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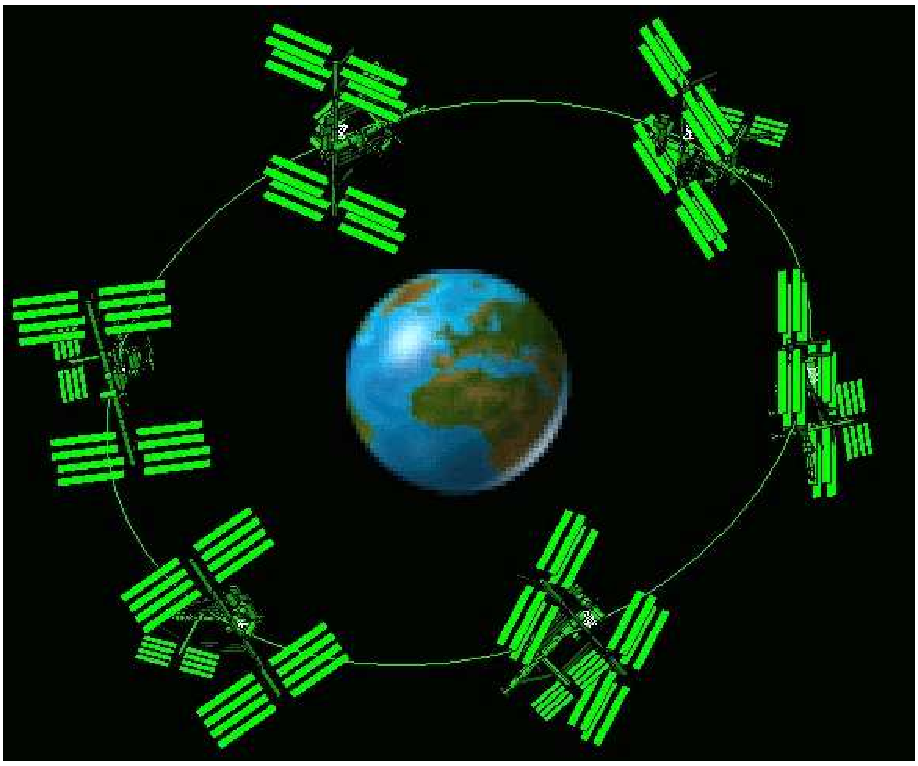

European Space Agency
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Abstract

This document contains the minutes of the 21st European Thermal and ECLS Software Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on the 30th and 31st October 2007. 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.

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Appendices

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21st European Workshop on Thermal and ECLS Software
ESTEC, Noordwijk, The Netherlands

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10:15	**Parallel thermal analysis with Linux clusters** Duncan Gibson, ESA/ESTEC, Netherlands
10:45	**GAETAN V5** : a Global Analysis Environment for Thermal Analysis Network Hélène Pasquier, CNES, France
11:15	**Coffee break**
11:45	**ESARAD radiative analyser** : Development status Julian Thomas, ALSTOM, UK
12:15	**Alstom Thermal Analysis Suite** Julian Thomas, ALSTOM, UK
13:00	**Lunch**
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09:00	**Thermo-elastic analysis of the LISA Pathfinder spacecraft** James Etchells, ESA/ESTEC, Netherlands
09:30	**Thermal design and analysis of the FMOS IR Camera** Allan Dowell, Rutherford Appleton Laboratory, UK
10:00	**Thermal Analysis for Re-Entry Vehicles** : Software needs and expectations Savino De Palo, Thales Alenia Space, Italy
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11:30	**Thermal Concept Design Tool Software** Matteo Gorlani, Blue Engineering, Italy
12:00	**ESATAP** : Handling large thermal results data with HDF5 François Brunetti, Dorea, France
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13:00	**Closure** Harrie Rooijackers, ESA/ESTEC, Netherlands

Day 1

Tuesday 30th October 2007

1.1 Welcome and introduction

H. Rooijackers (ESA/ESTEC) welcomed all of the participants to the workshop. He explained the main goals of the workshop were to provide a forum for discussion between the users and the developers, for the developers to present advances in the tools, and for the presentation of new methodologies. (See appendix A)

