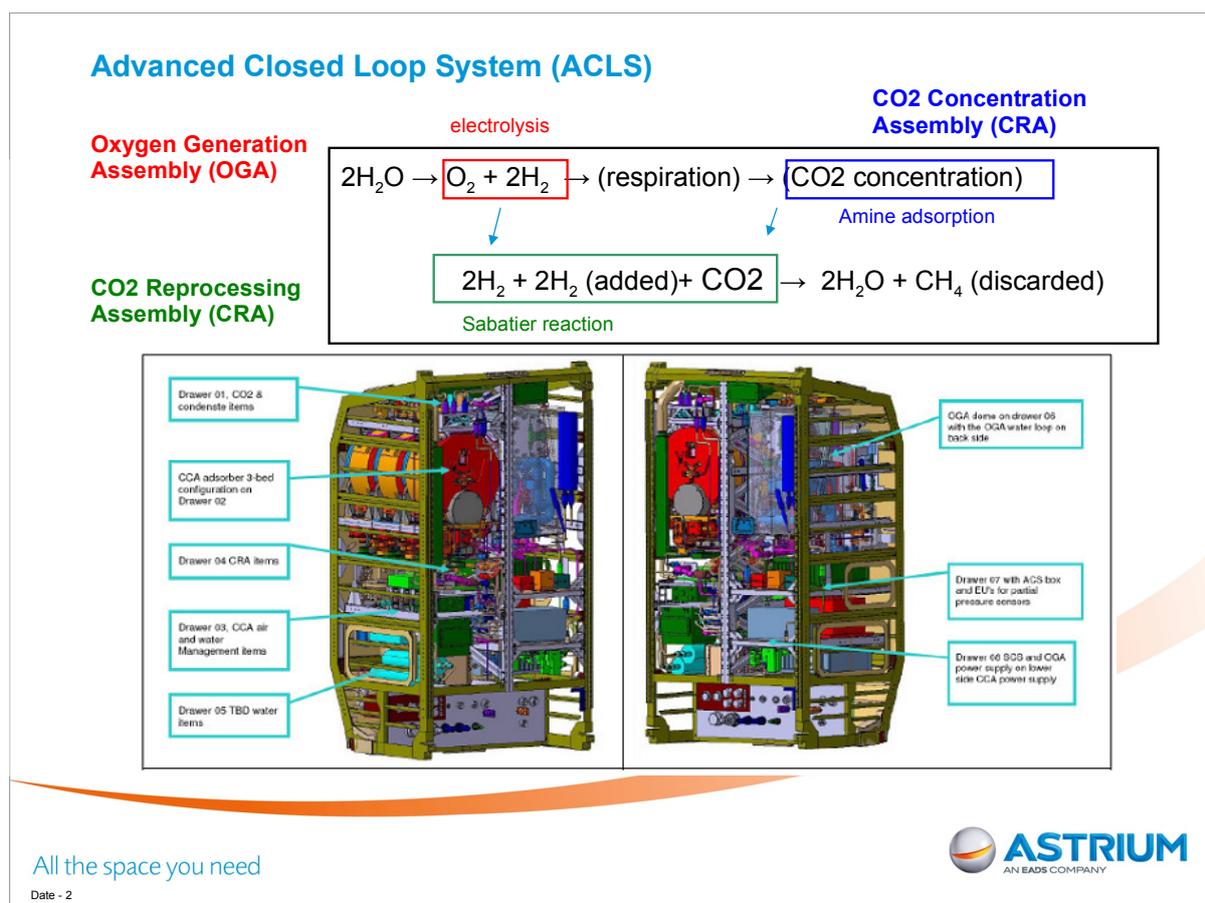
# ***Application of CADBench and ESATAN-TMS to the Advanced Closed Loop System***

**James Mulcahy. Astrium Space Transportation. Bremen**

**26th European Workshop on Thermal and ECLS Software  
20-21 November 2012, ESA ESTEC, Noordwijk**

All the space you need





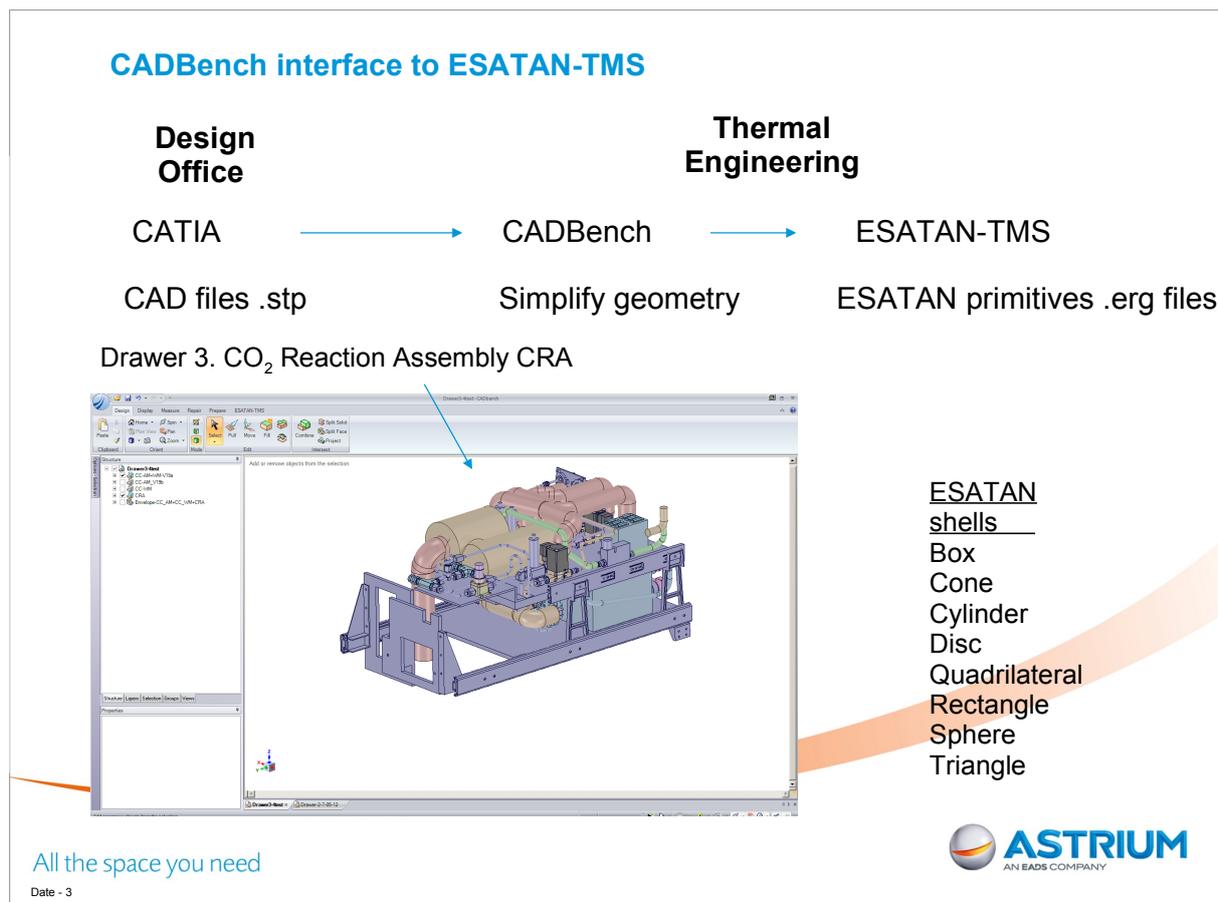
ACLS is double rack to be flown to the Columbus module of the ISS in the HTV June 2016. The system contains 8 drawers the most important 3 contain the CCA, CRA and the OGA. The remaining drawers contain the water management system WMS and various electronics.

The ACLS recycles CO<sub>2</sub> taken from the ISS and produces O<sub>2</sub>. The system is not 100% mass efficient since it requires a source of H<sub>2</sub> and discards methane produced in the reaction.

PDR is July 2012. CDR is July 2014.

Thermal Analysis of system poses problems as the geometry is complex and still undergoing revisions. Hundreds of components in system.

The use of CADBench was deemed necessary to enable rapid creation of GMM for thermal modelling.



CADBench is a plug in tool for ESATAN-TMS. The CADBench software is developed by SpaceClaim corporation. The company develops 3D software which is easy for engineers to use without needing to become CAD experts.

It allows the CAD geometry to be edited but does not include the full features of a program like CATIA.

For the thermal modeller these advanced CAD features are not required.

A number of automatic functions are included to rapidly simplify the CAD model.

The software has a built in converter that takes geometry and produces ESATAN-TMS geometry. The translator has shape recognition functionality.

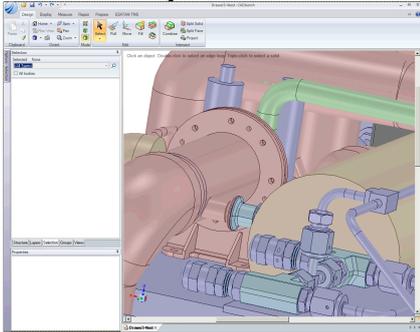
Only ESATAN-TMS shells will be recognised. If the components do not consist of these shells then the shape will be approximated by triangulation.

ESATAN-TMS can be launched automatically from CADBench to view exported geometry.

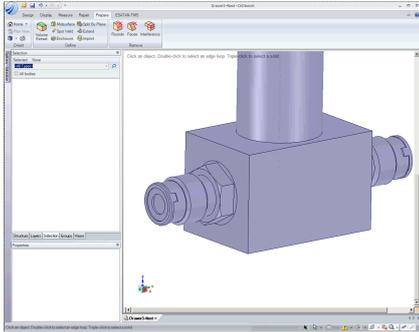
For the PDR in July Thermal Analysis will be carried out on a single drawer. The CRA which is on drawer 3 was selected.

## CADBench tools for geometry simplification

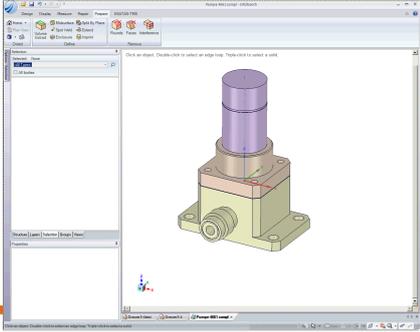
### Automatically fill small holes



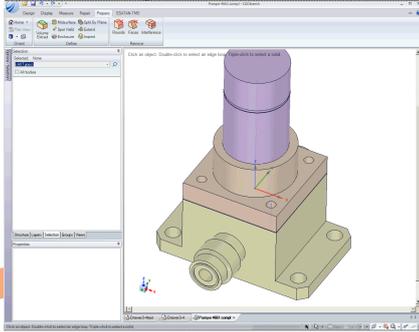
### Remove rounds



### Remove chamfers



### Use hot-keys



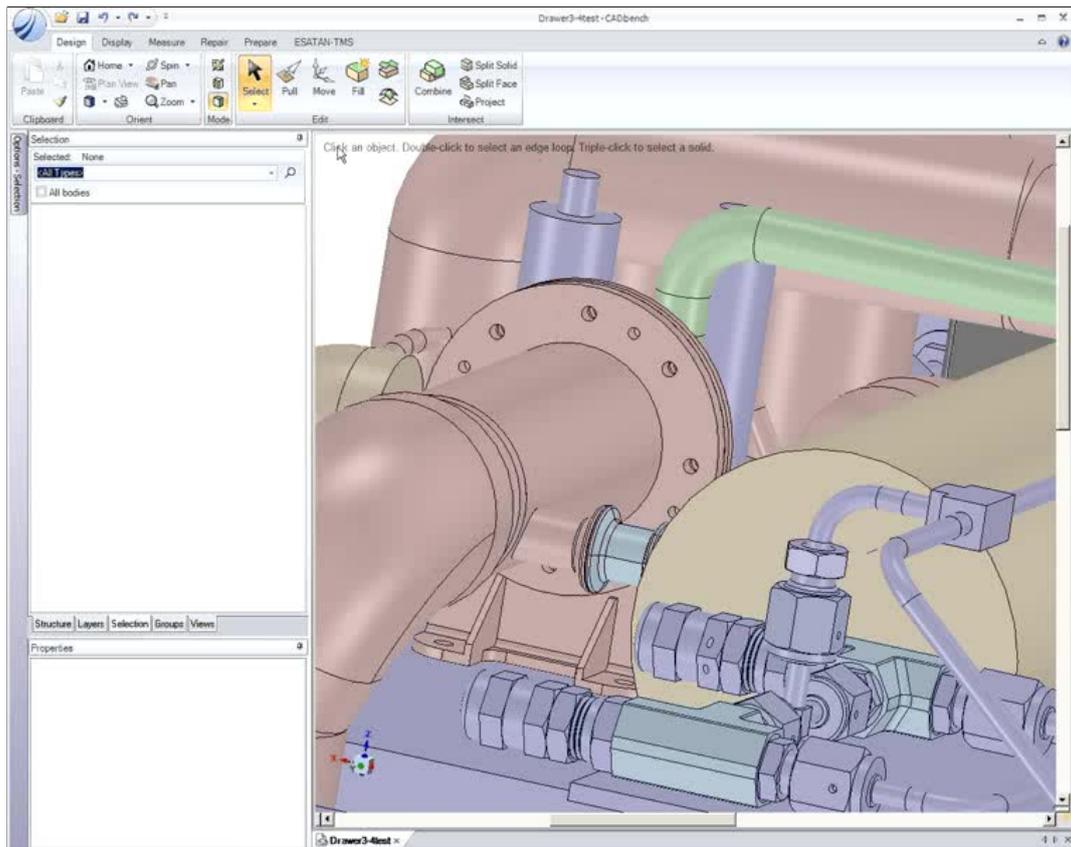
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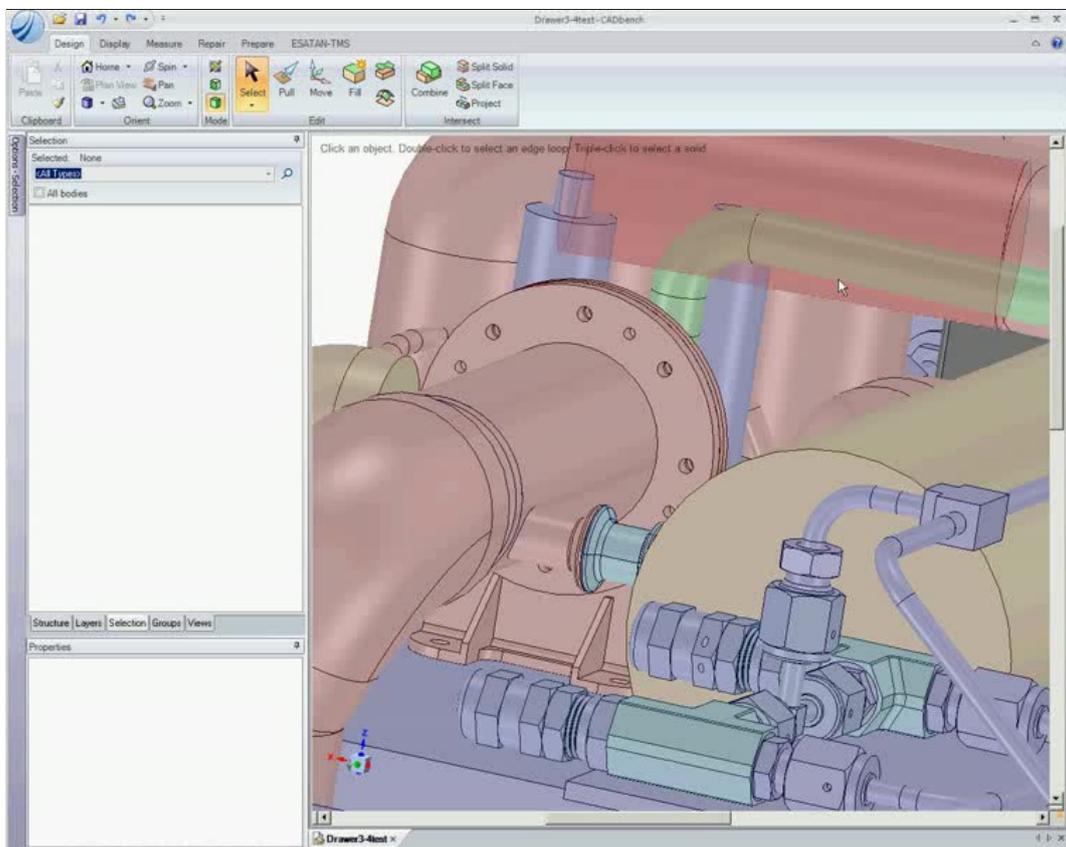
Date - 4

CADBench includes a number of tools for automatically removing features that are unwanted in order to simplify the geometry.

