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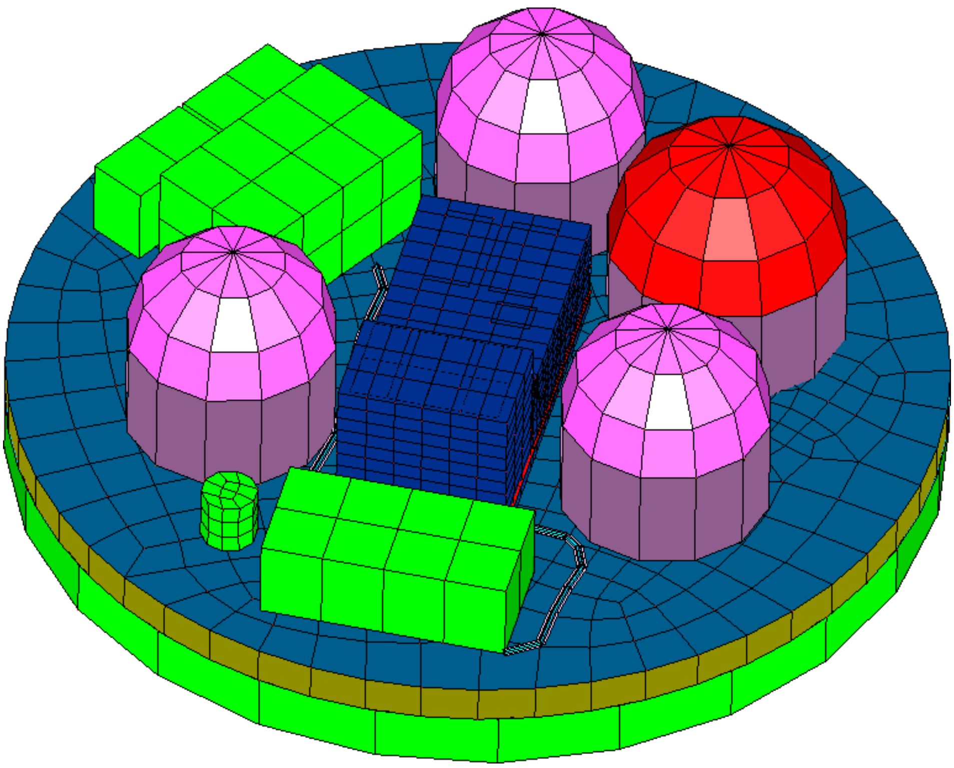

European Space Agency
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Abstract

This document contains the minutes of the 24th European Workshop on Thermal and ECLS Software held at ESA/ESTEC, Noordwijk, The Netherlands on 16–17 November 2010. It is intended to reflect all of the additional comments and questions of the participants. In this way, progress (past and future) can be monitored and the views of the user community represented. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.
Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under 'Workshops'.

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Day 1

Tuesday 16th November 2010

1.1 Welcome and introduction

H. Rooijackers (ESA/ESTEC) welcomed everyone to the workshop and outlined its main aims:

1. To promote the exchange of views and experiences amongst the users of European thermal and ECLS engineering analysis tools and related methodologies;
2. To provide a forum for contact between end users and software developers;
3. To present the status of thermal and ECLS engineering analysis tools and to solicit feedback for development;
4. To present new methodologies, standardisation activities, etc.

H. Rooijackers also introduced B. Laine (ESA/ESTEC). He explained that he was the new head of the Thermal Analysis and Verification section at ESA, and had taken over from O. Pin (ESA/ESTEC) at the start of September 2010. (See appendix A)

1.2 Presentation, demonstration of new TAS thermal software e-Therm and associated strategy

P. Hugonnot (Thales Alenia Space) presented a brief overview of the development of `e-Therm` as a replacement for `CORATHERM`, and described the long term strategy to extend the tool to cover the complete analysis process and possibly link to other disciplines. (See appendix B)
L. Tentoni (Thales Alenia Space) commented that the demonstrations had shown how to import models from `ESARAD` and CAD, and asked whether it was possible to build such models from zero. F. Brunetti (DOREA) said that the user could build models using `e-Therm` because it was a complete modeller, but said that it was also important to have an import facility from CAD. The demonstration had shown the import from `CATIA`-v5.
L. Tentoni asked whether there had been any cutting operations in the model shown in the demonstration. F. Brunetti said that the model had included cutting operations because this was a capability of the CAD tool. It was possible to click to select points in the CAD model, and that `e-Therm` would try to recognize geometric primitives and transfer them into the thermal model. L. Tentoni asked whether it was possible to use cutting operations when building the model yourself using `e-Therm`. F. Brunetti said that CAD models could be imported into `e-Therm`,

but e−Therm also provided primitives. The user could also create surfaces from 2D polylines and then mesh them using the GMSH mesher.
P. Ferreira (Max Planck Institute) commented that the video had shown many warnings during the import of the ESARAD model, and wondered what these errors were. F. Brunetti said that the warnings related to matching materials. The materials used by the existing internal model were already known, but those being imported from the external model were not yet known, and needed to be created in the reference database. This was the reason for the error messages.
B. Benthem (Dutch Space) observed that the video had shown a picture of 3D calculation on solid elements, and asked how to do this in ESARAD. F. Brunetti explained that the two videos were not linked: the first showed how to import a model from ESARAD; and the second showed how to import a model from PATRAN. The 3D calculation on solid elements related to the PATRAN model. F. Brunetti added that it was also possible to perform 3D meshing using the GMSH mesher, but then the user would need to use the e−Therm solver rather than ESATAN.
B. Benthem asked whether e−Therm also calculated radiative couplings. F. Brunetti said that it did, but only on the 2D thin shells that made up the skin of the model, and not on 3D solids. B. Benthem asked how the software took the radiative couplings into account. P. Hugonnot said that e−Therm made use of the EQUIVALE method that had been applied to 2D panels on telecom satellites for many years, and which had now been developed further for 3D.
B. Laine (ESA/ESTEC) had understood that the tool had already been released last year, and wondered whether there had been any feedback, and whether there were still plans to distribute the tool for free. F. Brunetti said that last year's release had been of the previous version, and what had been distributed had basically offered CIGAL2 pre- and post-processing. Thales now had e−Therm-1.0, and the next versions would contain full solvers because the CIGAL2 solvers could not perform all of the analysis chain. It would offer users simple import/export model capabilities and various calculations, but it didn't include the other analysis tools themselves. If users had already ESARAD or THERMICA then e−Therm could use them, but if users were missing these applications they would only be able to exchange models via STEP−TAS. He said that users needed the full integration of the analysis chain with STEP−TAS, and that this was now possible with e−Therm.
P. Hugonnot said that Thales would perform "corrective maintenance", so if users found and reported bugs then they would try to solve them. They were willing to look at adding new features as part of "evolutive maintenance" if needed, but they would need feedback from users. At the moment the tool addressed general user needs, and would be available on the market for a small distribution cost, and they hoped that they would receive community support.
B. Laine asked about the possibility of hot-line support: was there a telephone number that users could call? P. Hugonnot said that they would try to offer support as long as it didn't become too heavy. F. Brunetti added T. Basset (Thales Alenia Space) was happy for people to contact him with questions.

1.3 Exchange of Thermal Model Algorithms via STEP-TAS

A. Fagot (DOREA) presented some of the design considerations needed in TMMverter to handle the different features of ESATAN and SINDA/Fluint thermal mathematical models, and how these could be mapped via the STEP−TAS protocol. (See appendix C)
M. Bernard (Astrium) asked about the import of ESATAN models. He wondered whether they had considered creating a node export function that could be called from within ESATAN, rather than designing a new ESATAN model parser. A. Fagot said that one of the aims of TASverter was

to be independent of the software tools, and it was important to be able to import the tool formats without needing to have the tools themselves, although this raised problems because the tools were evolving. The `ESATAN` node export facility did not output any of the user logic, and `TMMverter` was a test to see if it would be possible to capture and exchange the user logic too. `TMMverter` was looking at importing ASCII models in order to simplify testing, because it was easier to read user logic in `FORTRAN` than trying to decode tool specific data files.
`TMMverter` was also trying to deal with the high-level concepts such as being able to convert a node definition loop into `STEP-TAS` rather than the specific `ESATAN` node definition loop. M. Bernard said that the `FORTRAN` syntax was more strict than `ESATAN`. A. Fagot agreed that the node definition was not easy to achieve in pure `FORTRAN`, but said that to handle user models, it was a question of parsing user code, and then applying the "visitor" design pattern to convert them.

1.4 Exchange of TMG thermal models via STEP-TAS

M. Bourbel (MAYA) described the implementation of `STEP-TAS` import/export facilities in `IDEAS/TMG` and `NX Space Systems Thermal` using the software development toolkit provided by the IITAS project sponsored by ESA. (See appendix D)
S. Leroy (DOREA) asked how they had tested the thermal node numbering on the node faces imported from `STEP-TAS`. M. Bourbel said that they had tested converting from `IDEAS/TMG` to other tools and back again to `NX-SST`, and compared the result. It was possible to compare the two models side by side.
S. Leroy wondered whether it was now possible to show the node numbering and shell meshing in `BagheraView`. M. Bourbel said that they had done the comparison in `NX-SST`: each primitive in `STEP-TAS` had a number, and during import they applied the same number in `NX-SST` and could then visualise it, but he admitted that it wasn't a convenient way to check the numbering.
S. Leroy said that their version of `BagheraView` did not show node numbering, so they had found it very difficult to check. M. Bourbel noted that the list of primitives shown in `BagheraView` also contained the element number that came from `NX-SST`.
S. Leroy noted that there could be cases where it was possible to modelize entities but still have errors in the conversion. M. Bourbel admitted that `NX-SST` did not support non-planar quadrilaterals, and that these had to be split into two triangles, and would result in a change in the model during conversion, but `NX-SST` did give a warning to the user that the nodal breakdown could change.
H. Brouquet (ITP Engines UK) asked whether there was any plan to make the `STEP-TAS` files available to allow testing of the European thermal tools. M. Bourbel said that all of the models were available from the IITAS repository. O. Svensson (ECAPS) asked whether users had access to these models. O. Pin (ESA/ESTEC) explained that there was a central repository available to the IITAS developers, and that although the models themselves were publicly available, the repository itself was only available to IITAS developers, and not to general users. The repository had been created for the IITAS partners in order to support the validation of the tools. H. Brouquet remarked that ITP had not been notified that the `IDEAS/TMG` models were now available in the repository.
A. Fagot (DOREA) asked about project continuity once the IITAS funding and development finished, and whether MAYA had also tested exchange with the other IITAS software such as `THERMICA` and `ESARAD`. M. Bourbel said that they had used the publicly available models, but had not had direct feedback from the other IITAS developers. As far as future work on

STEP-TAS was concerned, Maya had several TSS and ESARAD customers who were interested in exchanging models, and he expected to hear from them once they became aware of the release of the STEP-TAS interface.

1.5 Genetic algorithm shape optimisation of radiant heaters

B. Shaughnessy (RAL) presented high-level details of an old study into using genetic algorithms to calculate the shape of heating elements in electric cookers. He felt it important to highlight such alternative techniques. (See appendix E)
JP. Dudon (Thales Alenia Space) asked about the relative time taken in the preparation of the model, and how to choose the "best" solutions for input to the next generation of calculations, compared to the actual computation time. B. Shaughnessy said that when he had done the study, the preparation time had been mainly constrained by his own C++ capabilities, although the coding of the program had been straightforward. JP. Dudon explained that he had really meant the question from the user point of view. B. Shaughnessy admitted that the model had been very specific to the particular application. It had been relatively easy and quick to tune the parameters, but it had taken a few days of playing around in order to decide which parameters were needed, and their constraints. Once that had been decided, the run-time was then a few hours. He said that the main difficulty was choosing the parameters and the range of variation.
J. Persson (ESA/ESTEC) remarked that he didn't know whether the technique would be suitable for furnaces, but he saw that it could be interesting for thermal testing, especially for infra-red lamp analysis. B. Shaughnessy admitted that he had not tried this, but he had heard anecdotal evidence about thermal test problems due to heat gradients where he thought that this method might be useful.
B. Benthem (Dutch Space) noted that the example shown probably only had 8-10 degrees of freedom, and wondered whether it had really been necessary to try to optimise it using genetic algorithms. B. Shaughnessy answered that he could have used other techniques for the problem, but that this work had been part of a case study into using genetic algorithms. B. Benthem asked whether 8-10 parameters were typical for such a problem. B. Shaughnessy said that most systems using genetic algorithms needed to be developed with the particular problem and set of parameters in mind, as this would determine whether to use some sort of binary encoding for two-value parameters, or a floating point representation for parameters with a range of possible values. The combination and mutation of parameters to be passed to the next generation also needed to be tailored to the problem.
M. Gorlani (Blue Engineering) wanted to make the remark that this was interesting work, but also to remind everyone that Blue Engineering had done a study into stochastic algorithms for ESA in 2003, and that the results were available on the ESA site[1]. He said that for the last ten years he had been trying to take these methods further. B. Shaughnessy admitted that he was aware of the Stochastic study.
J. Etchells (ESA/ESTEC) asked whether the end result was sensitive to the choice of the mutation or crossover algorithm being used, and whether this could explain the differences between the triangle- and step-heating cases shown. B. Shaughnessy said that he remembered making some trials, and that it was difficult to optimise the mutation parameters. After making some initial trials, he had simply stuck with the same values. He had not looked into how to optimise it further.
B. Laine (ESA/ESTEC) said that he was aware that genetic algorithms were also being

[1] https://exchange.esa.int/stochastic/

investigated by Astrium Toulouse. F. Jouffroy (EADS Astrium) confirmed that they were looking at using genetic algorithms to correlate thermal models. At the moment they were only using the TMM scalar parameters, but the method showed that to improve the correlation there was a need for consistency between the test results and the prediction model. The prediction model had to be reasonably good otherwise the genetic algorithms would take too long to reach a solution. On the Astrium Toulouse side, all of the parameterization aspects of genetic algorithms had been performed in a previous study, and that they now no longer needed to consider the propagation and crossover aspects.
B. Shaughnessy said that he saw genetic algorithms as part of a separate tool for simple algorithms, such as how to determine the best heater position on a plate, but to then use the results from this separate tool in the main TMM. F. Jouffroy said it was clear that genetic algorithms had been shown to be a heavy method for optimisation. The Astrium Toulouse experience had been that the genetic algorithm approach always found the optimum solution in the end, and although their aim was always to find the best solution, in reality they were limited to using just 6 or 7 parameters in the correlation studies because of the computation time required.

1.6 Development of numerical tools for design and verification of ablative thermal protection systems

M. Giardino (Politecnico di Torino) gave a brief overview of the physical processes involved in ablation, and described the development of two tools to analyse models of 1D and 3D ablative decomposition. (See appendix F)
M. Komarek (L.K. Engineering) asked whether the models also included the external gas flow. M. Giardino said that they did not. The 1D code was based on a simple model from a 1969 NASA report for the Apollo missions, where the mass reduction was directly proportional to the gas ejection. The 3D code did not contain any reduction modelling, and only considered atmospheric pressure over time as an influence on the gas flux within the material.

1.7 ESATAN2SS tool — from ESATAN to Space State

D. Pietrafesa (Sofiter System Engineering) presented details of the `ESATAN2SS` tool for converting non-linear `ESATAN` thermal networks into linear State Space models. (See appendix G)
B. Benthem (Dutch Space) asked whether the method also handled radiative couplings, as these were non-linear with respect to temperature. Conductive couplings between nodes, GLs, were linear, but radiative couplings, GRs, were non-linear. D. Pietrafesa replied that the tool would also handle GRs, and that the software had been validated on both linear and non-linear models. It had been used on the Galileo models, which were non-linear.
M. Gorlani (Blue Engineering) assumed that the model was linearized at the beginning so that the tool could then handle it, and D. Pietrafesa confirmed this.
J. Etchells (ESA/ESTEC) commented that arithmetic nodes could not be added to the state vector, and wondered how the tool was able to handle their effect. D. Pietrafesa said that she did not know, and would need to ask colleagues.
B. Laine (ESA/ESTEC) asked about the linearization process, and whether there was a warning about being too far from the local state, and whether the temperatures would still be calculated correctly. D. Pietrafesa admitted that she did not know as she had not developed the tool.

1.8 ESATAN Thermal Modelling Suite — Product Developments & Demonstrations

C. Kirtley (ITP Engines UK) summarized the recent releases of ESATAN-TMS and described how the features that had been introduced were part of a roadmap defining the tool strategy, based on both feedback from users, and ITP's vision for an integrated modelling tool. He described some of the new features of ESATAN-TMS-r3, which was currently planned for release at the end of the month. H. Brouquet (ITP Engines UK) gave demonstrations of both the new features in the ESATAN-TMS Workbench, showing the import of finite element models, and the latest improvements to ThermNV. (See appendix H)
L. Tentoni (Thales Alenia Space) commented that there had been mention of the finite element mesh, and wondered whether this meant a particular mesh for use with the lumped parameter model. He was also concerned about lumped parameter nodes connected to finite element nodes and wondered whether they continued to be finite element nodes once values were assigned in the Workbench. H. Brouquet assured him that if they had been imported as finite element nodes then they would continue to be finite element nodes. C. Kirtley said that they continued to be finite element nodes but the usual Workbench calculations were available on them so the user could post-process them.
H. Kneistler (Astrium Space Transportation) asked about the availability on 64-bit Windows platforms. H. Brouquet said that this was a major item on their "to do" list, but the problem was the availability of the GNU FORTRAN compiler on 64-bit Windows. ITP had been looking at another compiler, but they still favoured using the open source GNU compiler in order to keep the cost down for the users He assured people that the 32-bit version would still work on 64-bit Windows machines. C. Kirtley said that ITP were doing their development on 64-bit machines. H. Brouquet said that they were not aware of any problems as long as the correct versions of Java, etc. were installed on the machine.
G. Sieber (Jena-Optronik) asked whether ITP had any test or experience of changing a lumped parameter model into a finite element model. H. Brouquet admitted that it would be possible to change the shell attributes from finite element to lumped parameter versions. He did not see any inherent problems as far as the software was concerned, but noted that the results would depend on whether the boundary conditions were applied to the corners of the mesh rather than the centre. He said that leaving the model as a finite element model would be much faster because there would be no need to run the automatic conductor generation as all of the node mesh would be congruent.
H. Rathjen (Astrium GmbH) asked whether the new combined finite element model capability was related to ESATAN/TMG or the ESATAN export facility provided by IDEAS/TMG. H. Brouquet replied that there was no connection at all, and that using the new finite element capability did not require having IDEAS/TMG.
A. Jarrier (DOREA) asked how the user could import the CAD STEP file and then display the baseline geometry without the mesh. H. Brouquet said that in the demonstration he had shown how to import the model using the CADconverter. He stressed that the CADconverter was not a CAD viewer. The shapes were imported into ESATAN-TMS, and if the converter recognised a collection of shapes as equivalent to a primitive geometry shape, then those shapes could be converted.
S. Leroy (DOREA) asked whether to display the CAD model they had added polyline or b-spline element handling. C. Kirtley said that when the CADconverter recognised such a surface it would bring it in and re-mesh it as triangles. S. Leroy asked whether the CADconverter would handle high-level shapes such as a thick cylinder. H. Brouquet said that a thick cylinder would be imported as a cylinder and two disks, but that these would be thin shells.

P. Ferreira (Max Planck Institute) asked how the node numbering was handled during model import. What happened if the node numbers were already used? H. Brouquet said that the numbers would not conflict because the nodes were only given numbers when the model was assigned, or when the user redefined a shell and set or changed the node number explicitly. C. Kirtley said that the import process involved importing the CAD geometry and applying a mesh, not importing the node. P. Ferreira asked what happened if he needed a different node number per triangle: would he need to go through them one-by-one? H. Brouquet admitted that if the user wanted to impose a specific node number then they would have to do this manually.
H. Rathjen asked whether there was a limit to the size of CAD model that could be imported. H. Brouquet said that some CAD models were very large, and that was the reason for trying to display the model hierarchy, so that the user could import the CAD model bit-by-bit, and then simplify or impose the mesh for each submodel. He admitted that if the CAD model was made up of 500,000 triangles in a flat hierarchy then maybe it would be too big to import.
B. Laine (ESA/ESTEC) wondered about being able to go back to the original finite element model and apply the results calculated by ESATAN-TMS. What happened if the user simplified the mesh? Would there still be some traceability? H. Brouquet said that the NASTRAN converter would keep a mapping file so that when the results were sent to the mechanical engineer, they would still see the same node number. H. Brouquet said that if the model had been imported using the CADconverter, the user would need to turn off the shape recognition option in order to avoid simplification and to retain the original mapping. If the model had been imported from NASTRAN then the node numbers were retained. The software would keep a record of the state of the model when it had been imported, and the state of the model now, and so would output the original node numbers where possible.
M. Komarek (L.K. Engineering) asked how the radiative couplings where handled for the finite element mesh. H. Brouquet said that the radiative calculations were done on the shell, regardless of whether that shell had a finite element or a lumped parameter mesh. However, with a finite element mesh, the GR would be associated with the corners of the mesh, and with a lumped parameter mesh the GR would be associated with the centre. The radiative calculations were done on the geometry, not the mesh if the shape recognition was enabled. C. Kirtley said that the user could create user-defined conductive interfaces if conductors were not created automatically as a result of non-congruent meshes between shells.

1.9 SYSTEMA 4.3.4

M. Baucher (EADS Astrium) presented recent developments of the SYSTEMA framework, which now allowed thermal calculations to be run on CAD as well as thermal models, import and export of STEP-TAS, and extended simulation facilities for all planets in the Solar System. (See appendix I)
H. de Wolf (Dutch Space) asked whether the moon calculations mentioned in the presentation were related to the Earth's moon, or any moon in the solar system. M. Baucher said that for the moment SYSTEMA provided details for the Earth's moon and the planets in the Solar System, but not for the moons of the planets. T. Soriano (EADS Astrium) added that simulation capabilities for specific moons could be made available to users on demand. He said that a recent study had needed details of one of the moons of Jupiter in order to handle the orientation of solar panels for a spacecraft in orbit, and that it had been possible to add this capability to SYSTEMA. There was one major problem: the moons of Jupiter did not have nice fixed Keplerian parameters because of the interactions with all of the other moons, and therefore it was necessary to update the orbit parameters for each analysis scenario.

1.10 THERMICA-THERMISOL 4.3.4

T. Soriano (EADS Astrium) described the new features in the latest release of THERMICA and THERMISOL, including multi-threading support for the ray-tracing, visualisation of the ray-tracing, a new approach to conductor generation, and changes to the multiple time-step algorithms. (See appendix J)
M. Bernard (Astrium) wanted to know more about the management of the multiple time-steps, and asked when the $VARIABLES2 block was run and therefore when the user had control of the execution again. T. Soriano said that the sub-timesteps were managed in exactly the same way as the main timesteps. Some nodes would not need recalculating for the sub-timesteps, and although they were really diffusive nodes, could be considered boundary nodes in the sub-timesteps. The same logic applied as usual, $VARIABLES1 would be called at the start of the timestep, and $VARIABLES2 at the end.
M. Bernard wanted more clarification. If he had a main timestep of 10s and sub-timesteps of 0.5s when would output be produced? T. Soriano said that $VARIABLES2 could be written to produce output at the times chosen by the user. M. Bernard asked when the output was done: was it at the end of the main timestep or the sub-timestep? T. Soriano said that if the user specified to have output every 500s or 1000s then the output would be called at those times. There would always be synchronisation so that the main timestep coincided with the desired output times. M. Bernard wondered what would happen if he had some post-processing in $VARIABLES2: would this be run every 10s or every 0.5s. T. Soriano answered that $VARIABLES2 would be run every 0.5s, but it was possible to add a control variable so that parts of $VARIABLES2 would only be handled as part of the main timestep.
J. Etchells (ESA/ESTEC) wondered about the ray-tracing on the CAD geometry, and asked whether this worked on NURBS or B-REP surfaces. T. Soriano said that the CAD geometry was imported "as-is" into SYSTEMA. He wasn't aware of any software system that displayed true curves and instead broke down such curves into small triangles for display. So THERMICA already had all of these small facets for the display of these shapes, and because of the improvements in the ray-tracing speed, could just use these small discretizations directly. J. Etchells commented that care would be required for specular surfaces. T. Soriano said that to handle specular surfaces the user should really change the CAD shape into one of the analytical shapes. This would give a better result, but there would still be a small error due to the stochastic nature of the ray-tracing.
B. Laine (ESA/ESTEC) asked whether THERMICA offered the new conductive coupling calculations by default, or whether the user could choose. T. Soriano said that the new conductive coupling calculation technique was the only method provided in SYSTEMA-v4. He said that it was very efficient, and was the only method he was aware of that had a mathematical proof and was consistent with the radiative calculations. He said that it also handled calculations on a non-compliant mesh without problems. The conductive couplings with a non-conformant mesh were well behaved, and mathematically proven. However, the new method was not yet fully implemented for all of the cutting surfaces at the moment.

1.11 TMRT

M. Bernard (Astrium) presented a tour of the Thermal Model Reduction Tool aimed at the user level. He explained that the TMRT provided a harmonisation of methods used in Astrium Toulouse and Thales Alenia Space in Cannes. (See appendix K)

P. Zevenbergen (Dutch Space) asked whether the tool also included a means of renumbering nodes within a model. M. Bernard said that the user could specify a node-to-node reduction, and so the `TMRT` could be used for node renumbering, but it would be very inefficient. It would be far easier to simply edit the model, or use shell scripts. He said that the `TMRT` was used in `e-Therm` to provide a route from `CORATHERM` to `ESATAN`, so it was used in a non-reduction mode there.
M. Gorlani (Blue Engineering) asked whether it would be possible to have a trial version of the `TMRT` to understand how it worked and whether it could be used as part of existing tool chains. He was interested in looking at the compliance between temperatures and powers within detailed and reduced models. M. Bernard said that it might be possible, but would need to be discussed. T. Soriano (EADS Astrium) explained that there would only be a small fee (probably about € 500) to cover the costs of distribution, compiling, and basic support, but he thought that it would be possible to have it for a short term for free.
M. Gorlani said he did not think that it would be possible to use the `TMRT` as a black box tool, and that the user would need some understanding of the method before using it. M. Bernard said that not all of the users in Astrium where experts who understood the full mathematical details. He said that sometimes the reduced model produced was not as good as expected, and the user did not always know why, even though they knew that they should be able to do better. So M. Bernard agreed that it was better to know the theory behind the tool. He said a possible second phase of the project would be to produce guidelines on how to use the method, but he thought that it would take at least a year before there would be any progress in such an activity.
B. Benthem (Dutch Space) asked whether the `TMRT` was able to handle temperature dependent conduction. M. Bernard said that, no, unfortunately it could not. The tool took the set of conductances as a whole, and was only able to extract fixed literal values. So if the TMM needed temperature dependent couplings there would be a problem extracting them from the model. M. Bernard suggested that it might be possible to work round this by limiting the analysis to specific temperature cases, and then generating reduced models for each of the temperature cases.
P. Zevenbergen asked about the use of the `TMRT` to determine the worst analysis cases. M. Bernard said that the `TMRT` could not know which steady state case it should use as the basis for the reduction. He suggested to use one reduced model for the expected hot case and another for the cold case. P. Zevenbergen wondered whether it would be possible to specify a temperature at the beginning and then let the tool choose accordingly.
B. Benthem asked what was required as input to the `TMRT`: a *.d file? MB replied that the `TMRT` required a *.d file, but with restrictions. The model could not make use of `$CONSTANTS` parameters within the data blocks. Everything was extracted as literal values or expressions, so temperature or time dependent conductors and capacitances were not handled. The user might need to make a snapshot at given fixed values so that the `TMRT` could extract them from the model.
P. Ferreira (Max Planck Institute) asked how it was possible to guarantee temperatures and fluxes in the reduced model were within 10% of those of the detailed model. Or could this only be achieved by a process of trial and error? M. Bernard said that there was no easy way of predicting the quality of the reduced model, hence the need for guidelines. If you looked at the theory, there were ways of treating the differences between the detailed and reduced models. It was necessary to consider the hypothesis of proportionality. If you reduced an isothermal plate and one with gradients, then the reduced isothermal plate would radiate more and so you would need to raise the temperature of the average node to compensate. If you had both hot and cold zones in the node, you would need to transport more power into the hot zone. If there were groups where the gradient was limited, then the problem would be limited and the difference between the detailed

and reduced models would be minimized. He said it was important to have a detailed thermal map in order to decide how to group nodes for the reduction process.
O. Pin (ESA/ESTEC) said that the `TMRT` was an interesting tool. He recalled that last year there had been discussion with Astrium UK about providing `TMRT` training in Stevenage. He wondered whether T. Soriano could talk to S. Price (Astrium UK) whether that would still be possible, or even whether it would be possible to have such a training in ESTEC.
M. Bernard said that the `TMRT` was available on Solaris, on 32-bit Linux and Windows platforms, and also on 64-bit Linux. He advised people that it was better to have the 64-bit version when trying to reduce complex models.
O. Pin wondered whether M. Bernard could say anything about the testing of the `TMRT`, and give an idea about the time taken for model reduction. M. Bernard said that the `TMRT` validation had just ended, and had raised an issue requiring a late bug correction in the last few weeks. There had been a lot of validation on simple test cases, and some more complex industrial test cases had been used to measure CPU time. In Astrium, where they had models of telecom payload panels with more than 40000 nodes, the old in-house tools had needed more than 4 hours to produce the reduced model. With `TMRT`, Dorea and Thales had improved efficiency and memory usage, a 43000 node model could be reduced in 2.5 hours, although this was on a machine with a lot of memory and a large disk. The time to perform the model reduction on simpler models of 3000 nodes was about 20s.

Day 2

Wednesday 17th November 2010

2.1 LHP module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses

F. Jouffroy (EADS Astrium) described the results of a partnership between the agencies, Astrium and Thales to produce a validated module for modelling loop heat pipes that could be included in both ESATAN and THERMICA. (See appendix L)
G. Sieber (Jena-Optronik) had understood that the test bed model had originally used a series of tabulated values, and that these had been replaced by the loop heat pipe module. He wanted to know whether there were any differences in results and computation time when using 12 loop heat pipes. F. Jouffroy said that for the Inmarsat model they had obtained a 2°C difference, but the reduced tabulated values didn't let the user see what happened within the condenser. They had found that they needed the loop heat pipe module to be able to understand the physical behaviour.

2.2 Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES

G. Parot (CNES) presented an overview of the various sorts of balloon systems that CNES had developed for use in atmospheric monitoring, and the differences in the thermal environment compared to space. She described the analysis of the thermal control systems within the payload gondola, and the results of a recent balloon flight campaign in Antarctica. (See appendix M)
T. Tirolien (ESA/ESTEC) wondered about the coupling with the power and accumulator model and asked whether the goal had been to model the behaviour depending on temperature, or to predict the temperature. G. Parot said that there was a power model and the thermal network and that they were coupled together. The main interest had been to know the charge on the batteries and accumulators for the predicted flight trajectory and duration. T. Tirolien asked whether the model had been provided by an external company, and was told that G. Parot had built it herself.
P. Ferreira (Max Planck Institute) said that the radiative environment was not the same as that of spacecraft in orbit and calculated by the space thermal tools. He asked how these additional non-orbital factors were handled. G. Parot said that it was necessary to calculate the factors based in the predicted trajectory. She used an Excel sheet for calculating various trajectory and related parameters such as the direct and diffuse solar flux, and other fluxes due to the different layers within the atmosphere. She felt that a proper tool needed to be developed for the calculation of the parameters relating to a given trajectory.

P. Ferreira noted that only one temperature had been used to describe the environment. G. Parot said that one temperature was used for the air temperature, and that the solar flux and view factors were taken into account.
P. Ferreira wondered about the worst case values that could be applied to all flights. Were there generic hot and cold cases, or did the worst cases differ for each trajectory? G. Parot said that it was difficult to define hot and cold cases, but she tried to define temperature margins for each trajectory by considering the solar fluxes, both direct and diffuse.
G. Sieber (Jena-Optronik) asked what inputs would be required for a thermal tool to calculate the boundary conditions. G. Parot said that the inputs would be elevation, latitude, time, and various things relating to clouds, such as the amount of cloud cover, altitude, type of cloud, and emissivity. The main outputs per trajectory would be the solar direct flux, and the diffuse flux, etc.

2.3 Thermal Concept Design Tool — 4th Year

M. Gorlani (Blue Engineering) described recent developments of the `TCDT` based on four years of use and feedback. The latest features include a material database, improved attitude handling and visualisation, better 3D viewer interactivity, and through-conductor calculations. (See appendix N)
B. Benthem (Dutch Space) asked about the post-processing of results that had been shown. Were these results imported from another tool, or did the `TCDT` have its own solver? M. Gorlani explained that the `TCDT` simulation manager provided the means for geometry definition, mission definition, and thermal network definition, and then to run the analysis. The radiative and thermal analysis could be run using `ESARAD` and `ESATAN` if they were available. `TCDT` could generate the models, launch the software, and then import the results for post-processing within `TCDT`. For example, it was possible to show the temperatures and fluxes in both steady state and transient. The user could follow all of the procedures of the thermal analysis from within `TCDT`, but the user first needed to provide the configuration needed to run the external tools.
P. Ferreira (Max Planck Institute) asked about the requirements of the Windows and Excel versions, because he had tried to install the `TCDT` and had encountered some problems. M. Gorlani said that the `TCDT` had been designed to work with Office 2003.

2.4 Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks

J. Burkhardt (EADS Astrium) gave a brief overview of the requirements and mathematical background for frequency domain thermal analysis and the linearization of thermal networks, and presented screenshots showing the user interface to the `TransFAST` software. (See appendix O)
B. Benthem (Dutch Space) asked what was the advantage of using `TransFAST` to extend the analysis into the time domain compared with standard `ESATAN`. J. Burkhardt said that the only advantage was the linearized system, so the solution should be faster. He noted that using analytical models made it easier to linearize the system and improve the speed. B. Benthem asked whether the main advantage was the CPU time required. J. Burkhardt said that there was a big improvement in CPU time.

2.5 Validation of the Martian Thermal Environment Modelling Method using Flight Data

S. Lapensée (ESA/ESTEC) described some of the challenges involved with modelling the Martian thermal environment, and how flight data from previous missions could be used to validate some of the model assumptions. (See appendix P)
M. Bernard (Astrium) asked whether S. Lapensée had found many correlation parameters on the model that could be improved, or was it more related to the environment. S. Lapensée said that for this mission, they had taken the environment and applied it to the spacecraft. They had needed to add variations to the surface finish due to the different levels of dust during the mission. They had assumed a fixed wind speed of 4m/s and had imposed the wind effect on the model. They had tried not to tweak the model.
M. Bernard said that they appeared to have achieved comparable results to the previous mission data. S. Lapensée said that some of the results were close to what had been achieved in the ground tests. The problem with the ground correlation was the lack of vacuum correlation because the lidar was not qualified to work in a total vacuum. The model predicted a temperature gradient across the structure, but the ground test did not show this due to convection effects. They had been reduced to hand calculations to confirm the results.
J. Etchells (ESA/ESTEC) commented on the lidar test and the effect of natural convection. He recalled the presentation by A. Quinn (Astrium UK)[1] at a previous workshop that had highlighted the Grashof number. S. Lapensée said that he was aware of that work, and said that it had not been possible to re-orient the lidar during the test because of the need for shooting through the chamber window. In the hand calculation for natural convection it is possible to show that it should occur under 1G on Earth, but the 0.3G of Mars was the threshold value of whether there would be natural convection or not.

2.6 Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests

J. Etchells (ESA/ESTEC) described the Large Solar Simulator test chamber at ESTEC and the requirements for the Bepi-Colombo testing. The mirror and lamp system of the LSS had been modified to produce a convergent light beam, giving 10 solar constants at the centre of the chamber. Innovative changes had been introduced to the `ESARAD` model of the chamber to produce the correct beam characteristics. (See appendix Q)
P. Ferreira (Max Planck Institute) wondered why there was such a noticeable asymmetry in the solar beam calculated in the model when this was not shown in the actual measurements from the LSS. J. Etchells said that the real LSS had a number of discrete lamps shining on a mirror consisting of approximately 50 petals, so the variations in the measured beam intensity were due to individual lamp and petal alignment effects. The `ESARAD` model of the LSS used real geometric shapes, but the rotation of the chamber relative to the axis of the parabola introduced an asymmetry.

[1] *Implementation of a Mars thermal environment model using standard spacecraft analysis tools*, Andy Quinn, 22nd European Workshop on Thermal and ECLS Software, 2008.

2.7 Workshop Close

H. Rooijackers (ESA/ESTEC) thanked everyone for coming, and gave special thanks to all of the people who had given presentations. He hoped to see everyone again at the next workshop.
Before finally closing the workshop, H. Rooijackers asked whether anybody had any comments about what they would like to see in the future.

- B. Shaughnessy (RAL) wanted to encourage more general presentations on thermal design. He felt that the workshop was currently biased too far towards presentations about specific tools. He wanted more papers of general interest that would raise awareness of work in progress.
- O. Pin (ESA/ESTEC) said that content of the presentations varied from year to year. Last year there had been lots of papers on analysis and design. It all depended on the users to contribute abstracts in time. He suggested that B. Laine (ESA/ESTEC), as his successor as head of section, could rename the workshop to reflect thermal analysis rather than thermal software.
- B. Laine wondered whether it would be possible to move the focus of the workshop to include more on engineering and testing.

Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Workshop objectives

esa

- To promote the exchange of views and experiences amongst the users of European thermal/ECLS engineering analysis tools and related methodologies
- To provide a forum for contact between end users and software developers
- To present (new versions of) thermal/ECLS engineering analysis tools and to solicit feedback for development
- To present new methodologies, standardisation activities, etc.

European Space Agency

24th European Workshop on Thermal and ECLS Software 2/12

ESA Team

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

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

European Space Agency

24th European Workshop on Thermal and ECLS Software 3/12

Programme

- Two-day programme
- Presentations of 30 min, including 5 minutes for questions and discussions
- Cocktails today after the workshop in the Foyer
- Dinner (optional) tonight in Noordwijk
- ESATAP training session 2nd day after lunch, approval ESA required

European Space Agency

24th European Workshop on Thermal and ECLS Software 4/12

Practical information

esa

- Presenters:
  If not done already please leave your presentation (PowerPoint or Impress and PDF file) with Duncan or Harrie before the end of Workshop.
- No copyrights, please!
- Workshop Minutes will be supplied to participants afterwards, on CD-ROM and on the Web.

European Space Agency

24th European Workshop on Thermal and ECLS Software 5/12

Practical information

esa

- Lunch: 13:00 - 14:00
- Cocktail today at 17:30 in the Foyer
- Check your details on the list of participants and inform the Conference Bureau of any modifications.
  Leave your email address!
- Taxi service and Shuttle service to Schiphol Airport
  contact ESTEC Reception ☎ ext. 54000, ESTEC.Reception@esa.int
  or Taxi Brouwer ☎ +31(0)71 361 1000, info@brouwers-tours.nl
- Workshop dinner tonight!

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24th European Workshop on Thermal and ECLS Software 6/12

Workshop diner

- in “La Galleria", Koningin Wilhelmina Boulevard 18, 2202 GT Noordwijk, ☎ +31(0)1719 17196
- fixed menu with choice of main course (fish, meat or vegetarian) for €33,50 p.p. incl. 2 drinks
  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

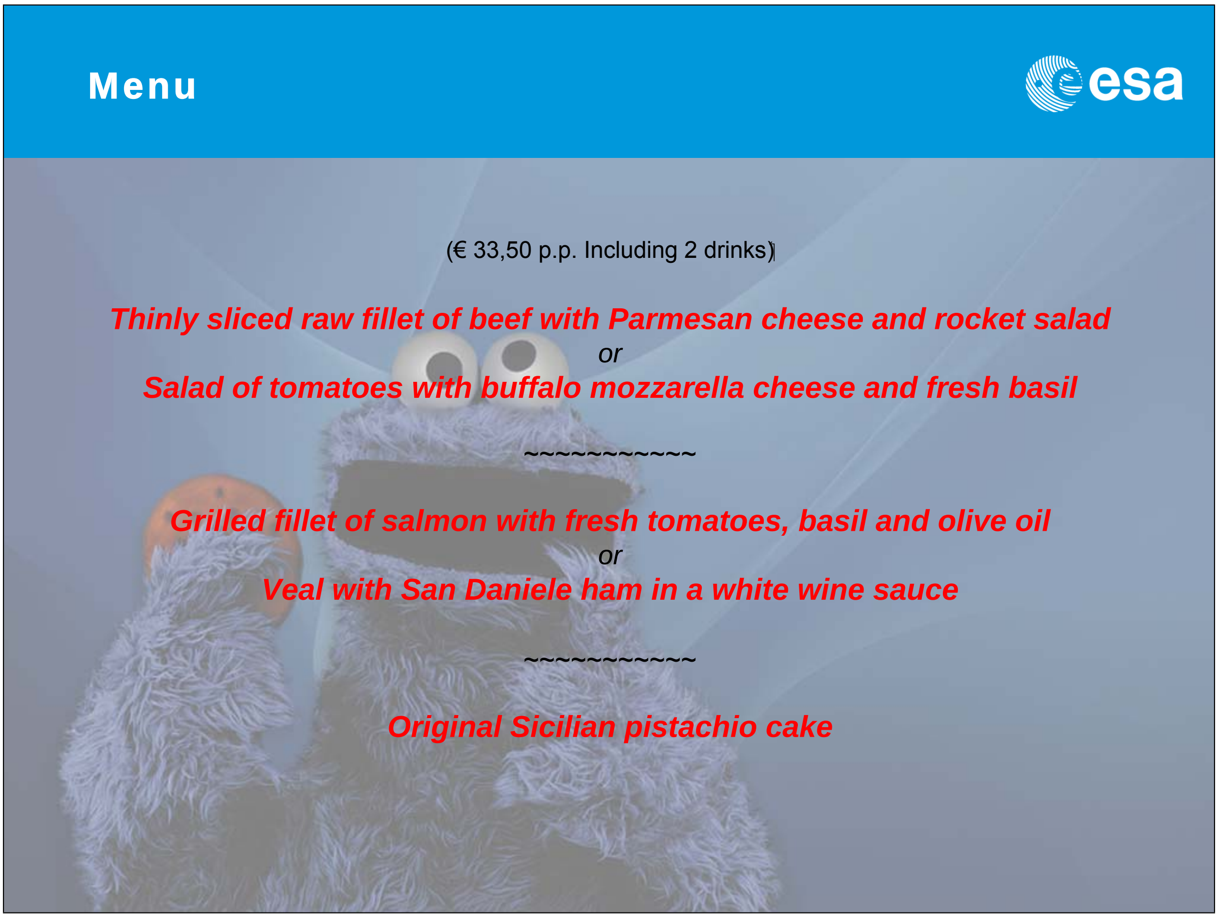
European Space Agency

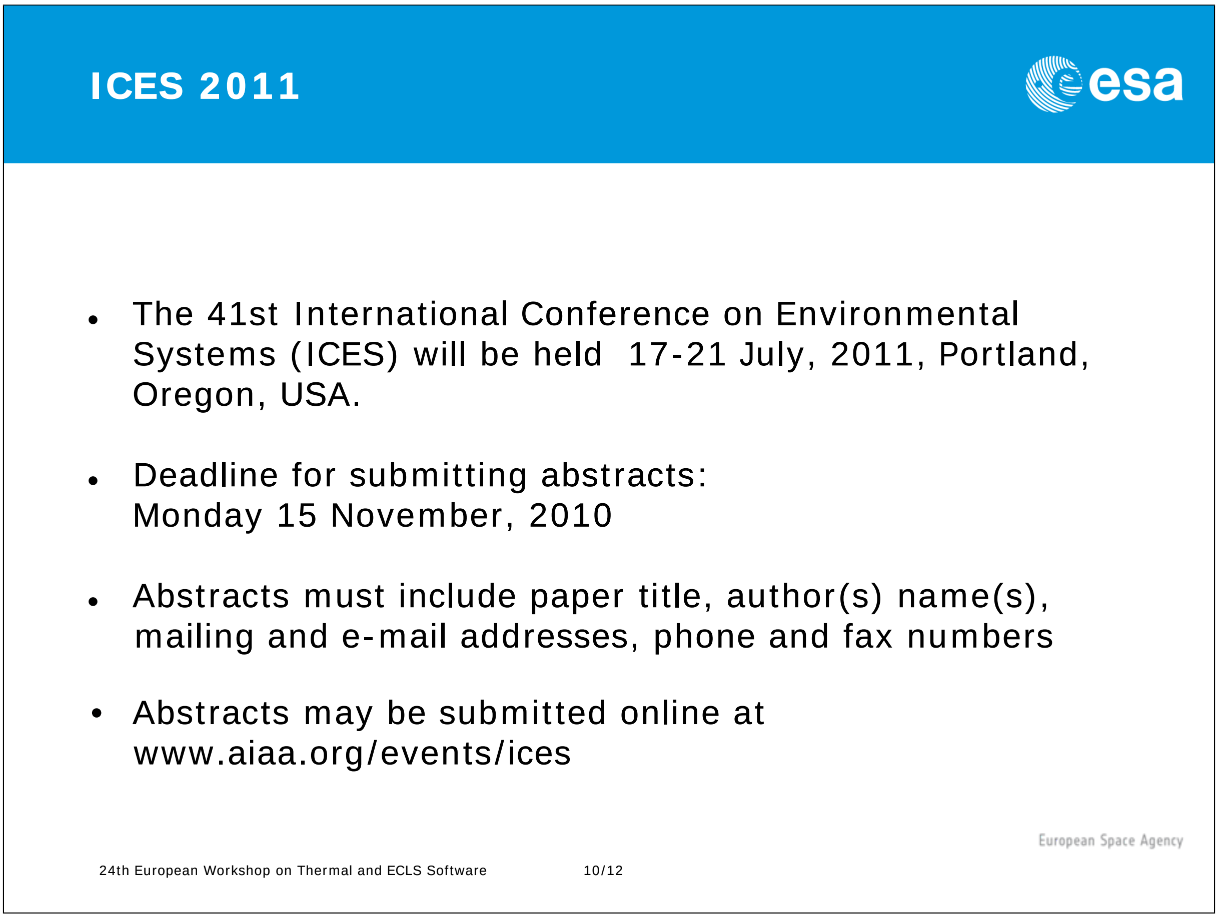
24th European Workshop on Thermal and ECLS Software 7/12

Restaurant “La Galleria”

European Space Agency

24th European Workshop on Thermal and ECLS Software 8/12


Menu
esa
(€ 33,50 p.p. Including 2 drinks)
Thinly sliced raw fillet of beef with Parmesan cheese and rocket salad
or
Salad of tomatoes with buffalo mozzarella cheese and fresh basil
~~~~~~~~~~~~
Grilled fillet of salmon with fresh tomatoes, basil and olive oil
or
Veal with San Daniele ham in a white wine sauce
~~~~~~~~~~~~
Original Sicilian pistachio cake


ICES 2011
esa
• The 41st International Conference on Environmental Systems (ICES) will be held 17-21 July, 2011, Portland, Oregon, USA.
• Deadline for submitting abstracts: Monday 15 November, 2010
• 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
European Space Agency
24th European Workshop on Thermal and ECLS Software
10/12

Appendix B

Presentation, demonstration of new TAS thermal software e-Therm and associated strategy

Thierry Basset   Jean-Paul Dudon   Patrick Hugonnot
(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) and its associated strategy. 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 including videos - sequence of file operations on a science / observation case, a 3D conductive module case (pump) - listing of evolutions and functions created and defining the modularity and compatibility of e-Therm using market tools by directly plug in or data standard exchange STEP-TAS.
Then, we will talk about industrialization strategy especially based on using our thermal software and on the integration of expert tools (2D-3D conductive module, Thermal model reduction tool, friendly pre pro for telecom applications, CORAFILE , modelling / meshing) in order to improve and standardize the analysis process, in order to gain in cost and quality and for better input/output traceability. In the near future, we are going to integrate all other modules (radiative module, solver and all the pre and post-processing modules developed initially for CORATHERM).
In parallel with this 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.
Moreover, it is possibly 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 ...

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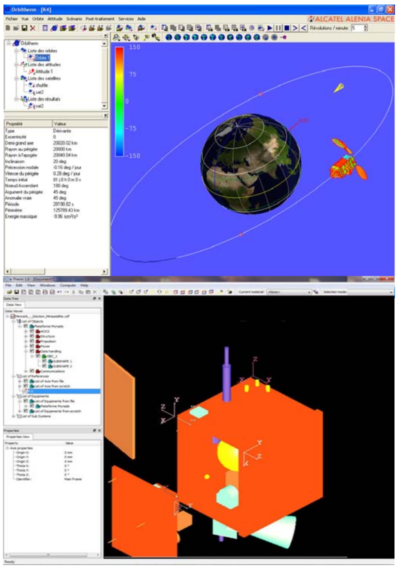
Presentation, Demonstration of new TAS thermal software e-Therm and associated strategy



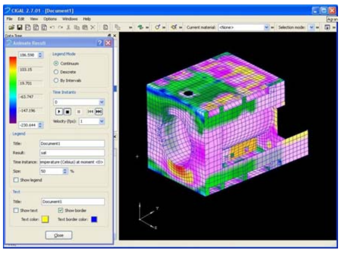
THALES ALENIA SPACE CANNES

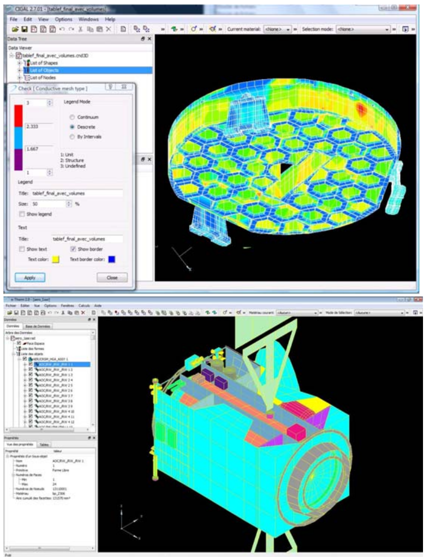
T. BASSET,

J-P. DUDON,

P. HUGONNOT,

F. BRUNETTI (DOREA)





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Schedule

1. **Introduction & objectives: industrialization strategy for expert tools**
2. **List of evolutions and function creation between reference release and e-Therm**
3. **Videos of the e-Therm 2010 release : sequence of file operations on a science / observation case and 3D conductive case (pump)**
4. **Modularity of e-Therm with market tools**
5. **Presentation of e-Therm : Final release (2.0)**
6. **Conclusion**

2

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1. Objectives : industrialization strategy

- **Thermal software strategy focused on CORATHERM using and its industrialisation via e-Therm :**
  - **Improvement of efficiency and performance / Competitiveness**
    - To improve and to standardize the analyse process in order to reduce the cost
    - Reactivity in term of user support and development control
  - **Improvement of quality process : Industrialisation by implementation of expert tools**
    - 2010 : Implementation of conductive tool (PLATEAU 2D-3D/EQUIVALE), TMRT, new post-pro functionalities into CIGAL2 = e-Therm V1.0
    - 2012 : integrate everything into e-Therm : radiative module, solver, all remaining pre and post-processing
    - Better reliability,input / output files traceability and modularity

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1. Objectives : strategy of openness of e-Therm

- **Presentation and free distribution of several of our modules (CIGAL2 pre and post-processing, 2D/3D conductive module), internally and externally (European community) :**
  - **Openness of e-Therm**
    - Investment in the data standard exchange (STEP-TAS)
    - External distribution (workshop 2008 –2009)
    - TAS Internal demonstrations : TAS - Toulouse for antenna applications, TAS - Turin for infrastructures and instruments, Thales Group : Electronic board applications division and electron tubes division, TAS Thermal Software Workshop 2010
  - **Principles :**
    - TAS owns the sources with maintenance ensured & funded (as agreed with the NESTA group) by :
      - TAS Cannes for corrective maintenance
      - Different customers for specific needs (adaptive and evolutive maintenance)
      - The agencies for more general needs (evolutive maintenance) : e.g. STEP standard exchange

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2. List of evolutions between initial release and e-Therm V1.0 (2010)

- **New functions of the model/mesh generator :**
  - Harmonization of primitives
  - Harmonization of material files (conductive)
  - Cross-section axes and planes in the model tree
  - Added the selection mode (cross-section plane and cross-section plane + mesh)
  - Radiative model management aids
  - In conductive session, distance calculation between elements, rotation function, rule implementation
  - Integrated heat pipe processing
- **Integration of thermal model reduction tool (TMRT) into e-Therm**
- **Integration of friendly pre pro for telecom applications into e-Therm**
  - Graphic construction of fully interactive model
  - Reading inputs issued from CAD (equipment, heat pipe)
- **Integration of 2D/3D conductive module into e-Therm**
  - Implementation of volumic mesh generator
  - Finite elements / TLP hybrid method processing for 3D conductive
- **Integration of interfaces with the market tools using the new exchange standard STEP-TAS V.6.0 (ESA funding via IITAS)**

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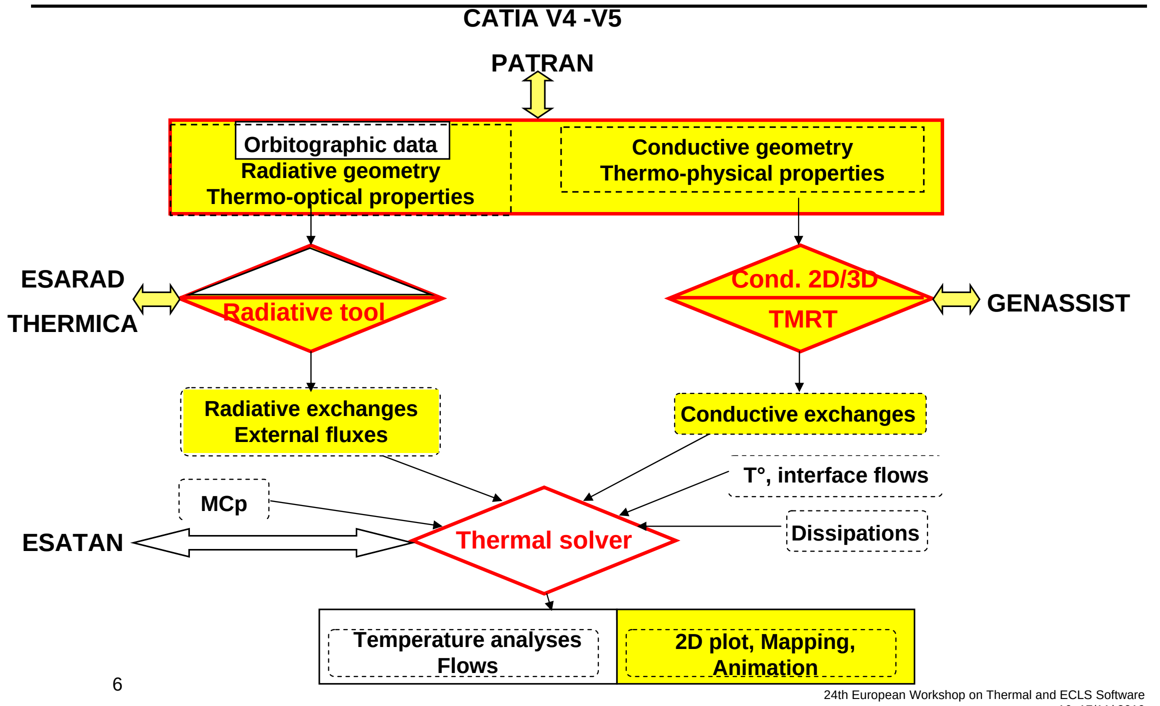
2. Overview of e-Therm 1.0



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3. Video of e-Therm (2010): sequence of file operations on a science & observation case & 3D conductive case (pump)

7

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4. Modularity of e-Therm with market tools

- **Modularity & compatibility**
  - **with ESATAN (via plug-in) : presented during Workshop 2009, the video showed the substitution of the internal TAS solver by ESATAN**
  - **with ESARAD (via plug-in) : see previous video on science & observation case**
  - **with THERMICA : to be done**

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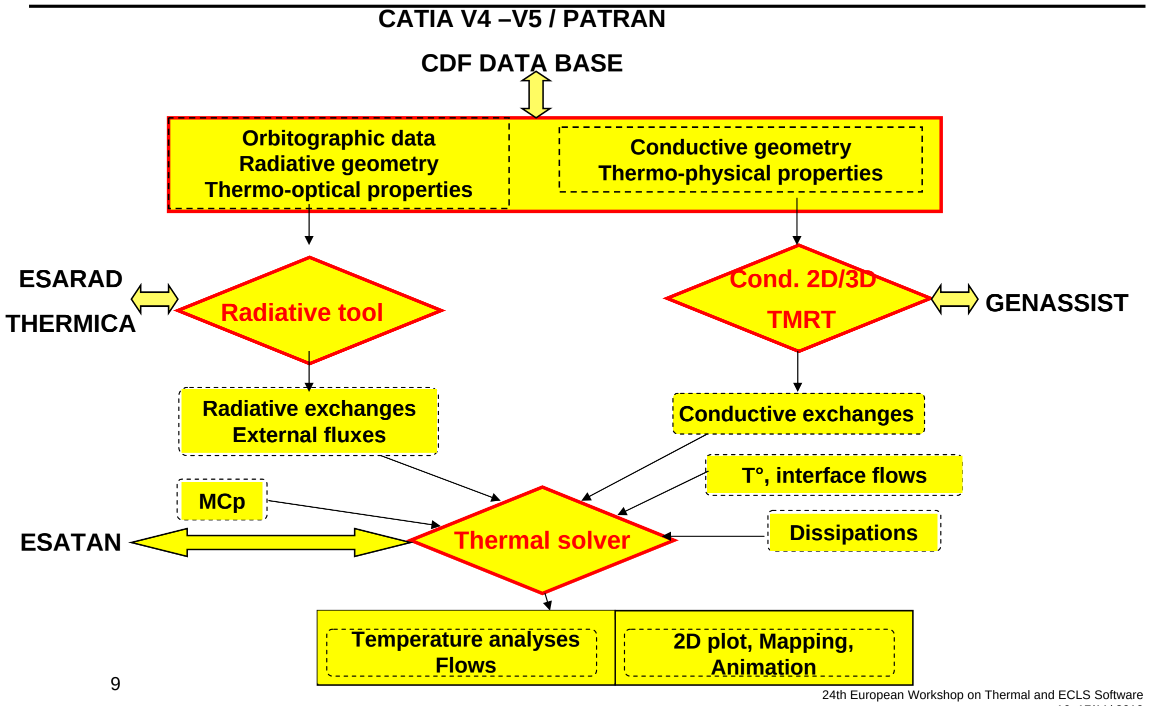
5. Presentation of e-Therm : Final release (2.0)



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6. Conclusion :

- **New e-Therm software available for free distribution :**
  - **contact = thierry.basset@thalesaleniaspace.com**
- **Principles : recall**
  - TAS owns the sources with maintenance ensured & funded (as agreed with the NESTA group) by :
    - TAS Cannes for corrective maintenance
    - Different customers for specific needs (adaptive and evolutive maintenance)
    - The agencies for more general needs (evolutive maintenance) : e.g. STEP standard exchange
- **Final release of e-Therm will be available on 2012**
- **Extension to other fields in physics**
- **ESA solicited for follow-on of STEP-TAS activities (GMM & TMM) : to be discussed during NESTA meeting ?**

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Appendix C

Exchange of Thermal Model Algorithms via STEP-TAS

Alain Fagot
(DOREA, France)

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

Abstract

In this presentation the next evolution of the exchange of thermal analysis models for space via STEP-TAS will be explained.
Apart from representing the pure passive thermal behaviour, space thermal analysis models have from the beginning (in the 60's) supported modeling of active behaviour, e.g.:

- thermostat or PID controlled heaters
- fluid lines
- Peltier elements
- thermal switches

and complex non-linear behaviour like temperature or pressure dependent material properties, interaction with hydraulic system elements and phase change in materials.
This was implemented in tools like ESATAN and SINDA through so-called user-defined logic blocks in a dedicated language called "MORTRAN", an extension of FORTRAN77. In order to fully exchange such thermal models TMMverter is developed, where TMM stands for Thermal Mathematical Model, the common name used for ESATAN and SINDA like thermal models. TMMverter is an extension of the existing TASverter tool. The first version will address the full exchange of thermal models between ESATAN and SINDA.
In order to achieve this complex task, a number of different data processing technologies and data exchange standards are combined:

- The ESATAN and SINDA model definition files are parsed using the ANTLR lexer/parser open source software.
- The structural parts of the models are converted into traditional STEP-TAS EXPRESS based data structures and .stp files, using a Python SDK generated with the Expressik tool.
- The user-defined logic (i.e. algorithmic) parts of the models are converted to a prefix mathematical language expressed in JSON (JavaScript Object Notation) and embedded into EXPRESS instances in the STEP-TAS .stp file.

This allows mapping from and back to the FORTRAN-based ESATAN and SINDA languages with minimal loss of information. The presentation will show how this approach could be beneficially used in many other applications.