1.2 Parallel thermal analysis with Linux clusters

D. Gibson (ESA/ESTEC) explained that the improvements in speed of both hardware and software were matched by the growth in complexity of thermal analysis models, and that new ways were needed to improve analysis throughput. He described the key points in the evolution of the hardware and software environment provided by the Analysis and Verification section for the thermal engineers in ESTEC that had led to the creation of a Linux cluster. He emphasised that although some level of parallel thermal analysis was available to everyone, the developers needed to provide more support to make it easier to use for an individual analysis case, and managers needed to start planning deployment and usage policy for competing analysis campaigns. (See appendix B[1])
U. Rauscher (Astrium GmbH) asked how the ESARAD parallel facility was used, and how all of the parallel results were merged at the end. D. Gibson explained that the user first created or loaded a radiative case into the ESARAD GUI. Under the Radiative Case menu there was an option to Save Analysis Files. On the dialog box that popped up, there was a Multiple Files option. If the user selected this option, ESARAD would save the calculations for the different overall orientations at the different orbit positions into separate batch files. It was then the user's responsibility how to run these batch files on the different remote machines. D. Gibson had written a shell script that first ran all of the VREF calculations on a list of remote machines, and then the HF calculations. For each job to access the ESARAD geometry and database, all of the jobs ran in a single directory that was shared across the network, and were synchronised using lock files created in the directory. As a result, there was no need to merge anything afterwards because each job had simply updated the central database.
O. Pin (ESA/ESTEC) stressed that it was ESA's role to support the European Thermal Community and to help maintain its competitiveness. He foresaw that parallel computing would become

[1] There was sufficient interest in the break to include the speaker's notes next to the slides.

important for industry because of the need to handle the continuing increase in model and mission complexity, and that Linux clusters could provide a favourable performance to cost ratio. The transfer of knowledge given in this presentation was important for both developers and users. To develop for, or to create, a cluster would require planning, investment, and people.
K. Caire (Thales Alenia Space) asked whether special scripts had been needed to merge the data from the multiple analysis case runs to enable post-processing. D. Gibson said that scripts had only been written to provide the framework to run each series of parametric cases. It had been left to the user to merge and extract the data that he required.
M. Huchler (EADS Astrium) asked how to handle the problem of multiple users running jobs. D. Gibson said that the queue management system allowed the configuration of the total number of active jobs, number of active jobs per user, and priority of particular jobs or users. Ultimately it was down to management to provide planning and define policy about which analysis campaigns had priority, just as it was at the moment.

1.3 New technology for modelling and solving radiative heat transfer using TMG

K. Duffy (MAYA) was unable to attend the workshop at the last moment, so there was no presentation, but his slides are included in the proceedings. Two new facilities are described: frequency dependent optical properties, which are important in cryogenic applications; and the parallelization of viewfactor calculations across multiple processors. (See appendix C)

1.4 GAETAN V5: a Global Analysis Environment for Thermal Analysis Network

H. Pasquier (CNES) presented the overall design case data hierarchy of `GAETAN`, and then demonstrated the new user interface for defining these cases. She then described the new `CONDOR` and `GENETIK` modules. (See appendix D)
E. Overbosch (Dutch Space) said that sometimes when looking for the worst case, the worst case also depended on the time constant of the object being considered. A large satellite would have a large time constant, whereas solar arrays would have a fast response time. He asked whether `GAETAN` handled this. H. Pasquier said that this was not implemented. `GAETAN` only looked for the 'worst' steady state value and did not consider the inertia of the satellite.
U. Rauscher (Astrium GmbH) asked whether the `GENETIK` module used the couplings or the geometrical model. H. Pasquier answered that it worked with both the radiative and conductive models and could do all calculations throughout the orbit.
HP. de Koning (ESA/ESTEC) said that the comparison shown had involved eight variables. He asked about the run time for a complete scan with `CONDOR` and `GENETIK`. H. Pasquier said that the run time depended on the initial thermal model, but `GENETIK` took longer because `CONDOR` only involved a single parameter. HP. de Koning asked what would happen when running the same mission in both tools. H. Pasquier said that the computation would take longer with `GENETIK`, but she did not remember the exact differences in time.
F. Jouffroy (EADS Astrium) asked how many radiative cases were calculated typically, because this determined the sizing. H. Pasquier agreed, but didn't have the number in her head. She would look on the system and tell him afterwards.[2]

[2] After the presentation she confirmed that all of the transient variations over the complete orbit were taken into account, and not just steady state.