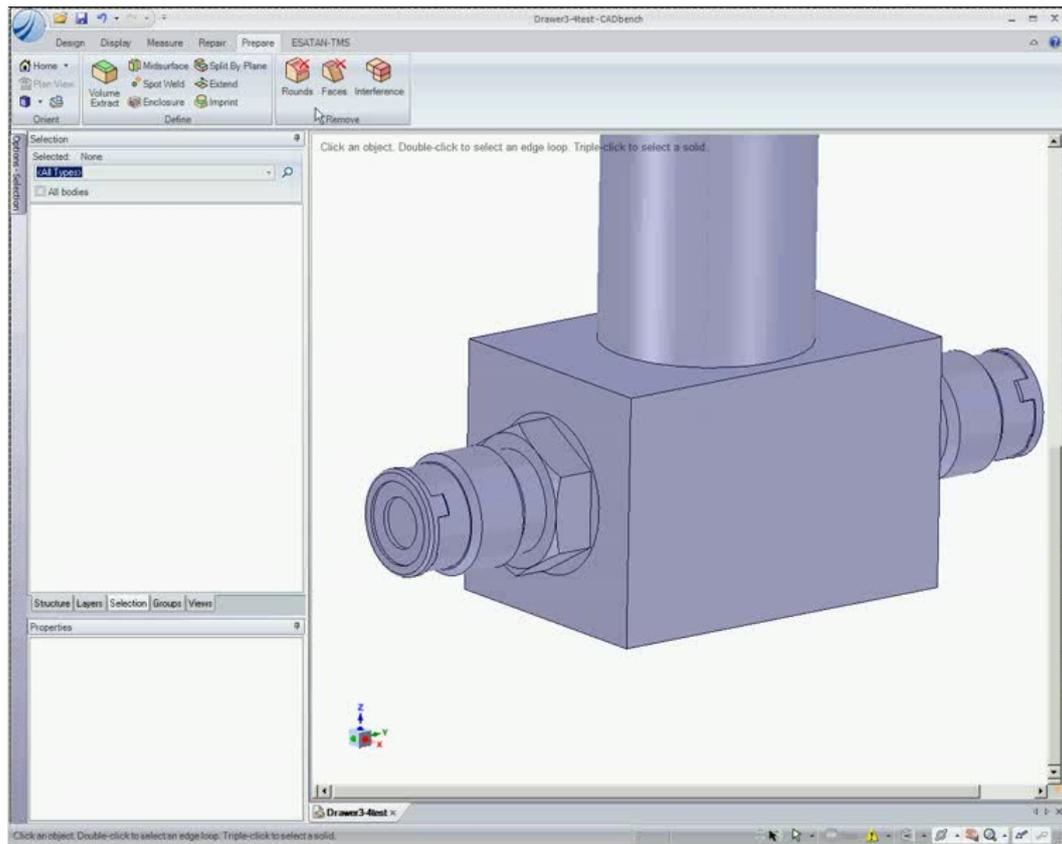
- 1 Small holes which have no effect on radiation couplings can be removed. Note that in selecting a hole, you can also select to remove all holes of the same diameter.
2. 3. Chamfers and rounds (fillet) can also be removed. Again selection can be based on all rounds of similar diameter, or all surfaces with the same area.
4. Editing is sped up through the use of keyboard hot-key. For example all the previous functions, Filling holes, chamfers or rounds (fillets) can all be done by selecting and typing F on the keyboard.



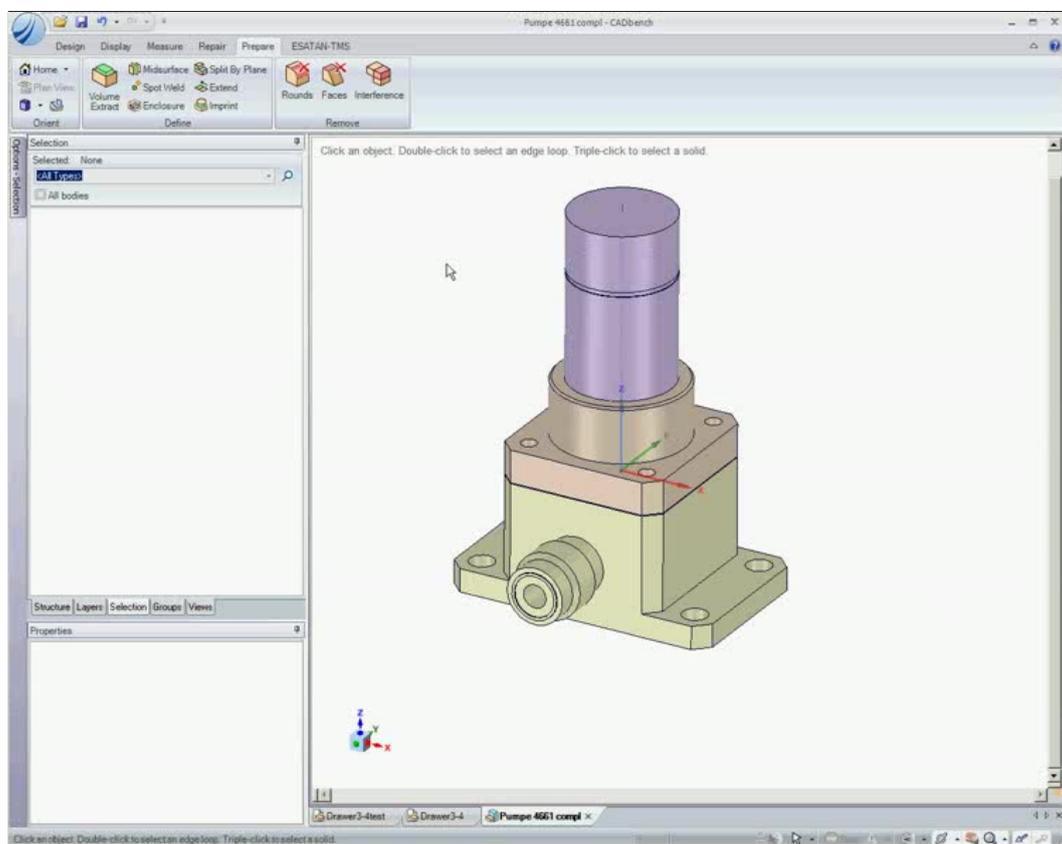
Slow Normal Fast Play/Pause Stop



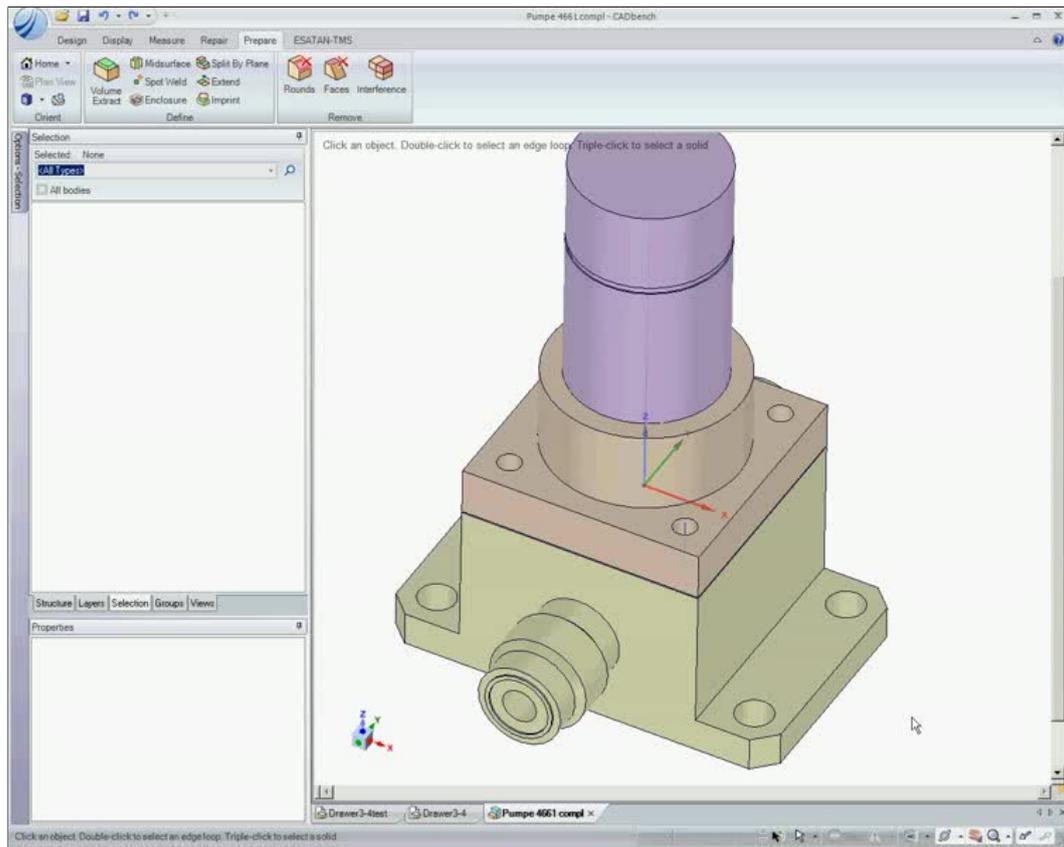
Slow Normal Fast Play/Pause Stop



Slow Normal Fast Play/Pause Stop

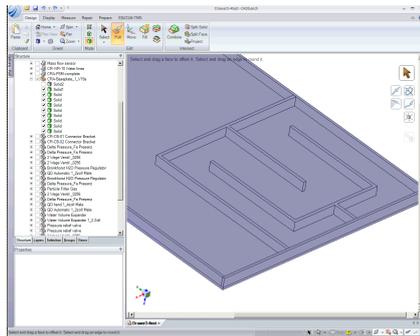


Slow Normal Fast Play/Pause Stop

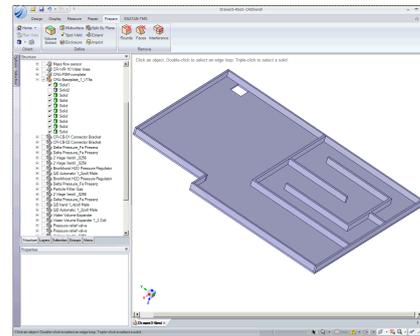


## CADBench tools for geometry simplification

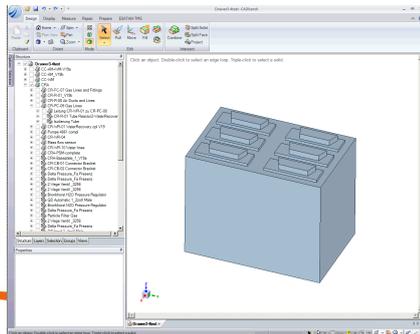
### Pull surfaces to remove details



### Take mid surfaces



### Use split by plane to break up component

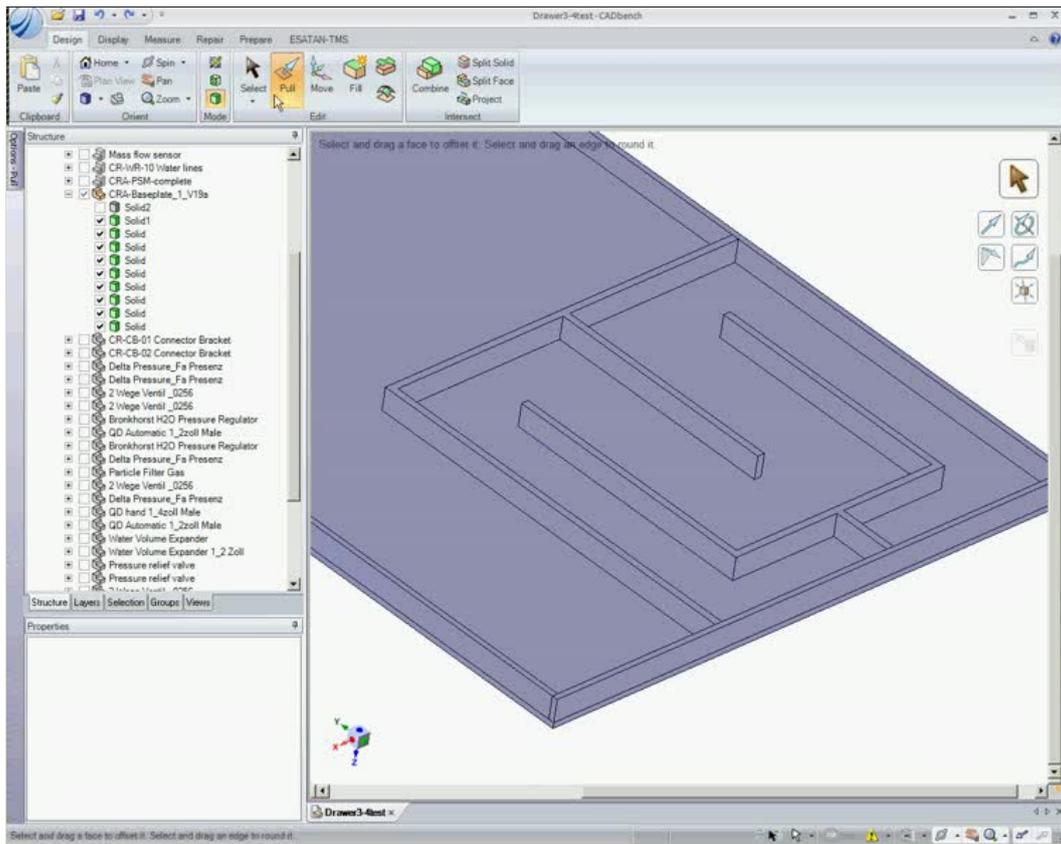


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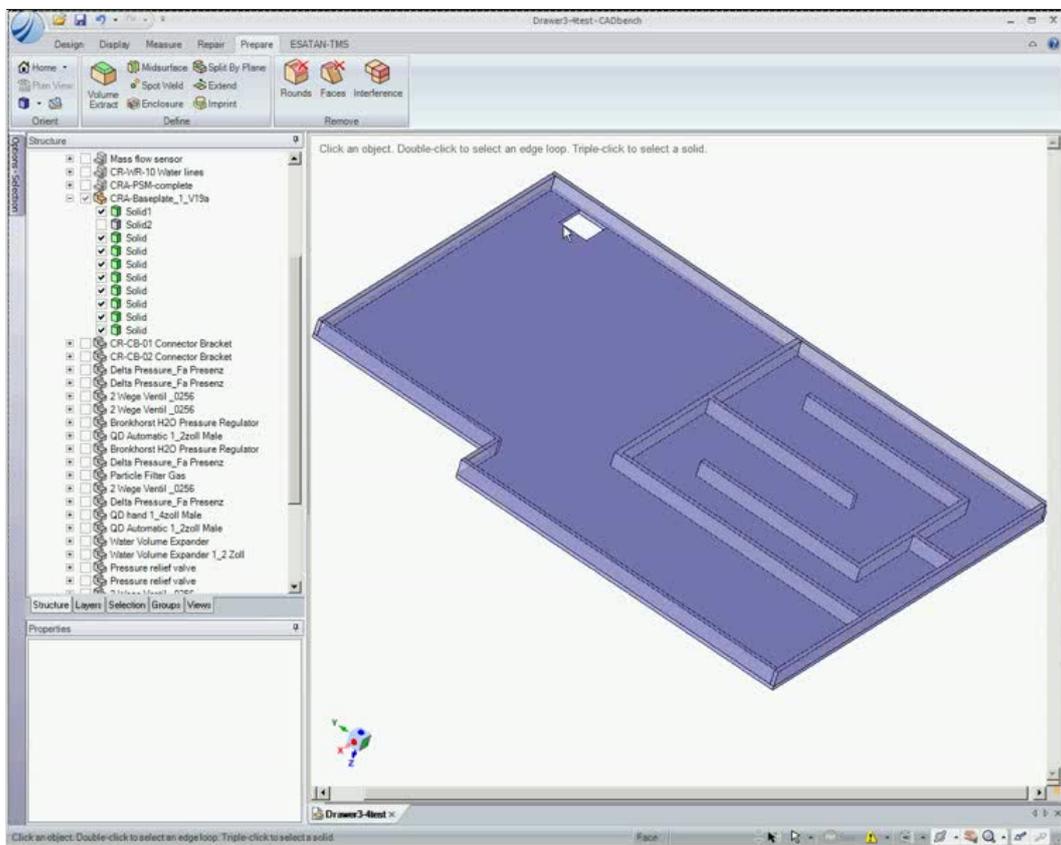
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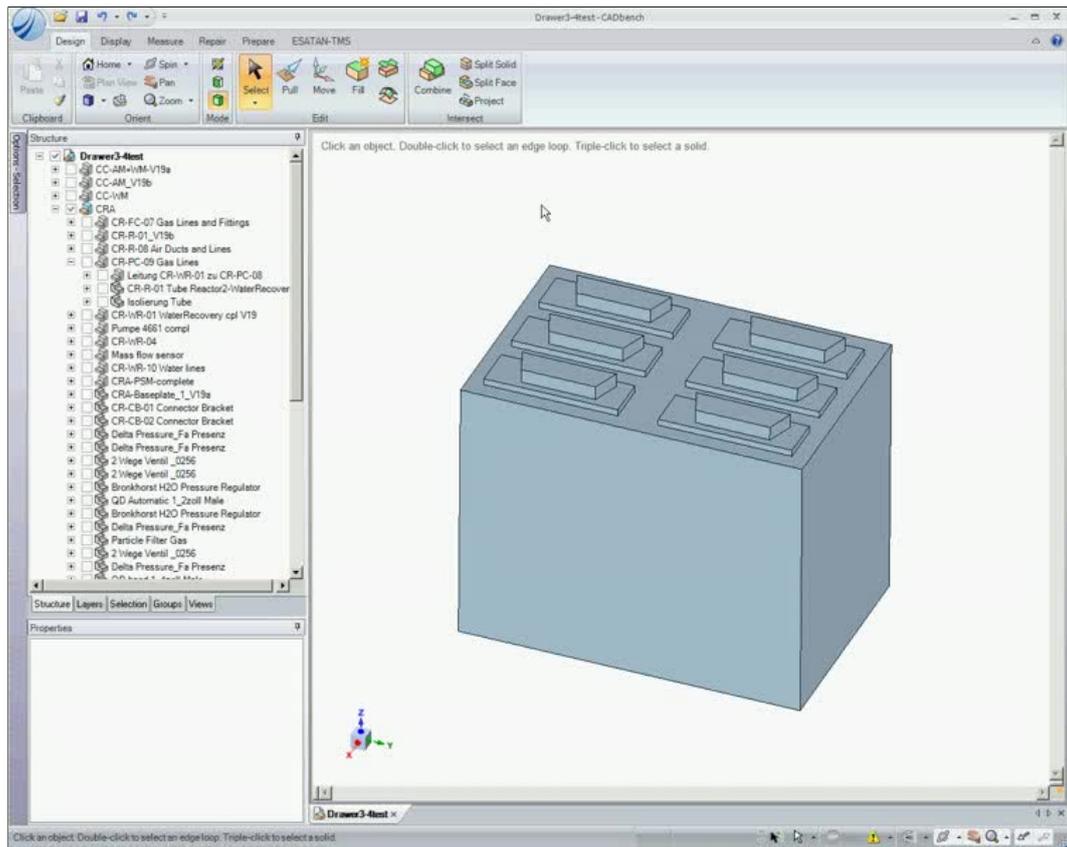
1. Surfaces can be pulled to remove features.
2. For thin surfaces where thickness is negligible a midsurface can be taken between two planes. This will result in a single surface imported into ESATAN.
3. One of the main issues is that in CADBench components are identified as single 3D object. To aid shape recognition it is necessary to split components into many smaller objects that are recognised ESATAN TMS shells



Slow Normal Fast Play/Pause Stop

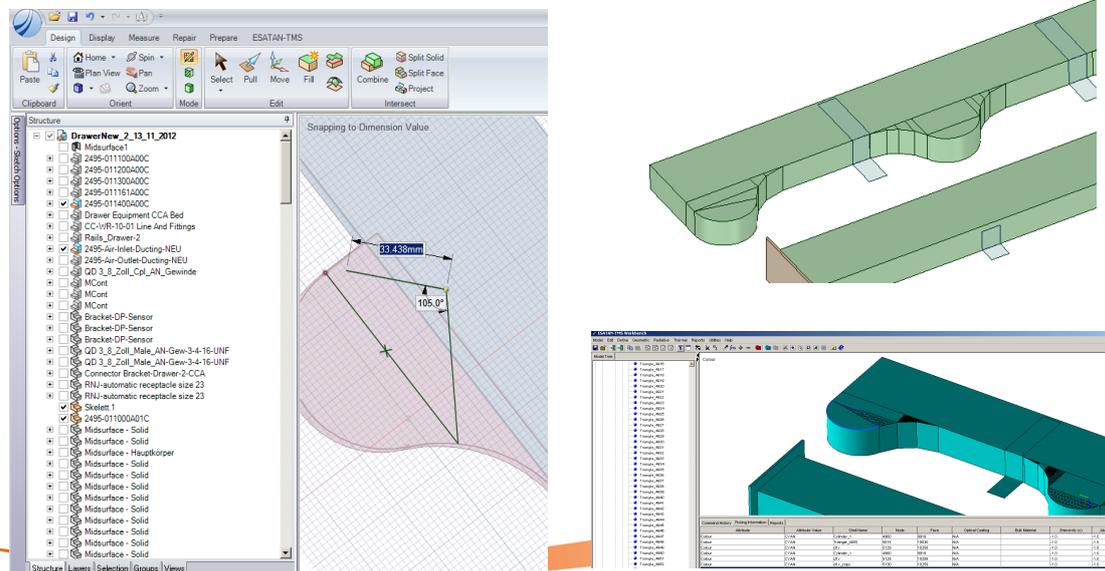


Slow Normal Fast Play/Pause Stop



## CADBench tools for geometry creation

Sketching dialog is not present in CADBench, however can create geometry with hotkeys. Press **L** to create line, **C** to create circle etc.