DOREA TECHNOLOGY
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Mechanical Engineering Department
Thermal and Structures Division
24th European Workshop on Thermal & ECLS Software
ESA/ESTEC, 16-17 November 2010
TMMverter
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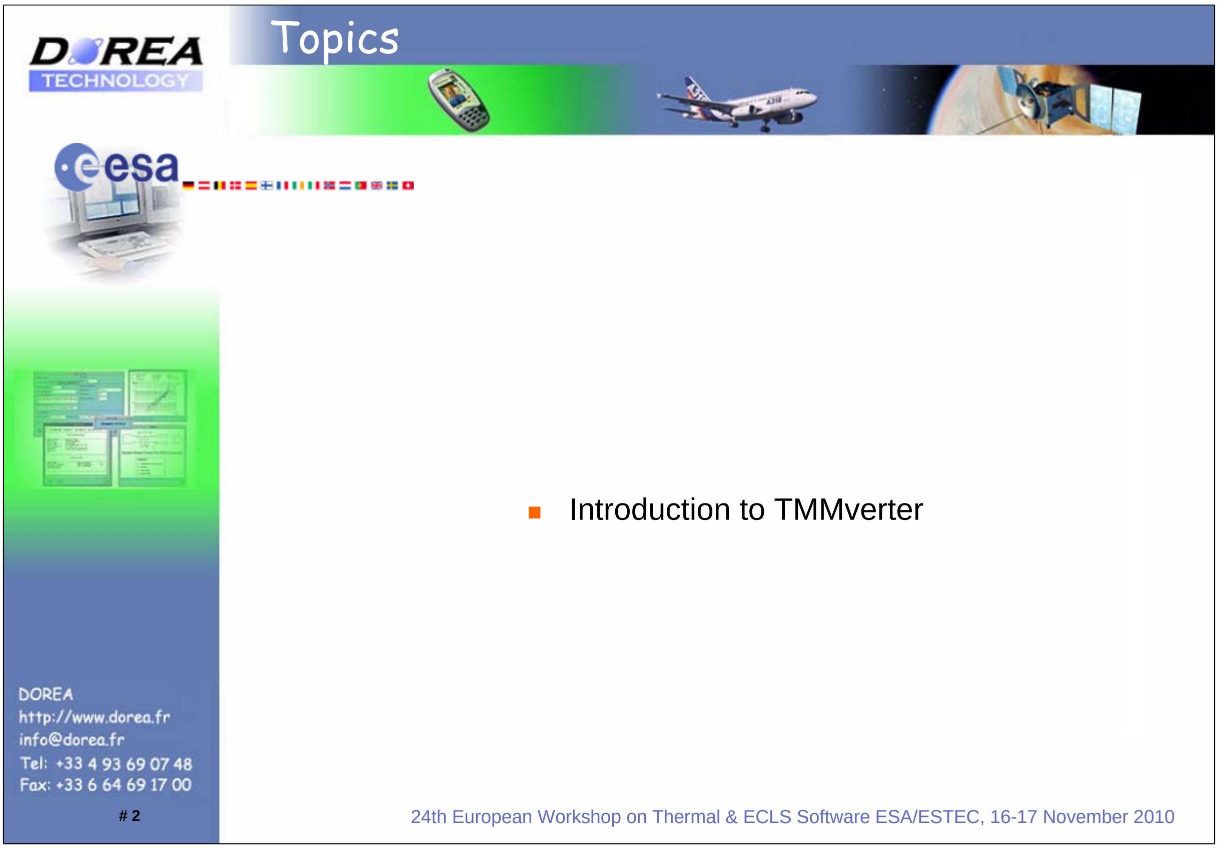
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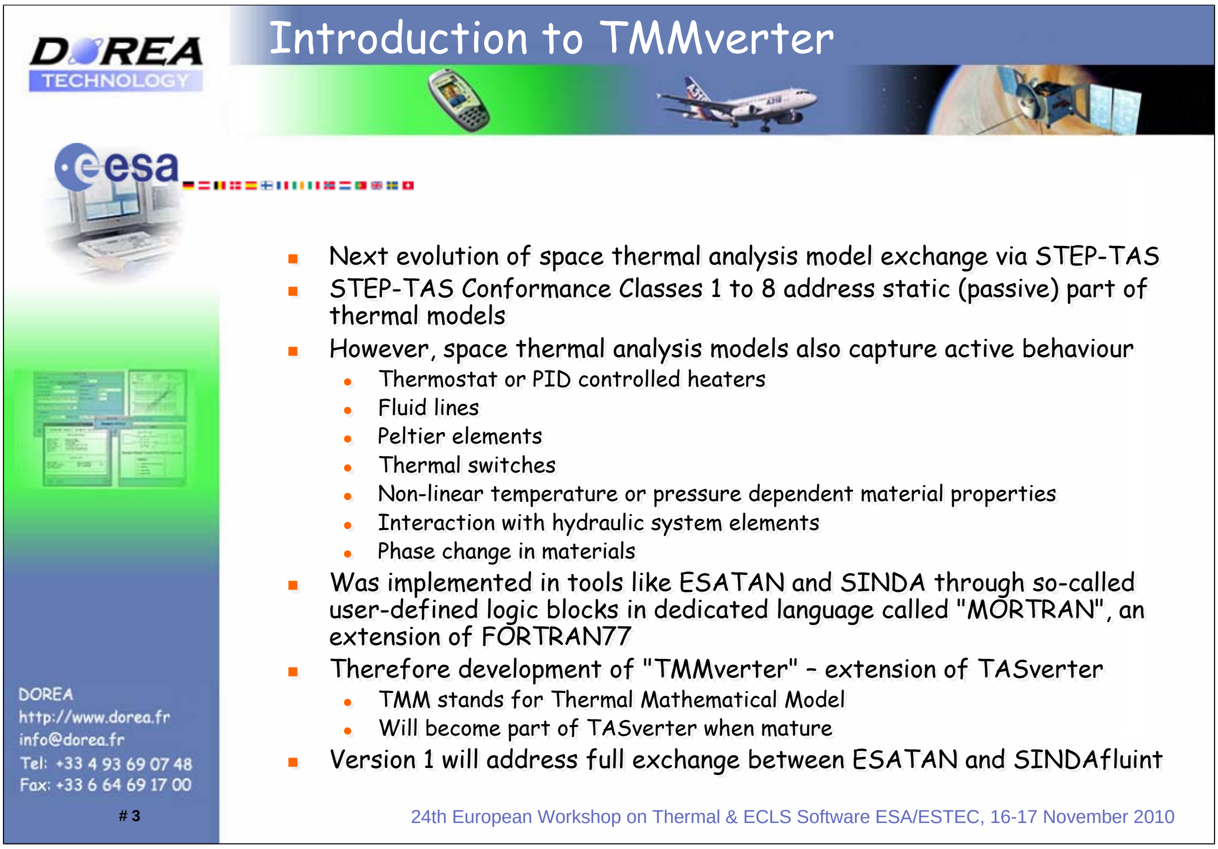
Introduction to TMMverter
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Next evolution of space thermal analysis model exchange via STEP-TAS
STEP-TAS Conformance Classes 1 to 8 address static (passive) part of thermal models
However, space thermal analysis models also capture active behaviour
Thermostat or PID controlled heaters
Fluid lines
Peltier elements
Thermal switches
Non-linear temperature or pressure dependent material properties
Interaction with hydraulic system elements
Phase change in materials
Was implemented in tools like ESATAN and SINDA through so-called user-defined logic blocks in dedicated language called "MORTRAN", an extension of FORTRAN77
Therefore development of "TMMverter" – extension of TASverter
TMM stands for Thermal Mathematical Model
Will become part of TASverter when mature
Version 1 will address full exchange between ESATAN and SINDAfluint
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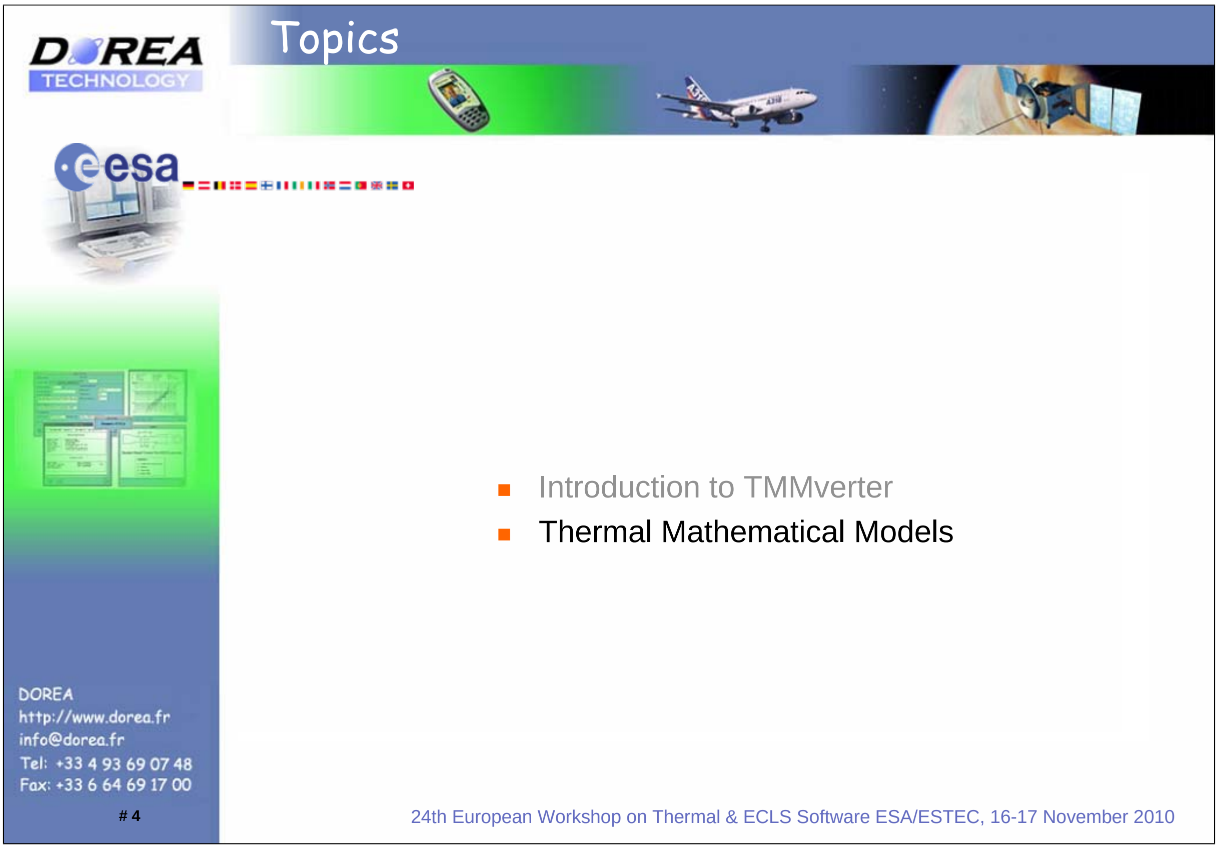
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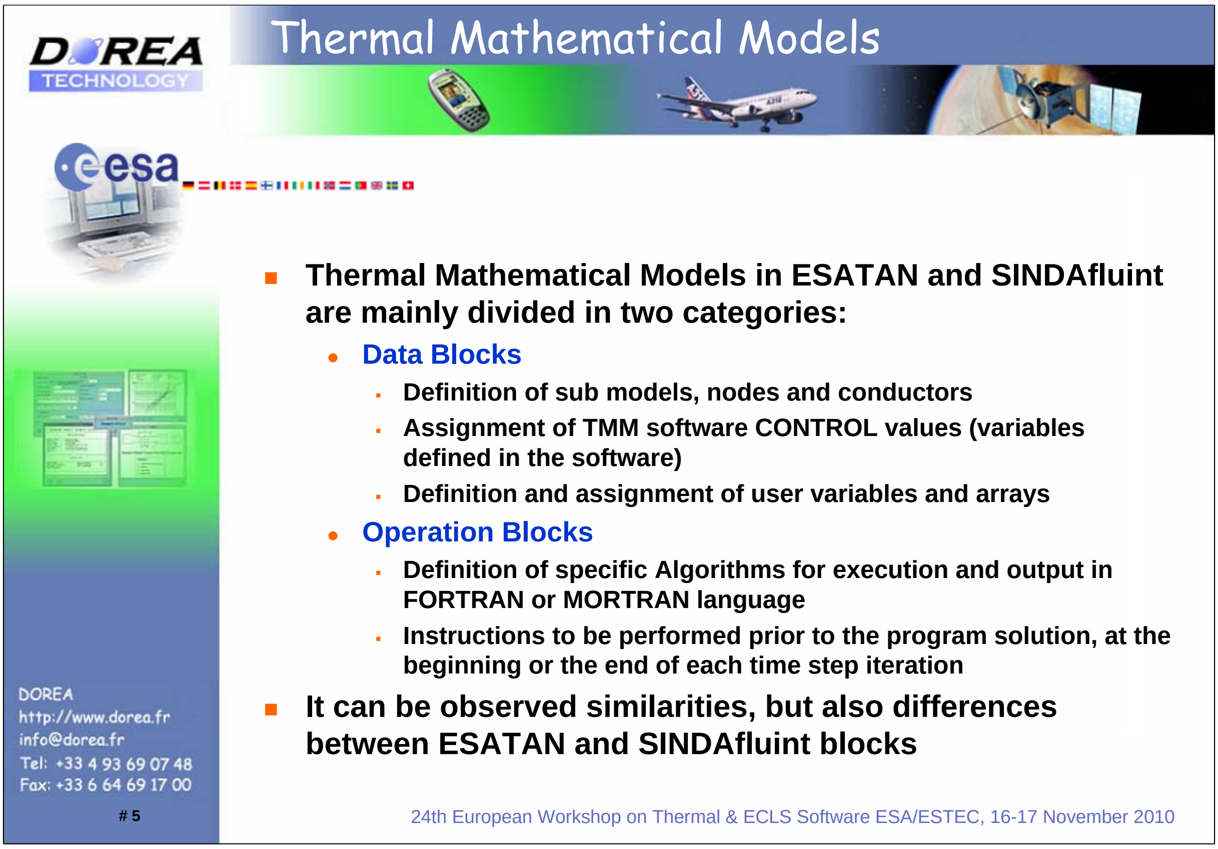
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Thermal Mathematical Models
Thermal Mathematical Models in ESATAN and SINDAfluint are mainly divided in two categories:
Data Blocks
Definition of sub models, nodes and conductors
Assignment of TMM software CONTROL values (variables defined in the software)
Definition and assignment of user variables and arrays
Operation Blocks
Definition of specific Algorithms for execution and output in FORTRAN or MORTRAN language
Instructions to be performed prior to the program solution, at the beginning or the end of each time step iteration
It can be observed similarities, but also differences between ESATAN and SINDAfluint blocks
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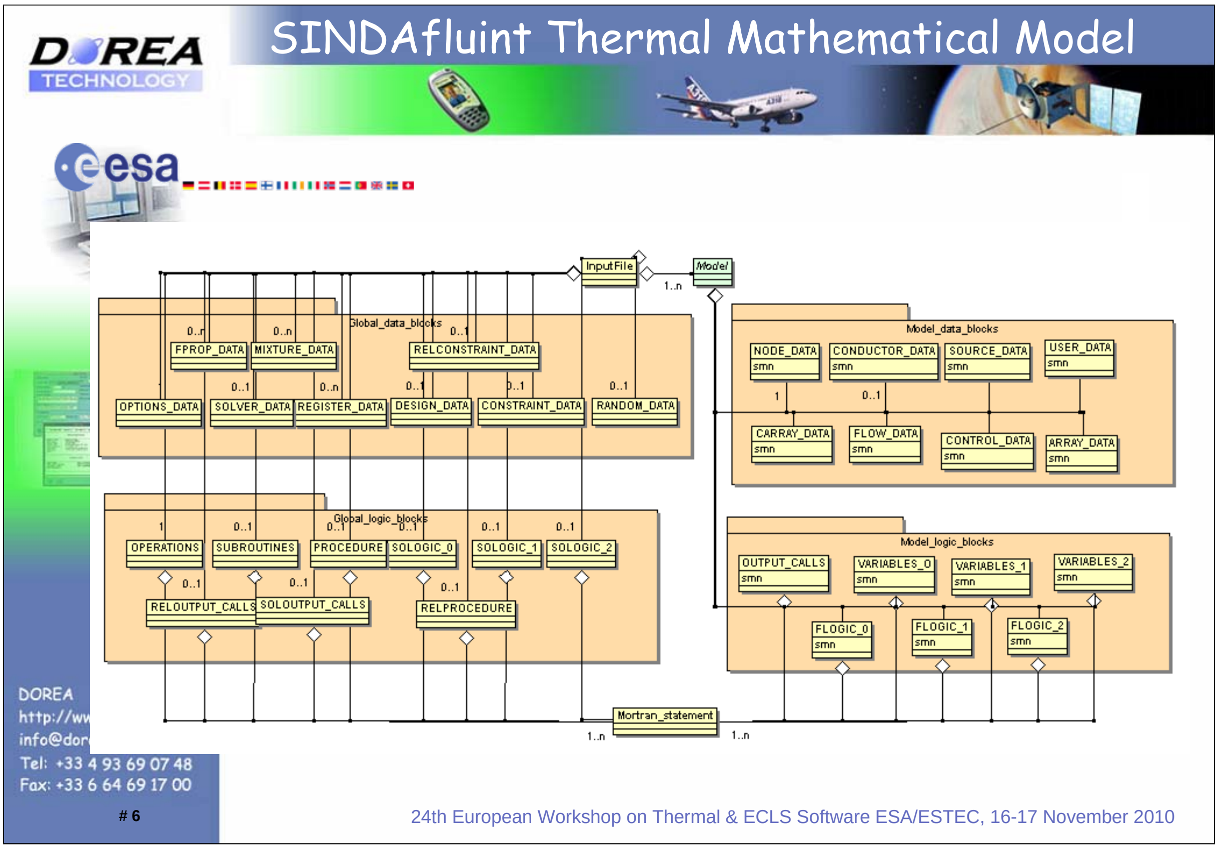
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SINDAfluint Thermal Mathematical Model
InputFile
Model
Global_data_blocks
FPROP_DATA
MIXTURE_DATA
RELCONSTRAINT_DATA
OPTIONS_DATA
SOLVER_DATA
REGISTER_DATA
DESIGN_DATA
CONSTRAINT_DATA
RANDOM_DATA
Model_data_blocks
NODE_DATA
CONDUCTOR_DATA
SOURCE_DATA
USER_DATA
CARRAY_DATA
FLOW_DATA
CONTROL_DATA
ARRAY_DATA
Global_logic_blocks
OPERATIONS
SUBROUTINES
PROCEDURE
SOLOGIC_0
SOLOGIC_1
SOLOGIC_2
RELOUTPUT_CALLS
SOLOUTPUT_CALLS
RELPROCEDURE
Model_logic_blocks
OUTPUT_CALLS
VARIABLES_0
VARIABLES_1
VARIABLES_2
FLOGIC_0
FLOGIC_1
FLOGIC_2
Mortran_statement
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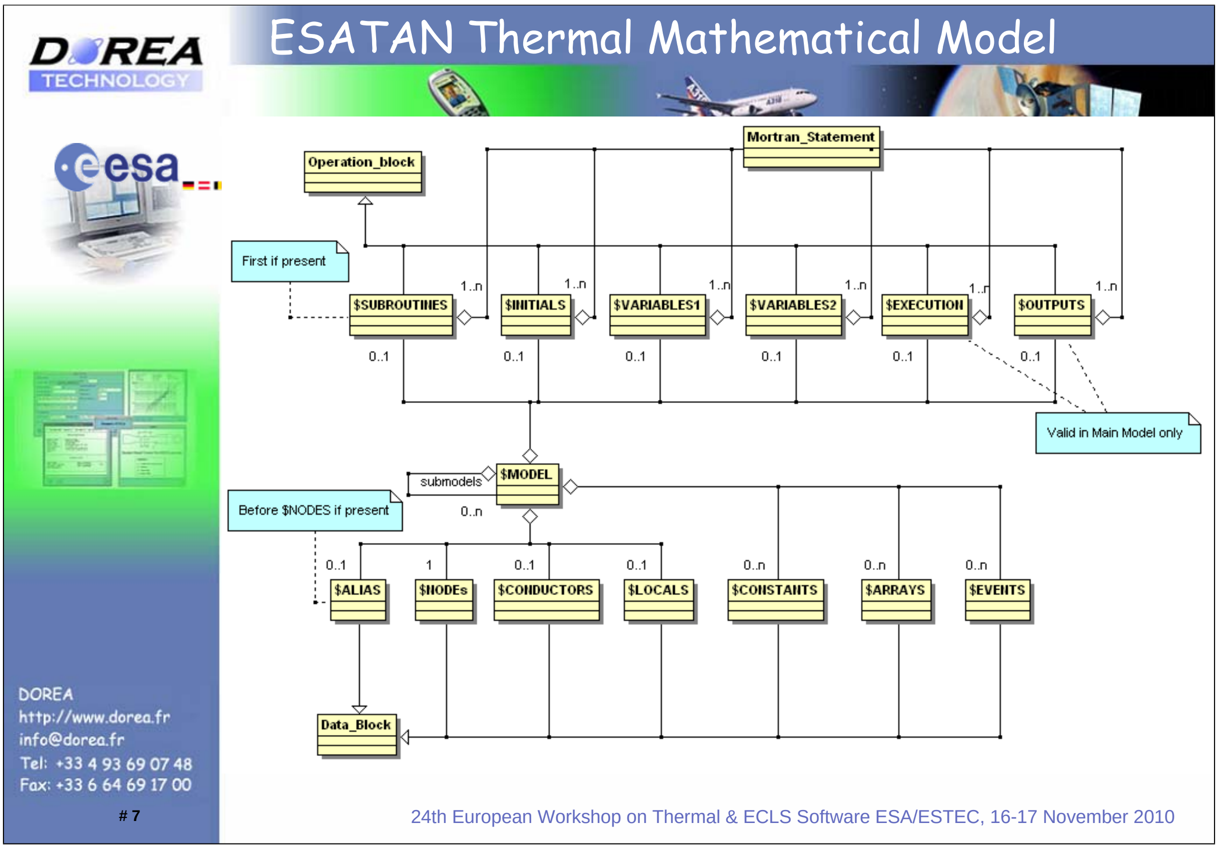
ESATAN Thermal Mathematical Model
DOREA TECHNOLOGY
esa
Operation_block
Mortran_Statement
First if present
$SUBROUTINES
$INITIALS
$VARIABLES1
$VARIABLES2
$EXECUTION
$OUTPUTS
Valid in Main Model only
submodels
$MODEL
Before $NODES if present
$ALIAS
$NODES
$CONDUCTORS
$LOCALS
$CONSTANTS
$ARRAYS
$EVENTS
Data_Block
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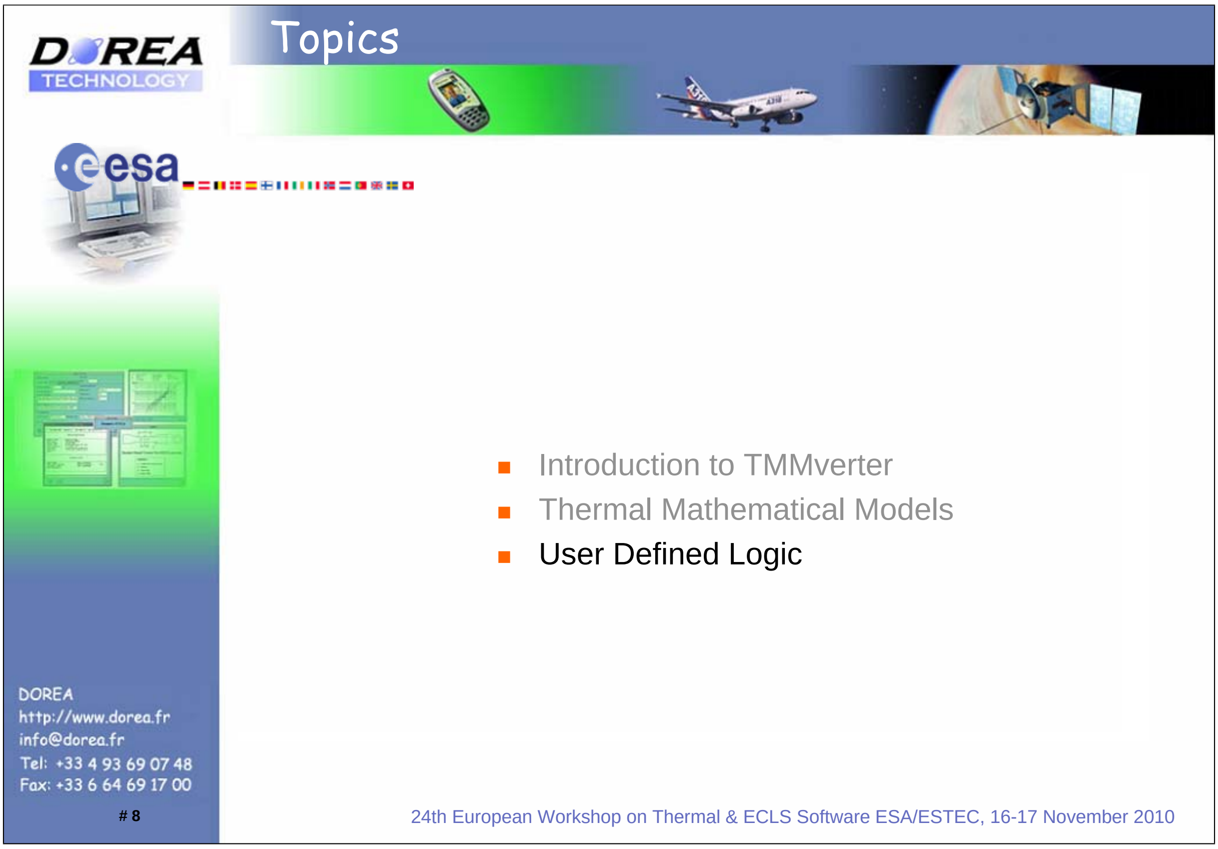
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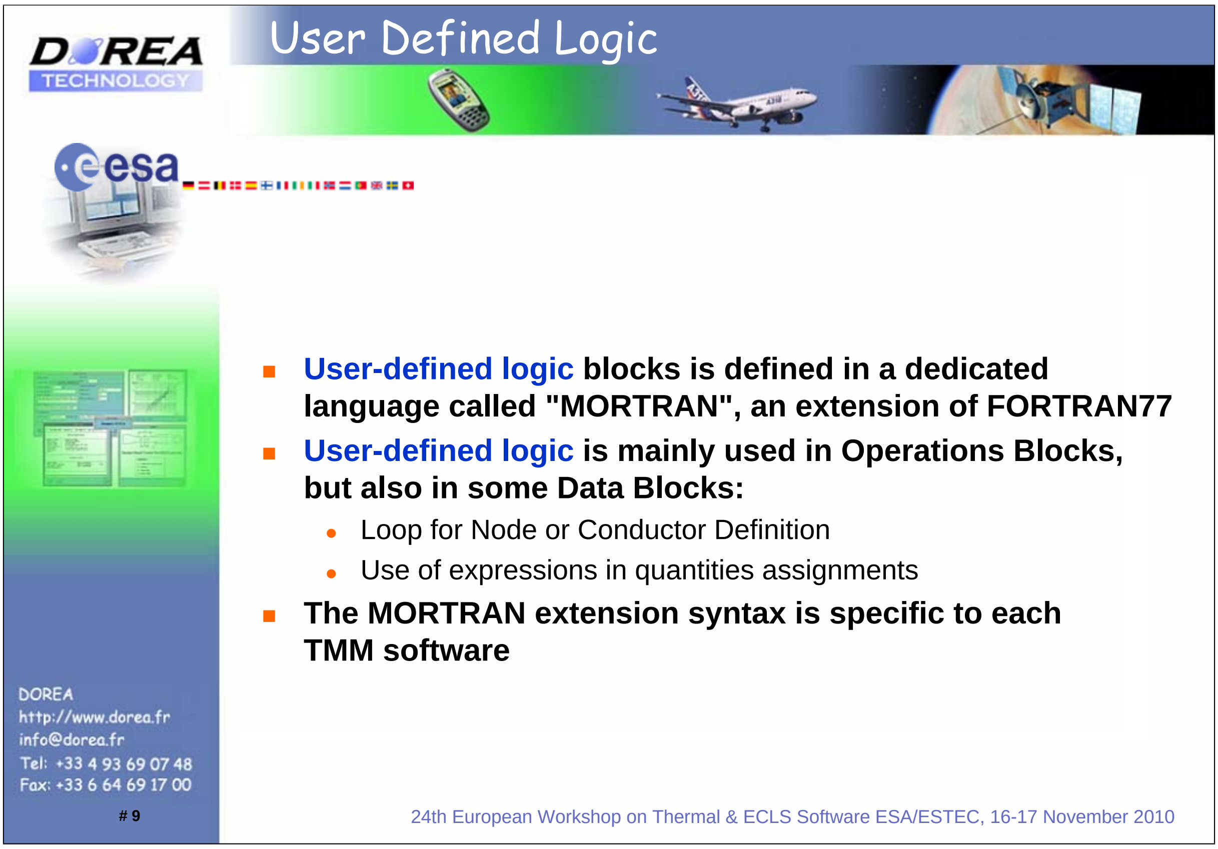
User Defined Logic
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User-defined logic blocks is defined in a dedicated language called "MORTRAN", an extension of FORTRAN77
User-defined logic is mainly used in Operations Blocks, but also in some Data Blocks:
Loop for Node or Conductor Definition
Use of expressions in quantities assignments
The MORTRAN extension syntax is specific to each TMM software
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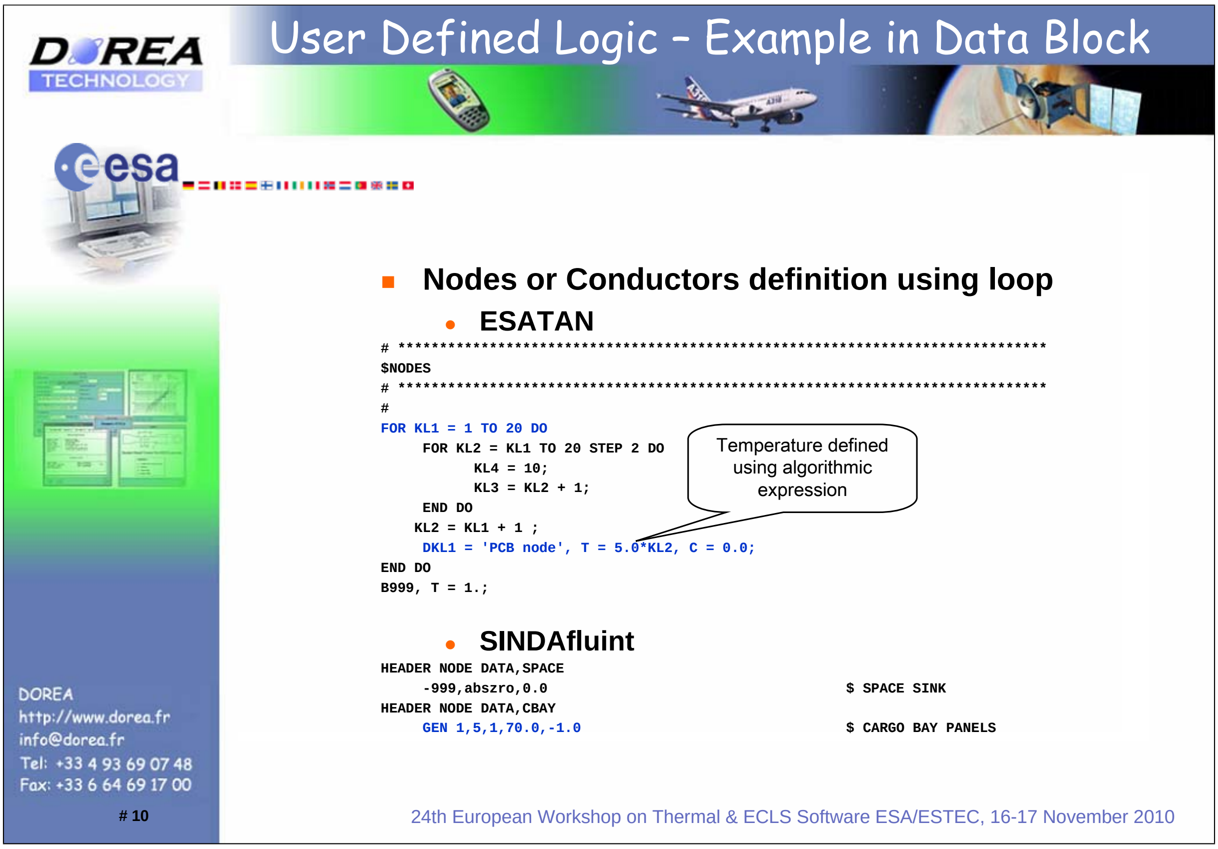
User Defined Logic – Example in Data Block
DOREA TECHNOLOGY
esa
Nodes or Conductors definition using loop
ESATAN
**
$NODES
**
#
FOR KL1 = 1 TO 20 DO
FOR KL2 = KL1 TO 20 STEP 2 DO
KL4 = 10;
KL3 = KL2 + 1;
END DO
KL2 = KL1 + 1 ;
DKL1 = 'PCB node', T = 5.0*KL2, C = 0.0;
END DO
B999, T = 1.;
Temperature defined using algorithmic expression
SINDAfluint
HEADER NODE DATA,SPACE
-999,abszro,0.0
$ SPACE SINK
HEADER NODE DATA,CBAY
GEN 1,5,1,70.0,-1.0
$ CARGO BAY PANELS
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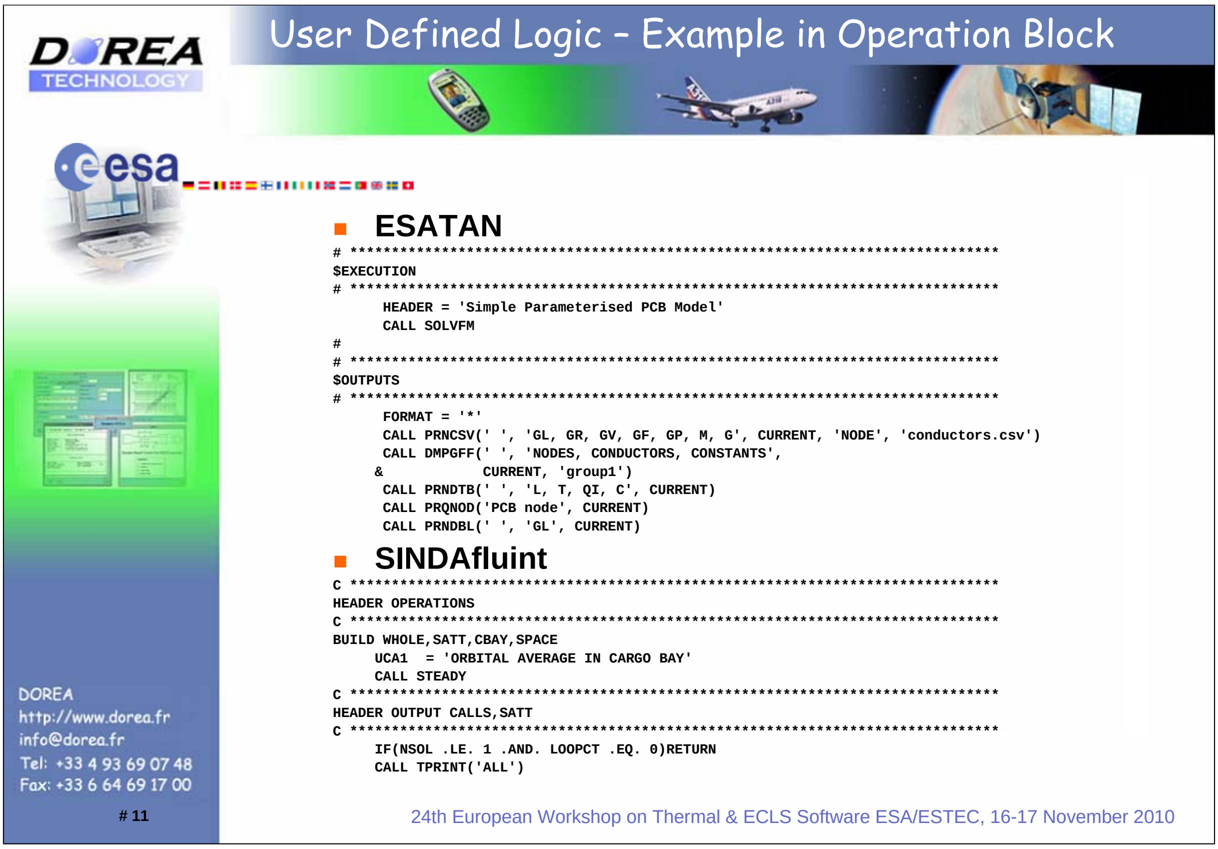
User Defined Logic – Example in Operation Block
DOREA TECHNOLOGY
esa
ESATAN
**
$EXECUTION
# **
HEADER = 'Simple Parameterised PCB Model'
CALL SOLVFM
#
**
$OUTPUTS
# **
FORMAT = '*'
CALL PRNCSV(' ', 'GL, GR, GV, GF, GP, M, G', CURRENT, 'NODE', 'conductors.csv')
CALL DMPGFF(' ', 'NODES, CONDUCTORS, CONSTANTS',
& CURRENT, 'group1')
CALL PRNDTB(' ', 'L, T, QI, C', CURRENT)
CALL PRQNOD('PCB node', CURRENT)
CALL PRNDBL(' ', 'GL', CURRENT)
SINDAfluint
C **
HEADER OPERATIONS
C **
BUILD WHOLE,SATT,CBAY,SPACE
UCA1 = 'ORBITAL AVERAGE IN CARGO BAY'
CALL STEADY
C **
HEADER OUTPUT CALLS,SATT
C **
IF(NSOL .LE. 1 .AND. LOOPCT .EQ. 0)RETURN
CALL TPRINT('ALL')
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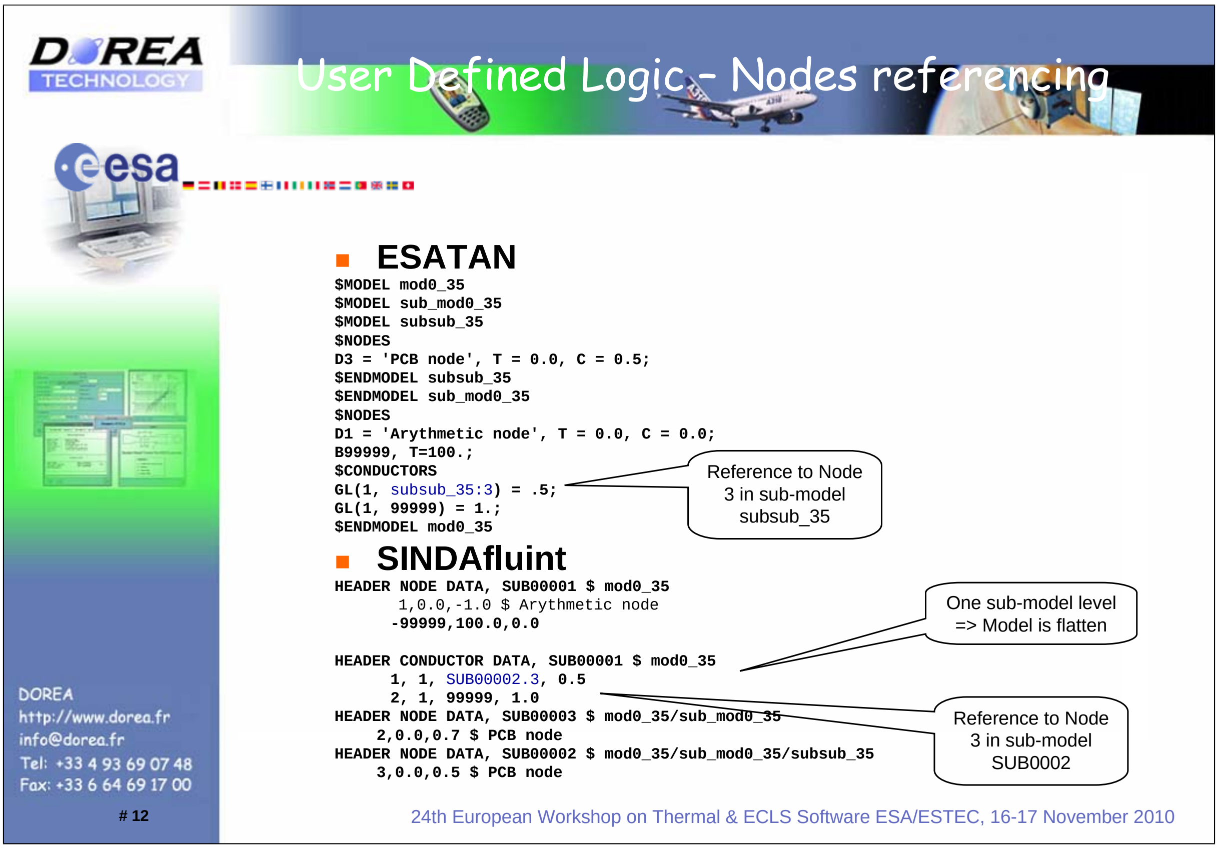
User Defined Logic – Nodes referencing
DOREA TECHNOLOGY
esa
ESATAN
$MODEL mod0_35
$MODEL sub_mod0_35
$MODEL subsub_35
$NODES
D3 = 'PCB node', T = 0.0, C = 0.5;
$ENDMODEL subsub_35
$ENDMODEL sub_mod0_35
$NODES
D1 = 'Arythmetic node', T = 0.0, C = 0.0;
B99999, T=100.;
$CONDUCTORS
GL(1, subsub_35:3) = .5;
GL(1, 99999) = 1.;
$ENDMODEL mod0_35
Reference to Node 3 in sub-model subsub_35
SINDAfluint
HEADER NODE DATA, SUB00001 $ mod0_35
1,0.0,-1.0 $ Arythmetic node
-99999,100.0,0.0
HEADER CONDUCTOR DATA, SUB00001 $ mod0_35
1, 1, SUB00002.3, 0.5
2, 1, 99999, 1.0
HEADER NODE DATA, SUB00003 $ mod0_35/sub_mod0_35
2,0.0,0.7 $ PCB node
HEADER NODE DATA, SUB00002 $ mod0_35/sub_mod0_35/subsub_35
3,0.0,0.5 $ PCB node
One sub-model level => Model is flatten
Reference to Node 3 in sub-model SUB0002
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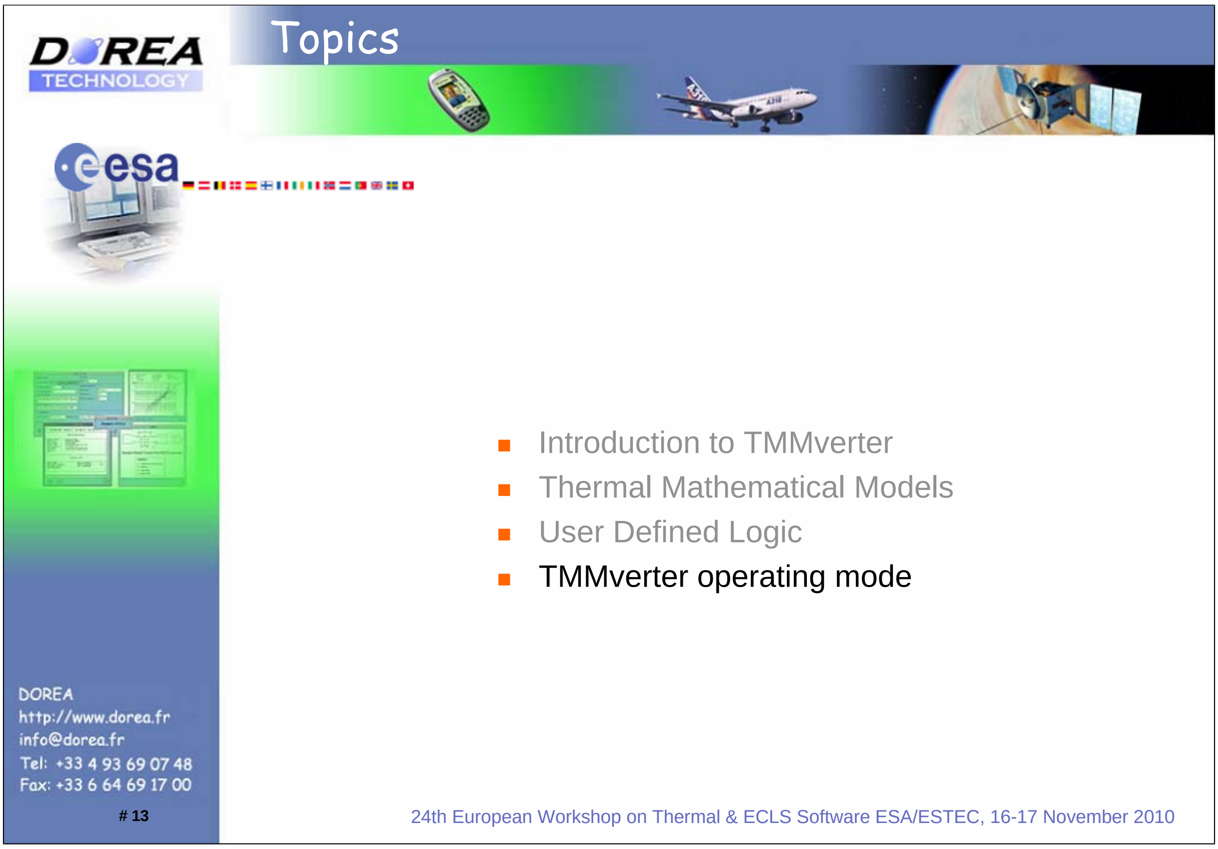
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User Defined Logic
TMMverter operating mode
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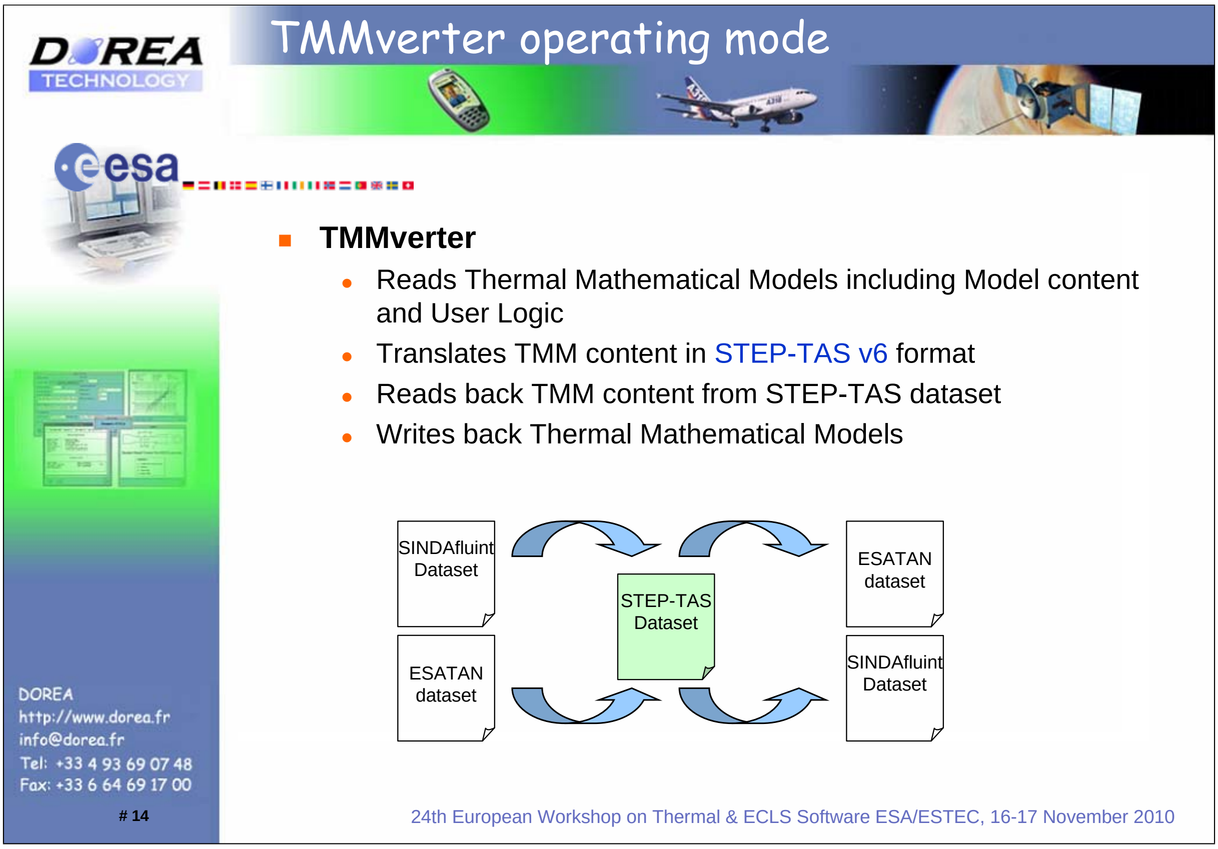
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TMMverter operating mode
TMMverter
Reads Thermal Mathematical Models including Model content and User Logic
Translates TMM content in STEP-TAS v6 format
Reads back TMM content from STEP-TAS dataset
Writes back Thermal Mathematical Models
SINDAfluint Dataset
ESATAN dataset
STEP-TAS Dataset
ESATAN dataset
SINDAfluint Dataset
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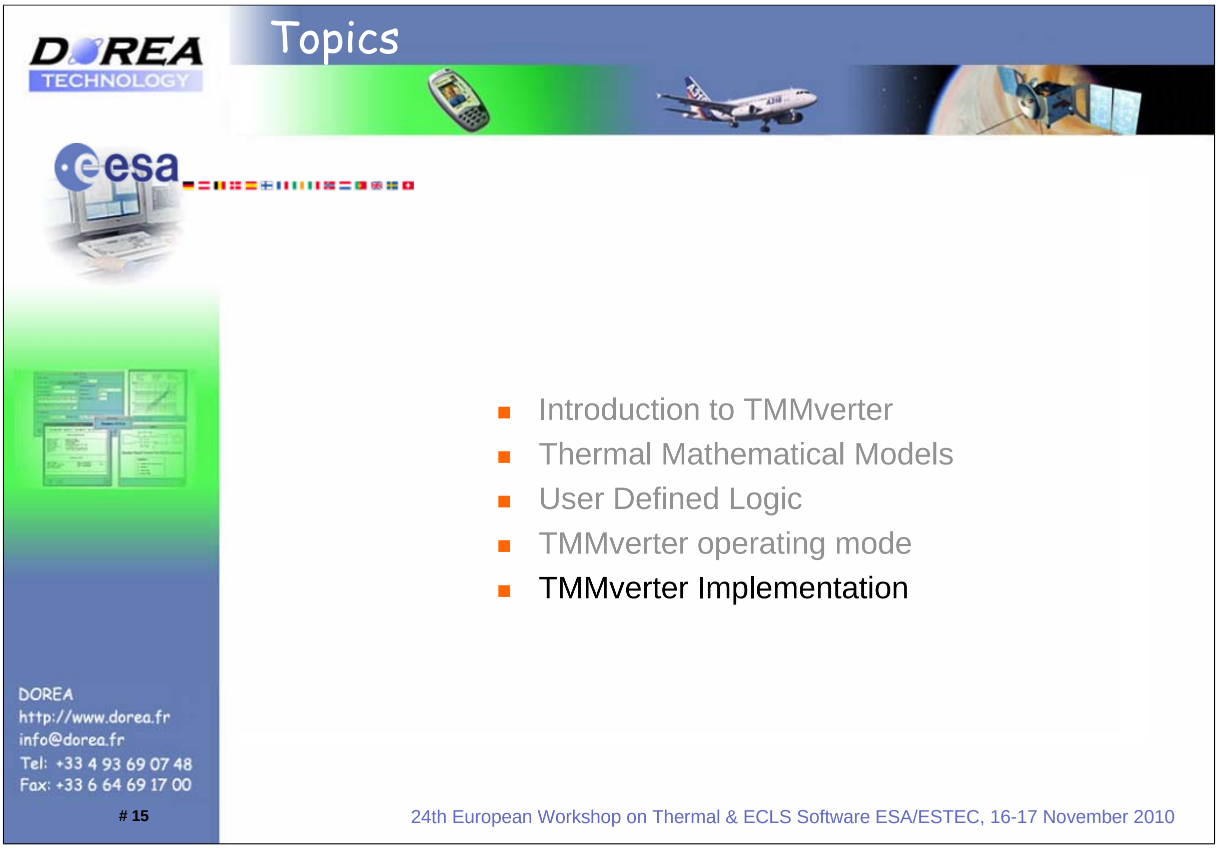
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TMMverter Implementation
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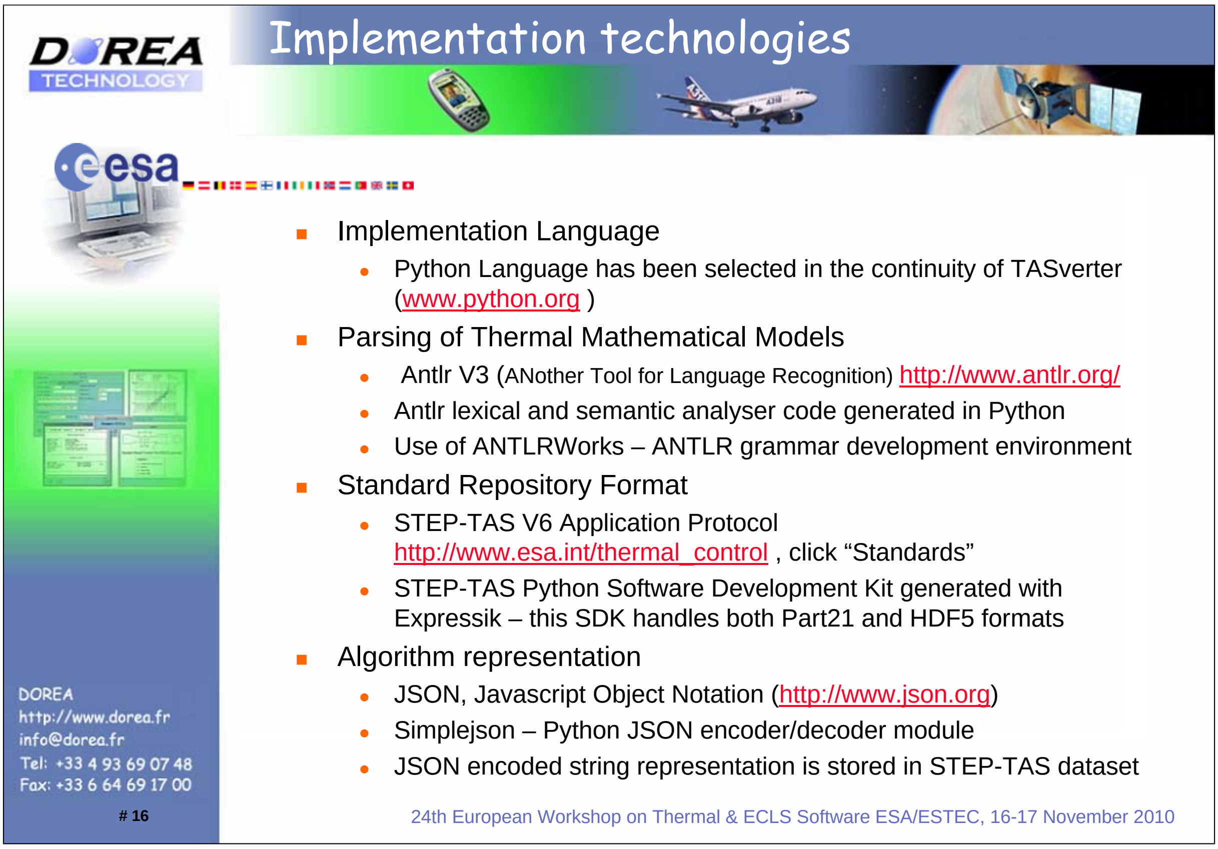
Implementation technologies
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Implementation Language
Python Language has been selected in the continuity of TASverter (www.python.org)
Parsing of Thermal Mathematical Models
Antlr V3 (ANother Tool for Language Recognition) http://www.antlr.org/
Antlr lexical and semantic analyser code generated in Python
Use of ANTLRWorks – ANTLR grammar development environment
Standard Repository Format
STEP-TAS V6 Application Protocol
http://www.esa.int/thermal_control , click “Standards”
STEP-TAS Python Software Development Kit generated with Expressik – this SDK handles both Part21 and HDF5 formats
Algorithm representation
JSON, Javascript Object Notation (http://www.json.org)
Simplejson – Python JSON encoder/decoder module
JSON encoded string representation is stored in STEP-TAS dataset
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General Architecture

- TMMverter architecture is organised around an Abstract Syntax Tree Model (AST)
  - The AST contains Class definitions of a common representation of TMM content (Blocks, Models, Nodes, Conductors, Mortran Statements, …).
  - The AST is a Run-time memory representation
- Thermal Mathematical Models are parsed with Antlr (lexical and semantic analysis)
  - The Antlr grammars populate the AST Model
- A Set of Visitor Design Patterns have been implemented on AST Model
  - TAS writer visitor
  - ESATAN writer visitor
  - SINDAfluint visitor
  - JSON visitor (generates JSON encoded string to write in STEP-TAS).

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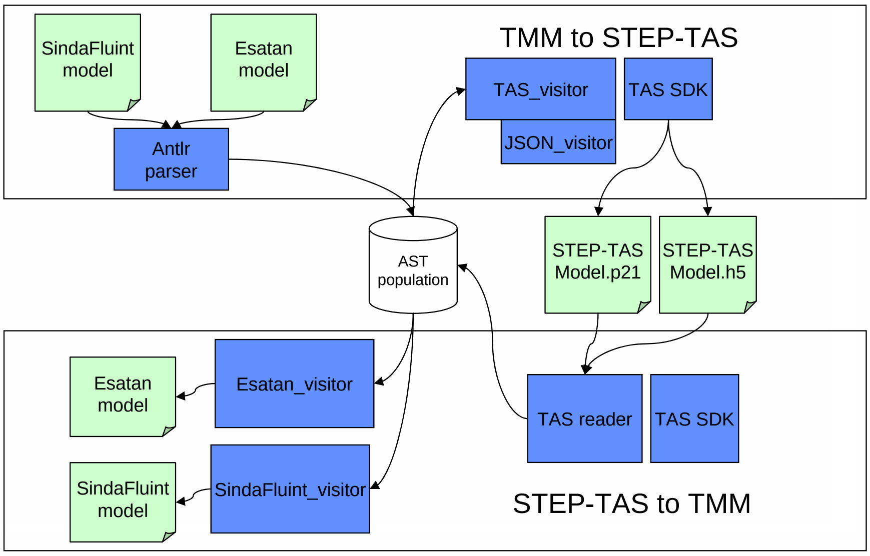
General Architecture #2



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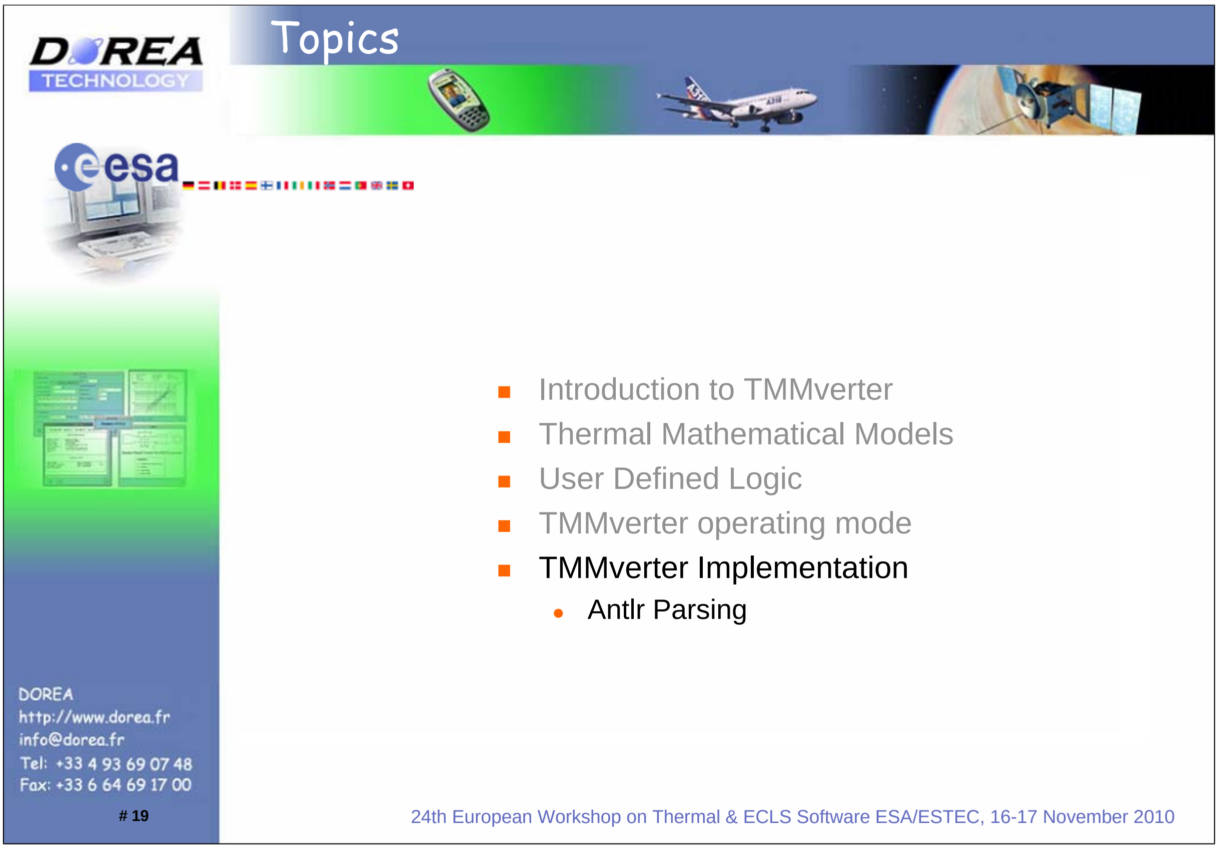
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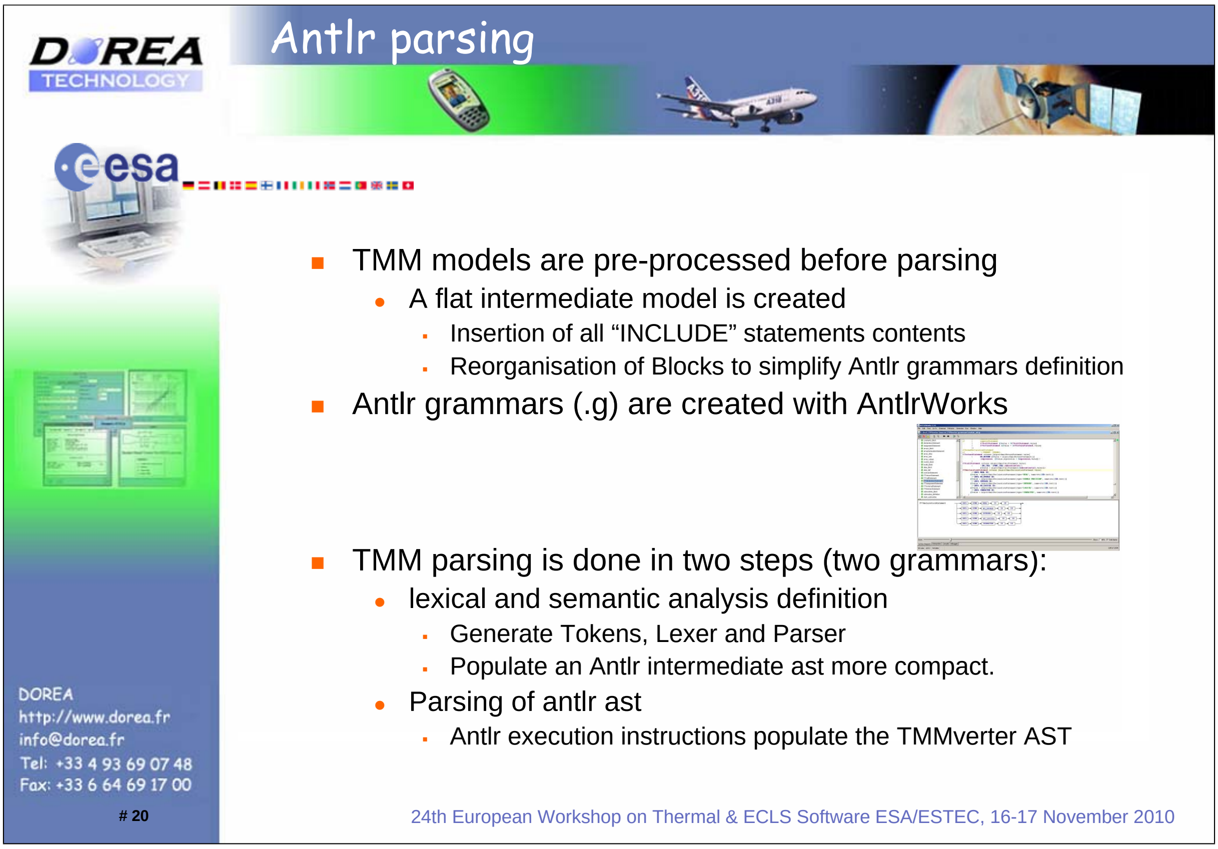
Antlr parsing
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TMM models are pre-processed before parsing
A flat intermediate model is created
Insertion of all “INCLUDE” statements contents
Reorganisation of Blocks to simplify Antlr grammars definition
Antlr grammars (.g) are created with AntlrWorks
TMM parsing is done in two steps (two grammars):
lexical and semantic analysis definition
Generate Tokens, Lexer and Parser
Populate an Antlr intermediate ast more compact.
Parsing of antlr ast
Antlr execution instructions populate the TMMverter AST
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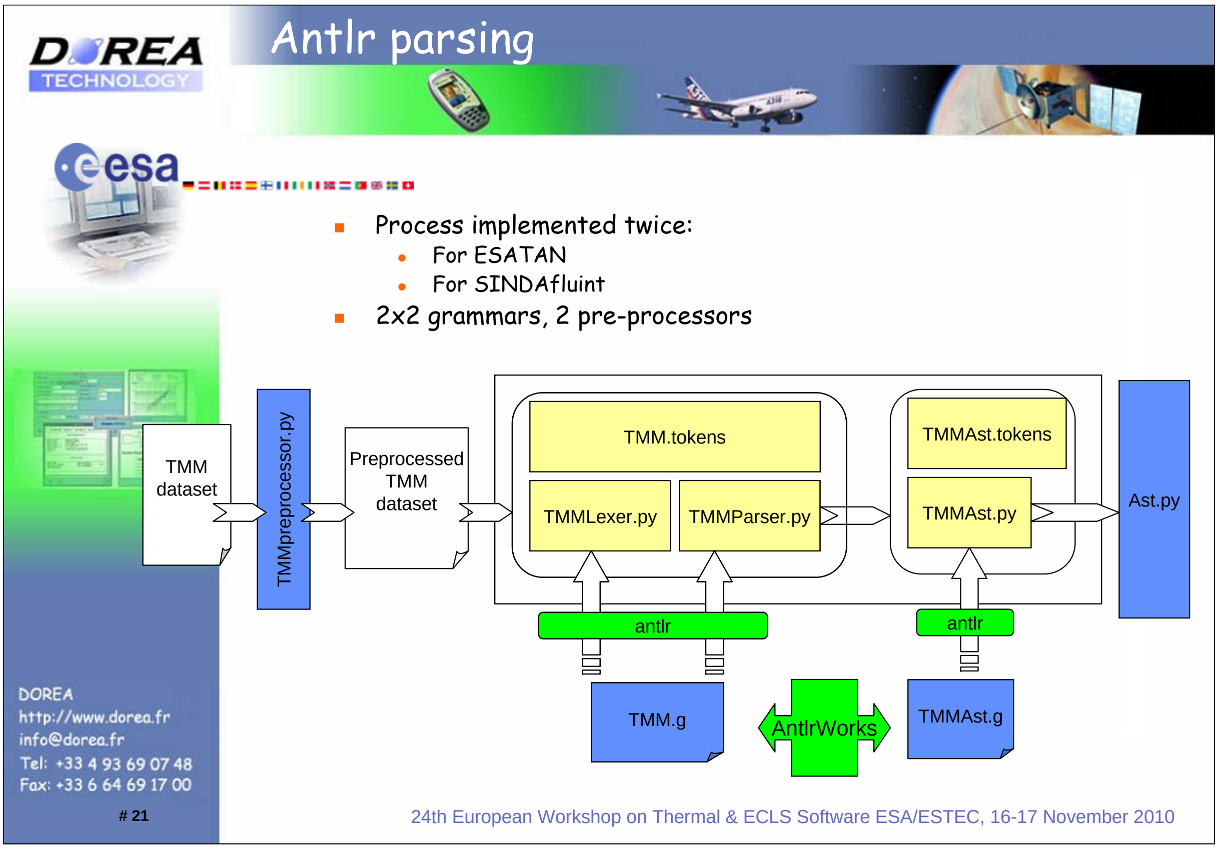
Antlr parsing
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Process implemented twice:
For ESATAN
For SINDAfluint
2x2 grammars, 2 pre-processors
TMM dataset
TMMpreprocessor.py
Preprocessed TMM dataset
TMM.tokens
TMMLexer.py
TMMParser.py
TMMAst.tokens
TMMAst.py
Ast.py
antlr
antlr
TMM.g
AntlrWorks
TMMAst.g
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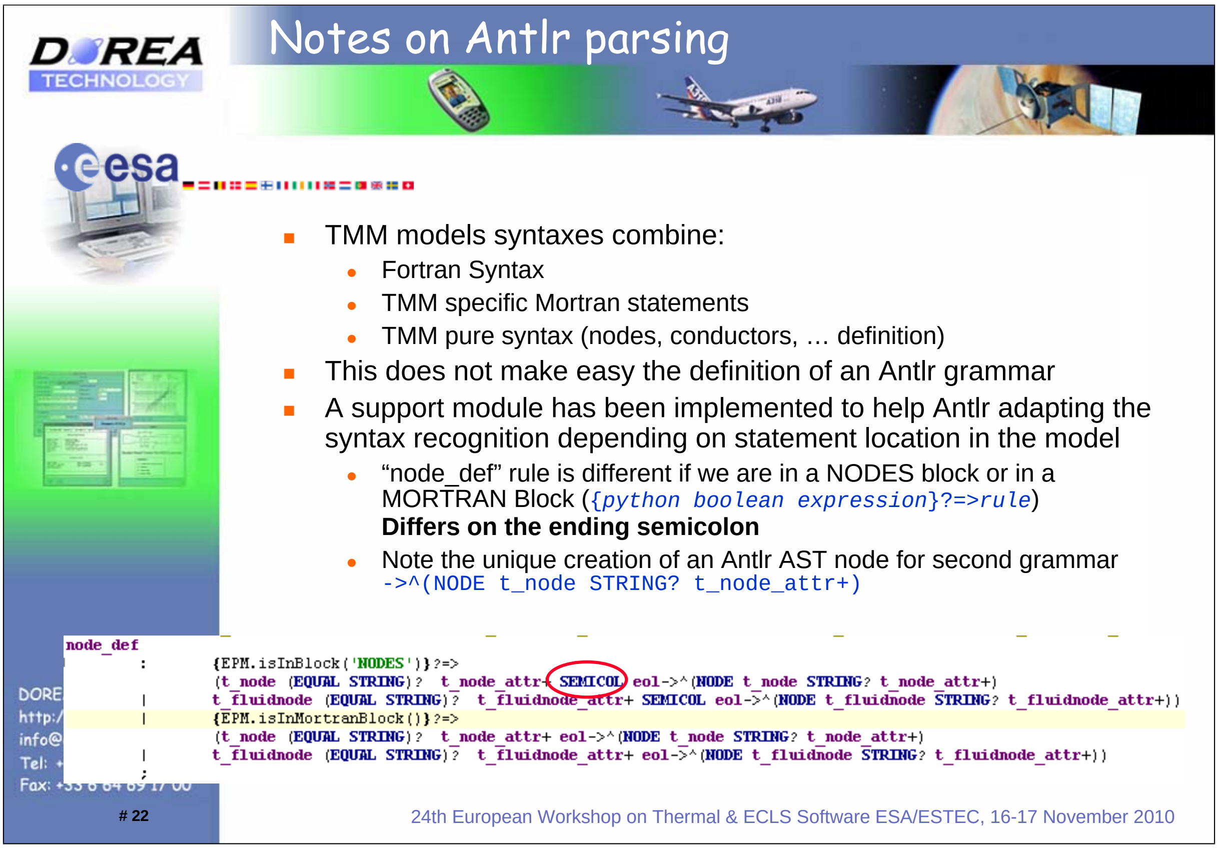
Notes on Antlr parsing
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TMM models syntaxes combine:
Fortran Syntax
TMM specific Mortran statements
TMM pure syntax (nodes, conductors, … definition)
This does not make easy the definition of an Antlr grammar
A support module has been implemented to help Antlr adapting the syntax recognition depending on statement location in the model
"node_def" rule is different if we are in a NODES block or in a MORTRAN Block ({python boolean expression}?=>rule)
Differs on the ending semicolon
Note the unique creation of an Antlr AST node for second grammar
->^(NODE t_node STRING? t_node_attr+)
node_def
: {EPM.isInBlock('NODES')}?=>
(t_node (EQUAL STRING)? t_node_attr+ SEMICOL eol->^(NODE t_node STRING? t_node_attr+)
| t_fluidnode (EQUAL STRING)? t_fluidnode_attr+ SEMICOL eol->^(NODE t_fluidnode STRING? t_fluidnode_attr+))
| {EPM.isInMortranBlock()}?=>
(t_node (EQUAL STRING)? t_node_attr+ eol->^(NODE t_node STRING? t_node_attr+)
| t_fluidnode (EQUAL STRING)? t_fluidnode_attr+ eol->^(NODE t_fluidnode STRING? t_fluidnode_attr+))
;
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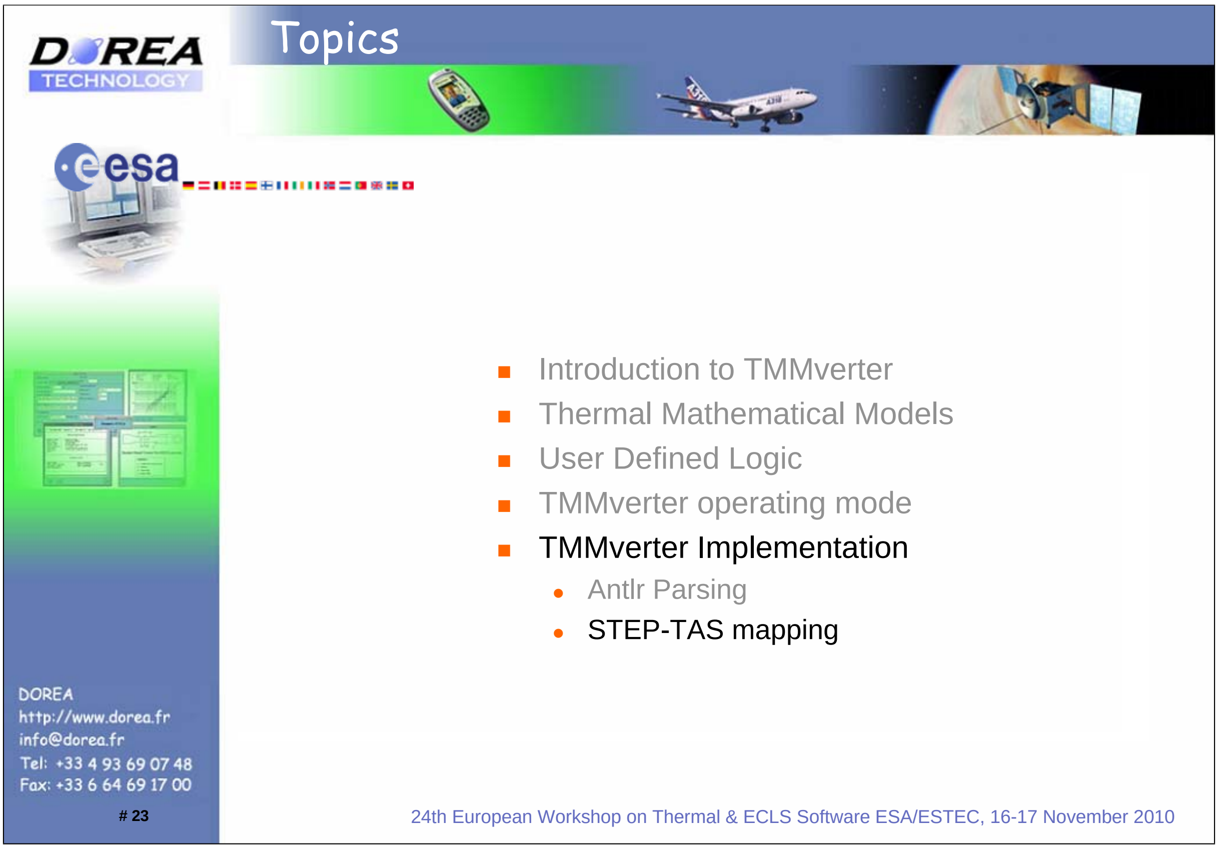
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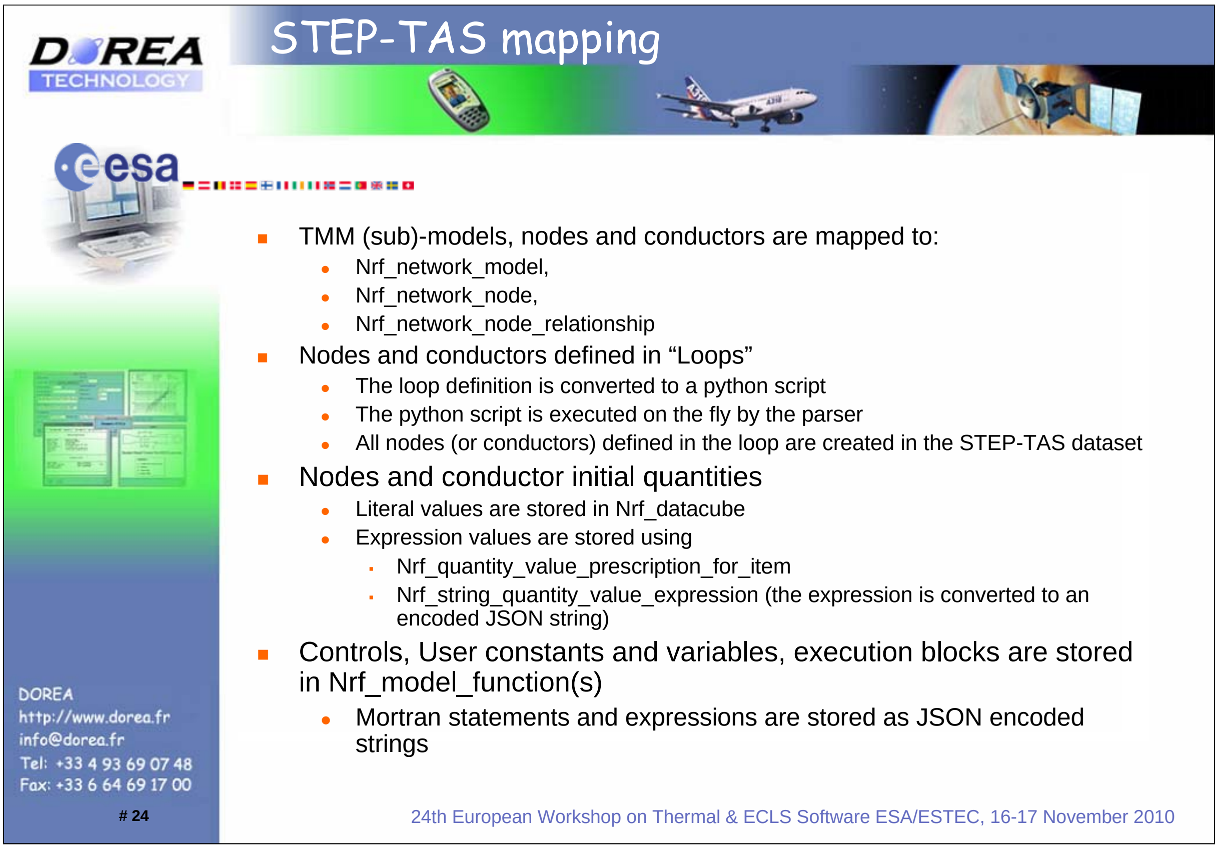
STEP-TAS mapping
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TMM (sub)-models, nodes and conductors are mapped to:
Nrf_network_model,
Nrf_network_node,
Nrf_network_node_relationship
Nodes and conductors defined in “Loops”
The loop definition is converted to a python script
The python script is executed on the fly by the parser
All nodes (or conductors) defined in the loop are created in the STEP-TAS dataset
Nodes and conductor initial quantities
Literal values are stored in Nrf_datacube
Expression values are stored using
Nrf_quantity_value_prescription_for_item
Nrf_string_quantity_value_expression (the expression is converted to an encoded JSON string)
Controls, User constants and variables, execution blocks are stored in Nrf_model_function(s)
Mortran statements and expressions are stored as JSON encoded strings
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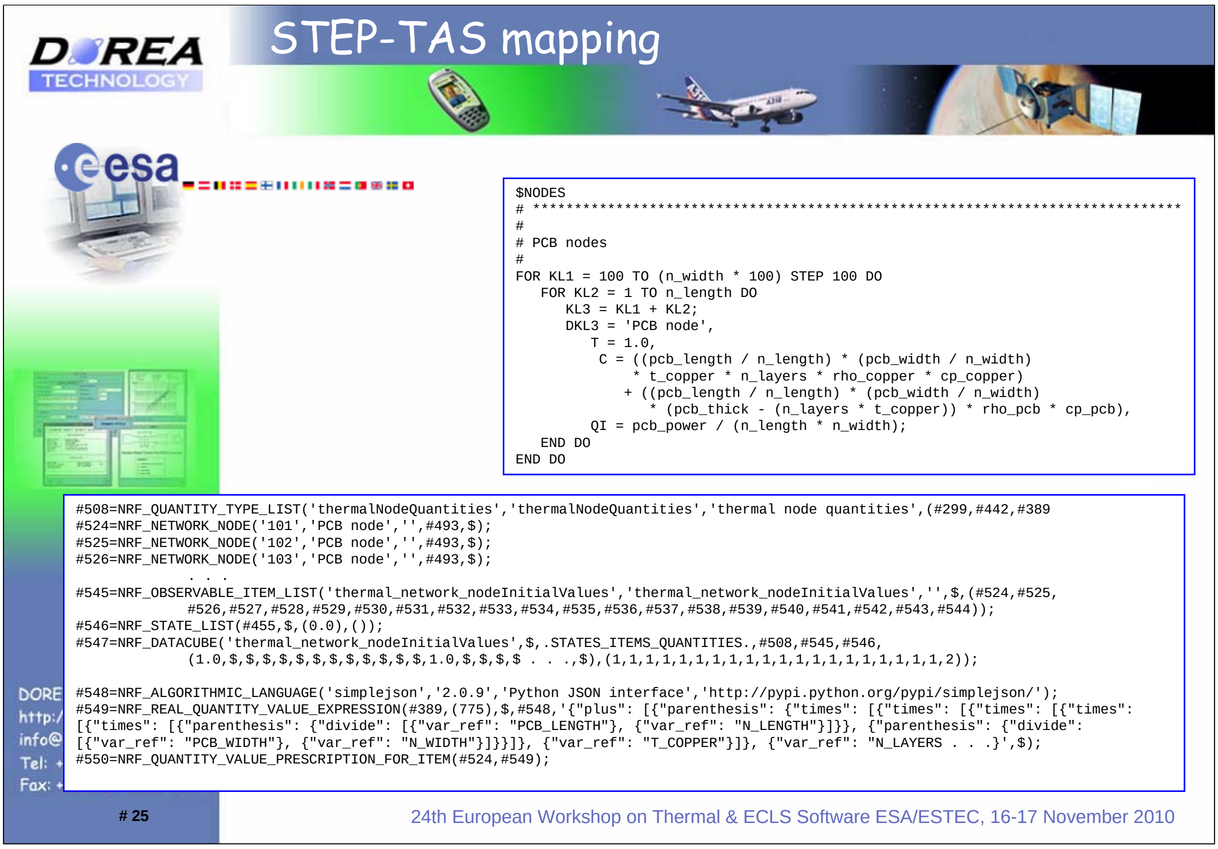

STEP-TAS mapping
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$NODES
***
#
PCB nodes
#
FOR KL1 = 100 TO (n_width * 100) STEP 100 DO
FOR KL2 = 1 TO n_length DO
KL3 = KL1 + KL2;
DKL3 = 'PCB node',
T = 1.0,
C = ((pcb_length / n_length) * (pcb_width / n_width)
* t_copper * n_layers * rho_copper * cp_copper)
+ ((pcb_length / n_length) * (pcb_width / n_width)
* (pcb_thick - (n_layers * t_copper)) * rho_pcb * cp_pcb),
QI = pcb_power / (n_length * n_width);
END DO
END DO
#508=NRF_QUANTITY_TYPE_LIST('thermalNodeQuantities','thermalNodeQuantities','thermal node quantities',(#299,#442,#389
#524=NRF_NETWORK_NODE('101','PCB node','',#493,$);
#525=NRF_NETWORK_NODE('102','PCB node','',#493,$);
#526=NRF_NETWORK_NODE('103','PCB node','',#493,$);
. . .
#545=NRF_OBSERVABLE_ITEM_LIST('thermal_network_nodeInitialValues','thermal_network_nodeInitialValues','',$,(#524,#525,
#526,#527,#528,#529,#530,#531,#532,#533,#534,#535,#536,#537,#538,#539,#540,#541,#542,#543,#544));
#546=NRF_STATE_LIST(#455,$,(0.0),());
#547=NRF_DATACUBE('thermal_network_nodeInitialValues',$,.STATES_ITEMS_QUANTITIES.,#508,#545,#546,
(1.0,$,$,$,$,$,$,$,$,$,$,$,$,1.0,$,$,$,$ . . .,$),(1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,1,2));
#548=NRF_ALGORITHMIC_LANGUAGE('simplejson','2.0.9','Python JSON interface','http://pypi.python.org/pypi/simplejson/');
#549=NRF_REAL_QUANTITY_VALUE_EXPRESSION(#389,(775),$,#548,'{"plus": [{"parenthesis": {"times": [{"times": [{"times": [{"times":
[{"times": [{"parenthesis": {"divide": [{"var_ref": "PCB_LENGTH"}, {"var_ref": "N_LENGTH"}]}}, {"parenthesis": {"divide":
[{"var_ref": "PCB_WIDTH"}, {"var_ref": "N_WIDTH"}]}}]}, {"var_ref": "T_COPPER"}]}, {"var_ref": "N_LAYERS . . .}',$);
#550=NRF_QUANTITY_VALUE_PRESCRIPTION_FOR_ITEM(#524,#549);
25
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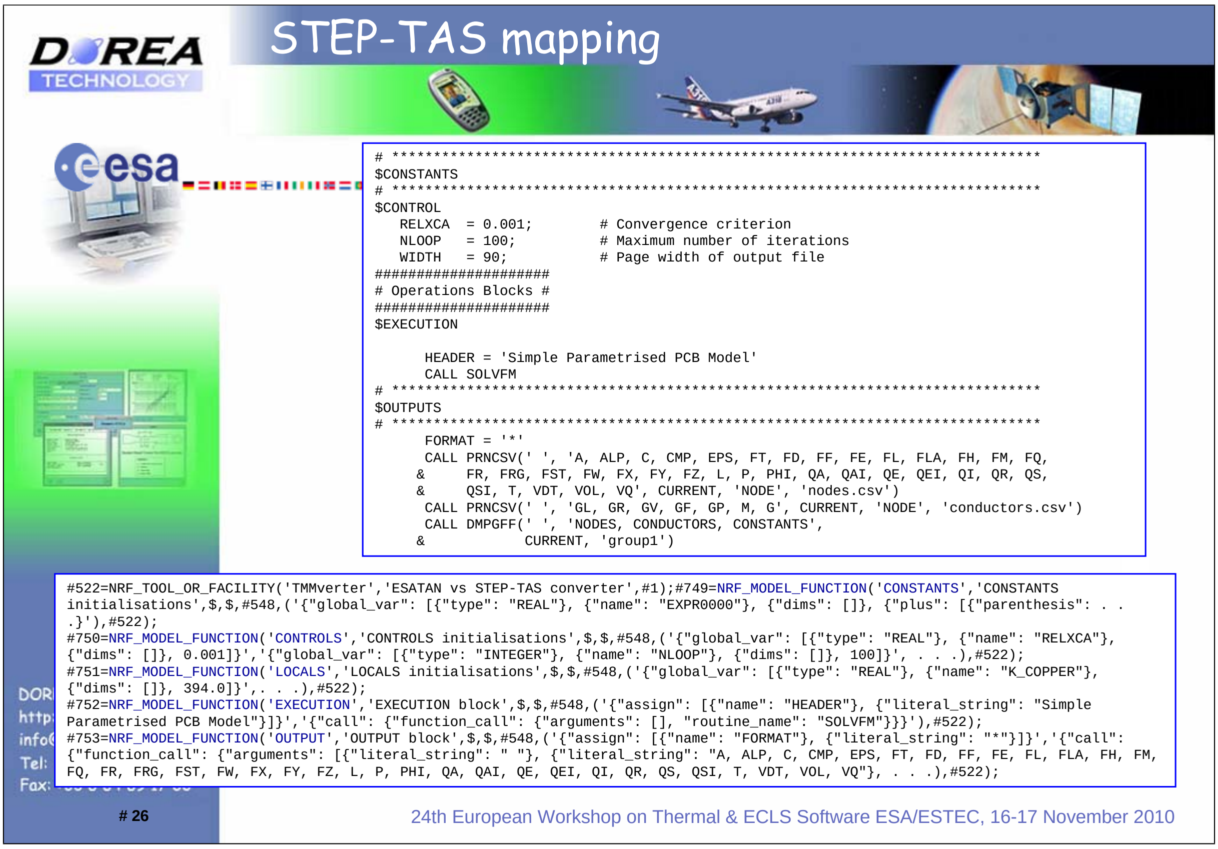

STEP-TAS mapping
DOREA TECHNOLOGY
esa
***
$CONSTANTS
***
$CONTROL
RELXCA = 0.001; # Convergence criterion
NLOOP = 100; # Maximum number of iterations
WIDTH = 90; # Page width of output file
#####################
Operations Blocks
#####################
$EXECUTION
HEADER = 'Simple Parametrised PCB Model'
CALL SOLVFM
***
$OUTPUTS
# ***
FORMAT = '*'
CALL PRNCSV(' ', 'A, ALP, C, CMP, EPS, FT, FD, FF, FE, FL, FLA, FH, FM, FQ,
& FR, FRG, FST, FW, FX, FY, FZ, L, P, PHI, QA, QAI, QE, QEI, QI, QR, QS,
& QSI, T, VDT, VOL, VQ', CURRENT, 'NODE', 'nodes.csv')
CALL PRNCSV(' ', 'GL, GR, GV, GF, GP, M, G', CURRENT, 'NODE', 'conductors.csv')
CALL DMPGFF(' ', 'NODES, CONDUCTORS, CONSTANTS',
& CURRENT, 'group1')
#522=NRF_TOOL_OR_FACILITY('TMMverter','ESATAN vs STEP-TAS converter',#1);#749=NRF_MODEL_FUNCTION('CONSTANTS','CONSTANTS
initialisations',$,$,#548,('{"global_var": [{"type": "REAL"}, {"name": "EXPR0000"}, {"dims": []}, {"plus": [{"parenthesis": . .
.}'),#522);
#750=NRF_MODEL_FUNCTION('CONTROLS','CONTROLS initialisations',$,$,#548,('{"global_var": [{"type": "REAL"}, {"name": "RELXCA"},
{"dims": []}, 0.001]}','{"global_var": [{"type": "INTEGER"}, {"name": "NLOOP"}, {"dims": []}, 100]}', . . .),#522);
#751=NRF_MODEL_FUNCTION('LOCALS','LOCALS initialisations',$,$,#548,('{"global_var": [{"type": "REAL"}, {"name": "K_COPPER"},
{"dims": []}, 394.0]}',. . .),#522);
#752=NRF_MODEL_FUNCTION('EXECUTION','EXECUTION block',$,$,#548,('{"assign": [{"name": "HEADER"}, {"literal_string": "Simple
Parametrised PCB Model"}]}','{"call": {"function_call": {"arguments": [], "routine_name": "SOLVFM"}}}'),#522);
#753=NRF_MODEL_FUNCTION('OUTPUT','OUTPUT block',$,$,#548,('{"assign": [{"name": "FORMAT"}, {"literal_string": "*"}]}','{"call":
{"function_call": {"arguments": [{"literal_string": " "}, {"literal_string": "A, ALP, C, CMP, EPS, FT, FD, FF, FE, FL, FLA, FH, FM,
FQ, FR, FRG, FST, FW, FX, FY, FZ, L, P, PHI, QA, QAI, QE, QEI, QI, QR, QS, QSI, T, VDT, VOL, VQ"}, . . .),#522);
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DOREA TECHNOLOGY

Topics

- Introduction to TMMverter
- Thermal Mathematical Models
- User Defined Logic
- TMMverter operating mode
- TMMverter Implementation
  - Antlr Parsing
  - STEP-TAS mapping
  - User Logic encoding in JSON

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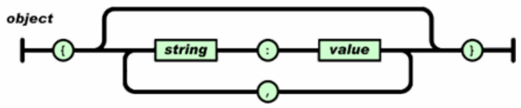
DOREA TECHNOLOGY

User Logic encoding in JSON

- The JSON (Javascript Object Notation) format has been selected for encoding the Mortran/Fortran user logic embedded in ESATAN and SINDAfluint .
- JSON is built on two structures:
  - A collection of name/value pairs. In various languages, this is realized as an object, record, struct, dictionary, hash table, keyed list, or associative array.
  - An ordered list of values. In most languages, this is realized as an array, vector, list, or sequence.



- Python implementation of JSON
  - JSON objects are defined with Python Dictionaries
  - JSON ordered list of values are defined with Python Lists
  - **encode** and **decode** methods convert JSON Python objects to Strings and vice versa
- The most suitable approach to capture user-defined logic in a neutral was found to be so called "prefix notation", as it is also used in MathML and a number of other mathematical interchange formats as well as e.g. the Lisp programming language.
  - The following simple mathematical expression:
    3+4*5
    could be written in prefix notation as:
    (plus 3 times(4 5))
    and in JSON format:
    {"plus" : [3, {"times" : [4, 5]}]}

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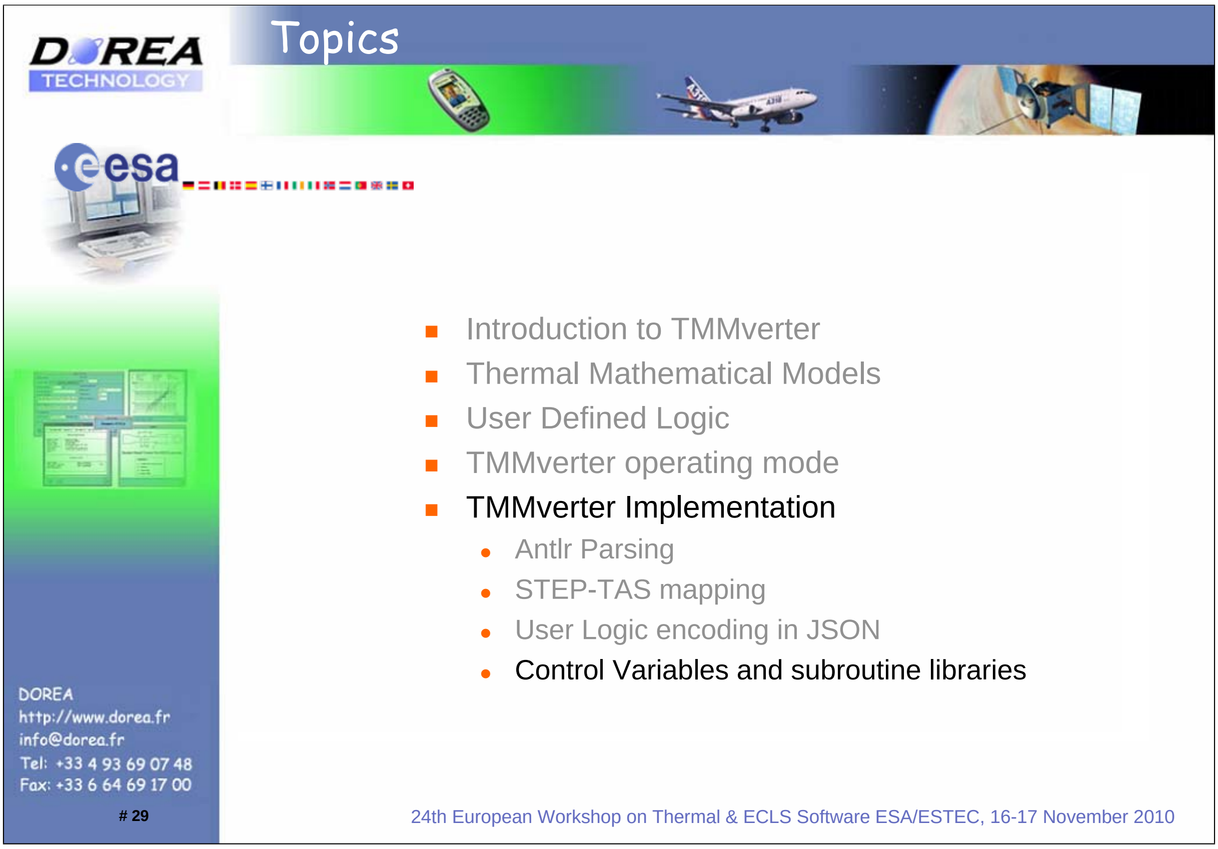
Topics
DOREA TECHNOLOGY
esa
Introduction to TMMverter
Thermal Mathematical Models
User Defined Logic
TMMverter operating mode
TMMverter Implementation
Antlr Parsing
STEP-TAS mapping
User Logic encoding in JSON
Control Variables and subroutine libraries
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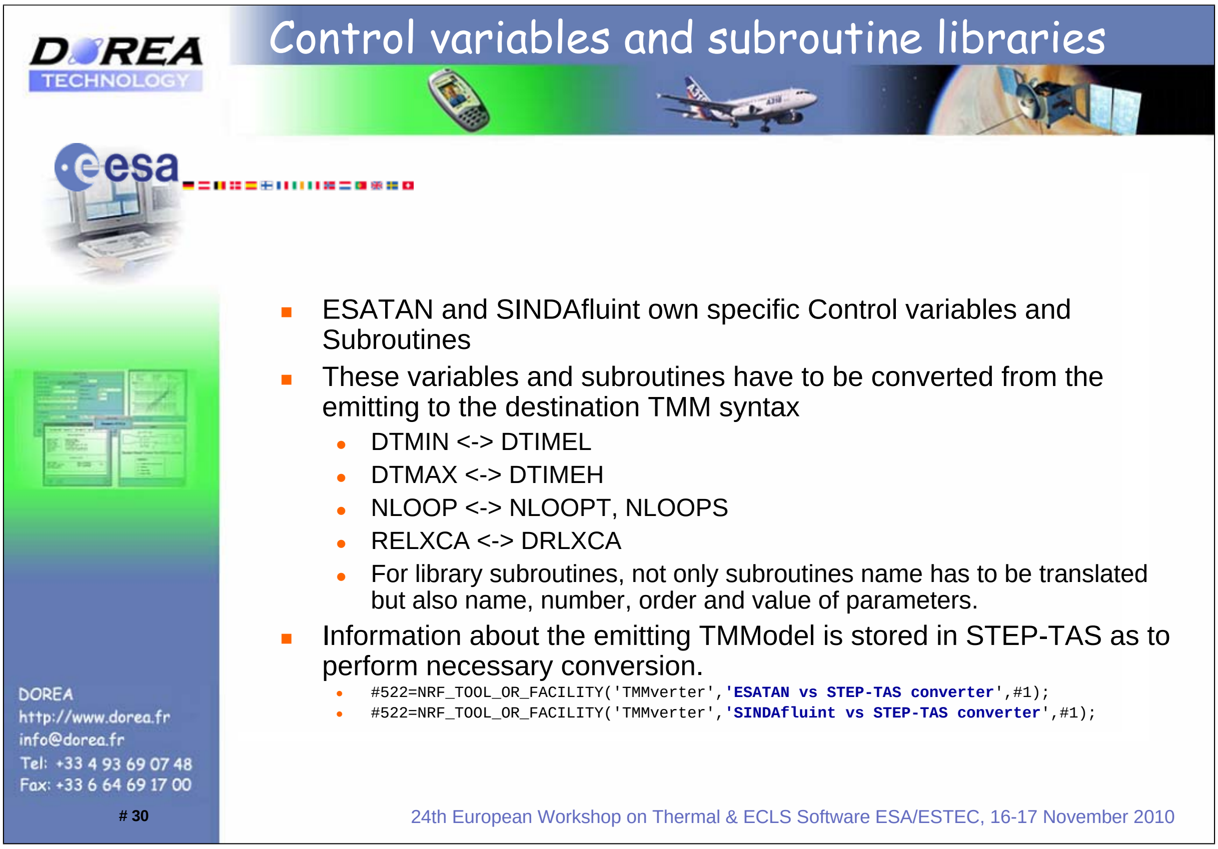
Control variables and subroutine libraries
DOREA TECHNOLOGY
esa
ESATAN and SINDAfluint own specific Control variables and Subroutines
These variables and subroutines have to be converted from the emitting to the destination TMM syntax
DTMIN <-> DTIMEL
DTMAX <-> DTIMEH
NLOOP <-> NLOOPT, NLOOPS
RELXCA <-> DRLXCA
For library subroutines, not only subroutines name has to be translated but also name, number, order and value of parameters.
Information about the emitting TMModel is stored in STEP-TAS as to perform necessary conversion.
#522=NRF_TOOL_OR_FACILITY('TMMverter','ESATAN vs STEP-TAS converter',#1);
#522=NRF_TOOL_OR_FACILITY('TMMverter','SINDAfluint vs STEP-TAS converter',#1);
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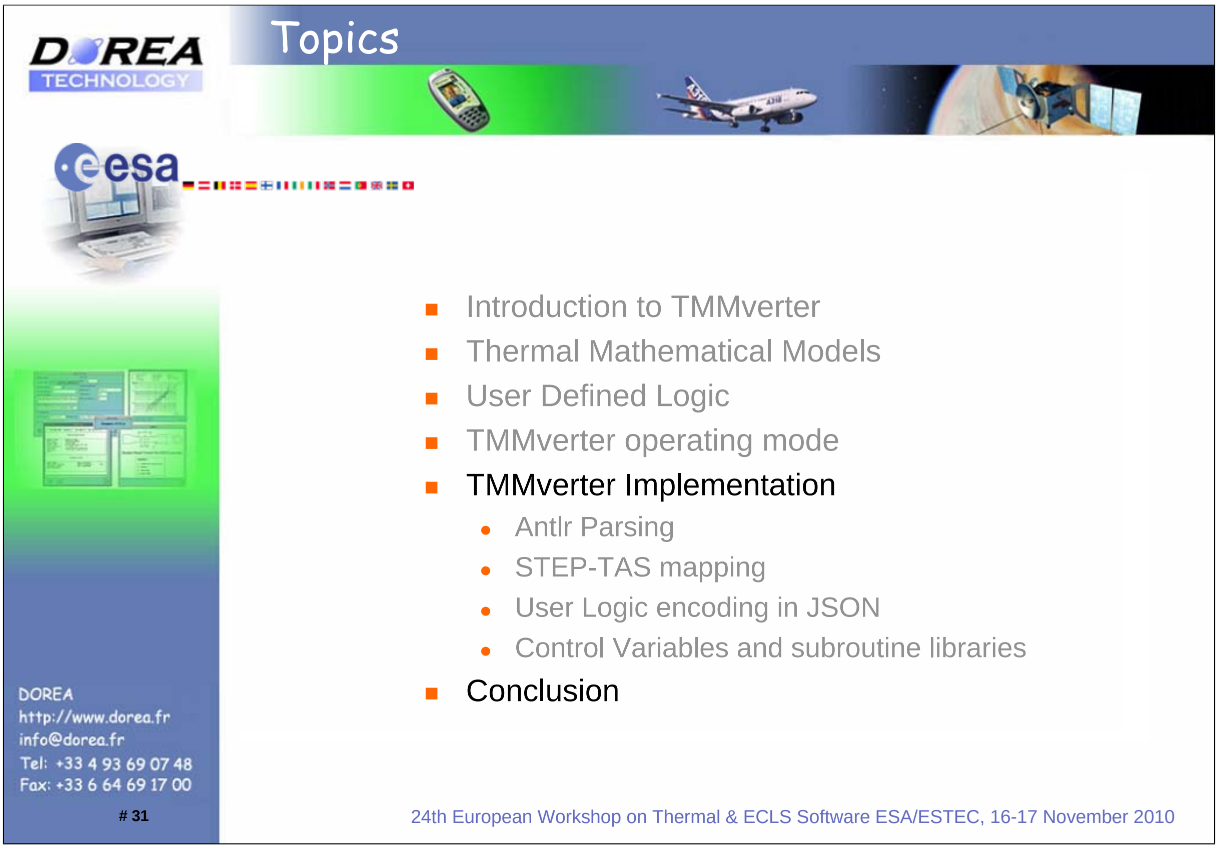
DOREA TECHNOLOGY
Topics
esa
Introduction to TMMverter
Thermal Mathematical Models
User Defined Logic
TMMverter operating mode
TMMverter Implementation
Antlr Parsing
STEP-TAS mapping
User Logic encoding in JSON
Control Variables and subroutine libraries
Conclusion
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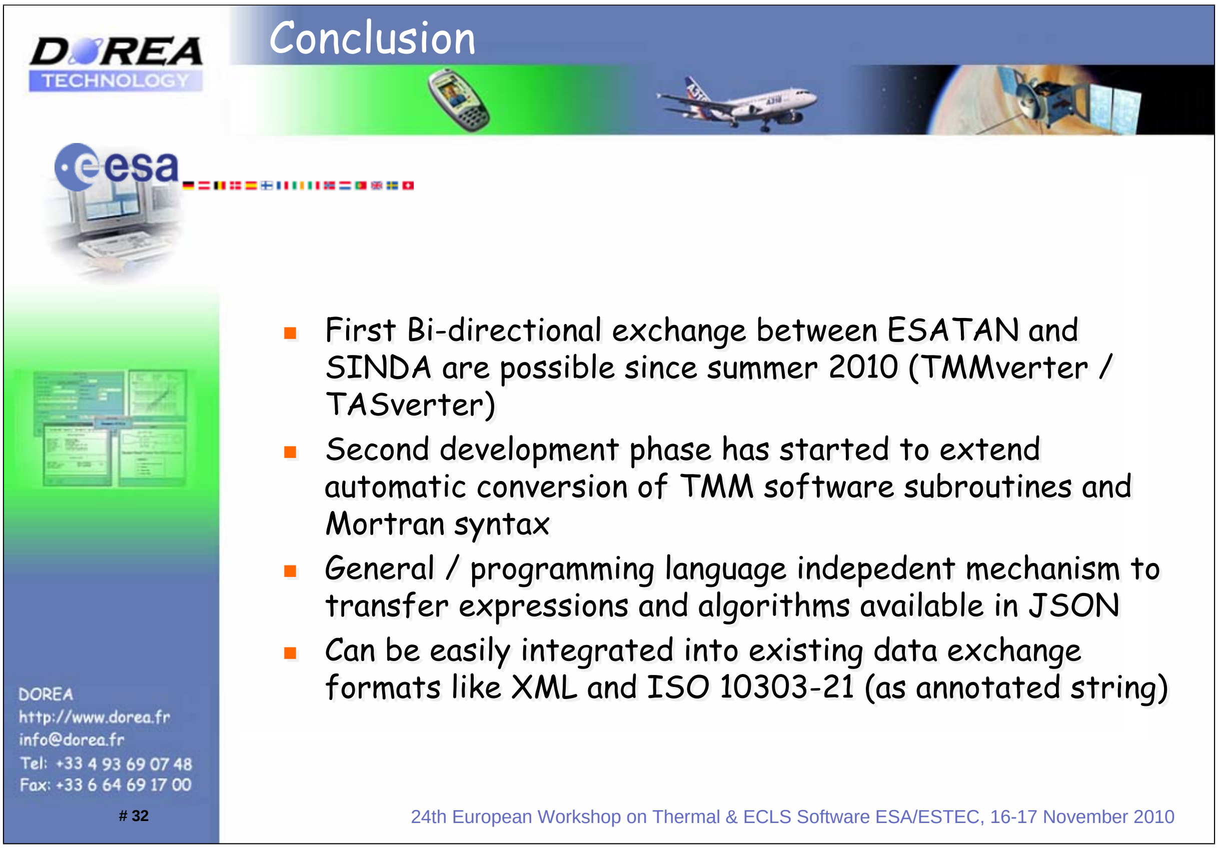
DOREA TECHNOLOGY
Conclusion
esa
First Bi-directional exchange between ESATAN and SINDA are possible since summer 2010 (TMMverter / TASverter)
Second development phase has started to extend automatic conversion of TMM software subroutines and Mortran syntax
General / programming language indepedent mechanism to transfer expressions and algorithms available in JSON
Can be easily integrated into existing data exchange formats like XML and ISO 10303-21 (as annotated string)
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Appendix D

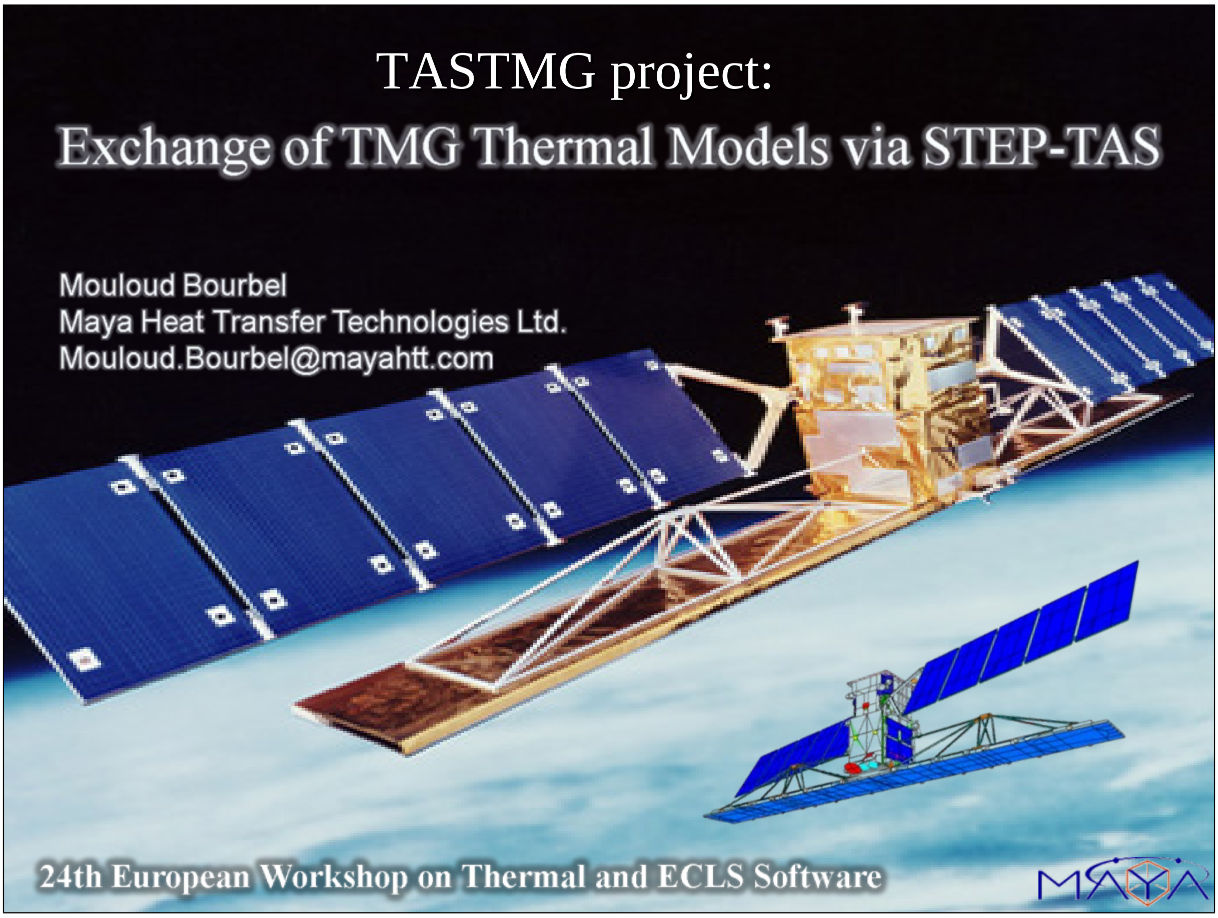
Exchange of TMG thermal models via STEP-TAS

Mouloud Bourbel
(Maya, Canada)

Abstract

In the late 90's, the European Space Agency "ESA" started the development of an information exchange standard for space thermal analysis models. This standard was based on ISO 10303, which is informally known as STEP "Standard for the Exchange of Product model data". The new standard was named STEP-TAS "Thermal Analysis for Space". Since then, STEP-TAS development has been completed. The standard has been documented and extensively tested

Recently, STEP-TAS has been implemented into Maya's TMG family of products, which includes NX I-deas TMG, Femap TMG and NX Space Systems Thermal. This new capability greatly simplifies thermal model exchange between Maya's TMG family of products and other thermal analysis packages.