1.5 ESARAD radiative analyser - Development status

J. Thomas (ALSTOM) summarized the new ESARAD features that had been presented at the previous workshop and that had been released earlier in the year. He went on to describe the latest developments that would be available in ESARAD 6.2 that was planned for release in November. These features included: the creation and visualisation of non-geometric nodes and conductors, with boundary conditions; the improved analysis case interface; improved orbital ephemeris support and the import of external orbit data; the CAD interface for reading AP203 files, removing holes and features, and simplifying the mesh triangulation. (See appendix E)

R. Nadalini (Active Space Technologies) asked whether the imported orbit definitions needed to be Keplerian or whether they could be a set of vectors. J. Thomas said that they could be vectors, as shown in the example, and ESARAD extracted the positions.

Someone asked which publically available tool had been used for the triangulation of the imported STEP AP203 file. J. Thomas said that they had initially used a component of OpenCASCADE, but now used ExpressMesh, which was the professional version and which provided better meshing capabilities than the free open source version.

R. Patricio (Active Space Technologies) asked about the origin of the STEP AP203 files and whether the CAD interface handled all AP203 features. J. Thomas joked that like any standard, its interpretation was not standard. However, they had tested AP203 models coming from CATIA, UNIGRAPHICS, HyperMesh and PATRAN. The example model shown during the demonstration had come from CATIA.

R. Patricio asked whether the file had been produced via Baghera View. J. Thomas replied that the file had been taken directly from CATIA. He expected to find some cases that could not be translated, and that further work would be needed on the converter. He said that the converter was already useful now.

F. Jouffroy (EADS Astrium) asked whether the management of both geometrical and non-geometrical nodes in ESARAD meant the end of the ESATAN input file. J. Thomas said he could envisage a time when the user would no longer need to edit the ESATAN input file to be able to run a large proportion of typical analysis cases. However, there were certain use cases that were hard to foresee, so although they were trying hard to remove the need to edit the ESATAN text file, they did not want to remove the possibility of working with the text file completely. No tool could handle all use cases. He felt they could reach 95% of use cases, and they were handling more use cases with each release. For example, ESARAD now allowed specification of boundary conditions in the steady state, but did not yet allow boundary conditions for transient runs. J. Thomas said that, as noted in another presentation, ESARAD could now run ESATAN, so it was now possible to capture lots of things with a single ESARAD run and files.

J. Thomas then gave a demonstration of the new features. There were no further questions.

1.6 Guidelines for high accuracy thermal modelling. Experiences and results from ESA study: Improvement of thermal analysis accuracy

U. Rauscher (Astrium GmbH) summarized the critical design issues on the GAIA and LISA Pathfinder spacecraft and why high accuracy was required, and then described the findings of an ESA-funded study into different parts of the analysis chain. These included model pre-processing in ESATAN, the steady state and transient solvers, with a comparison against THERMISOL. He described the number of rays fired in ESARAD, and using the random number seed to demonstrate confidence in the results. (See appendix F)

P. Poinas (ESA/ESTEC) asked whether there had been any investigation into the number of rays fired in ESARAD in order to get accurate temperature results in ESATAN. U. Rauscher said that the study had looked at using different random number seeds and increasing the number of rays until consistent results were achieved. P. Poinas noted that U. Rauscher had said that the heat flow was more important so in that case why not use the GRs rather than looking at the temperatures. U. Rauscher answered that they did not have a rule that said they had to look at the temperatures, but agreed that if the GRs did not change then the temperature results should be the same.

HP. de Koning (ESA/ESTEC) wanted to make a point about using the random number seed for providing some level of confidence in the results. He had proposed a feature to allow multiple runs using different random number seeds, and then determine the standard deviation of the GRs produced. This would then give some idea of the accuracy without having to solve the whole temperature and heat imbalance chain to see how to get a reproducible result.

1.7 ESATAN Thermal Suite - Development status

C. Kirtley (ALSTOM) began with a summary of the current versions of the tools in the ESATAN Thermal Suite, namely FHTS, ThermXL and ThermNV. He went on to describe the developments and improvements that would be available in the release to be made immediately after the workshop. He stressed the importance of feedback from the users during the previous workshop and via the User Survey in shaping what had been included. New features in ESATAN 10.2 would include: thermal stability analysis routines; extensions to the Peltier element and PID controller; and improved output of the thermal model data and GFF results data. New features in ThermXL 4.6 would include: compatibility with Windows Vista and Office 2007; integration with new features of ESARAD 6.2; and built-in thermostat and PID controller modelling. (See appendix G)

H. Brouquet (ALSTOM) would describe the latest version of ThermNV during a later presentation.

K. Caire (Thales Alenia Space) wanted to know whether the new versions would address some of the problems described in the previous "high accuracy" presentation, because she had also experienced similar problems. She had a model with refined meshing on specific parts which then led to large and small nodes with very small conductors between them, which then gave rise to problems with relaxation. C. Kirtley agreed that dissimilar nodes, where one was very large or very small, could clearly lead to numerical problems, but he said that it was difficult to comment without looking at the model.