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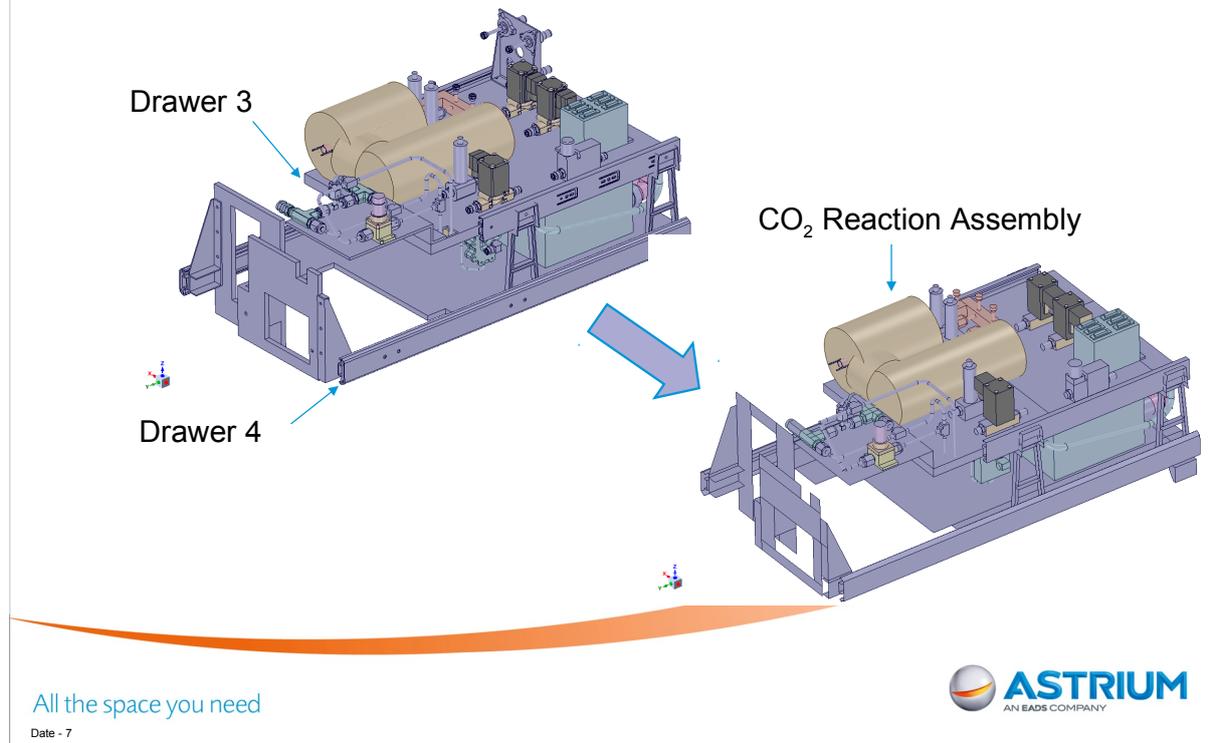
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The CADBench tool seems tailored to edit existing CAD files rather than create new geometry. The geometry dialog box is not present in the GUI of the current CADBench version but it is possible to draw in the model by entering sketch mode and using hotkeys to instruct the software to draw a line or circle. The geometry can then be created by selecting points in the GUI.

Seems more a bug than a feature. But it's a useful bug. Allows shapes which will not be reconized automatically to be approximated.

### Simplification of Drawer 3 (CRA) in CADBench



Gas lines omitted initially from model building to simplify construction and focus on heat dissipating components that are connected to the heat plate. These can be added at a later date.

Only radiation and conduction are considered. No conduction through gas. The heat removed by convection at the cold plate attached to the base-plate is considered.

## Export of geometry to ESATAN-TMS

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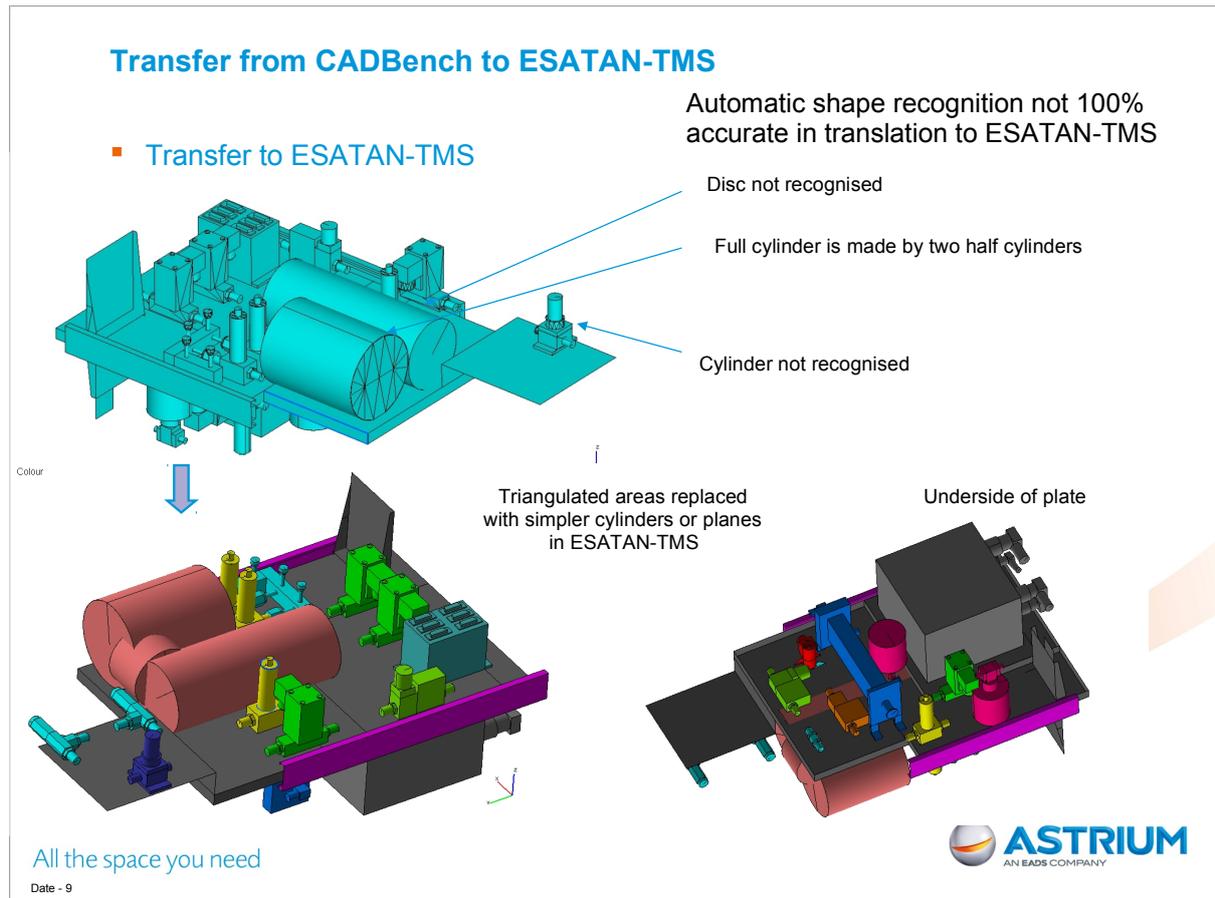
Date - 8

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Exported dialog box provides a variety of parameters for varying how CADBench converts CAD file to erg.

Shape recognition works for simple primitives most of the time. There is an issue with triangulating some discs and cylinders.

Unknown shapes are triangulated. There is a trade off between accurately capturing shape and having excessive shells.



Automatic generation of ESATAN-TMS shells use shape recognition algorithm. Some issues with unnecessary triangulation of standard primitives, discs and cylinders in particular.

This requires some manual editing of the ESATAN-TMS geometry to reduce the number of shells. Too many shells in the GUI in ESATAN can cause memory problems, increases radiation coupling calculation etc.

## Editing geometry in ESATAN-TMS

**\*\* Don't delete.** Cut unwanted shells from model and purge model.

Right click shells

Geometry structure and naming preserved from CAD file

Unwanted triangular shells can be quickly edited in GUI

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The geometry structure is preserved from the CAD file.

The triangulated shape provides points from which simpler shells can be created in ESATAN-TMS. Then the triangles can be removed.

Deleting shells directly in the GUI is very slow and for large numbers of shells it can cause the software to freeze or crash. The work-around for this problem is to cut unwanted shells from the model and past the shells outside the model. Unassign achieves the same effect. Then purge the model. The purge function is found under Model – menu at the top right of the GUI.

Purging removes all shells not assigned to the model.

## Editing geometry in ESATAN-TMS GUI

**\*\* Take care editing translated combinations of shells.**

Points selected in GUI are always referenced to model origin.

```
Point POINT_1390
X Co-ordinate 0.0175
Y Co-ordinate -0.0175
Z Co-ordinate 0.007
```

Set transform to [0, 0, 0, 0, 0, 0].  
Edit in GUI.  
When finished reapply transformation

```
*** TRANSFORMATION ***
x_ang = 0.0000, y_ang = -0.0000, z_ang = -1.6773e-007
x_dist = 0.0798, y_dist = -0.0060, z_dist = 0.9330
```

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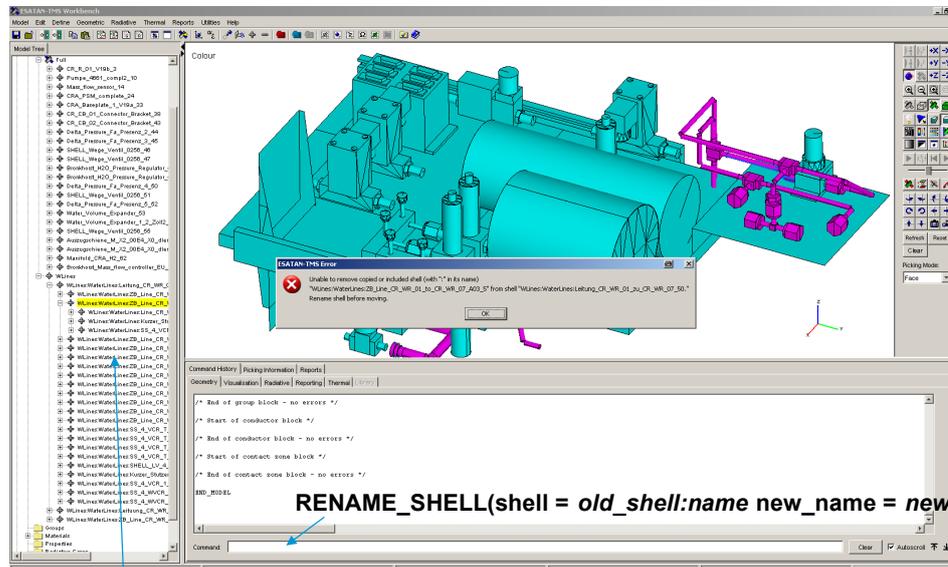
Highlighted pressure sensor has a transformation applied to it.



When using selecting geometry points for editing the model in the ESATAN-TMS GUI. The point values returned are defined by the absolute x, y and z distance from the model origin. When editing combinations of shells which have a translation applied to them this will result in geometric errors. The workaround is to record the translation of the combination. Set it back to the origin. Edit the combination as desired in the GUI and then re-apply the original translation.

## Updating geometry by using Include Geometry, Include Model

The text file .erg where the geometry is saved can be edited directly in ESATAN-TMS



To avoid shell naming conflict. Newly included geometry is prefaced with new\_shell\_name:

This can create problems later on as shown in error message

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It is desirable to be able to work on separate components at different times and then import them into an overall ESATAN-TMS model at different times.

When translating geometry from CADBench ESATAN-TMS names the created shells sequentially as they are created, rectangle\_1, rectangle\_2 etc.

These shells are often defined in terms of real points which are also named sequentially and will also conflict.

ESATAN-TMS avoids problems by prefacing shells with Shell name and a colon. Why colon. Cannot normally name shells with colon in them. Cannot copy. Have to first rename.

Naming becomes very long.

It is possible but far too time consuming to change the shell names in the GUI.

One effective way to deal with this issue is to edit the .erg text file directly using a find and replace function to change the shell names. The .erg file is much bigger and contains more information than the .sysbas file used in THERMICA and therefore not as easy to manually edit.

Its also possible to enter in commands directly to the command window. So a list of name changes can be prepared in a text file and the commands can be copied all together into the command window.

Including model seems to be initially less problematic. However I have seen errors and crashes when building cumulatively, i.e. including a model which itself includes a model. Java runtime error about inaccessible memory.

## Material Properties and Radiative Calculations

**Bulk Properties**

Inactive internal surfaces

Shells with external facing side 2 grouped together

Manually edited components are only radiatively active

■ NON\_GEOMETRIC  
 ■ PASSIVE  
 ■ THERMALLY\_ACTIVE  
 ■ ACTIVE  
 ■ INACTIVE

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Shells can easily have material and thermo-optical properties applied to them. Each shell has a two sides and each of these sides can have different properties.

When importing geometry some shells will have side 1 facing out and others will have side 2 facing out. For the radiation calculation it is necessary to have the inner surfaces inactive.

Shell activity can be corrected by visual checking and editing.

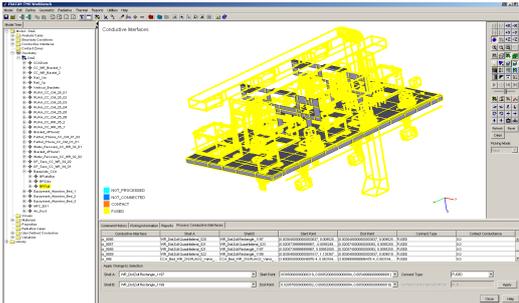
Ideally a solution where the shell can be selected and the side automatically reversed would be very useful. This was mentioned in a presentation last year

However it is worthwhile to group together in the model tree, shells with side 2 facing externally. This makes it much easier to change entire groups of shell properties later on rather than having to manually pick each shell.

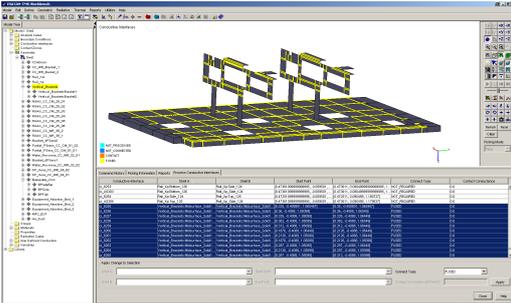
Can take care when initially importing the geometry from CADBench to correct it so that side 1 is always facing out.

Multiple radiation cases can be run for example with different emissivities and the model can be run with these separate cases.

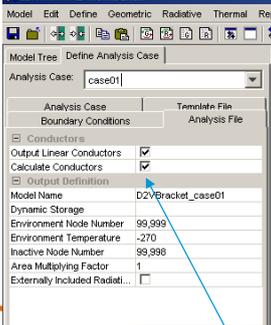
### Automatic Conductance Generation



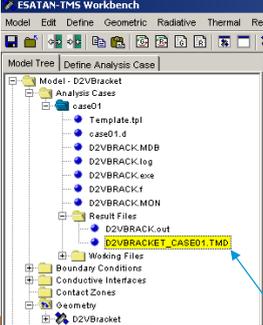
Apply *Not Required* to remove I/Fs of no interest



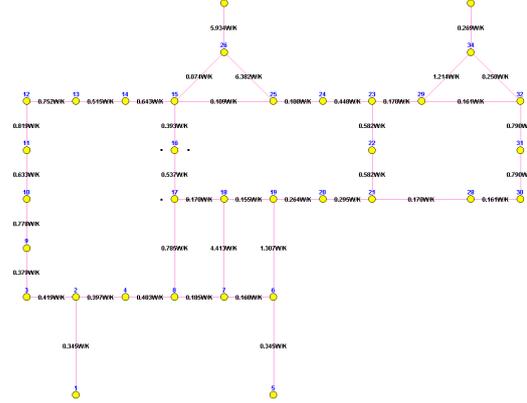
Order alphabetically and select based on shell name of interest. Apply *Fused* to connect shells



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Output linear conductors



View network with ThermNV



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ACG initially detects all planar I/Fs. This makes visualisation difficult. Apply Not Required to all but I/F of interest to remove display from the GUI.