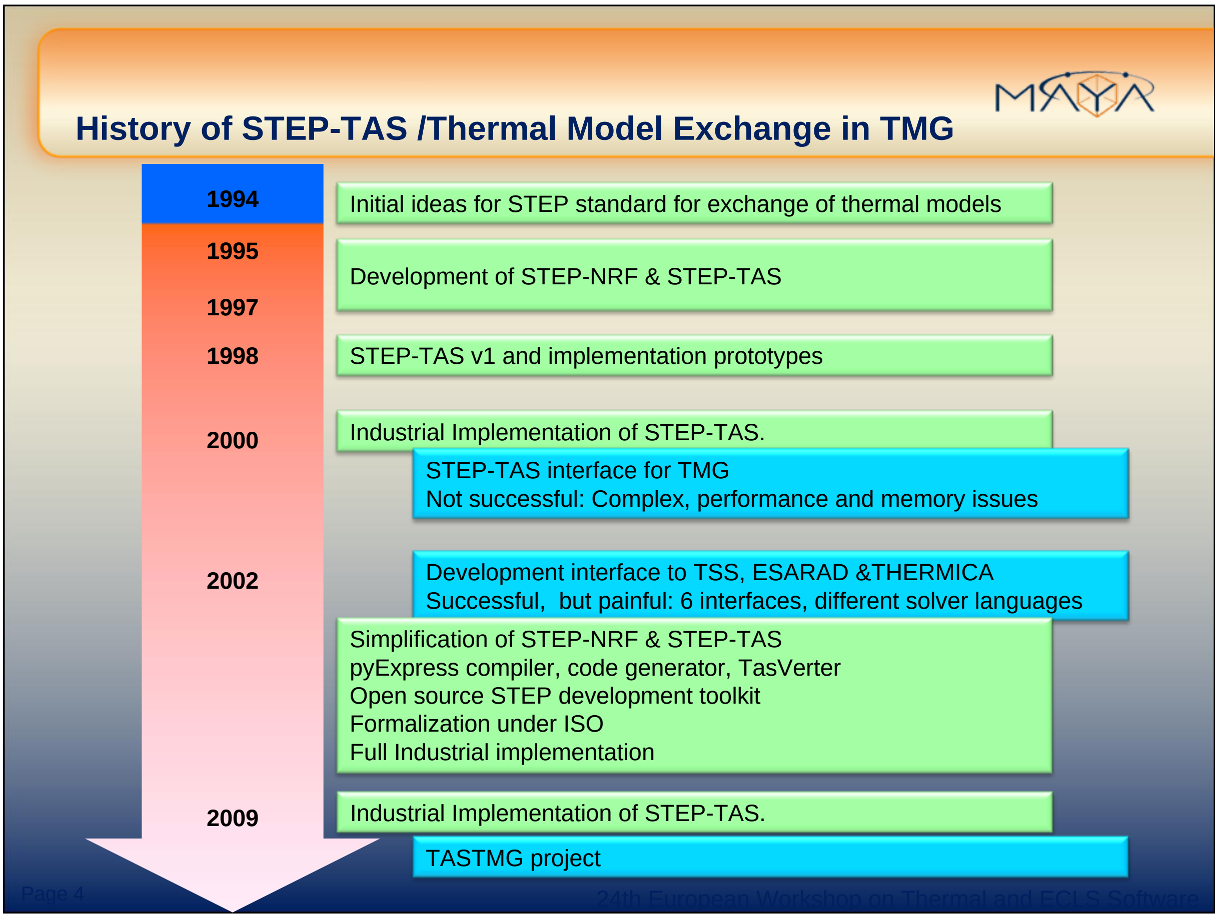


Agenda

- Description and Implementation of TASTMG project
- Validation & Testing of TASTMG Implementation
- Demo of TASTMG Integration in NX Space Systems Thermal

Page 2 24th European Workshop on Thermal and ECLS Software


TASTMG project
INNOVATE MORE


History of STEP-TAS /Thermal Model Exchange in TMG
1994
Initial ideas for STEP standard for exchange of thermal models
1995
1997
Development of STEP-NRF & STEP-TAS
1998
STEP-TAS v1 and implementation prototypes
2000
Industrial Implementation of STEP-TAS.
STEP-TAS interface for TMG
Not successful: Complex, performance and memory issues
2002
Development interface to TSS, ESARAD &THERMICA
Successful, but painful: 6 interfaces, different solver languages
Simplification of STEP-NRF & STEP-TAS
pyExpress compiler, code generator, TasVerter
Open source STEP development toolkit
Formalization under ISO
Full Industrial implementation
2009
Industrial Implementation of STEP-TAS.
TASTMG project
Page 4
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Objectives of TASTMG project
MAYA
Implement STEP-TAS Import / export Facility with in TMG family of products.
Validate & Test the implementation.
Create TMG part of the public STEP-TAS acceptance testsuite.
Page 5
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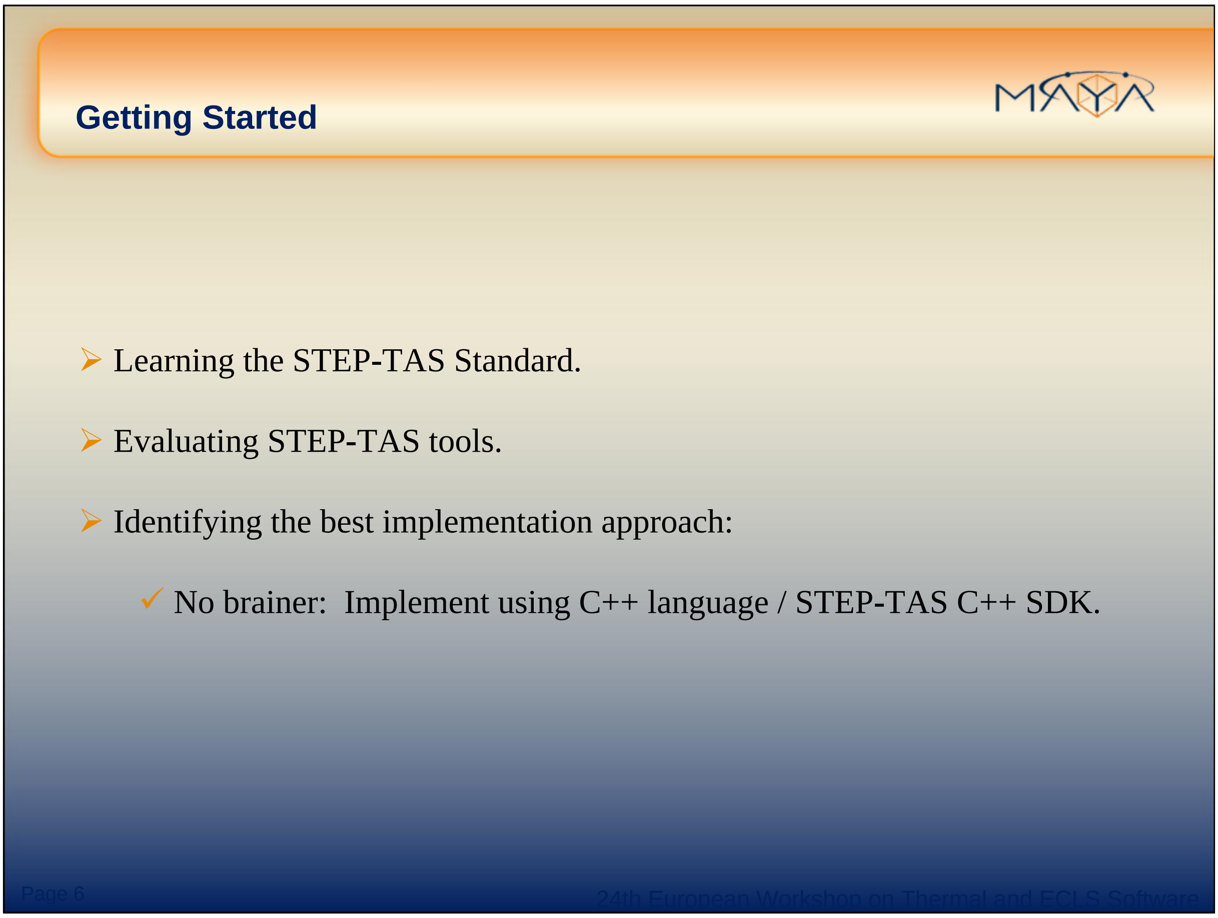
Getting Started
MAYA
Learning the STEP-TAS Standard.
Evaluating STEP-TAS tools.
Identifying the best implementation approach:
No brainer: Implement using C++ language / STEP-TAS C++ SDK.
Page 6
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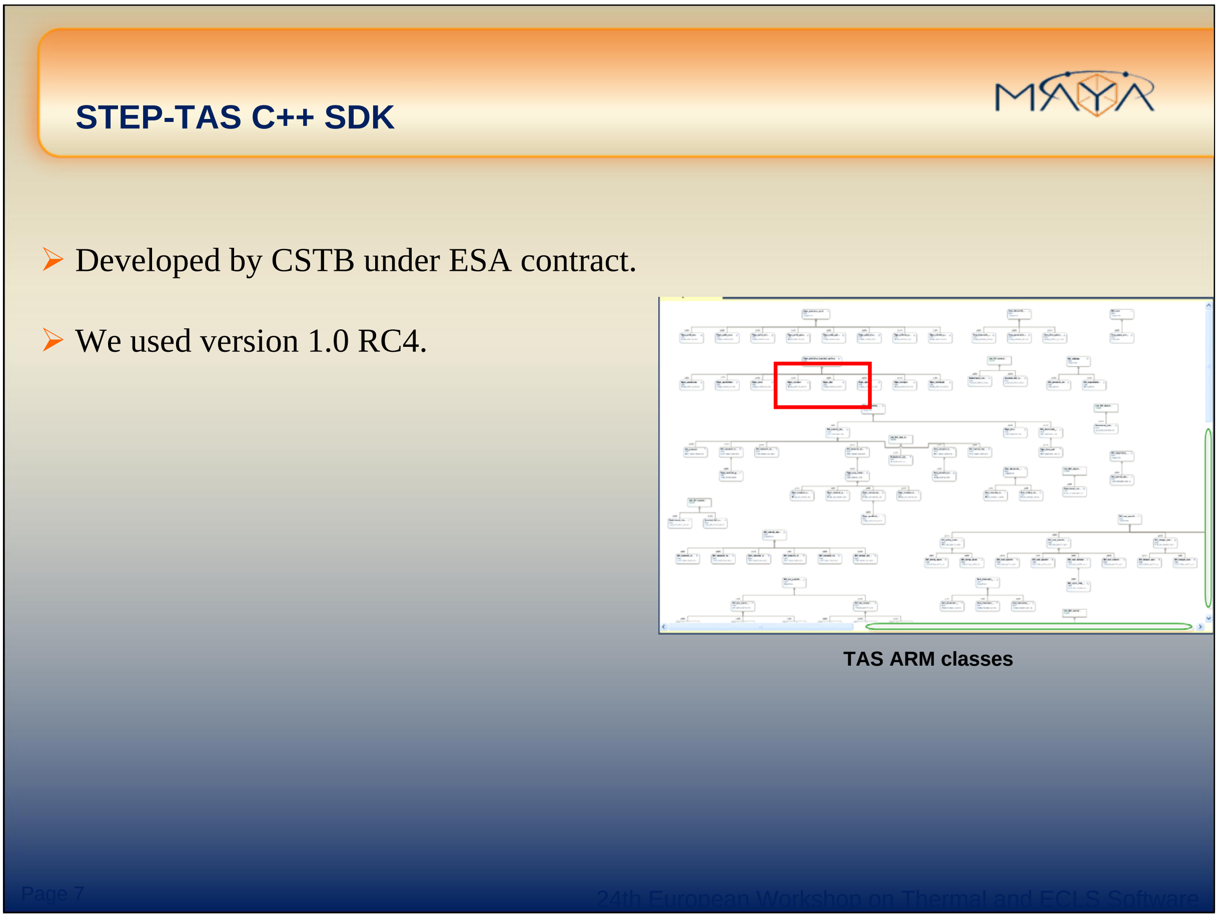
STEP-TAS C++ SDK
MAYA
Developed by CSTB under ESA contract.
We used version 1.0 RC4.
TAS ARM classes
Page 7
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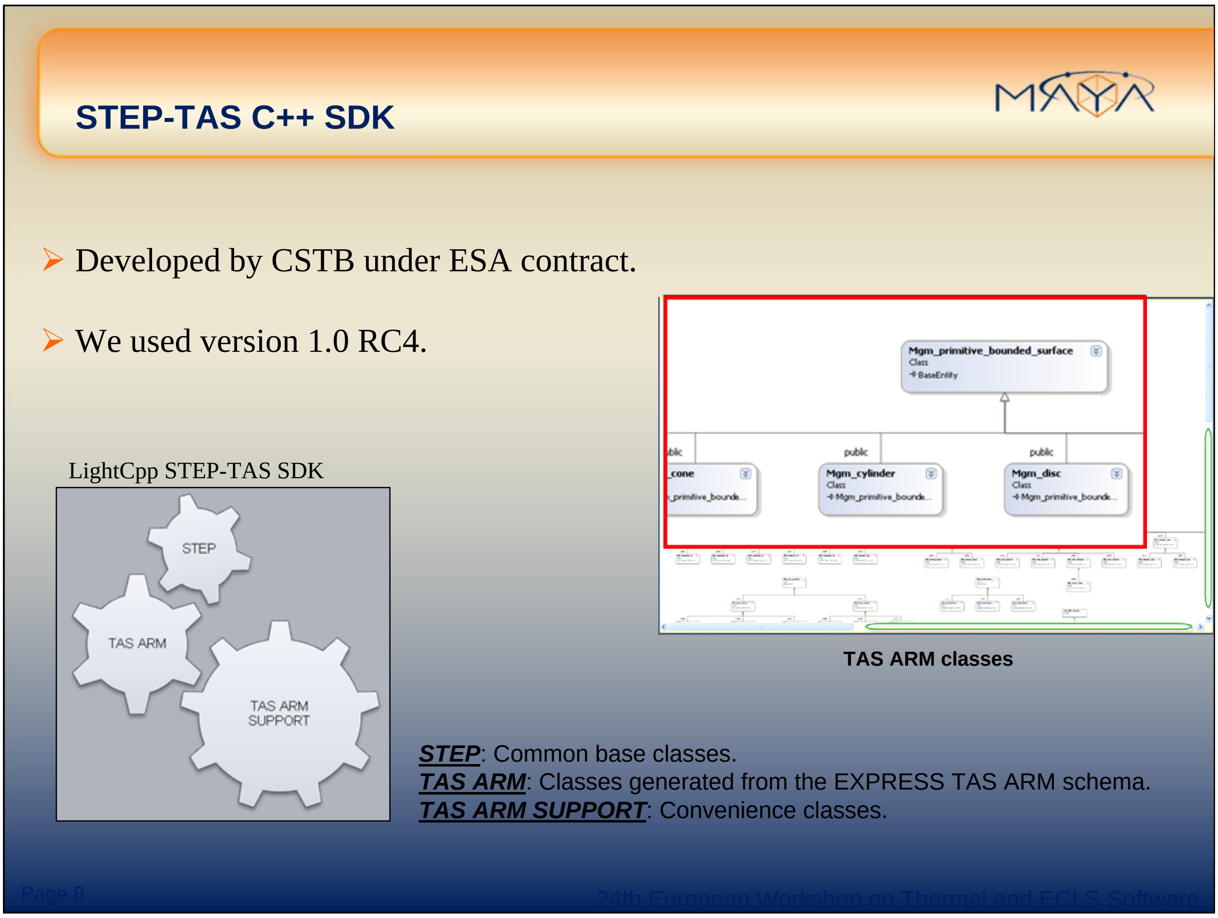
STEP-TAS C++ SDK
MAYA
Developed by CSTB under ESA contract.
We used version 1.0 RC4.
Mgm_primitive_bounded_surface
Class
BaseEntity
public
public
Mgm_cylinder
Class
Mgm_primitive_bounde...
Mgm_disc
Class
Mgm_primitive_bounde...
TAS ARM classes
LightCpp STEP-TAS SDK
STEP
TAS ARM
TAS ARM SUPPORT
STEP: Common base classes.
TAS ARM: Classes generated from the EXPRESS TAS ARM schema.
TAS ARM SUPPORT: Convenience classes.
Page 8
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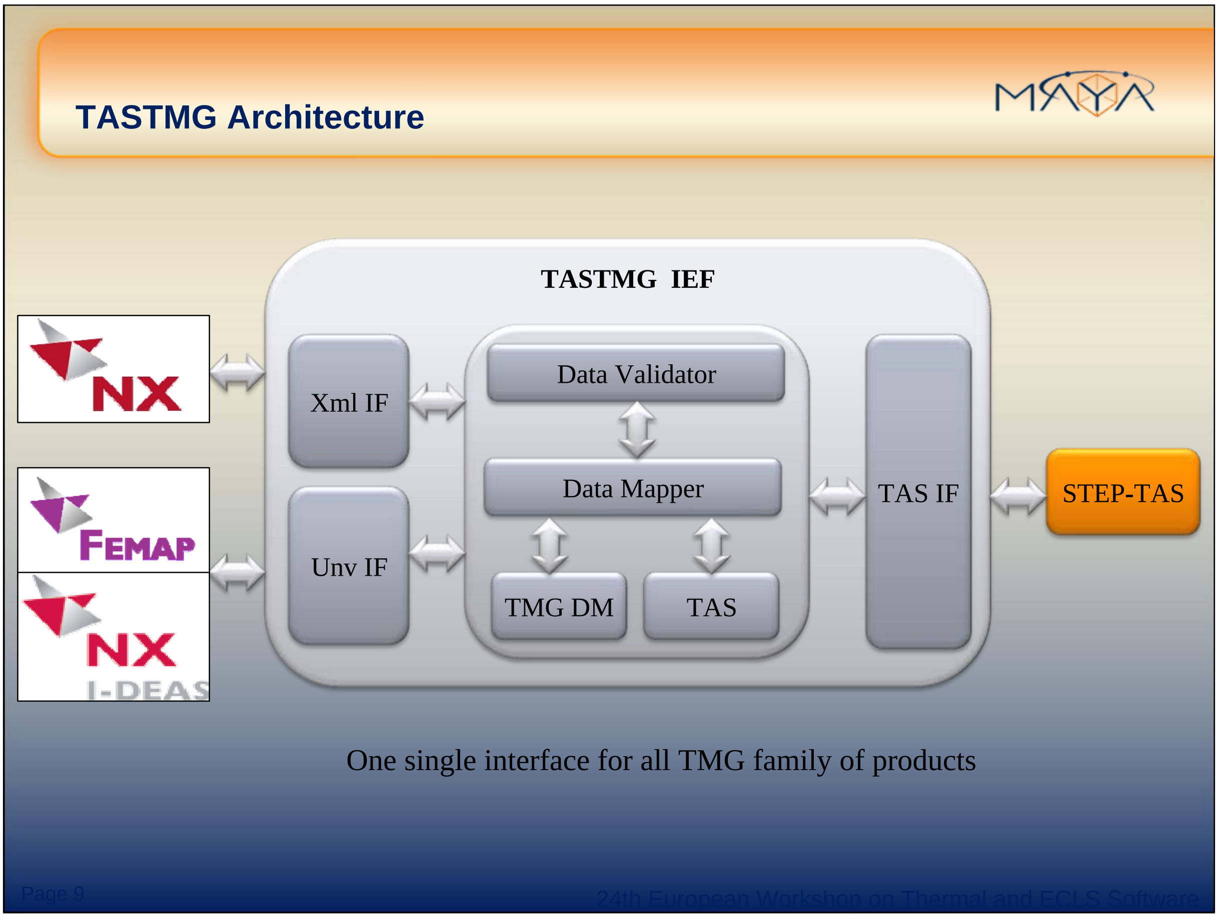
TASTMG Architecture
TASTMG IEF
NX
Xml IF
Data Validator
Data Mapper
TAS IF
STEP-TAS
FEMAP
NX
I-DEAS
Unv IF
TMG DM
TAS
One single interface for all TMG family of products
Page 9
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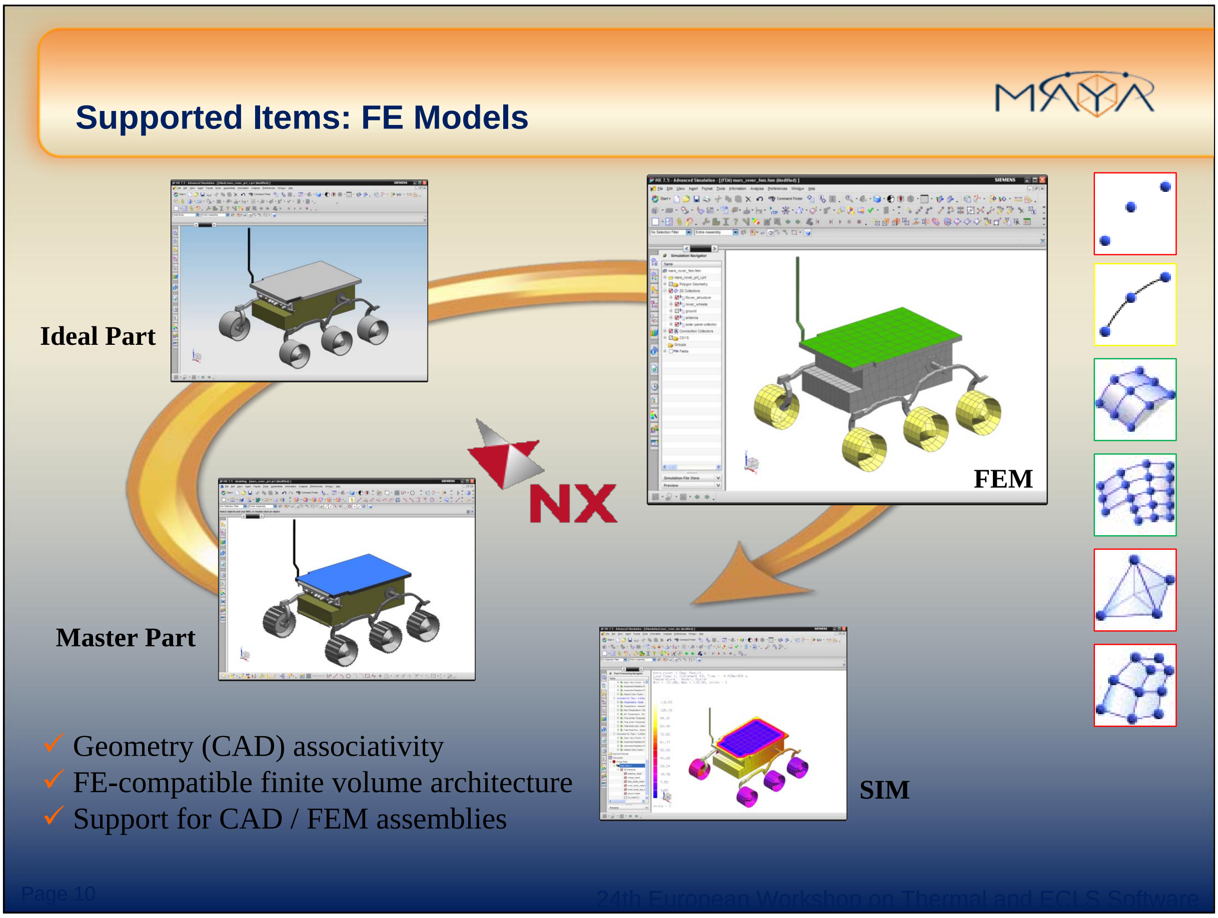
Supported Items: FE Models
Ideal Part
FEM
NX
Master Part
SIM
Geometry (CAD) associativity
FE-compatible finite volume architecture
Support for CAD / FEM assemblies
Page 10
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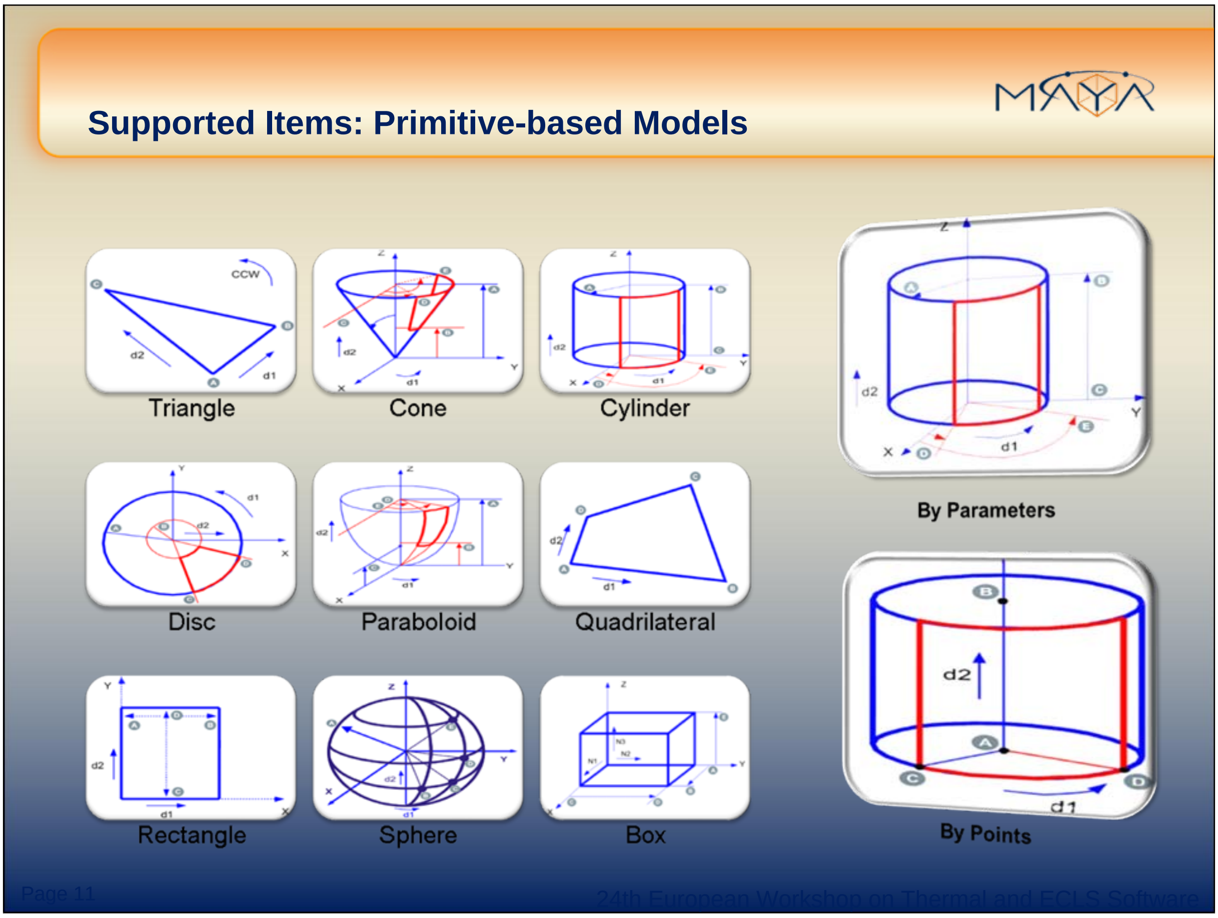
Supported Items: Primitive-based Models
MAYA
Triangle
Cone
Cylinder
Disc
Paraboloid
Quadrilateral
Rectangle
Sphere
Box
By Parameters
By Points
Page 11
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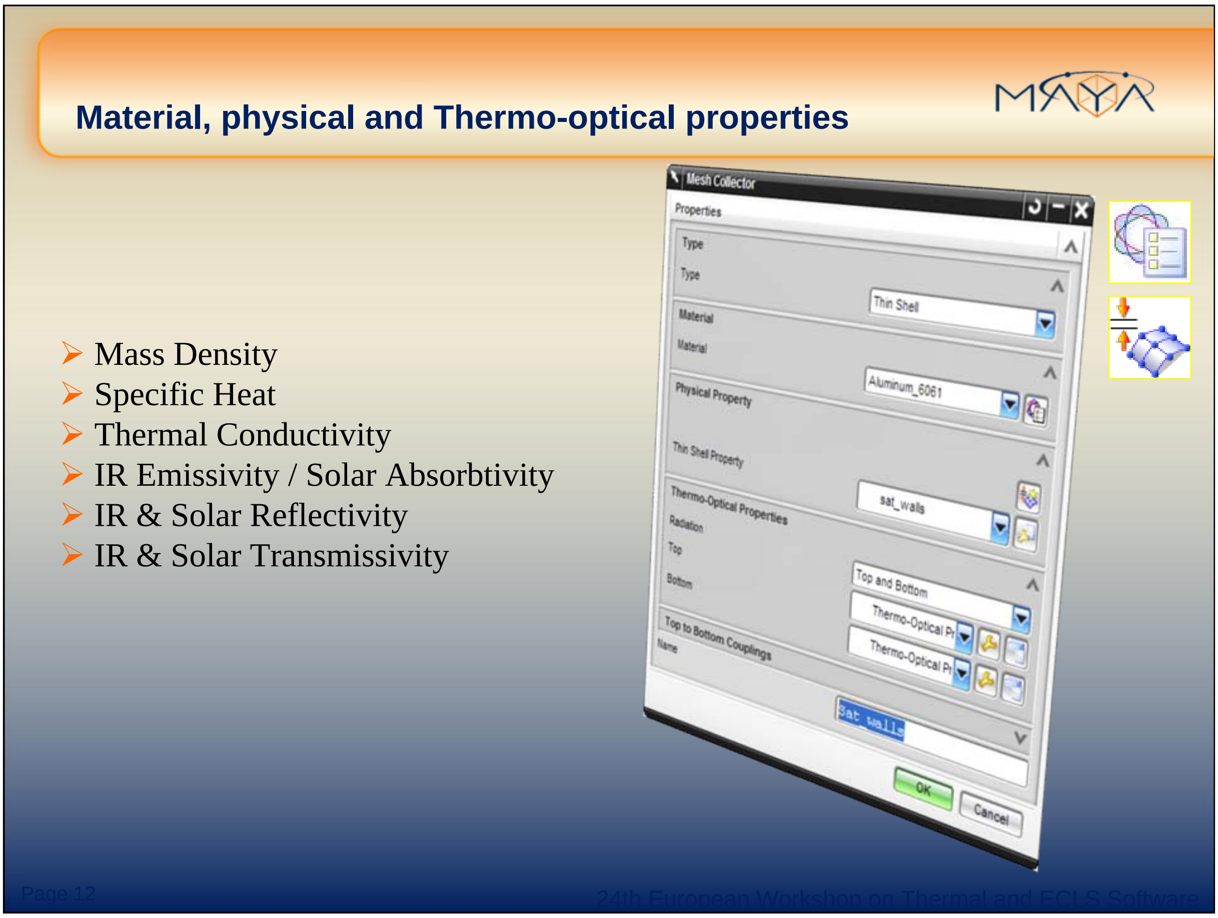
Material, physical and Thermo-optical properties
MAYA
Mass Density
Specific Heat
Thermal Conductivity
IR Emissivity / Solar Absorbtivity
IR & Solar Reflectivity
IR & Solar Transmissivity
Mesh Collector
Properties
Type
Thin Shell
Material
Aluminum_6061
Physical Property
Thin Shell Property
sat_walls
Thermo-Optical Properties
Radiation
Top
Bottom
Top and Bottom
Top to Bottom Couplings
Name
Sat_walls
OK
Cancel
Page 12
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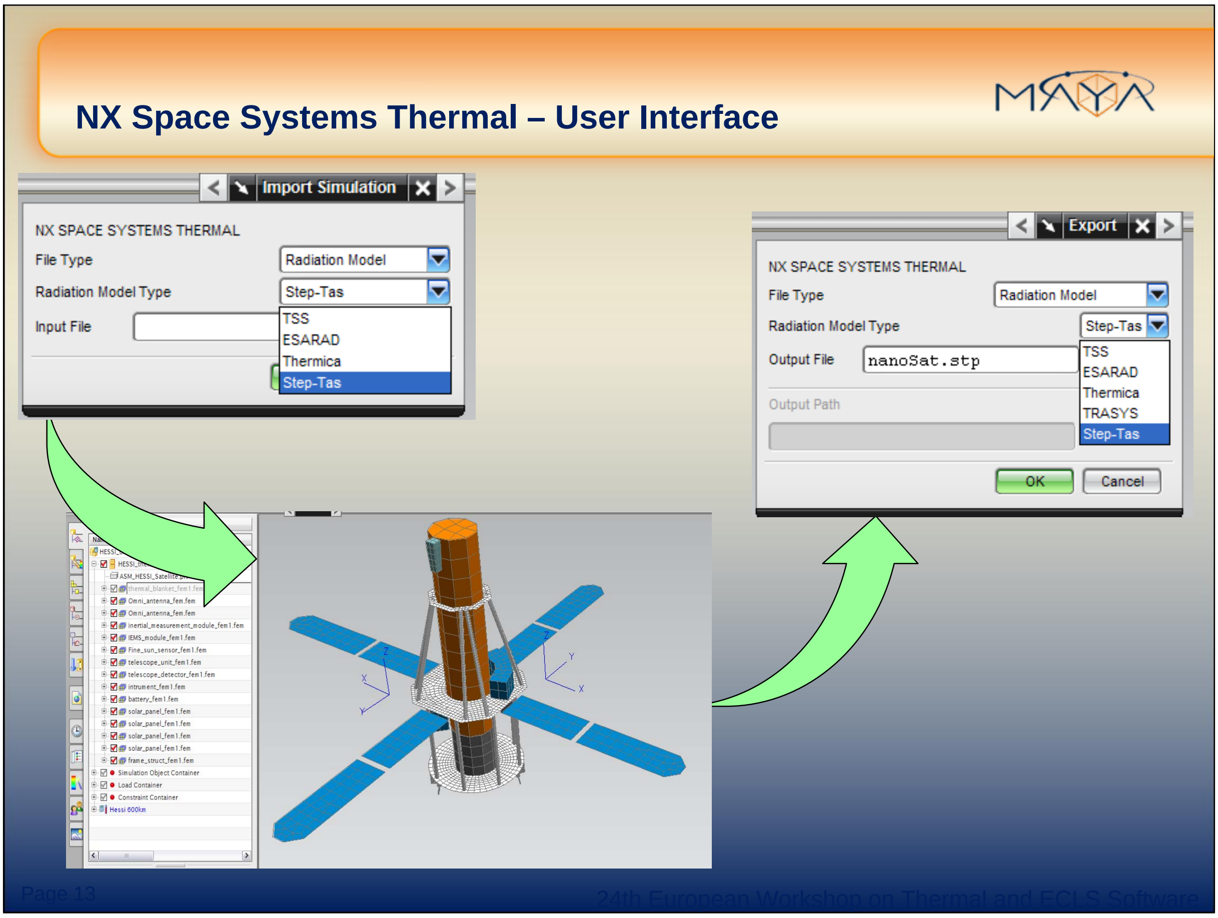
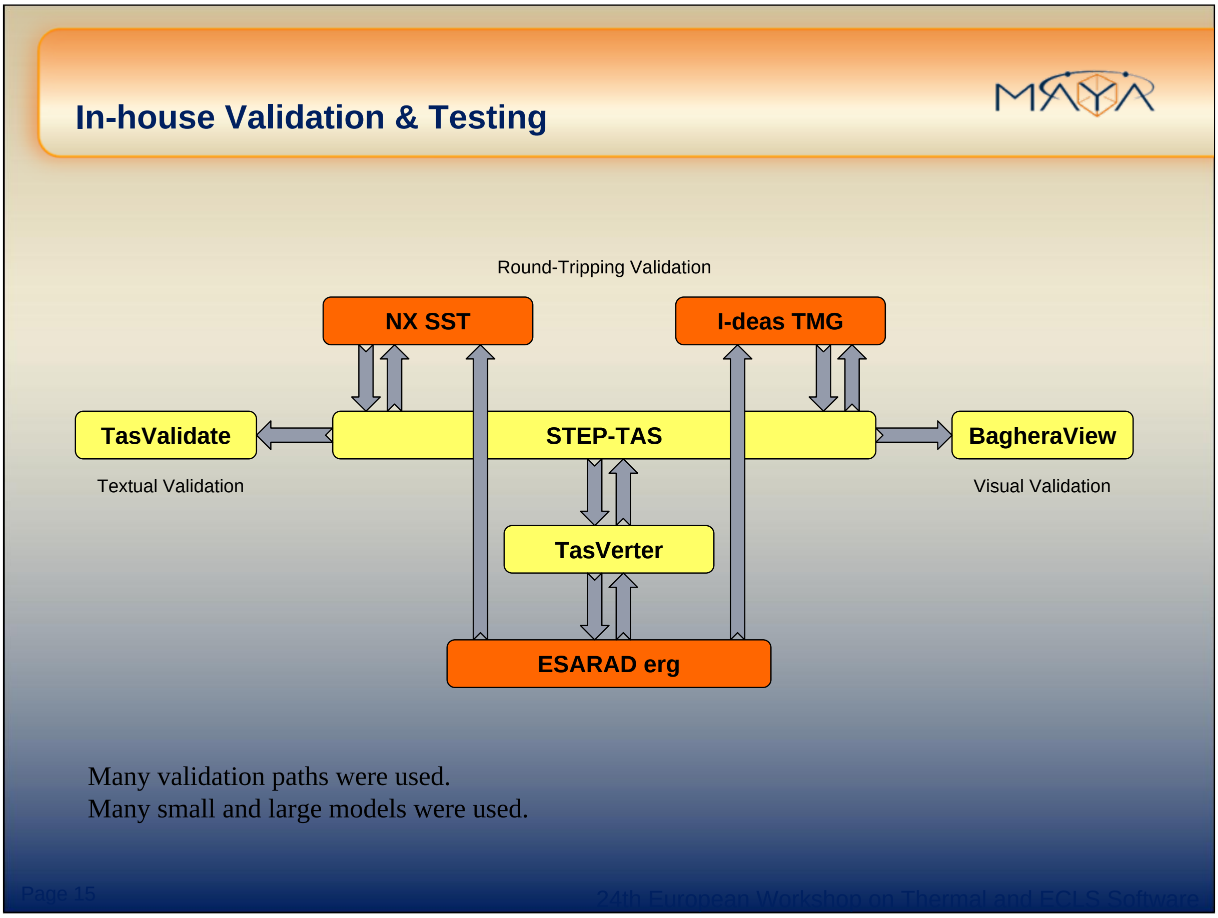

NX Space Systems Thermal – User Interface
MAYA
Import Simulation
NX SPACE SYSTEMS THERMAL
File Type
Radiation Model
Radiation Model Type
Step-Tas
Input File
TSS
ESARAD
Thermica
Step-Tas
Export
NX SPACE SYSTEMS THERMAL
File Type
Radiation Model
Radiation Model Type
Step-Tas
Output File
nanoSat.stp
Output Path
TSS
ESARAD
Thermica
TRASYS
Step-Tas
OK
Cancel


Validation & Testing
INNOVATE MORE


In-house Validation & Testing
MAYA
Round-Tripping Validation
NX SST
I-deas TMG
TasValidate
STEP-TAS
BagheraView
Textual Validation
Visual Validation
TasVerter
ESARAD erg
Many validation paths were used.
Many small and large models were used.
Page 15
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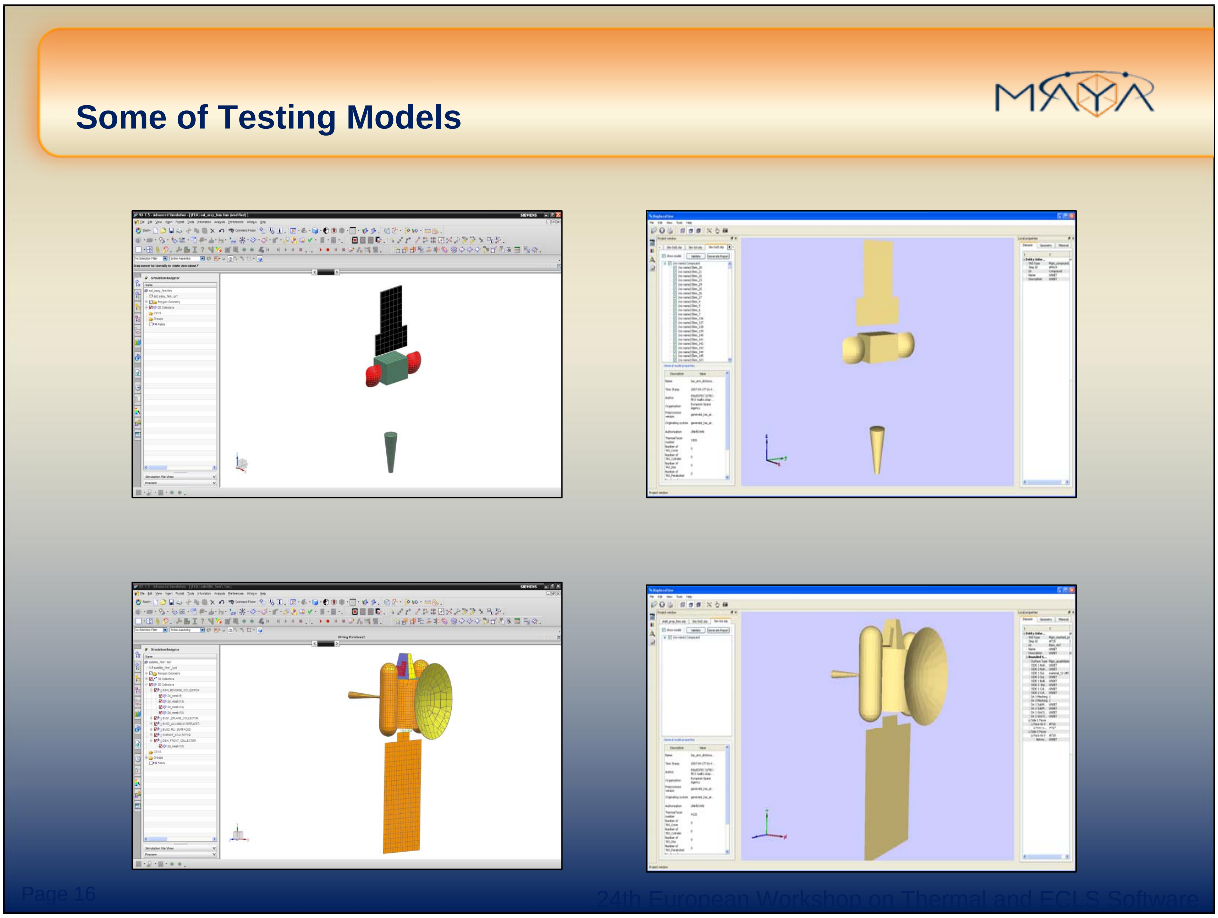
Some of Testing Models
MAYA
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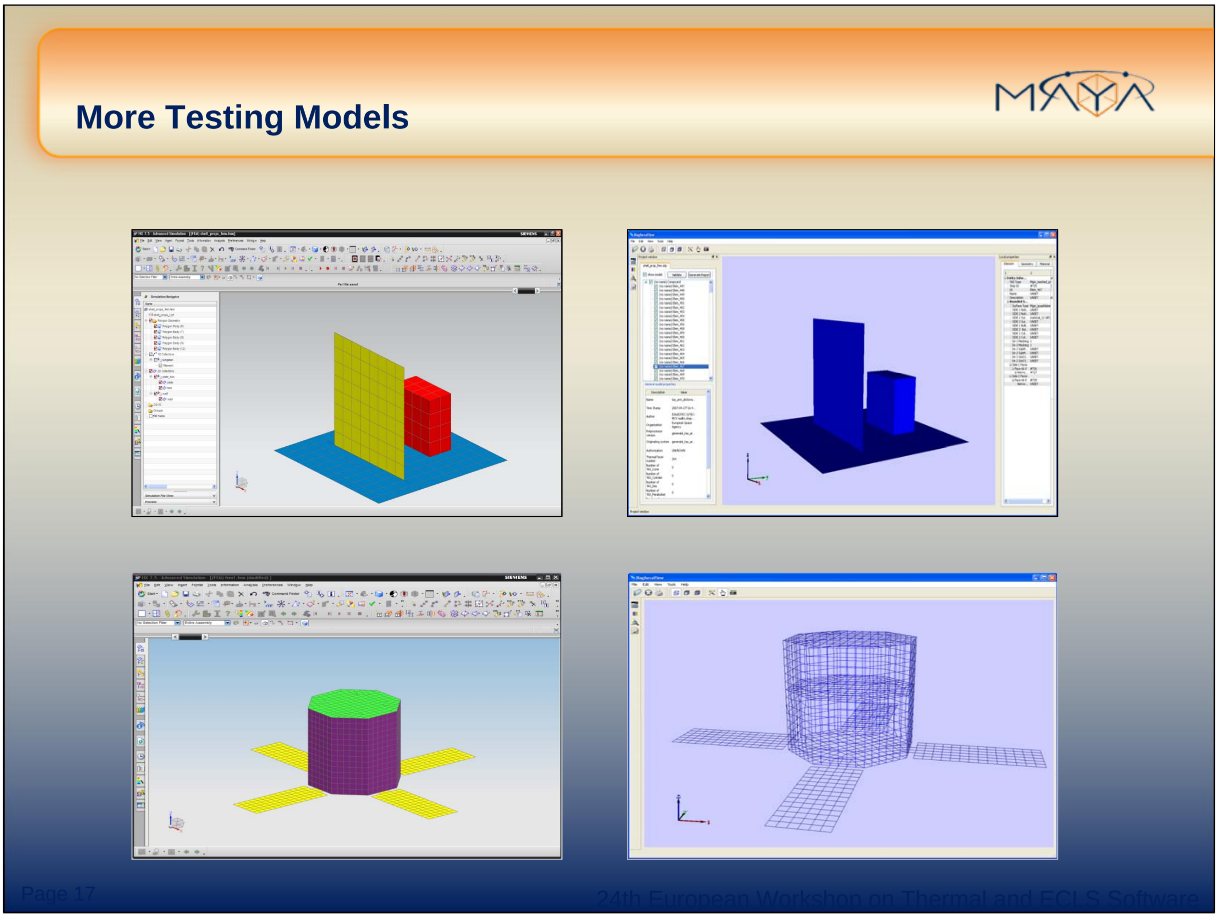
More Testing Models
MAYA
Page 17
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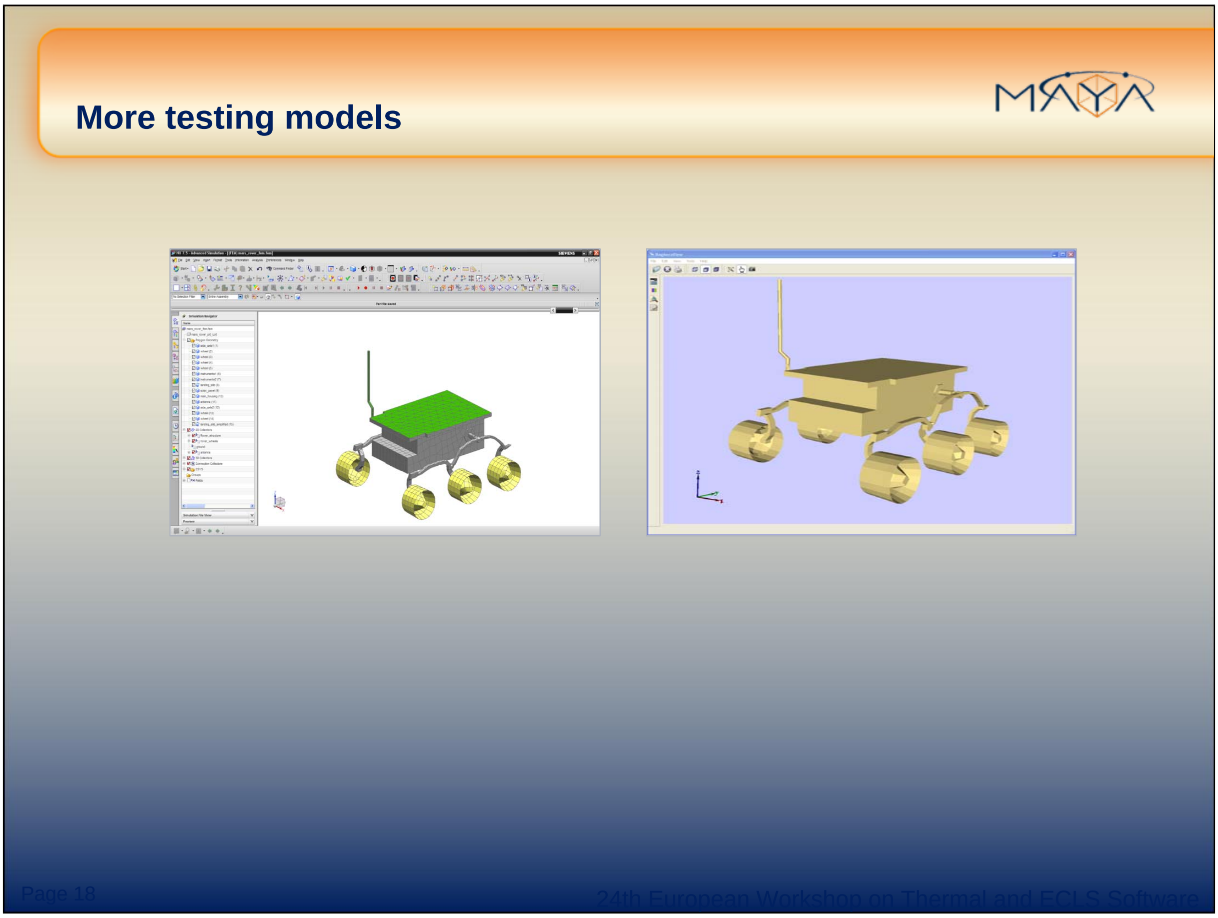
More testing models
MAYA
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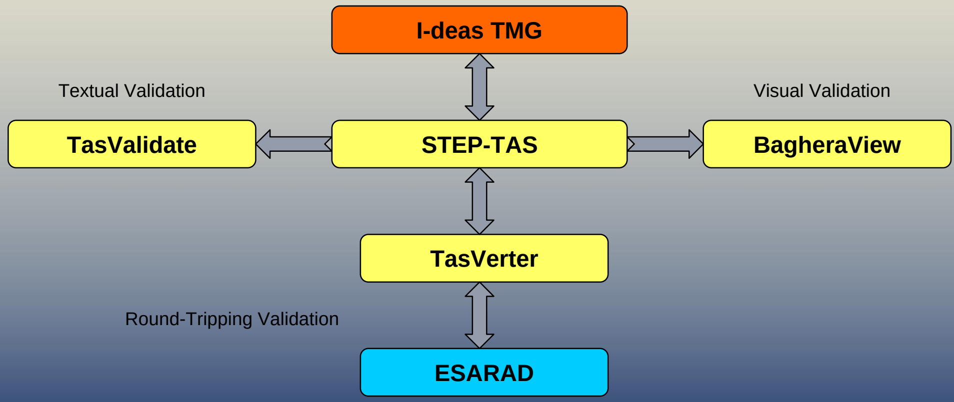
Off-site Validation & Testing

Hosted by EADS Astrium

Environment

- I-deas TMG version 12m1 / TASTMG beta rev.100225
- BagheraView-422
- TasValidate-v6
- TasVerter r2008-07-08
- ESATAN-TMS r2 (including Esarad)



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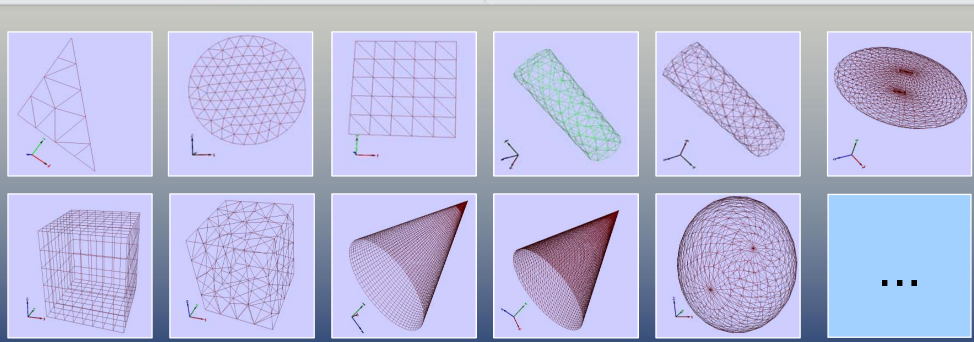
Validation – Exchange of different geometries

Test Cases	Models
• 2-dimensional geometry models	
▪ Triangle	002, 003, 004, 005
▪ Disc	102, 103, 104, 105
▪ Rectangle	112, 113, 114, 115, 900
• 3-dimensional geometry models	
▪ Box	400, 401, 800
▪ Cylinder	202, 203
▪ Discus	300
▪ Cone	500, 501
▪ Sphere	620
▪ Paraboloid	700



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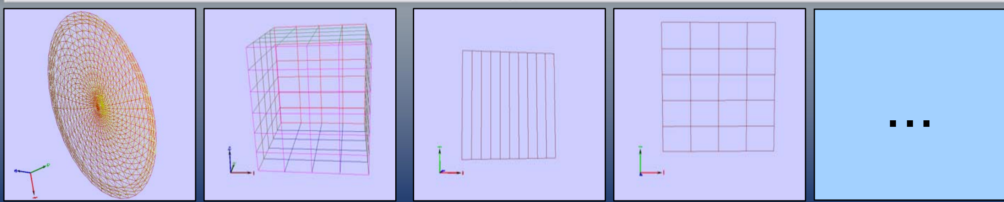
Validation – Exchange of different Meshes

Test Cases	Models
• Element Family	
▪ Lumped Mass	UpperStage
▪ Beam	UpperStage
▪ Thin Shell	All modeles
▪ Solid	UpperStage
• Element Order (Thin Shell)	
▪ Linear	002, 004, 102, 104, 112, 114, 202, 300, 400, 401, 500, 501, 620, 700, 800, 900, UpperStage, PCB
▪ Parabolic	003, 005, 103, 105, 113, 115, 203, 800, 900, UpperStage
• Element Topology (Thin Shell)	
▪ Tria	002, 003, 102, 103, 112, 113, 202, 203, 300, 401, 500, 501, 620, 700, UpperStage
▪ Quad	004, 005, 104, 105, 114, 115, 400, 500, 620, 700, 800, 900, UpperStage, PCB
• Free Meshing	002, 003, 004, 005, 102, 103, 104, 105, 202, 203, 401, 804, UpperStage
• Mapped Meshing	112, 113, 114, 115, 300, 400, 500, 501, 620, 700, 800, 801, 804, 900, UpperStage, PCB



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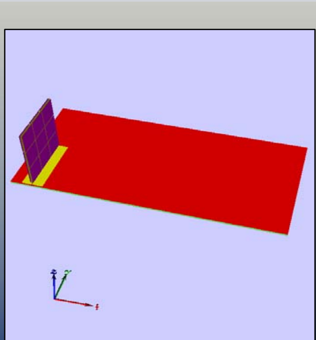
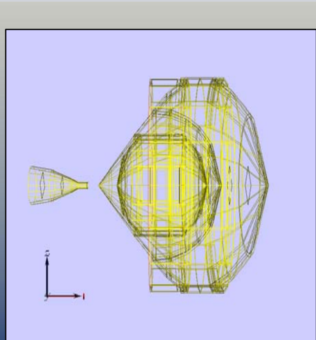
Validation – Materials & Physical Properties

Test Cases	Models
• Material Type	
▪ Isotropic	All models
▪ Anisotropic	800
▪ Orthotropic	800, UpperStage
• Material Property Types	
▪ Null Property	UpperStage
▪ Constant	800, UpperStage, PCB, all others
▪ Table	800, UpperStage
▪ Functions	800
• Physical Properties	800, 801, 804, UpperStage, PCB
• Active and Passive Side definition	900





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Demo
INNOVATE MORE


TASTMG, HessiSat, IIS, MarsRover
TASTMG
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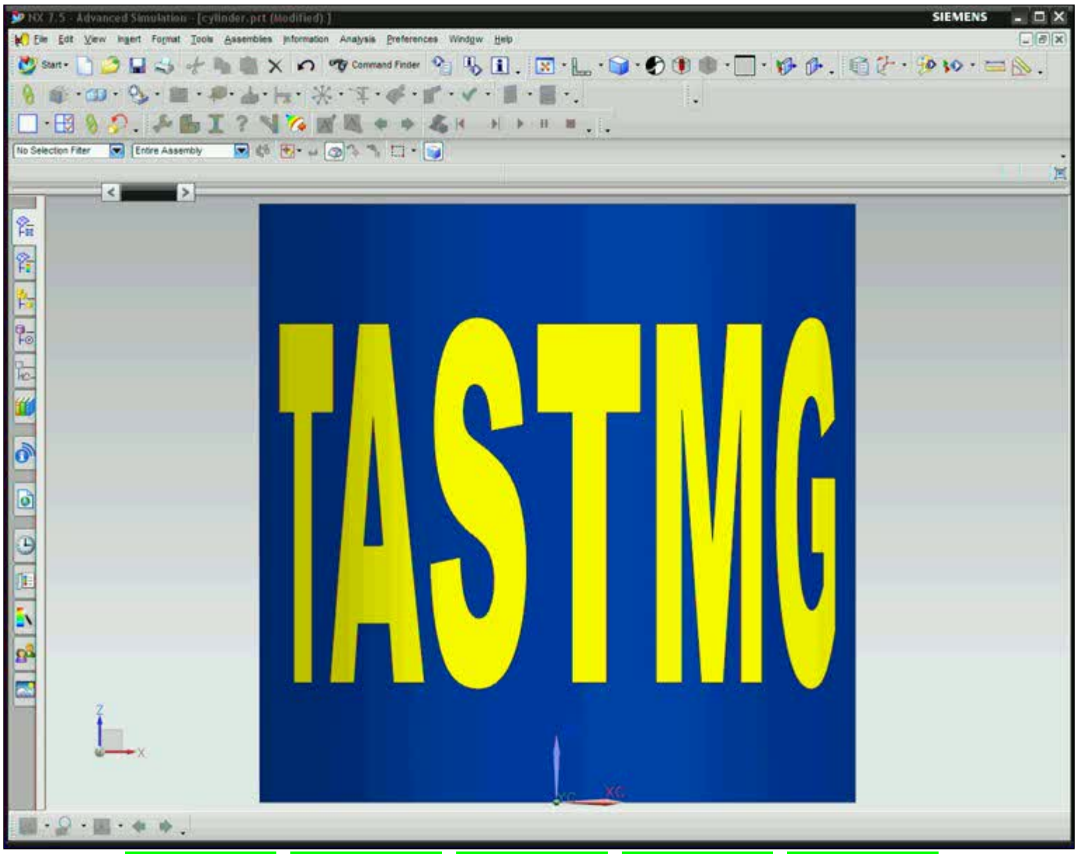
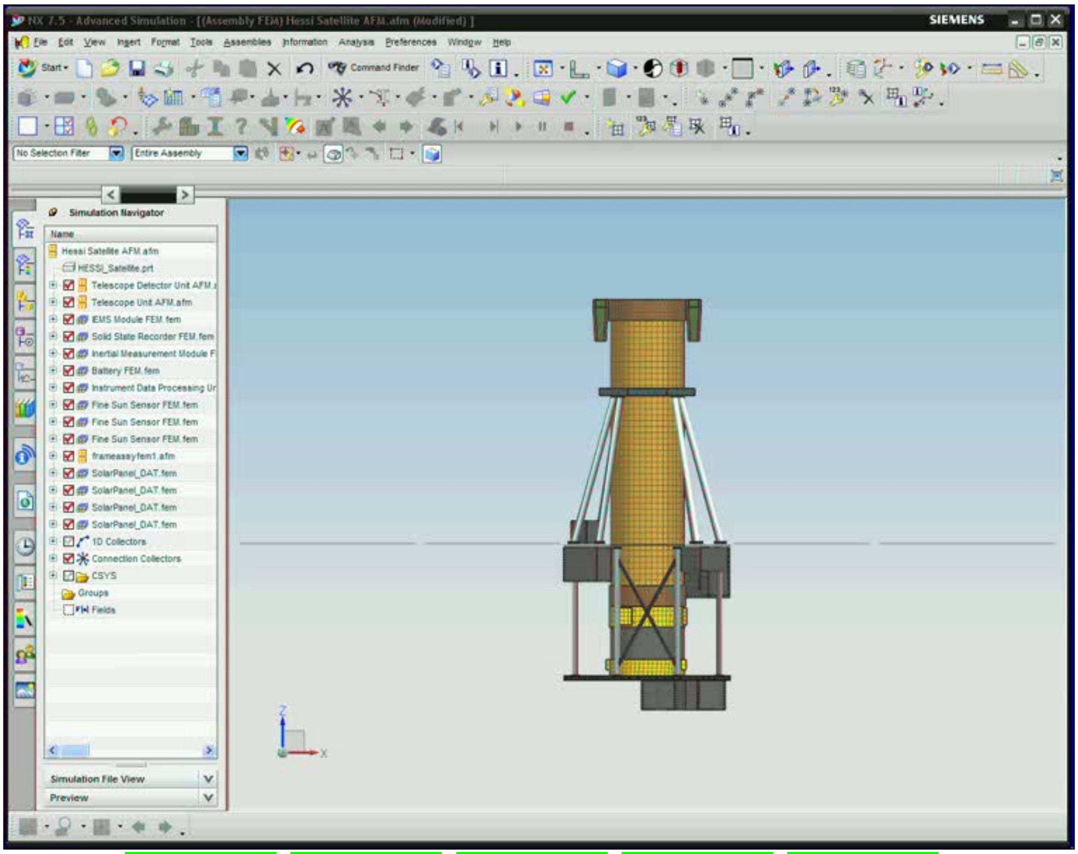
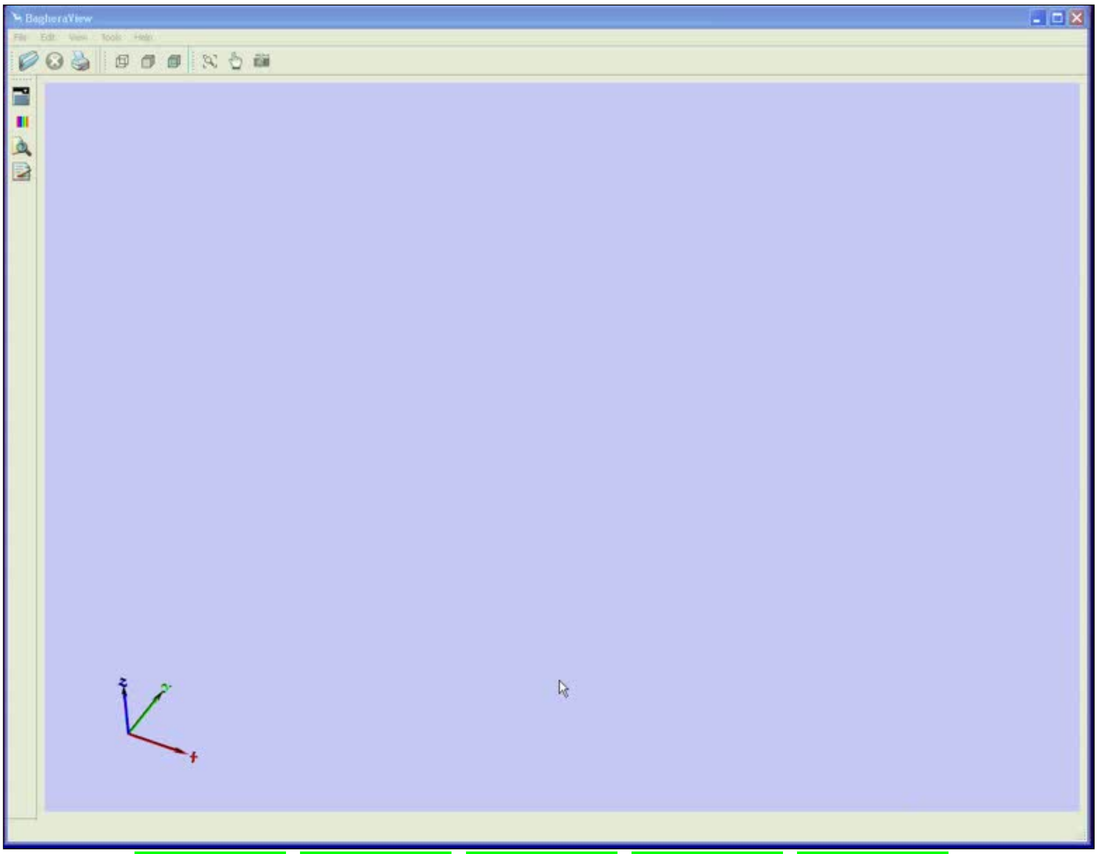


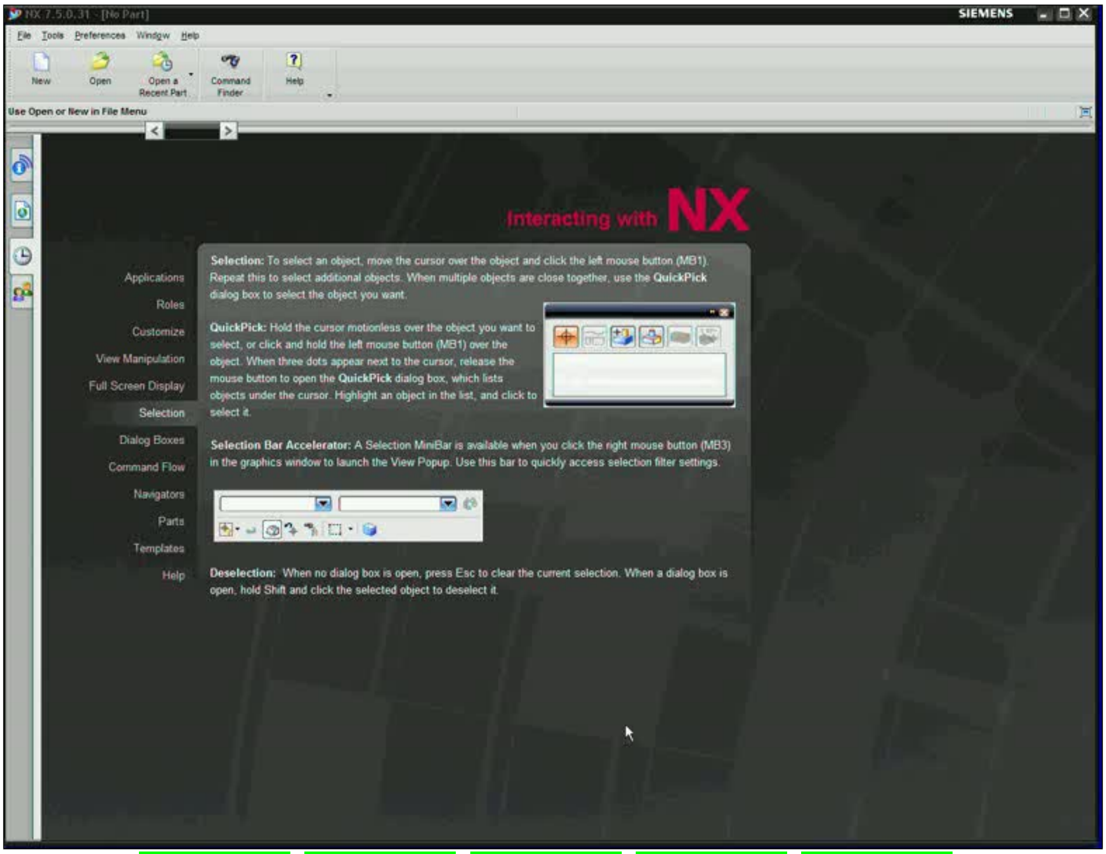
Slow Normal Fast Play/Pause Stop



Slow Normal Fast Play/Pause Stop

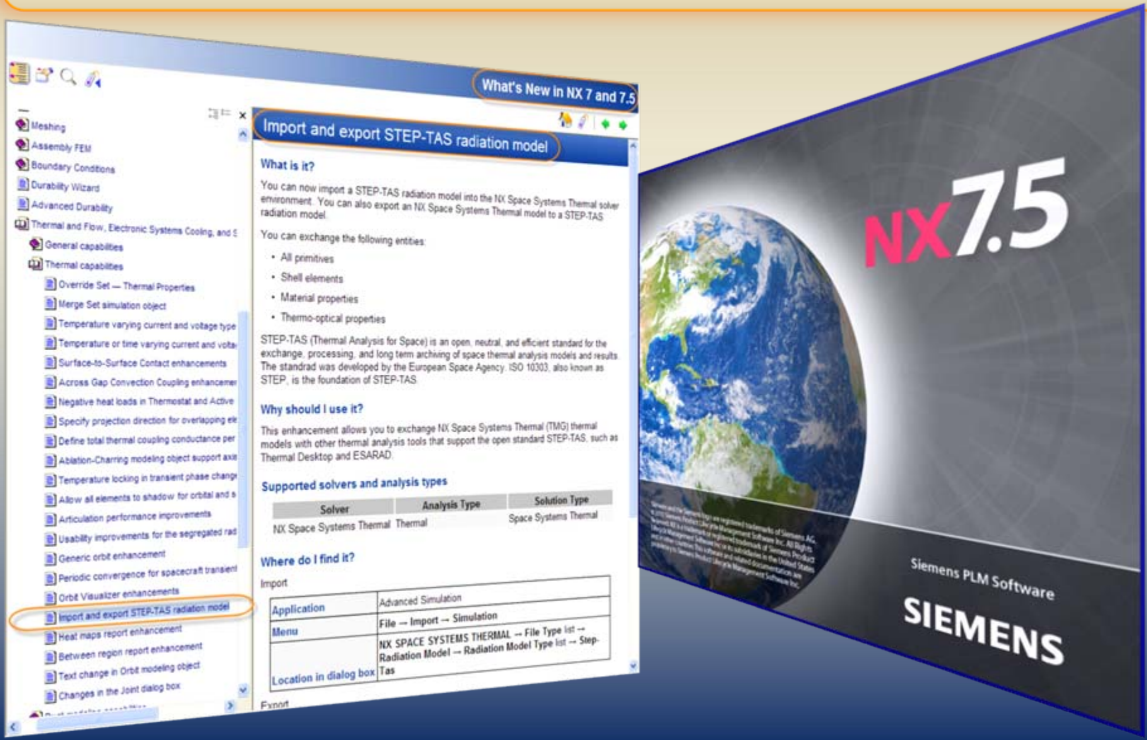


Slow Normal Fast Play/Pause Stop



Slow Normal Fast Play/Pause Stop

TASTMG v1.0 was released in NX7.5.0



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Acknowledgement

We do want to acknowledge ***Hans Peter de Koning*** from ESA/ESTEC, who was absolutely instrumental to the STEP-TAS development and provided support during the implementation of STEP-TAS interface in TMG.

A special thanks to:

Eric Lebegue from CSTB for providing C++ toolkit and STEP-TAS tools.

Harold Rathjen from EADS Astrium for conducting the validation and testing of TASTMG project.

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Thank you
INNOVATE MORE

Appendix E

Genetic algorithm shape optimisation of radiant heaters

Bryan Shaughnessy
(RAL, United Kingdom)

Abstract

The shape of radiant heaters can influence significantly the radiation distribution and therefore the effectiveness of heating processes. I will present an automated shape optimisation technique for tubular radiant heaters. A Genetic Algorithm was developed that optimises parameters describing the heater shape with respect to a user-specified radiation distribution over a work-piece. Three sample cases are presented that show the developed GA to be successful.

Genetic Algorithm Shape Optimisation of Radiant Heaters

Bryan Shaughnessy

RAL Space

RAL Space

Background

- Present previous research on shape optimisation of radiant heaters
- Is there an opportunity to include this or a similar approach in a thermal analysis tool?

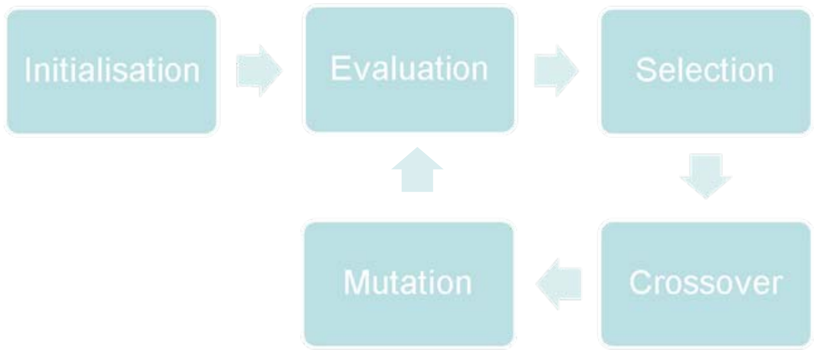
Applications

- Fluids loop routing
- Heater placement
- Thermal shield geometry

Genetic Algorithms (GAs)

- Evolve a population of candidate solutions
- Candidate solutions encoded as chromosomes
- Mathematical operations on chromosomes simulate evolution
  - Based on probability functions
  - GA parameters/probabilities may require tuning

Genetic Algorithms



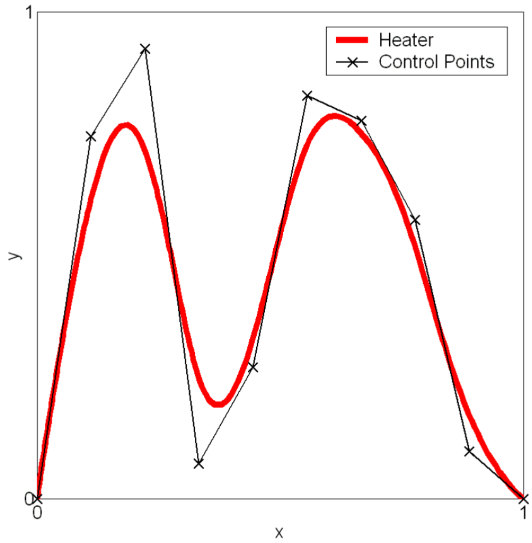
Brief Definitions

- Evaluation
  - Decode all chromosomes, solve, and rank
- Selection
  - Chromosomes selected for new population.
- Crossover
  - Promote exchange of information to produce ‘offspring’ solutions
- Mutation
  - Introduce variability into the population

Shape Representation

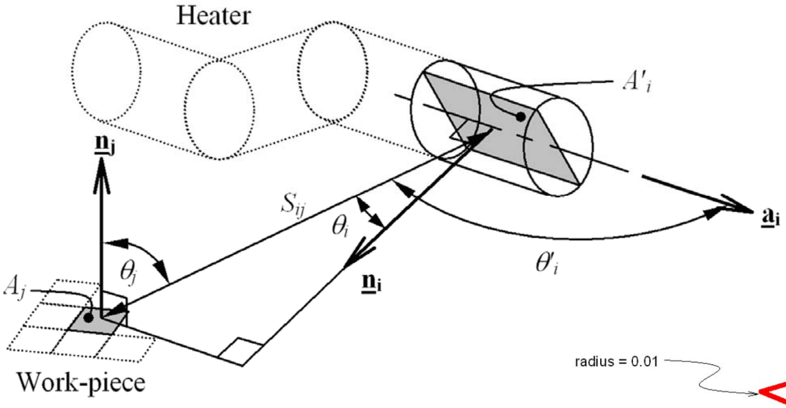
- Not practical to represent shapes in terms of coordinates
- B-Spline representation used
  - Complex shapes defined using small number of control points
  - Chromosome is the vector of control points: $[x_1, y_1, x_2, y_2, \ldots\ldots x_n, y_n]$
- Constraints (end-points, range of ordinates)

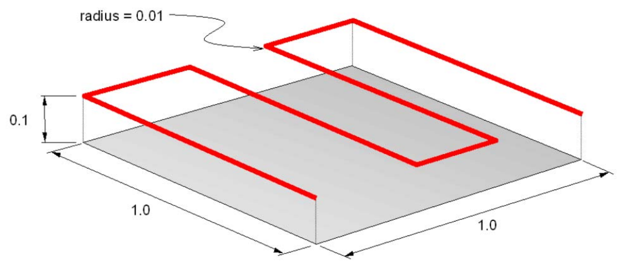
Geometry defined by B-Spline



RAL Space

Radiative Model





RAL Space

Performance Measure

- Compare view-factor distribution with a user-defined distribution
- Distributions normalised and average difference calculated
- Average difference → 0 for better heaters
- Population selection
  - Random selection using a cumulative density function
  - ‘Elitist’ approach

Initialisation of first Population

- Random initialisation of control points could give shapes with self-intersections
- To avoid this:
  - x-ordinates distributed evenly
  - y-ordinates allocated randomly

Crossover

- Select pairs of chromosomes according to probability P_c
- Swap the coordinates of each pair at a random point
- Example:

Before Crossover

A	B	C	D	E	F

1	2	3	4	5	6

After Crossover

A	B	3	4	5	6

1	2	C	D	E	F

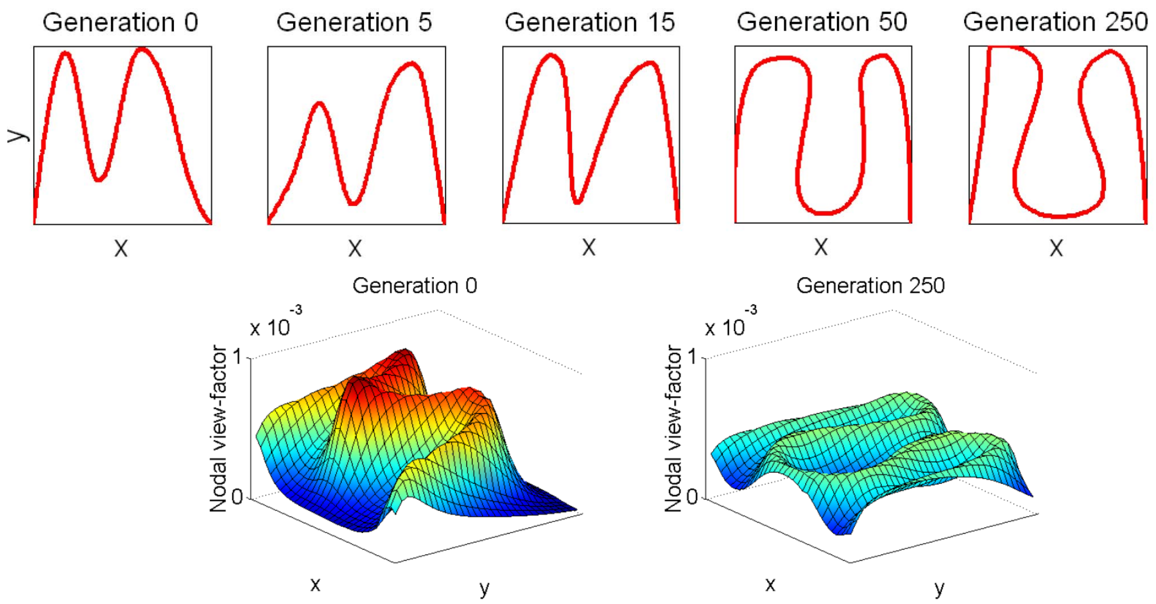
RAL Space

Mutation

- Ordinates selected according to probability P_m
- Selected ordinates modified by a random amount within a maximum allowable deviation
- Important because generates new control-points
  - With the floating-point representation, crossover does not generate new control-points

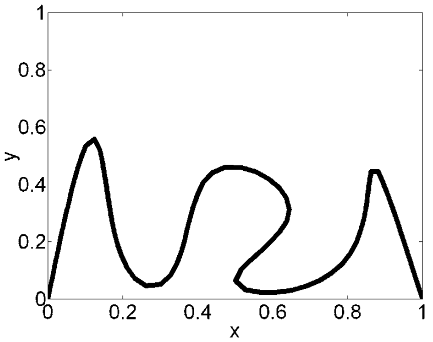
RAL Space

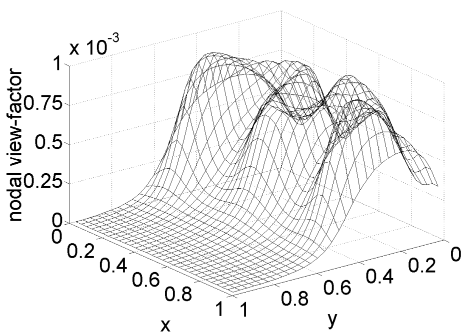
GA Simulation – Uniform



RAL Space

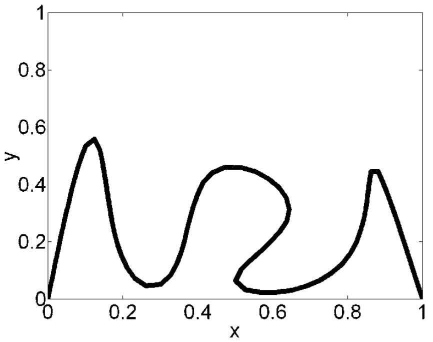
GA Simulation – Step

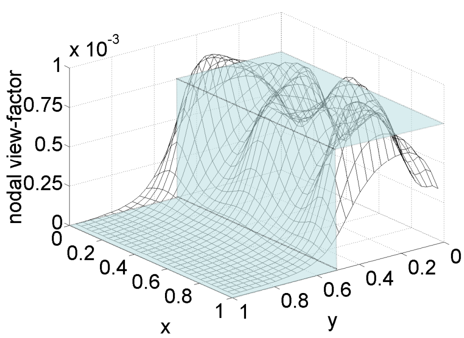




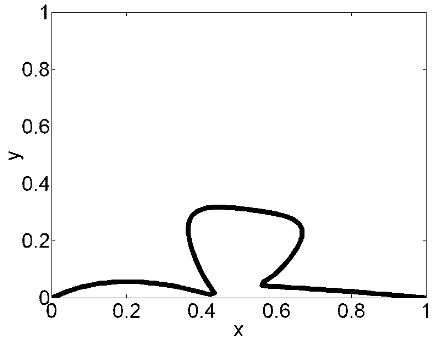
RAL Space

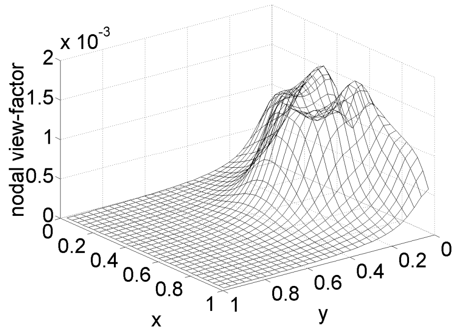
GA Simulation – Step



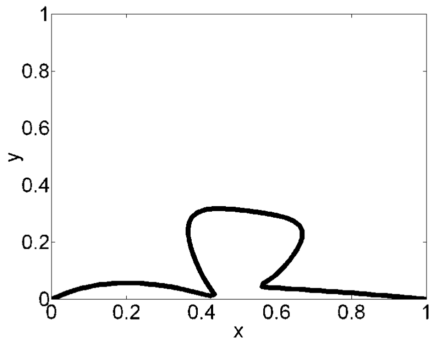


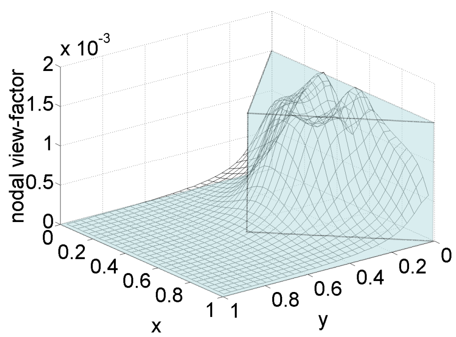
GA Simulation – Triangular Step





GA Simulation – Triangular Step





Conclusions

- Effective method of optimising radiant heater shapes
- Wider application?
  - Requires fast solvers
  - Requires effective methods of constraining/avoiding unrealistic geometry

Reference

- B. M. Shaughnessy and M. Newborough. “Genetic Algorithm Shape Optimisation of Radiant Heaters for Thermal Processing Applications”. International Symposium on Advances in Computational Heat Transfer, 2001

Appendix F

Development of numerical tools for design and verification of ablative thermal protection systems

Marco Giardino Elena Campagnoli
(Politecnico of Turin, Italy)

Gianni Pippia
(Sofiter System Engineering, Italy)

Massimo Antonacci
(Thales Alenia Space, Italy)

Abstract

In recent years there has been a great collaborative work between Thales Alenia Space Italia and the Energetic Department of Politecnico of Turin devoted to the study of ablative heat shields. Two different numerical tools for the analysis of the behaviour of charring ablative materials have been developed within the frame of a co-founded internal research program.
The first of these tools, called Ablatherm, is a Matlab®-based code that can be used during the initial design phase: it implements a simple model (that uses a very reduced set of material properties), it has a short case settings time and execution time and it is very flexible (it can be used both through a script file or a Graphical User Interface). This tool was tested using analytical benchmarks and real test cases and is now used by TAS-I for heat shield design.
The second tool, still under development, uses the state of the art both for the model and for the tool implementation, in order to perform rapid, full 3D simulations. This tool, developed on OpenFoam platform, implementing a more complex model and requiring higher test case setup time and a huge amount of material data that must be provided for a full run, is mainly intended for final verification of the full system configuration. For an intermediate design phase, it is also possible to use this second tool with a reduced set of parameters.