U. Rauscher (Astrium GmbH) asked about the thermal stability example where SOLVIT had been called before the stability solver [SLFRTF]. Was there any linearisation of the system and how did the results compare to those shown during the Astrium presentation? C. Kirtley said that the system was linearised because moving away from a linear system could lead to stability problems. The validation had involved long transient runs and watching the response of the system. This would be discussed in detail during the following presentation.

U. Rauscher asked whether there were any guidelines on when to use the solver. J. Strutt (ALSTOM) said that the solver used a linearised method so there were some limits on the accuracy, but to give precise limits would be impossible. The accuracy would depend on the model. If it was a linear model, or a radiative model with no temperature variation then the guidelines for linearisation would be that temperature variation should be much less than $\frac{2}{3}T_e$ (where T_e was the equilibrium temperature field used for the linearisation). If the model had a higher value, then it would be outside the linearisation. C. Kirtley asked whether there were any guidelines. J. Strutt repeated that it was not really possible to give fixed guidelines because they were so strongly related to the model, relaxation criteria, etc.

1.8 LISA Pathfinder thermal stability analysis

D. Fertin (ESA/ESTEC) presented the mission requirements and the need to be able to demonstrate that the 'noise' produced during analysis would be within acceptable levels and would not swamp the stringent thermal variation requirements during flight. He described the concept of a power density spectrum using a simple thermal filter model, and how this could be derived from ESATAN results. He then showed how the same technique could be applied to the LISA model. (See appendix H)
J. Etchells (ESA/ESTEC) commented that U. Rauscher (Astrium GmbH) had already raised the transfer function approach during his presentation. J. Etchells said that if you assumed a linearised system, then it would be possible to use superposition, but then there would be a loss of phase information. D. Fertin said that was why he had asked for a dump of all of the ESATAN matrices so that he could then calculate the state space matrices that handled phase. The result showed that although the FEEP CPU is the major source of the thermal disturbance, it was also related to the variations in other five power sources.

1.9 Thermal model correlation using Genetic Algorithms

F. Jouffroy (EADS Astrium) described why thermal model correlation against test data was difficult and presented details of a study to determine whether genetic algorithms could be used to optimise the process. He described how genetic algorithms worked and how they had investigated the effect of population size, and varying the effect of crossover and mutation to alter the model parameters during subsequent analyses. He described the effects using two test models. (See appendix I)
E. Overbosch (Dutch Space) asked how to handle the fact that in practice there might be a measurement error of 0.5°C for a thermocouple, but the correlation required only a 0.1°C variation, as given in the example. F. Jouffroy answered that it would always be possible to stop the genetic algorithm at an earlier point because the same level of accuracy was not needed. But the approach still needed further investigation.
E. Overbosch asked what happened if the stop criterion was a 2°C variation, but there were three families of solutions within the 2°C range, but with different parameters being changed (e.g. one with different optical properties, one with different heater power or thermostat settings). If there were three right answers, how was the "correct" parameter chosen? A given family of parent solutions could have clusters of potential parameter solutions that satisfied the correlation limits. F. Jouffroy said that it was necessary to limit the parameter solutions to those that had physical meaning within the system.
M. Gorlani (Blue Engineering) noted that the genetic algorithm approach had been compared with a random method, and wanted to know which one. F. Jouffroy said that they had simply run 4000 cases with random values for some of the parameters.
HP. de Koning (ESA/ESTEC) asked whether the genetic algorithm approach had been compared against methods used in existing stochastic tools, such as the hypercube, which had a mathematical basis for the optimisation. F. Jouffroy said that N. Durand (DSNA), his partner in the study, had discussed using the latin hypercube with J. Etchells (ESA/ESTEC), but further investigation was required.

1.10 SYSTEMA V4 - New framework for THERMICA

C. Theroude (Astrium Satellites) gave a brief overview of the history of the SYSTEMA framework, and described the philosophy behind the infrastructure where it was possible to construct a complex mission without a complete satellite geometry. He went on to demonstrate importing a CAD model and then constructing a simpler version of it by picking points from it, and then showed the mission visualisation and animation. (See appendix J)
There were no questions.