Use ordering options in dialog under main GUI to get only shells and components of interest.

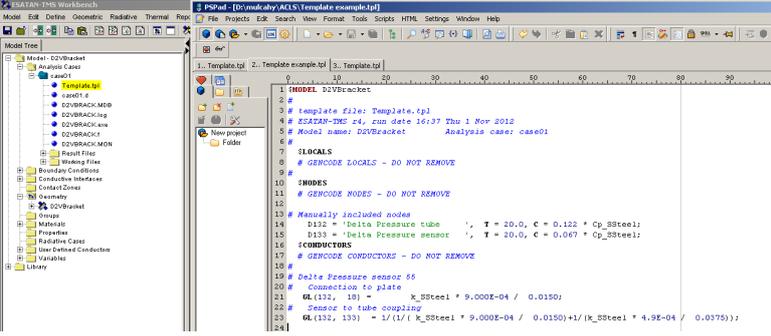
Ensure output linear conductors is applied. Leave node number as 0 on nodes that you want automatically calculated.

It can be seen that when using the split by plane tool in CADBench you need to be thinking about how you want your nodal network to look when the geometry is ESATAN-TMS

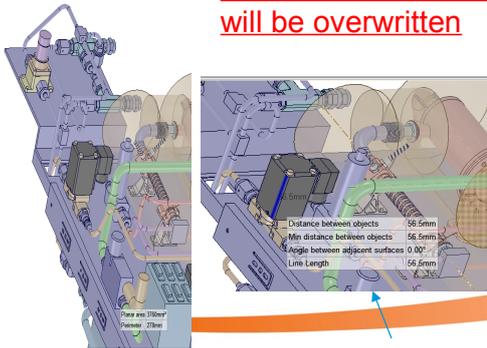
A case needs to be run to generate the TMD file to view the nodal network in ThermNV. Might be nice to not have to run the model to view the conductor matrix.

### Manual nodal and conductor generation in ESATAN-TMS

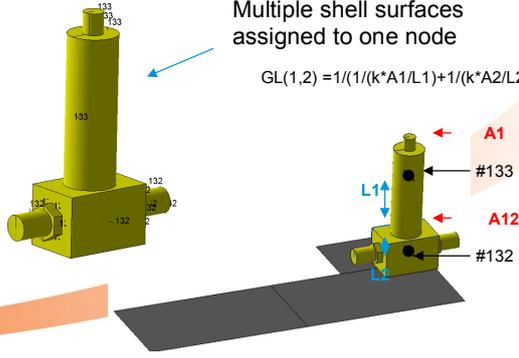
Manual modification of TMM should be done to template file



Untick or modifications will be overwritten



Multiple shell surfaces assigned to one node

$$GL(1,2) = 1/(1/(k \cdot A1/L1) + 1/(k \cdot A2/L2))$$


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CADBench provides measuring tools



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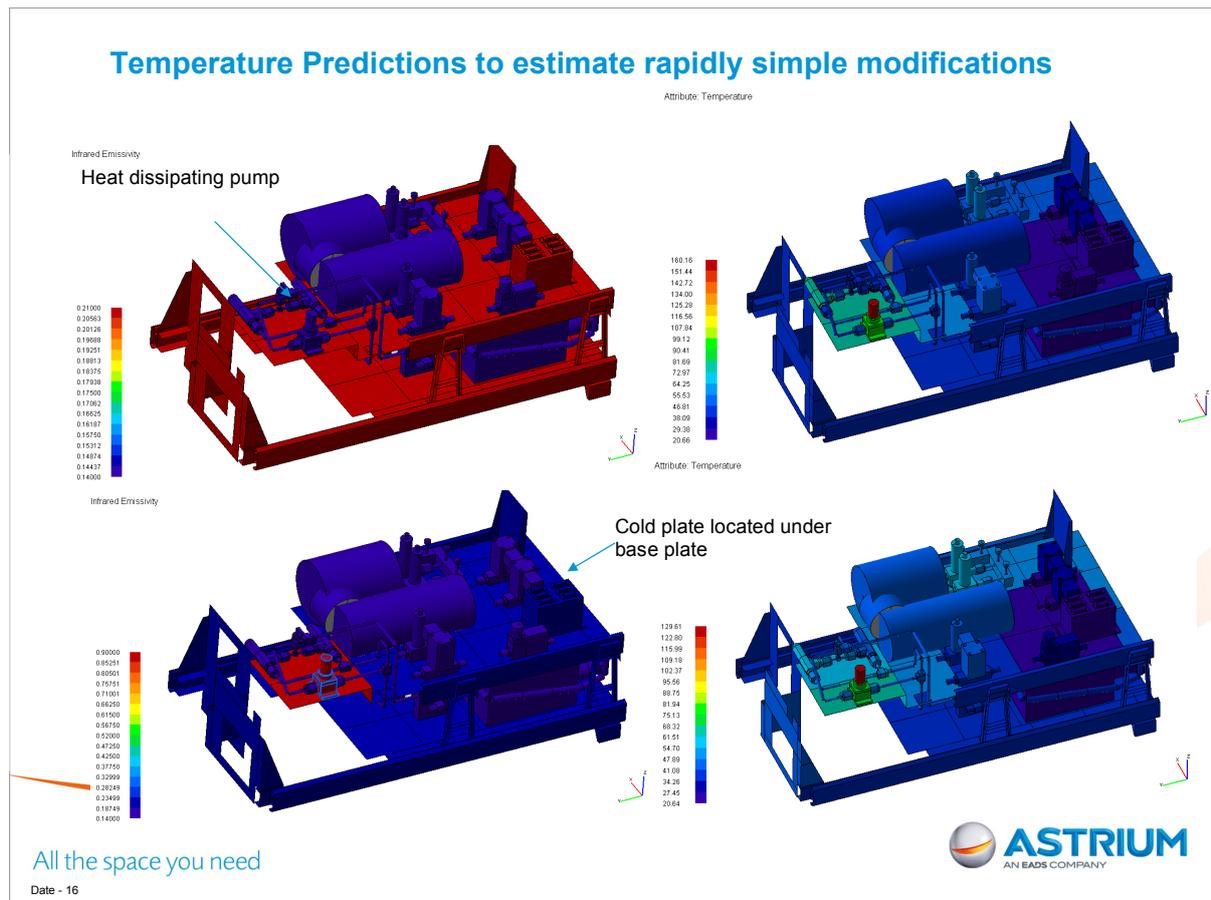
ESATAN-TMS calculates node capacitance and conductors for thin shells only not solid components

Certain parts such as the base plates can be quickly modelled but others such as solid valves must be evaluated manually and input into the thermal model.

Capacitance based on volume and conductor based on areas and lengths measured in CAD file.

When adding manual modifications to the TMM, these should be added to a template file not the analysis file.

Otherwise any changes in the GUI such as a new radiation calculation will overwrite the manual changes in the analysis file. When modifying the template manually, ensure that when you rerun analysis the box for generating a new template file is **not ticked** or the template will be overwritten.



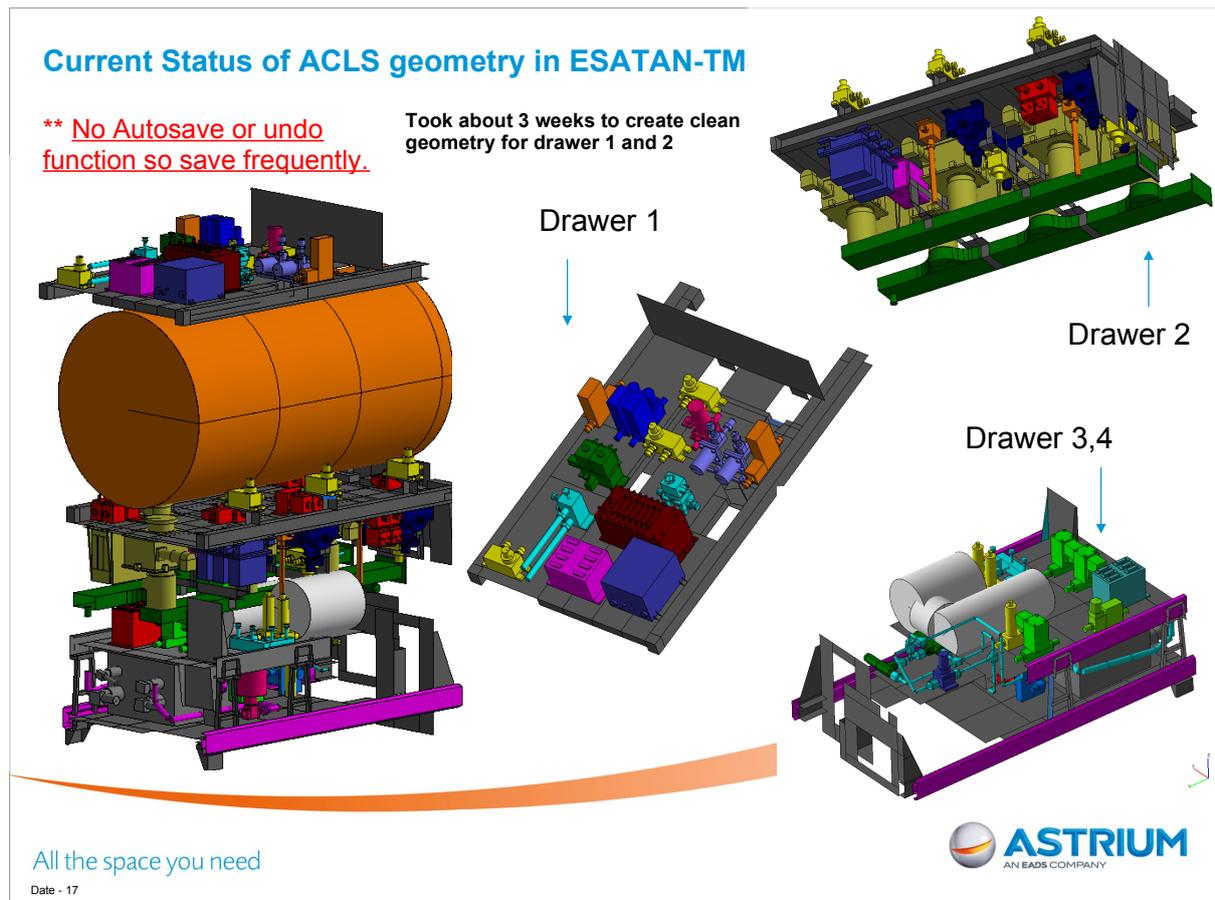
Initial analysis carried out assumed the outer insulated surface of the CRA (CO<sub>2</sub> reaction Assembly) was at 45 celcius.

The full ACLS rack will be crowded with other heat dissipating components so a relatively warm surrounding radiative sink temperature of 40 C was taken.

The coldplate maintained components relatively cool. Although a water pump located far from the cold plate dissipating 14W was found to reach relatively high temperatures.

A quick measure for mitigating the hotspot was to investigate modifying the surface emissivity of the pump and its surroundings. This did drop temperatures by 30 C.

Further measures can be investigated relatively quickly in ESATAN-TMS, e.g. adding radiator surface to pump, changing material of pump adapter, increasing plate thicknesses, adding thermal straps etc.



The current status of the ACLS geometry in ESTAN-TMS is highlighted. Drawer 3 4 has been run as a steady state thermal model. Drawer 1 and 2 are ready to begin radiative calculations.

There is a definite improvement in productivity with experience. Initial to create the geometry of drawer 3 and 4 took about a month. To create drawers 1 and 2 which have more components took about three weeks.

## Conclusions

- The CADBench plug-in is very effective for taking 3D CAD files and converting to Thermal Geometric Models.
- The software has a learning curve but a user can quickly learn how to simplify CAD files to get clean geometry for thermal radiation calculations.
- Design changes can be rapidly transferred to thermal models.
- The ESATAN-TMS software helps automate calculations in some areas while allowing the user direct access to the TMM for solutions not easily implemented in the GUI.
- The ACLS model proved a good task for investigating the abilities of the current software. Outlining its advantages and highlighting remaining challenges.

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Date - 18



For the ACLS drawer 4 analysed the project took ~ 6 weeks to go from CAD data to first thermal analysis results. This time included the user becoming familiar with the CADBench software.

The deadlines for this project are challenging with final design on the layout of the system still undergoing changes.

CADBench and ESATAN-TMS gives us the ability to work directly from CAD files as they are updated. This allows the thermal analysis to respond much more rapidly to changes.

Work can be performed concurrently rather than waiting for a frozen design to be set before beginning thermal analysis. Its also useful to be able to suggest specific design changes based on thermal analyses before becoming too far along the design path.



## Appendix R

### Mercury Planetary Orbiter Solar Array Thermal and Power Modelling

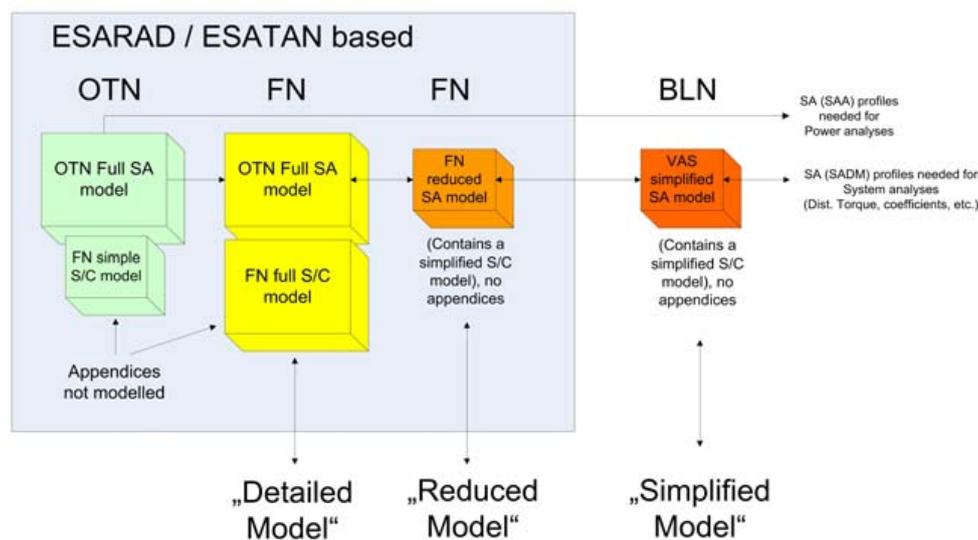
Martin Altenburg  
(Astrium GmbH, Germany)

### Abstract

BepiColombo is a major joint European and Japanese mission to send a planetary explorer to Mercury. As such BepiColombo is exposed to high thermal loads. One of the most critical subsystems on BepiColombo is the MPO Solar Array.

This presentation gives a short overview of the "simplified" thermal solar array model, which has been derived from the "detailed" and "reduced" model and is used to analyse thermal and power performance on the spacecraft. The "simplified" model uses the attitude and position of the spacecraft and SADM with respect to Mercury to determine the temperature of the hottest solar array cell. The "simplified" model will be used by ESA to generate solar array drive profiles in the course of mission planning.

#### SA Thermal Model Development Process



The presentation will look into two different approaches for solving the thermal network. The first is applied by the "reduced" solar array model, with an interface script for solving temperature dependent moving geometry iterations with ESATAN TMS. The second approach is followed by the "simplified" solar array model, which uses an independent mathematical description of the thermal loads from Sun and Mercury on the Spacecraft without relying on classical thermal analysis tools. Results obtained by these two approaches are compared vice versa and with results calculated by the "detailed" model in consideration of numerical effort and accuracy of the temperature results. In addition, a short outlook for the further development of the "simplified" model and the power model will be given.