DEVELOPMENT OF NUMERICAL TOOLS FOR DESIGN AND VERIFICATION OF ABLATIVE THERMAL PROTECTION SYSTEMS

Marco Giardino (Politecnico of Turin, Italy)
Elena Campagnoli (Politecnico of Turin, Italy)
Gianni Pippia (Sofiter System Engineering, Italy)
Massimo Antonacci (Thales Alenia Space, Italy)

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- Ablative heat shields
- Characteristic of the used models
- 1D model –" *AblaTherm*"
  - Specifications
  - Necessary data
  - Implementation
  - Validation vs. CMA
  - Validation vs. SAMCEF Amaryllis
- 3D model
  - Specifications
  - Necessary data
  - Implementation
  - Test case definition
  - Test case results
  - Validation vs. "*AblaTherm*"
- Future works

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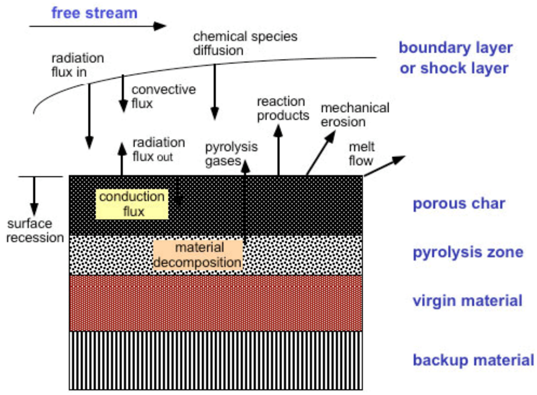
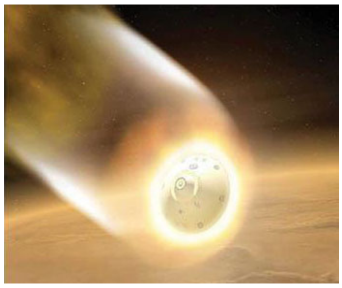
Ablative heat shields

- Not reusable.
- Light weight.
- Adaptable to mission constraints.
- Heat insulation properties enhanced through material degradation.
- Suitable for entry vehicle and SRCs.





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Characteristic of the used models

1D MODEL "*ABLATHERM*"

- Local 1D assumption.
- Simple model.
- Reduced set of parameters.
- Multi layer capability.
- Extremely low set up time and execution time.
- Ideal during initial design phase.

3D MODEL

- Full 3D Cartesian solver.
- State of the art model.
- High number of parameters (possible use of a reduced set).
- Multiple material within the domain
- Is not too much user friendly.
- Relatively long set up and run time.
- To be used for final, full body simulation.

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1D Model – Analytical model

- One equation model (energy conservation)+BC:

$$\begin{cases} \left(\rho c_p(\rho,T)\right)\dfrac{\partial T}{\partial t}+-\dfrac{\partial}{\partial x}\left(\lambda(\rho,T)\dfrac{\partial T}{\partial x}\right)+H(T)\dfrac{\partial \rho}{\partial t}=0 \\ T(t=0)=T_0(x) \\ \lambda\dfrac{\partial T}{\partial x}(x=0,t)=q_c(t) \\ \lambda\dfrac{\partial T}{\partial x}(x=s(t),t)=q_w(t) \end{cases}$$

- Charring material (Arrhenius equation).
- Internal heat flux $q_c(t)$: adiabatic, convective and/or radiative heat flux.
- Surface heat flux boundary condition:

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

1D Model – Necessary data

- Material properties:
  - Virgin and charred densities.
  - Arrhenius coefficients.
  - Pyrolysis reaction and surface recession enthalpy.
  - Temperature dependence of specific heat, thermal conductivity, surface emissivity, both for virgin and charred material.
- Heat flux data (as function of surface temperature, cold wall evaluation, net values).

1D Model - Implementation

- Finite Element Method (FEM) discretisation.
- Non linear Newton-Raphson method for fast and accurate non linearity resolution (surface radiation).
- Automatic grid generation, with linear plus logarithmic spacing; for multi layer cases, the number of elements per layer calculated through mean conductivity.
- Blowing evaluation at run time.
- Initial steady state temperature distribution evaluation.
- Implemented using Matlab© environment .
- Usable as command line function or through a Graphical User Interface (GUI).

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1D Model - Validation vs. CMA

- Performed by means of comparison with commercial 1D software (CMA):
  - Test cases → sizing of a silicon based ablator on different areas of the external surface of a re-entry vehicle.
  - Available thermal-ablative properties have been implemented in both codes.
  - Thermal simulation extended in the 1D simplified code to the reproduction of the convective and radiative heat exchange inside the vehicle.
  - The pyrolysis heat behaviour as function of material temperature has been introduced in AblaTherm.
- W.r.t. CMA, AblaTherm does not account for:
  - Surface transport of chemical energy.
  - Convective transfer by pyrolysis gases: $\rho c_P \frac{\partial T}{\partial t} = \lambda \frac{\partial^2 T}{\partial x^2} + \frac{\partial \lambda}{\partial x}\frac{\partial T}{\partial x} - H\left(-\frac{\partial \rho}{\partial t}\right) + \frac{\dot{m}_g}{A}\frac{\partial h_g}{\partial x}$
- Difference in sizing results lower than <10%.

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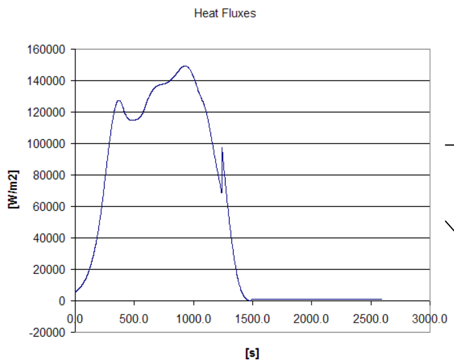
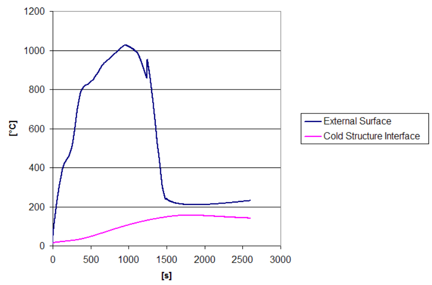
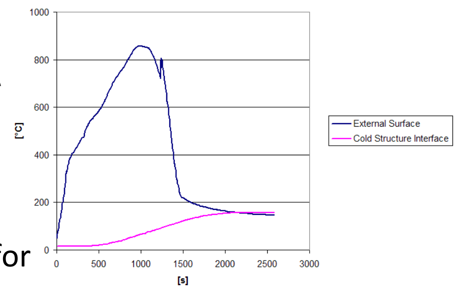
1D Model - Validation vs. CMA





CMA simulation



AblaTherm simulation

- Case on vehicle re-entry.
- Different modelling of surface thermo-chemistry.
- Sizing results (i.e. shield thickness) differ for less than 10%.

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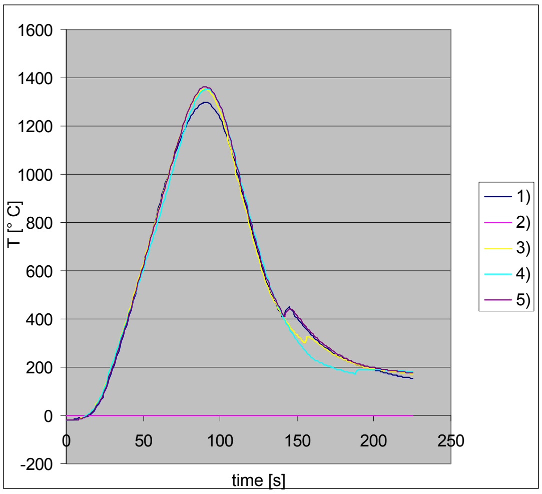
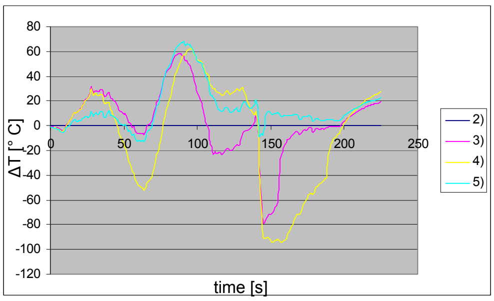
1D Model - Validation vs. SAMCEF Amaryllis

Comparison with simulation results of a Mars entry vehicle frontshield:

SHIELD SURFACE





1) Amaryllis simulation results
2) Empty
3) AblaTherm results, with prescribed heat fluxes correction
4) AblaTherm, with ABLAT heat fluxes correction
5) AblaTherm, with foam conductivity as function of atmospheric pressure

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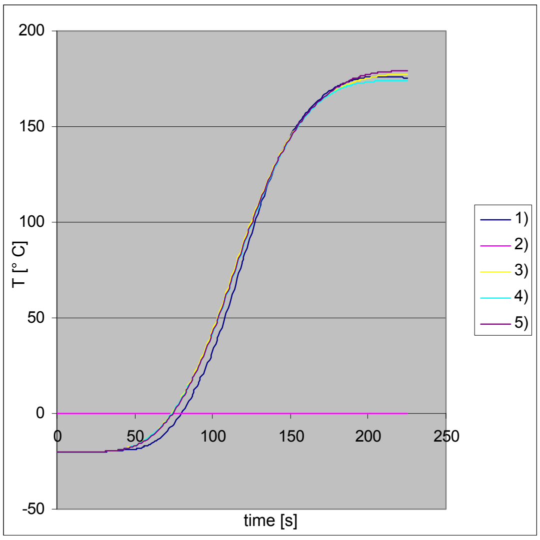
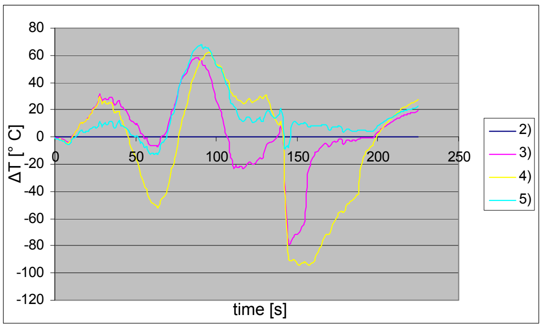
1D Model - Validation vs. SAMCEF Amaryllis

Comparison with simulation results of a Mars entry vehicle frontshield:
ABLATIVE/COLD STRUCTURE INTERFACE





1) Amaryllis simulation results
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4) AblaTherm, with ABLAT heat fluxes correction
5) AblaTherm, with foam conductivity as function of atmospheric pressure

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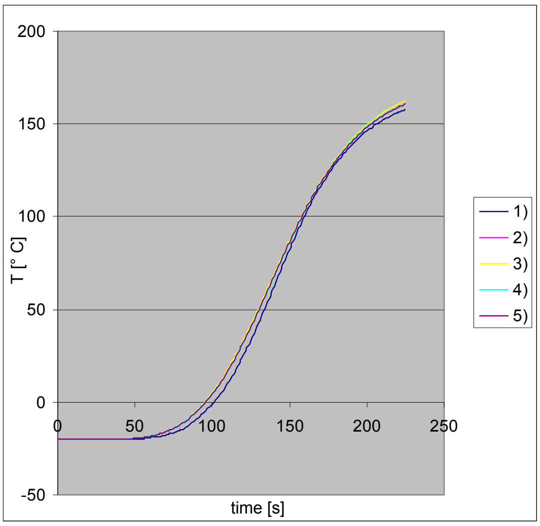
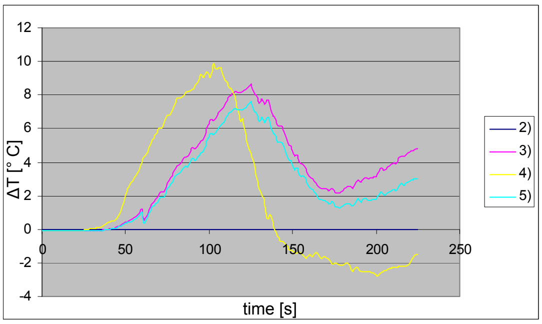
1D Model - Validation vs. SAMCEF Amaryllis

Comparison with simulation results of a Mars entry vehicle frontshield:
COLD STRUCTURE/INTERNAL FOAM INTERFACE





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5) AblaTherm, with foam conductivity as function of atmospheric pressure

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3D Model – Analitical model

- 3 equation model (energy, solid mass and gas mass conservation equations) + closure equations (Ideal gas law, Darcy law) + BC (Amar, A. J. “Modeling of One-Dimensional Ablation with Porous Flow Using Finite Control Volume Procedure”, *North Carolina State University,* **2006**).

$$
\begin{cases}
\frac{d}{dt}\int_V \rho e dV + \oint_{\partial V} \phi \rho_g h_g \vec{v}_g \cdot \vec{n} dS - \oint_{\partial V} k \nabla T \cdot \vec{n} dS - \oint_{\partial V} \rho h \vec{v}_{mesh} \cdot \vec{n} dS = 0 \\
\frac{d}{dt}\int_V \rho_i dV - \oint_{\partial V} \rho \vec{v}_{mesh} \cdot \vec{n} dS = \int_V \dot{m}_i dV \qquad \text{for } i = 1,..,n \\
\frac{d}{dt}\int_V \phi \rho_g dV + \oint_{\partial V} \phi \rho_g \vec{v}_g \cdot \vec{n} dS - \oint_{\partial V} \phi \rho_g \vec{v}_{mesh} \cdot \vec{n} dS = \int_V \dot{m}_g dV \\
\vec{v}_g = -\frac{K}{\phi \mu} \nabla p \\
p = \rho_g \frac{\Re T}{M_g}
\end{cases}
$$

- Pyrolysis gas in local thermal equilibrium.
- Pyrolysis energy absorption through mixture internal energy evaluation.
- Charring material (Arrhenius equation).
- Surface BC under development.

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3D Model – Necessary data

- Material and gas properties:
  - Virgin and charred sub-densities and Arrhenius coefficients for each decomposition reaction, material composition coefficients.
  - Solid: temperature dependence of specific heat, thermal conductivity, surface emissivity, both for virgin and charred material. Extent of reactions dependence of porosity and gas permeability.
  - Gas: temperature dependence of specific heat, gas molecular mass and viscosity.
  - Formation enthalpy and reference temperature for virgin, char and gas.
- BC: different standard conditions, some specific under development.

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3D Model - Implementation

- Finite Volume Method (FVM) discretization.
- Implemented using the open source OpenFOAM suite. Advantages:
  - parallel run in both shared and distributed memory machines (MPI protocol, on workstation or clusters).
  - Based on open source platform (Linux) and open source suite.
- Use unstructured grid (complex geometric shapes, different cell shapes).
- Grid importation capabilities.
- Simplified model wich can run neglecting the gas effects (non gas data needed)

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3D Model test case

- Geometry and grid: 10x10 cm, 100x400 cells.
- Boundary conditions:
  - North side: time variable, uniform external heat flux :

$$q(t)=\left((t<100)\cdot 11e6\cdot\left(\sin \pi t/100\right)^2+(t\geq 100)1000\right)\left[W/m^2\right]$$

    with surface reradiation; time variable uniform pressure:

$$p(t)=\frac{2e5}{200}\cdot t\ [Pa]$$

  - South and East side: adiabatic and impermeable.
  - West side: impermeable, time variable uniform temperature:

$$T(t)=2500\cdot\left(\sin\left(\frac{\pi t}{1000}\right)\right)^2+300\,[K]$$

- Material data: PICA15 - NASA TM 110440 (1997).

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3D Model Results – 1

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- Performances: solution time on a 8-core workstation → 1400 s.
- Following movie description:
  - Background color: material density (red → max, blue → min).
  - Colored lines: isotemperature lines, colored with temperature scale; lines at [(300:20:400) (600:200:3800)] K.
  - Vectors: oriented using pyrolysis gas velocity and colored using pyrolysis gas velocity magnitude.

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ThalesAlenia Space

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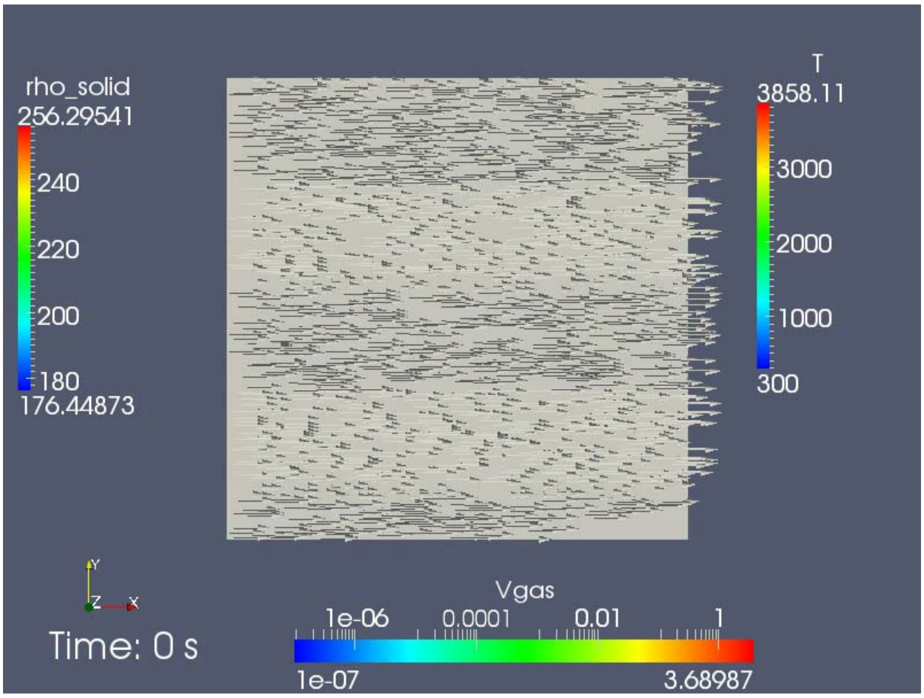

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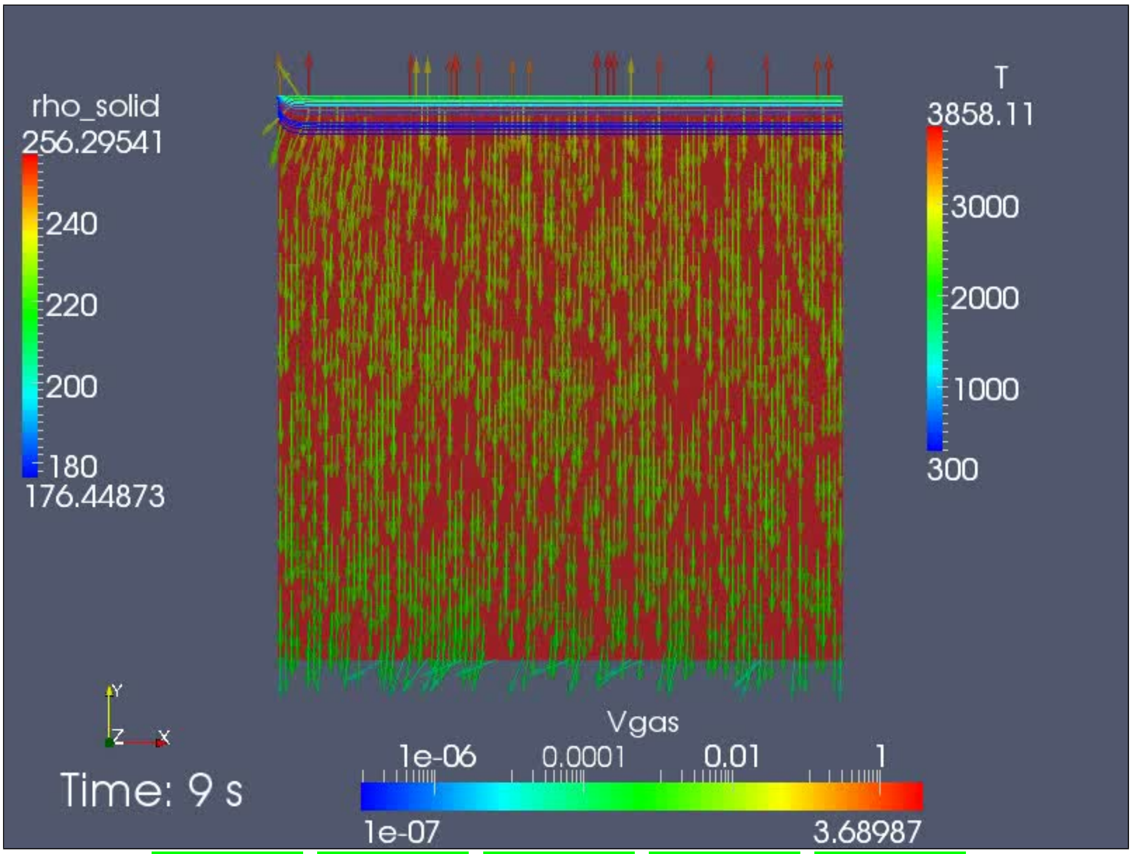

Slow Normal Fast Play/Pause Stop

3D Model Validation vs. AblaTherm

- The solutions obtained using the two codes are compared. To perform the comparison, the following steps were performed:
  - Ablatherm run was performed neglecting surface recession and applying the same profile for the heat flux (without the blowing correction).
  - 3D code run: temperature solution extracted on the East side of the domain (negligible 2D effects).

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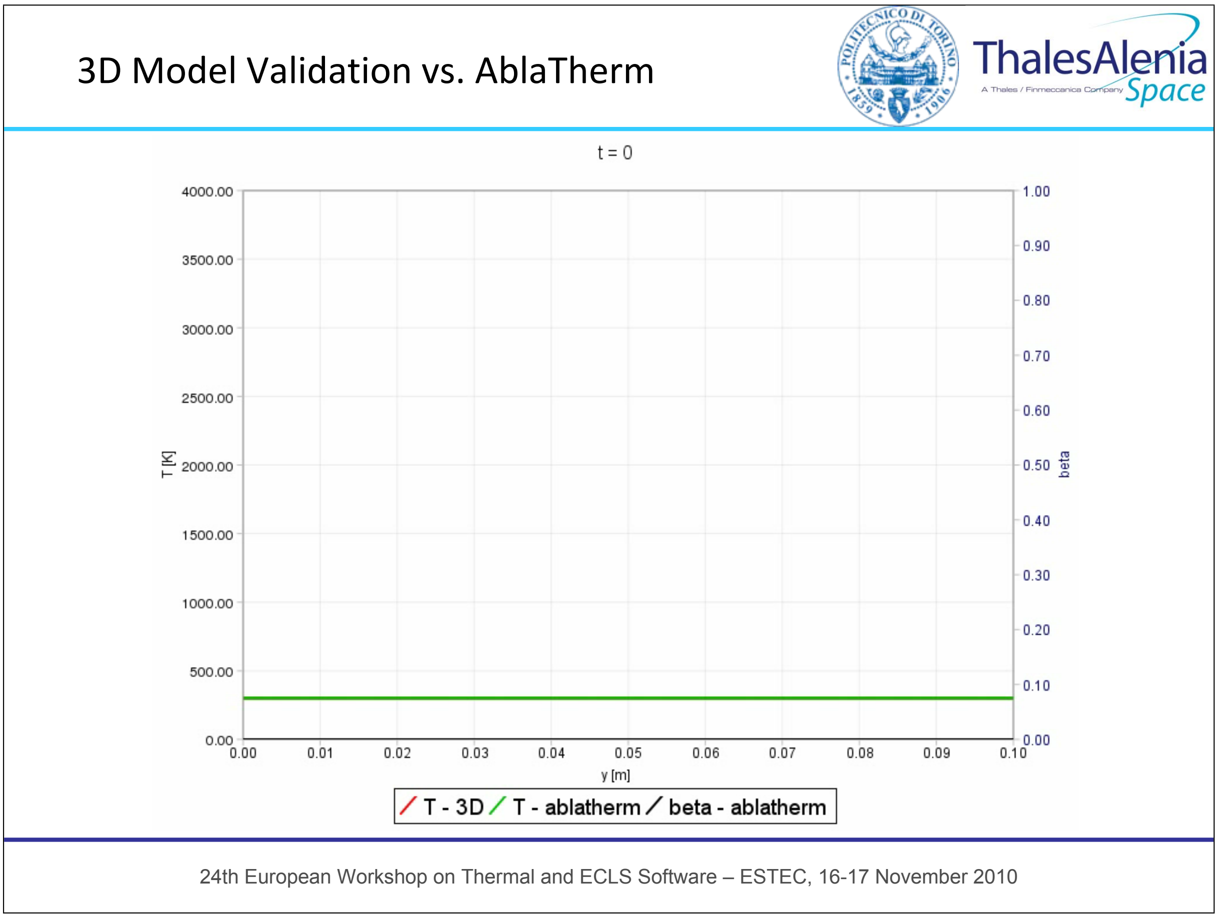
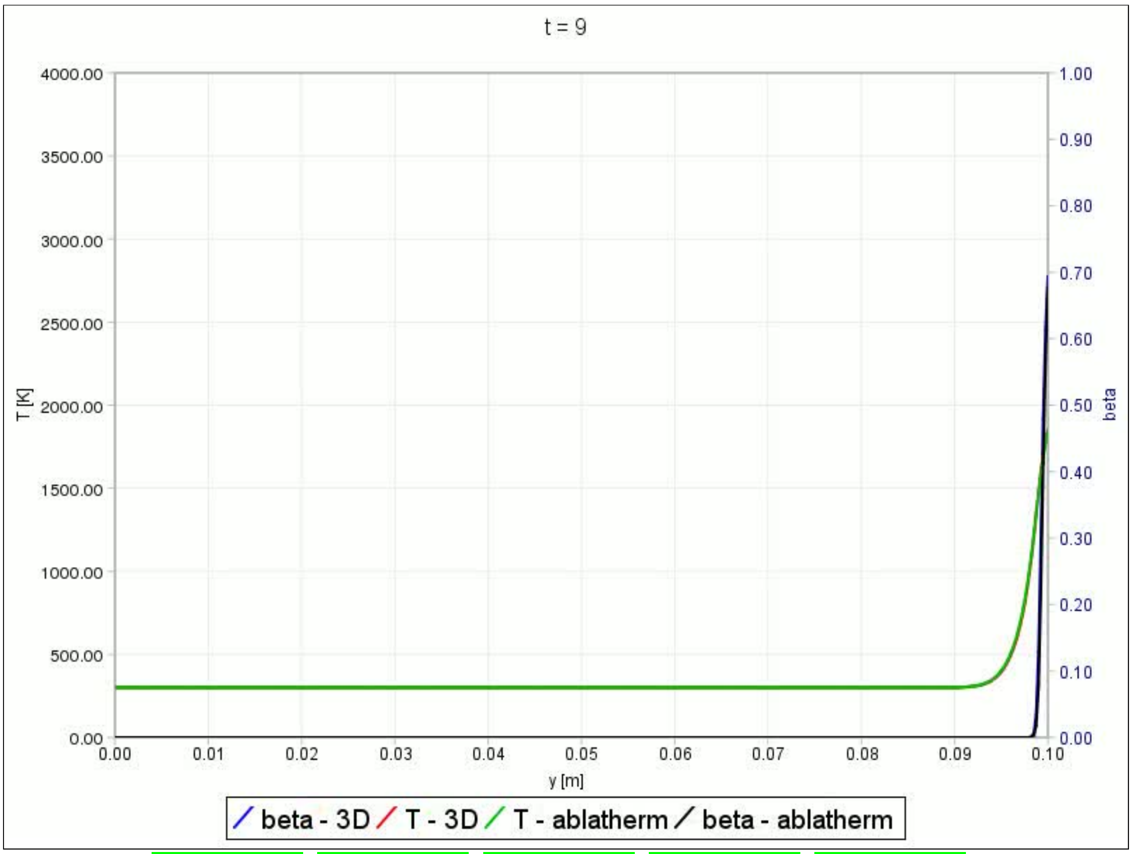
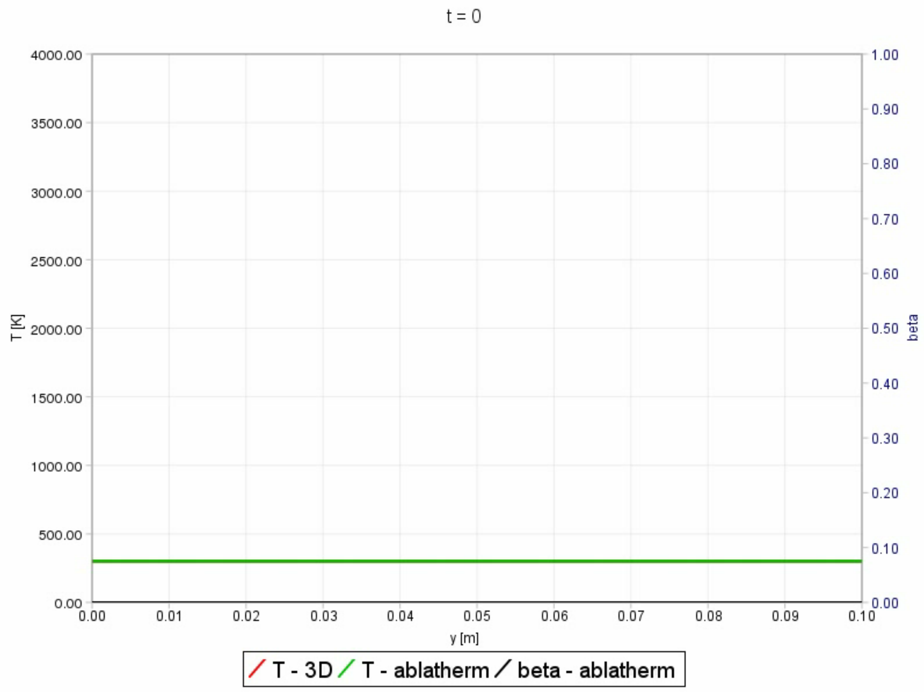




Slow Normal Fast Play/Pause Stop

3D Model Validation vs. AblaTherm



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Future works

- Finalization of the 3D code:
  - surface recession models implementation.
  - Different surface heat flux Boundary Conditions implementation.
- Studies for integration with ESATAN.

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ANY QUESTIONS?

THANKS FOR YOUR ATTENTION.

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Appendix G

ESATAN2SS tool
from ESATAN to Space State

Savino De Palo
(Thales Alenia Space, Italy)

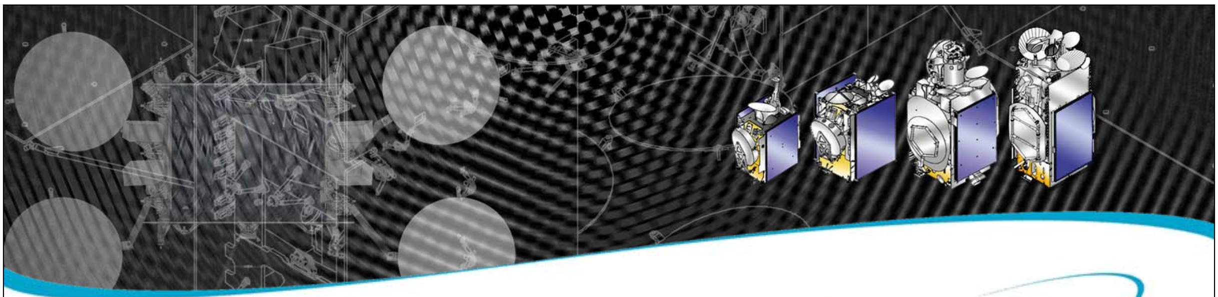
Donata Pietrafesa
(Sofiter System Engineering, Italy)

Abstract

ESATAN2SS tool, developed and working in MATLAB, is a fast means to compute Linear Time-Invariant (LTI) models directly from ESATAN TMMs: in other words it translates ESATAN (non-linear) thermal networks into (linear) Space State models by computing matrixes A, B, C, D.

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

Its main field of application is the design of control systems, such as the design of heaters with PID control laws, based on GOCE and HERSCHEL heritage.
To speed up the design of such systems it is useful to apply the (linear) Control System theory. For this purpose, it is usually required to have a model in the form of Space State (SS) or equivalent Laplace Transfer Functions (LTF). ESATAN2SS provides a simple and user-friendly way to derive the SS form by linearization of heat balance equations. In turn, the equivalent LTF can be derived with the simple formula $G(s) = C(sI - A)^{-1}B + D$.
The tool has been verified for several models: in all these cases the LTI models provides the same response as the original TMMs, showing that the ESATAN2SS linearisation correctly represents the thermal network. To make its utilization easier for first-time users, it is available in-house with simple run test cases documented as tutorials.
The navigation spacecraft Galileo is the first application of ESATAN2SS on a complex model, with significant analysis time savings. From now on, it is planned to use ESATAN2SS on all future applications where the use of Control System theory could have a positive impact both on design optimization and analysis time.



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ESATAN2SS

Savino De Palo – *TAS-I Turin*

Donata Pietrafesa – *SSE Turin*

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Table of Contents

Page 2

- Introduction
- Esatan Data
- Input / Output options
- Software Validation
- Galileo experience
- Lessons learnt
- Conclusions

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Introduction

Page 3

- What does it do?

ESATAN2SS → from ESATAN to State Space

ESATAN – TMM → State Space

$T = f\,(Q, GL, GR, C\ldots)$

$$\begin{cases} \dot{x} = Ax + Bu \\ y = Cx + Du \end{cases}$$

A state matrix

B input matrix

C output matrix

D feedthrough matrix

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Introduction

Page 4

x (state vector) → Temperatures array for nodes with C≠0

u (input vector) → Temperature boundaries array + Heat Loads array (over all non-boundary nodes)

y (output vector) → Temperatures array (also for C=0)

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Introduction

Page 5

- Why develop it ?
  - (linear) Control System theory → **Speed up** heaters active control systems design
- Why State Space form?
  - Control designer requires a model as → **State Space** / **Transfer Function**

SS → by linearization of heat balance equations

LTF → $G(s)=C(sI-A)^{-1}B+D$

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Introduction

Page 6

ESATAN2SS 2.6 main features:

- MATLAB script → Pre-parsed version (esatan2ss.p, esatan2sshelp.m)
- Automatic recognition of Arithmetical Nodes → $T_{\text{NODES with C=0}} \notin x$
- No GUI → >>[A B C D] = ESATAN2SS (‘MODELNAME’)
- Tested only on Windows XP 32-bit with Matlab R2009b

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Esatan Data

Page 7

- Run ESATAN TMM (version 10.2 or later) → Steady State Conditions
- Perform CALL DMPTHM (see Esatan User Manual) → .csv files

.csv files — to be moved → ESATAN2SS working directory

- *MODELNAME.nl.csv* → Type, Number, Label, Model
- *MODELNAME.nd.csv* → *T, C, Q*
- *MODELNAME.gl.csv* → *GL*
- *MODELNAME.gr.csv* → *GR*
- *MODELNAME.gf.csv* → NOT REQUIRED

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Input / Output options

Page 8

>>[A B C D] = ESATAN2SS ('MODELNAME')

Overall
LTI SS model
of Esatan Model *MODELNAME*

Sparse Matrices: A, B, C, D →

B =

(2,1)	2.0000
(3,1)	1.0000
(1,2)	0.2000
(2,2)	0.0500
(1,3)	0.2000
(2,4)	0.5000
(3,5)	0.5000

>>[A B C D Model] = ESATAN2SS ('MODELNAME')

.name →	Esatan model name
.date →	file data damping date
.solver →	Esatan version
.x0 →	x_0 data
.x0list →	x_0 list
.u0 →	full u_0 data
.u0list →	full u_0 list
.y0 →	full y_0 data
.y0list →	full y_0 list

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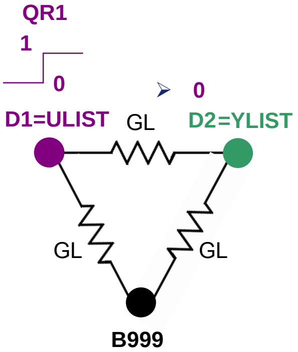
Input / Output options

Page 9

>>[A B C D] = ESATAN2SS ('MODELNAME', ULIST, YLIST)



ULIST: Cell Array defining the **Input** parameters (u variable)

- Boundary node (B type) → T_{NODE}
- Diffusive node (D type) → Q_{NODE}
- No arguments (i.e. ULIST={ }) → All Inputs

YLIST: Cell Array defining the **Output** parameters (y variable)

- Only diffusive nodes (D type)
- No arguments (i.e. YLIST={ }) → All Outputs

ULIST & YLIST → same format of *MODELNAME.nl.csv*

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Input / Output options

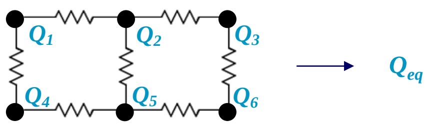
Page 10

>>[A B C D] = ESATAN2SS ('MODELNAME', ULIST, YLIST, TUNIT, UFLAG, YFLAG)

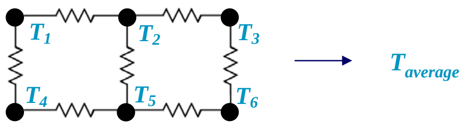
TUNIT: Character defining **Temperature Unit**

- 'C' → Celsius (default)
- 'K' → Kelvin

UFLAG: Boolean defining **Single Weighted Input** (default FALSE)



YFLAG: Boolean defining **Single Weighted Output** (default FALSE)



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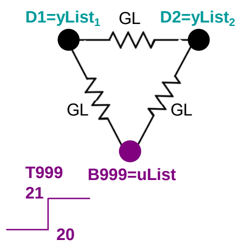
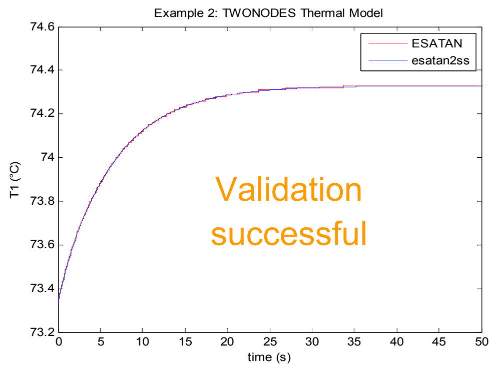
Software Validation

Page 11

Software Validation Method:

- Matlab *step* function responses vs. ESATAN transients





Documented with validation / training cases:

- Linear and Non-linear models
- Model complexity increasing

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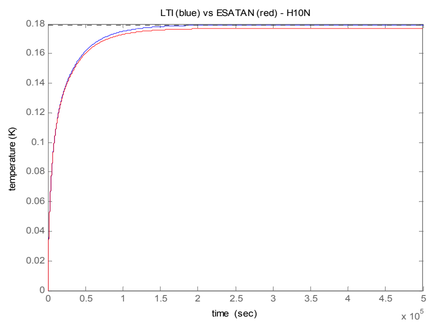
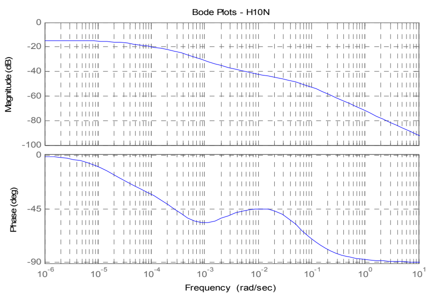
Galileo Experience

Page 12

GALILEO heaters chains:

- Used to compute SS and then LTF
- Reduced TMM model (~400 nodes) due to RAM issues
- Gain differences up to 5%:
  - TMM non-linearity: *GL = f(T)*
  - False steady state conditions (< 0.01 °C)





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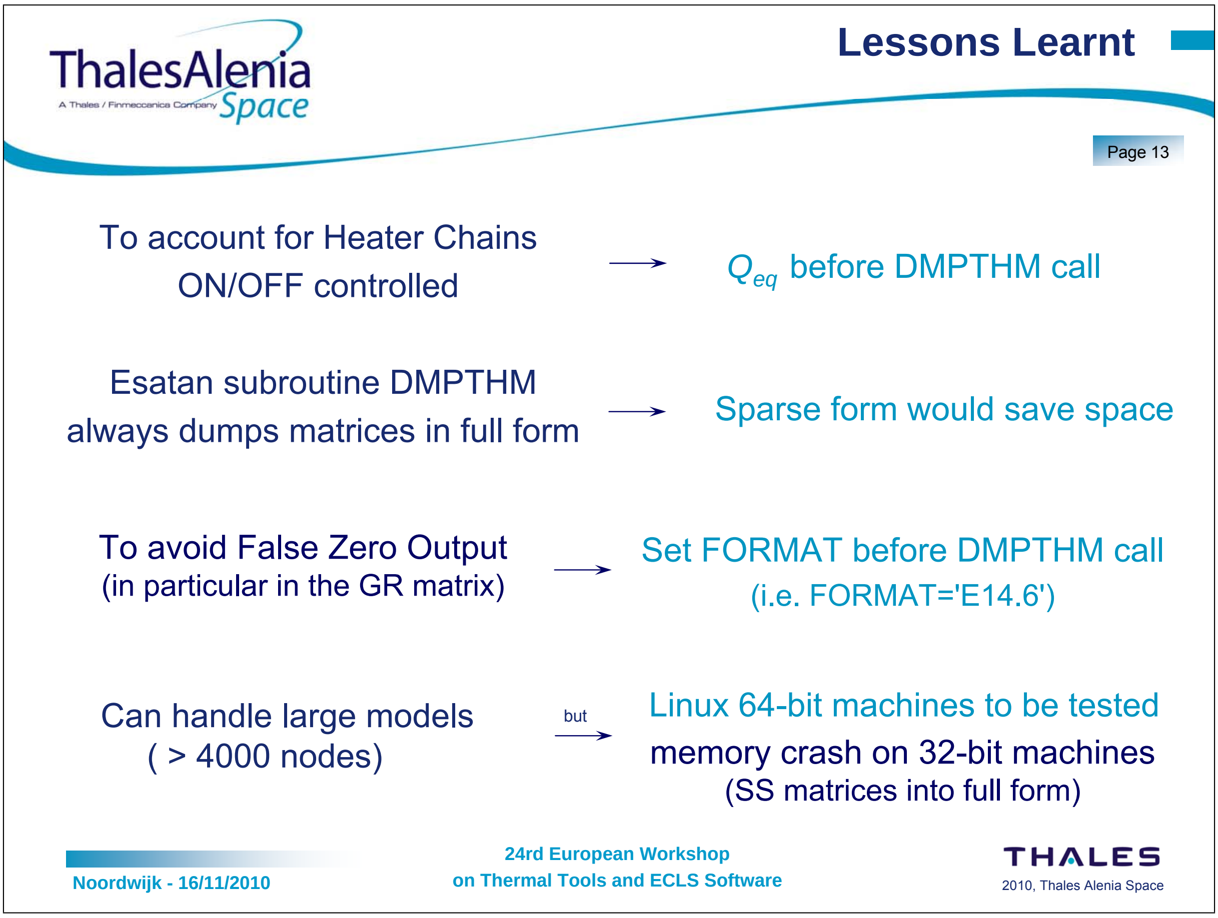
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Lessons Learnt
Page 13
To account for Heater Chains ON/OFF controlled → Q_{eq} before DMPTHM call
Esatan subroutine DMPTHM always dumps matrices in full form → Sparse form would save space
To avoid False Zero Output (in particular in the GR matrix) → Set FORMAT before DMPTHM call (i.e. FORMAT='E14.6')
Can handle large models (> 4000 nodes) but → Linux 64-bit machines to be tested
memory crash on 32-bit machines
(SS matrices into full form)
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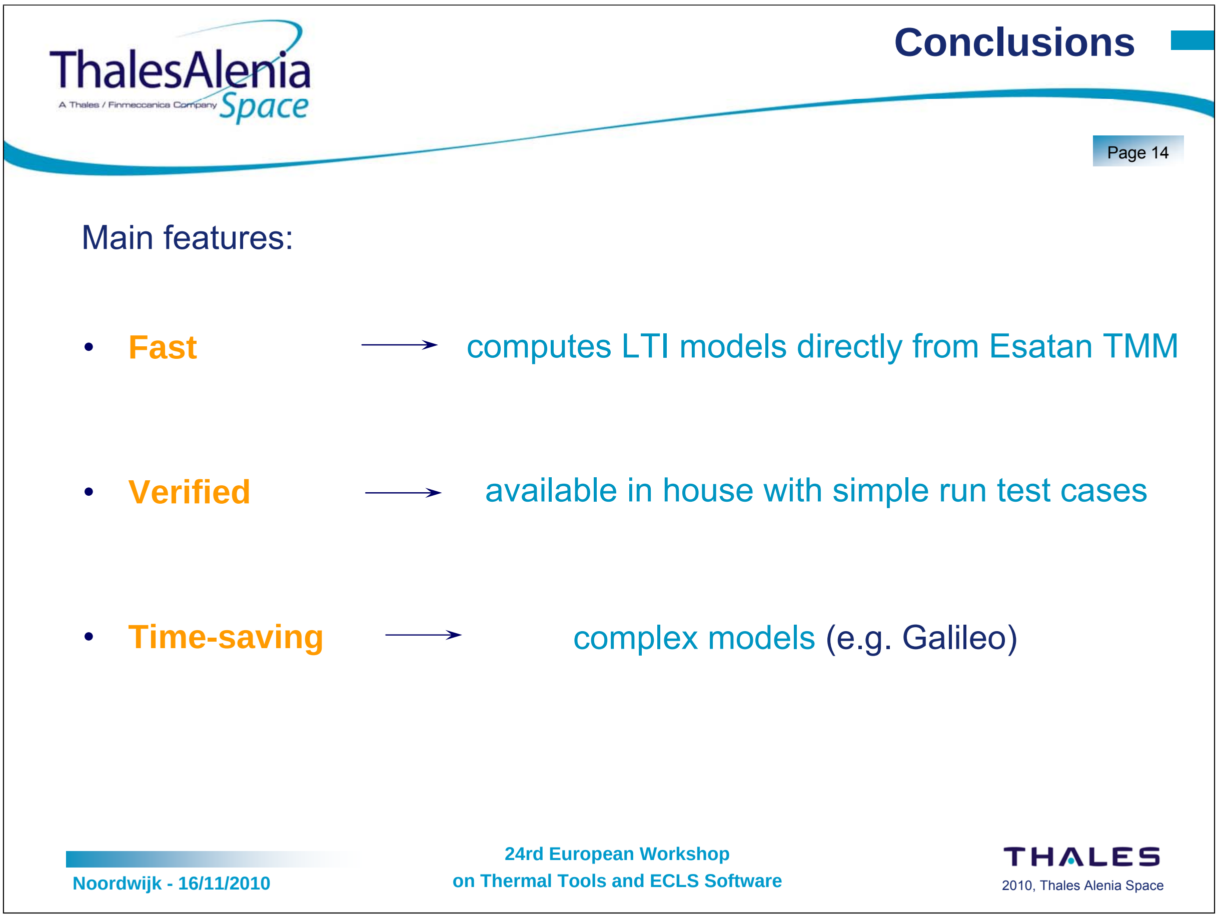
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Conclusions
Page 14
Main features:
• Fast → computes LTI models directly from Esatan TMM
• Verified → available in house with simple run test cases
• Time-saving → complex models (e.g. Galileo)
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Appendix H

ESATAN Thermal Modelling Suite
Product Developments & Demonstrations

Chris Kirtley Henri Brouquet
(ITP Engines UK, United Kingdom)

Abstract

The presentation presents the overall status of the product, outlining the developments going into the next release.
Two demonstrations will be shown, running through the process of building and post-processing a model, demonstrating all the new functionality. The first demonstration focuses on building and running the model in Workbench, the second post-processing the data within Workbench and ThermNV.

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ESA/Estec, Noordwijk, the Netherlands

ESATAN Thermal Modelling Suite Product Status

Author: Chris J Kirtley & Henri Brouquet
Date: 16th November 2010

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Presentation

ITP Engines UK

- Introduction
- Current developments
  - Demonstration
- Conclusion

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Introduction
ITP Engines UK
An ITP Group Company
• Our vision remains unchanged,
– Provide a complete and efficient thermal modelling environment
• Functionality to meet your current & future modelling requirements
• Provide a high-quality and fully validated product
– Efficient end-to-end integration within a multi-disciplinary engineering environment
– Backing this up with professional customer support services
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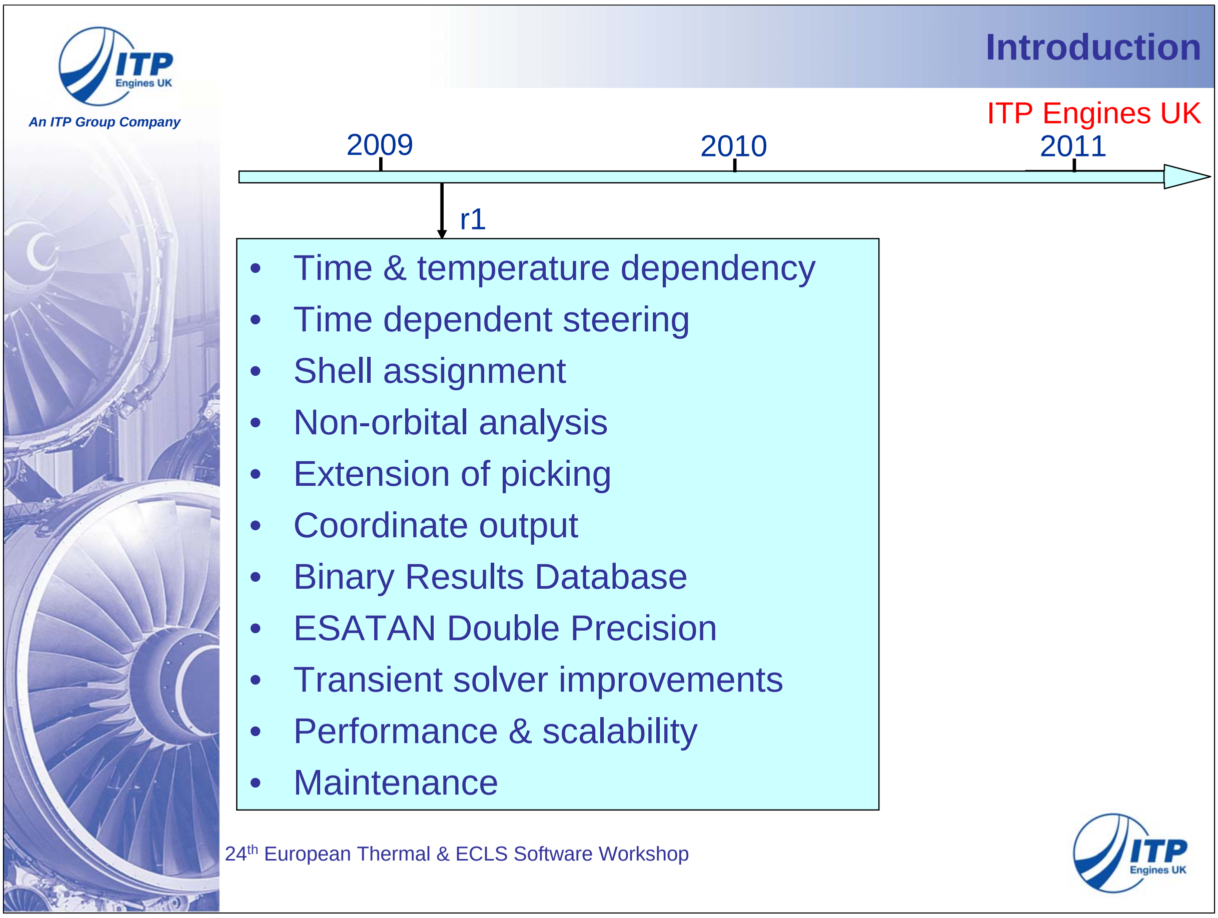
Introduction
ITP Engines UK
An ITP Group Company
2009
2010
2011
r1
• Time & temperature dependency
• Time dependent steering
• Shell assignment
• Non-orbital analysis
• Extension of picking
• Coordinate output
• Binary Results Database
• ESATAN Double Precision
• Transient solver improvements
• Performance & scalability
• Maintenance
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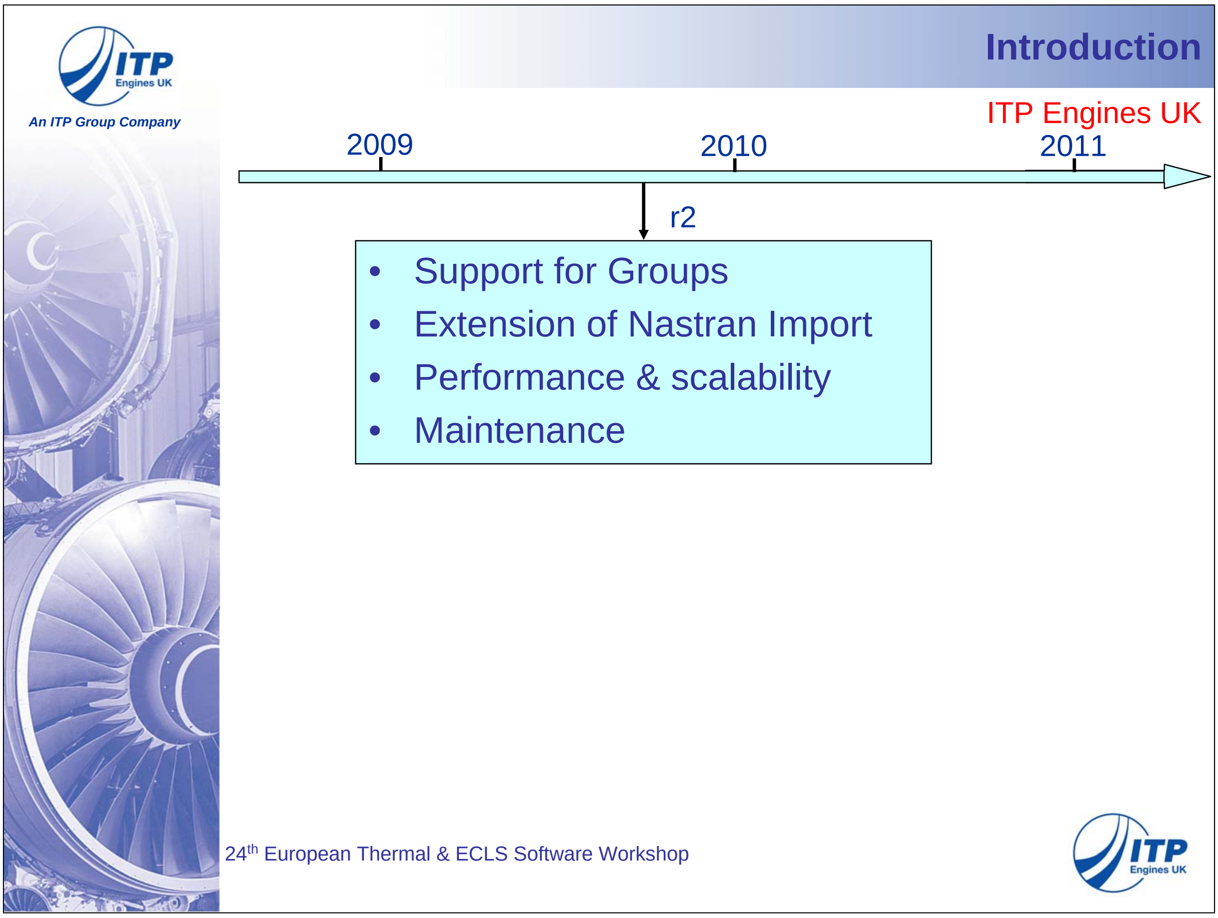
Introduction
ITP Engines UK
An ITP Group Company
2009
2010
2011
r2
• Support for Groups
• Extension of Nastran Import
• Performance & scalability
• Maintenance
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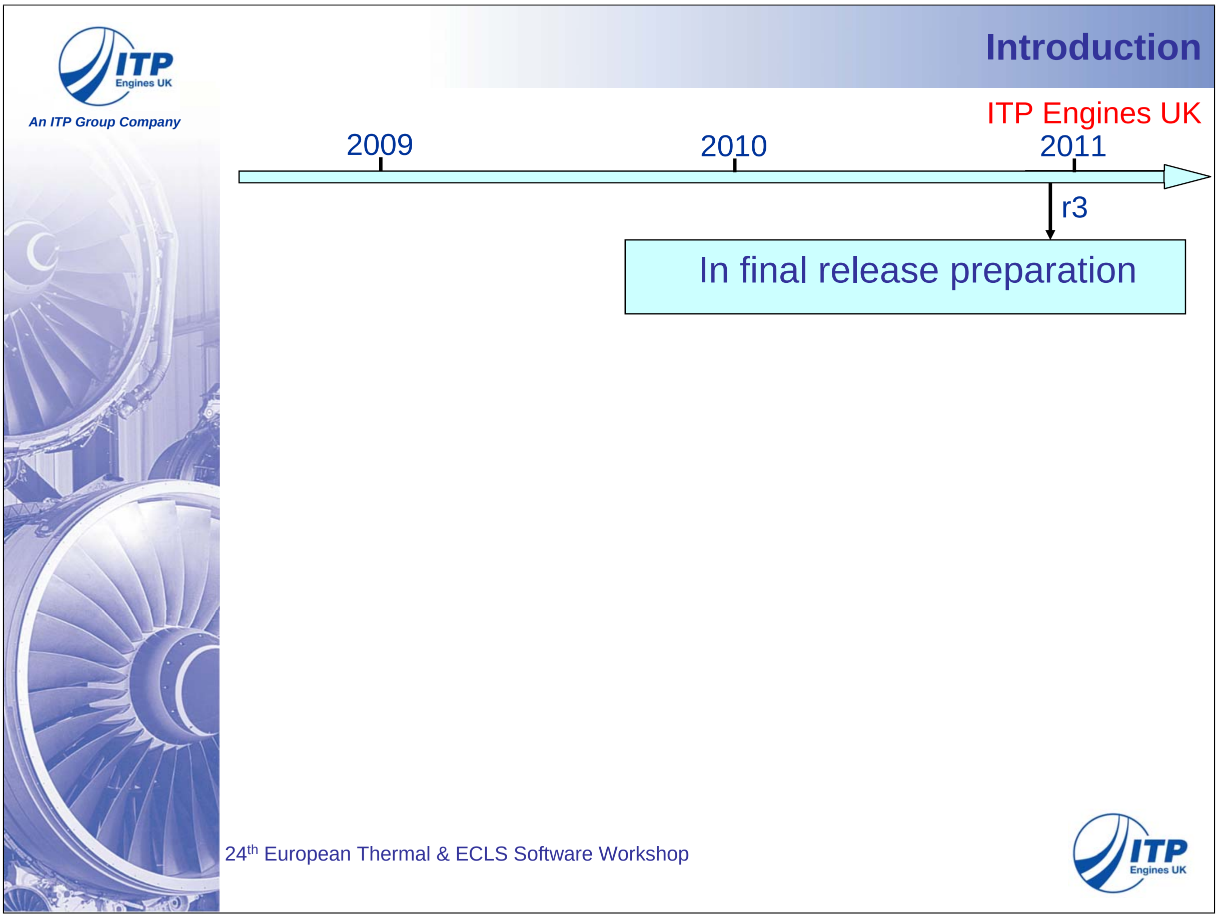
Introduction
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2009
2010
2011
r3
In final release preparation
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Current Developments

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- ESATAN-TMS r3
  - Import of CAD Geometry
  - Enhanced Model Tree
  - Combined Finite Element / Lumped Parameter
  - Enhanced Model Rotation
  - New Thermal Steady State Solver

    demonstration

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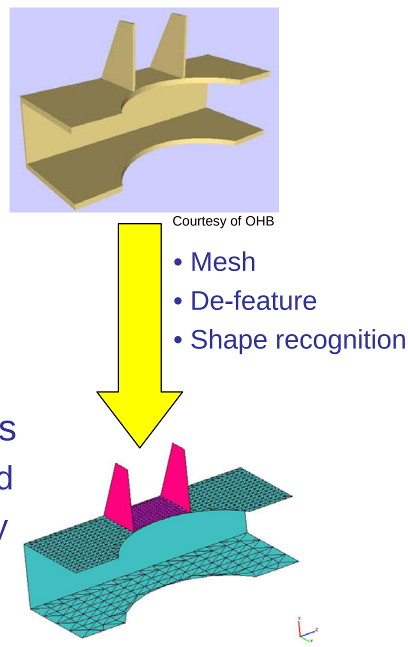
Import of CAD Geometry

ITP Engines UK

- Detailed assessment of the modelling process
  - Iterative process
  - Re-import geometry
    - Mesh refinement
    - Remove features
    - Shape recognition
  - Modify imported model
  - Core product requirements
    - Interactive geometry build
    - Performance & scalability
    - Extension of CAD import



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Import of CAD Geometry

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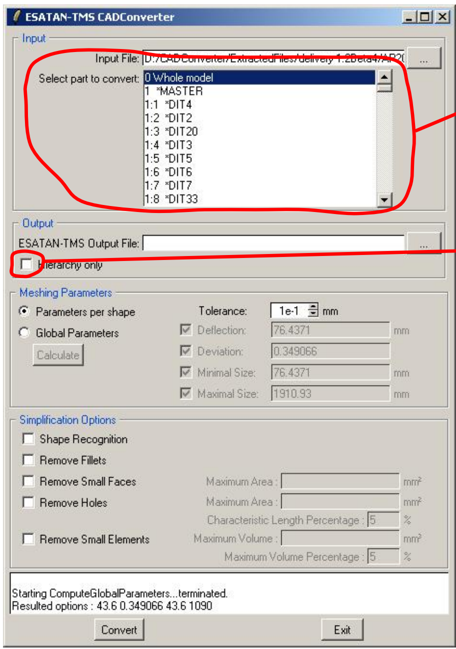
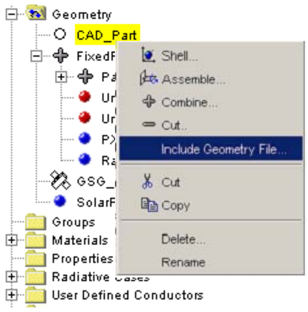


- Extension of interface
- Visualise CAD model hierarchy
- Select & extract sub-hierarchy
- Include empty hierarchy
- Direct include of geometry



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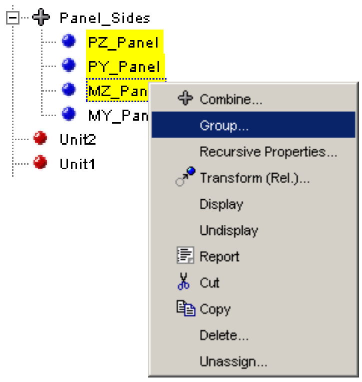
Enhanced Model Tree

ITP Engines UK

- Aims,
  - Speed up model creation
  - Handle large models
- Model tree now supports
  - Cut, copy & paste
  - Drag & drop
  - Highlight selected shells
  - Multiple select
  - Rename
  - Recursive delete



- Performance significantly improved

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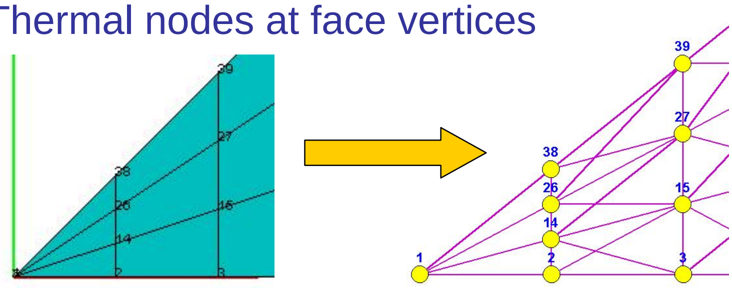
Combined Finite Element / Lumped Parameter

ITP Engines UK

- Aims,
  - Extend analysis capability by combining strengths
  - Reduce overall modelling time
- Response to user survey feedback
- Option to generate FE or LP mesh
  - New shell property

    `analysis_type = "FINITE_ELEMENT“`
- Thermal nodes at face vertices



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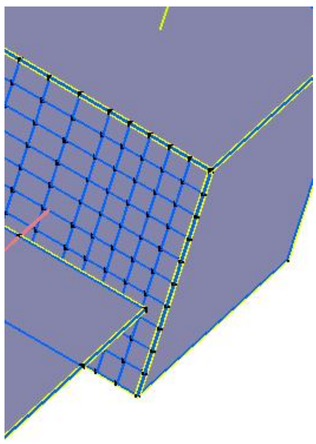
Combined Finite Element / Lumped Parameter

ITP Engines UK

- Radiative analysis performed on true geometry
  - Maintain accuracy
  - Face based calculation
  - REFs mapped from faces to thermal node
- Connectivity,
  - Assumed where FE mesh congruent
    - CIs can be used to introduce contact conductance
  - CIs defined between FE – LP
    - ACG supports LP – LP & FE – LP connections
  - Visualise “Free Edges”



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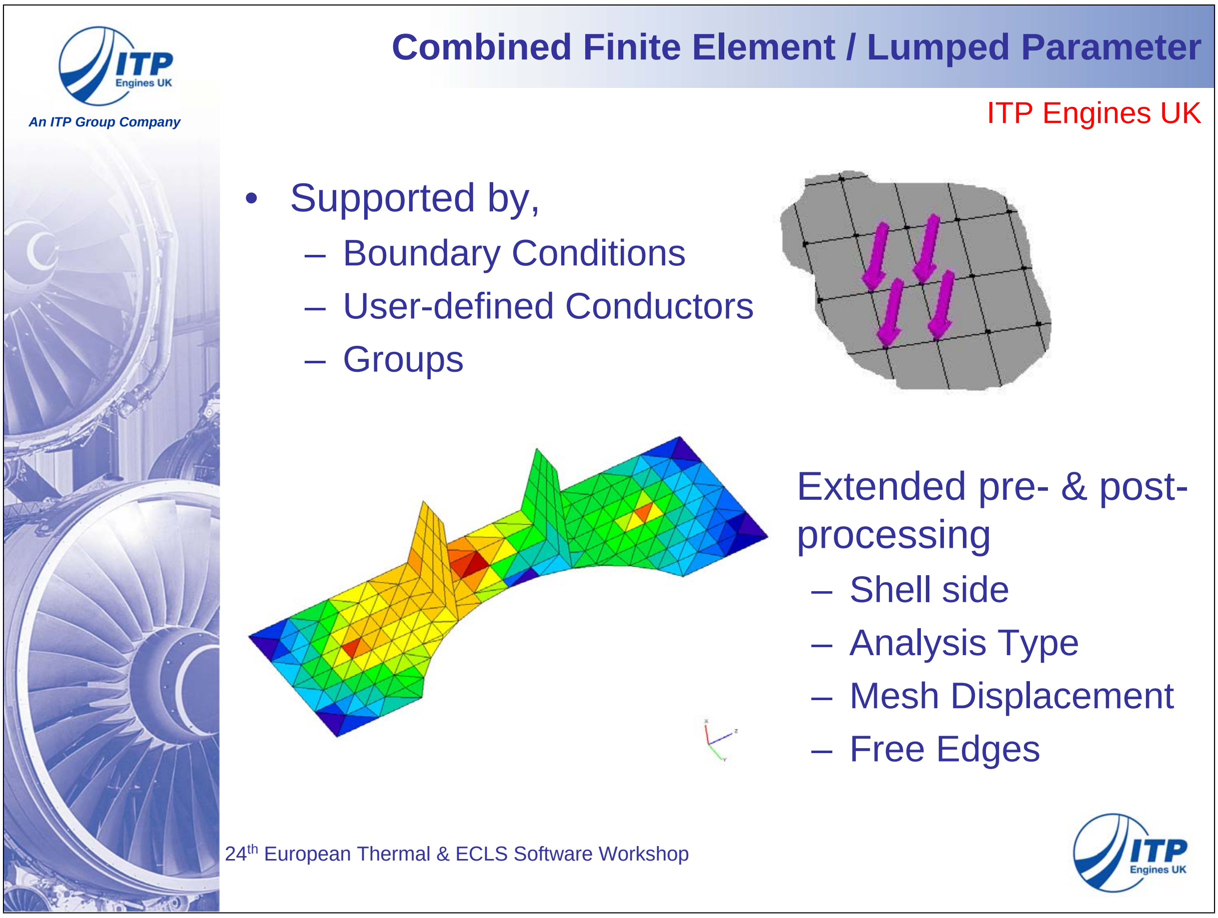
Combined Finite Element / Lumped Parameter
ITP Engines UK
An ITP Group Company
• Supported by,
– Boundary Conditions
– User-defined Conductors
– Groups
Extended pre- & post-processing
– Shell side
– Analysis Type
– Mesh Displacement
– Free Edges
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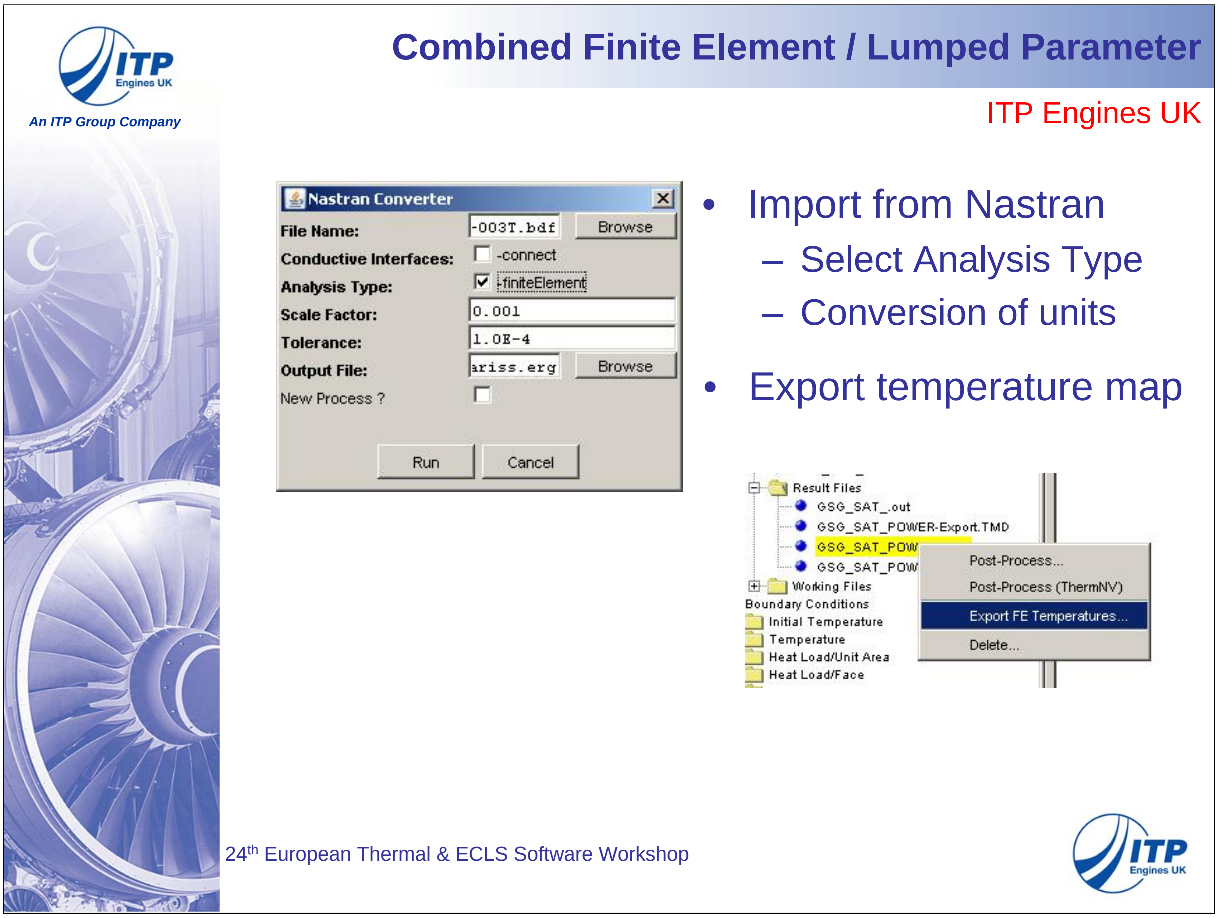
ITP Engines UK


Combined Finite Element / Lumped Parameter
ITP Engines UK
An ITP Group Company
Nastran Converter
File Name:
-003T.bdf
Browse
Conductive Interfaces:
-connect
Analysis Type:
-finiteElement
Scale Factor:
0.001
Tolerance:
1.0E-4
Output File:
ariss.erg
Browse
New Process ?
Run
Cancel
• Import from Nastran
– Select Analysis Type
– Conversion of units
• Export temperature map
Result Files
GSG_SAT_.out
GSG_SAT_POWER-Export.TMD
GSG_SAT_POW
GSG_SAT_POW
Working Files
Boundary Conditions
Initial Temperature
Temperature
Heat Load/Unit Area
Heat Load/Face
Post-Process...
Post-Process (ThermNV)
Export FE Temperatures...
Delete...
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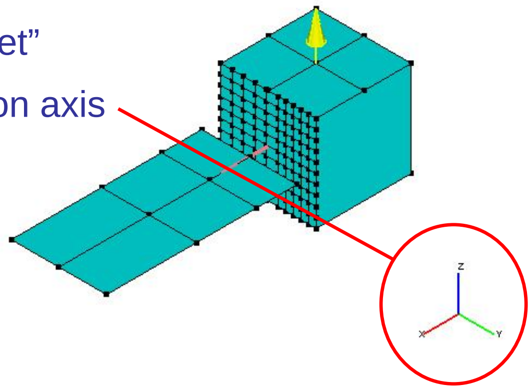
Enhanced Model Rotation

ITP Engines UK

- Enhanced model orientation
  - Rotation about centre of displayed model
  - Fit to view via “Reset”
  - Display of orientation axis



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New Thermal Steady State Solver

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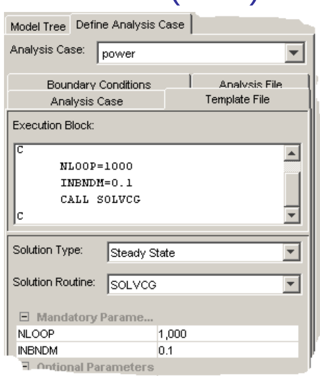
- New thermal steady state solver SOLVCG
  - Conjugate gradient iterative method
  - Low memory requirements
  - Good convergence properties
    - Convergence on nodal energy imbalance (RSS)
    - Optional convergence on global energy imbalance

```
$CONSTANTS
$CONTROL
INBNDM = 1.0E-3;
INBALR = 1.0E-2;
```



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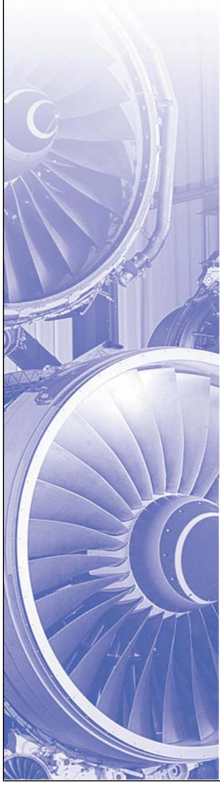

Current Developments

ITP Engines UK

- ESATAN-TMS r3
  - Import of CAD Geometry
  - Enhanced Model Tree
  - Combined Finite Element / Lumped Parameter
  - Enhanced Model Rotation
  - New Thermal Steady State Solver

demonstration

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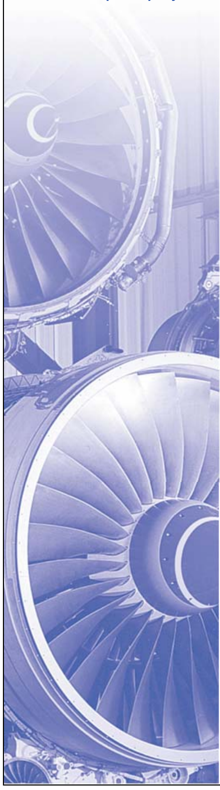

Demonstration

ITP Engines UK

- Visualise CAD hierarchy
- Import CAD hierarchy only / undefined shells
- Rename shell
- Extract sub-component of CAD model
- Include Geometry option
- Model rotation
- Orientation axis
- Recursive delete
- Cut, copy & paste in model tree
- Multiple select in model tree
- Drag & drop in model tree
- Highlight selected shells
- FE analysis option on shells
- Visualisation of “Free Edges”
- Right-click menu
- Mesh/geometry refinement
- Shell side overlay
- Display of boundary conditions on FE shells / Nodes
- New thermal steady state solver SOLVCG
- Contour plotting
- Remove mesh outline

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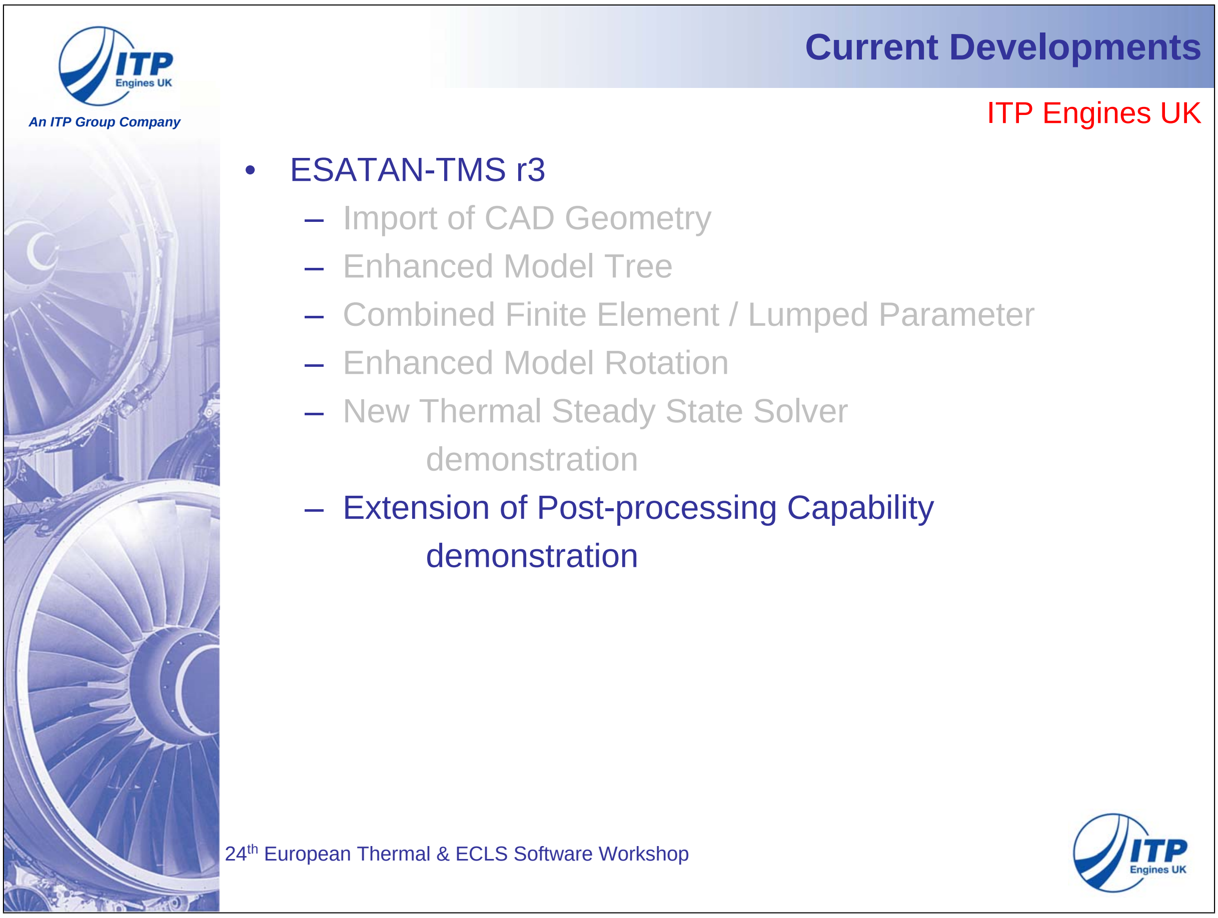
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Current Developments
ITP Engines UK
• ESATAN-TMS r3
– Import of CAD Geometry
– Enhanced Model Tree
– Combined Finite Element / Lumped Parameter
– Enhanced Model Rotation
– New Thermal Steady State Solver
demonstration
– Extension of Post-processing Capability
demonstration
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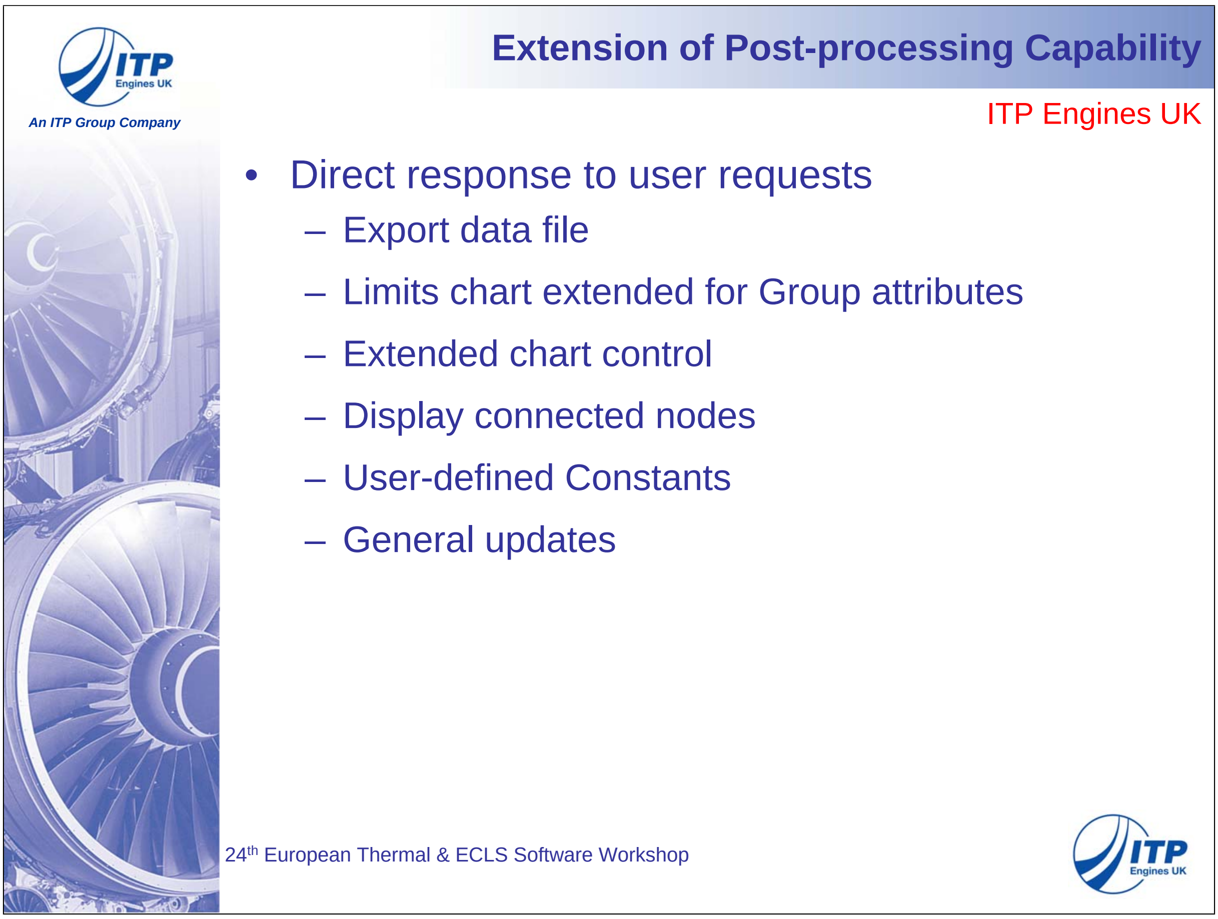
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Extension of Post-processing Capability
ITP Engines UK
• Direct response to user requests
– Export data file
– Limits chart extended for Group attributes
– Extended chart control
– Display connected nodes
– User-defined Constants
– General updates
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Extension of Post-processing Capability

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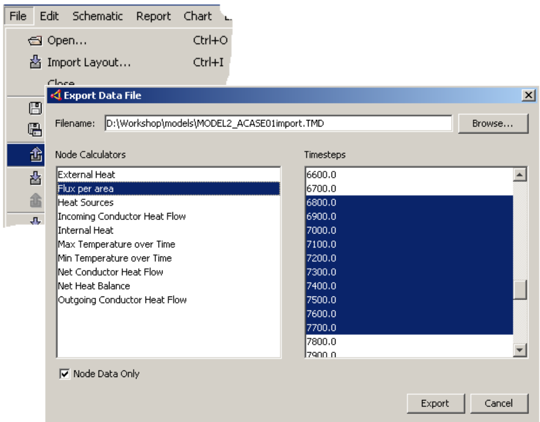
- Export data file,
  - Aim: Ability to calculate derived parameters and post-process in Workbench.
  - Export Data File option
  - Select,
    - TMD export file
    - Derived attributes
    - Time step(s)
    - Node data only option



  - Post-process data within Workbench.