1.11 THERMICA Suite - Complete thermal analysis package

T. Soriano (Astrium Satellites) presented developments in THERMICA, THERMISOL and POSTHER, and their integration into SYSTEMA V4. He described the limitations of the current linear conductor generation algorithm in THERMICA, and announced that it would be replaced with a "Volume Element" approach. He also announced changes to the $VARIABLES blocks in THERMISOL in order to produce speed improvements in the solution routines: $VARIABLES1 would only contain temperature dependent code, and $VARIABLES2 would contain time dependent code. He then described the POSTHER post-processing tool. (See appendix K)
HP. de Koning (ESA/ESTEC) raised objections to the change in meaning of the $VARIABLES blocks. He said that $VARIABLES1 and $VARIABLES2 had established meanings in ESATAN and SINDA, and that they were known terms that everyone understood. He felt that it was dangerous to reuse such names for new functionality because it would become quite confusing in practice. T. Soriano agreed that it could be confusing, and had thought about it. However, unless the $VARIABLES2 block contained output routines, then the old way was compatible with the new way. The new way had the advantage of better accuracy and was faster. Provided there was no output in $VARIABLES2 then there would be no risk.
O. Pin (ESA/ESTEC) asked what would happen to time dependent data in an ESATAN model if it were run in THERMISOL. T. Soriano said that it would be the same as having the data in $VARIABLES2 but the interpolation would be called many times and would waste time, but if the time dependencies were isolated in $VARIABLES2 and the temperature dependencies in $VARIABLES1 then there would be speed improvements. O. Pin said that this had been available in ESATAN for years. H. Brouquet (ALSTOM) confirmed that this was what was recommended in ESATAN. T. Soriano disagreed because he believed that the Crank-Nicolson implementation was wrong. He said that using the median time for the interpolation was not optimum and was not true Crank-Nicolson. Proper Crank-Nicolson allowed automatic time-stepping and better time switching for thermostats and switching logic. The current implementation was adequate for small time-steps, but a better scheme was really needed for large time-steps. Currently the $VARIABLES1 and $VARIABLES2 blocks were not called at one specific moment in the solution.
O. Pin argued that this was new functionality, and should therefore be identified as such by using a new label, otherwise it would be confusing for users migrating models between ESATAN and THERMISOL. HP. de Koning agreed that developers had to be careful about overloading existing functionality. He gave the examples of SINDA and Cullimore and Ring's implementation of SINDA that introduced a $VARIABLES0 block for initial conditions. The changes made sense, but there was always the need to be careful with naming. T. Soriano said it was important to make the concepts consistent, but he could change the names before the release.
C. Kirtley (ALSTOM) said that the Crank-Nicolson implementation in ESATAN did not use the mean time: it called $VARIABLES1 at the start of the time-step and called it again at the end.

J. Strutt (ALSTOM) said that TIMEM was not the mean time. T. Soriano said that TIMEM was the time to be used for the flux evaluation so that the value would fit correctly, for example, if implemented using Runge-Kutta with four points, then TIMEM would switch from TIME0 to the required times at the extra points. Crank-Nicolson was known to simulate from TIME0 to TIMEN. J. Thomas (ALSTOM) disagreed, but said that there should be further discussions after the presentation. *[See clarifications below]*

S. Price (Astrium UK) asked whether this version of THERMISOL was currently in use in Astrium Toulouse. T. Soriano said it was not yet available, but would be part of the THERMICA 4.2 release. S. Price submitted that everyone else was still using the correct definitions of $VARIABLES1 and $VARIABLES2, and that if an ESATAN model were converted to THERMISOL there would no problems with the current version, but there would be with THERMICA 4.2. T. Soriano responded that there would be no problems in 4.2 provided that no output was being done in $VARIABLES2. S. Price concluded that users would be obliged to change their existing models.