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Noordwijk, 20-21 November 2012

## Mercury Planetary Orbiter Solar Array Thermal and Power Modelling

Martin Altenburg, Dipl.-Ing.  
Thermal Engineering and Analysis

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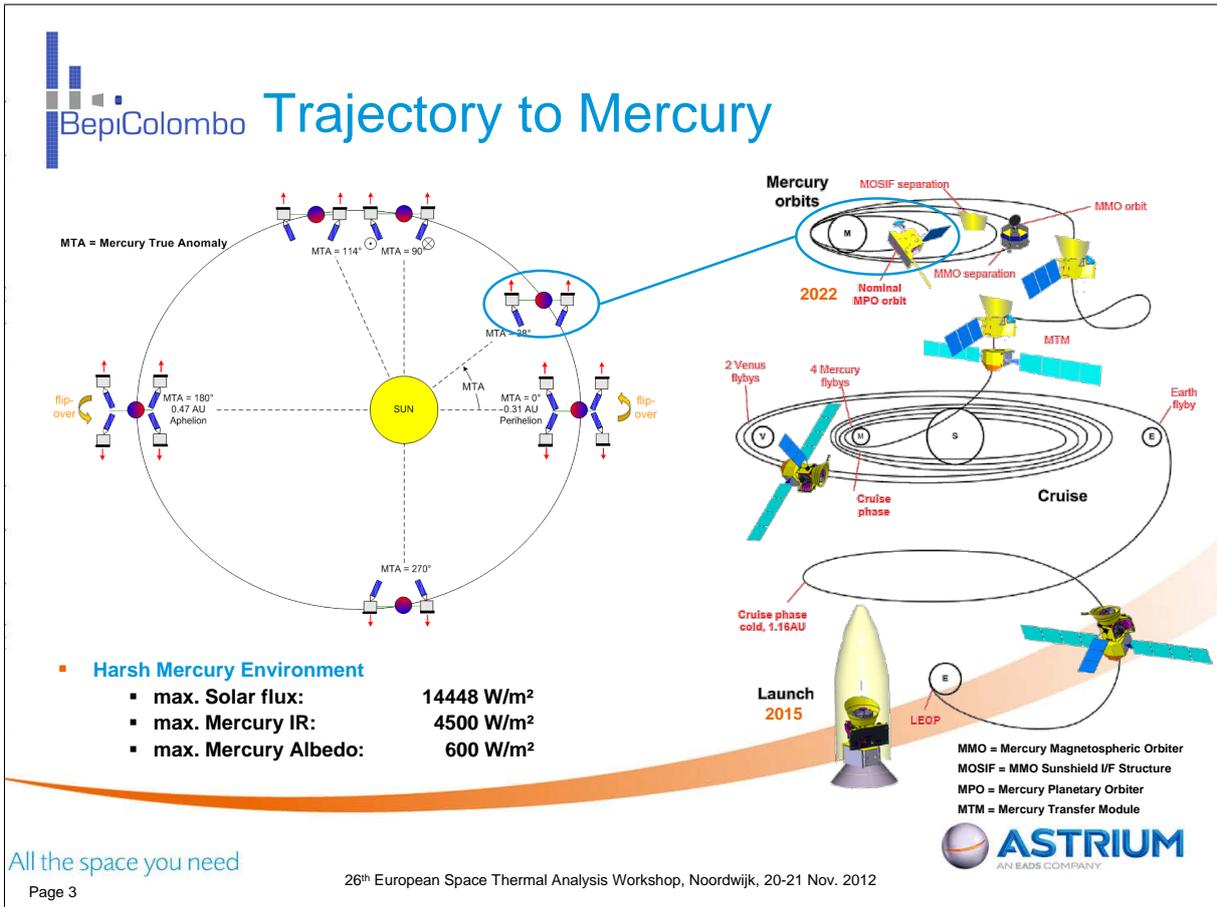
## Mercury Planetary Orbiter Solar Array Thermal and Power Modelling

- Trajectory to Mercury
- SA development process
- SADM profile generation
- Comparison detailed & simplified model (GMM)
- I/F to power model
- Summary

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Page 2

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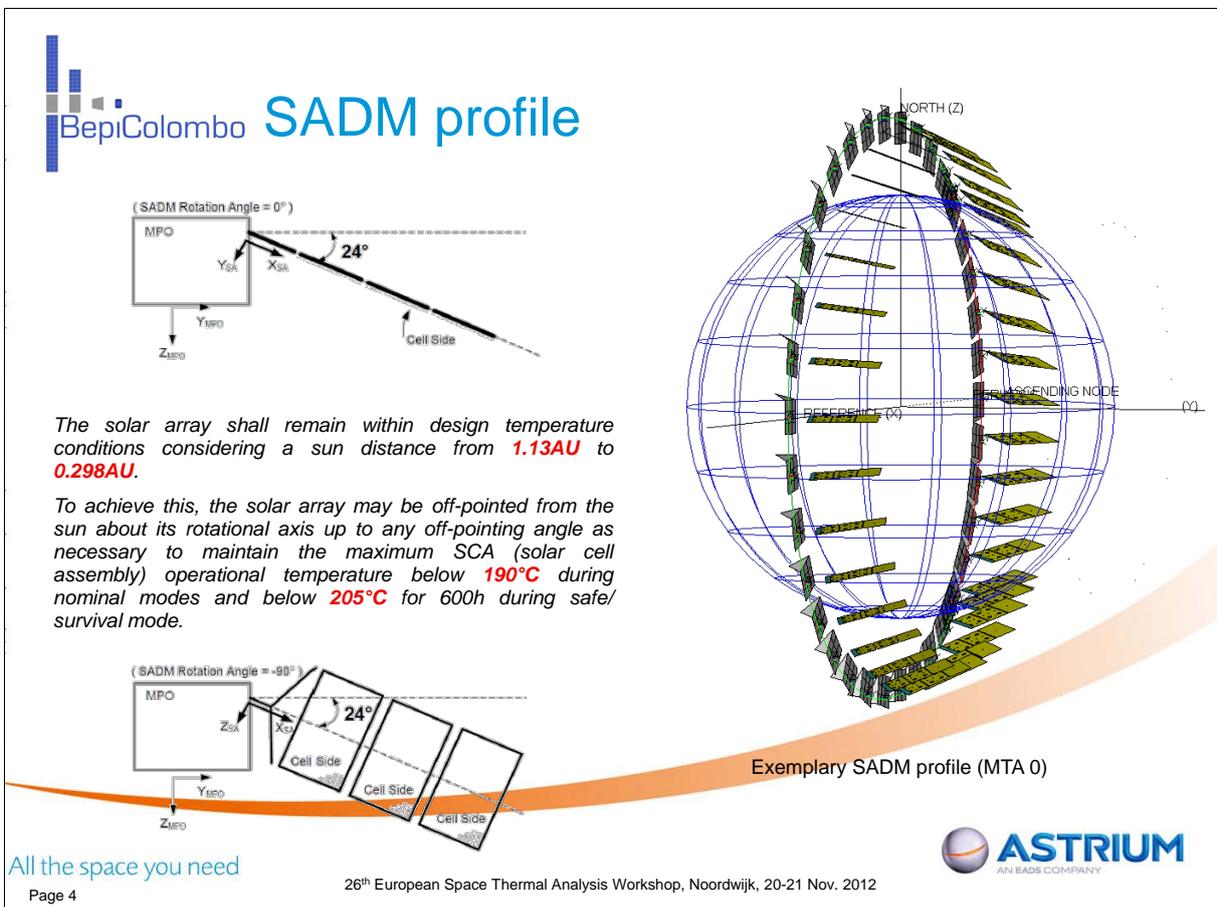




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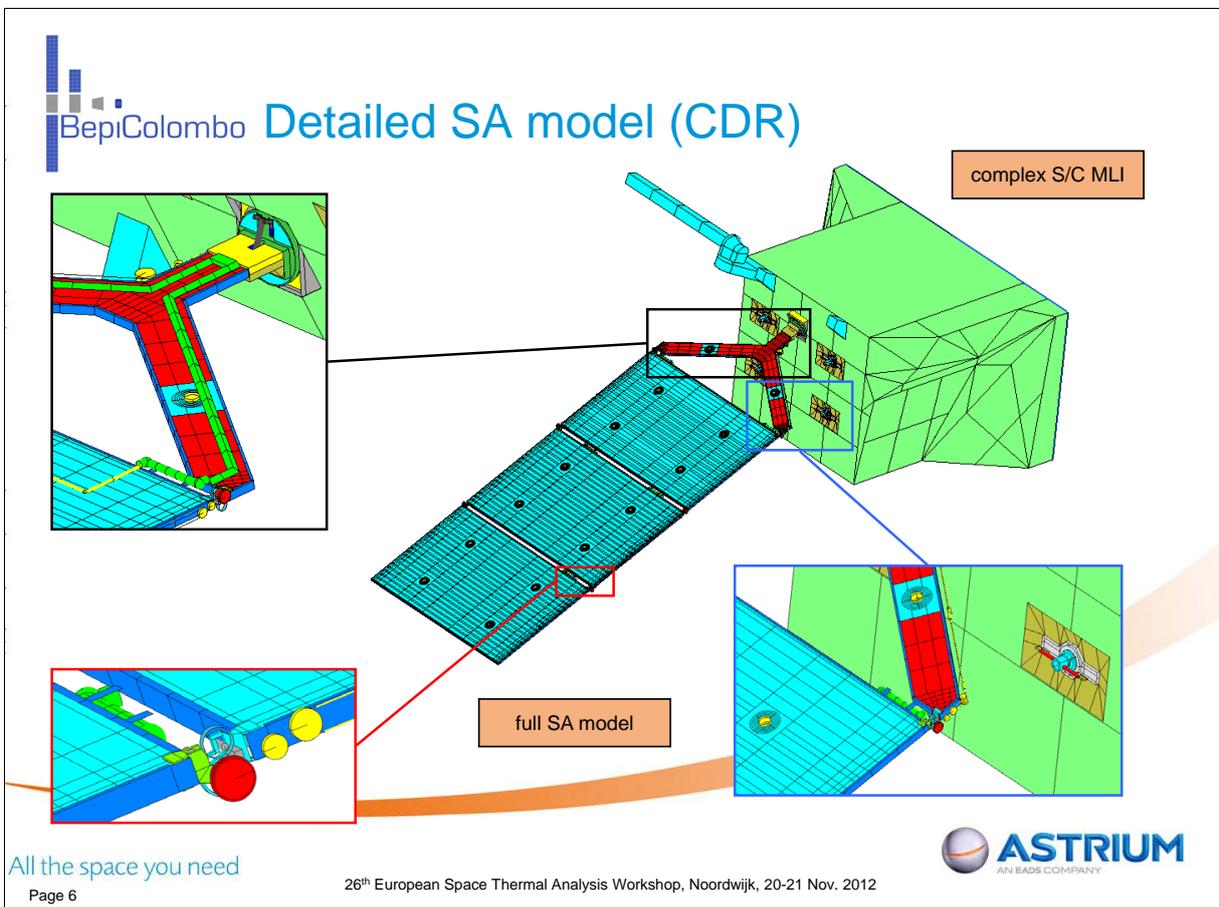
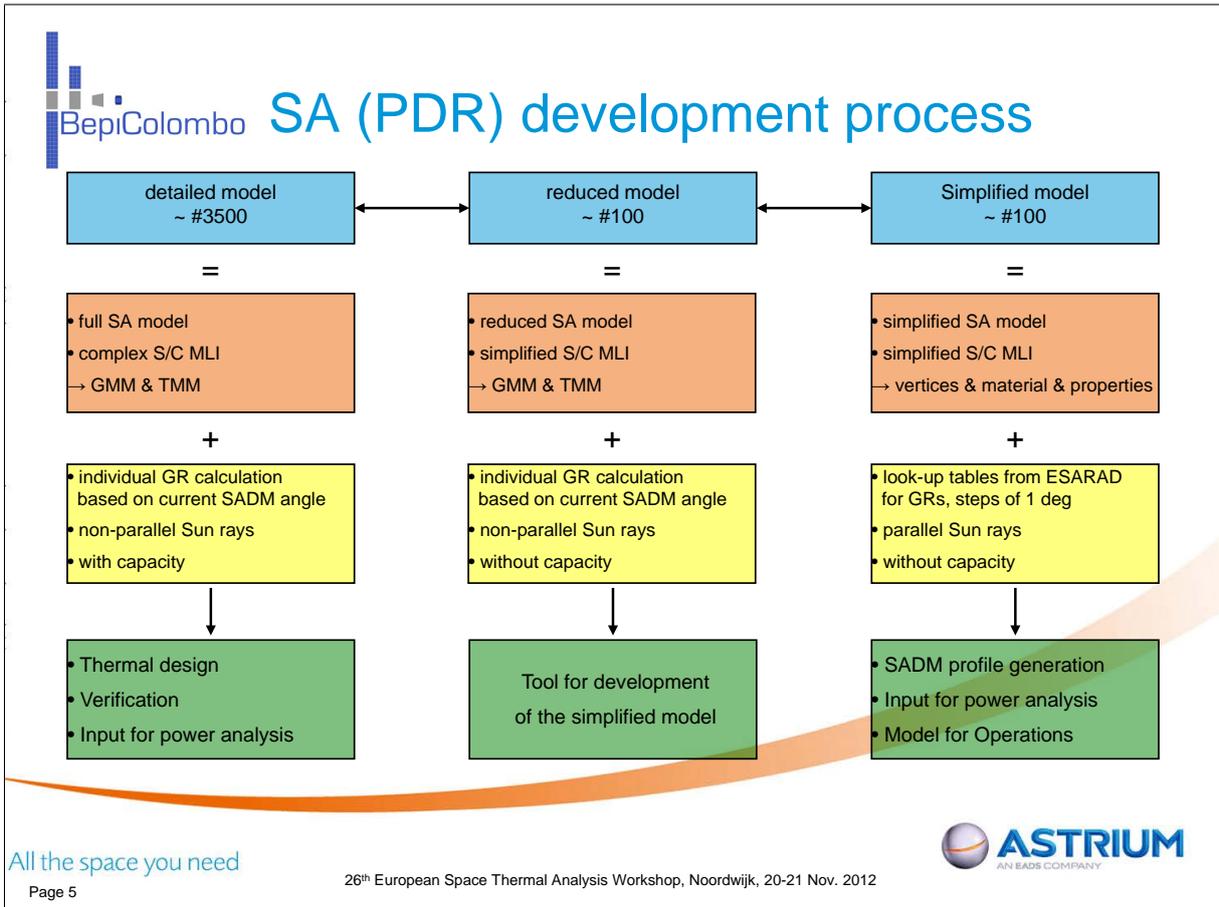
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### BepiColombo Reduced & simplified SA model

**simplified S/C MLI**

SADM = 0°:

Solar Panel 1  
Solar Panel 2  
Solar Panel 3

Rotation axis

**reduced SA model**

```

...
$ Vertices;
# ID; X2; Y2; Z2; Location
1211;-0.555;1.61985;0; # SCA 121x
1212;-0.555;1.63985;0
1213;-0.555;1.65235;0
1214;-0.515;1.65235;0
1215;-0.515;1.63985;0
1216;-0.515;1.61985;0
...
$ Nodes;
# ID; Label; Vertices; Optical ID; Node size [m²]
1210;P1_SCA1_cell;1211;1212;1215;1216;104;0.0008
1211;P1_SCA1_osr;1212;1213;1214;1215;103;0.0005
...
                    
```

**simplified SA model**  
(vertices, material, properties)

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### BepiColombo SADM profile generation – reduced model

**set of data (k = 1...n)**

- solar constant
- orbit definition
- S/C position, pointing
- accuracy parameter
- target temperature
- target power

MCRT = Monte Carlo ray tracing  
k = orbit position (0...360°)  
i = number of iterations

**set of output (k = 1...n)**

- max cell temperature
- S/C position
- SADM profile
- accuracy
- ...

```

graph TD
    GMM[ECL] --> MCRT1((MCRT))
    MCRT1 --> Eclipse{Eclipse ?}
    Eclipse -- true --> InputK1[input (k)]
    InputK1 --> Eclipse
    Eclipse -- false --> Flux[flux calculation  
GR calculation  
SADM (i)]
    Flux --> LaRoche((LaRoche*))
    LaRoche --> Temp[max cell temp (i)]
    Temp --> Check[IT_target - T_cell_max < ε ?]
    Check -- true --> OutputK[SADM (k)  
T_max_cell (k)]
    Check -- false --> Flux
    OutputK --> InputK2[input (k)  
(SADM range)]
    InputK2 --> Eclipse
    GMM --> MCRT2((MCRT))
    TMM[TMM (S/C position)] --> LaRoche
    style OutputK fill:#ffff00
                    
```

**set of data (k = 1...n)**

- solar constant
- orbit definition
- S/C position, pointing
- accuracy parameter
- target temperature
- target power

MCRT = Monte Carlo ray tracing  
k = orbit position (0...360°)  
i = number of iterations

**set of output (k = 1...n)**

- max cell temperature
- S/C position
- SADM profile
- accuracy
- ...