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Extension of Post-processing Capability

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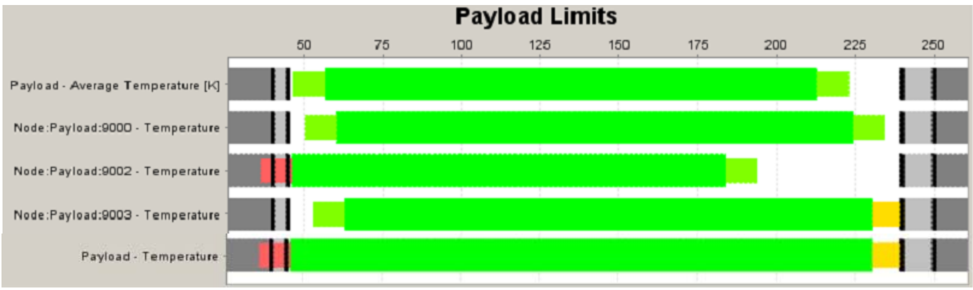
- Request to plot overall min and max temperature of a Group
  - Limits chart extended for Group attributes
  - Allows range of an attribute to be displayed



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Extension of Post-processing Capability

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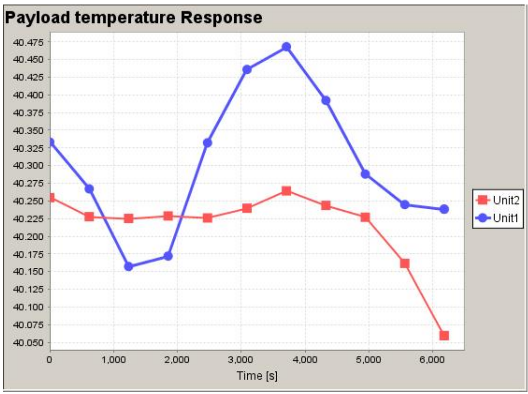
- Extended chart control,
  - Chart title
  - Series
    - Name
    - Line style
    - Line colour
    - Marker style/font
  - Markers On/Off



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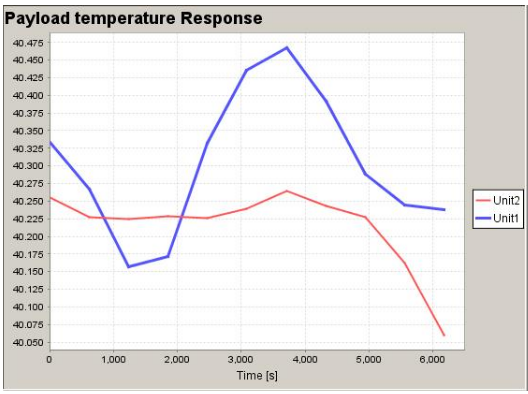
Extension of Post-processing Capability

ITP Engines UK

- Extended chart control,
  - Chart title
  - Series
    - Name
    - Line style
    - Line colour
    - Marker style/font
  - Markers On/Off



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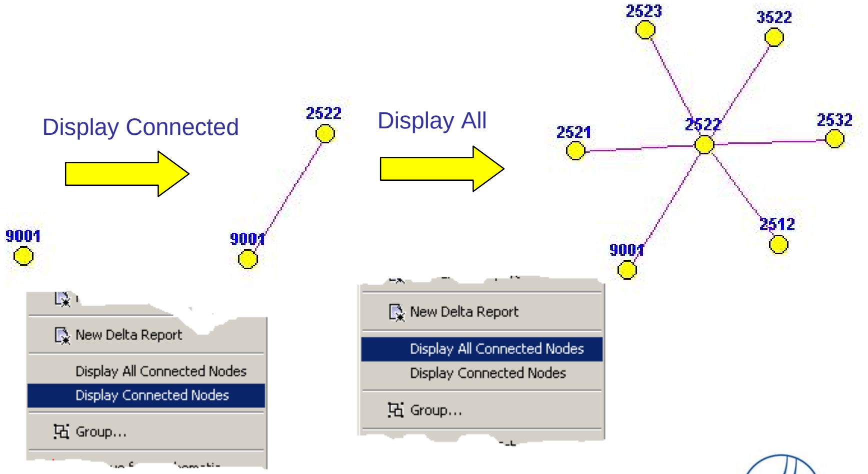
Extension of Post-processing Capability

ITP Engines UK

- Display connected nodes,
  - Ability to display nodes connect to given node(s)
    - Controlled by conductor filter
    - Display all OR only directly connected nodes



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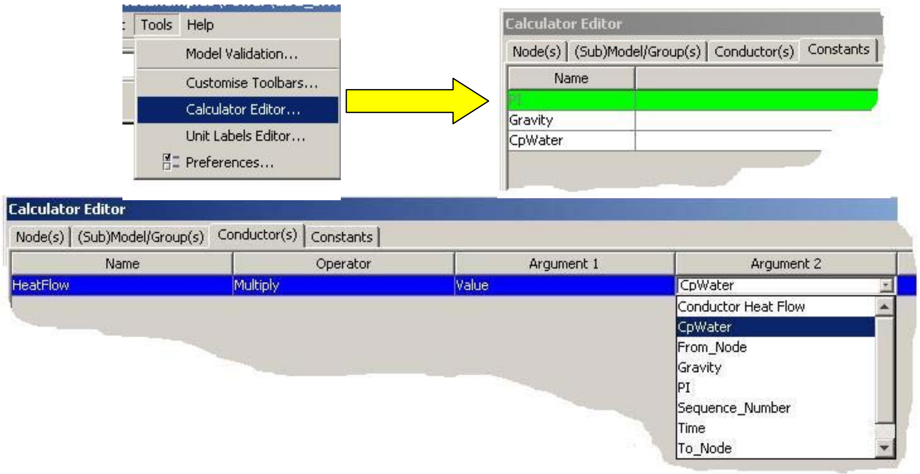
Extension of Post-processing Capability

ITP Engines UK

- User-defined Constants
  - Calculators extended to allow definition of Constants
    - Used in expressions defining further attributes



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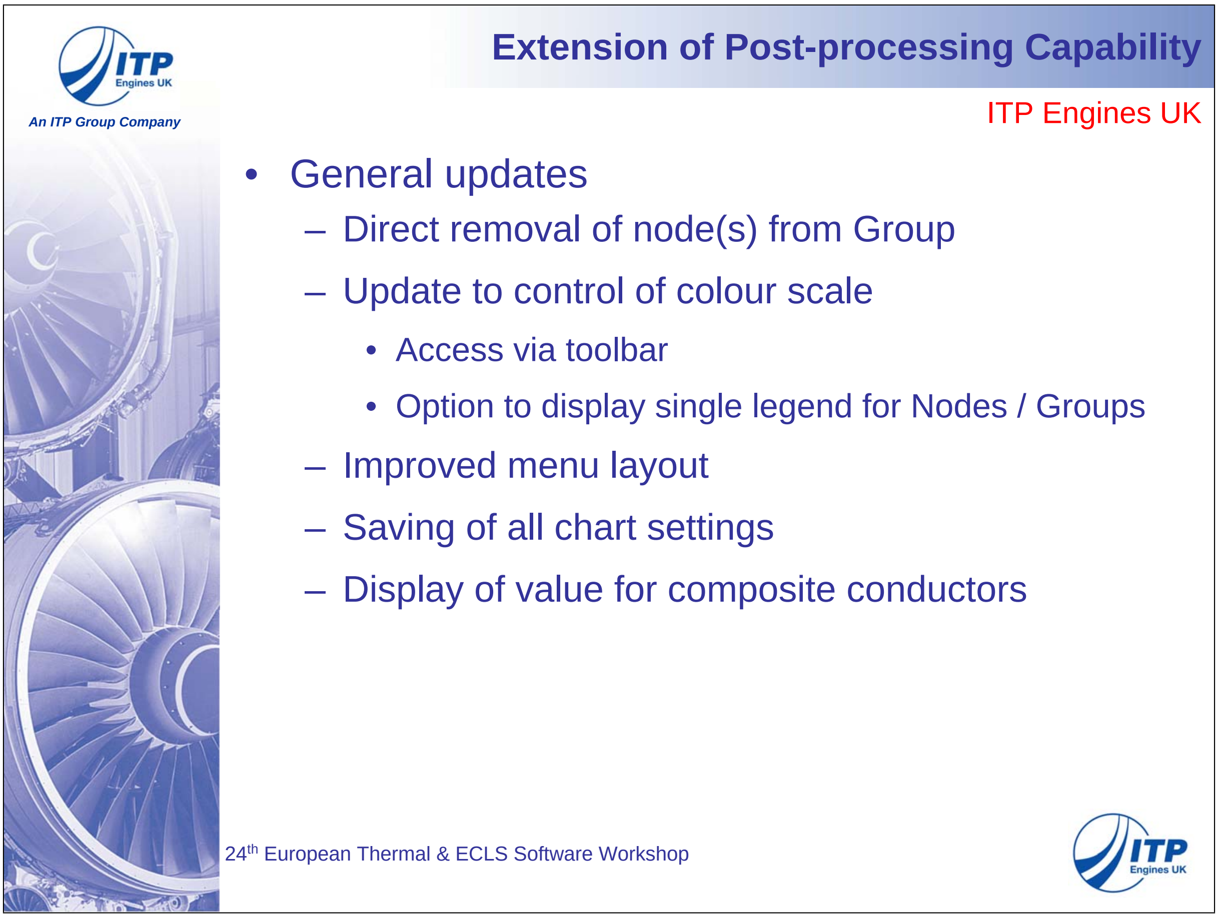
ITP Engines UK
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Extension of Post-processing Capability
ITP Engines UK
• General updates
– Direct removal of node(s) from Group
– Update to control of colour scale
• Access via toolbar
• Option to display single legend for Nodes / Groups
– Improved menu layout
– Saving of all chart settings
– Display of value for composite conductors
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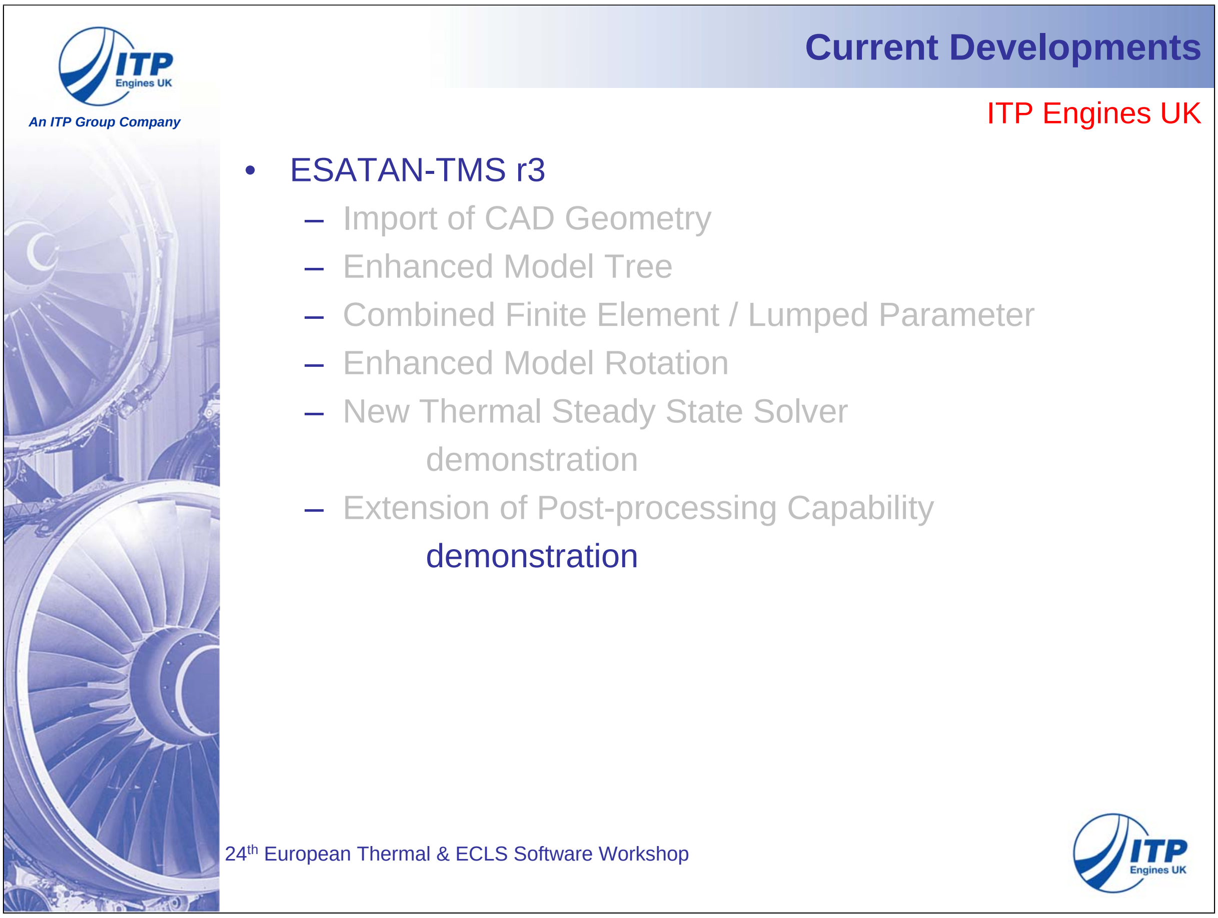
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Current Developments
ITP Engines UK
• ESATAN-TMS r3
– Import of CAD Geometry
– Enhanced Model Tree
– Combined Finite Element / Lumped Parameter
– Enhanced Model Rotation
– New Thermal Steady State Solver
demonstration
– Extension of Post-processing Capability
demonstration
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Demonstration

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- Display connected nodes
- Colour scale
- Remove node(s) from Group
- Extended chart control
- Limits chart extended for Group attributes
- Export data file
- Post-process derived attributes in Workbench

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Current Developments

ITP Engines UK

- ESATAN-TMS r3
  - Import of CAD Geometry
  - Enhanced Model Tree
  - Combined Finite Element / Lumped Parameter
  - Enhanced Model Rotation
    - demonstration
  - New Thermal Steady State Solver
  - Extension of Post-processing Capability
    - demonstration
  - Import / Export STEP-TAS
  - Ray Visualisation
  - Maintenance

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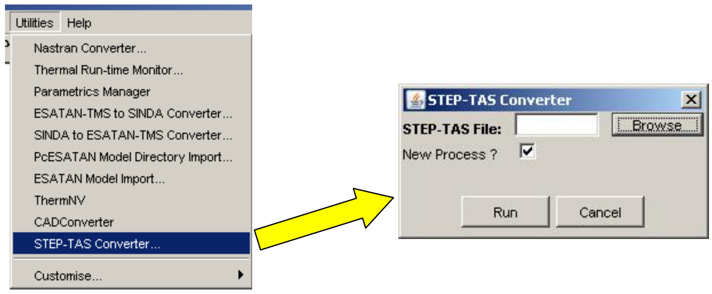
Import / Export STEP-TAS

ITP Engines UK

- Import/export geometry from/to STEP-TAS
- Output from ESA IITAS project

- Import STEP-TAS definition into Workbench



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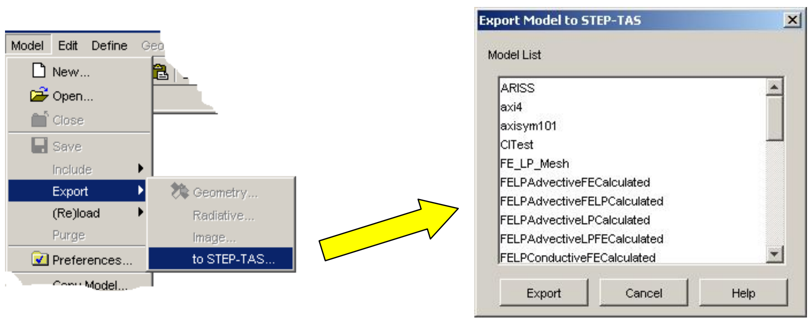
Import / Export STEP-TAS

ITP Engines UK

- Import/export geometry from/to STEP-TAS
- Output from ESA IITAS project

- Export from Workbench to STEP-TAS



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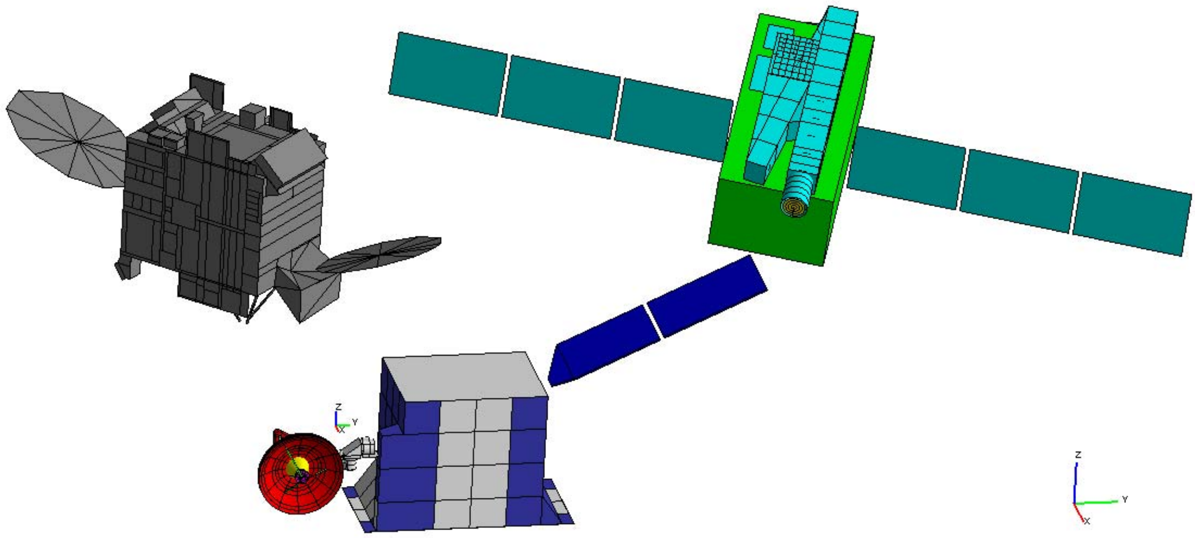
Import / Export STEP-TAS

ITP Engines UK



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Ray Visualisation

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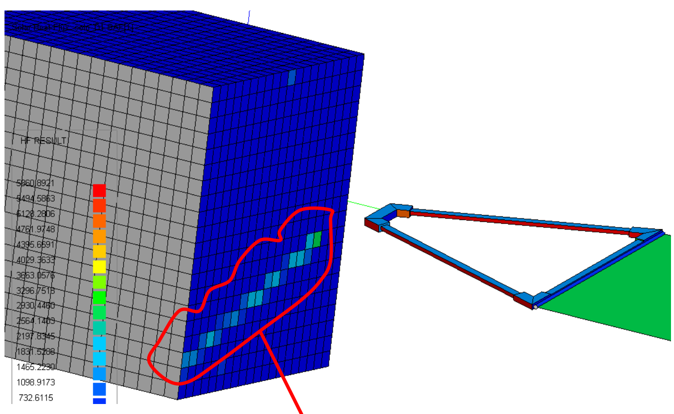
- Customer driven requirement
  - Critical to control solar rays
  - Ability to visualise any solar ray hitting a face
  - Tracking solar ray from other surface



Courtesy of Astrium UK

  - Define Group of faces

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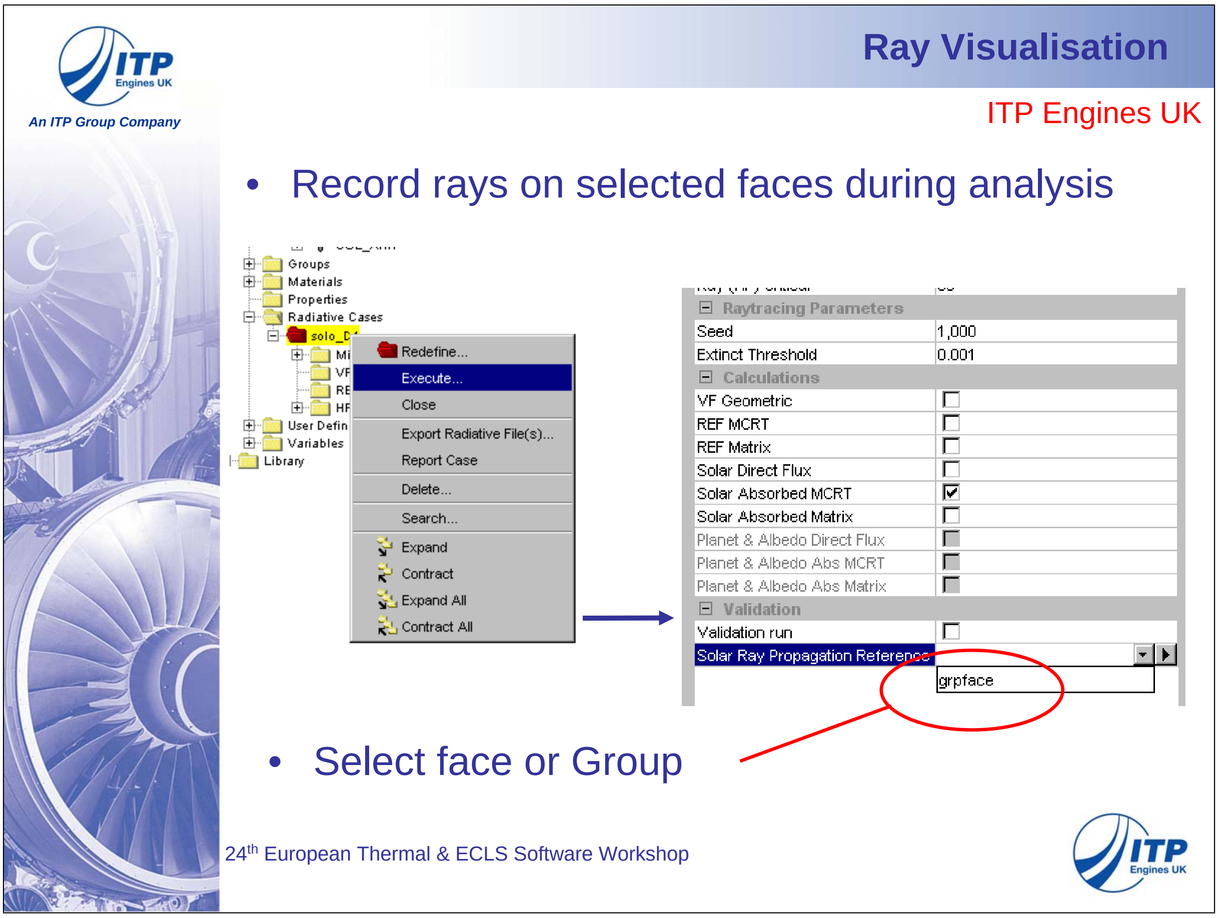
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Ray Visualisation
ITP Engines UK
• Record rays on selected faces during analysis
Groups
Materials
Properties
Radiative Cases
User Defin
Variables
Library
Redefine...
Execute...
Close
Export Radiative File(s)...
Report Case
Delete...
Search...
Expand
Contract
Expand All
Contract All
Raytracing Parameters
Seed
1,000
Extinct Threshold
0.001
Calculations
VF Geometric
REF MCRT
REF Matrix
Solar Direct Flux
Solar Absorbed MCRT
Solar Absorbed Matrix
Planet & Albedo Direct Flux
Planet & Albedo Abs MCRT
Planet & Albedo Abs Matrix
Validation
Validation run
Solar Ray Propagation Reference
grpface
• Select face or Group
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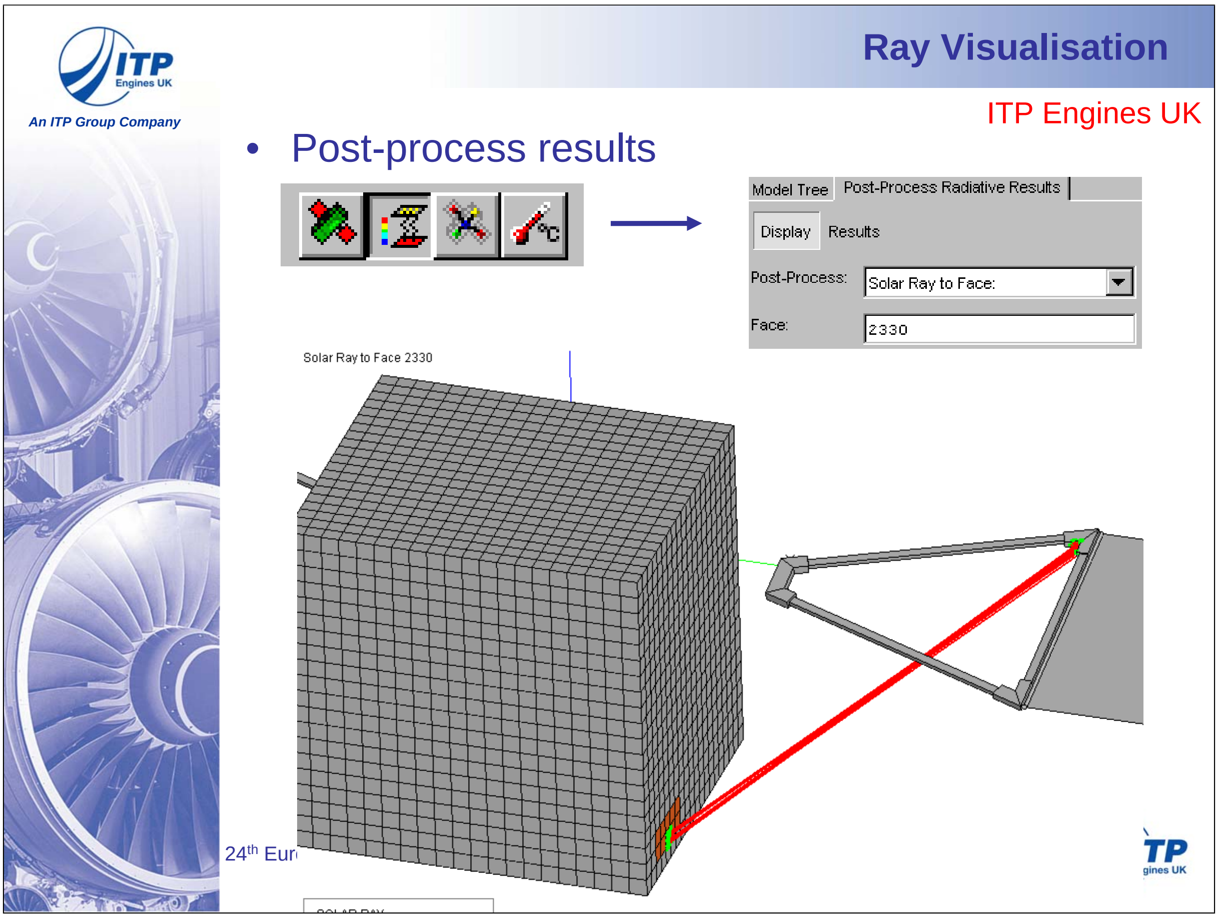
ITP Engines UK
An ITP Group Company
Ray Visualisation
ITP Engines UK
• Post-process results
Model Tree
Post-Process Radiative Results
Display
Results
Post-Process:
Solar Ray to Face:
Face:
2330
Solar Ray to Face 2330

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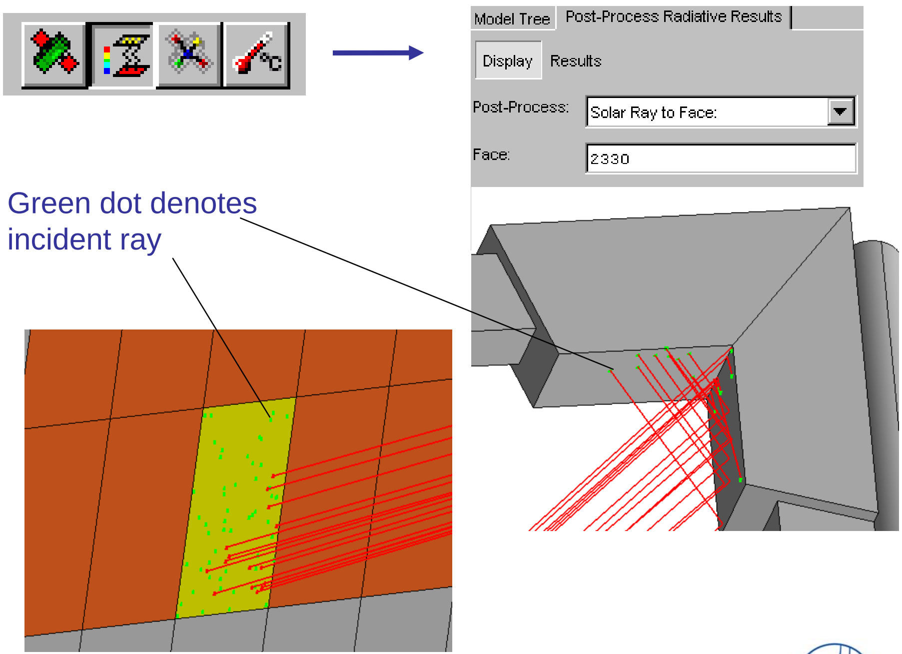
Ray Visualisation

ITP Engines UK

- Post-process results



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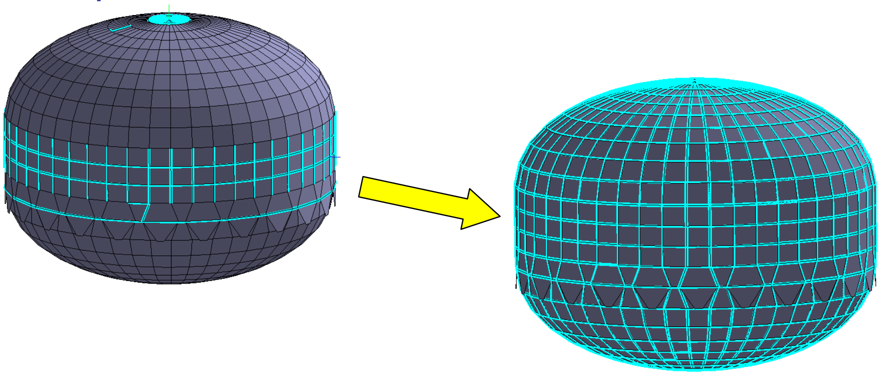
Maintenance

ITP Engines UK

- Performance & scalability improvements
- Port to 64-bit Linux
  - Built as a 64-bit application
  - Requires update of the licence manager, FLEXnet
- Improved Conductive Interface detection



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Conclusion

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- ESATAN-TMS r3 being finalised for release
  - Significant development of the product
  - Major developments include,
    - Interactive geometry build capabilities
    - Enhanced process of working with CAD models
    - Combined FE / LP analysis
    - Enhanced post-processing

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Conclusion

ITP Engines UK

- User survey
  - Thank you for input
  - Analysis of input underway
  - Use your input to steer our development
- Congratulations to our competition winner

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www.esatan-tms.com
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ITP Engines UK

Appendix I

SYSTEMA 4.3.4

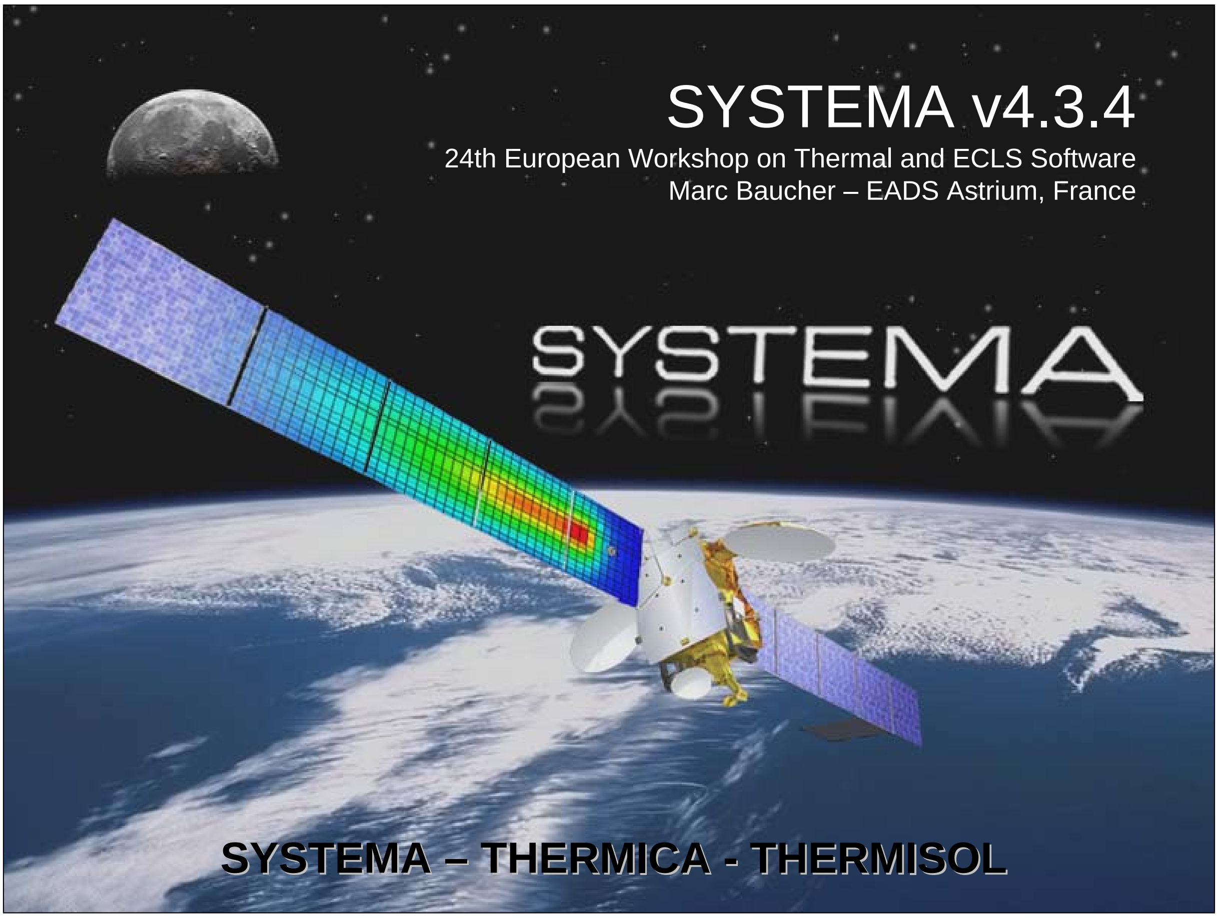
Marc Baucher
(EADS Astrium, France)

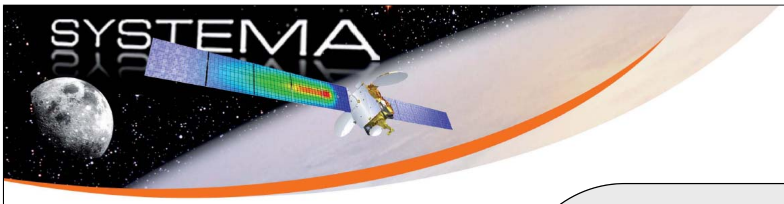
Abstract

Thermal computation on mechanical and CAD models
SYSTEMA 4.3.4 introduces even more flexibility in geometrical modeling. Mechanical or CAD models can be imported from NASTRAN or I-DEAS (BLK BDF), CATIA (Step AP-203) or other tools (VRML). The THERMICA/THERMISOL tool chain can then be executed on these models without any shape modification or with partial modifications (for example to suppress some details, simplify some elements or create analytical shapes to replace discretized curved geometries).
Furthermore, SYSTEMA offers a large panel of intuitive tools to simplify geometry and easily assemble, compare and modify mechanical and thermal models. The version 4.3.4 now also allows saving within the model all the help items such as grids, lines or points which have been used to interactively create shapes).

STEP-TAS interface
For the last two years, we have been working with ESA and CSTB to get a complete STEP-TAS interface. It is now possible to directly import from SYSTEMA this format which will be converted to a v4 model, meshing and material databases.
Thanks to the v4 upgrades, this conversion is compliant with most of the STEP-TAS features. Boolean cuts are handled for prism and cylinder truncations and will also include the cutting plane next year. Distinct sides numbering are also available from version 4.3.4. The list of restrictions between the STEP-TAS capabilities and the SYTEMA ones have then been decreased to only a few elements such as the cutting plane, grid spacing (but they will both be implemented next year) and the sub-grid.
This import/export options have already been successfully tested on many cases, including industrial ones from the IITAS test plan but also additional cases.
This interface can already be activated in version 4.3.3 and will be fully available in version 4.3.4.

Wide Mission simulation
SYSTEMA v4 has been developed with the concern of managing the complete solar system in order to simulate any mission. The localization of all planets is known with an accuracy of a hundred kilometers at any time. In addition, rotational frames of the Earth, the Moon and other planets are also available and allow the definition of landed missions.
The mission viewers have been extended with predefined camera positions (from/to the Sun, Velocity, a planet ...) and the possibility to represent the kinematics frames animated with the spacecraft. This realistic rendering is particularly helpful to understand the behavior of the implemented mission, especially when complex kinematics have been used. In addition to the analytical definition, it is now possible to study specific configurations thanks to 2 new options. The "Fix Sun" option can be used to freeze the relative movement of the planets and Sun to their positions at the beginning of the simulation. Also a "search" function is available to find the next date of a given Sun declination.





Versions

- Version 4.3.3
  - December 2009

    Presented at the 2009 ECLS Workshop
- Version 4.3.4
  - December 2010

    Next release

SYSTEMA :
Mechanical model import
Integrated material edition
Meshing on both sides
Step-Tas interface
Ray paths display in 3D view
STK ephemerid and attitude import
Advanced mission 3D view
Mission report

THERMICA :
Gebhart factor computation on CAD & mecha models
High performances ray-tracing

THERMISOL :
New ESATAN features implemented
Improvement of convergence
New post-processing features
Multi time-step transient algorithm
Thermisol working station on Windows

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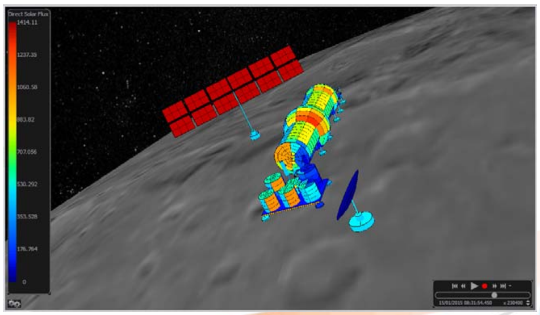
SYSTEMA

Contents

- Focus on :
  - Thermal computation on CAD and mechanical models
    Import models from various software and run the THERMICA/THERMISOL toolchain
  - Step-Tas interface
    Compliance of Systema with ESA exchange format
  - Wide mission simulation
    Analytic and realistic simulation



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SYSTEMA

Mechanical & CAD Interfaces

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SYSTEMA

CAD & mechanical models

- SYSTEMA is compatible with :
  - I-Deas & Nastran
    BDF (BLK) : geometry organized by MID & PID with mechanical identifier
  - Catia models
    Step AP203 : geometry in a tree structure
  - Other tools
    VRML v2 : geometry

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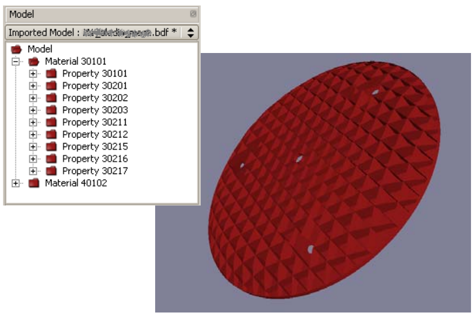
SYSTEMA

CAD & mechanical models

I-Deas & Nastran BLK interface

- Importing features



  - Imported shapes are ready to work
    - Triangles & quadrangles
    - Coordinate systems taken in account
  - Items are organized
    - Shapes are sorted by mechanical material and property (MID/PID)
    - Mechanical numbering is imported
  - SYSTEMA manages complete mechanical models
    - High detailed models can be imported

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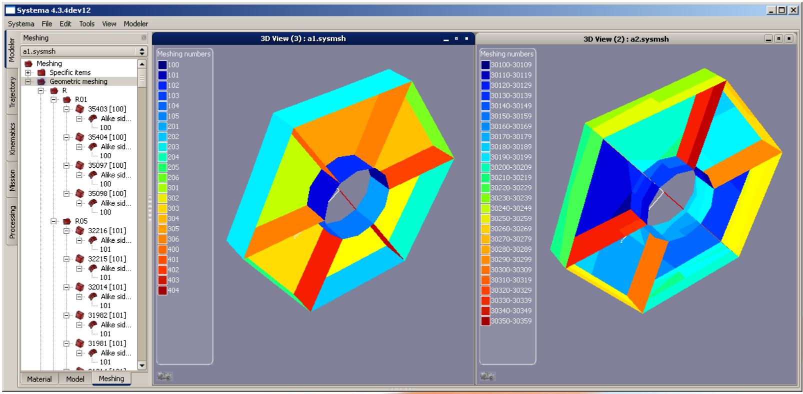
SYSTEMA

CAD & mechanical models

I-Deas & Nastran BLK interface

- Numbering
  - Building the thermal numbering from the mechanical numbering
    - Thanks to the sorting by MID & PID, shapes are grouped by components
    - Nodes can be quickly condensed or gathered in sub-models
    - Numbering comparison : thermal and mechanical meshing on the same geometry



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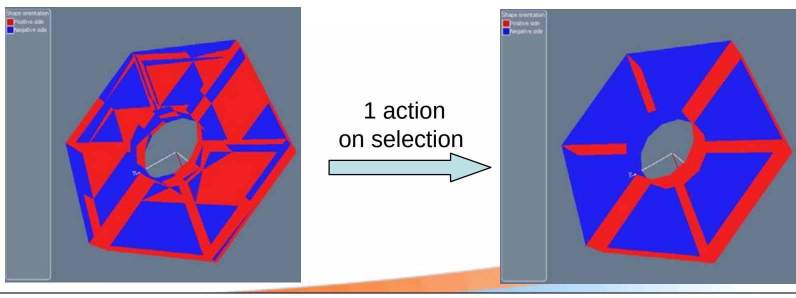
SYSTEMA

CAD & mechanical models

I-Deas & Nastran BLK interface

- Thermal properties
  - Material
    - Thermal materials can be easily assigned to all the shapes, thanks to inheritance properties and the built hierarchy based on MID and PID
  - Shapes orientation management
    - SYSTEMA allows to visualize shape orientation
    - By one action, reverse the orientation of selected shapes



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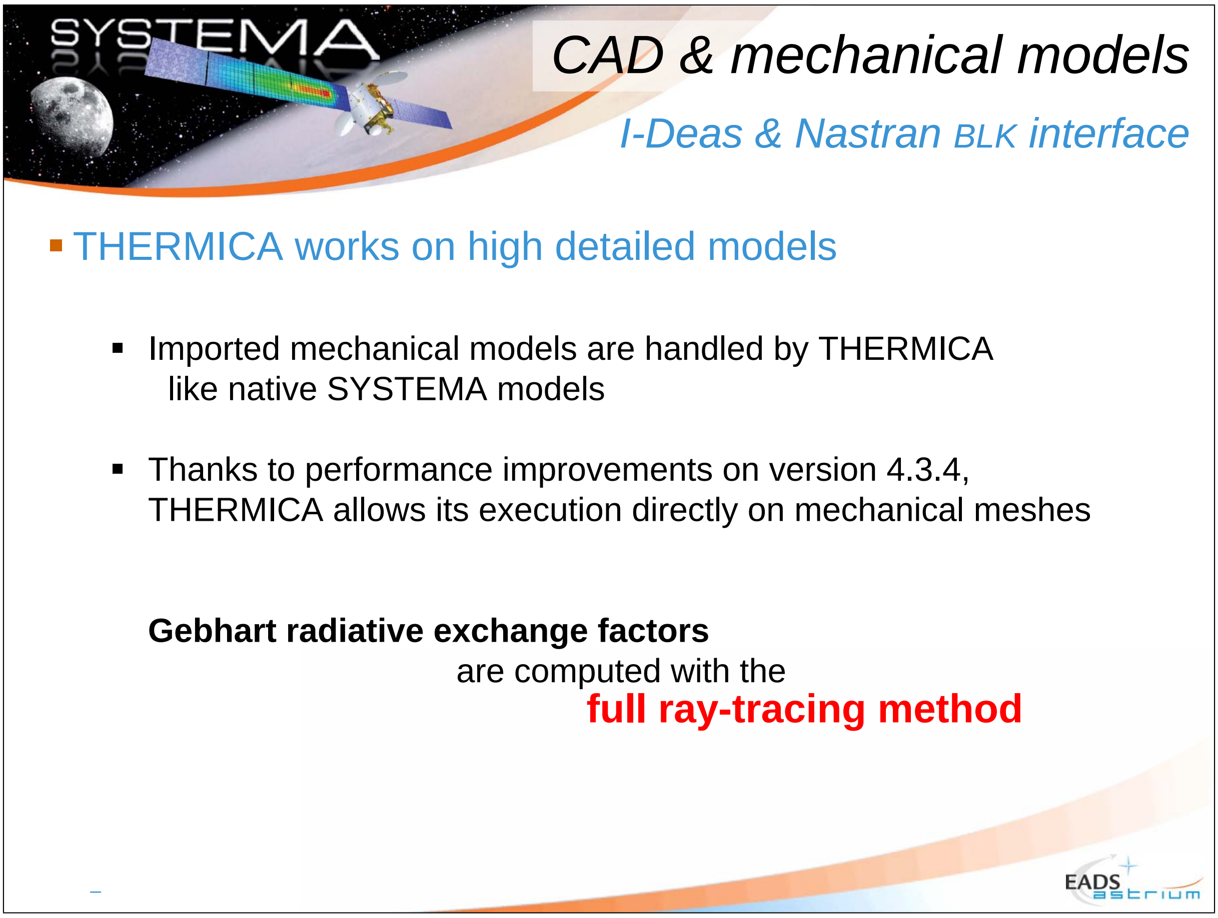
SYSTEMA
CAD & mechanical models
I-Deas & Nastran BLK interface
THERMICA works on high detailed models
Imported mechanical models are handled by THERMICA like native SYSTEMA models
Thanks to performance improvements on version 4.3.4, THERMICA allows its execution directly on mechanical meshes
Gebhart radiative exchange factors
are computed with the
full ray-tracing method
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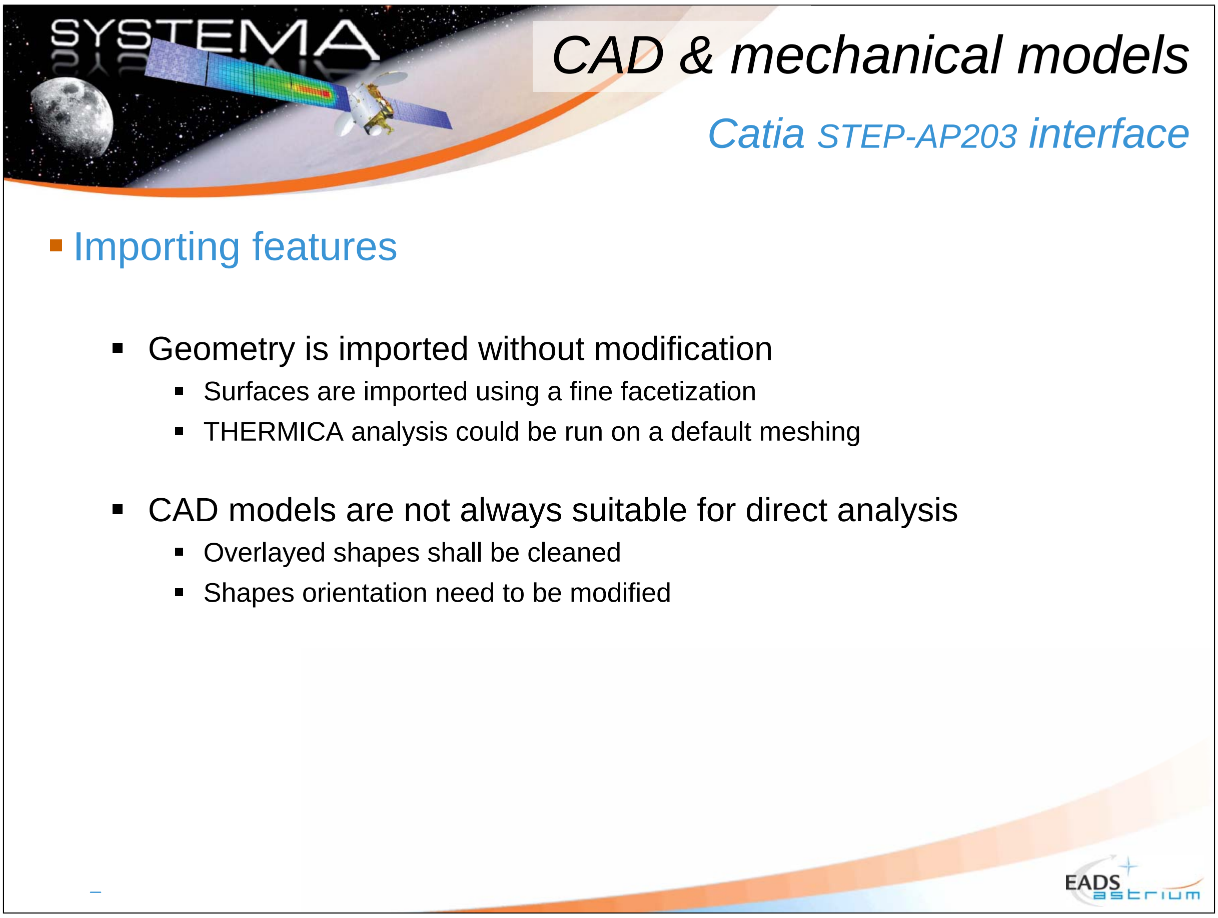
SYSTEMA
CAD & mechanical models
Catia STEP-AP203 interface
Importing features
Geometry is imported without modification
Surfaces are imported using a fine facetization
THERMICA analysis could be run on a default meshing
CAD models are not always suitable for direct analysis
Overlayed shapes shall be cleaned
Shapes orientation need to be modified
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CAD & mechanical models

Catia STEP-AP203 interface

Geometry modifications

- Volumes with small thickness are modelled where it would be preferred to use a plane surface
  - Shape orientation shall be reversed to be homogeneous
  - Activity shall be turned off in the inner
- Two ways to deal with detailed geometry
  - Geometry can be used as it (with possible condensation)
  - Otherwise, SYSTEMA offers advanced tools to simplify the model

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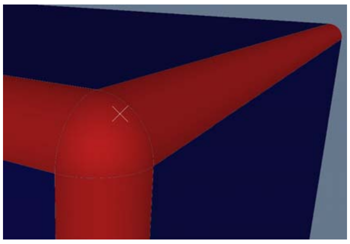
CAD & mechanical models

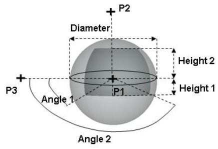
Catia STEP-AP203 interface

Geometry simplification

- Help items
  - Points, lines and planes creation
    - Middle, curve and sphere centers
    - Intersection line / plane and line / line
  - Help items are stored with the model

- Large choice of shapes definition
  - +60 shape types : interactive and static creation
  - Contextual documentation





This shape is a truncated sphere. The part of sphere is defined between the two bases and between angle1 and angle2 with respect to the direction of the axis P1P2.

- Point 1 : center of the sphere (P1)
- Point 2 : point defining with P1 the sphere's axis to define the bases (P2)
- Point 3 : point defining with P1 and P2 the plane of angular truncation (P3)
- Diameter : diameter of the sphere
- Height 1 : height of the first sphere's base relatively to P1
- Height 2 : height of the second sphere's base relatively to P1
- Angle 1 : start angle of the sphere relatively to the plane of angular truncation
- Angle 2 : stop angle of the sphere relatively to the plane of angular truncation

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SYSTEMA

CAD & mechanical models

Catia STEP-AP203 interface

How to work with CAD model

- Import the whole CAD model
  - Simplify some parts, where it is rentable
  - Use as it the rest of the geometry without modification
- Integrate CAD component in an existing thermal model
  - Use copy/paste feature and frame transformation to integrate the CAD submodel in a existing thermal model

–

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SYSTEMA

CAD & mechanical models

Conclusion

- New versions of SYSTEMA & THERMICA provide tools to easily perform **full ray-tracing analysis** on mechanical, CAD and VRML models
- If the imported model is already built for a physical analysis, it just requires to set thermal materials and numbering
- Otherwise, ergonomic tools help user to simplify the interesting geometry, orientate shapes and assemble models.

The simplification of the whole model is no longer required

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SYSTEMA

STEP-TAS Interface

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SYSTEMA

STEP-TAS

- STEP-TAS exchange format
  - Thanks to a collaboration with ESA and CSTB, SYSTEMA is compliant with STEP-TAS format : geometry, materials, meshing rules and thermal network nodes
  - Tested on industrial case
  - Integrated in SYSTEMA :
    - Can be activated in v4.3.3
    - Fully available in coming v4.3.4

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STEP-TAS

STEP-TAS detailed compliance

Shapes	Compliant for all common shape types. SYSTEMA Antenna and revolved shapes not exported
Frame transformations	Compliant
Boolean cutter	Triangle prism and cylinder cutters are supported. SYSTEMA Generic prism is not exported. STEP-TAS infinite half-space is not supported but will be integrated in next releases
Thermal materials	Compliant with the SYSTEMA material database.
Meshing rules	Supported except of grid spacing (will be integrated in next releases) and sub-grid
Thermal numbering	Compliant thanks to management of both sides in SYSTEMA v4.3.4

Wide Mission Simulation

SYSTEMA

Wide mission simulation

Analytic and realistic simulation

- Realistic space mission
  - Ephemerids of solar system planets are computed by SYSTEMA :
    Mission is configured by giving dates of interest

- Analytic parameters to define
  a worth case configuration
  - Dates of interests can be defined by:
    - Solar declination, Beta angle
    - Longitude and lattitude
    - Season dates (solstices and equinoxes)

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SYSTEMA

Wide mission simulation

Mars Rovers and Ground Stations

- SYSTEMA provide an easy way to define ground objects
  - Just longitude and latitude on the planet are required

- Solar flux variations for THERMICA analysis
  - Daily variations due to the Mars rotational frame
  - Season variations due to the Mars orbit

- Earth and Sun pointing laws
  - Beta angle and pointing misalignment
    can be displayed in real time

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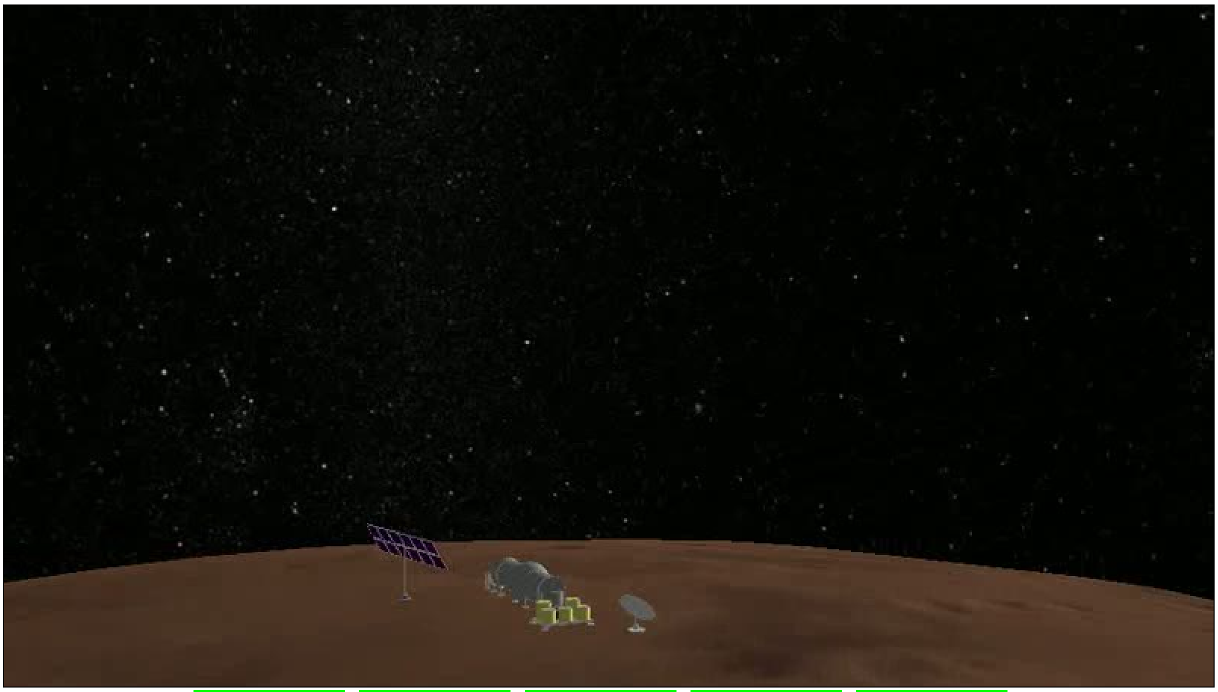
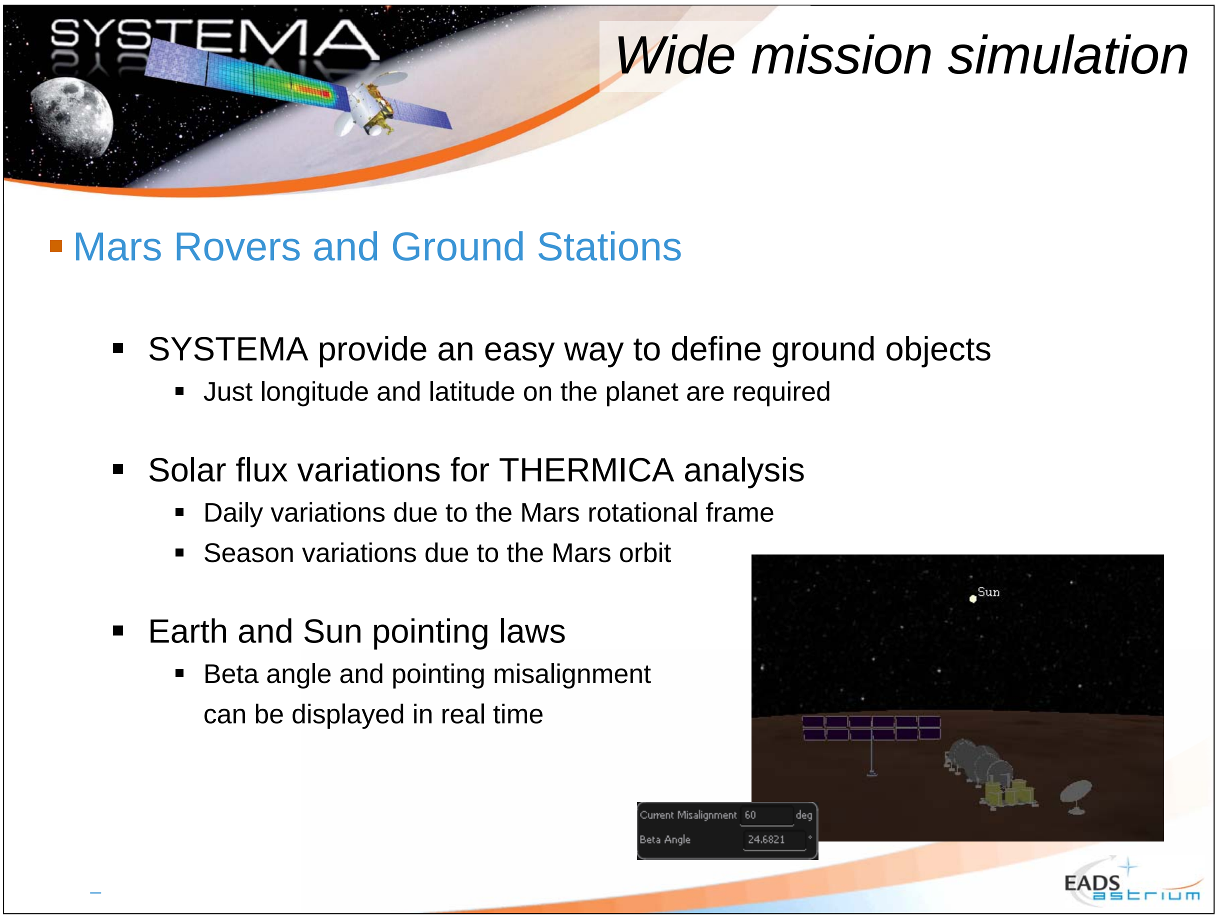
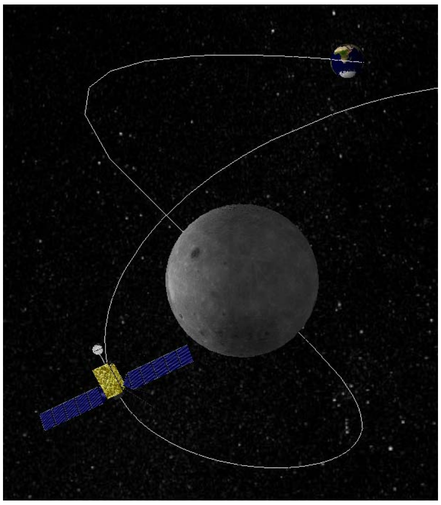


Slow Normal Fast Play/Pause Stop

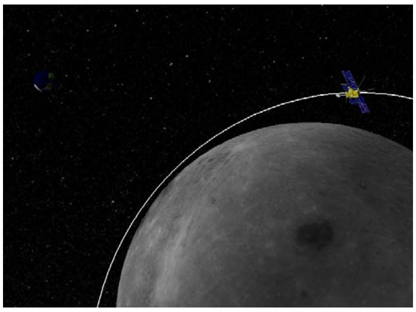


Wide mission simulation

- Moon orbiter



- Realistic Moon behaviour for solar and Moon albedo & IR fluxes
  - Daily and season rotations of Earth
  - Moon orbit and its rotational frame



- Dynamic follower camera
  - Camera Fixed in local orbital frame
  - View from / to Sun, the Earth or the Moon
  - Locking in planet rotational or inertial frame

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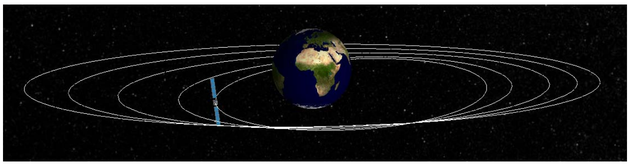
Wide mission simulation

- STK and CSV interfaces



- Both STK and CSV format are supported in import
  - STK : ephemerid .e format and attitude .a format
  - CSV : simple text files exported from Excel or other tools
- Trajectory satellite orbits
  - Position (and velocity in option) can be provided in cartesian or longitude / lattitude / altitude in rotational or inertial reference
  - Keplerian propagator or quadratic interpolation
- Kinematics attitude and behaviour
  - Attitude can be provided in quaternion or rotation matrix
  - Attitude are defined on a local orbital frame, a inertial frame or any pointing direction available in SYSTEMA

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

Appendix J

THERMICA-THERMISOL 4.3.4

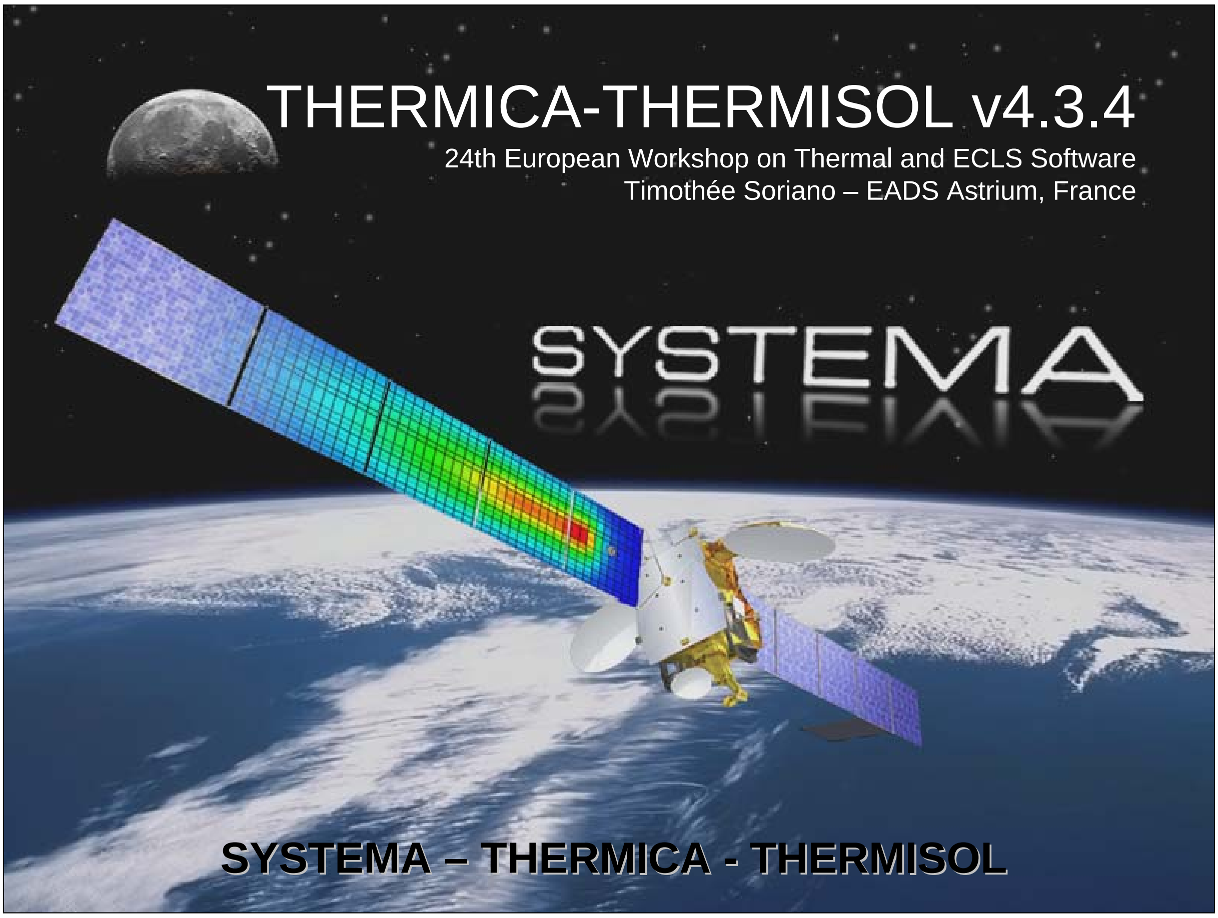
Timothée Soriano
(EADS Astrium, France)

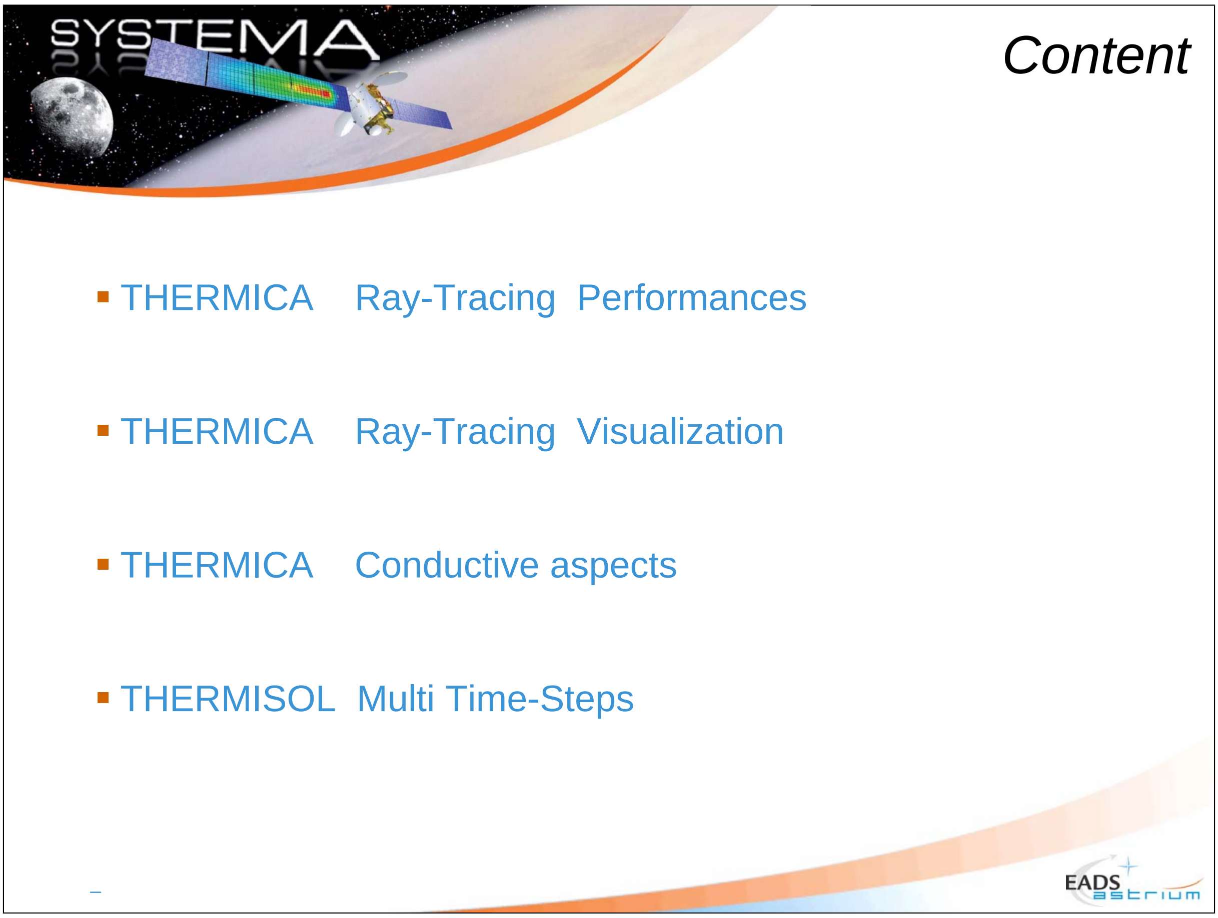
Abstract

THERMICA Performances
For its latest version 4.3.4, one major concern was the computation performance. The ray-tracing algorithm has been reviewed in order to speed-up its execution. Besides, THERMICA is now multi-threaded which allows to take benefit of the computer performance. Results and CPU time will be compared on significant cases, demonstrating that not only the accuracy of the v4 has been improved but the execution time has also become one of the strengths of THERMICA.

Ray-tracing visualization
Another major feature of the 4.3.4 version is the ray-tracing display in 3D view. In order to understand THERMICA results, ray paths can be displayed around the spacecraft visualization in the realistic mission render. User is free to navigate around rays and geometry, to filter by bouncing or emitting meshes, and to display in a same view results as shape color or textual value.

THERMISOL Evolutions
Performance issues have also been raised for complex models such as satellite systems including biphasic fluid loops. This kind of models requires small time-steps in order to converge. Therefore we decided to investigate on the multi time-steps algorithm already studied a few years ago. The principle of this algorithm is to adjust the main time-step so a certain percentage of the nodes (usually about 95%) have a good accuracy. For the other nodes, an adequate sub-step is used in order to get a full convergence of the system.


THERMICA-THERMISOL v4.3.4
24th European Workshop on Thermal and ECLS Software
Timothée Soriano – EADS Astrium, France
SYSTEMA
SYSTEMA – THERMICA - THERMISOL


SYSTEMA
Content
THERMICA Ray-Tracing Performances
THERMICA Ray-Tracing Visualization
THERMICA Conductive aspects
THERMISOL Multi Time-Steps
EADS astrium

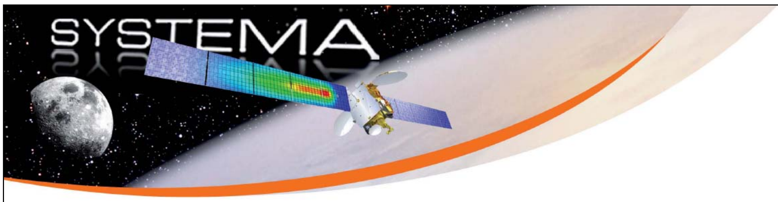
Content

THERMICA

Ray-Tracing Performances

THERMICA
Ray-Tracing Performances

- THERMICA 4.3.4
  - **Double Precision Multi-threaded software**
  - Uses a wide voxels discretization **optimized** for better performances
  - Accuracy problems are avoided thanks to **error controls** in the ray-tracing process
  - Performs computation **directly** on thermal nodes, then symmetries the results
  - Write **compressed** hdf5 files (rad.h5 and optional box.h5)
  - Uses dynamic memory allowing more **complex models**



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Ray-Tracing Performances

▪ Execution Time Comparison

- Machine used:
  - ➢ Red Hat Linux 64bits with 2 quad core processors
- Model description:
  - ➢ Telecommunication External model composed of 3500 meshes
  - ➢ Geo-stationary orbit with 16 orbital positions and kinematics body
- Execution Time Summary:

Versions	3.2.32	4.3.4		
Number of threads	1	1	4	8
Radiation Solar Flux	83 min 5 min	28 min 2 min	11 min 1 min	10 min 1 min
Total Time	88 min	30 min	12 min	11 min
Ratio vs 3.2.32		**2.93**	**7.33**	**8**

Ray-Tracing Improvements **+ Multi-threading**

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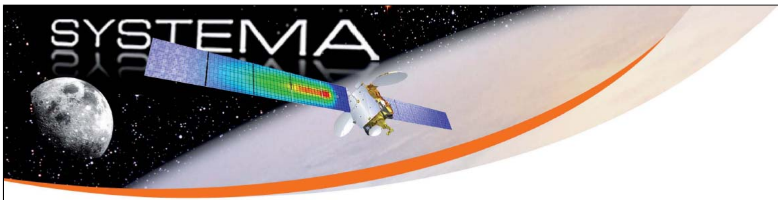

THERMICA

Ray-Tracing Performances

▪ Ray-Tracing Performances: Conclusion

THERMICA v4.3.4 is a high-performance ray-tracing algorithm

- ➢ The performances mainly depend on the number of rays.
- ➢ The complexity of the model has a limited impact on the CPU time but increases the amount of necessary RAM

This improvements allow to:

- ➢ Decrease the execution time (by about 7 on a quad core machine)
- ➢ Increase the model complexity
- ➢ Use directly CAD geometries on a thermal model

The v4 has now a performance level never reached in thermal analysis software

It is optimized for accuracy, fast execution and lower hard-drive memory usage

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Ray-Tracing Visualization

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THERMICA

Ray-Tracing Visualization

Ray-Tracing Visualization

- It is now possible to store all the computed rays in a hdf5 file
- The rays can then be easily viewed in SYSTEMA with filtering options
  - By emission node
  - By impacted node
  - Between nodes

  } with multi-selection is available
- SYSTEMA can handle an incredible amount of rays without a lost of 3D performances

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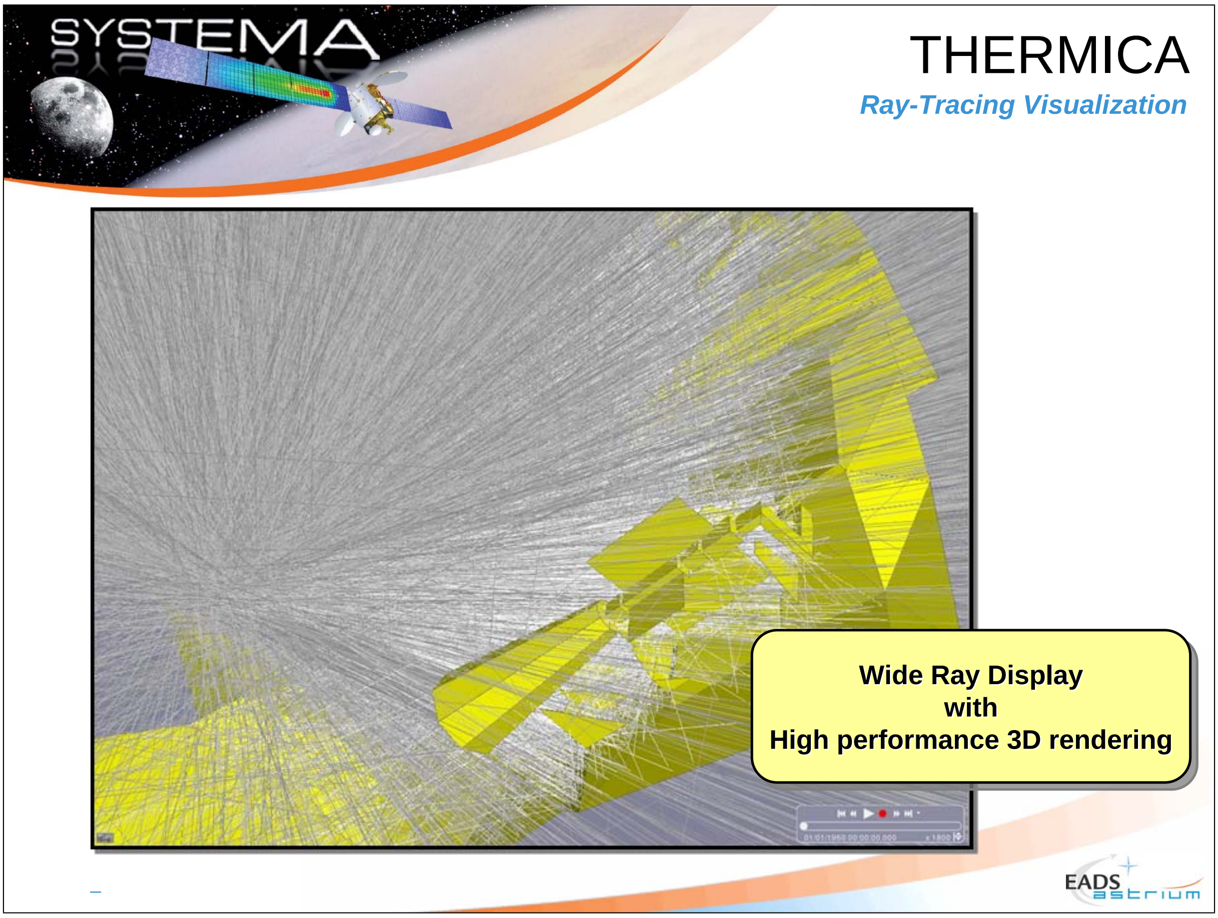
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Ray-Tracing Visualization
Wide Ray Display
with
High performance 3D rendering
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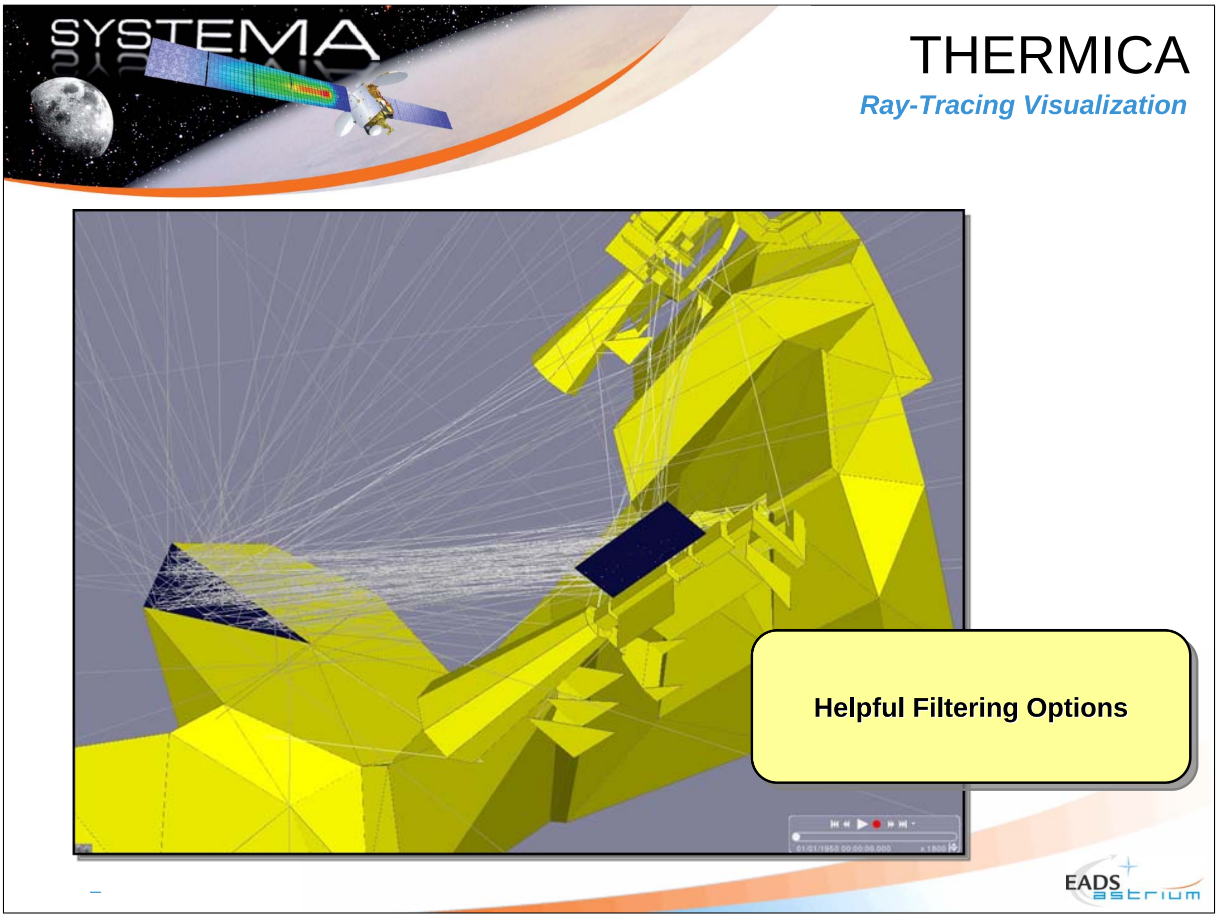
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THERMICA
Ray-Tracing Visualization
Helpful Filtering Options
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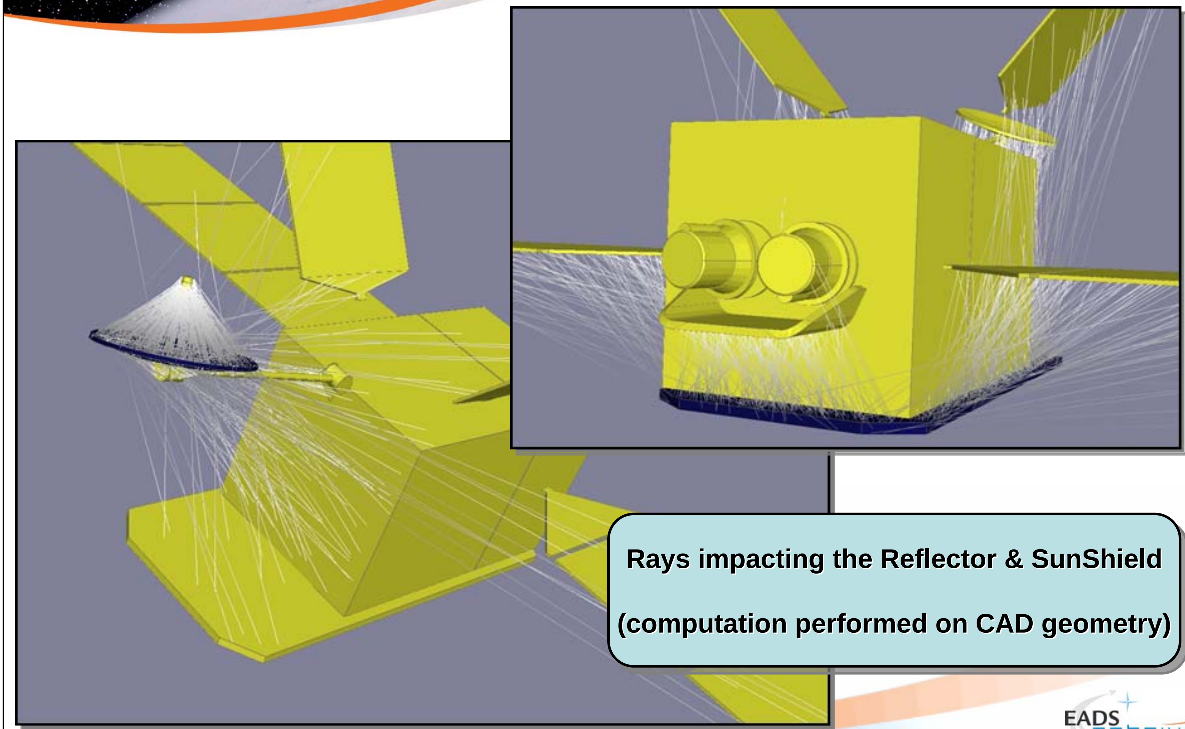
THERMICA

Ray-Tracing Visualization



Rays impacting the Reflector & SunShield

(computation performed on CAD geometry)

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Content

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Conductive Aspects

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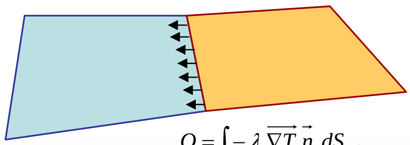
Conductive Couplings

Conduction Principle

- **Generality**
  - The conduction is driven by the Fourier's law $Q = \int_V -div(\lambda.\overrightarrow{gradT})\ dV = \int_C -\lambda.\overrightarrow{\nabla T}.\vec{n}\ dC$
  - The power exchanged by conduction between 2 shapes depends on the temperature gradient at their common frontier



$$Q = \int_{Edge} -\lambda.\overrightarrow{\nabla T}.\vec{n}\ dS_{Edge}$$

  - The temperature gradient between 2 shapes cannot be determined only with the knowledge of their average temperatures

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Conductive Couplings

Conductive Couplings topologies

- **Shape-to-Shape couplings (without edge nodes)**
  - This topology usually requires the following hypothesis:
    - The average temperature of a shape is located at its center
      ➔ *implies linearity of the temperature profile inside each shape*
    - The temperature gradient at the frontier is more or less $\Delta T / length$
      ➔ *implies linearity of the temperature profile across the 2 shapes*
  - Limitations:
    - A linear temperature profile is equivalent to have only conductive fluxes
      ➔ *the mesh size shall be decreased to minimize the surface fluxes*
    - There is no mathematical evidence of the couplings solving equations
      ➔ *it is not possible to quantify the error made*

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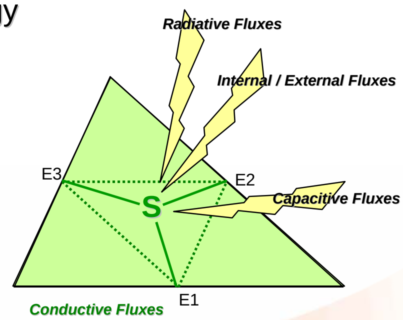
Conductive Couplings

Conductive Couplings topologies

- Necessity of the Edge Nodes
  - They are used to compute the temperature gradients on their dimension
  - This information is required to compute accurately the conductive flux
- Possible couplings using a “edge node” topology
  - It can be demonstrated that it exists an infinite set of couplings on a shape which are linearly exact
  - Among all those possibilities, it is also possible to demonstrate that it exists one and only one solution consistent with the radiative mesh
  - This solution lays on only one hypothesis:

    The surface flux shall be uniform on the surface



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Conductive Couplings

The Reduced Conductive Network method is now mathematically demonstrated

- Key points of the demonstration
  - Definition of all linear solutions in a triangle (6 parameters to be defined)

    A set of 5 equations can be written to define them

    A 6th coefficient can be of any value $(\forall a \in \Re^{+})$
  - Introduction of a tiny power on the triangle surface $\tilde{Q}_S = \varepsilon_S$

    Then the 6th equation becomes $\exists a \;/\; \tilde{T}_S = T_S + a.\varepsilon_S + o(\varepsilon_S^2)$

    Meaning that not all solutions of the linear case are solutions of this problem

    But it exists at least one solution among them (which we don’t know…)

  The error made on the temperature is proportional to the power ε_S

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Conductive Couplings

- Key points of the demonstration

  ➢ The Detailed Conductive Network: Study of a shape with significant surface powers

  If we discretize the shape into small triangles, the surface power (supposed uniform) is distributed to the submesh. Each submesh triangle is then conform to the previous case. We write a detailed conductive network on the submesh. This detailed conductive network is written with unknown values of the a *coefficients.*

  ➢ Reduction of the detailed network: creation of the reduced network

  It can also be demonstrated that there is an exact reduction of the detailed network under the only hypothesis of a uniform surface flux.