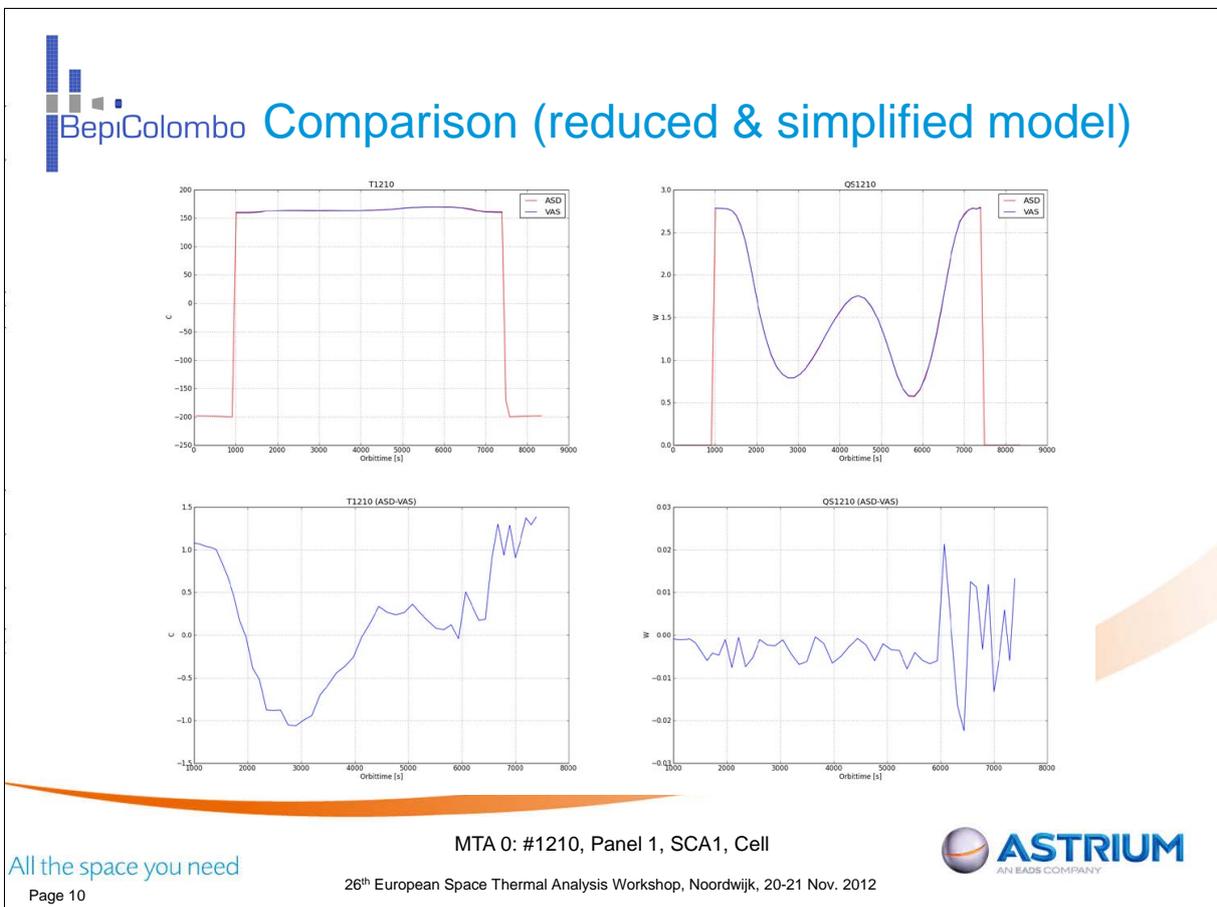
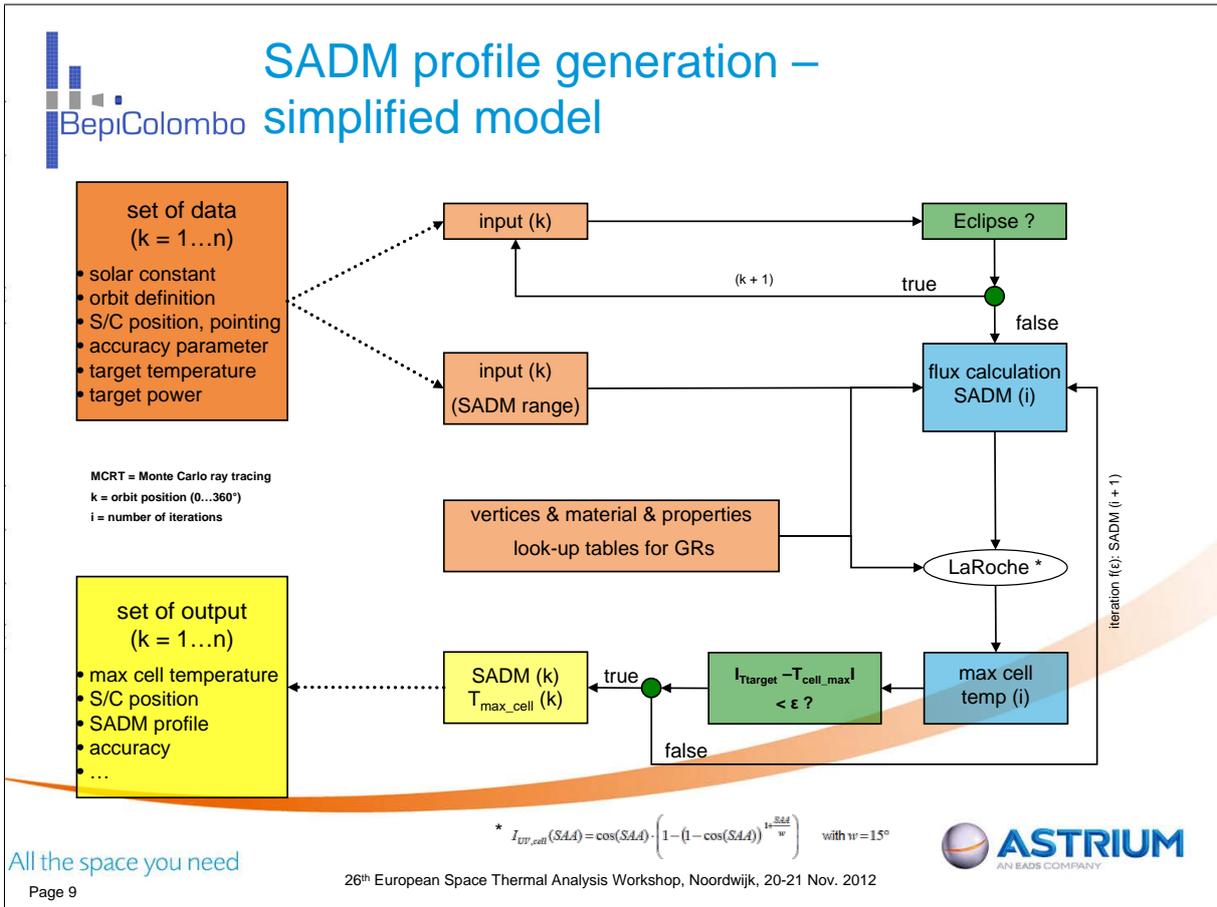
$I_{UV,cell}(SAA) = \cos(SAA) \cdot \left( 1 - \left( 1 - \cos(SAA) \right)^{\frac{1+\cos(SAA)}{w}} \right)$  with  $w = 15^\circ$

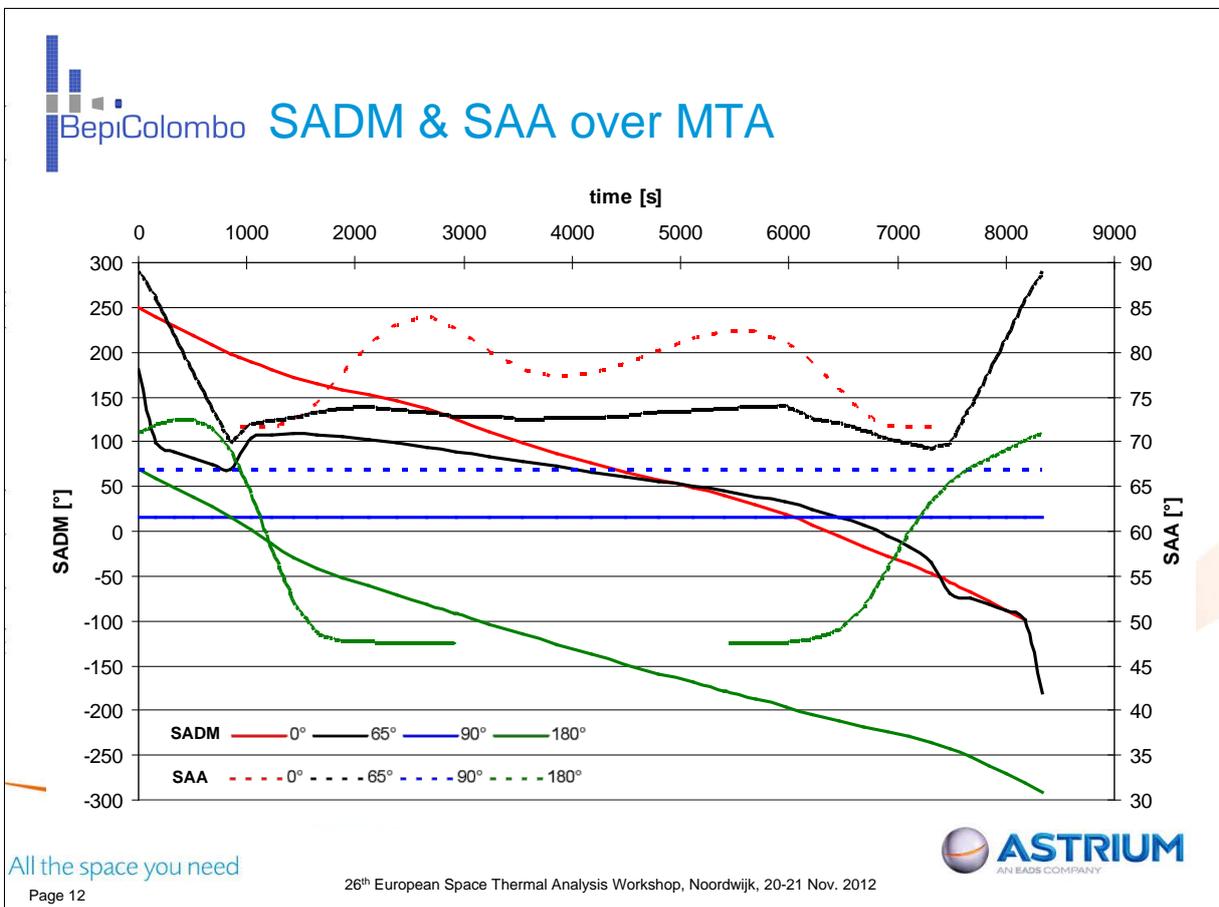
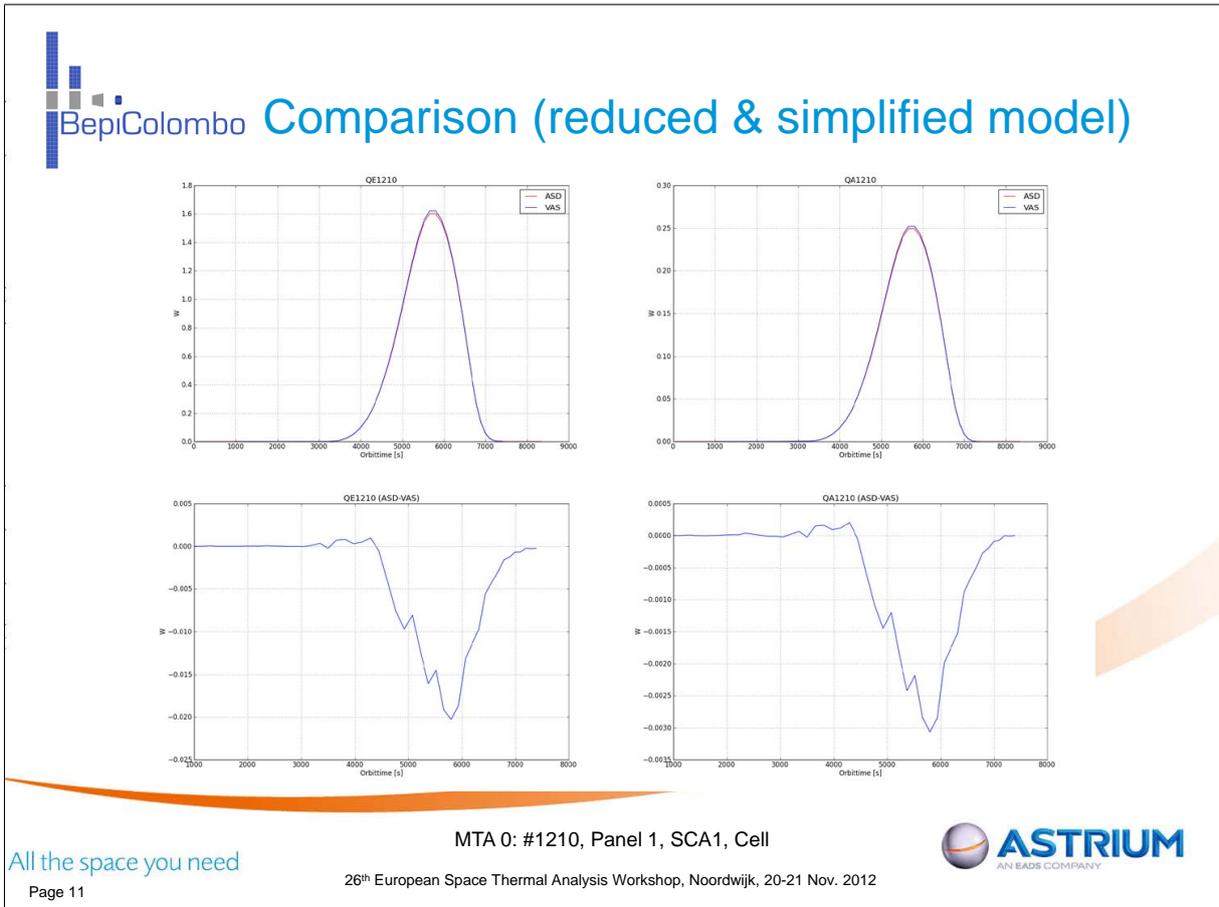
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## BepiColombo I/F to power model

- Exchange file
  - Trajectory information
  - For every trajectory point:
    - Quaternions describing S/C attitude and SADM rotation angle
- Processed and imported into Power-Systema
- SAA computed by Power-Systema matches with SAA computed by thermal engineering
- NOT part of interface, but implemented in Power-Systema:
  - Cosine correction for power and temperature computation
  - Planet geometry and temperature distribution
  - View factors and illumination of geometrical surfaces

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## BepiColombo Summary

- Development of simplified SA model (PDR status) to support operational actions (ESA)
- Verification of simplified model against reduced and detailed model (PDR status)
- Calculation of SADM profiles, with less computational effort (reduced: 2 - 3 days / simplified: 15 – 30 min) und (identical) high accuracy
- Easy SADM profile and temperature prediction for interesting MTAs (without using thermal S/W and also possible without thermal skills)

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## BepiColombo Improvement

- **GMM/TMM:**
  - Iteration of maximum, minimum angle or fluxes for target temperature (SA, antenna, ...) or power (SA)
  - SADM velocity time tables
  - Parameter cases for GMM (each orbit position)
  
- **Post-processing of moving geometry:**
  - Visualisation of angle vector
  - "Ray to Face": output of numbers, not only visualisation

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## Appendix S

### Dynamic Thermal Spacecraft Simulator based on nodal mathematical model

Anthony Mollier  
(Thales Alenia Space, France)

François Brunetti  
(Dorea, France)

### **Abstract**

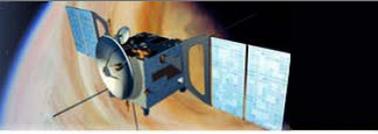
To improve the quality and reliability of the dynamic spacecraft simulator, Thales Alenia Space Cannes asked DOREA to implement the thermal real-time simulator based on the thermal mathematical model (TMM) provided by thermal analysis team.

Both SYSTEMA/Thermisol (from EADS Astrium) and ETHERM (from Thales Alenia Space) nodal models have been converted and integrated into a new DSS product line called SCSIM (SpaceCraft SIMulator). A set of ESA tools were used in an industrial context to solve this technical challenge: reduction tool TMRT (without reduction) has been used to convert TMM from SYSTEMA/Thermisol nodal definition; STEP-TAS and TASverter to convert geometrical model from THERMICA and thermal post processing tool ESATAP for thermal model comparison and debugging.

Ray-tracing calculator and temperatures resolution from internal ETHERM core module (former CORATHERM) have been successfully improved to fit the real-time constraints. Parallelisation has been largely used to make the calculation most reactive in order to fit as much as possible the physics behaviour.

New SCSIM based on TMM has been successfully validated on Alphasat (@bus platform) and O3B Networks satellite.







**Mechanical Engineering Department  
Thermal and Structures Division**

## SCSIM-TCS

### Thermal Dynamic Simulator

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[francois.brunetti@dorea.fr](mailto:francois.brunetti@dorea.fr)

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## Content of the Presentation







- Introduction
- Introduction to SCSIM
- Problems to solve
- TMM model requirements
- TMM/GMM model conversion from thermal analysis
  - Using TASverter (STEP-TAS) and TMRT
- TMM/GMM model comparison and debugging
  - Using ESATAP and DMPTAS
- SCSIM-TCS integration
- SCSIM-TCS performances
- Conclusion from TAS

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## Introduction





- **The challenge was:**
  - to implement a DSSS (Dynamic Spacecraft System Simulator) integrating a thermal simulator based on the TMM model used by thermal analysis,
  - but also to use the same software bricks than thermal analysis (here ETHERM former CORATHERM calculator).
  
- **The gains are:**
  - To have a better fit with thermal analysis specifications as an input of the DSSS.
  - To have a generic implementation independent from the spacecraft model.
  - To benefit of a thermal calculator able to behave as much as possible as the physics,
  - To reduce convergence time of thermal simulator development.

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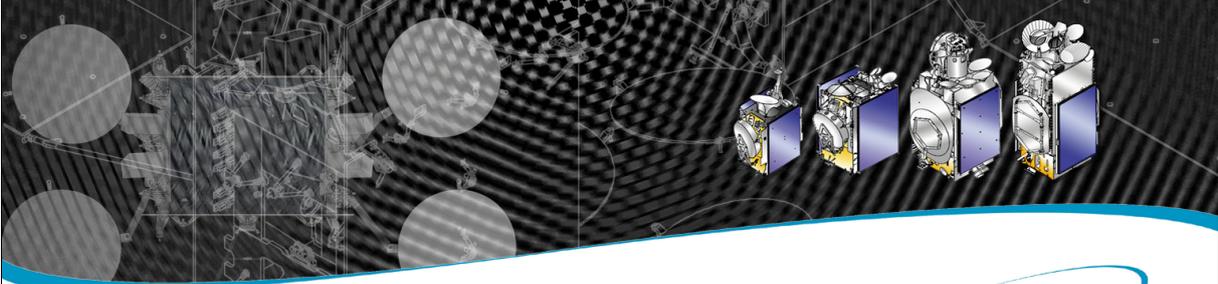
## Introduction to SCSIM





[SCSIM Introduction](#)

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# SCSIM Simulation Platform

ThalesAlenia Space

DPL  
21/07/11

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**Introduction**

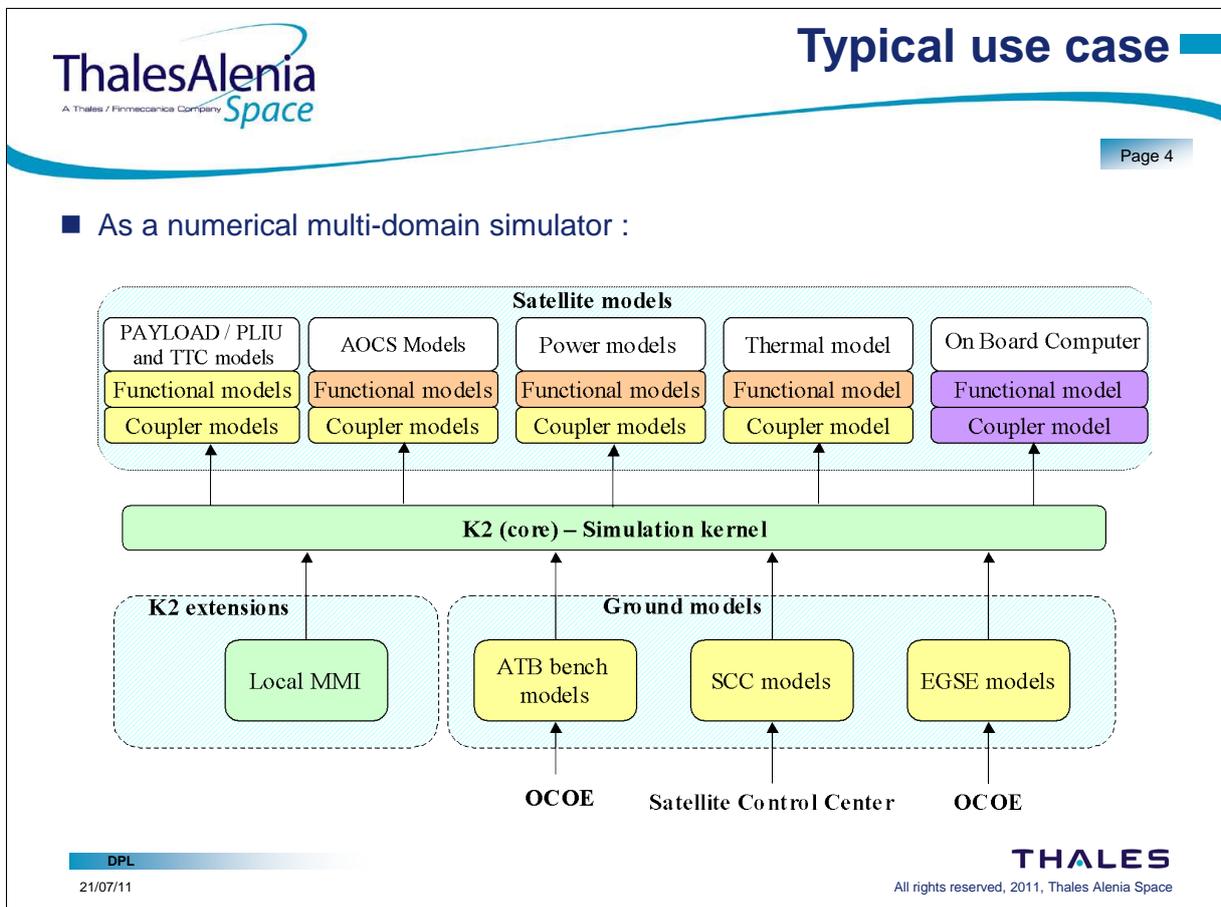
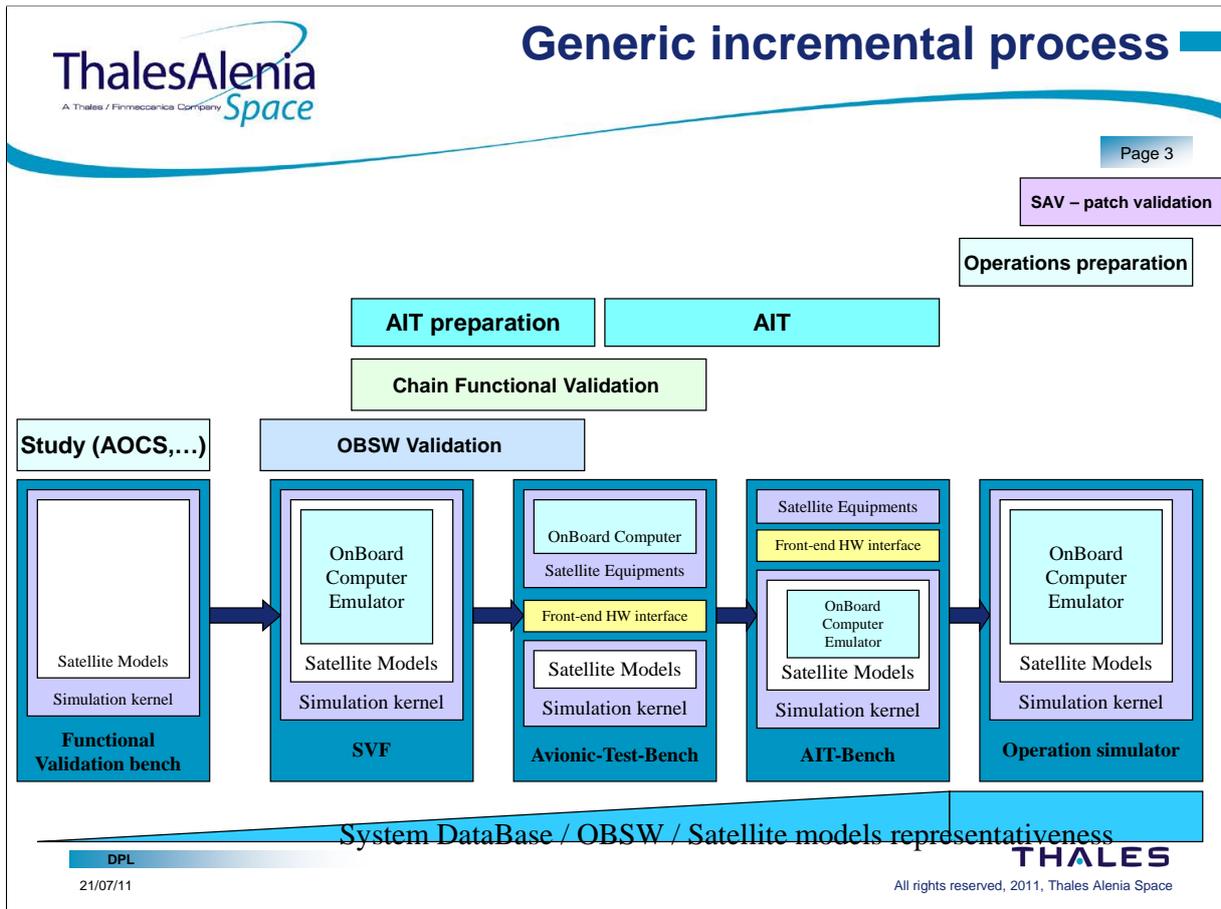
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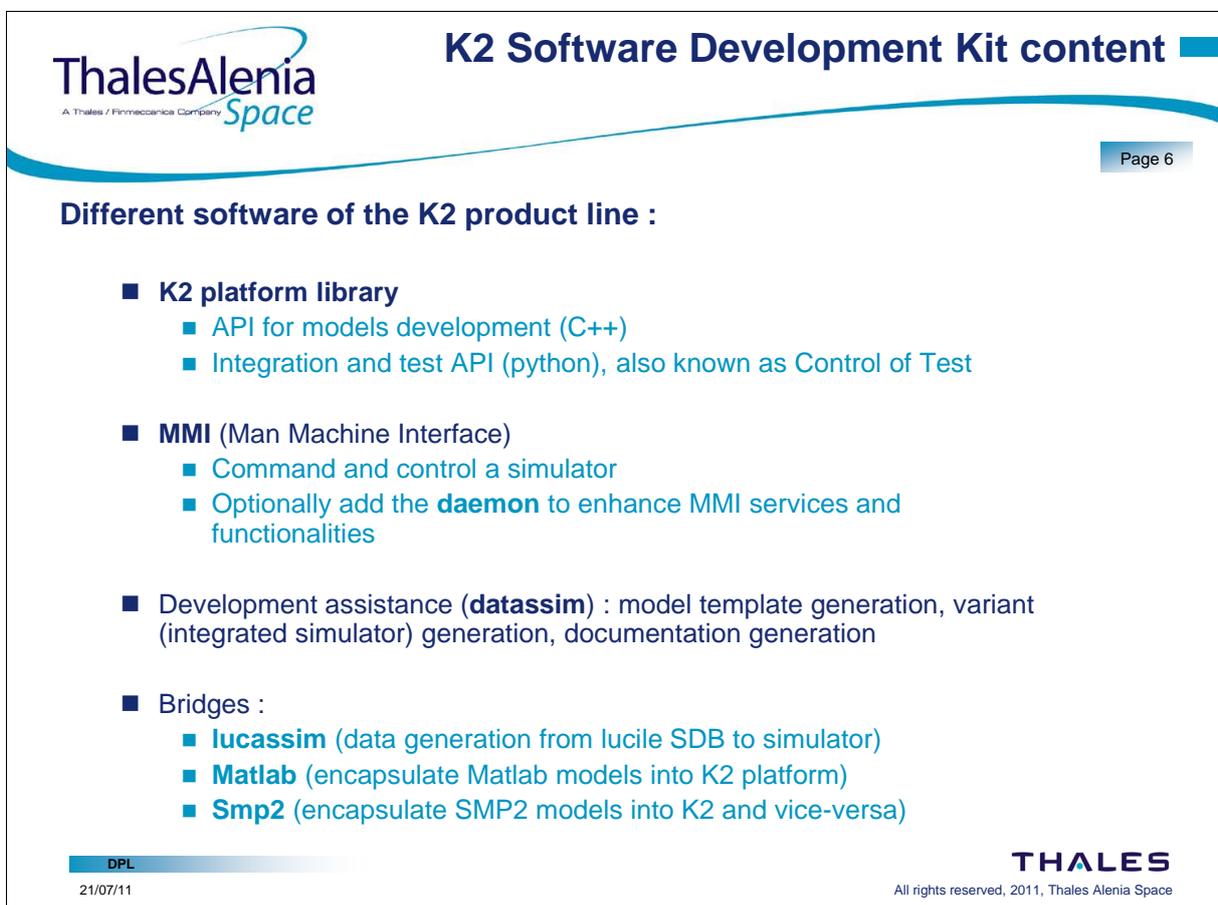
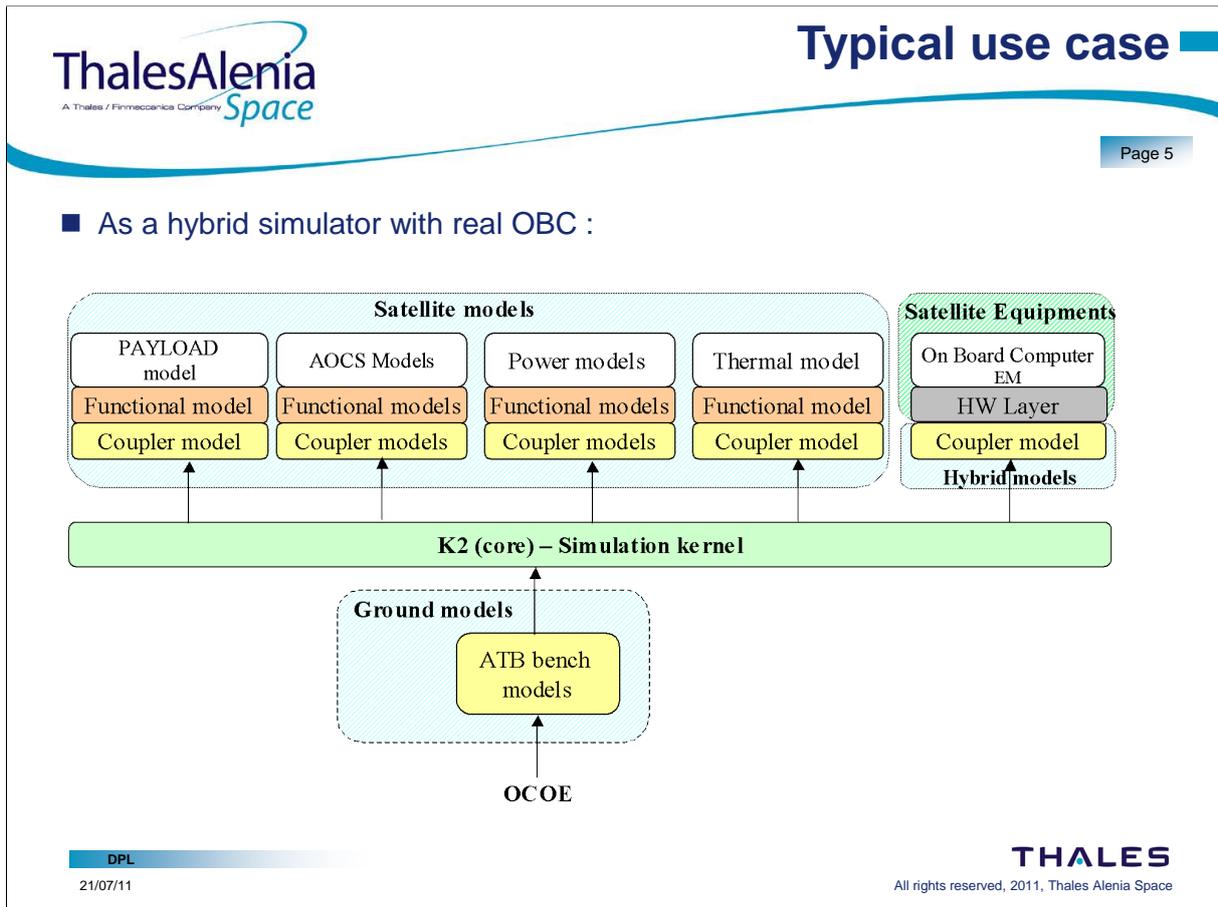
- K2 “simulators” are used for several satellites families :
  - **Constellation** : Globalstar 2, O3B, IRIDIUM NEXT
  - **Telecom** : SpaceBus 4000, Alphabus / @SAT
  - **OOS** : Sentinel 3, GKT, EXOMARS, MTG FCI
  
- K2 is used inside numerical multi-domain simulators to perform verification of :
  - OBSW validation procedures
  - OBSW patches in SAV phases
  - Functional Chain Validation procedures
  - AIT Test sequences
  - Operational procedures
  
- K2 is also used inside hybrid simulators with Hardware-In-The-Loop to realize any test bench :
  - Avionics Test Bench for Functional or AIT phase
  - Platform Simulator for Payload AIT
  - AIT bench or EGSE for Satellite AIT

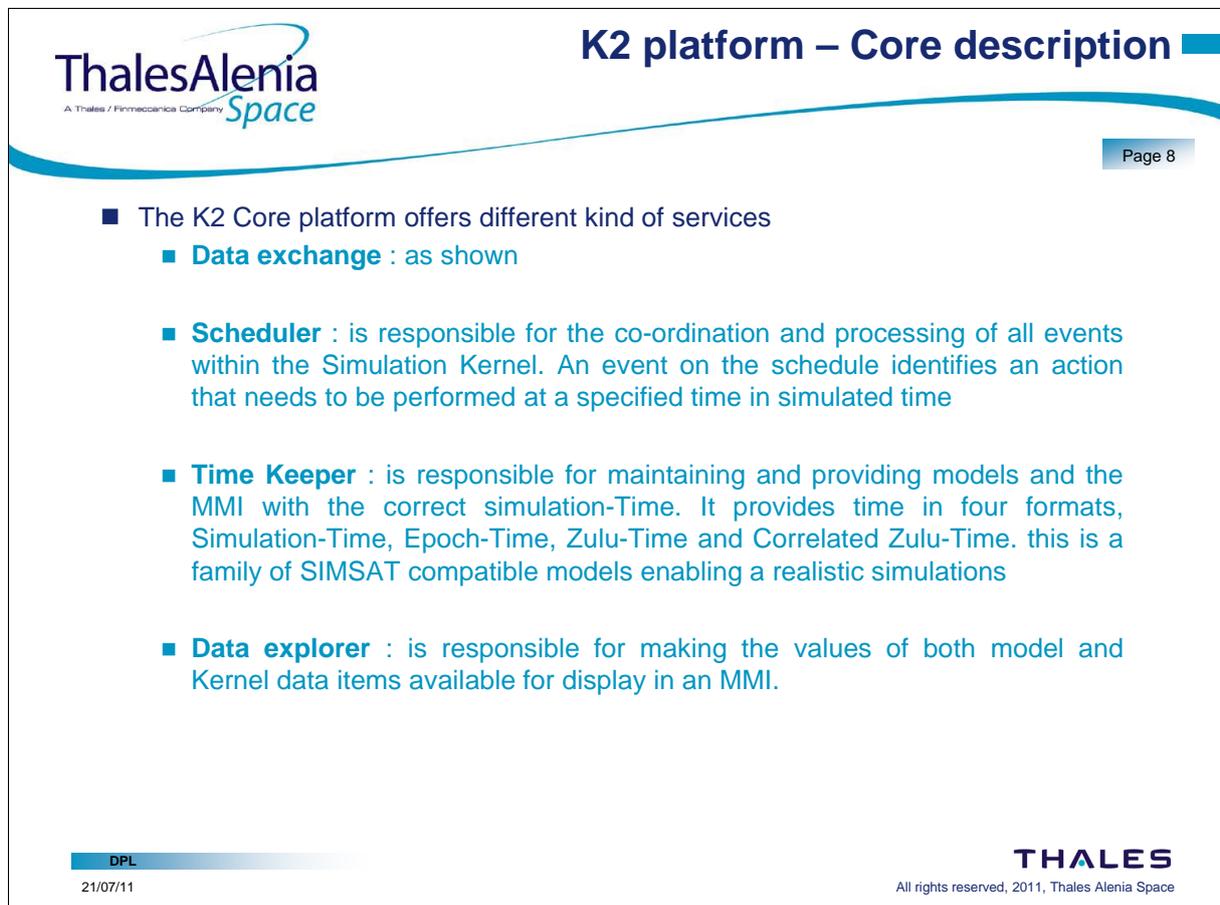
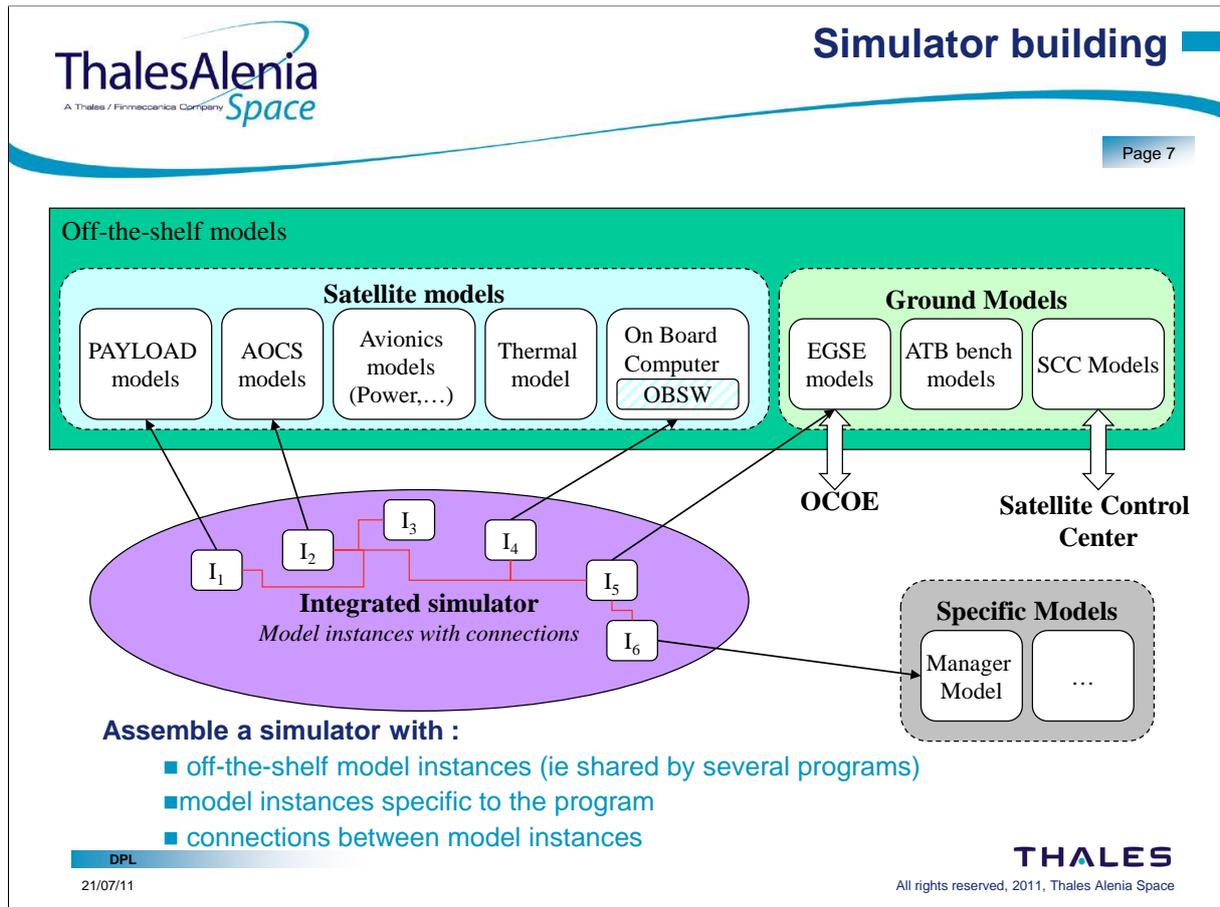
*This generic approach will be presented at ESA Workshop SESP in September 2012*