  This reduction do not sum the error made on each triangle but average those errors !!!!

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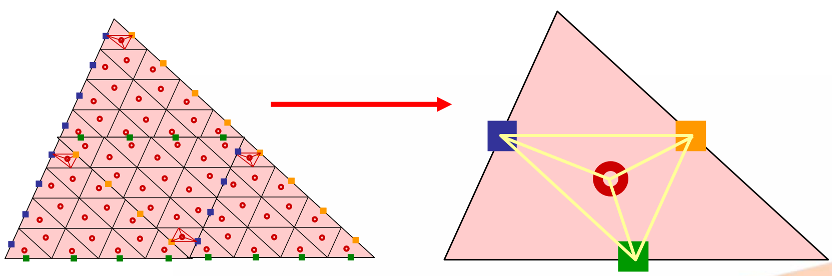
Conductive Couplings

Demonstration conclusion

Even if the analytical description of the couplings is not known, and even if the detailed network is written using only a linear solution (and not the solution of the real problem), The reduction of such network tends to the exact solution of the problem as the submesh size decreases.



Detailed Conductive Network *Reduced Conductive Network*

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Conductive Couplings

The RCN method

- Disadvantages
  - Creates an edge nodes structure
  - The conductive flux is given by a few couplings contributions
- Advantages
  - The conductive fluxes are accurately computed
  - It lays on the same hypothesis than the radiative couplings and external fluxes
  - The mesh size is dimensioned according to the radiative constraints
    - ➪ reducing the mesh for conductive aspects is not necessary and even meaningless
    - ➪ the nodal network can be composed with less surface nodes

The RCN is the only 2^{nd} order known method which is Mathematically consistent with our thermal analysis

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Multi Time-Steps

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THERMISOL

Multi Time-Step

Problematic

The integration of complex elements in a thermal model may implies a need of a reduced time-step for converging the numerically sensitive sub-part of the model…

… even if the majority of the nodes has a less constraint thermal environment and could be solved with a much greater time-step.

Recent examples are given by the integration of LHP fluid loops in the THERMISOL models

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Multi Time-Steps

The Multi Time-Step: A possible Solution

- Needs to find a compromise
  - On one hand, a converged solution can only be obtained with small time-steps
  - On the other hand, we want to save CPU Time (so increase the time-steps)
- Not an easy task
  - Obviously, the integration of a numerically sensitive element such as a LHP sub-model has globally an impact on the entire model, even if the temperature variations are smoother on the majority of the model
  - The use of a sub-time shall be carefully studied

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THERMISOL

Multi Time-Steps

Principles

- THERMISOL computes a 2nd order solution and a good error estimation at the 3rd order
- Nodes are divided into 2 categories: with an acceptable error / with too much error
- A sub time-step may be used for the rejected nodes group
- The other nodes are interpolated according to their quadratic temperature profiles
- All node's temperatures are recomputed at the rendez-vous. The solutions are compared and the entire time-step (prime+subs) is validated or rejected

No mathematical evidence of the convergence

- The errors are only estimations and the interdependences of the nodes do not allow a mathematical justification of the re-computation of a sub-group only.
- The complex interactions in a thermal model makes it difficult to pre-define groups of sensitive nodes
- Precautions shall be taken: the multi time-steps algorithm needs to verify that the subdivision of the thermal model in 2 groups is valid

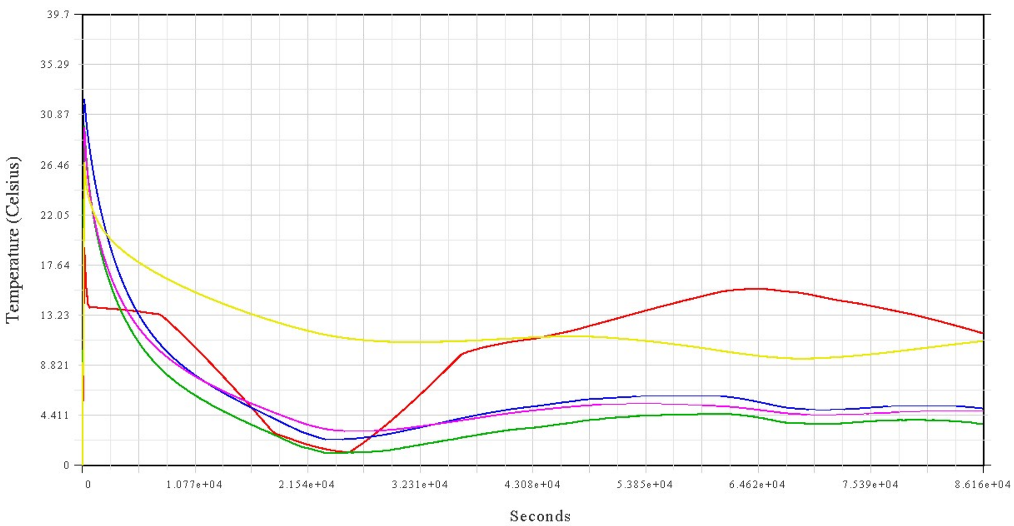
THERMISOL

Multi Time-Steps

Example: a telecommunication satellite including 12 LHP

- Fixed Time-Step of 1s :

Convergence: Excellent / Execution Time: 160 minutes



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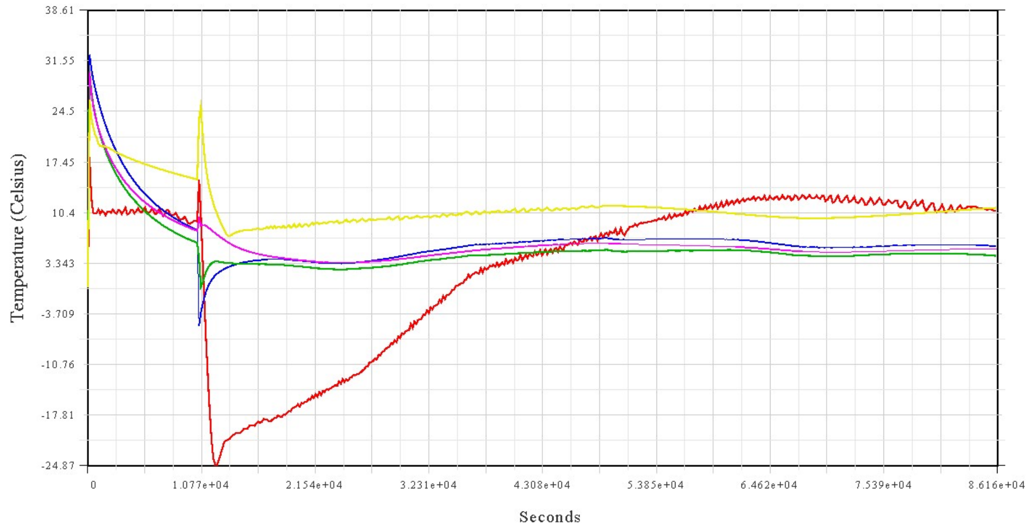
Multi Time-Steps

- Fixed Time-Step of 10s :
  Convergence: Very bad / Execution Time: 55 minutes



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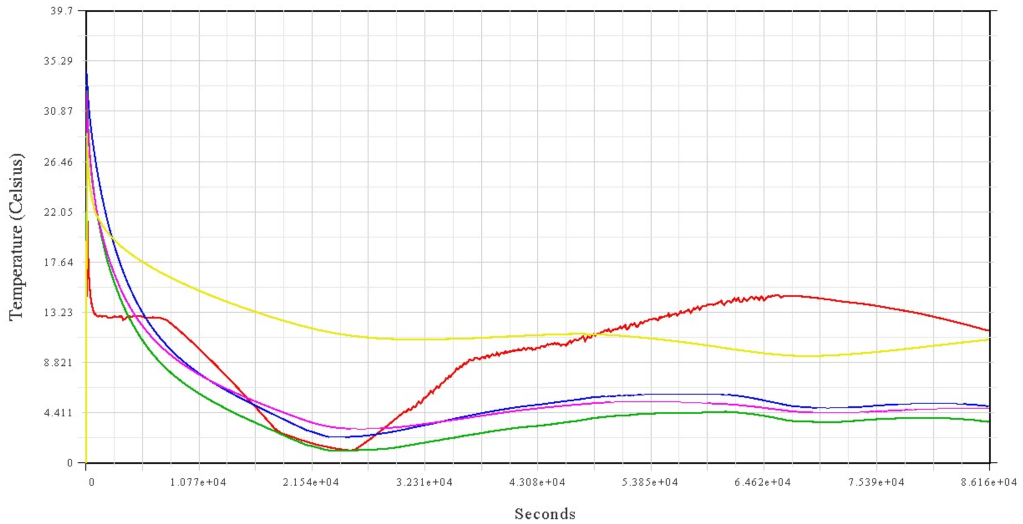
Multi Time-Steps

- Multi Time-Step of 10s / 0.5s :
  Convergence: Acceptable / Execution Time: 75 minutes



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Multi Time-Steps

Multi Time-Steps conclusions

- This algorithm has a completely automatic behavior
  - The prime time-step may be fixed or automatically adjusted
  - The sub-division of nodes is automatically computed
  - The sub-step is automatically computed
- The accuracy is well managed
  - Errors are systematically double-checked before and after any sub-step establishment
  - Users constraints (time-steps limitations) are taken into account
- Convergence / CPU Time : a good compromise
  - See the previous slides

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Multi Time-Steps

Next step: consolidation of the algorithm

- Minimize rejected computations
  - Automatic prime-step leads to a lot of rejected computations (which increases CPU time)
- Minimize the number of nodes to re-compute
  - All arithmetic nodes are systematically recomputed – need to find an alternative
- Validation of the convergence vs time compromise
  - More cases shall be studied to identify rules and possible improvements of the algorithm

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THERMISOL - Applications
Automatic time-step adjustment

Appendix K

TMRT

Mathieu Bernard
(EADS Astrium, France)

Thierry Basset
(Thales Alenia Space, France)

James Etchells
(ESA/ESTEC, The Netherlands)

Abstract

The presentation will start with the introduction of the need to perform a thermal model reduction and present TMRT as one solution for the task.
Then the general working principles of TMRT and the way of using the toll will be presented. In conclusion, the availability of the tool will be announced.
The presentation will be user oriented and aim at convincing people to try TMRT.

Thermal Model Reduction Tool

TMRT

24th European Workshop on Thermal & ECLS Software

Mathieu BERNARD – ASTRIUM

Thierry BASSET – THALES ALENIA SPACE

François BRUNETTI – DOREA

James ETCHELLS – ESA

16/11/2010

All the space you need

Overview

- Thermal Model Reduction Needs
- TMRT Origins
- TMRT Reduction Working Principle
- TMRT Other Functionalities
- TMRT User Interface

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Thermal Model Reduction Needs

- To cope with contract:
  - Delivering a sub-system reduced thermal model is often contractual with a specified maximum number of nodes and a specified accuracy.
  - With a little number of nodes, a sub-system reduced thermal model is easier to integrate at system level and easier to understand.
- To improve complex element modelling process:
  - The modelling of complex element can be performed using a great number of thermal nodes and simple coupling definitions.
  - Then, it can be reduced to cope with thermal analysis needs.

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TMRT Origins

- The will to harmonize reduction methods (CNES, ESA, THALES ALENIA SPACE & ASTRIUM)
- Existing tools in THALES ALENIA SPACE and ASTRIUM based on the same methodology:
  - EQUIVAL in THALES ALENIA SPACE
  - THERMIRED in ASTRIUM
- Methodology efficiency proven
- Either tool could not be commercialized as is.

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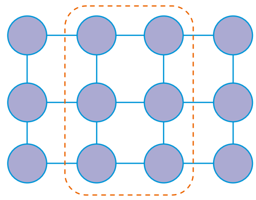
TMRT Reduction Working Principle

- A reduction is defined by making groups of nodes:
  - Each group defines a reduced model node: $T_A = \sum_G a_{AG} T_G$
  - The groups should be made considering the hypothesis of proportionality of the non-conductive powers: $P_G = a_{GA} P_A$



- The reduced model is valid as long as the hypothesis above is well respected.

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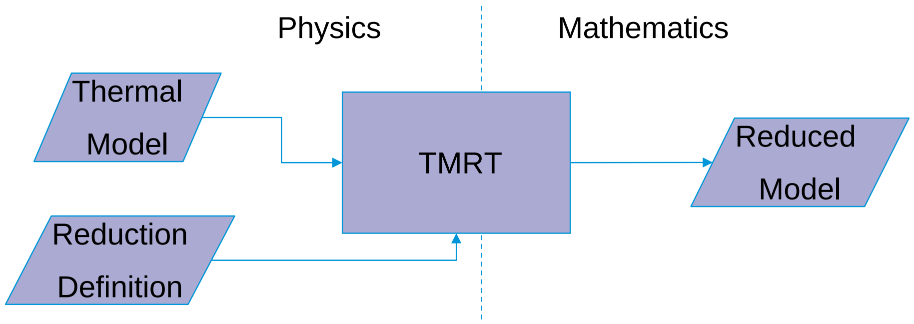
TMRT Reduction Working Principle

- Equivalent Reduction: linear conductors of the reduced model must be considered as a whole, not individually.



- Works with ESATAN/THERMISOL format and CORATHERM format.

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TMRT Reduction Current Applications

- In THALES ALENIA SPACE and ASTRIUM, the model reduction based on this methodology is used to reduce:
  - Telecom payload panels.
  - Antenna assemblies.
  - Electronic units.
  - Instruments.
  - Spacecraft models for launcher analyses.
  - Brackets.

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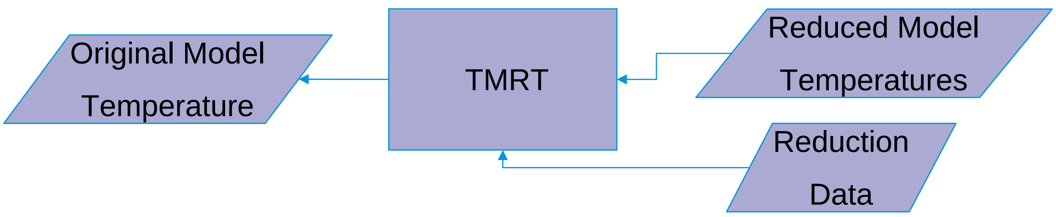
TMRT Other Functionalities

- Temperature Recovery (Secondary Functionality):



- Advanced Functionalities:
  - Node suppression
  - Power distribution
  - Post-processing nodes
  - Reduced model filtering

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TMRT User Interface

- TMRT User Interface consists in a series of menus:
  - For specifying the TMRT use case.
  - For specifying the input and output files.

```
          ****************************************************
          */------------------------------------------------\*
          *|                                                |*
          *|              TMRT Batch interface              |*
          *|                                                |*
          *\------------------------------------------------/*
          ****************************************************

                           Version 1.0

 Choice of the TMRT Use Case:

    - To perform a Reduction, enter:                                   (1)
    - To perform a Filtering, enter:                                   (2)
    - To perform a Temperature Recovery, enter:                        (3)
    - To perform a whole chain
      (Reduction/Solver/Temperature Recovery),enter:                   (4)

    - To quit, enter:                                                  (0)
```

```
   Choice of the TMRT Inputs/Output files:

      - For Inputs and Outputs in CORATHERM format, enter:                    (1)
      - For Inputs and Outputs in ESATAN/THERMISOL format, enter:             (2)
      - For Inputs in CORATHERM format and
        Outputs in ESATAN/THERMISOL format, enter:                            (3)
      - For Inputs in ESATAN/THERMISOL format and
        Outputs in CORATHERM format, enter:                                   (4)

      - To quit, enter:                                                       (0)
Name of the Detailed Thermal Model ESATAN/THERMISOL input file?
Name of the TMRT Calculation input file (type '+' for default filename
BASIC1.CASTMRT) ?
Name of the Collective Node Definition Input file (type '+' for default filename
BASIC1.CNF)?
Name of the Reduced Thermal Model THERMISOL/ESATAN output file (type '+' for
default filename BASIC1R.d)?
Name of the TMRT Model (type '+' for default filename BASIC1)?
Save the answers to file (Y/N)?
```

- TMRT can be launched without going through the menus by providing an answer file.

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TMRT Availability

- TMRT is a now available.
- It is license protected.
- Licenses can be obtained by contacting ASTRIUM THERMICA service (fee covering maintenance & distribution costs)
- Documentation is available:
  - User Manual
  - Theoretical Manual

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Conclusion

- TMRT is a powerful thermal model reduction tool now available to the community.
- It can be used to perform very simple reductions or complex ones.
- Reduction definition is performed manually by the user. Modules on thermal modelling tool could be developed in order make it more user friendly.
- Such modules could also be used to perform the geometrical reduction.

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Annexes

- TMRT Reduction Example
- TMRT Theory

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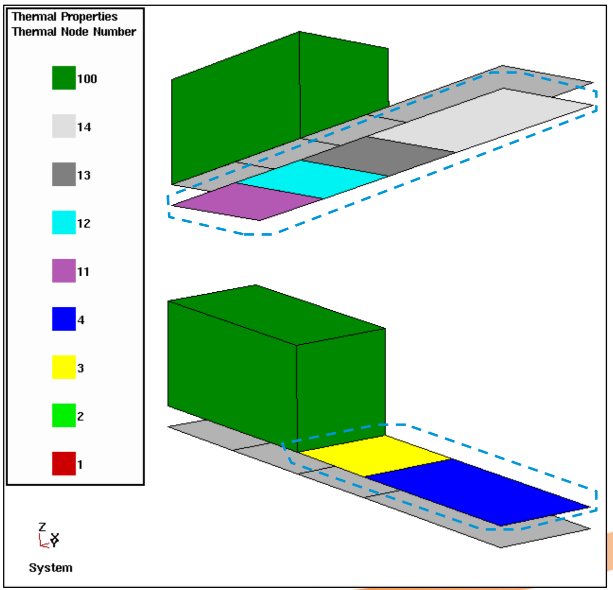
TMRT Reduction Example



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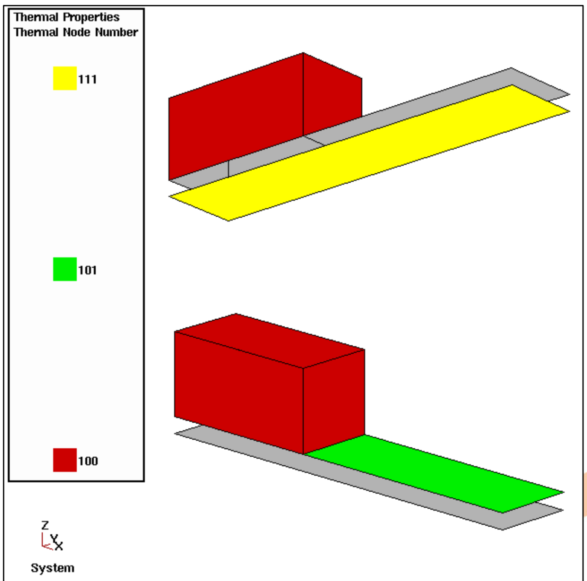
TMRT Reduction Example

```
$SUPPRESSED
1  100
$Q
2  100
3
$NREC
3
4
#
$AVERAGE
CAPACITANCES
$101
3  1
4  1
$102
11  1
12  1
13  1
14  1
#
```



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TMRT Theory

- Thermal System: $CT + M\frac{\partial T}{\partial t} = q + p = q'$
- Projection Method: $T = R\hat{T}$ $\quad \tilde{R}^t\left[CR\hat{T} + MR\frac{\partial \hat{T}}{\partial t}\right] = \tilde{R}^t[q' + r]$

$$\hat{C}\hat{T} + \hat{M}\frac{\partial \hat{T}}{\partial t} = \hat{q}'$$

$$\hat{C} = \tilde{R}^t CR, \qquad \hat{M} = \tilde{R}^t MR, \qquad \hat{q}' = \tilde{R}^t q'$$

- Guyan-Irons Reduction:

$$\begin{bmatrix} C_{\alpha\alpha} & C_{\alpha\beta} \\ C_{\beta\alpha} & C_{\beta\beta} \end{bmatrix} \begin{Bmatrix} T_\alpha \\ T_\beta \end{Bmatrix} = \begin{Bmatrix} q'_\alpha \\ q'_\beta \end{Bmatrix} \qquad T = \begin{Bmatrix} T_\alpha \\ T_\beta \end{Bmatrix} = R\hat{T} = RT_\alpha$$

$$R = \begin{bmatrix} I_\alpha \\ -C_{\beta\beta}^{-1}C_{\beta\alpha} \end{bmatrix}, \qquad \tilde{R}^t = R^t = \begin{bmatrix} I_\alpha & -C_{\alpha\beta}C_{\beta\beta}^{-1} \end{bmatrix}$$

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TMRT Theory

- Linear Constraints: $g = AT$
- Lagrangian Multipliers:

$$g = 0 = AT \qquad \begin{bmatrix} C & A^t \\ A & 0 \end{bmatrix} \begin{Bmatrix} T \\ \lambda \end{Bmatrix} = \begin{Bmatrix} q' \\ 0 \end{Bmatrix}$$

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TMRT Theory

- TMRT Equation:

$$\begin{bmatrix} C_{KK} & C_{KS} & C_{KG} & 0 & 0 \\ C_{SK} & C_{SS} & C_{SG} & 0 & 0 \\ C_{GK} & C_{GS} & C_{GG} & 0 & A_{AG}^{t} \\ 0 & 0 & 0 & 0 & A_{AA} \\ 0 & 0 & A_{AG} & A_{AA} & 0 \end{bmatrix} \begin{Bmatrix} T_K \\ T_S \\ T_G \\ T_A \\ \lambda \end{Bmatrix} = \begin{Bmatrix} q'_K \\ q'_S \\ q'_G \\ q'_A \\ 0 \end{Bmatrix}$$

$$T_{A_i} = \sum_{i \in G_i} a_{A_i i} T_i \qquad T_A = A_{AG} T_G$$

$$g = \begin{bmatrix} A_{AG} & A_{AA} \end{bmatrix} \begin{Bmatrix} T_G \\ T_A \end{Bmatrix} = A \begin{Bmatrix} T_G \\ T_A \end{Bmatrix} = 0$$

$$A_{AA} = -I_A$$

$$C_{\alpha\alpha} = \begin{bmatrix} C_{KK} & 0 \\ 0 & 0 \end{bmatrix}, \qquad C_{\beta\beta} = \begin{bmatrix} C_{SS} & C_{SG} & 0 \\ C_{GS} & C_{GG} & A_{AG}^{t} \\ 0 & A_{AG} & 0 \end{bmatrix},$$

$$C_{\alpha\beta} = C_{\beta\alpha}^{t} = \begin{bmatrix} C_{KS} & C_{KG} & 0 \\ 0 & 0 & A_{AA} \end{bmatrix}$$

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TMRT Theory

- TMRT Reduced Equations:

$$\hat{C} = C_{\alpha\alpha} - C_{\alpha\beta} C_{\beta\beta}^{-1} C_{\beta\alpha}$$

$$\hat{M} = M_{\alpha\alpha} + C_{\alpha\beta} C_{\beta\beta}^{-1} M_{\beta\beta} C_{\beta\beta}^{-1} C_{\beta\alpha}$$

$$\hat{q}' = q'_{\alpha} - C_{\alpha\beta} C_{\beta\beta}^{-1} q'_{\beta}$$

$$T_{\beta} = -C_{\beta\beta}^{-1} C_{\beta\alpha} T_{\beta} + C_{\beta\beta}^{-1} q'_{\alpha}$$

All the space you need

Date - 18

Appendix L

LHP module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses

Frédéric Jouffroy
(EADS Astrium, France)

Anne-Sophie Merino
(Thales Alenia Space, France)

Amaury Larue de Tournemine
(CNES, France)

Abstract

A Loop Heat Pipe (LHP) is a key two-phase technology for reaching, at low mass and cost, the heat transportation capability needed by recent advanced space missions, either in terms of large amounts of heat to be transferred (more than 10 kW) or of reduced temperature gradients between dissipative units and the corresponding radiator area.

Although LHP technology is now available to be included in future systems, its practical use for industrial projects is in practice related to the possibility of predicting the thermal behaviour and mutual thermal interactions between LHPs and a space system. The objective of a LHP software module is to provide a sufficient LHP model for system analyses that can be easily plugged into usual thermal models developed by European space industry (ie based on Esatan and Thermica thermal solvers).

A LHP Module has been developed through a partnership including ESA and CNES agencies, and EADS Astrium and Thales Alenia Space (TAS) industrial companies. EADS Astrium was mainly in charge of the software development while TAS efforts were focused on validation.

The LHP Module is based on the use of the standard ESATAN $ELEMENT feature such that it can be directly interfaced as a submodel with any existing model. A standard simple evaporator model is used, involving 3 or 5 thermal nodes depending on data provided by the LHP supplier. Tubing (vapour line, condenser and liquid line) modelling developed includes thermal and hydraulic aspects. The meshing is to be defined by the thermal engineer according to and consistent with the one existing in the corresponding system model (radiators and panels). Several different tubing sections can be set for liquid and vapour lines in order to take into account for instance the different flexible sections for a deployable radiator; it is also possible to model multi-condensers with up to 5 parallel branches.

The LHP software module is mainly dedicated to transient problems, allowing to predict LHP stop and start events. Steady-state situations can in practice be handled by running stabilized transient cases. In order to ease integration of LHPs within system models, the different LHP components (fluid used and hardware parts: evaporator, condenser, vapour and liquid line hardware) and assembly are defined in separate external files to be referenced in the system model; this reduces the changes to be applied to the system model as much as possible and enables the construction of libraries of component files for future reuse.

Validation of the LHP module has been performed through comparison of temperature predictions with measurements for different hardware and configurations, including flight measurements, such as Inmarsat-IV, Delphrad and Com2plex. Correlation less than 5° could be obtained in many cases.

The LHP module is available for the European thermal space community as a "black box" tool compatible with available Thermisol v4.3.3 and the next version of Esatan planned to be released by end 2010.

LHP Module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses

Frédéric JOUFFROY, EADS Astrium

Anne-Sophie MERINO, Thales Alenia Space

Amaury LARUE DE TOURNEMINE, CNES

24th European Workshop on Thermal and ECLS Software

16-17 November 2010

Agenda

- Introduction
- Software presentation
- Software validation
- Availability

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Agenda

- Introduction
- Software presentation
- Software validation
- Availability

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Context

- LHP : An emerging technology for heat transfer
- Need for a tool able to predict system-LHP thermal interactions and behaviour by using European usual space thermal software
  - Esatan solver
  - Thermica solver
- Involvement of agencies & prime contractors
  - CNES
  - ESA
  - ASTRIUM
  - TAS

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Modelling capabilities

- LHP behaviour
  - Thermo-hydraulic heat transfer
    - Tubing nodes+fluid nodes modelling, mass flow prediction
    - All heat transfer configurations managed (cooling & heating)
      - Vapour & liquid 1-phase heat transfer
      - 2-phases vapour/liquid heat transfer.
  - LHP start & stop prediction (unit switch on/off)
    - Minimum/maximum acceptable transferred power
    - Evaporator-reservoir gradient
- LHP configurations
  - Evaporator: designs supported through generic simplified modelling
  - Vapour line: Different tubing sections (flexible, rigid)
  - Condenser: Multiple branches
  - Liquid line: Different tubing sections

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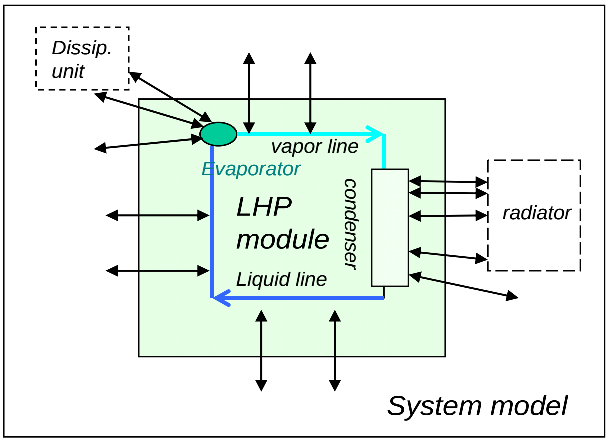
Interaction with system model

- Several LHPs can be used within a system model
- Any radiative/conductive interface can be modelled
- Tubing meshing (vapour line, condenser, liquid line) to be defined according to system model need



Interface modelling has a strong influence on results !

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Implementation concept

- Esatan & Thermica solver compatibility:
  - LHP designed as a $ELEMENT submodel to be plugged into system model
    - → No limitation on number of LHPs used but impact on CPU time
    - → No limitation on interface definitions (couplings LHP-model)
- Generic tool adaptable to various LHP designs
  - LHP HW and fluid definition done through external files
- 'Blackbox version' for delivery to subco & partners
  - Compiled version protects confidential source code
  - Reduces source code length
    ⇒cuts pre-processing & compilation duration when many LHPs are plugged into system model

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Agenda

- Introduction
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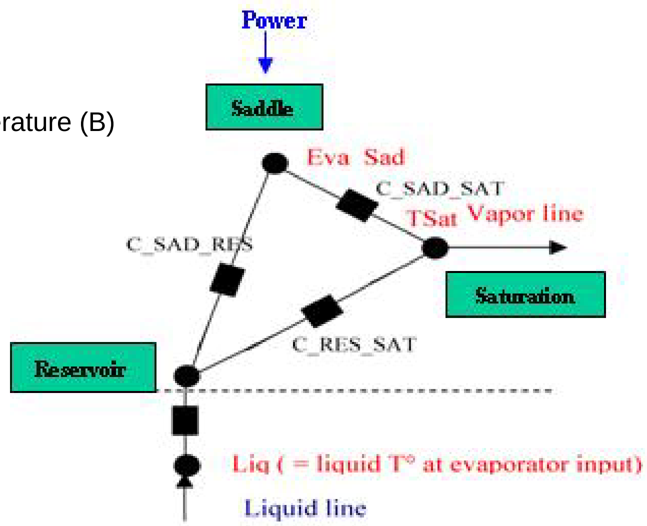
Evaporator modelling

- Evaporator
  - Built-in reduced definition : 3 nodes/couplings only used for computation
    - Reservoir (D)
    - Evaporator body (D)
    - Fluid saturation temperature (B)



  - Possible 5 nodes/couplings definition: internal conversion to 3 nodes

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LHP definition & use

- Hardware components
  - One file per LHP item (Evaporator, vapour line, condenser, liquid line, fluid)
    - Geometrical & physical properties
- Component assembly:
  - *LHP configuration integration file*
    - Calls for Hardware component files
    - Defines meshing for condenser &lines: nb of nodes, regular or not
    - Global parameters: total fluid mass
    - Initial conditions: temperature & heating
- Use in system model: $ELEMENT
  - Default parameter values can be superseded ($substitutions)
    - Data structure dimensions
    - Debug mode for file read
    - …

```
$MODEL LMAIN
$MODEL LHP1
$ELEMENT LHP
$SUBSTITUTIONS
…….
```

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Tool execution

- Transient conditions
  - Time step must be compatible with LHP time constant ≈ a few seconds
    - ⇒ ***Potential critical computation duration for large system models***
    - ⇒ Need for improving TMM computation speed
      - Thermica solver spatial time step variation (Multi-step capability)
      - …

- Steady-state conditions
  - Intrinsic LHP model instability
  - Cyclic convergence (repetitive min & max TSAT value for LHP node) is automatically detected when occurring ⇒ Warning + early stop of execution.
    - ⇒ ***run the model in 'stabilized' transient mode***

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LHP Operation reporting in *.out* file:

- Physical characteristics & SW operation reporting
  - *to be done in system model:* CALL LHP1:OUTPUTLHP

```
|------------------------------------------------------------
|                  MODEL CONTROL PARAMETERS
| CURRENT INSTANT (TIMEM)                    :        89956.00
| CURRENT TIME STEP (DTIMEU)                 :            2.00
| NUMBER OF ITERATIONS (LOOPCT)              :               4
| CONVERGENCE CRITERIA (RELXCC)              :      -0.404E-05
| NUMBER OF LHP OPERATION EMITTED WARNINGS   :              11
| NUMBER OF LHP START/STOP EVENTS            :               3
|------------------------------------------------------------
|                 LHP THERMAL CHARACTERISTICS
| HEAT INPUT (W)                             :           1.195
| HEAT TRANSPORT (W)                         :           1.482
| FLUID SATURATION TEMPERATURE (°)           :           23.20
| EFFECTIVE SUBCOOLING (°)                   :           10.32
| EVAPORATOR CONDUCTANCE saddle-fluid (W/K)  :           10.22
| CONDENSER CONDUCTANCE fluid-saddle (W/K)   :            0.08
| TOTAL LHP CONDUCTANCE saddle-saddle (W/K)  :            0.08
| ...
```

- All changes in condition status are output
  - ⇒Start/Stop events tracked

```
*** LHP INITIAL OPERATION STATUS AT TIME =   5.0   ***
 LHP defined in submodel LHP1 should OPERATE
     Power at evaporator=  194.1   >= [min op] specified power=  0.0
     Power at evaporator=  194.1   <= [max op] specified power=  500.0
     Δ (saddle,reservoir)=  57.05 - 43.6 = 13.4 >= Min. op. Δ =1.0E-02
     Total pressure head in loop=  5134.5   <= Max.sustainable evaporator
pressure head=  50000.0

*** LHP OPERATION EVENT ***
 LHP defined in submodel LHP1 should STOP around TIME=  20.0
   Insatisfied conditions :
     Power at evaporator=  -14.002  <   [min op] specified power=  0.0
```

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Agenda

- Introduction
- Software presentation
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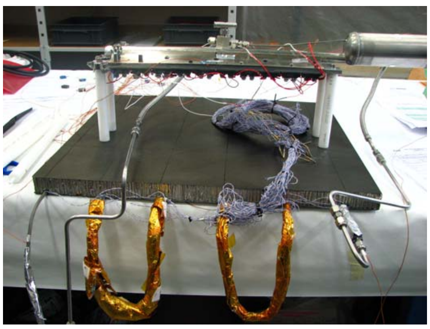
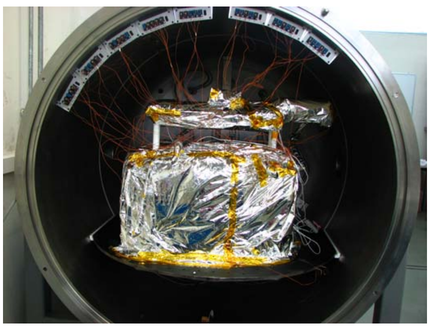
LHP2 radiator test case

- Ground vacuum test
  - LHP² evaporator hardware
  - Condenser tubing embedded in radiator panel
  - Radiator facing temperature controlled cold plate

TEST



MODEL



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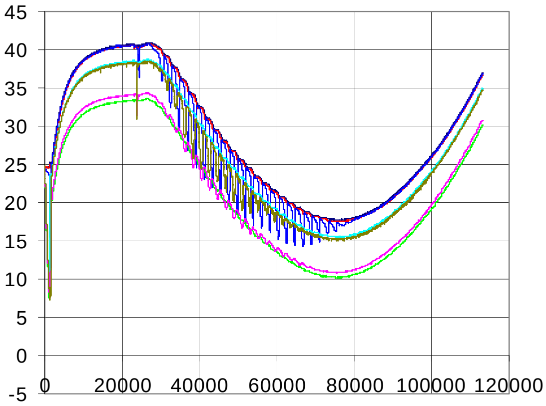
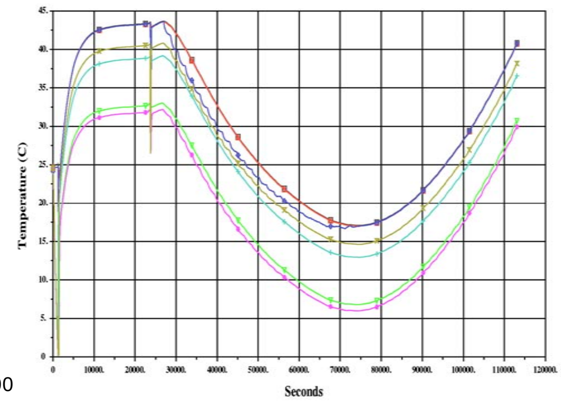
LHP2 radiator test case

- Correlation to test results performed
  - Constant power source 50W, cold plate: -10→-55→-10 °C
  - Good simulation of specimen behaviour
  - Correlation < 5°C

TEST



MODEL



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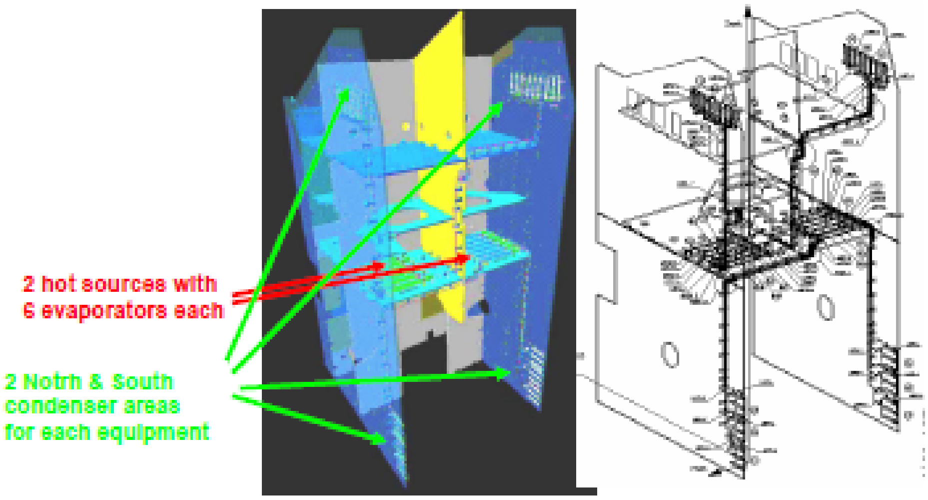
INMARSAT 4

- Use of 12 LHPs to cool 2 highly dissipative units

INMARSAT 4 LHP configuration



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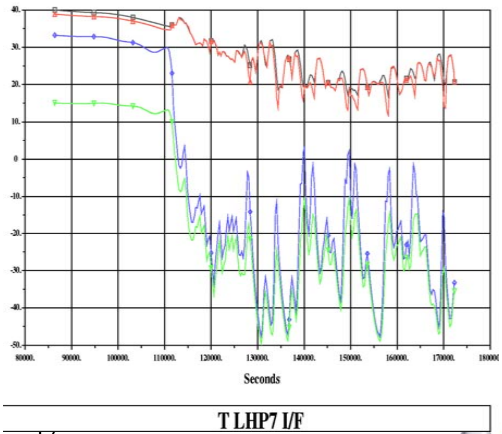
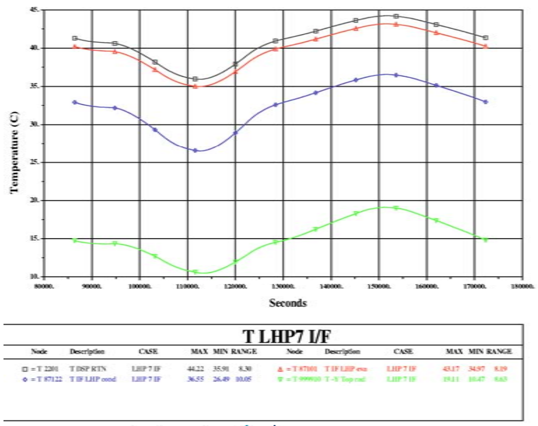
INMARSAT 4

- Interfacing LHP module with S/L model
  - Evaporator-condenser power tabulated conductances replaced by 12 LHP modules instances
  - Discrepancies to flight measures < 8°C
  - Time step reduction needed ⇒ Computation duration ≈x 10

Initial time step



Reduced time step



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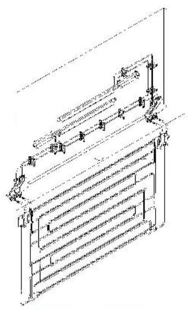
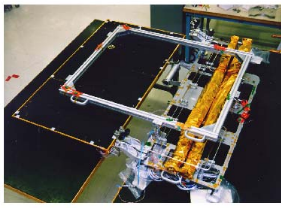
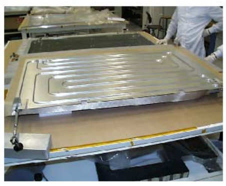
DELPHRAD

- DEployable Lightweight High Performance RADiator EM
  - 2 LHPs
  - Condenser embedded in radiator
    - 3 // branches per condenser
    - Each condenser connected to one side of the radiator
  - Liquid lines:
    - 3 parts: fixed on Spacecraft wall, flexible, fixed embedded in the radiator
    - Conductive & radiative exchanges
  - Vapor lines:
    - 2 parts: fixed on Spacecraft wall, flexi
    - Conductive & radiative exchange with







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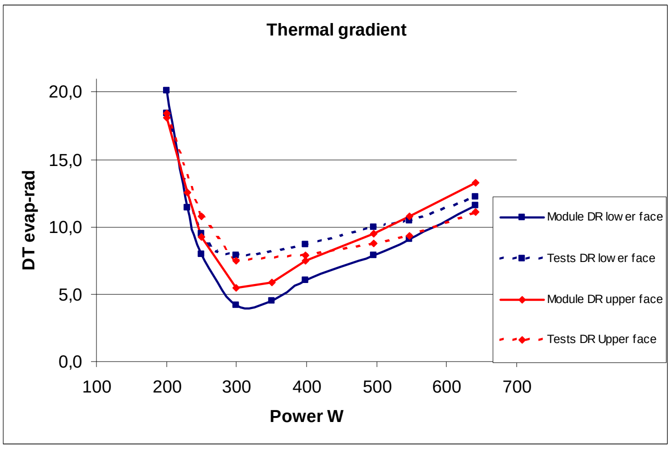
DELPHRAD

- Thermal gradient vs Power with stabilised results



Transition @ 300W observed for test and simulation results

- Good simulation of Start Up & Shut Down
  - temperature level
  - stabilisation duration

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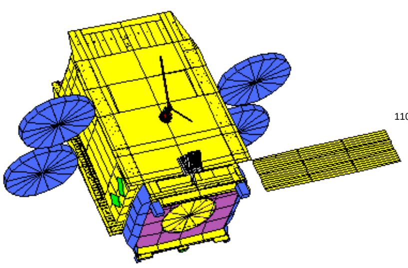
@BUS Prospective activity

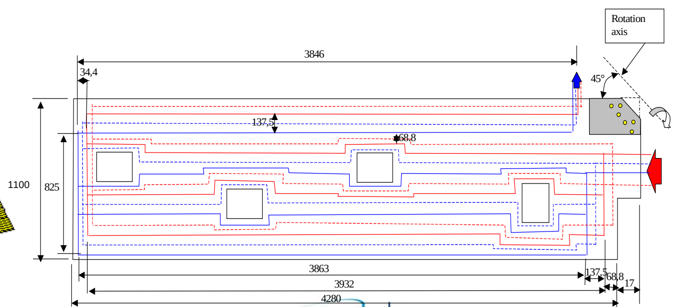
- DPR with 4 LHPs added to @BUS CDR model in order to:
  - **Validate the use of the LHP module in a large system model**
  - **Evaluate the impact in terms of CPU time**

⇒ **No evaluation of the thermal DPR performance**

⇒ **Power added to maintain the same temperature level on HP crossing**

-





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@BUS conclusion

- LHP module can be coupled to Spacecraft system model (system simulations of EQ and SS performed with success)
- Overall time step had to be decreased from 50 s to 1 or 2s
  - ⇒CPU time multiplied by 24 (8 days wrt 8 hours) wrt @BUS model without LHPs

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Agenda

- Introduction
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Software availability

- Black box version
  - Confidential code put in object library, to be used as other user-defined libraries
  - Availability for last version v2.6.2
    - Thermica solver: OK, for version >= v4.3
    - Esatan : planned 01-2011 for new version delivered November 2010
- Available for free to the community
  - Black box version + Software User Manual + Installation manual
  - On-line support : organisation still to be defined (limited support during guarantee period)
  - Contacts:
    - Astrium: frederic.jouffroy@astrium.eads.net
    - TAS: anne.sophie.merino@thalesaleniaspace.com
    - CNES: Amaury.Laruedetournemine@cnes.fr

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LHP MODULE : CONCLUSION

- Ability for European industry to use standard thermal software to predict thermal behaviour of space systems including LHPs
- Modular component approach
  → Creation of libraries of components for re-use
    - Evaporators
    - Fluids
    - condensers
- Validated through many test cases
- Computation time consuming:
  → Requires thermal solver performance improvement to deal with large models
  → Use of LHP module may be restricted to a few start/stop verification & sizing cases.
- Perspectives : New functionalities to be implemented (by-pass, Peltier, isolator, …)

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APPENDIXES

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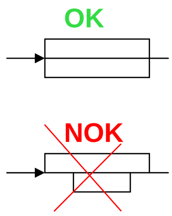
Lines modelling

- Tubing nodes (D type)
  - Vapour line:
    - up to 99 nodes & 5 sections to define flexible & rigid parts
  - Condenser
    - Up to 398 nodes
    - Up to 5 fully parallel branches

    Note: No intermediate topology applicable for computation



  - Liquid line
    - Up to199 nodes & 5 sections

  <u>Possible use of standard homogeneous tubing heating</u>
- Fluid nodes mapped to tubing nodes (B type)

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LHP definition: hardware components

- On file per LHP item
  - Evaporator (mini-LHP, LHP²,…) *.EVAPHW
  - Vapour line (config specific) *.VAPLHW
  - Condenser (generic or specific) *.CONDHW
  - Liquid line (config specific) *.LIQLHW
  - Fluid (NH3,Water) *.PPTY
- *Example: condenser*
  - Number of branches
  - Length for each branch
  - Tubing
    - Hydraulic & thermal diameters
    - Linear conductance & capacitance

Files can be shared/reused for multiple LHP use & different applications (fluids, evaporators, condensers)

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Interface definition

- Couplings to be added in system model
  - Exemple GL(LHP1:101;20101)=xxxx;
  - Must be consistent with tubing meshing definition
- Evaporator I/F
  - To power source
  - Conductive & radiative heat leaks for body & reservoir
- Condenser I/F
  - To radiator
  - To heat sink (North-south HP for Telecom application)
- Liquid line
  - Radiative & conductive heat leaks (through attachement feet)
- Vapour line
  - Generally considered as adiabatic (only tubing-fluid exchanges taken into account)

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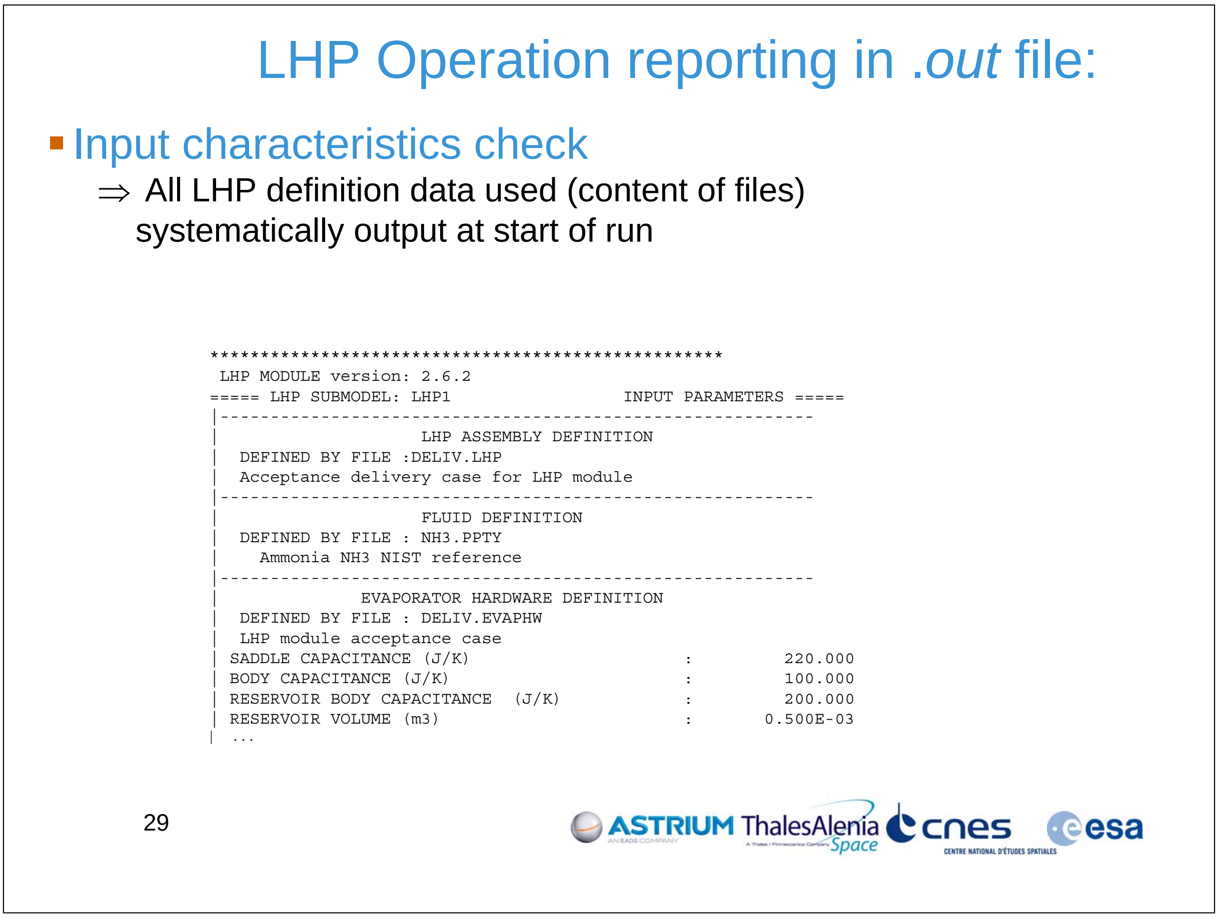
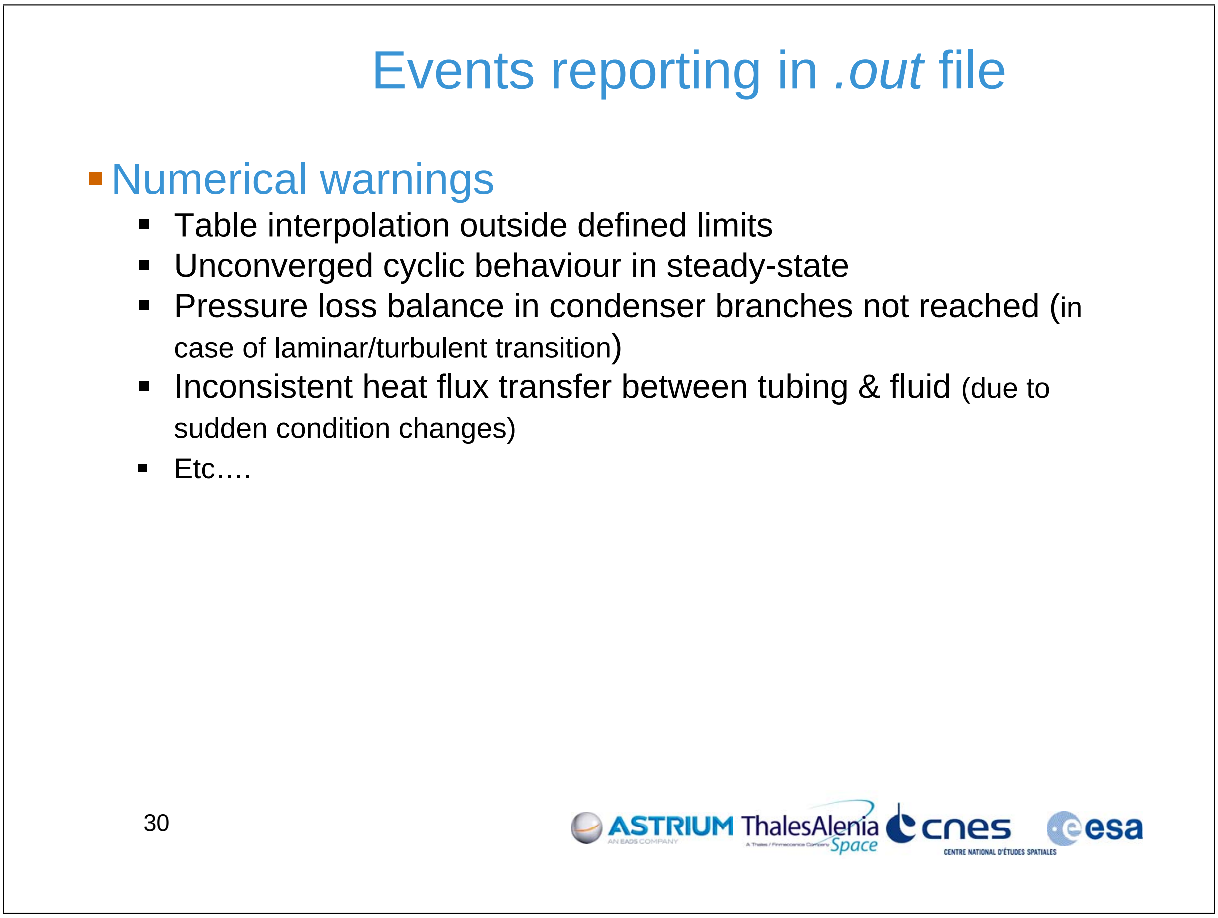

LHP Operation reporting in .out file:
Input characteristics check
⇒ All LHP definition data used (content of files) systematically output at start of run
****
LHP MODULE version: 2.6.2
===== LHP SUBMODEL: LHP1 INPUT PARAMETERS =====
LHP ASSEMBLY DEFINITION
DEFINED BY FILE :DELIV.LHP
Acceptance delivery case for LHP module
FLUID DEFINITION
DEFINED BY FILE : NH3.PPTY
Ammonia NH3 NIST reference
EVAPORATOR HARDWARE DEFINITION
DEFINED BY FILE : DELIV.EVAPHW
LHP module acceptance case
SADDLE CAPACITANCE (J/K) : 220.000
BODY CAPACITANCE (J/K) : 100.000
RESERVOIR BODY CAPACITANCE (J/K) : 200.000
RESERVOIR VOLUME (m3) : 0.500E-03
...
29


Events reporting in .out file
Numerical warnings
Table interpolation outside defined limits
Unconverged cyclic behaviour in steady-state
Pressure loss balance in condenser branches not reached (in case of laminar/turbulent transition)
Inconsistent heat flux transfer between tubing & fluid (due to sudden condition changes)
Etc….
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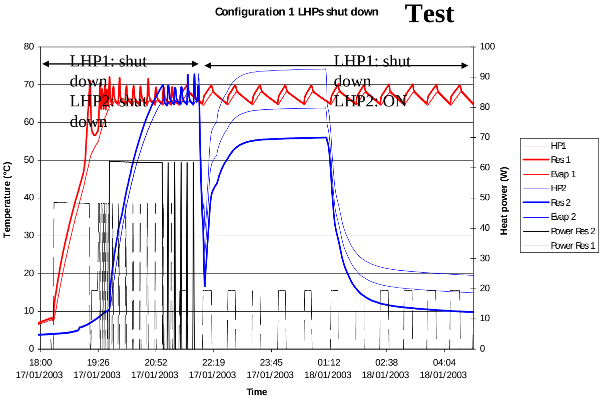
DELPHRAD

Start up & Shut down simulation

Good simulation of SU & SD in term of temperature level & Stabilisation duration: **Test (73 min)/**

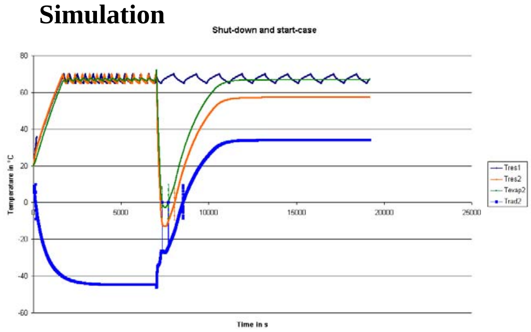
Simulation (67 min)

Test



		Start up	Shut Down
LHP1	Before 7000s After 7000s		50W on CC 20W on CC
LHP2	Before 7000s After 7000s	965W	50W on CC

Simulation



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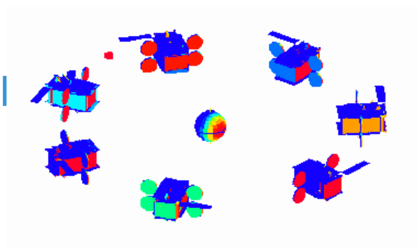
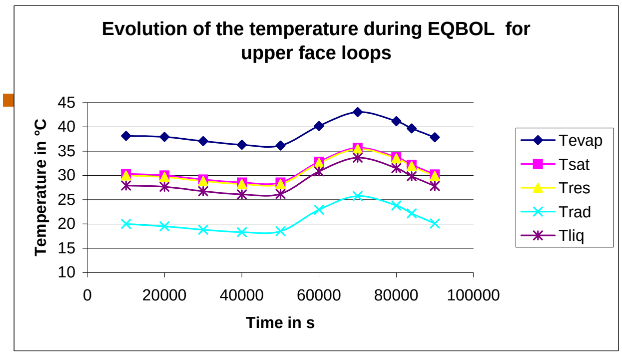
@BUS

@BUS DPR Simulation –EQ BOL



T=0s



Power on LHP1= 779W
Power on LHP2= 781W
Power on LHP3= 773W
Power on LHP4= 772W

Additional Power rejected by DPR= 3100W (HR= 672W/m²)

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Appendix M

Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES

Gaël Parot
(CNES, France)

Abstract

Different kinds of stratospheric & troposheric terrestrial aerostats and planetary balloons are developed and used by CNES in order to answer the various demands of the international scientific community. Each type of terrestrial balloon has its own flight domain. It is supposed to fly all over the Earth, to be launched at any time and from everywhere. Hence the aerostats can see various external thermal environments.

The thermal aspects are taken into account in the overall design and verification process of the aerostat (balloon envelope, operational and payload gondolas). The balloon's thermal environment has also a significant effect on the aerostat in-flight behaviour (flight physics) and is of first importance for long-duration flights due to the limited electrical power available. Thus, thermal models are used during balloon campaigns. The results of the thermal and energy balance (for a predicted trajectory) are one of the information considered to decide on the feasibility of a flight.

The contents of the presentation are as follows:

- Overall presentation of CNES aerostats
- Terrestrial aerostats thermal environment
- Thermal engineering (main concerns)
- An example of thermal analysis / ConcordIasi campaign (long duration flight)
  Prediction of gondolas autonomy in terms of electrical energy: presentation of the thermal models (use of THERMICA and ThermXL tools)

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CENTRE NATIONAL D'ÉTUDES SPATIALES

CNES BALLOON VEHICLES

Thermal Control Engineering

Use of ThermXL & THERMICA

Gaël PAROT

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CONTENTS

- Overall presentation of CNES's aerostats
- Aerostat thermal environment on Earth
- Thermal engineering (main concerns)
- An example of thermal analysis / Concordiasi project, McMurdo 2010 campaign (long duration flights)
  - Prediction of gondolas autonomy in term of electrical energy
  - Presentation of the thermal models, elaborated with THERMICA and ThermXL

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CNES aerostats

Aerostats are mainly used for scientific missions :

- To study the Earth atmosphere (components, motion): troposphere and stratosphere
- For the study of sciences of the universe (astronomy, planets exploration)

Different kinds of balloons have been developed by CNES in order to answer the various demands of the scientists

The Earth balloons derive into 4 families:

- BSO, or "Ballon Stratosphérique Ouvert" / Zero Pressure balloon
- MIR, or "Montgolfière InfraRouge" / Infrared montgolfiere
- BPS, or "Ballon Pressurisé Stratosphérique" / Super Pressure Balloon
- BTT, or "Ballon Traceur Troposphérique"

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BSO (Zero Pressure Balloon)

<u>Main characteristics:</u>

- The biggest !
- Volume is from 3000 to 1200000m^3
  the envelop surface of the biggest BSO is as large as 14 soccer fields
- Payload up to 2 tones
- Flight duration : ~several hours to a few days
- Elevation : 20 to 43 km
- Filled with helium

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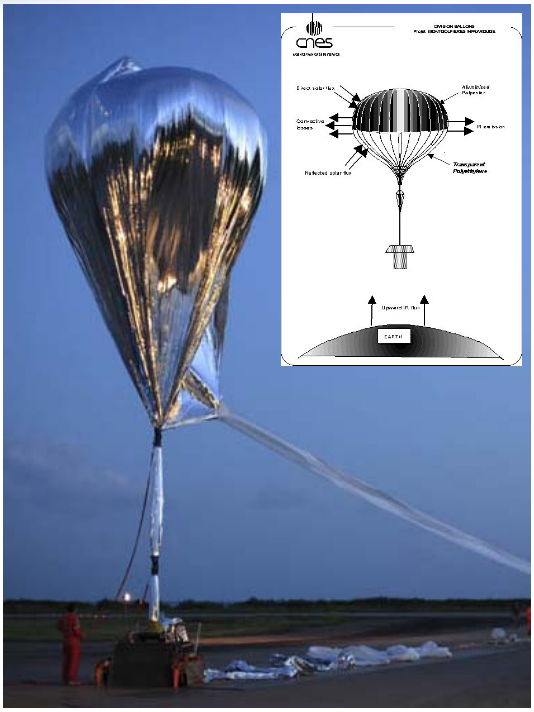
MIR (IR montgolfiere)

Main characteristics:

- Hot air balloon
- The upper part is aluminized in order to capture the IR ascending heat flux (lower part is translucent to the IR flux)
- Volume is 45000m^3
- Payload is 40 to 60kg
- Flight duration : ~several weeks / up to some months
- Elevation : 28 to 30km during the day, 18 to 22km during the night



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BPS (Super Pressure Balloon)

Main characteristics:

- Pressurized balloon
- Different sizes: 8.5m, 10m and 12m diameter

  16 m under development
- Payload is up to 40kg
- Flight duration : up to 3 months, and more
- Elevation : 18 to 20km

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BTT: BPCL, Nano Balloon and the Aeroclipper

Aeroclipper main characteristics :
Under development
Specificity is the use of a "guiderope"
Will be used to investigate large oceanic areas (dedicated to measurements in both atmosphere and sea)

BPCL main characteristics :
Pressurized balloon
Diameter is 2.5m
Gondola located inside the balloon
Flight duration : up to 1 month
Elevation : 1 to 2km

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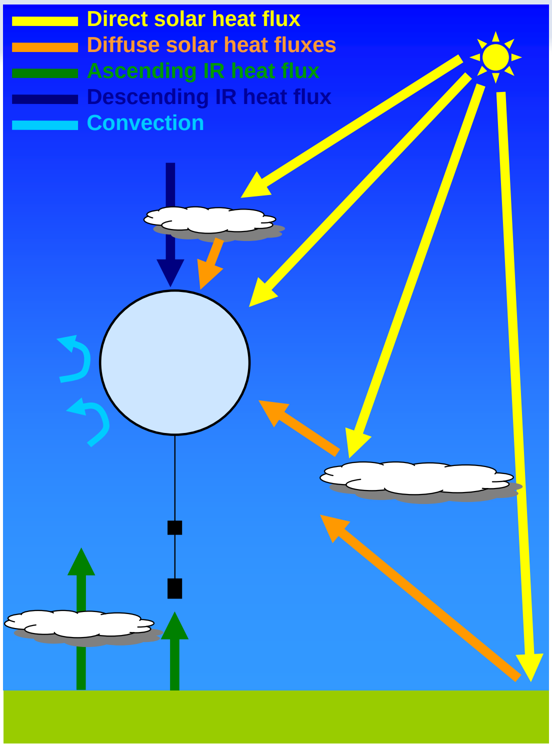
Terrestrial external thermal environment

As aerostats may fly all over the Earth and for at least a few days, they would be submitted to significant variations in term of thermal environment:

- **Pressure / temperature profile**
- **Solar radiation: direct and diffuse heat fluxes (albedo included)**
- **Ascending and descending IR heat fluxes**

They have to be sized in order to be reliable regarding the significant thermal environment variations at the day/night and flight scales



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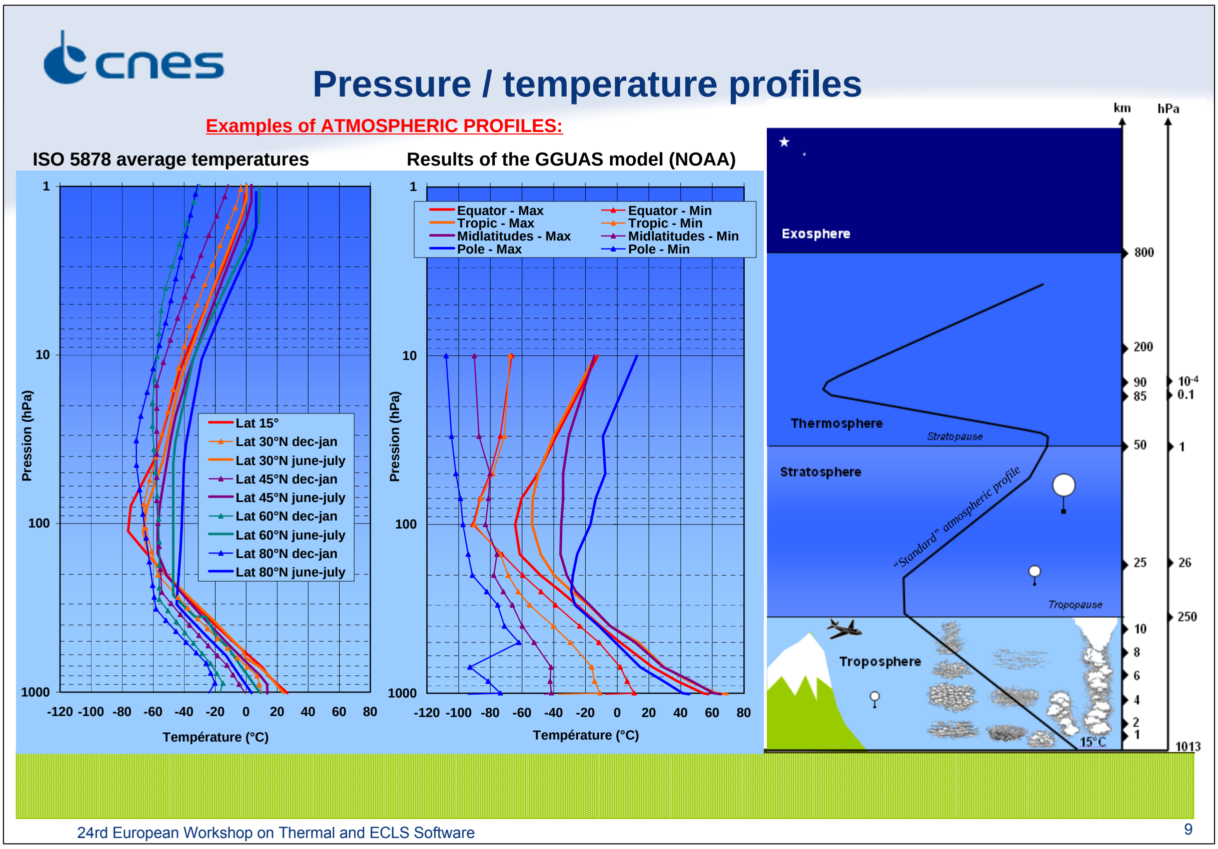
cnes
Pressure / temperature profiles
Examples of ATMOSPHERIC PROFILES:
ISO 5878 average temperatures
Results of the GGUAS model (NOAA)
Lat 15°
Lat 30°N dec-jan
Lat 30°N june-july
Lat 45°N dec-jan
Lat 45°N june-july
Lat 60°N dec-jan
Lat 60°N june-july
Lat 80°N dec-jan
Lat 80°N june-july
Pression (hPa)
Température (°C)
Equator - Max
Tropic - Max
Midlatitudes - Max
Pole - Max
Equator - Min
Tropic - Min
Midlatitudes - Min
Pole - Min
km
hPa
Exosphere
Thermosphere
Stratopause
Stratosphere
"Standard" atmospheric profile
Tropopause
Troposphere
15°C
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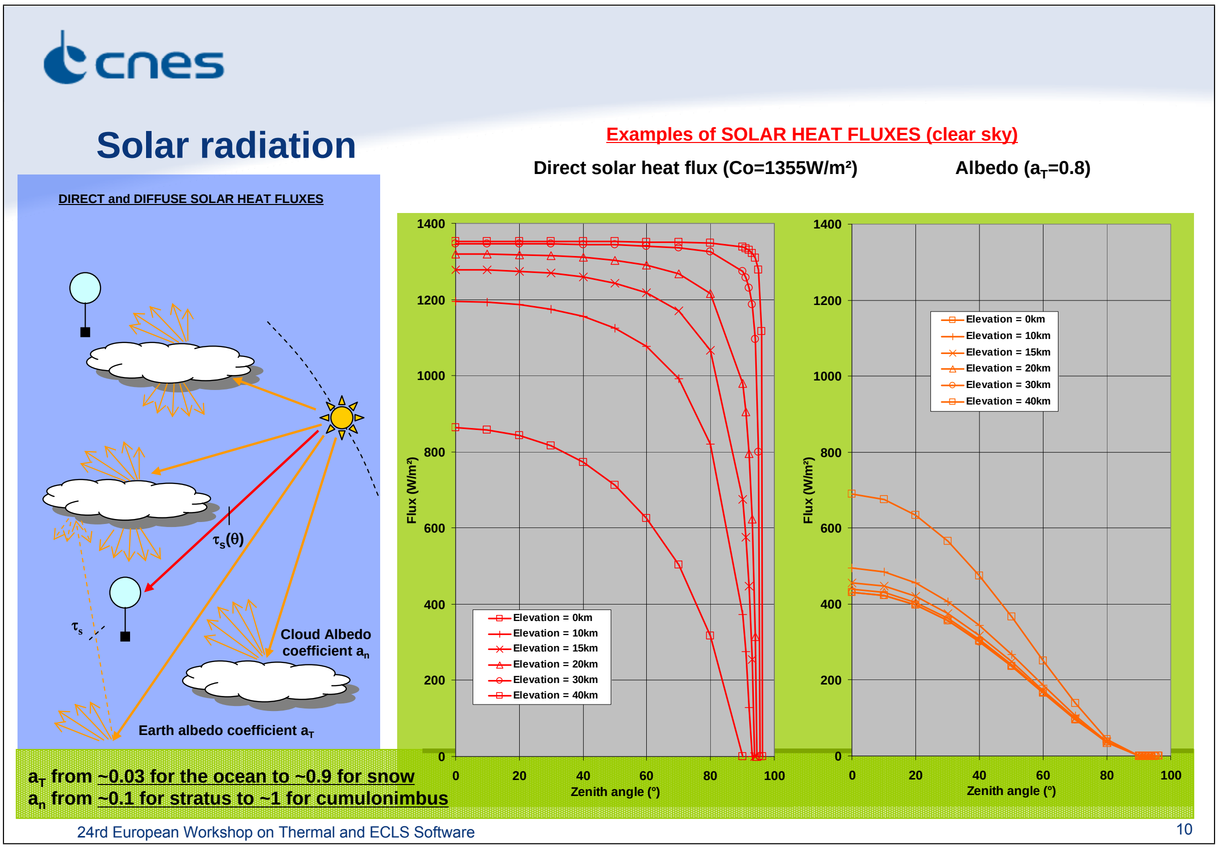
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Solar radiation
DIRECT and DIFFUSE SOLAR HEAT FLUXES
τs(θ)
Cloud Albedo coefficient an
Earth albedo coefficient aT
Examples of SOLAR HEAT FLUXES (clear sky)
Direct solar heat flux (Co=1355W/m²)
Albedo (aT=0.8)
Elevation = 0km
Elevation = 10km
Elevation = 15km
Elevation = 20km
Elevation = 30km
Elevation = 40km
Flux (W/m²)
Zenith angle (°)
aT from ~0.03 for the ocean to ~0.9 for snow
an from ~0.1 for stratus to ~1 for cumulonimbus
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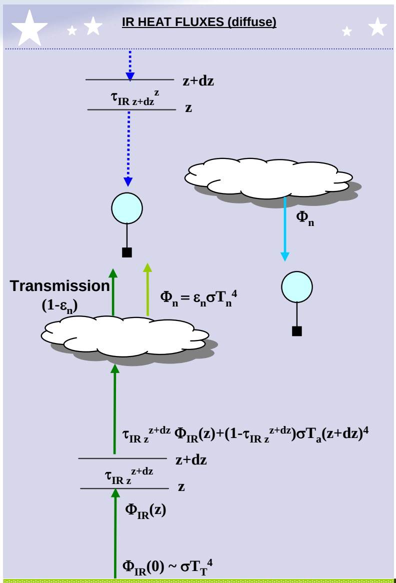
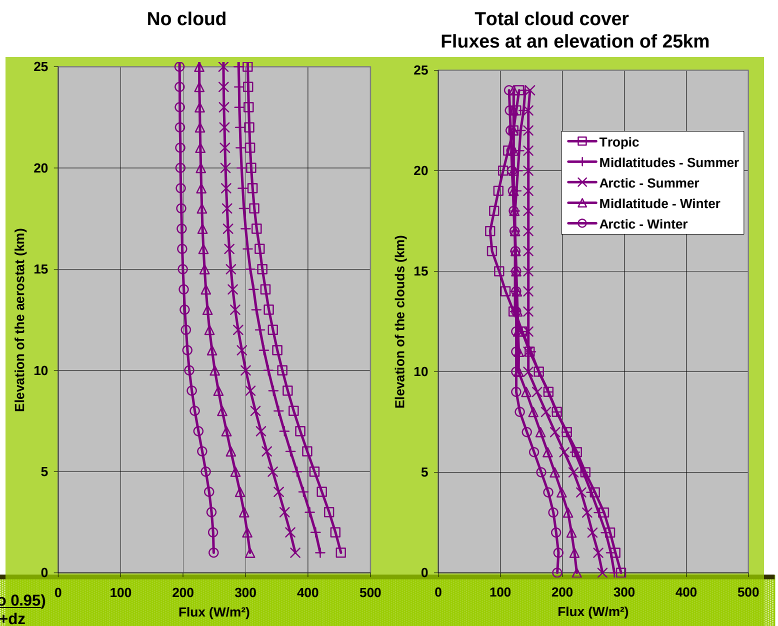
IR radiation



Examples of ASCENDING IR HEAT FLUXES



ε_n: cloud emissivity in the IR wavelength (from ~0.7 to 0.95)
$\tau_{IR\ z}^{\ z+dz}$: transmission of the air slice between z and z+dz elevations

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Aerostat thermal engineering

Main concerns

- **Balloon**
  - Thermal balance is taken into account in flight physics models
  - CNES In-house dedicated flight physics tools are used, which conjugate thermal behavior of the gas and the envelope within flight physics and gas motion
- **Suspended devices (gondolas as an example)**
  - Thermal science is considered in design and verification process whatever the kind of aerostat and suspended device
  - Use of commercial space thermal softwares
  - i.e.: THERMICA for radiative heat exchanges, ThermXL for heat balance
  - Thermal science plays also an important role for the prediction of gondolas energy autonomy for long duration flights (BPS) → confer next slides (Concordiasi project)

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CONCORDIASI

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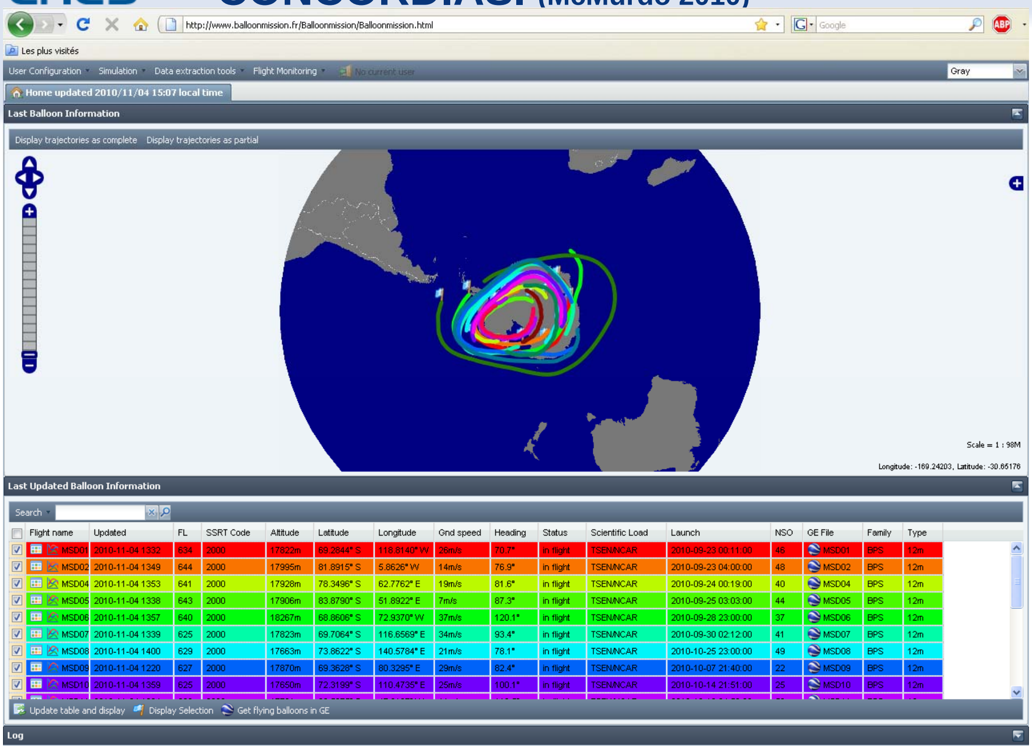
CONCORDIASI (McMurdo 2010)