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## K2 Components Off-the-shelf

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- K2 simulator target : Linux 64 bits and 32 bits
  
- MMI target : full java program, can run on JRE 6 supported platform.
  
- K2 3rdparty components : mostly based on open source software
  - Gcc 4.3.3
  - Python 2.6
  - Swig 1.3
  - Java 6
  - ...

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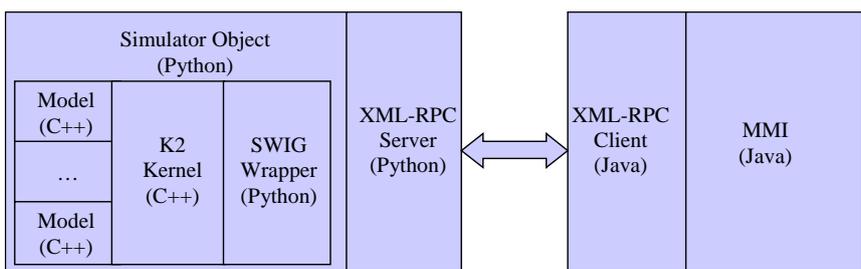


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## MMI

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- The Man-Machine Interface (MMI) is the part of the simulation infrastructure that provides the graphical, user-friendly, configurable interface to any simulator.
  
- Local MMI are in charge of :
  - **initialization**
  - **simulation control**
  - **events activation**
  - **failures activation**
  - **internal variables control**
  - **Satellite Database control and command**
  - **Mimics display**
  - **Graph display**
  
- Design :



```

    graph LR
      subgraph SO [Simulator Object Python]
        subgraph MO [Model C++]
          M1[Model C++]
          M2[...]
          M3[Model C++]
        end
        subgraph KW [K2 Kernel C++]
          K[K2 Kernel C++]
        end
        subgraph SW [SWIG Wrapper Python]
          W[SWIG Wrapper Python]
        end
      end
      SO --- XMLRPC_S[XML-RPC Server Python]
      XMLRPC_S <--> XMLRPC_C[XML-RPC Client Java]
      XMLRPC_C --- MMI[MMI Java]
      
```

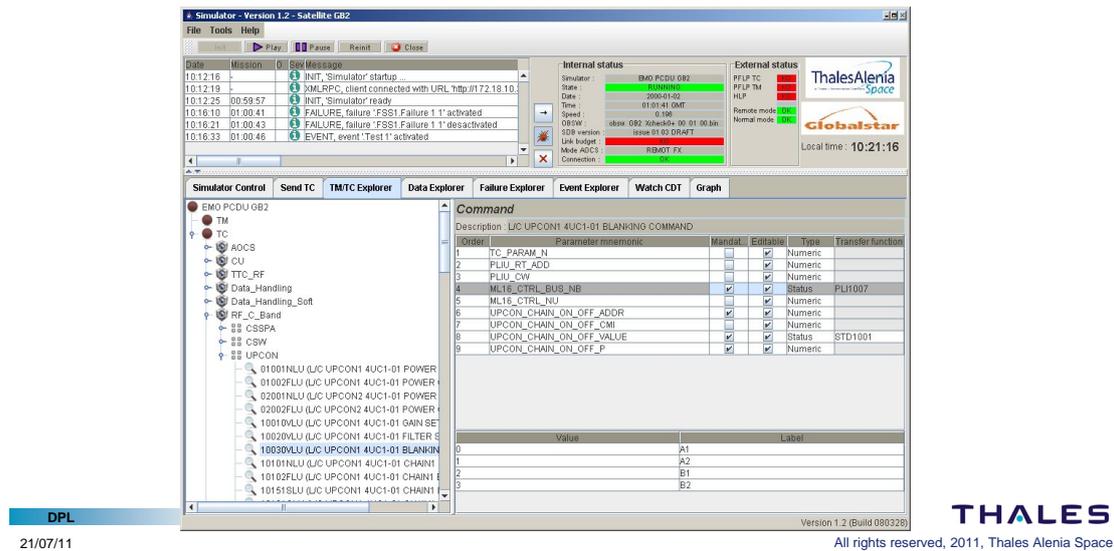
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- The “SDB explorer” panel provides the following features:
  - Quick access to SDB TM / TC data sorted by subsystem / equipments
  - Perform SDB TC send
  - Perform SDB TM decommutation



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Version 1.2 (Build 080328)

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## Problems to solve



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### ■ DSSS has to compute in real time:

- to take care of equipment powers as input,
- the solar, albedo and IR earth fluxes depending on the spacecraft attitude,
- the temperatures based on a static conductive and radiative matrices, updated according to external fluxes,
- the SA movements.

### ■ DSSS requirements:

- Performances have to be improved, ray tracing and temperatures recalculation based on geometry and nodal model, especially during SHM or spin.

### ■ TMM and GMM conversion:

- TMM models come from THERMISOL, ESATAN and ETHERM
- GMM models come from ESARAD, THERMICA and ETHERM.






## Solutions




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- **Real time solution:**
  - Few benches have been made to measure calculator speeds, and it appears that ETHERM (based on CORATHERM optimized code) is the faster of know calculators. Temperature time tick (Runge Kutta) for a model up to 3500 nodes is performed in 19ms (linux machine with i7-3610 processor).
  
- **Model requirements:**
  - Models have now to be reduced in order to have the best time response on stress cases (SC spin for instance).
  - TMRT (ESA/EADS Astrium/TAS tool) for nodes reduction for instances,
  - Actually manual reduction of number of faces for @sat (performed by EADS Astrium team).

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## TMM model requirements




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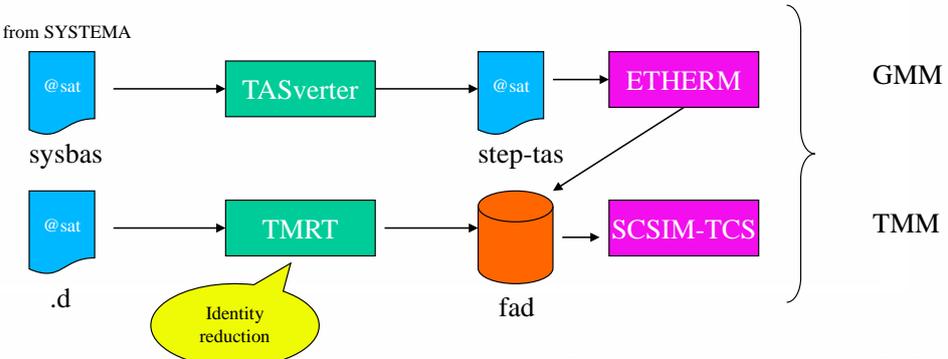
- **Use of model reduction:**
  - As far as we knew before implementation, real time requirements implied to have a limited number of nodes and faces.
  - Reduced nodal model for temperatures recalculation,
  - Reduced geometry for external fluxes calculation.
  
- **Applied for models:**
  - DSSS using SCSIM-TCS is succesfully validated for @sat (EADS Astrium/TAS) and O3B (TAS) that have been reduced:
    - ✓ 470 nodes and 950 faces for Alphasat
    - ✓ 3200 nodes and 1250 faces for O3B.

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## TMM/GMM models conversion

- **TMM conversion:**
  - @sat models have been converted (SSEOL, SAFE) into ETHERM format (former CORATHERM) using TMRT with no reduction.
- **GMM conversion**
  - @sat models have been converted into STEP-TAS via TASverter and read by ETHERM.



```

    graph LR
      subgraph SYSTEMA
        S1["@sat"]
        S2["@sat"]
      end
      subgraph GMM
        TAS[TASverter]
        S3["@sat"]
        ETHERM[ETHERM]
      end
      subgraph TMM
        TMRT[TMRT]
        fad[(fad)]
        SCSIM[SCSIM-TCS]
      end
      S1 --> TAS
      S2 --> TMRT
      TAS --> S3
      S3 --> ETHERM
      TMRT --> fad
      fad --> SCSIM
      ETHERM -.-> SCSIM
      ETHERM -.-> GMM
      SCSIM -.-> TMM
      IR((Identity reduction)) -.-> TMRT
      
```

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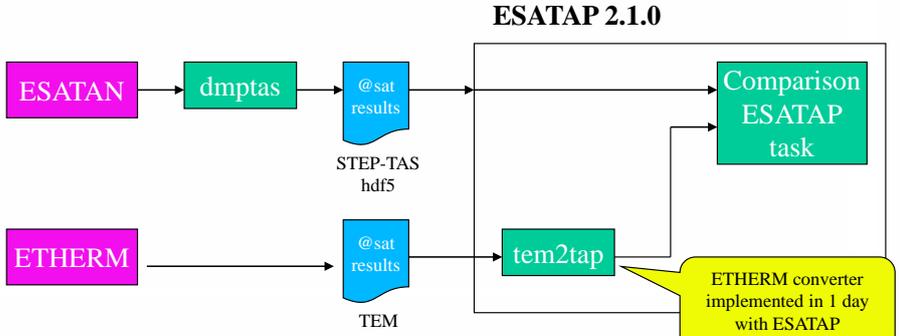
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## TMM/GMM model comparison and debug

- **Model conversion:**
  - Run on ESATAN:
    - ✓ DMPTAS to import results (1 orbit) from ESATAN
  - Run on ETHERM:
    - ✓ Implementation of a specific box to read in CSV format the temperatures from ETHERM for 1 orbit



```

    graph LR
      ESATAN[ESATAN] --> dmptas[dmptas]
      ETHERM[ETHERM] --> tem2tap[tem2tap]
      dmptas --> S1["@sat results"]
      S1 --> S2[STEP-TAS hdf5]
      S2 --> C[Comparison ESATAP task]
      tem2tap --> S3["@sat results"]
      S3 --> TEM[TEM]
      TEM --> C
      C --- I[ETHERM converter implemented in 1 day with ESATAP]
      
```

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## TMM/GMM model comparison and debug



- A dedicated ESATAP component and task has been implemented to calculate time constants for each node (formula taken from ETHERM / RPT):
  - calculated from temperatures, capacitances, GR and GL for each nodes, for model on ESATAN format.

ESATAP =>

- ESATAP was an asset to:
  - 1) Reduce temperature calculation time by analysing and tuning the time constants for temperature cycles convergence,
  - 2) Identify the nodes with very small capacitances (near to zero) and fix some capacitances in the original model.

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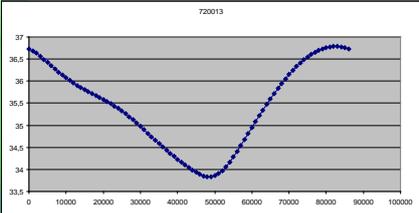
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## TMM/GMM model comparison and debug

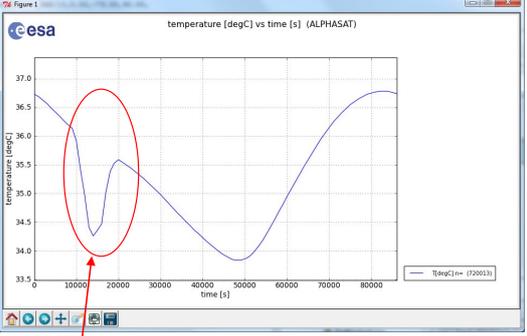


- Another problem was detected by ESATAP when comparing temperatures on thermistances during 1 orbit:



720013

from EADS Astrium,  
node 214



Anomaly

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## TMM/GMM model comparison and debug



- **Investigation:**
  - A dedicated ESATAP component has been implemented in order to calculate all the conductive and radiative (internal and external) paths to nodes with powers.
  
- **Given result after analysis all the leaf nodes that have powers:**
  - A difference is noted for a power ( $Q_5$ ) from some external nodes during a short period of time.
  - The decrease of the temperature for these nodes is due to the shadow of the reflector.
  - After having analysed the GMM, we found that transmissivity was not correctly set on the GMM.

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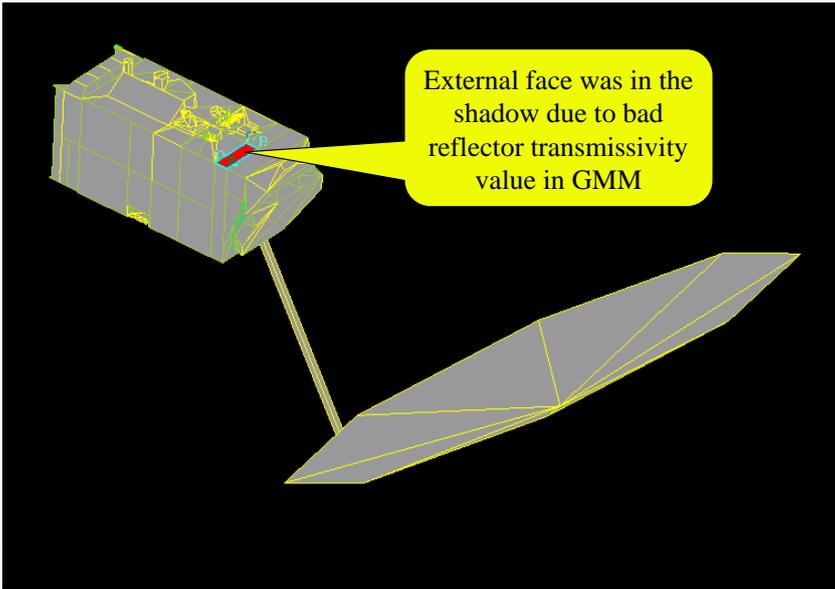
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## TMM/GMM model comparison and debug



ETHER 3D View



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## SCSIM-TCS integration



- **SCSIM-TCS:**
  - Standalone thermal simulator connected via TCP-IP with the SCSIM scheduler,
  - Multi-threading has been largely used for communication process but also to separate external fluxes and temperatures calculations.
- **ETHERM modules integration:**
  - ETHERM 1.3 view surfaces, solar and albedo flux, earth IR calculator (SV) and temperatures calculator (RPT) have been integrated into SCSIM-TCS.
- **Capabilities:**
  - Temperatures recalculation according to equipment power real-time settings (from OBS) including regulation,
  - Solar, earth vector and fluxes handling in real time and thresholds handling,
  - Multi-configurations (new GMM/TMM) is handled and conf switches are taken into account in less than 1 s,
  - Regulation can be switched on/off for debugging.

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## SCSIM-TCS performances



- **Size of the reduced models:**
  - @sat: 470 nodes, 956 faces
  - Stress test model: 3500, 1300 faces
- **Measured at DOREA, from a dedicated stress test:**
  - Initialisation : 110 ms (loading ETHERM model)
  - Solar + Albedo + IR recalculation : 23s of CPU
  - T° calc in 1 loop of 80 iterations : 1500ms of CPU
- **Measured from Alphasat model:**
  - Initialisation : 110 ms (loading ETHERM model)
  - Solar flux calculation : 6.8s of CPU
  - T° calc in 1 loop of 32 iterations : 500 ms of CPU
- **Precision:**
  - Compared to @sat thermal analysis results, SCSIM-TCS temperatures restitution confidence is from +/- 0.1 degC to +/- 1.7 degC for the max on thermistances.

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## Conclusion



- **Actually, the SCSIM-TCS has been integrated into SCSIM**
- **The full SCSIM including thermal simulator SCSIM-TCS is accepted for the following S/C:**
  - Alphasat (EADS Astrium as prime),
  - O3B (O3B Networks Ltd)
- **In the near future (2013 / 2014):**
  - Iridium Next
  - Turkmenistan Telecom Satellite

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