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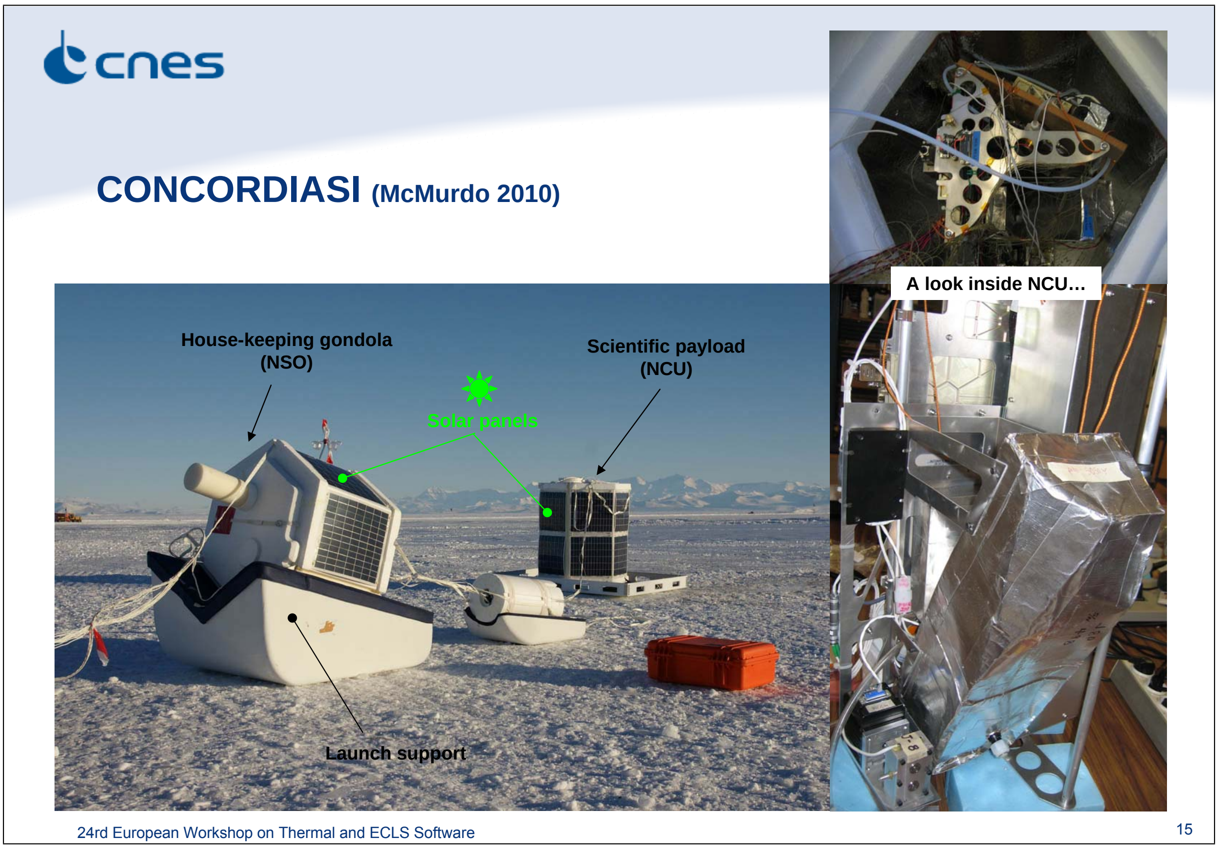
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CONCORDIASI (McMurdo 2010)
A look inside NCU…
House-keeping gondola (NSO)
Scientific payload (NCU)
Solar panels
Launch support
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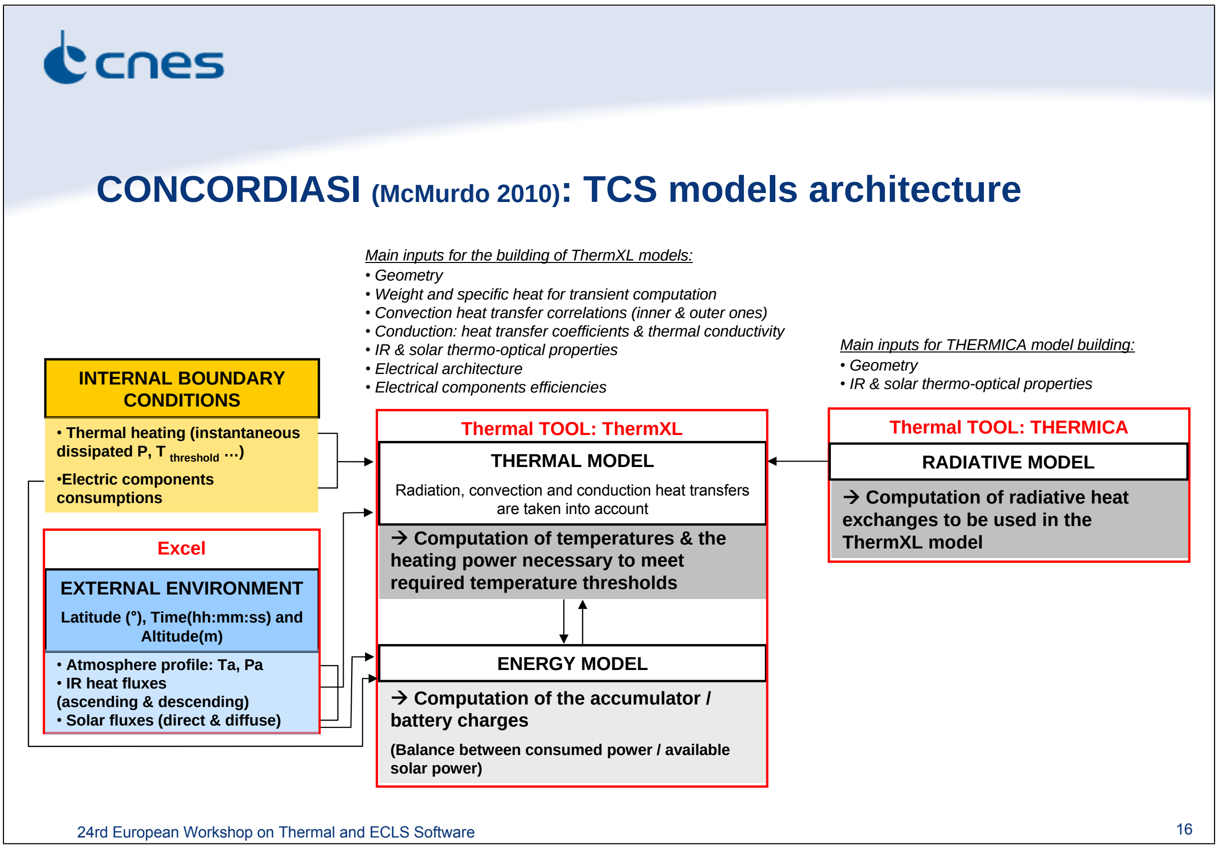
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CONCORDIASI (McMurdo 2010): TCS models architecture
Main inputs for the building of ThermXL models:
• Geometry
• Weight and specific heat for transient computation
• Convection heat transfer correlations (inner & outer ones)
• Conduction: heat transfer coefficients & thermal conductivity
• IR & solar thermo-optical properties
• Electrical architecture
• Electrical components efficiencies
Main inputs for THERMICA model building:
• Geometry
• IR & solar thermo-optical properties
INTERNAL BOUNDARY CONDITIONS
• Thermal heating (instantaneous dissipated P, T threshold …)
•Electric components consumptions
Excel
EXTERNAL ENVIRONMENT
Latitude (°), Time(hh:mm:ss) and Altitude(m)
• Atmosphere profile: Ta, Pa
• IR heat fluxes (ascending & descending)
• Solar fluxes (direct & diffuse)
Thermal TOOL: ThermXL
THERMAL MODEL
Radiation, convection and conduction heat transfers are taken into account
→ Computation of temperatures & the heating power necessary to meet required temperature thresholds
ENERGY MODEL
→ Computation of the accumulator / battery charges
(Balance between consumed power / available solar power)
Thermal TOOL: THERMICA
RADIATIVE MODEL
→ Computation of radiative heat exchanges to be used in the ThermXL model
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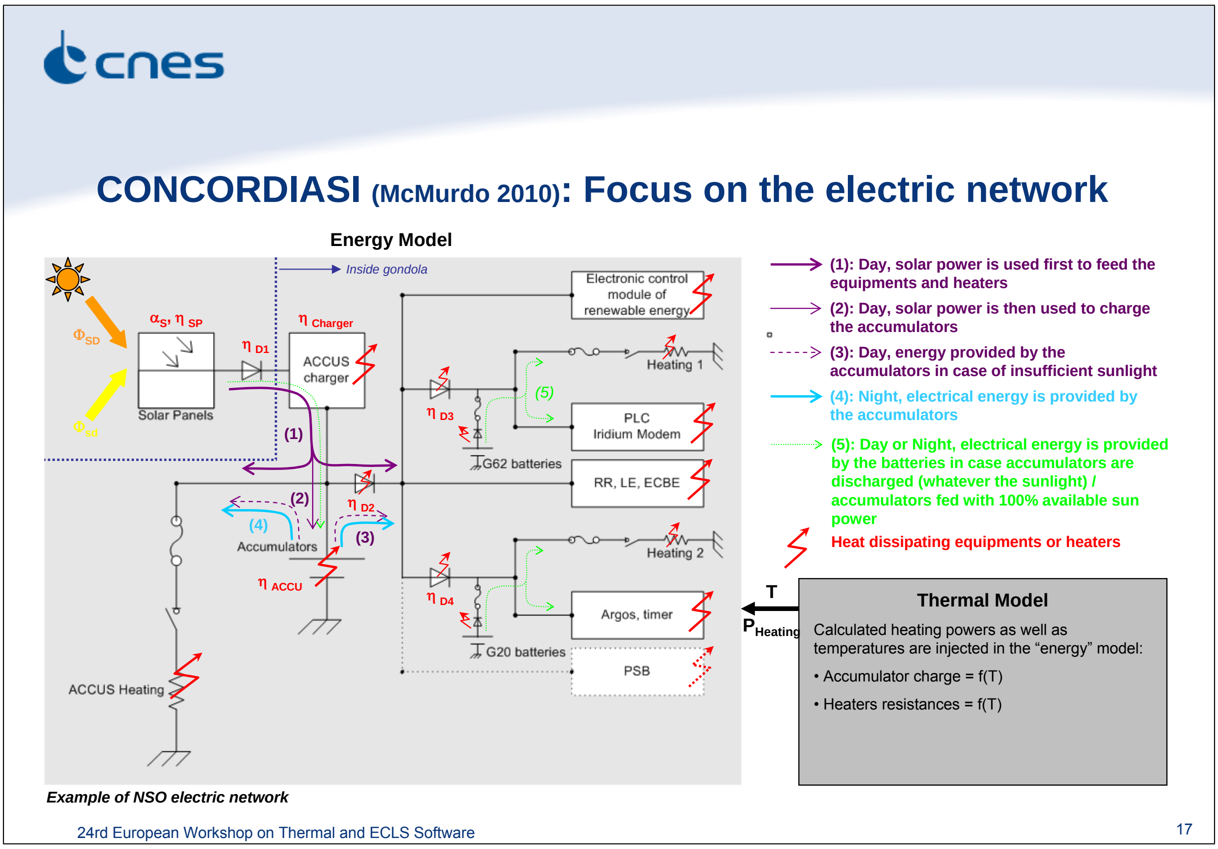
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CONCORDIASI (McMurdo 2010): Focus on the electric network
Energy Model
Inside gondola
Electronic control module of renewable energy
Solar Panels
ACCUS charger
Heating 1
PLC Iridium Modem
G62 batteries
RR, LE, ECBE
Accumulators
Heating 2
Argos, timer
G20 batteries
PSB
ACCUS Heating
(1): Day, solar power is used first to feed the equipments and heaters
(2): Day, solar power is then used to charge the accumulators
(3): Day, energy provided by the accumulators in case of insufficient sunlight
(4): Night, electrical energy is provided by the accumulators
(5): Day or Night, electrical energy is provided by the batteries in case accumulators are discharged (whatever the sunlight) / accumulators fed with 100% available sun power
Heat dissipating equipments or heaters
T
P Heating
Thermal Model
Calculated heating powers as well as temperatures are injected in the “energy” model:
• Accumulator charge = f(T)
• Heaters resistances = f(T)
Example of NSO electric network
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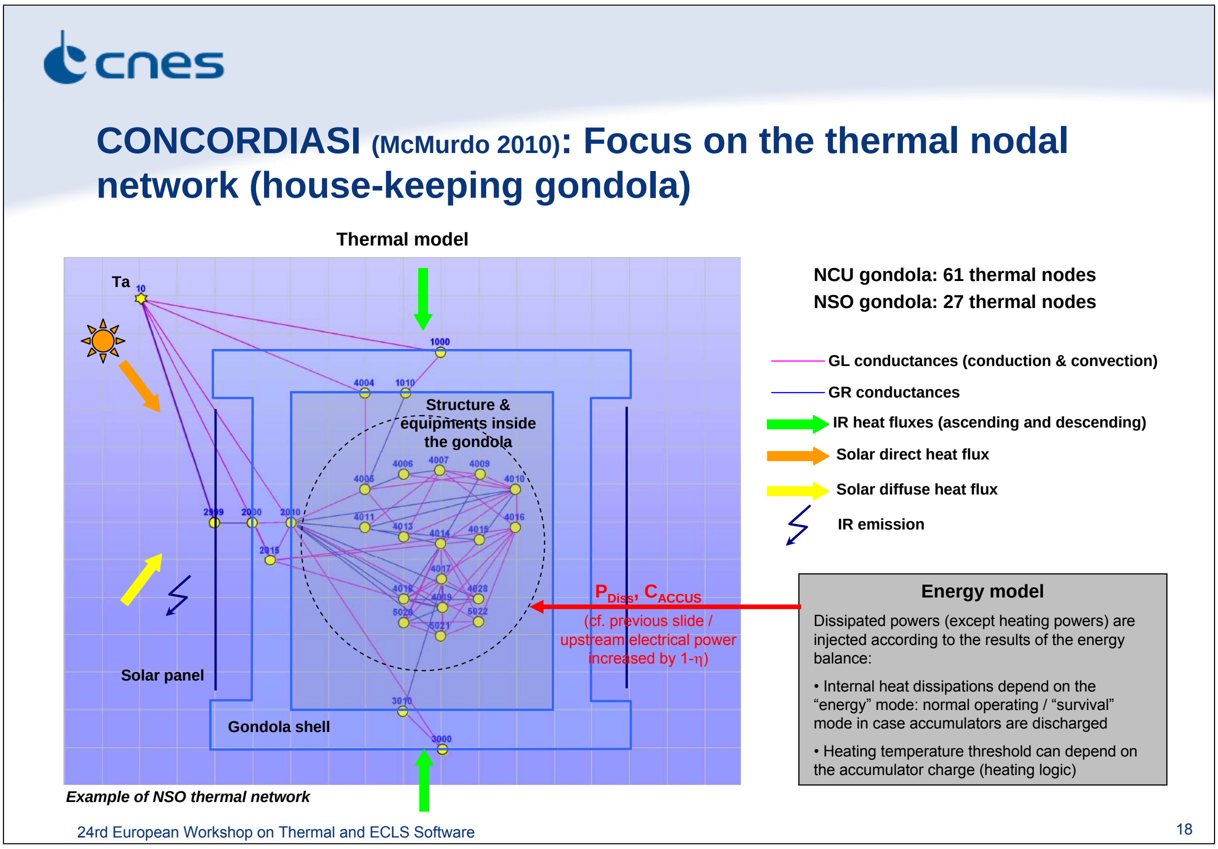
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CONCORDIASI (McMurdo 2010): Focus on the thermal nodal network (house-keeping gondola)
Thermal model
Ta
Structure & equipments inside the gondola
Solar panel
Gondola shell
P Diss, C ACCUS
(cf. previous slide / upstream electrical power increased by 1-η)
NCU gondola: 61 thermal nodes
NSO gondola: 27 thermal nodes
GL conductances (conduction & convection)
GR conductances
IR heat fluxes (ascending and descending)
Solar direct heat flux
Solar diffuse heat flux
IR emission
Energy model
Dissipated powers (except heating powers) are injected according to the results of the energy balance:
• Internal heat dissipations depend on the “energy” mode: normal operating / “survival” mode in case accumulators are discharged
• Heating temperature threshold can depend on the accumulator charge (heating logic)
Example of NSO thermal network
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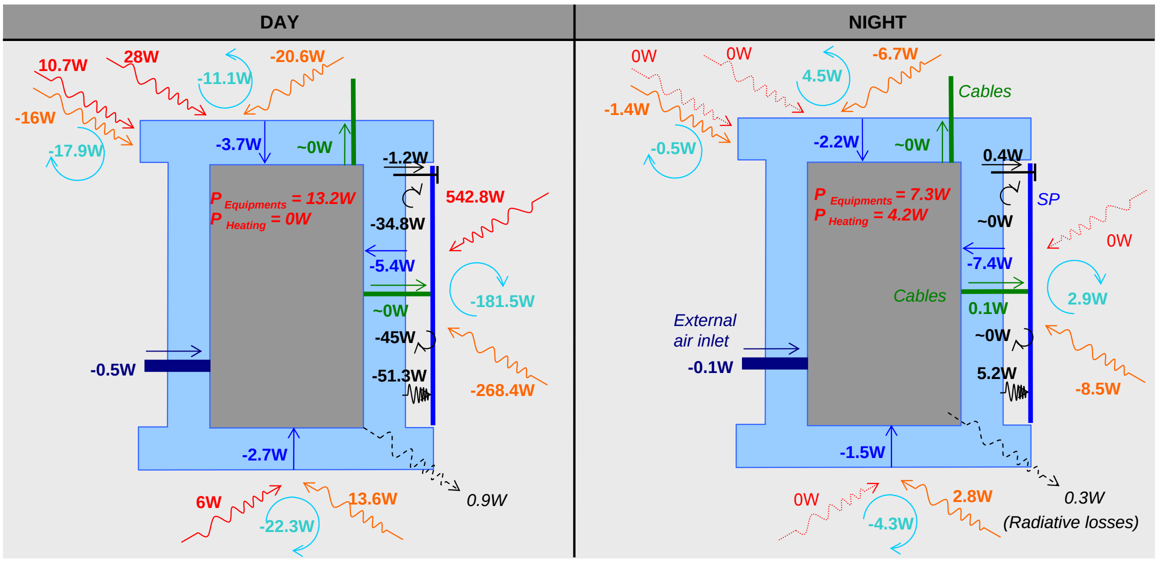
CONCORDIASI (McMurdo 2010): Thermal balance (payload gondola)

Solar radiation
IR radiation (absorbed + emitted)
Convection



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CONCORDIASI (McMurdo 2010): Justification for ThermXL use

ThermXL: interesting tool for different reasons:

- Low temperature gradient inside gondolas due to good thermal insulation → nodal network is appropriated
- Small thermal model (from ~30 to 60 thermal nodes)
- Short computation time → allows to treat a large amount of cases, results are available in a short time (very useful for predictions before launch)
- Elaboration of a conjugated energy/thermal model is easy

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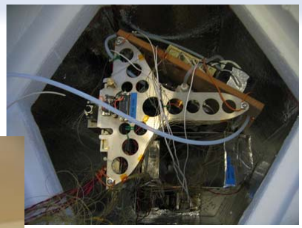
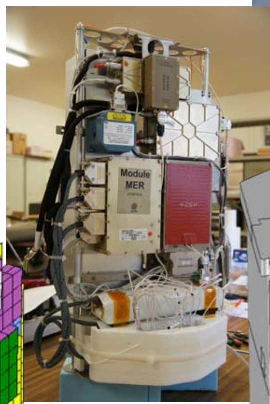
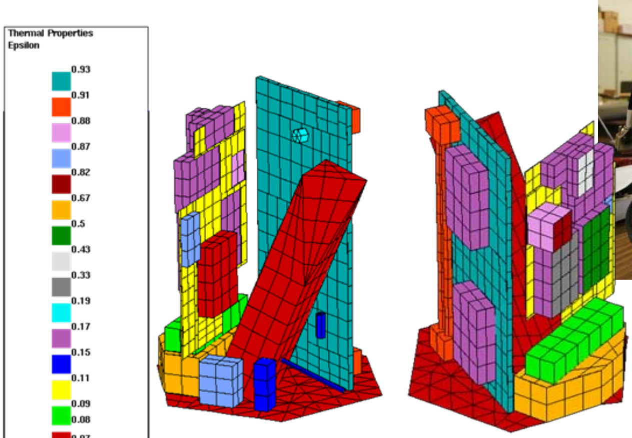
CONCORDIASI (McMurdo 2010): THERMICA model overview

THERMICA model elaborated for
scientific payload gondola:

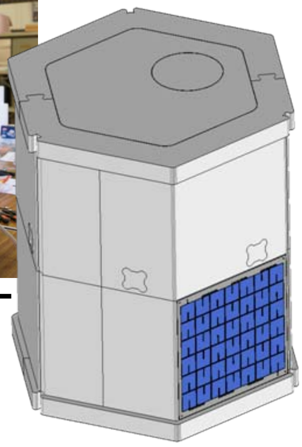


Top view of open gondola





NCU THERMICA model overview (inside NCU)



NCU CATIA mock-up

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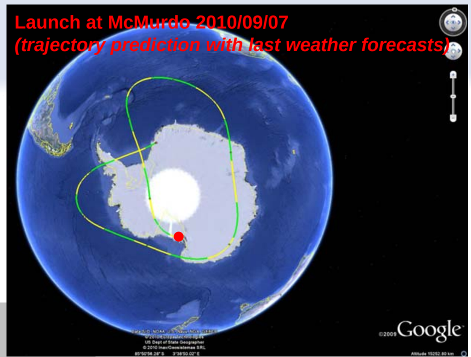
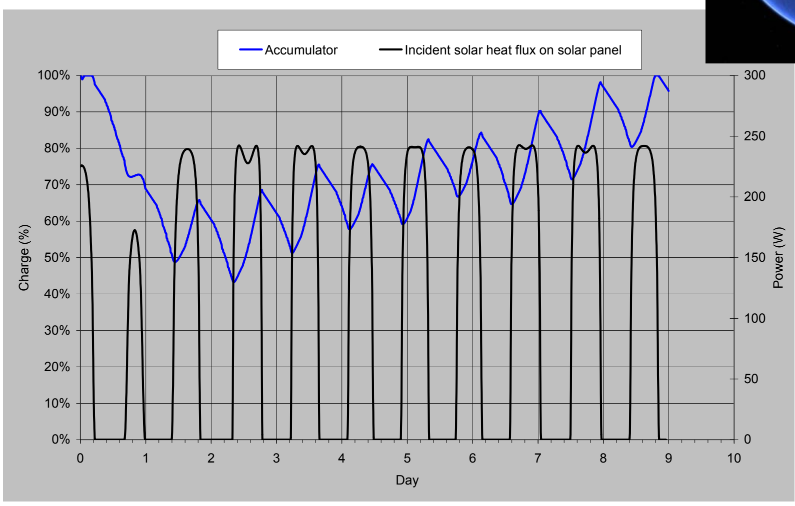
CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola





Conservative assumptions have been taken regarding the external environment (low IR ascending flux & albedo)

The first 3 days of flying are the worst because the sunlight is limited, and there is not enough solar power to feed the equipments

It results in a significant decrease of the accumulator charge at the flight beginning

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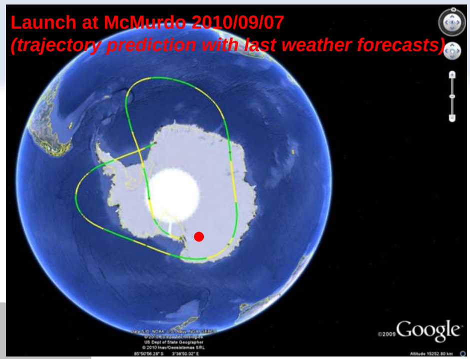
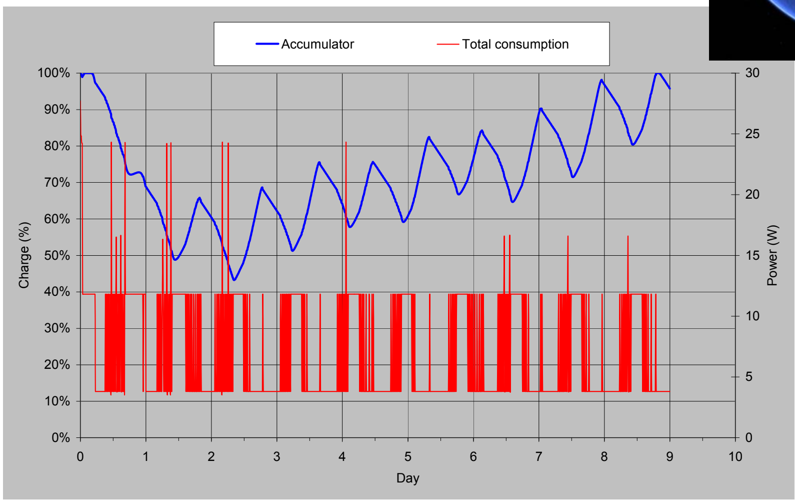
CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola





Increase of electrical consumption during the first 3 days of flying, due to a greater need for heating

It contributes to the decrease of the accumulator charge during this period

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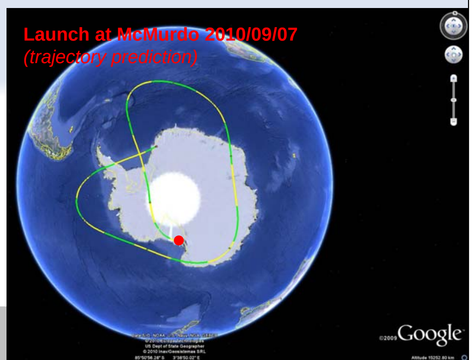
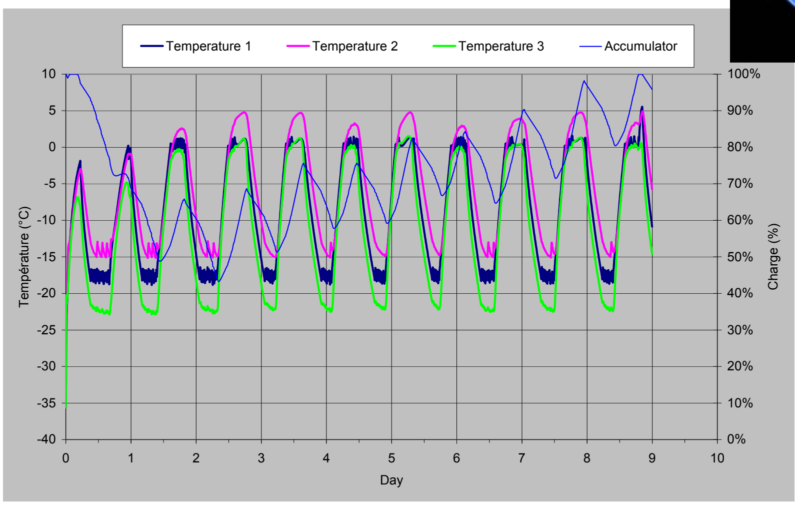
CONCORDIASI (McMurdo 2010): Example of prediction House-keeping gondola





Heating is enough to maintain the equipments at the required temperatures

Computed temperatures between -25°C and +5°C for an overall dissipated power of ~6.9W (heating power of ~3.1W included)

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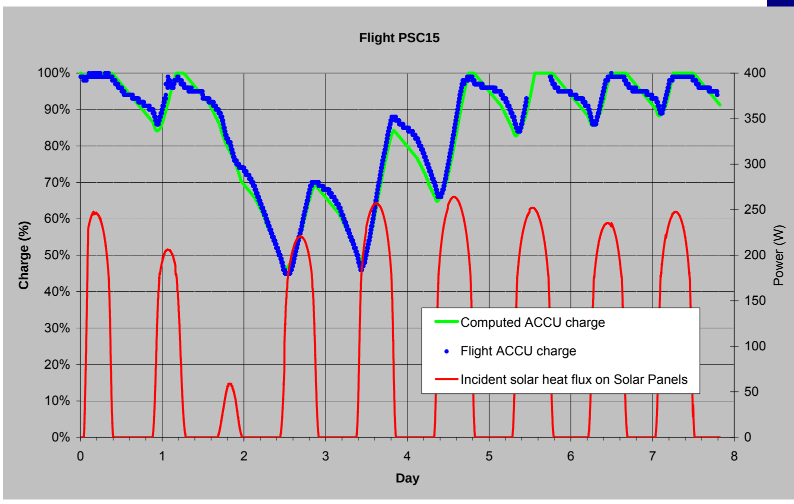
CONCORDIASI (McMurdo 2010): Flight PSC15 House-keeping gondola Restitution of the in-flight behavior



In-flight measurements: air temperature & pressure

Aerostat's trajectory is known

Remaining uncertainties: IR ascending heat fluxes, the Albedo

→ To be consolidated

Nevertheless, encouraging results are obtained

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CONCLUSION

- **CNES offers different kinds of terrestrial aerostats, which are supposed to fly all over the Earth and to be launched at any time and from everywhere**
  - → Significant effort must be provided in order to get a better knowledge of external environment (in-flight measurements) & thermal tool to be developed for calculating external boundary conditions
- **Thermal science is considered in design and verification process, and it concerns both the envelops and gondolas**
  - Balloon activity is very specific
  - Employing the thermal tools used in Space Industry is under investigation (there are other applications than BPS gondolas / McMurdo campaign)
- **Thermal aspects play an important role in the autonomy of renewable energy gondolas (cf. Concordiasi project / McMurdo campaign)**
  - ThermXL tool is appropriated to conjugated thermal / energetic analysis or relatively small TCS nodal models &THERMICA is also well appropriated for the computation of radiative exchanges into the gondolas

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Any questions ?...
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Appendix N

Thermal Concept Design Tool
4th Year

Andrea Tosetto   Matteo Gorlani
(Blue Engineering, Italy)

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

The TCDT is in the 4th year of distribution and maintenence. 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 first applications of the tool in space projects have been done also in BLUE Engineering where the TCDT has been used for geometrical, thermal modelling and results postprocessing. Notwithstanding the TCDT has been designed for pre-phase A and phase A, thanks to its flexibility the tool has been very useful and efficient also for analysis and design activities in later phases of projects.
The TCDT version 1.4.0, developed within this year, is ready for the delivery to the European Thermal Community. This last version implements the following new functionalities required by the users:

- the Material DB
- user defined S/C attitudes
- 3DViewer interactivity
- normal thermal conductivity in the geometric nodes definition

The engineers can easily use TCDT models of older versions thanks to the automatic converter provided by the 1.4.0 version.

Thermal Concept Design Tool Distribution & Maintenance

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

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Sheet 1

Overview

- Background
- Version 1.4.0 Improvements
- Maintenance Activity
- Modeling with TCDT

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Sheet 2

Background

4° YEAR OF DISTRIBUTION & MAINTENANCE STARTED APRIL 2010

- 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 1.4.0 will be available before the end of 2010

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Sheet 3

TCDT 1.4.0 Improvements

- **Adding Normal Conductivity to surfaces**
- **Material Database**
- **User defined attitudes**
- **Improved 3D Viewer and Modeltree**
- **Version Converter**

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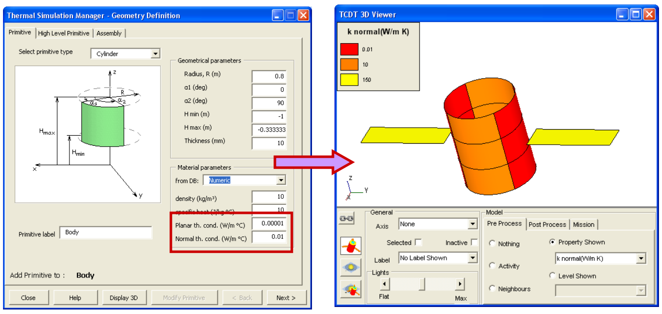
Sheet 4

TCDT Improvements (1/8)

Adding normal conductivity to GMM surfaces.

Geometric Properties:					Bulk Properties				Side1 Activity	Solar Optical Properties Side1		
Dim2	Dim3	Dim4	Dim5	Dim6	C	K∥	K⊥	Density		α	τ	spec ρ ra
0.35	270	360	0	1	1	150	100	1	Yes	1	0	0
0.35	180	270	0	1	1	150	100	1	Yes	1	0	0
0.35	90	180	0	1	1	150	100	1	Yes	1	0	0
0.35	0	90	0	1	1	150	100	1	Yes	1	0	0
0.7	270	360	0	1	1	150	100	1	Yes	1	0	0

Normal conductivity can be displayed as the pre-process data in the 3D Viewer and it is used to calculate the linear conductor between Side1 and Side2 thermal nodes



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Sheet 5

TCDT Improvements (2/8)

Material Database feature

Material data can be stored:

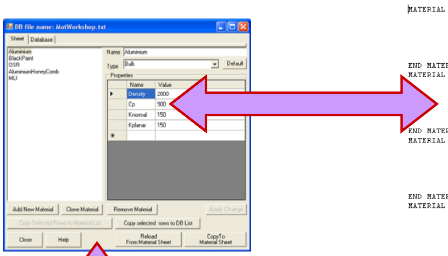
- in a xls sheet
- in a human readable ASCII file.

It is possible to exchange data from sheet and the file.

The predefined materials type are:

- bulk (density, capacitance etc)
- Coating (optical properties)

They are mainly used in the geometry definition



```
MATERIAL : Aluminium
         TYPE : Bulk
         PROPERTY : Density = 2800
         PROPERTY : Cp = 900
         PROPERTY : Knormal = 150
         PROPERTY : Kplanar = 150
END MATERIAL
MATERIAL : Aluminium1
         TYPE : Bulk
         PROPERTY : Density = 3000
         PROPERTY : Cp = 900
         PROPERTY : Knormal = 150
         PROPERTY : Kplanar = 150
END MATERIAL
MATERIAL : Aluminium11
         TYPE : Bulk
         PROPERTY : Density = 2300
         PROPERTY : Cp = 900
         PROPERTY : Knormal = 150
         PROPERTY : Kplanar = 150
END MATERIAL
MATERIAL : black
         TYPE : Coating
         PROPERTY : IrEps = 0.9
         PROPERTY : IrTau = 0
         PROPERTY : IrRefl = 0
         PROPERTY : UvAlp = 0.8
         PROPERTY : UvTau = 0
         PROPERTY : UvRefl = 0
END MATERIAL
```

Material Name	Material Type	Property Name	Property Value	Property Name	Property Value
Aluminium	Bulk	Density	2800	Cp	900
BlackPaint	Coating	IrEps	0.8	IrTau	0
OSR	Coating	IrEps	0.8	IrTau	0
AluminiumHoney	Bulk	Density	2800	Cp	900

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Sheet 6

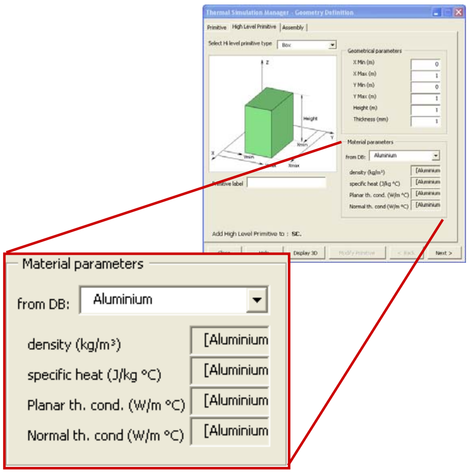
TCDT Improvements (3/8)

Material Database feature

Once the Material data is stored it can be used:

- In the TCDT related cells
- In the geometry definition forms (bulk and coatings)

Properties can be user defined.



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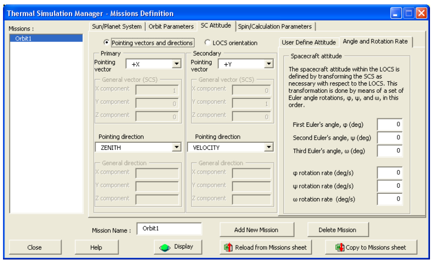
Sheet 7

TCDT Improvements (4/8)

User Defined Attitudes

Time dependent attitudes can be defined in the Mission definition form and stored in the new relevant sheet.

To be compatible with the new ESATAN-TMS R2 these movements are added to both the *Pointing Vectors and Directions* and to the *LOCS orientation.*



TCDT User Defined Attitude

Orbit Name	Point Nr	Time	Phi	Psi	Omega
Orbit1	1	1000	45.0	0.0	0.0
Orbit1	2	2000	90.0	0.0	0.0
Orbit1	3	3000	45.0	0.0	0.0
Orbit1	4	4000	0.0	45.0	0.0
Orbit1	5	5000	0.0	90.0	0.0
Orbit1	6	6000	0.0	45.0	0.0

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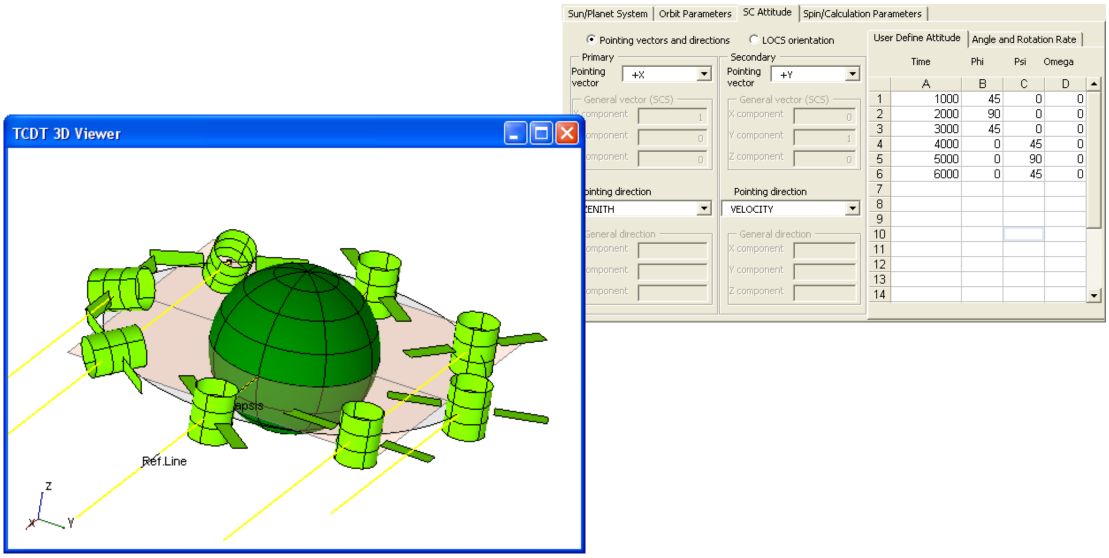
Sheet 8

TCDT Improvements (5/8)

User Defined attitudes



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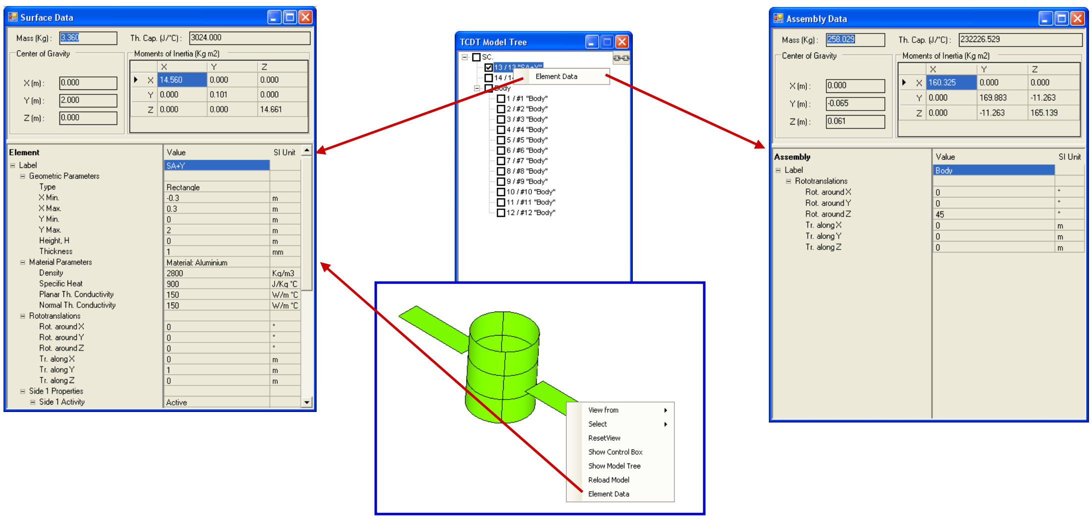
Sheet 9

TCDT Improvements (6/8)

Improved 3DViewer and ModelTree



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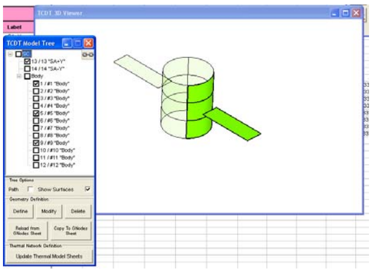
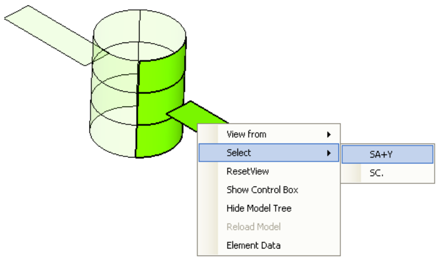
Sheet 10

TCDT Improvements (7/8)

Improved 3DViewer and ModelTree



Selection of surfaces can be done directly from the 3D Viewer by pushing ctrl + left click. The selection is reflected to the ModelTree



The 3D Viewer context menu have now the possibility to select the clicked surface or the relevant parents.

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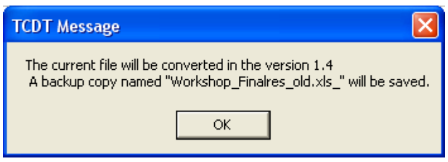
Sheet 11

TCDT Improvements (8/8)

Version Converter

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



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TCDT Maintenance Activity

Removed Limitations

Usage of spaces in folder names is no longer a limitation for external tools located in the user PC.

- Possibility to use spaces in models folder with external tools.
- Possibility to use spaces in results folder with external tools.

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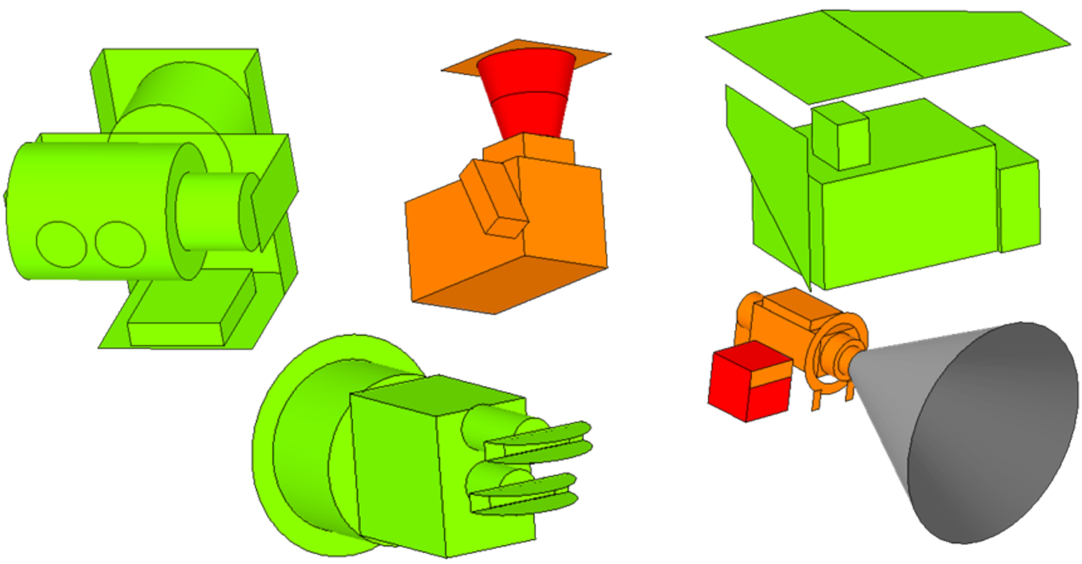
Working with the TCDT

EXOMARS Orbiter Payloads



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TCDT Tips

With the TCDT is possible to :

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

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TCDT Team

DISTRIBUTION & MAINTENANCE

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Appendix O

Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks

Martin Altenburg Johannes Burkhardt
(EADS Astrium Friedrichshafen, Germany)

Abstract

The presentation will discuss further developments of the software tool TRANSFAST which transfers the classical thermal network to a standard linear control system followed by solving this linearized system either in the time domain or in the frequency domain. Application of this type of analysis becomes more and more important for current & future science missions which require ultra-stable S/C structures, with extremely demanding thermo-elastic stability requirements during operation. Present examples are the Gaia and the LISA/LISA Pathfinder missions. For these missions the thermal analysis accuracy has to be significantly improved because verification by on-ground testing is difficult or even impossible. The approach promises significant advantages compared to standard methods, delivering more accurate results with limited numerical effort.

The presentation will present two different numerical methods for solving one key issue, the inversion of the thermal system matrix, which is mandatory for transferring the system in the frequency domain. The methods are called ***D****irect* ***I****nversion of the* ***T****ransformed System Matrix* (DIT) and ***C****onditioned* ***E****valuation of the* ***F****requency Response* (CEF) and will be compared with respect to numerical effort and performance.

Furthermore new post-processing features of the S/W tool will be addressed, allowing e.g. easy requirements breakdown to subsystems from the overall thermal stability requirement in early project phases, figure O.1.

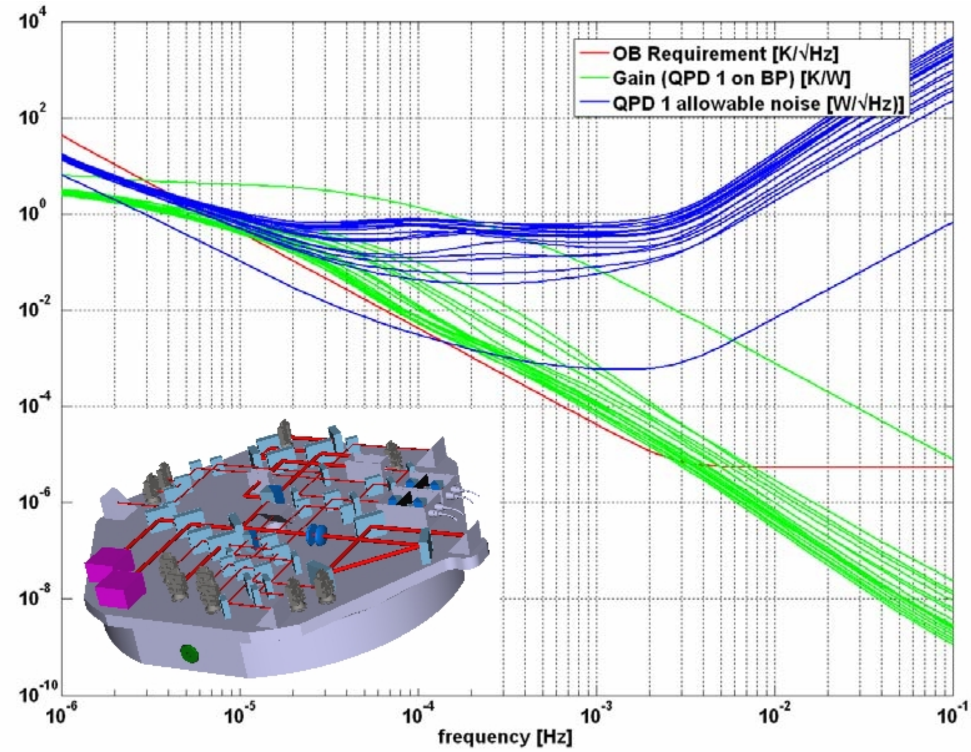

Figure O.1: Dissipation stability requirement derivation for photodiodes (QPD) on the LISA optical bench; SIMO calculation: single input (QPD 1), multiple output (base plate nodes)

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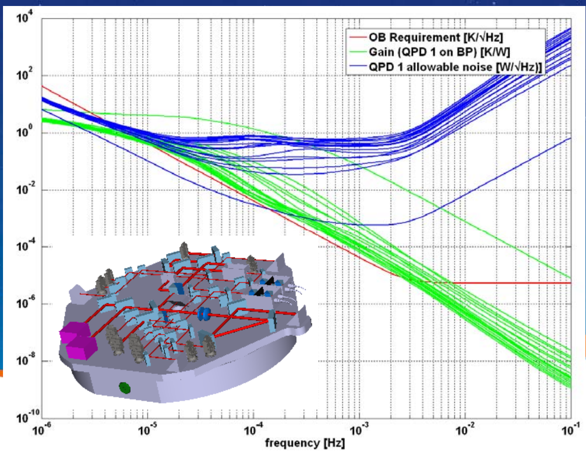
Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks

Martin Altenburg & **Johannes Burkhardt**



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Overview

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Motivation for S/W tool development

- Current & future science missions require ultra-stable S/C structures
- Extremely demanding thermo-elastic stability requirements during operation
- Present examples: Gaia & LISA/LISA Pathfinder missions
- Thermal analysis accuracy to be significantly improved because verification by on-ground testing is difficult (high effort) or even impossible
- Linearization approach promises significant advantages compared to standard methods, delivering more accurate results with limited numerical effort
- S/W tool shall contain **all** analysis steps including pre- to post-processing and shall provide a **graphical user I/F (GUI)** for easy usage by “normal” users, not familiar with the numerical implementation.

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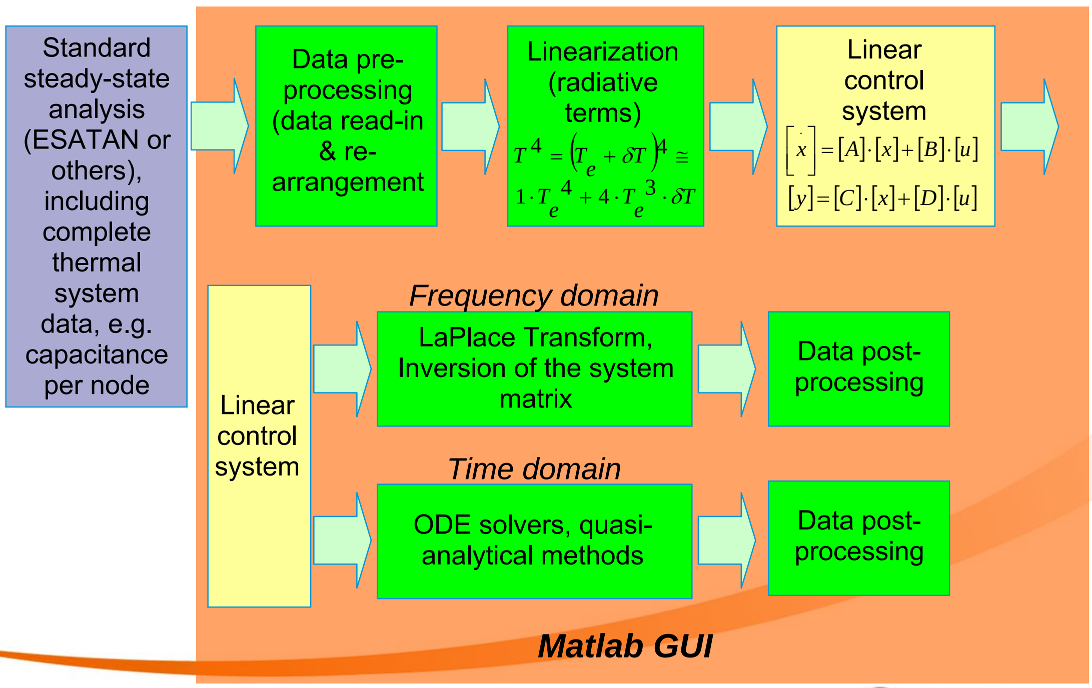
Methodology (schematic overview)



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Inversion of the System Matrix

- Applying the Laplace Transformation

$$s \cdot X(s) - x(0) = A \cdot X(s) + B \cdot U(s) \qquad s = \sigma + i\omega$$

- Introduction of I(s) and Rearrangement

$$X(s) = (s \cdot I - A)^{-1} \cdot (x(0) + B \cdot U(s))$$

$$Y(s) = C \cdot (s \cdot I - A)^{-1} \cdot B \cdot U(s) + D \cdot U(s)$$

- Transfer Function G provides relation between output and input

$$\frac{Y(s)}{U(s)} = C \cdot (s \cdot I - A)^{-1} \cdot B + D \quad \rightarrow \quad G(j\omega) = C \cdot (-A + j\omega \cdot I)^{-1} \cdot B + D$$

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Inversion of the System Matrix – Options

1. Gain (singular values) calculation via Eigen values

$$gain = \sqrt{eig(G^{-1} \cdot G)}$$

- Only for square systems and same direction of the Eigen vectors
- Can handle only SISO systems → not suited for our application

2. Singular value decomposition (SVD)

$$\sigma_i(G) = \sqrt{\lambda_i \cdot (G^T \cdot G)} \qquad \text{with} \qquad G = U \sum V^T$$

- For a fixed frequency, G is decomposed into input/output rotation U/V and a scaling matrix ∑
- Can handle systems from SISO up to MIMO
- In praxis use of MATLAB routines, gain = svd (G) → **D**irect **I**nversion of the **T**ransformed system Matrix (DIT)

3. Linear time-invariant system (LTI)

- gain = sigma (G) → **C**onditioned **E**valuation of the **F**requency response (CEF)

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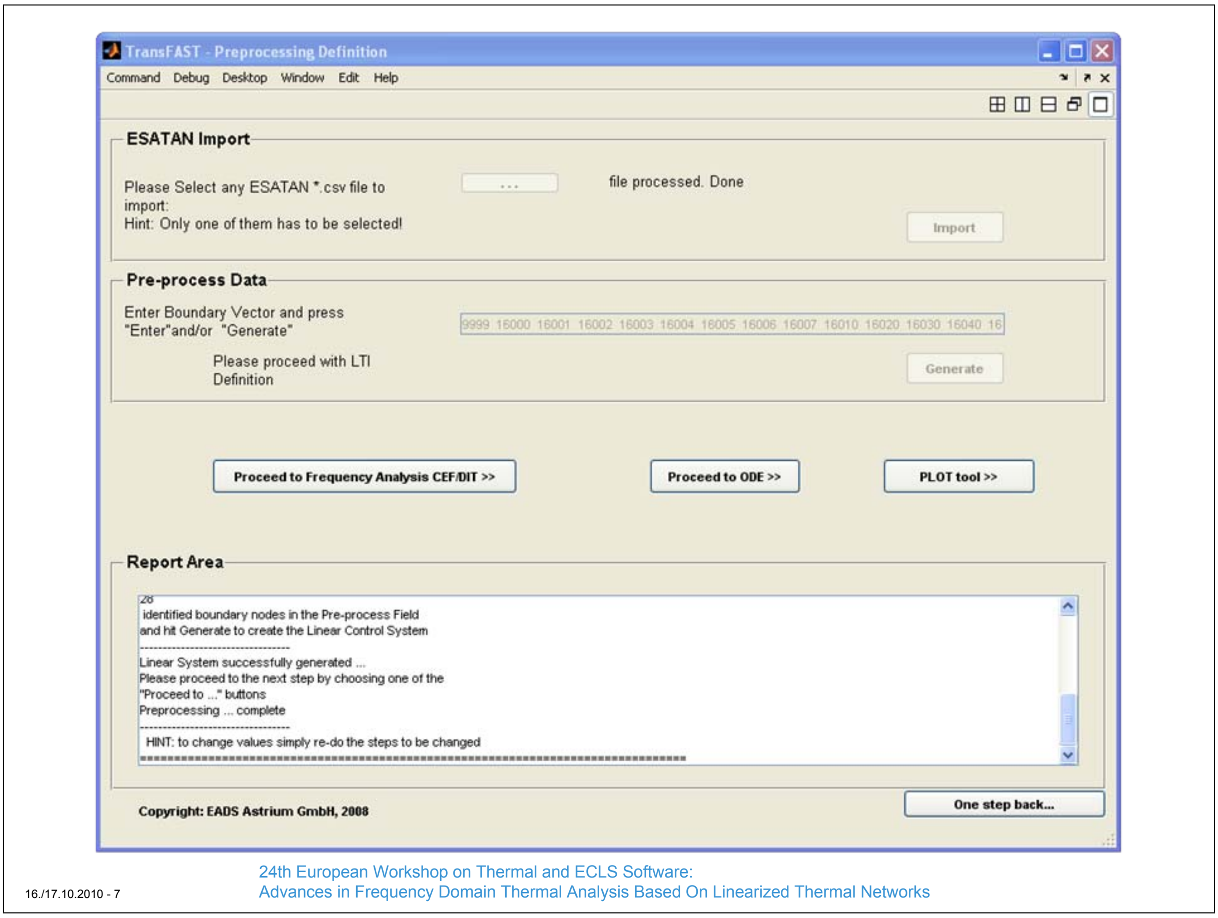
TransFAST - Preprocessing Definition
Command Debug Desktop Window Edit Help
ESATAN Import
Please Select any ESATAN *.csv file to import:
Hint: Only one of them has to be selected!
file processed. Done
Import
Pre-process Data
Enter Boundary Vector and press "Enter"and/or "Generate"
9999 16000 16001 16002 16003 16004 16005 16006 16007 16010 16020 16030 16040 16
Please proceed with LTI Definition
Generate
Proceed to Frequency Analysis CEF/DIT >>
Proceed to ODE >>
PLOT tool >>
Report Area
identified boundary nodes in the Pre-process Field
and hit Generate to create the Linear Control System
Linear System successfully generated ...
Please proceed to the next step by choosing one of the
"Proceed to ..." buttons
Preprocessing ... complete
HINT: to change values simply re-do the steps to be changed
Copyright: EADS Astrium GmbH, 2008
One step back...
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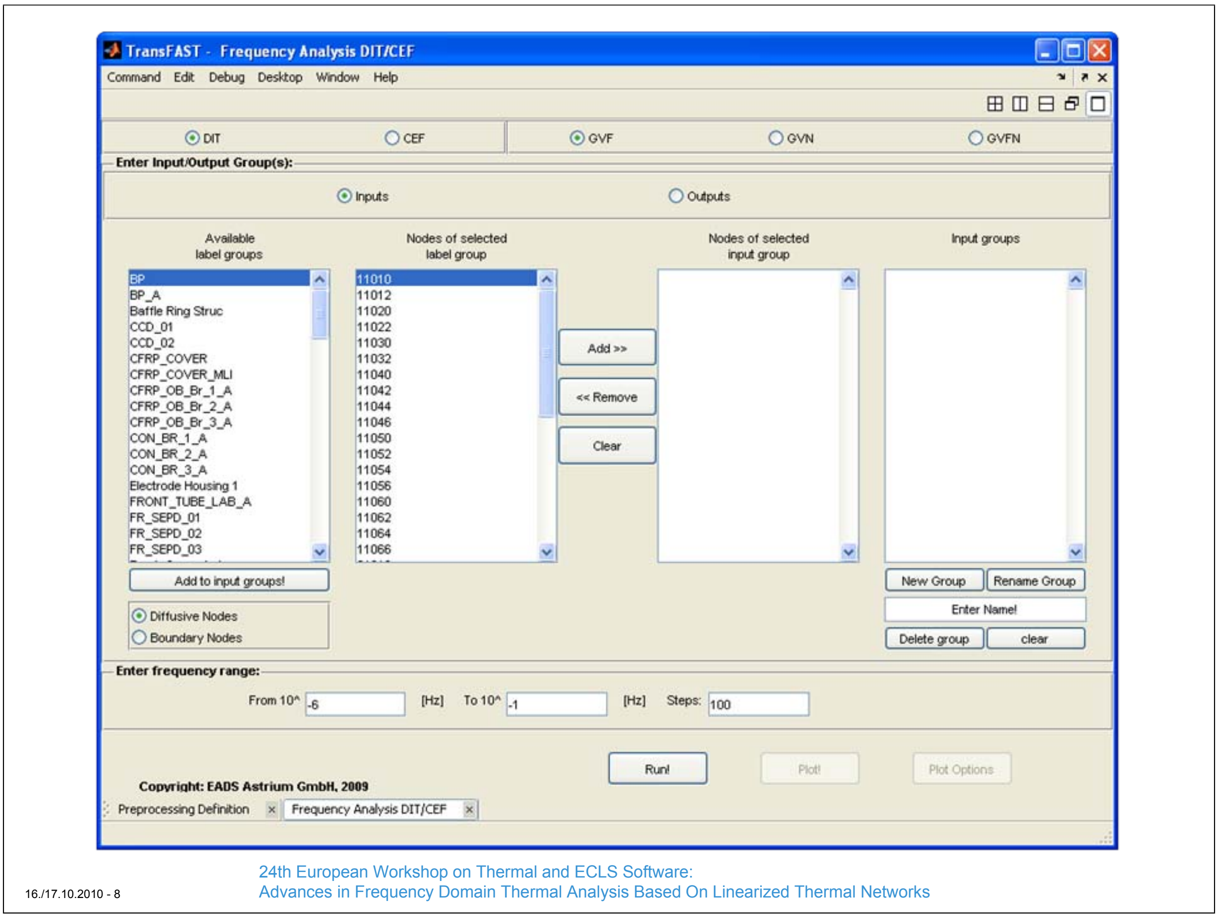
TransFAST - Frequency Analysis DIT/CEF
Command Edit Debug Desktop Window Help
DIT CEF GVF GVN GVFN
Enter Input/Output Group(s):
Inputs Outputs
Available label groups
Nodes of selected label group
Nodes of selected input group
Input groups
BP
BP_A
Baffle Ring Struc
CCD_01
CCD_02
CFRP_COVER
CFRP_COVER_MLI
CFRP_OB_Br_1_A
CFRP_OB_Br_2_A
CFRP_OB_Br_3_A
CON_BR_1_A
CON_BR_2_A
CON_BR_3_A
Electrode Housing 1
FRONT_TUBE_LAB_A
FR_SEPD_01
FR_SEPD_02
FR_SEPD_03
11010
11012
11020
11022
11030
11032
11040
11042
11044
11046
11050
11052
11054
11056
11060
11062
11064
11066
Add >>
<< Remove
Clear
Add to input groups!
Diffusive Nodes
Boundary Nodes
New Group
Rename Group
Enter Name!
Delete group
clear
Enter frequency range:
From 10^ -6 [Hz] To 10^ -1 [Hz] Steps: 100
Run!
Plot!
Plot Options
Copyright: EADS Astrium GmbH, 2009
Preprocessing Definition
Frequency Analysis DIT/CEF
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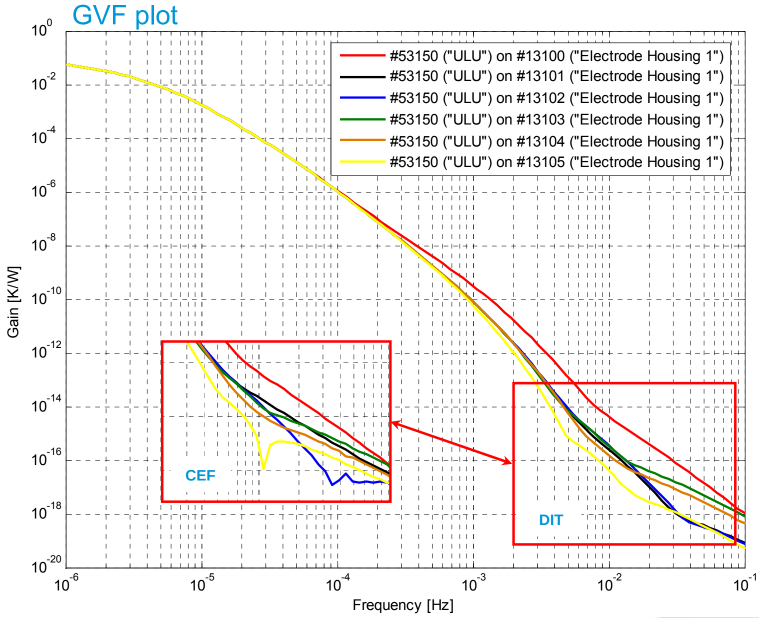
DIT vs. CEF, Exemplary Results

GVF plot



Input # 53150, Output GRS Electrode Housing (MOSA1), DIT

Nodes	Inputs	Outputs	CEF	DIT
675	1	1	4 s	11 s
675	1	5	15 s	11 s
1640	1	1	17 s	1530 s
1640	1	5	83 s	1530 s

DIT vs. CEF, Computation Time for GVF

- Highly consistent results in the range of interest (gain)
- Limited number of outputs: CEF faster than DIT
- DIT doesn't show numerical noise problems

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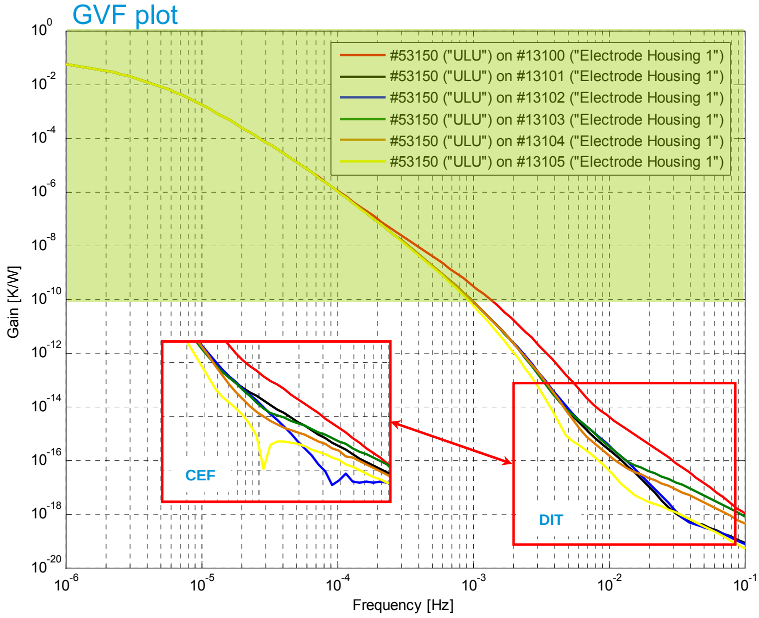
DIT vs. CEF, Exemplary Results

GVF plot



Input # 53150, Output GRS Electrode Housing (MOSA1), DIT

Nodes	Inputs	Outputs	CEF	DIT
675	1	1	4 s	11 s
675	1	5	15 s	11 s
1640	1	1	17 s	1530 s
1640	1	5	83 s	1530 s

DIT vs. CEF, Computation Time for GVF

- Highly consistent results in the range of interest (gain)
- Limited number of outputs: CEF faster than DIT
- DIT doesn't show numerical noise problems

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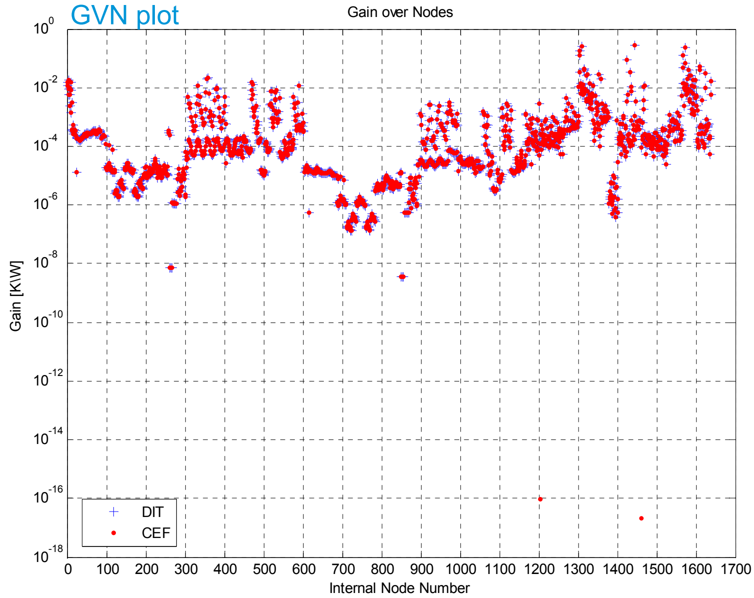
DIT vs. CEF, Exemplary Results

GVN plot



Input # 53150, frequency 10^{-4} Hz

Nodes	Inputs	Outputs	CEF	DIT
675	1	675	408 s	1 s
675	2	675	816 s	4 s
675	5	675	2040 s	6 s
1640	1	1640	> 3 h	15 s
1640	2	1640	> 3 h	45 s
1640	5	1640	> 3 h	90 s

DIT vs. CEF, Computation Time for GVN

- In case of many outputs: DIT much faster than CEF
- Absolute difference (CEF-DIT) < 10^{-9} K/W

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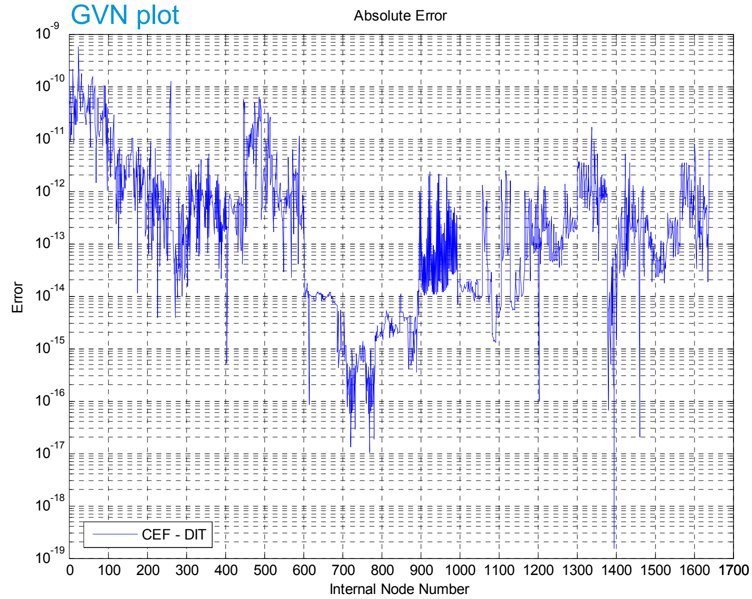
DIT vs. CEF, Exemplary Results

GVN plot



Input # 53150, frequency 10^{-4} Hz

Nodes	Inputs	Outputs	CEF	DIT
675	1	675	408 s	1 s
675	2	675	816 s	4 s
675	5	675	2040 s	6 s
1640	1	1640	> 3 h	15 s
1640	2	1640	> 3 h	45 s
1640	5	1640	> 3 h	90 s

DIT vs. CEF, Computation Time for GVN

- In case of many outputs: DIT much faster than CEF
- Absolute difference (CEF-DIT) < 10^{-9} K/W

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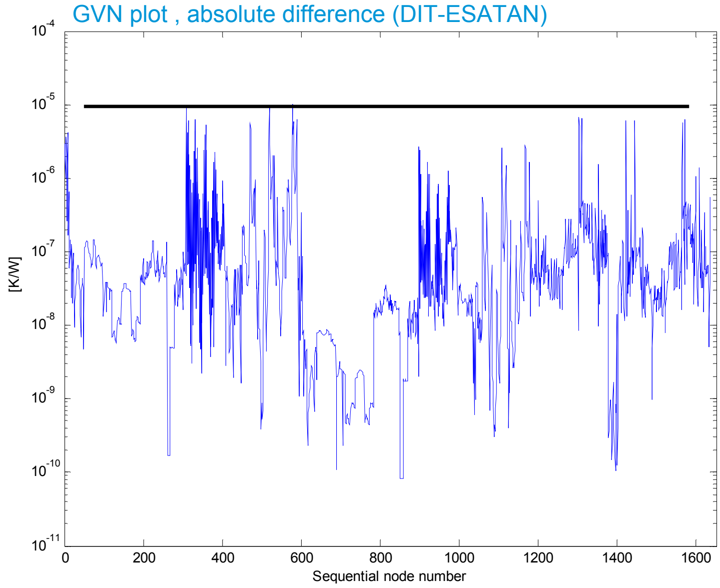
Comparison with ESATAN built-in solver

GVN plot , absolute difference (DIT-ESATAN)



Input # 53150, frequency 10^{-4} Hz

Case	In / Out / Freq.	ESTAN	CEF / DIT
GVF	1 / 1 / 100	370 s	20 s (CEF)
GVF	1 / 5 / 100	370 s	96 s (CEF)
GVN	1 / 1640 / 1	370 s	18 s (DIT)
GVN	5 / 1640 / 1	370 s	18 s (DIT)
GVFN	1 / 1640 / 100	370 s	1900 s (DIT)
GVFN	5 / 1640 / 100	370 s	1900 s (DIT)

ESTAN vs. CEF/DIT, Computation Time for GVN

- ESATAN routines SLFRTF & DMPFR used
- Absolute difference < 10^{-5} K/W
- Post processing included in calculation time for DIT & CEF
- ESATAN: No built-in plot feature

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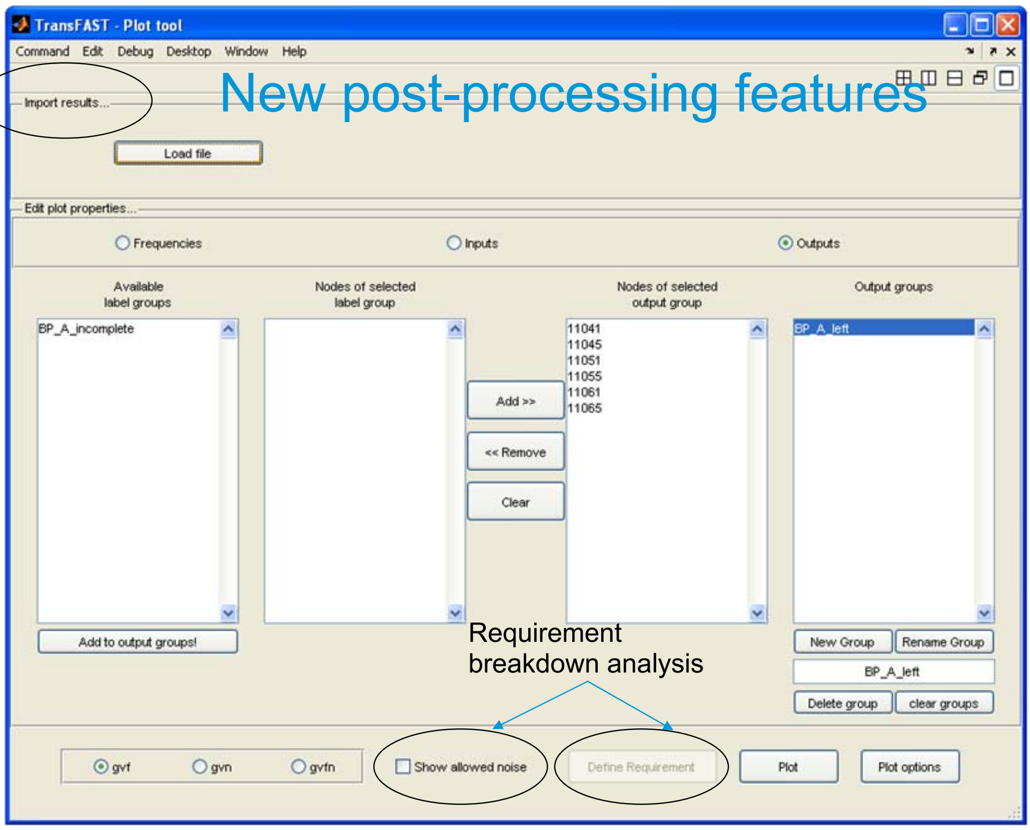
New post-processing features



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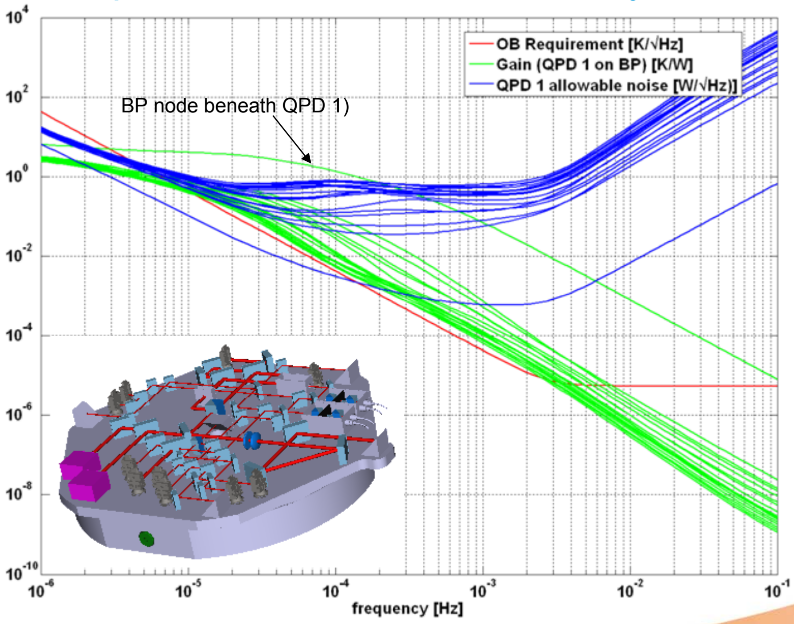
Post-processing example: Requirement breakdown to subsystem level



- Thermal stability requirement for LISA Optical Bench
- GVF plot for QPD 1 noise input on OB base plate (SIMO calculation) (QPD mounted on BP)
- Allowable QPD 1 noise
- After apportionment of overall stability requirement to subsystems and adding of margins, individual stability requirements for subsystems & components can be easily derived and be used as input for subsystem specifications

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Summary

- S/W tool development w.r.t frequency domain analysis based on linearized thermal systems completed
- Powerful and user-friendly GUI incl. post-processing features
  - Easy calculation process
  - Design and Model check
  - Advanced data evaluation (requirement analysis)
- Two methods (DIT & CEF) for solving the key issue, the inversion of the system matrix implemented and verified
- Method selection depending on specific type of calculation (GVN, GVF, GVFN)
- Abs. difference to ESATAN built-in solver < 10^{-5} K/W (significantly larger than between DIT & CEF, < 10^{-9} K/W)
- Extension to time domain analysis (ODE & QA) under development

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Appendix P

Validation of the Martian Thermal Environment Modelling Method using Flight Data

Stéphane Lapensée
(ESA/ESTEC, The Netherlands)

Abstract

The Martian surface environment is complex to model since it is composed of multiple diurnal flux inputs and temperature sinks. The Mars environment is similar to Earth's since it undergoes seasonal changes in its weather pattern. Through the past Mars missions, the surface environment has been study extensively. New discoveries are made and scientists are having a deeper understanding of the Martian surface environment. Several engineering tools and analysis methods have been developed over the years and are used to predict and model the thermal environment for future missions. However, there are fundamental questions that are raised regarding the precision of these tools and methods. Therefore, one solution would be to perform a validation by correlating thermal model results to flight data. However, the surface environment is very dynamic in terms of wind speed and direction as well as the fluctuation in the atmospheric dust content. Therefore, it is difficult to accurately determine the exact environmental condition through one Martian day in order to perform a correlation. Nevertheless, performing such an exercise will give us a certain level of confidence on the tools and analysis methods.
The presentation will give an overview of the tools available to determine the thermal environment and will explain how such an environment can be modeled using IDEAS/TMG. Furthermore, the tools and analysis method will be validated by comparing thermal model results with flight data from the Phoenix Meteorological Instrument.

Background Information

- Several tools and analysis methods are used in the frame of the Exomars Program
  - Basic questions are asked regarding the accuracy of the tools and analysis methods to predict the Martian Environment
- Validation with flight data provides excellent feedback but it is not always possible or easy to perform
  - Few successful surface missions
  - Availability of flight data and correlated thermal models
  - Lack of Knowledge of the surrounding environment
  - In case of science instruments, science objective and science data have priority over engineering data, hence very few monitoring points
  - Time and budget allocation for thermal model correlation to flight data is not always a priority
    - No news is good news approach
- Any type of comparison with flight data provides confidence in the tools and methods, which in the end is a validation.

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Martian Environment

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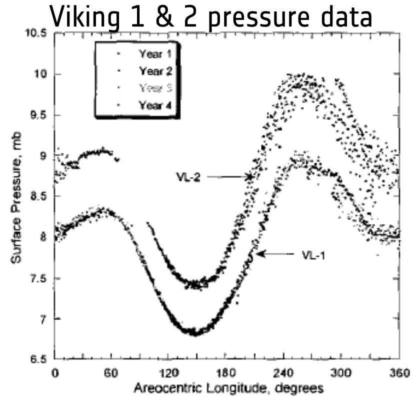
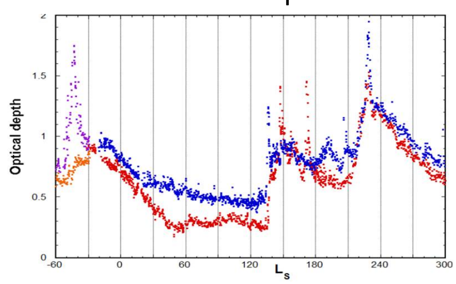
- Seasonal Variations that are repeatable
  - Solar Declination due to Mars axis inclination
  - Pressure variation caused by CO2 Migration
  - Atmospheric Dust increases due to storms
- Thermal designs are based on multiple Landing Sites scenarios since the landing site is selected very late in the program
  - Cope with large temperature extremes due to surface properties and seasons
  - Extremes are scattered across multiple landing site scenarios and not within one specific landing site
    - Due to different latitudes of landing sites
- In order to perform correlation, a good knowledge of landing site during operations is required
  - Atmospheric Conditions changes daily
  - Wind speed and direction
  - Surface temperature and pressure

Viking 1 & 2 pressure data



MER A & B Atmospheric Data



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LMD 1D Flux Engineering Tool to determine the Mars Environment

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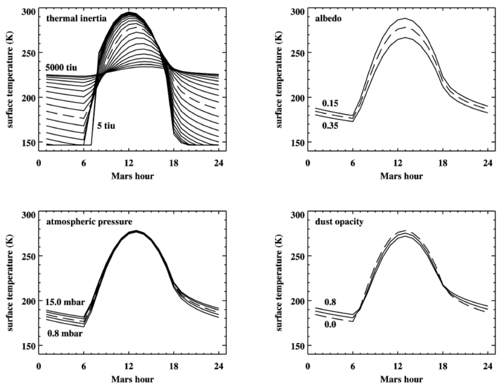
- Based on a global circulation model developed by Laboratoire de Météorologie Dynamique, through ESA Contract
  - http://www-mars.lmd.jussieu.fr/
- Produces surface temperature and solar flux profiles to be used in thermal analysis
- LMD validated 1D flux tool with Pathfinder and Viking data,
  - higher precision at Latitude -50° to 50°
- Independent comparison with JPL 1D Flux tool output was performed
- The input parameters to LMD Flux Tool are:
  - Areocentric longitude, Ls
  - Landing site latitude
  - Ground pressure
  - Atmospheric opacity
  - Local surface Albedo
  - Thermal inertia of near-surface ground layer
  - Infrared emissivity of bare ground

Effect of ground temperature on varying parameters



Ref: Apparent thermal inertia and the surface heterogeneity of Mars, Nathaniel E. Putzig and al. 2007

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LMD 1D Energy Balance Heat Fluxes Output

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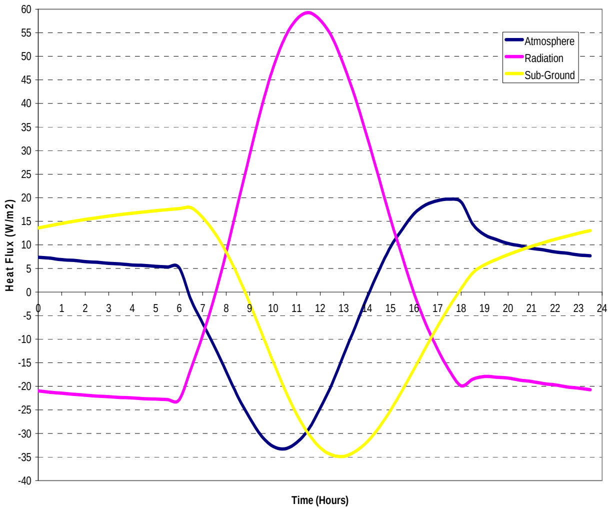
- Basic Thermal modelling software can reproduce
  - Radiative exchange
  - Ground Conductive exchange
- What is missing is the Mars atmospheric turbulent mixing model, which can be imported into the analysis from the LMD Tool
- LMD Flux tool can be used as a reference by extracting the energy balance data and compared to thermal simulation
- Always have a reference horizontal flat plate in the model in order to cross check results with Environmental inputs



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JMars Public Application

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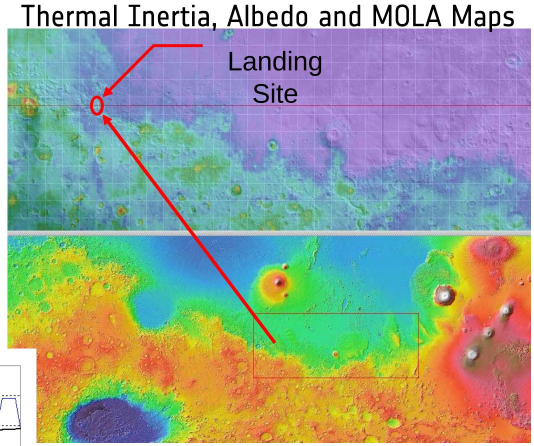
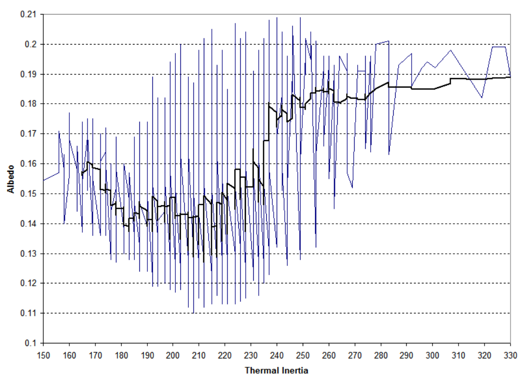
- JMars, Java application, public access to Mars remote sensing data, http://jmars.asu.edu/
- Excellent tool to extract Albedo, Thermal inertia and Altitude
  - Thermal Emission Spectrometer (TES) Albedo Maps, Mars Global Surveyor
  - TES Thermal Inertia Maps (Christensen 2001 and Putzig 2007)
  - Mars Orbiter Laser Altimeter, (MOLA) Altitude Maps, Mars Global Surveyor
- Export data to Excel for manipulation

Thermal Inertia, Albedo and MOLA Maps





Generated Albedo vs Thermal Inertia Plot for specific landing site

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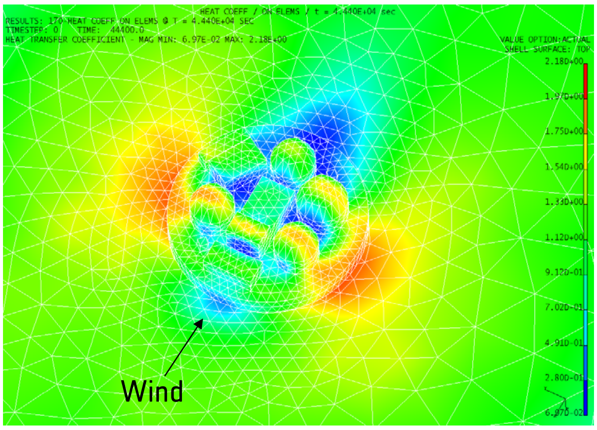
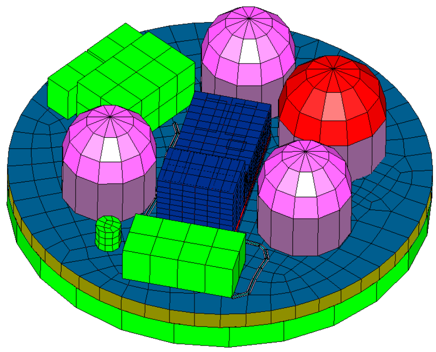
Thermal Analysis Software Tools

- Exomars Industrial team is currently using ESARAD/ESATAN for the thermal analysis of the 2016 and 2018 Exomars missions
  - Facilitates the exchange of thermal models
  - Mars Surface modeling method has been developed (Presented at previous ECLS Workshops)
- ESTEC has separate models of the EDM and Rover in I-DEAS/TMG
  - Independent cross checks with industry models
  - Allows coupling analyses between CFD and surface thermal





2016 EDM TMG Thermal Model

7 Heat Transfer Coefficients calculated with TMG/CFD

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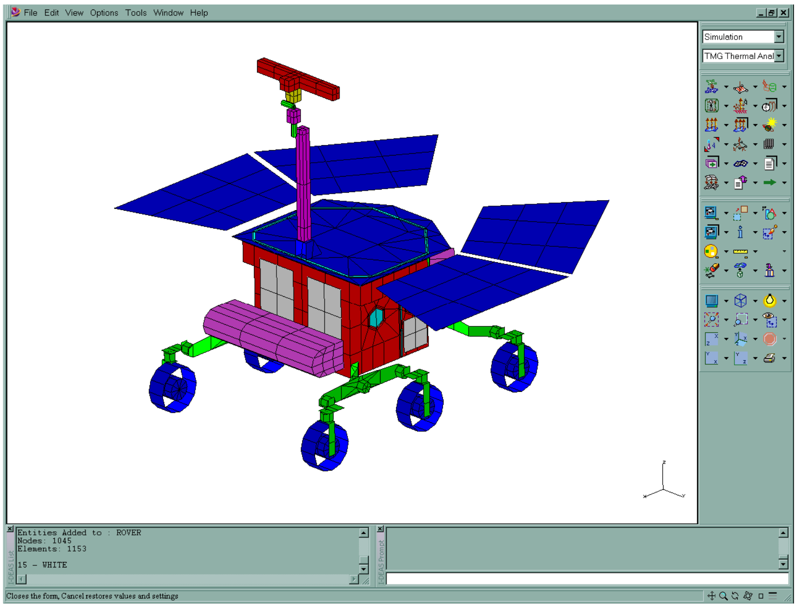
I-Deas/TMG Interface

- I-Deas/TMG has a built-in capability for planet body surface analysis
- Direct and diffuse solar fluxes can be modeled
- "Space" Nodes are used to model the Sky temperature
- Ground is modeled through dedicated elements
- Wind modeled with fixed or variable heat transfer coefficients or coupled through CFD



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Diurnal Solar Heating Interface

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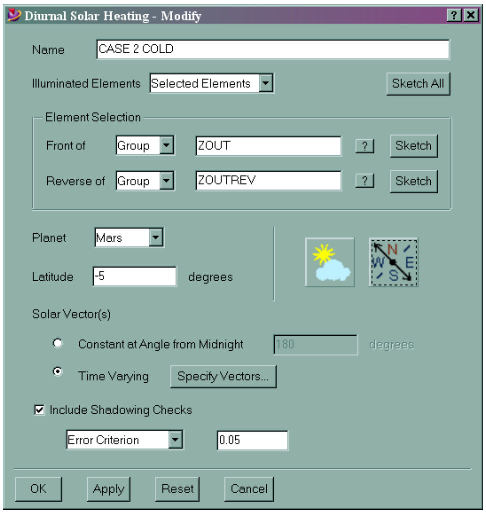

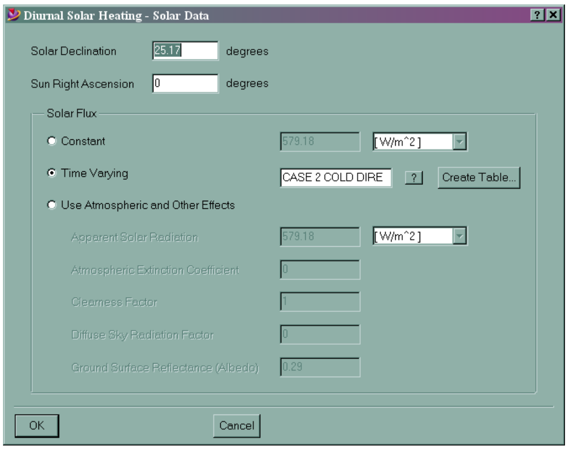

- TMG can model Atmospheric effects
  – Models are currently based on Earth Environment and not relevant to Mars
- Input time dependant Solar Flux values obtained from LMD Flux tools
  – Need to correct direct solar flux since LMD 1D calculates for a horizontal Plate
  – Sun Elevation and Azimuth data is generated by LMD Flux Tool

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Diffuse Solar Flux

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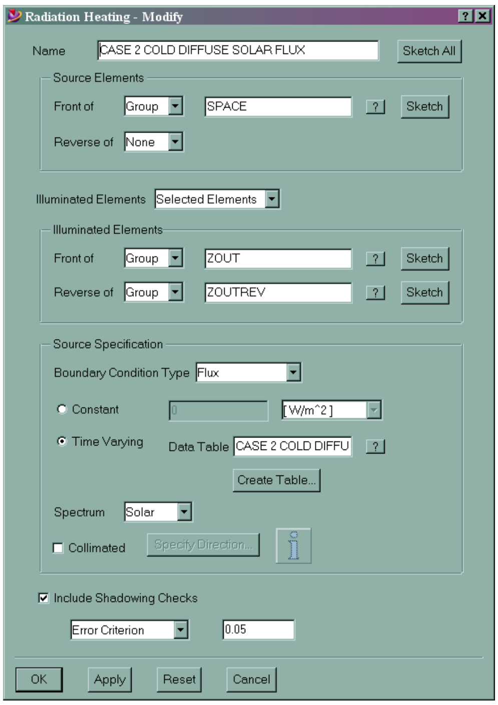
- Radiation Heating Option is used to model the Diffuse Solar Flux
- Radiation heating has the ability to emit in IR or Solar spectrum
- Source elements can be either the “Space” Node or a transparent Dome can be erected around the model to emit the Diffuse Solar flux



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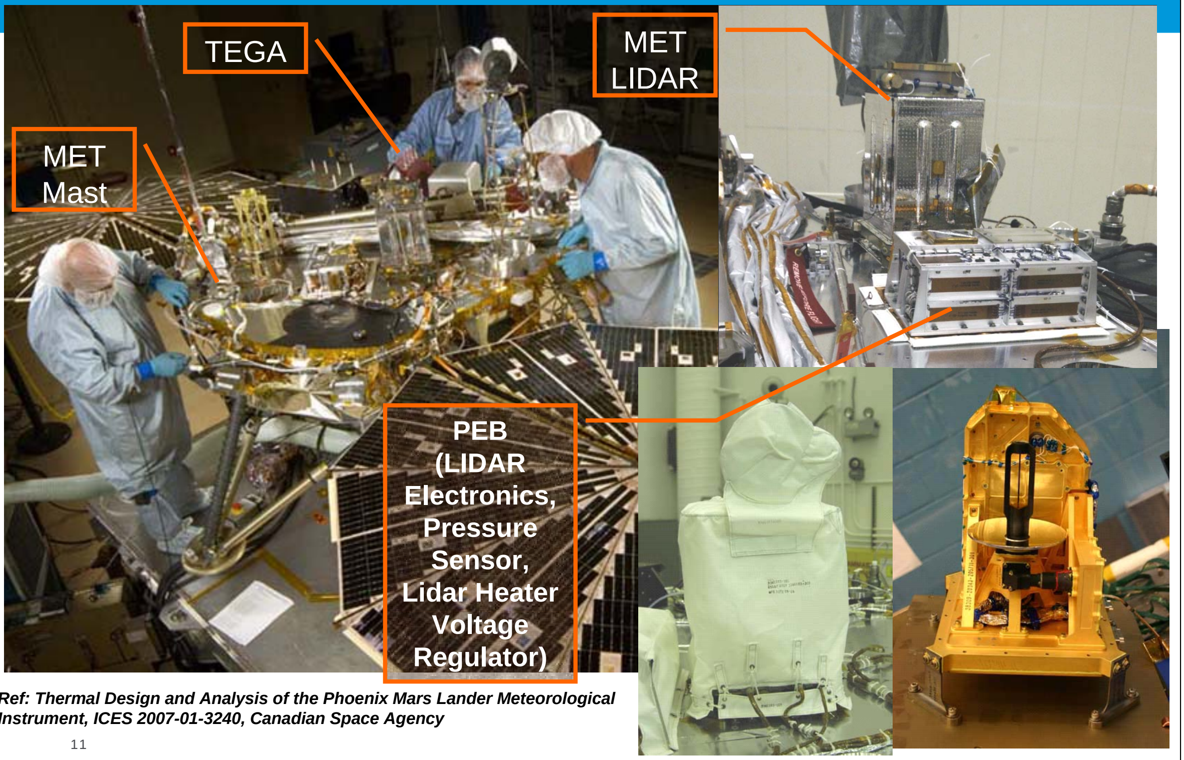
Validation using Phoenix MET Instrument Flight Data



Ref: Thermal Design and Analysis of the Phoenix Mars Lander Meteorological Instrument, ICES 2007-01-3240, Canadian Space Agency

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Thermal Characteristics of the MET Instrument

- Thermal Characteristics of the LIDAR
  - Fiberglas thermal blanket with Betacloth as an exterior layer
  - Thermally isolated from the Spacecraft Deck
  - Main heat loss contributor is the Sky
  - Temperature sensor located on the LIDAR Chassis
- Thermal Characteristics of the Mast Base
  - Thermally coupled to the spacecraft deck
  - Low emissivity finish
  - Sensitive to Solar fluxes
  - Main heat loss contributors are natural and forced convection
  - Temperature sensor located on the Mast Base

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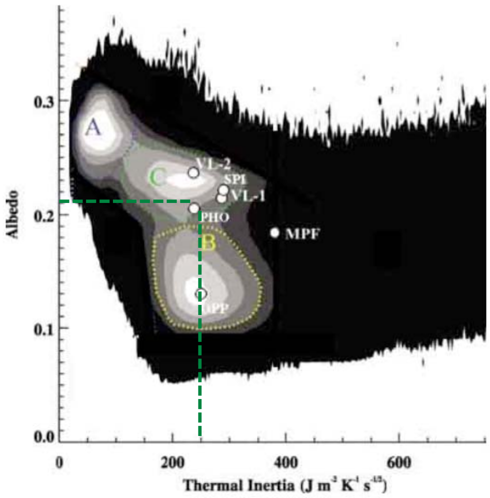
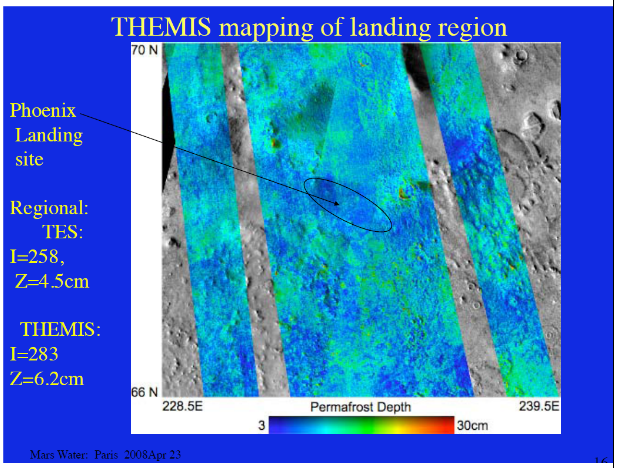
Albedo and Thermal Inertia Mapping of Landing Site

Phoenix Landing Coordinates: 68.218830N 234.250778E,
Landing Mars Solar Longitude (Ls)= 76.6. Mars Spring, May 25th 2008
Albedo = 0.21, Thermal Inertia 250



Ref: RELATIONSHIPS BETWEEN REMOTE SENSING DATA AND SURFACE PROPERTIES OF MARS LANDING SITES. M. P. Golombek and al, 2009



Ref: Martian High latitude permafrost depth and surface-cover thermal inertia distribution: Josh Bandfield and al., 2008

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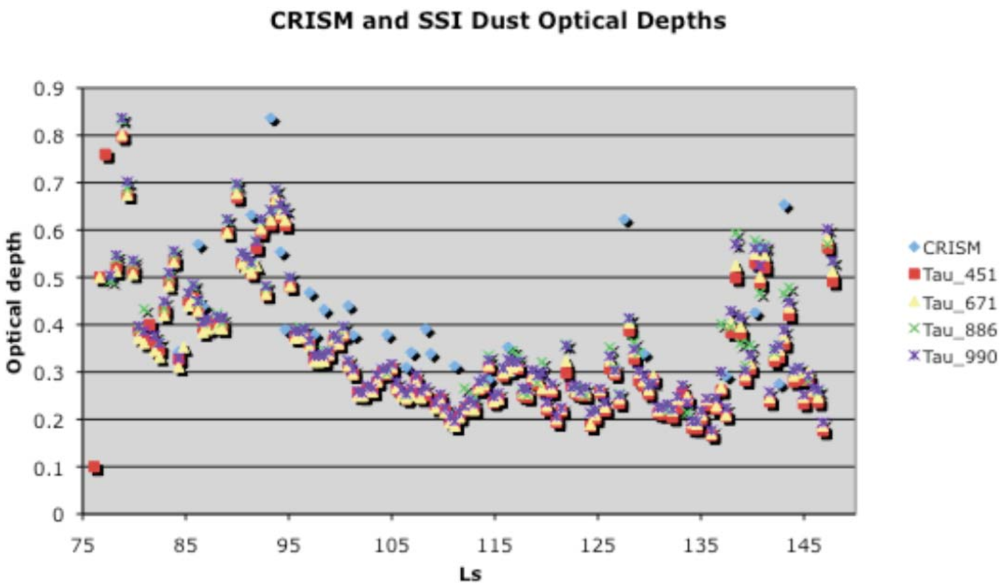
Phoenix Landing Site Optical Depth Measurements



Ref: PHOENIX AND MRO COORDINATED ATMOSPHERIC SCIENCE. L. K. Tamppari et al., 2009

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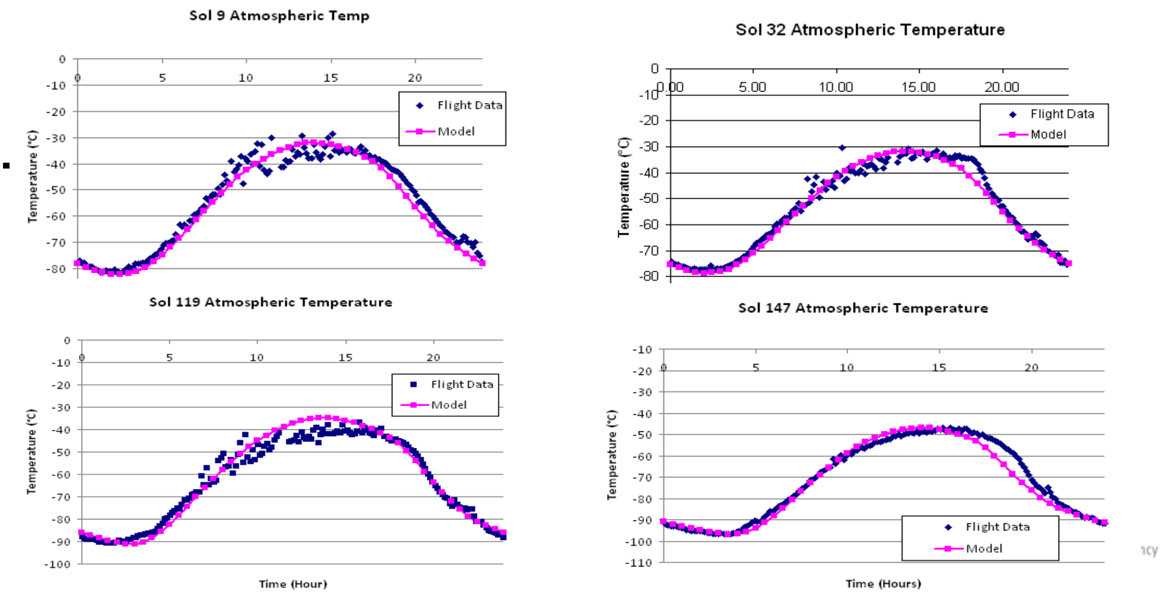
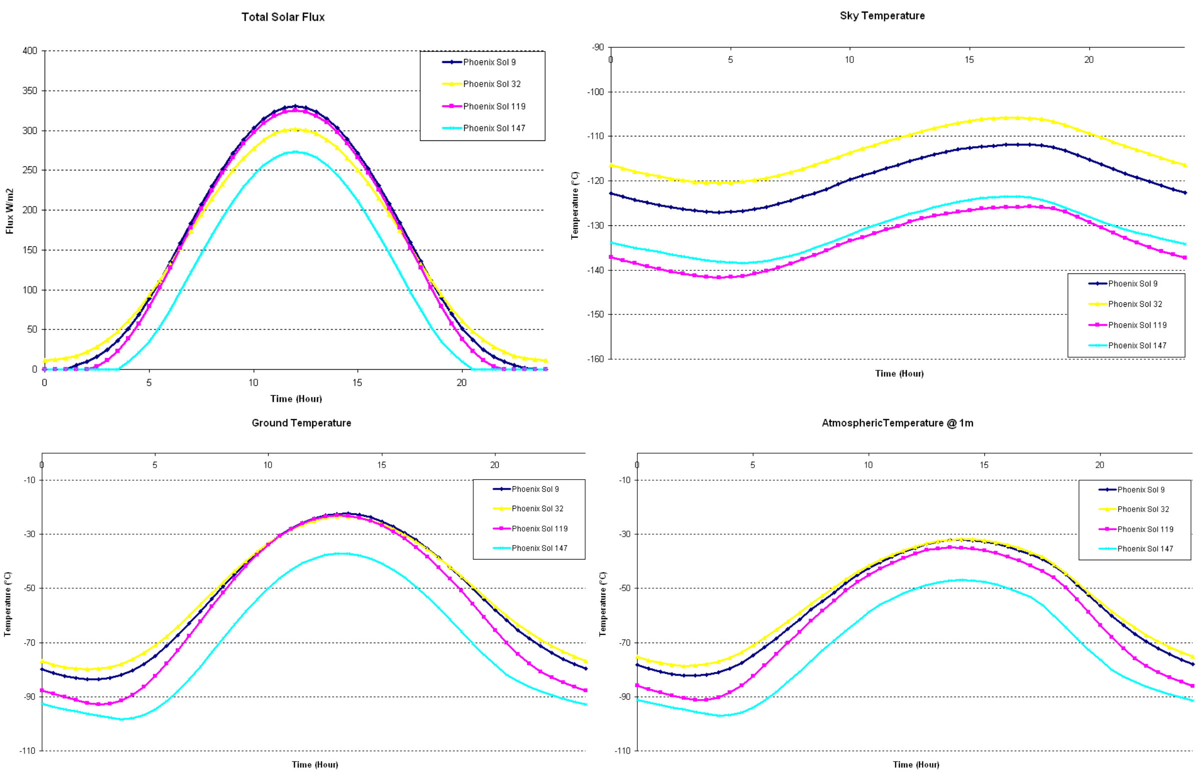
Estimates of the Phoenix Landing Site Environment Parameters

Description	Optical Depth T	Surface Albedo	Ls	Pressure Pa	Thermal Inertia (J m-2 K-1 s-1/2)	Solar Declination	Ground Emissivity	Latitude (oN)
Phoenix Sol 9	0.5	0.24	80.48	835	250	24.8	0.98	68.2
Phoenix Sol 32	0.65	0.24	90.79	801	220	25.2	0.98	68.2
Phoenix Sol 119	0.24	0.24	131.88	733	200	18.6	0.98	68.2
Phoenix Sol 147	0.5	0.26	145.82	733	210	14.0	0.98	68.2

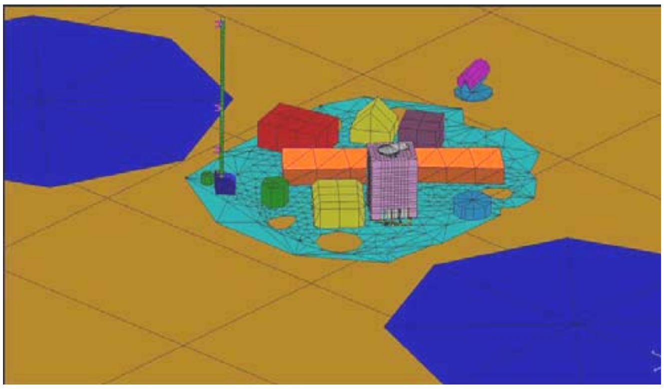


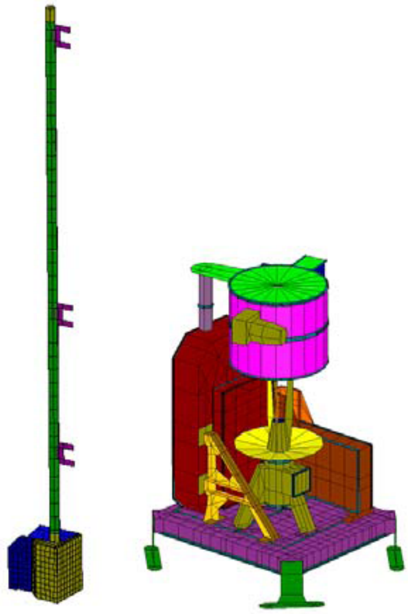
Calculated Phoenix Boundary Conditions using LMD 1D Flux Tool



Phoenix MET Thermal Model

- Thermal Model was built by the Canadian Space Agency
- Generated and analyzed using I-DEAS NX12 and TMG 12
- Model Correlated by Ground Testing in a Martian Thermal Environment





Ref: Thermal Design and Analysis of the Phoenix Mars Lander Meteorological Instrument, ICES 2007-01-3240, Canadian Space Agency

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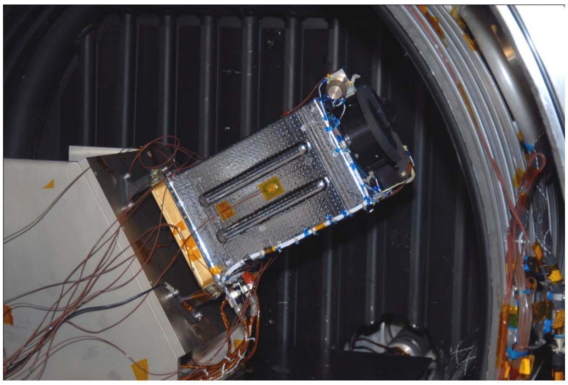
MET LIDAR Thermal Testing

- Tested in an 8 mBar CO_2 environment in order to verify
  - Thermal design
  - Thermal distortion effect on alignment
  - Performance over temperature
- Thermal chamber temperature varied from 30°C to –100°C
  - CO_2 will condense below –100°C
- Natural Convection inside the LIDAR during testing was significant
  - Heat transfer coefficient correlated to test data and adjusted for Mars gravity



Ref: Thermal Design and Analysis of the Phoenix Mars Lander Meteorological Instrument, ICES 2007-01-3240, Canadian Space Agency

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Phoenix Measured Wind Speed over the mission

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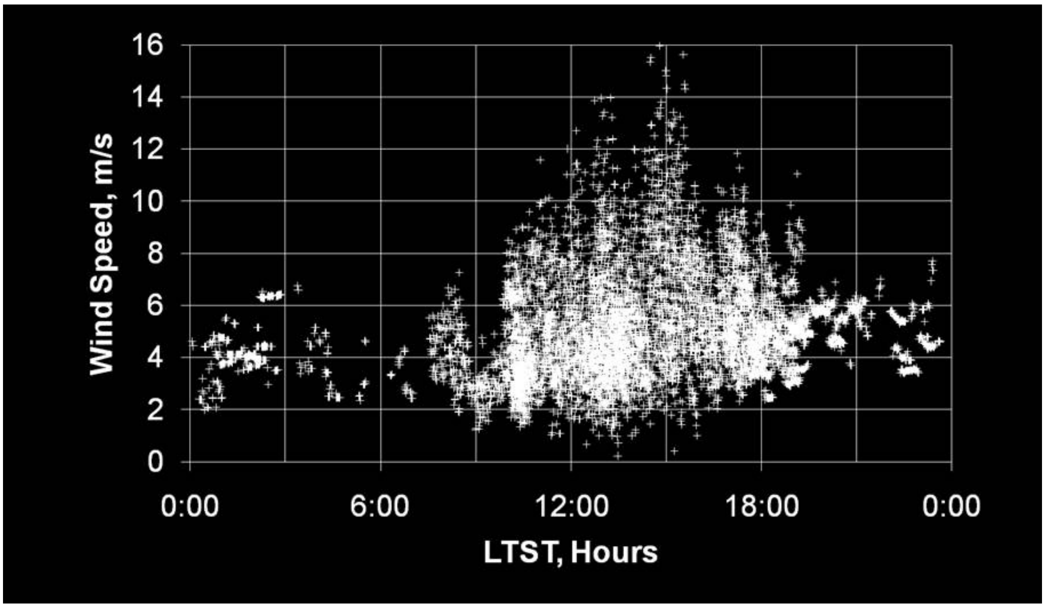

Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data, ICES 2010 AIAA 2010-6195, Stéphane Gendron and al., Canadian Space Agency

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Calculated Forced Convection Coefficients

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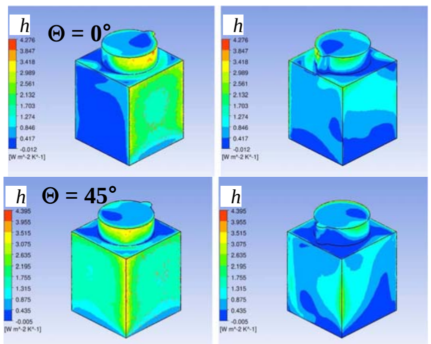
Heat Transfer Coefficients Calculated using CFD

U_∞ (m/s)	Θ (degrees)	h_{avg} (W/m²/K)	h_{min} (W/m²/K)	h_{max} (W/m²/K)
4.14	0	0.94	0.00	4.30
4.14	45	1.12	0.00	4.40



$$0.94 \le h_{avg} \le 1.18 \text{ W/m}^2\text{/K}$$

Box Shape Empirical Equation for Heat Transfer Coefficient

$$\frac{hd}{k_f} = 0.102 \cdot \mathrm{Re}_{df}^{0.675} \cdot \mathrm{Pr}_f^{\frac{1}{3}}$$

h=0.91 W/m²/K for 4 m/sec Wind

Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data, ICES 2010 AIAA 2010-6195, Stéphane Gendron and al., Canadian Space Agency

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Phoenix Instrument Flight Data Available through Public Website

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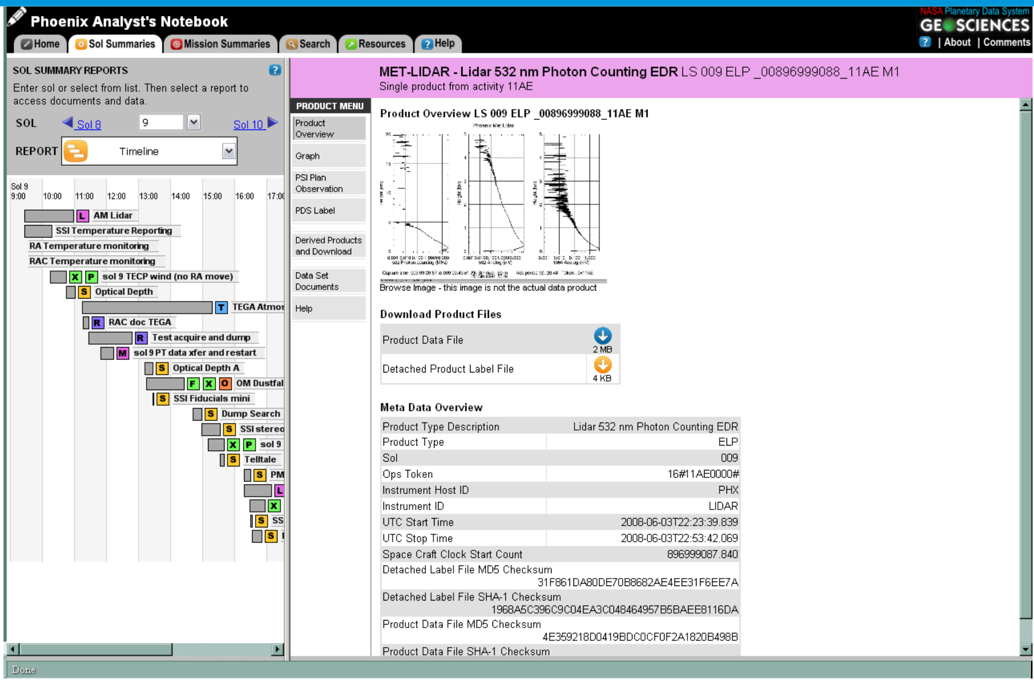

21 *Ref: http://an.rsl.wustl.edu/phx/solbrowser/default.aspx* European Space Agency

LIDAR Simulated and Flight data Comparison for SOL 32-33

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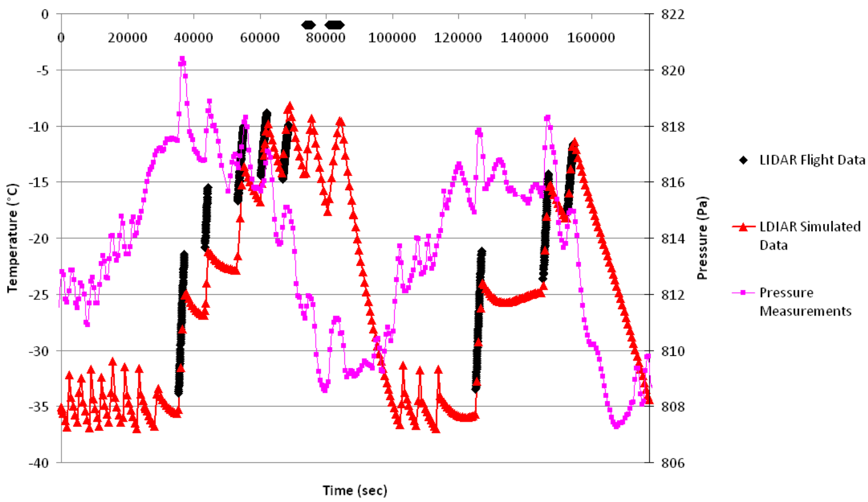
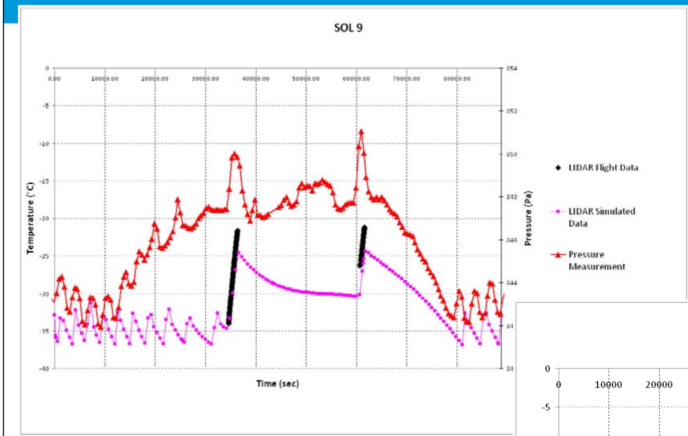
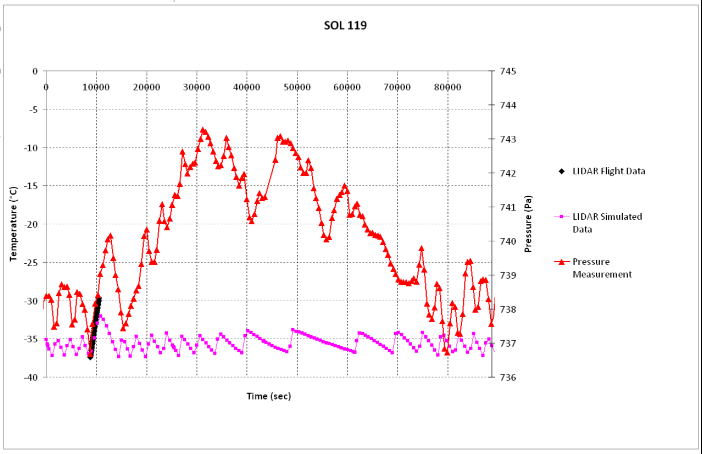
- Pressure sensor located on the PEB, which housed the LIDAR electronics and LIDAR Keep Alive Heater Voltage Regulator
- Temperature variations affect the pressure measurements, which provide information on the duty cycle of the LIDAR heater



22 ***Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data, ICES 2010 AIAA 2010-6195, Stéphane Gendron and al., Canadian Space Agency*** European Space Agency

LIDAR Simulated and Flight data Comparison for SOL 9 and 119





Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data

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MAST Base and TEGA Simulated and Flight data Comparison

- Larger temperature differences when compared to the LIDAR data
- Uncertainty in the optical finish, as well as the level of accumulated Dust
- Forced Convection uncertainty, wind gust/speed and direction, blockage effects
- Large Temperature difference for the TEGA instrument could be related to the power dissipation during operations since TEGA model used is based on assumptions

Sol #	LTST (hrs:min)	MAST ITB Flight T (°C)	MAST ITB Model T (°C)	MAST ITB ΔT (°C)	TEGA Flight T (°C)	TEGA Model T (°C)	TEGA ΔT (°C)
9	2:36	-68,1	-82,2	-14,2	-69,9	-72,4	-2,5
	15:07	-12,9	-26,0	-13,2	-15,1	-23,8	-8,7
32	2:48	-69,4	-78,2	-8,9	-67,8	-69,8	-2,0
	14:29	-13,6	-22,7	-9,2	-14,9	-23,1	-8,2
119	2:45	-77,8	-89,9	-12,2	-81,5	-80,1	1,4
	14:18	-16,5	-27,4	-11,0	-7,3	-32,1	-24,8
147	3:26	-85,9	-98,2	-12,4	-90,6	-92,1	-1,5
	14:24	-24,8	-40,8	-16,1	11,0	-43,2	-54,2

Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data

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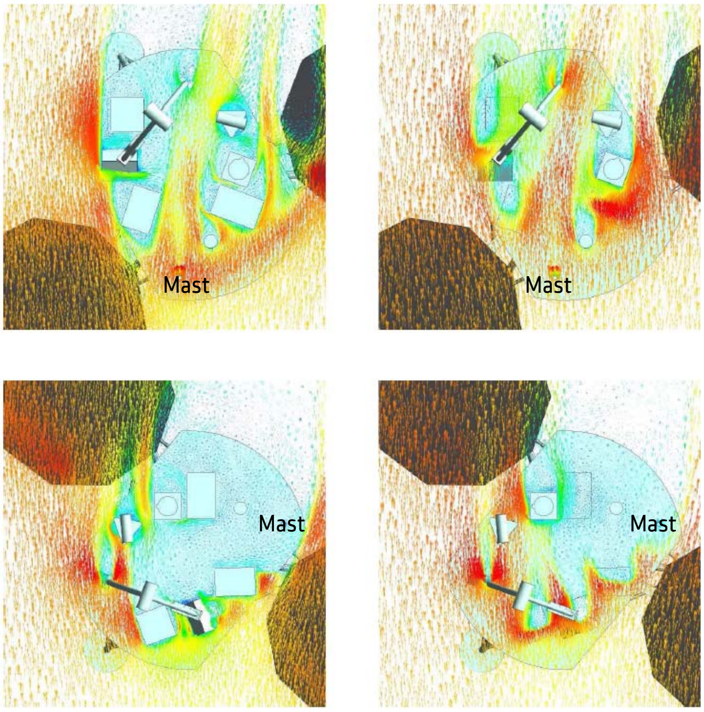
Phoenix Lander Wind Profile Predictions

- Depending on the wind direction, the MET Mast Base may experience significant wind blockage



Ref: Phoenix Mars Lander Mission: Thermal and CFD Modeling of the Meteorological Instrument based on Flight Data, ICES 2010 AIAA 2010-6195, Stéphane Gendron and al., Canadian Space Agency

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Conclusion

- Analysis methods is in agreement with flight data even though the process to determine the environment relies on remote sensing data and atmospheric models, which have a certain uncertainties
- Model of the LIDAR correlates very well since it is less sensitive to wind effects
- MET Mast predicted temperatures have a 9°C to 16°C difference with the flight data.
  - Mainly due to the optical finish uncertainty and wind blockage effects
- This aspect will be critical for the Exomars 2016 Lander mission
  - Further investigation could be performed on the Phoenix Flight data in order to further explain the temperature differences, e.g. including variable heat transfer coefficient

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Acknowledgement

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Canadian Space Agency
Stéphane Gendron, Guanghan Wang, Xin Xiang Jiang,
Darius Nikanpour

University of Alberta
Jeffrey A. Davis, Carlos F. Lange

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Appendix Q

Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests

James Etchells Duncan Gibson Philippe Poinas Giulio Tonellotto
(ESA/ESTEC, The Netherlands)

Abstract

To enable environmental testing of the Bepi Colobo S/C modules in a representative environment the Large Space Simulator (LSS) at ESTEC has been adapted to provide 10 solar constants illumination. This presentation introduces the modifications to the LSS ESATAN-TMS models that were made at ESTEC to enable test predictions to be made by the Bepi Colombo project team.

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Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests

J. Etchells, D. Gibson, P. Poinas, G. Tonellotto
ESA/ESTEC, TEC-MT

24th European Workshop of Thermal and ECLS Software
16th – 17th November 2010

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Description of Large Space Simulator (LSS)

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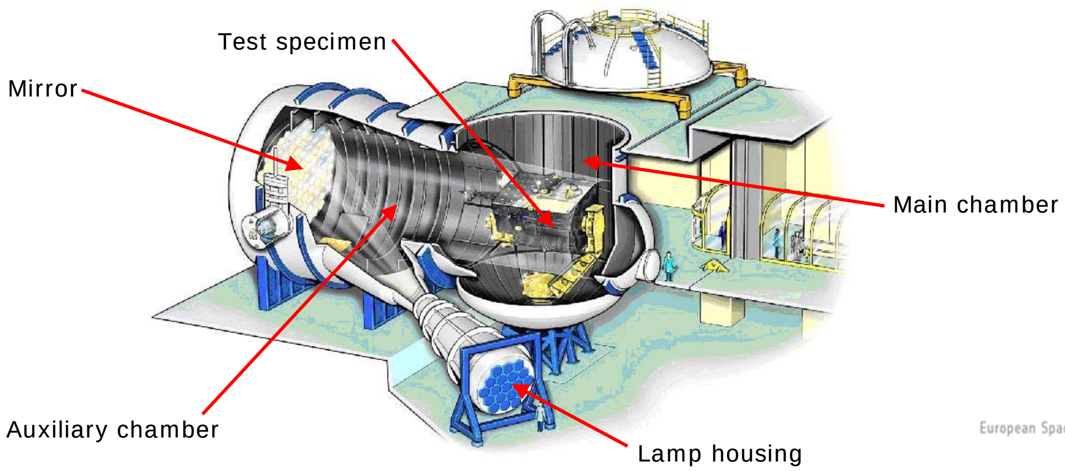
- LSS is Europe's largest vacuum test facility for S/C
- Standard sun simulator can provide >2700 Wm^{-2} with 6m diameter
- Main chamber is 15m height and 10m diameter



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Test Chamber Thermal Models (1)

- ESATAN-TMS Radiative models of the LSS have been available for some years on exchange portal: https://exchange.esa.int
  - Original LSS model produced by P. Poinas
  - Model converted to Thermica format in 2005 – no Boolean ops.
- Current models are representative for "standard" S/C thermal tests
  - Herschel test highlighted that "warm" items in the chamber (ports, windows...) must be included in model
  - For cryogenic tests improvement are underway

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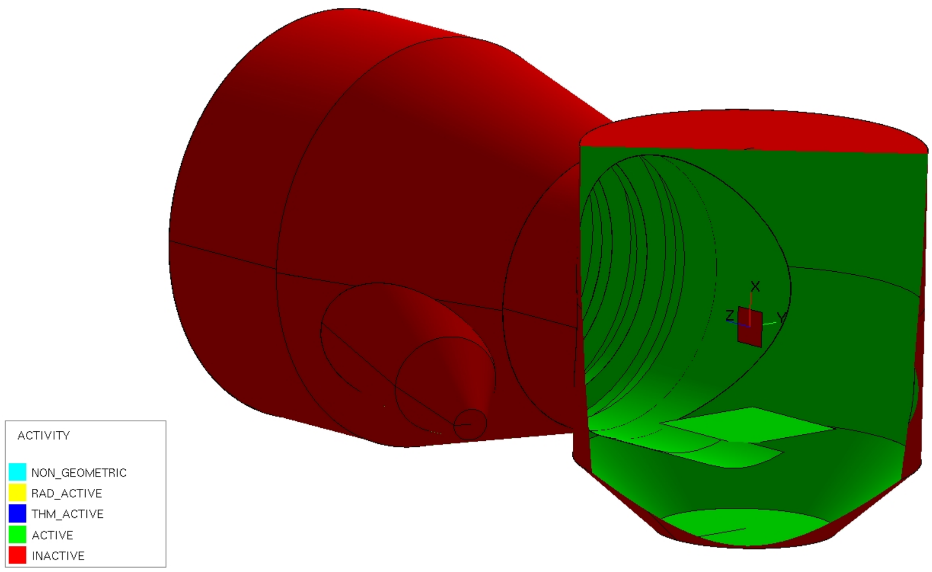
Test Chamber Thermal Models (2)



LSS Model Available on Exchange

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Modifications to LSS for Bepi-Colombo (1)

esa

- Initial requirement was to have up to 10 solar constants (up to 13,780 Wm^{-2}) for the sun simulator with beam diameter 3 metre
  - Initial baseline was to replace lamps with 32kW lamps and adjust collimation mirrors to achieve 10SC
  - But, 32kW lamps were not possible so 25kW lamps used and beam diameter further reduced to 2.7m
- Bepi-Colombo MMO, MOSIF, MTM and MPO will be testing in the modified LSS

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Modifications to LSS for Bepi-Colombo (2)

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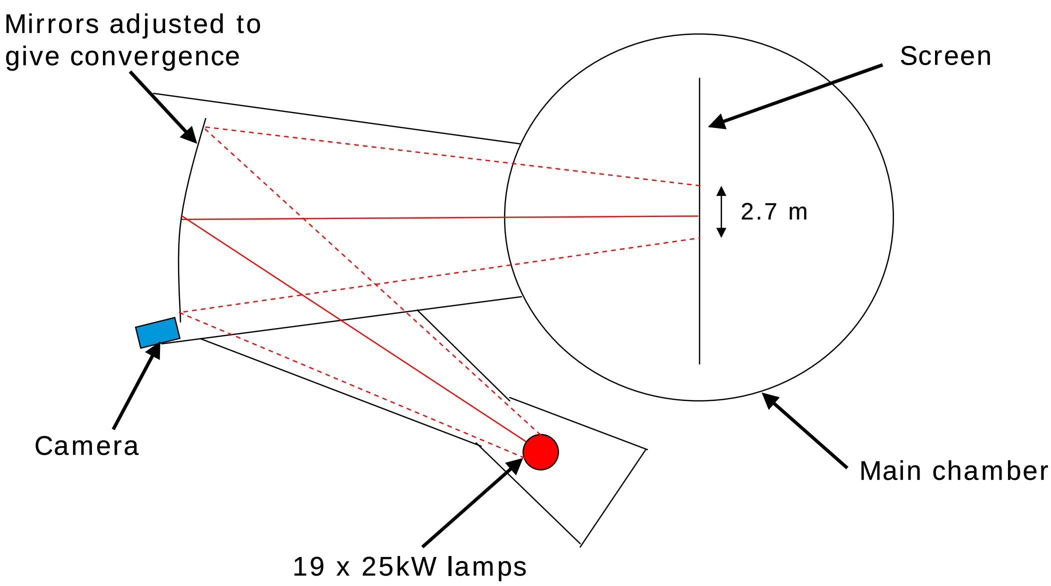

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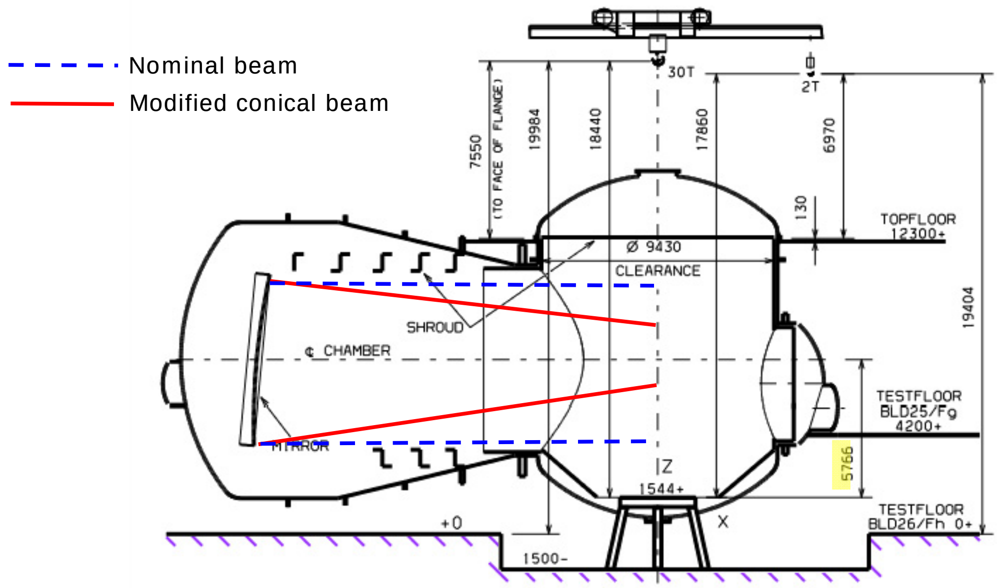
Modifications to LSS for Bepi-Colombo (3)



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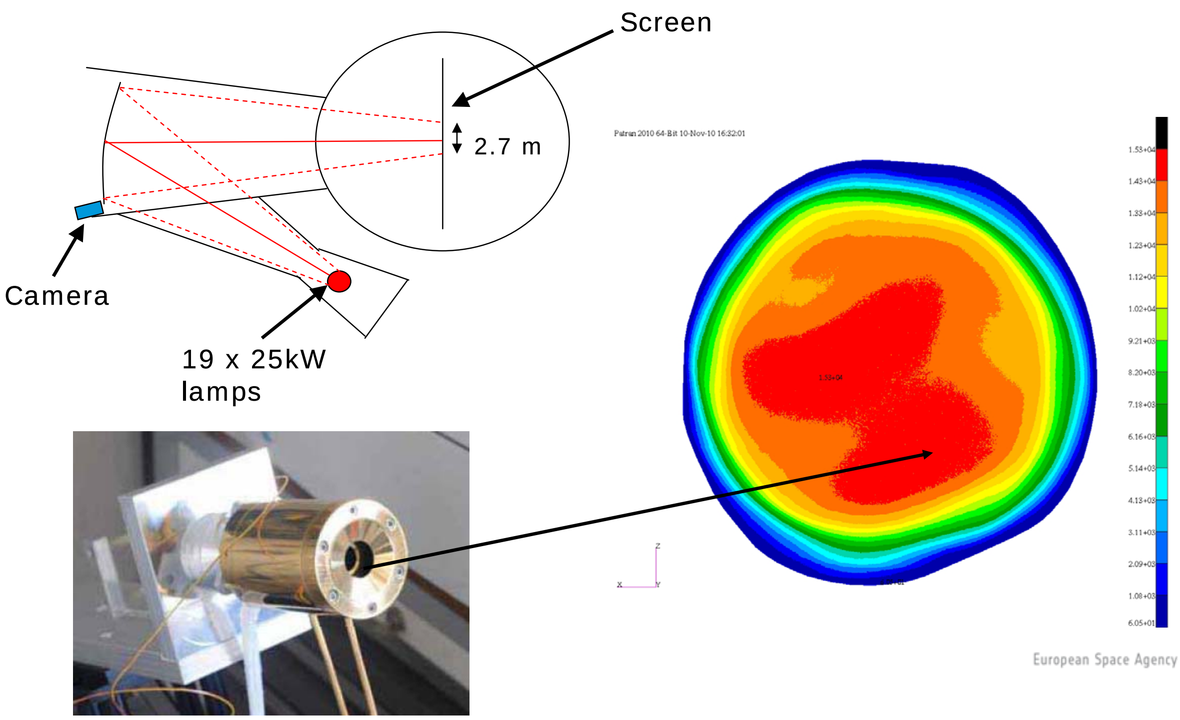
Measurement of Beam Intensity (1)



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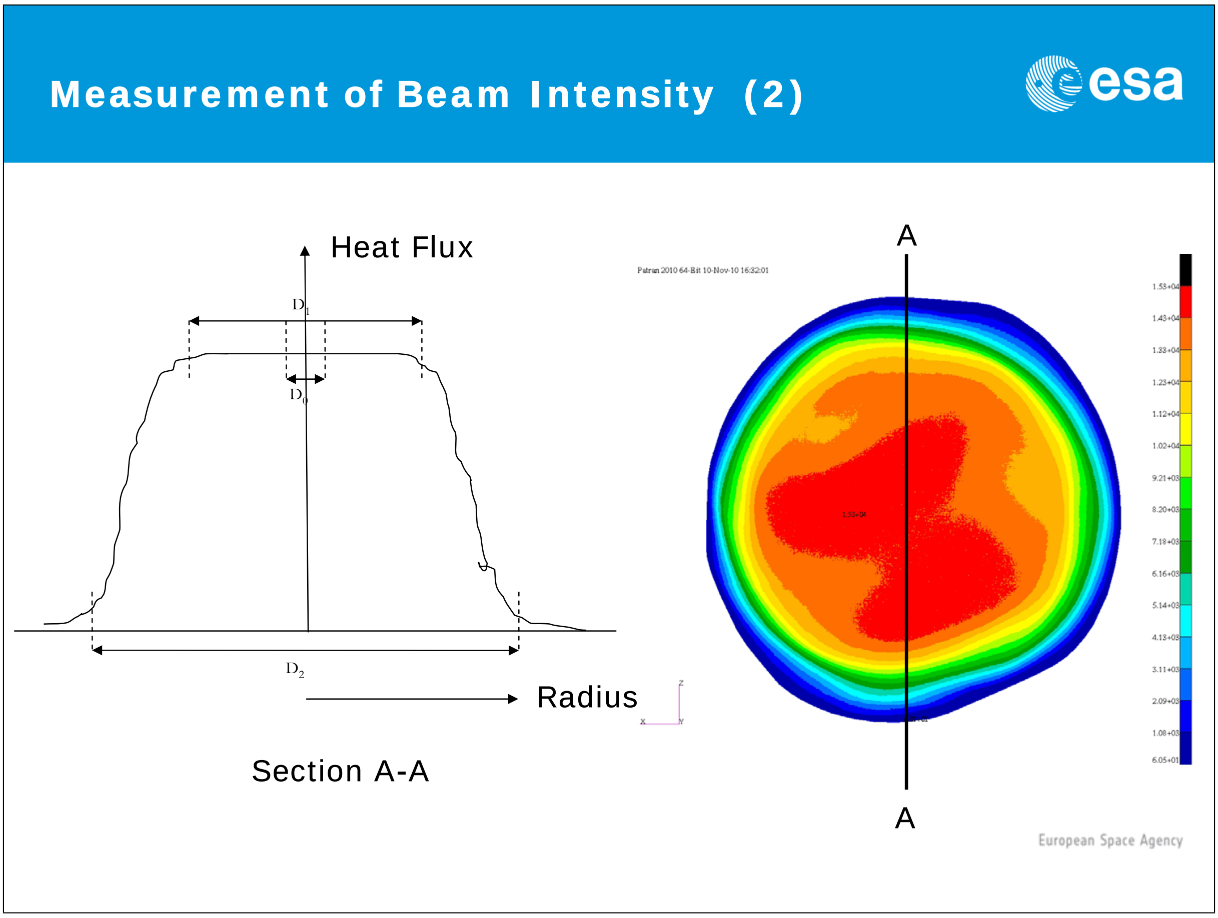
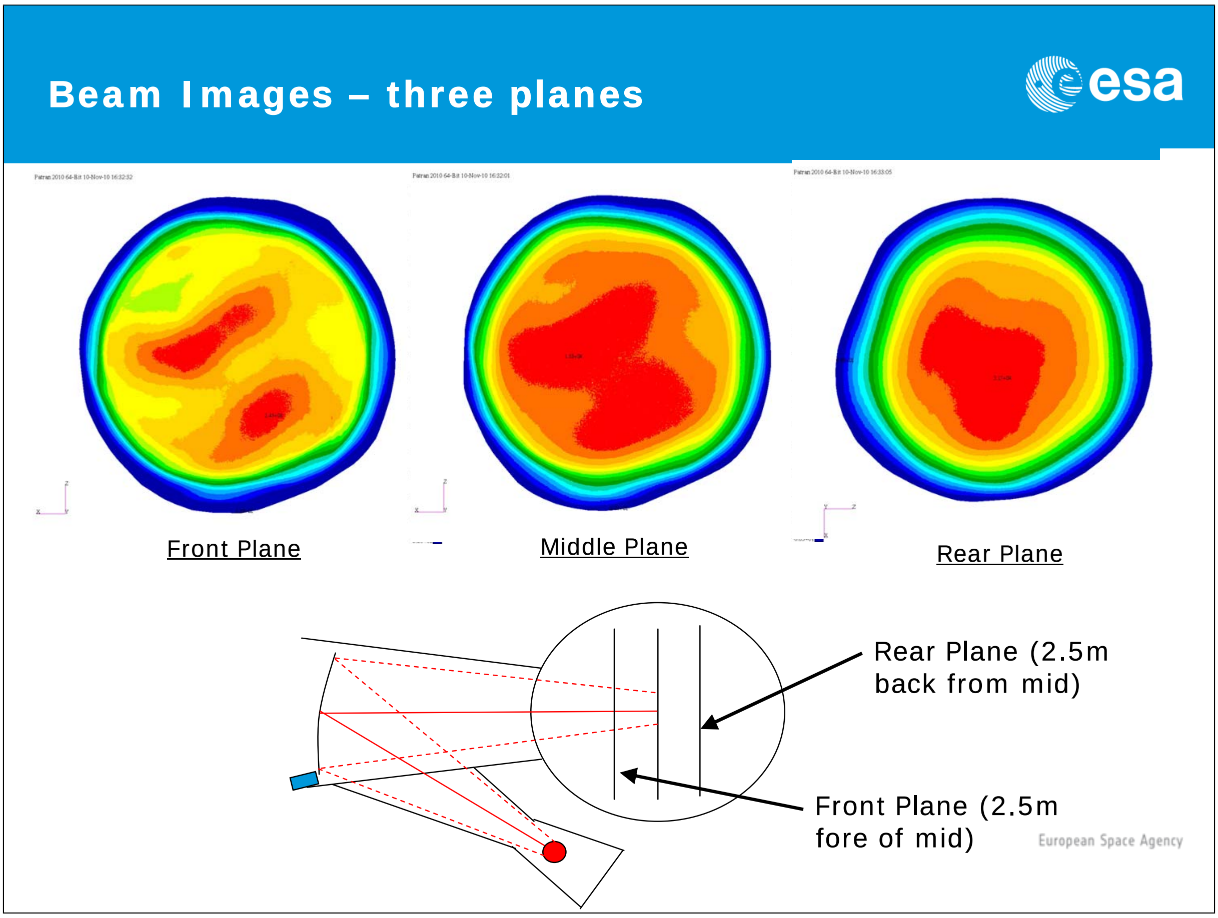

Measurement of Beam Intensity (2)
esa
Heat Flux
D1
D0
D2
Radius
Section A-A
A
A
European Space Agency


Beam Images – three planes
esa
Front Plane
Middle Plane
Rear Plane
Rear Plane (2.5m back from mid)
Front Plane (2.5m fore of mid)
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Modelling of the Beam in ESATAN-TMS Radiative

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Requirements

- To correctly model the beam the following characteristics must be correctly represented
  a. Conical shape of the beam with correct convergence angle
  b. Correct beam intensity (10 SC close to the centre)
  c. Beam edge drop off

Modelling Approach

- Builds on previous work in Astrium (D), ESTEC
- To achieve the requirements above the following methods are used:
  a. Parabolic reflector to converge light rays
  b. Edge drop off modelled using a semi-transparent filter
  c. Flux level tuned using solar flux override

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Modelling Beam Convergence with Parabolic Reflector (1)

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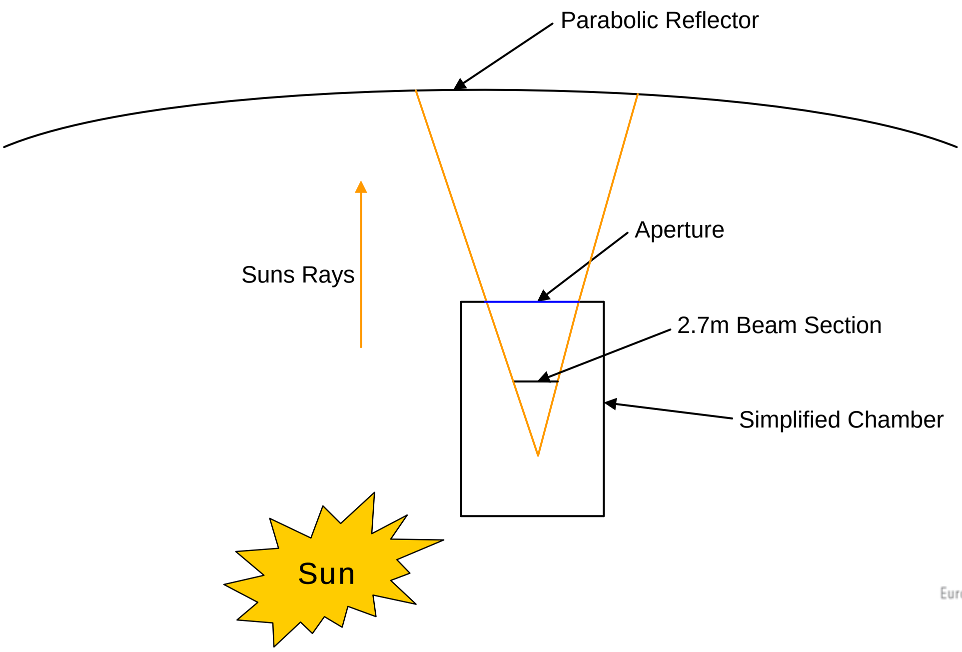

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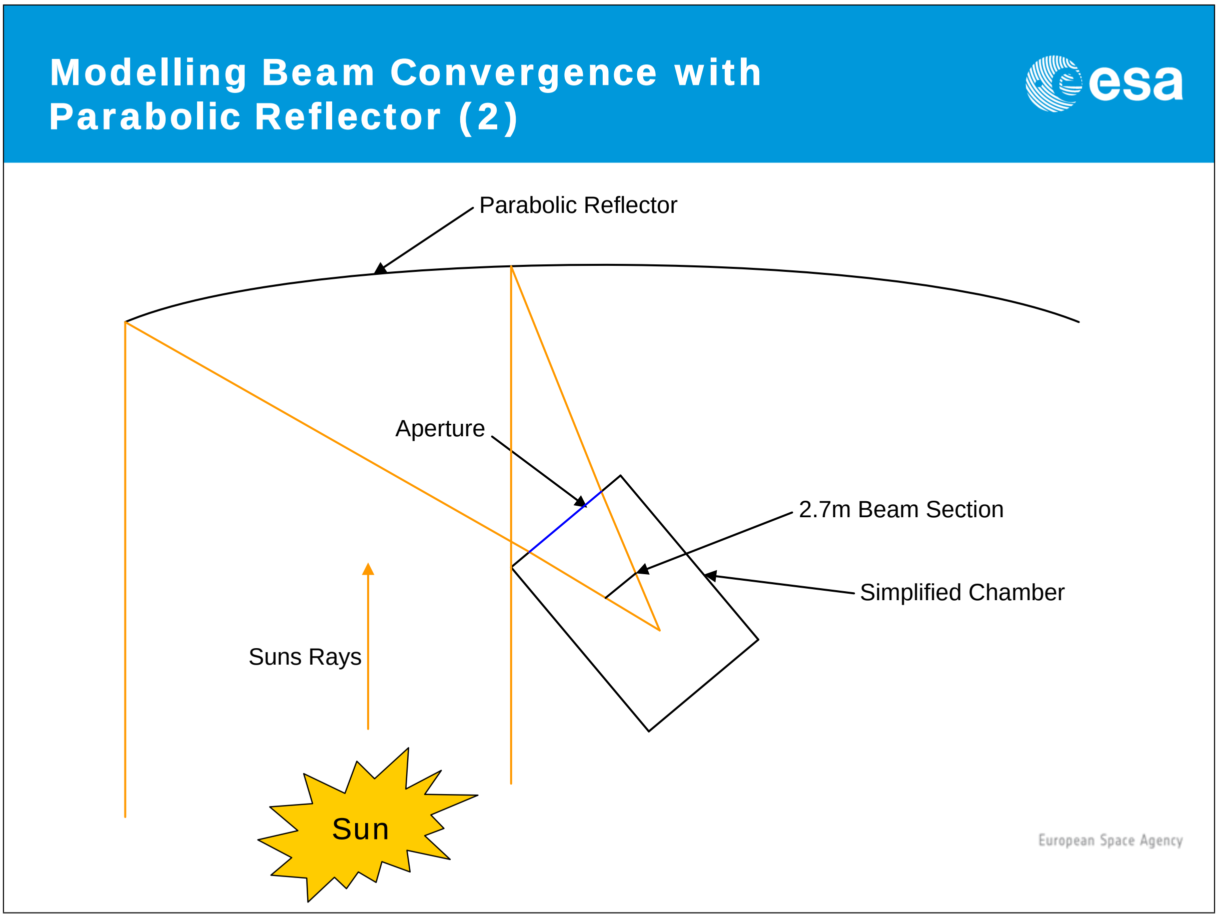
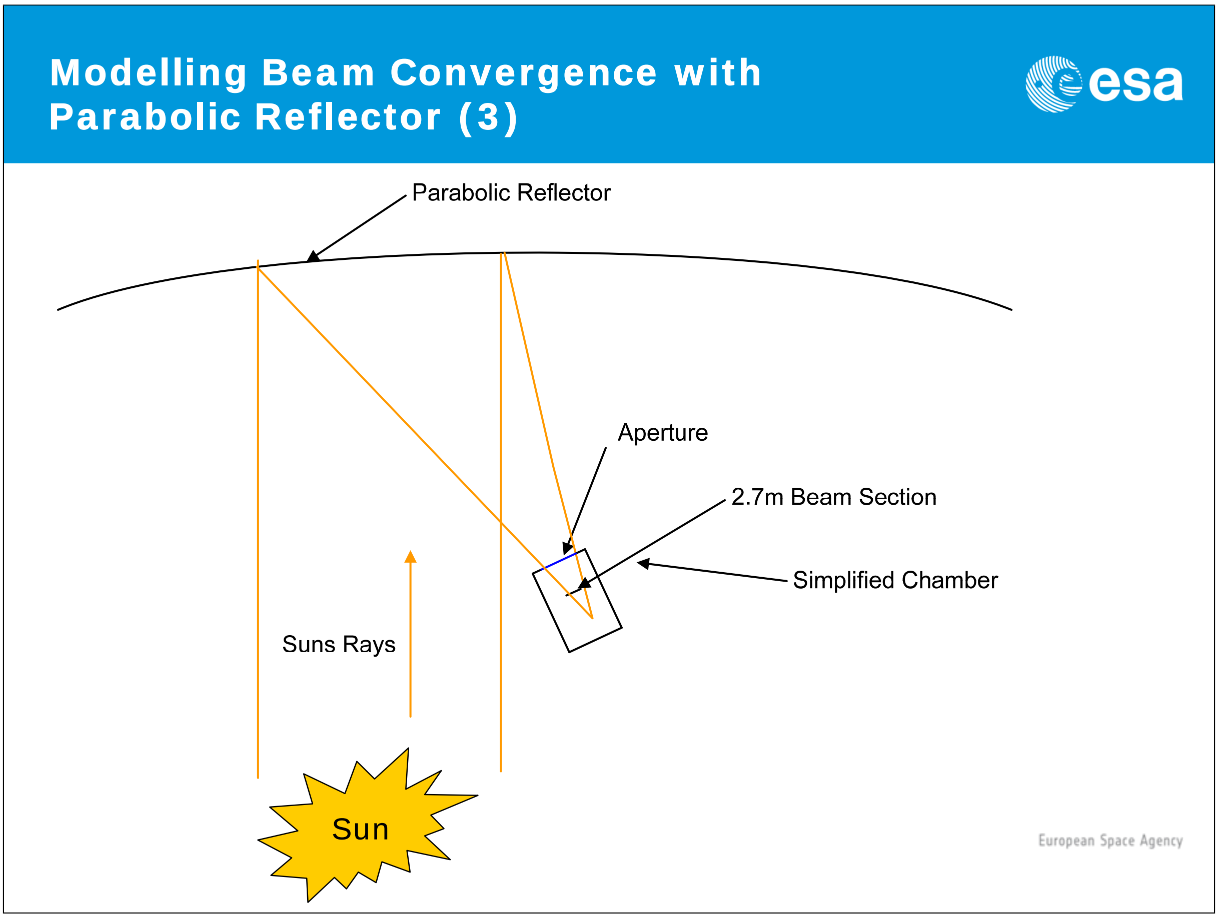
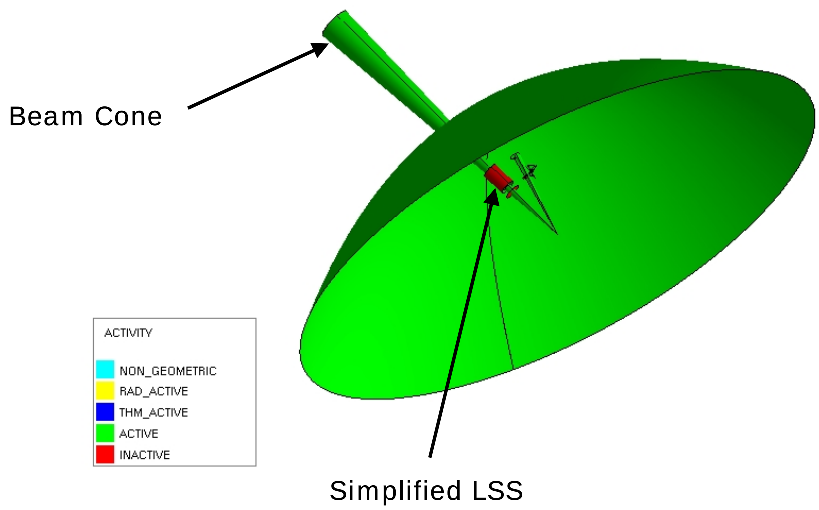

Modelling Beam Convergence with Parabolic Reflector (2)
esa
Parabolic Reflector
Aperture
2.7m Beam Section
Simplified Chamber
Suns Rays
Sun
European Space Agency


Modelling Beam Convergence with Parabolic Reflector (3)
esa
Parabolic Reflector
Aperture
2.7m Beam Section
Simplified Chamber
Suns Rays
Sun
European Space Agency

Implementation in ESATAN-TMS Radiative (1)



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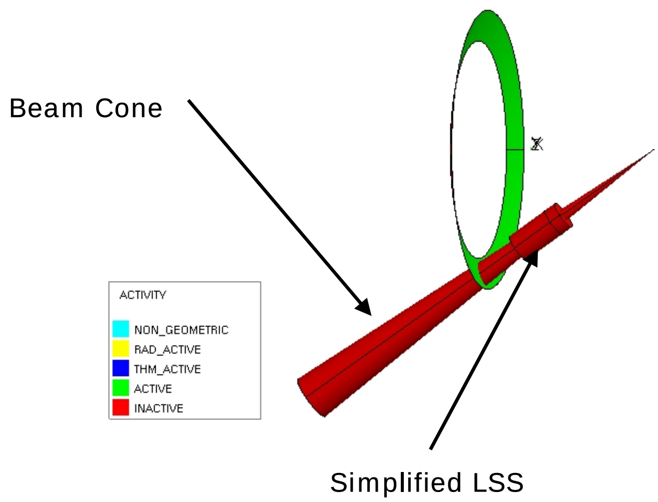
Implementation in ESATAN-TMS Radiative (2)



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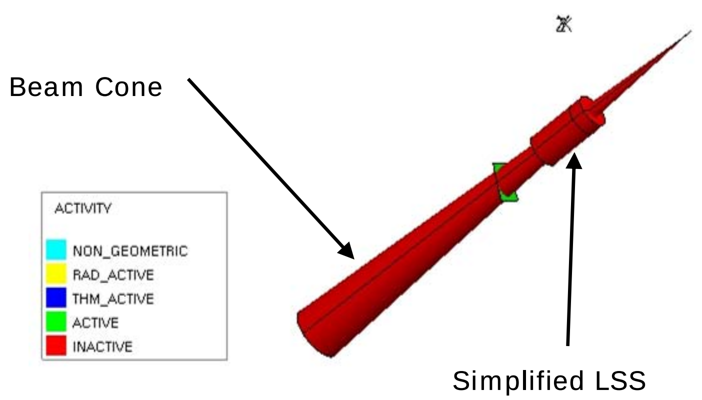
Implementation in ESATAN-TMS Radiative (3)



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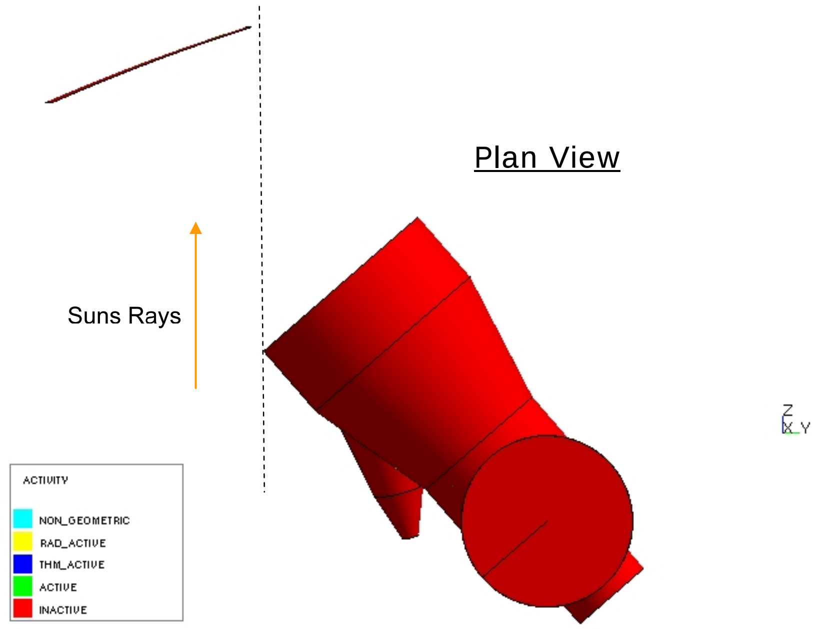
Implementation in ESATAN-TMS Radiative (4)



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Implementation in ESATAN-TMS Radiative (5)

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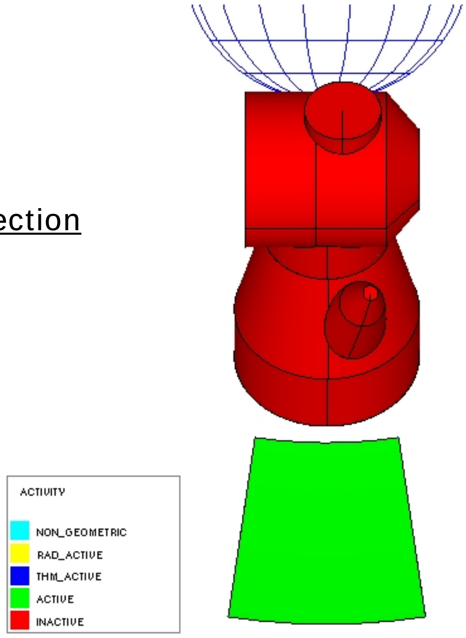
View from sun direction



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Model Verification Approach

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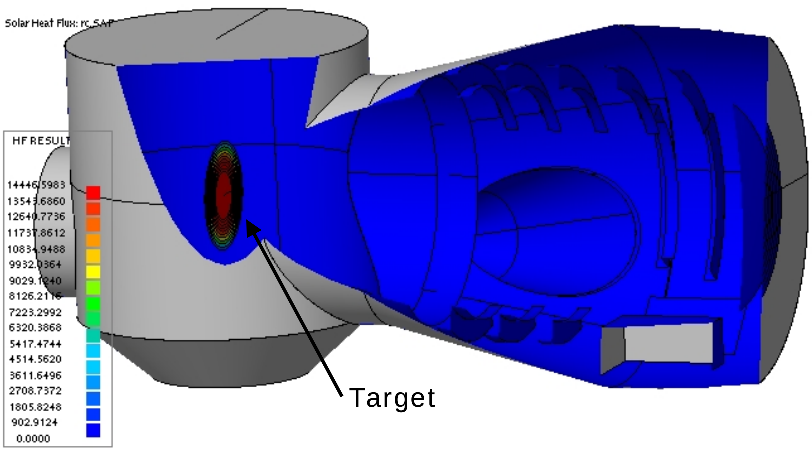
- Model verification using a black "target" inside the main chamber, in particular:
    - Sensitivity of results to number of rays fired (MCRT statistics)
    - Effect of reflector distance / size
    - Effect of reflector asymmetry



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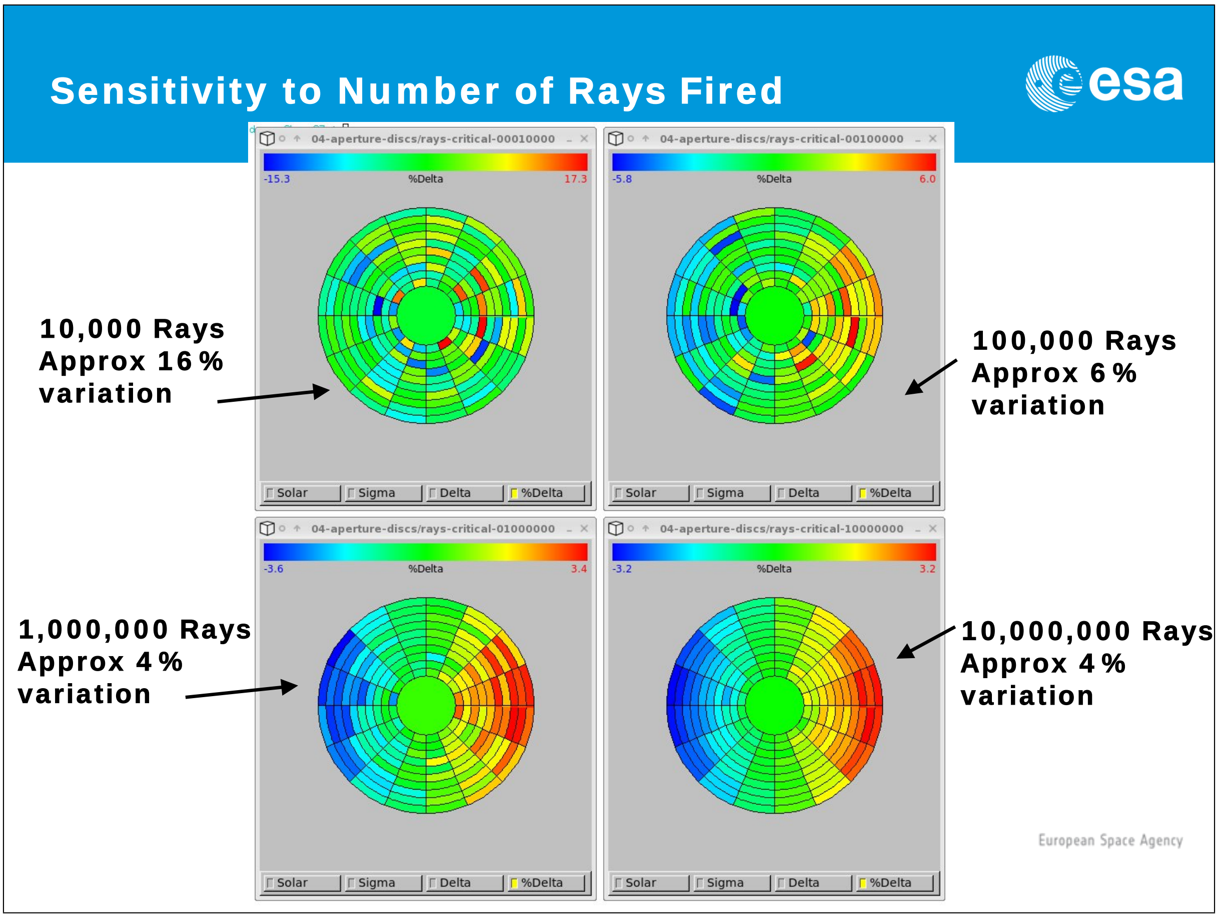
Sensitivity to Number of Rays Fired
esa
04-aperture-discs/rays-critical-00010000
-15.3
%Delta
17.3
04-aperture-discs/rays-critical-00100000
-5.8
%Delta
6.0
04-aperture-discs/rays-critical-01000000
-3.6
%Delta
3.4
04-aperture-discs/rays-critical-10000000
-3.2
%Delta
3.2
Solar Sigma Delta %Delta
10,000 Rays
Approx 16%
variation
100,000 Rays
Approx 6%
variation
1,000,000 Rays
Approx 4%
variation
10,000,000 Rays
Approx 4%
variation
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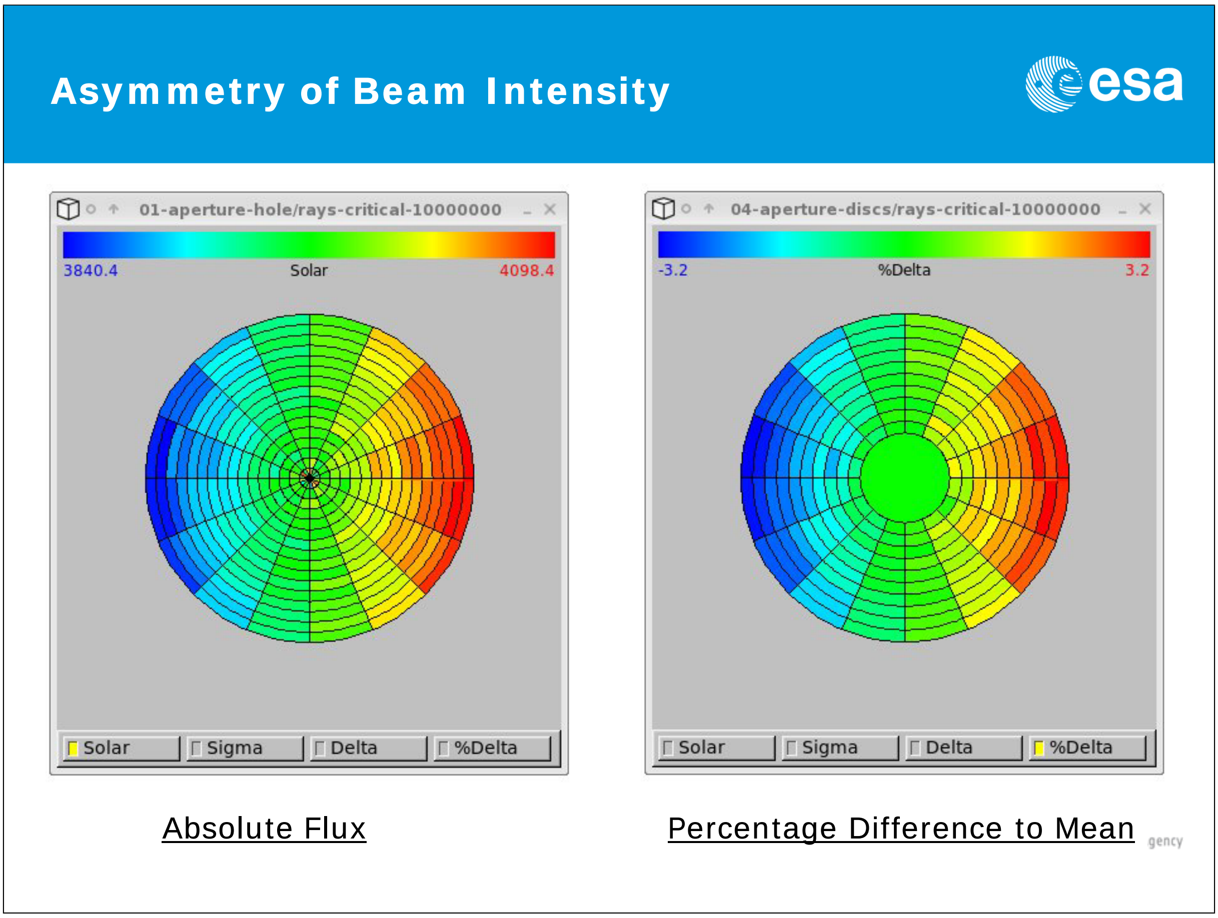
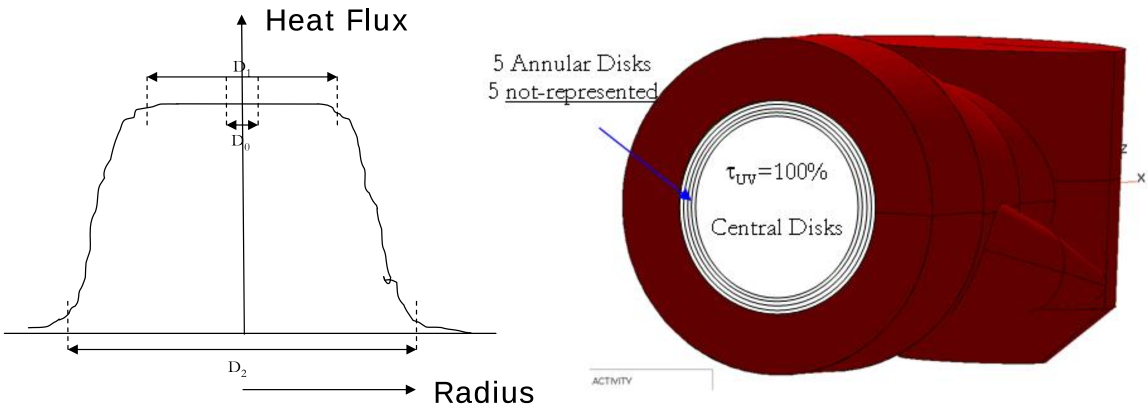

Asymmetry of Beam Intensity
esa
01-aperture-hole/rays-critical-10000000
3840.4
Solar
4098.4
Solar Sigma Delta %Delta
04-aperture-discs/rays-critical-10000000
-3.2
%Delta
3.2
Solar Sigma Delta %Delta
Absolute Flux
Percentage Difference to Mean

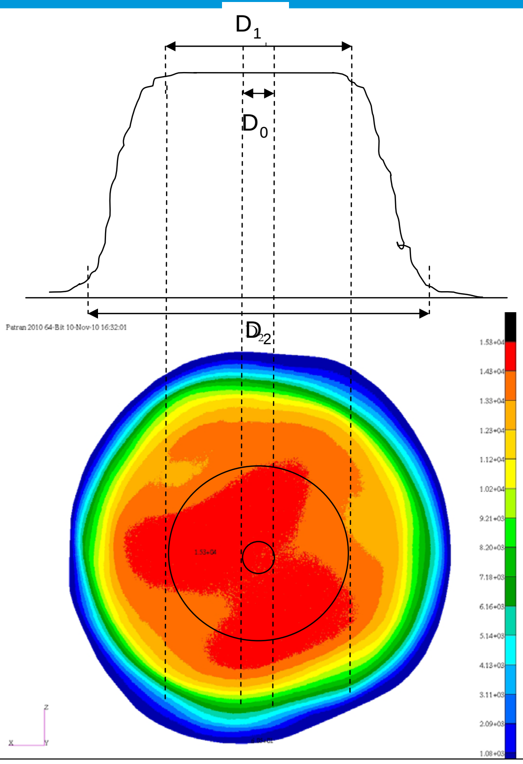
Tuning of Beam Intensity (1)

- Tuning of beam intensity and matching of "drop off" achieved using semi-transparent filter mask over aperture
  - Central disk surrounded by annuli
- Overall flux level tuned using solar flux override



View from Reflector

Tuning of Beam Intensity (2)



$$\int_0^{D_0} \Phi \frac{2\pi D}{4}\, dD = \Phi_{central} \frac{\pi D_0^2}{4}$$

D0 Definition – Reference Flux

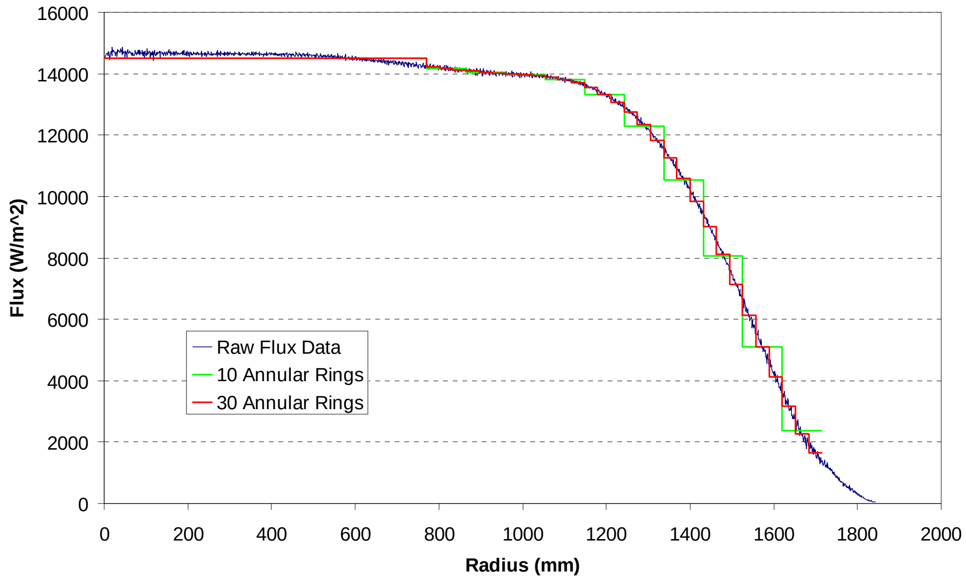
$$\int_0^{D_1} \Phi \frac{2\pi D}{4}\, dD = 0.99\, \Phi_{central} \frac{\pi D_1^2}{4}$$

D1 Definition – Central Flux

$$P_{tot} = \int_0^{D_2} \Phi \frac{2\pi D}{4}\, dD = 0.995 \int_0^{\infty} \Phi \frac{2\pi D}{4}\, dD$$

D2 Definition – Total Power

Tuning of Beam Intensity (3)



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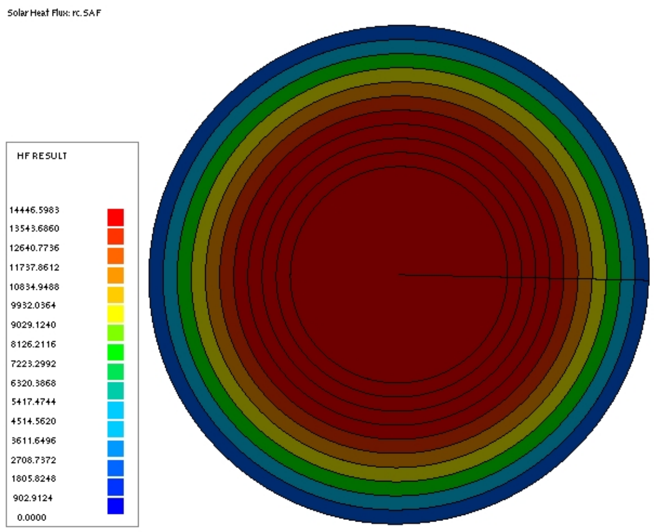
Tuning of Beam Intensity (4)

- Using partially transparent annuli the correct beam heat flux can be tuned for the middle plane
- Image below shows absorbed flux on the target
    - correct flux level obtained in centre
    - Drop-off effect is captured



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Conclusions and S/W Feature Requests

esa

Conclusions

- Modelling of beam convergence, intensity and drop-off has been achieved
- Correlation with measurement data is acceptable for middle plane
  - Some differences are expected with front/back plane
- Extensive sensitivity analysis was carried out to understand ray tracing effects
  - Model with S/C may be computationally demanding due to large number of rays required

S/W Feature Requests

- A lamp or similar entity would be useful – both IR and solar
- Refractive index for lensing could also have been used

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Appendix R

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