H. Rooijackers (ESA/ESTEC) brought T. Soriano back to the slide showing linear conductor calculations using the triangle example. He asked whether the triangle was a reduced integration element. If so, it was not the correct element to use for the analysis shown because it was not a linear element. T. Soriano replied that it was possible to assume a linear temperature profile internally. H. Rooijackers said that the derivation was inherently incorrect because it involved making a 2D solution from a 1D element. T. Soriano admitted that this was why the old linear conductance algorithm had problems where plugging the triangles together resulted in an error. The formula $\frac{\lambda}{l}E$ applied to 1D elements, but was now being applied to 2D elements and this introduced errors, as had been shown in the example with the square. H. Rooijackers argued that it introduced errors because the element was linear and the configuration shown could never result in a correct solution. It was not possible to link the mid-side temperatures in this way. T. Soriano argued that the approach was described in the documentation of IDEAS/TMG. H. Rooijackers said that in a finite element system this would be correct. It was possible to map from the 2D to the 1D case, but not vice versa without using the element shape functions. He said that he did not know enough about the workings of TMG to be able to judge the details of the approach, but felt that such usage in TMG could not be correct. HP. de Koning explained that TMG did use a finite element mesh, but not the finite element forumulation in the solver, rather a finite volume approach that is close to the (linear) lumped parameter approach. He said that the idea of a finite volume mesh was like that used in CFD to calculate the mass flow through the volume element boundaries. T. Soriano argued that by using a linear temperature profile, the much more strict method was more suitable for calculating the conductive links.

Clarifications

The following is a clarification provided by Alstom Aerospace after the workshop regarding the handling of the time variables by the two Crank Nicolson solvers within ESATAN:

> *Since release 8.9 (2003), ESATAN has included a Crank-Nicolson solver called SLCRNC. In this solver, $VARIABLES1 is evaluated at the beginning of the time step with TIMEM = TIME0 = t(n) and then again at the end of the time-step, during iterations, with TIMEM = TIMEN = t(n+1). Thus, quantities in $VARIABLES1 are evaluated at both t(n) and t(n+1). Time-dependent interpolations, etc. should use TIMEM for this reason. For SLCRNC, TIMEM is not therefore the mean time, and Crank-Nicolson is followed without needing to change in meaning of $VARIABLES1 or $VARIABLES2.*

> *`SLFWBK` implements a variation of Crank-Nicolson in which it is assumed that all conductances, capacitances and heat loads are constant over the time step. `TIMEM` is set to the mean time over the time step, but is not directly addressed by the solver. This variable should be used in time-dependent evaluations according to the approximation* $0.5(\Phi(n) + \Phi(n+1)) \approx \Phi(0.5(t(n) + t(n+1)))$.

After the workshop T. Soriano sent a follow-up e-mail that contained clarifications to the initial draft of this document for ESA, and further technical discussion with Alstom about Crank-Nicolson solvers. Concerning the proposed changes in `THERMISOL` he concluded:

> *I understand this matter goes very deep in the Crank-Nicolson scheme but I believe that it can help having a better convergence and also faster. Keeping the "classical" way of modelling using the `$VARIABLES1` and `$VARIABLES2` is not wrong. I am just saying we can do better.*

Day 2

Wednesday 31st October 2007

2.1 Thermo-elastic analysis of the LISA Pathfinder spacecraft

J. Etchells (ESA/ESTEC) presented the challenges involved in a shadow engineering activity to verify that the thermal variation requirements for LISA Pathfinder could be met. The first problem involved bringing the different structural and thermal models written using different tools up to the same reference baseline. Then there was the issue of the lack of convergence in the model because of the isolation of the test masses from the rest of the thermal network, and which was solved by introducing linear conductors during an initial steady state calculation and by subsequently disabling these couplings. Problems with temperature drift during the transient solution were investigated using `EcosimPro`. The final stage was mapping the resulting temperatures from the thermal to the structural models by calculating overlay data using `TASverter` and `SINAS`. He gave a quick demonstration of how this could be achieved for a small model of an instrument mounted on a panel. (See appendix L)
M. Gorlani (Blue Engineering) asked about `SINAS` and whether a direct link to `PATRAN` was available. J. Etchells said that a `PATRAN` PCL-library add-on for `SINAS` was available for Windows via the Exchange web site[1], although the version shown during the demonstration had been from ESTEC's Linux development version.

2.2 Thermal design and analysis of the FMOS IR Camera

A. Dowell (RAL) presented the design and modelling of a ground-based infra-red camera that would form part of a spectrograph coupled to an 8m telescope in Hawaii. He described the main aspects of the construction, and how these had been modelled in `ESARAD`, including the problems encountered when modelling the parabolic lens assemblies and how this had been handled in `ESATAN`. (See appendix M)
HP. de Koning (ESA/ESTEC) asked whether it would have made the thermal design easier if it had been possible to model refraction in the `ESARAD` ray tracing code. A. Dowell agreed that it would have made it simpler, but in reality the heat load through the lenses did not contribute much compared to the parasitic loads through the cryocooler. He said that the camera was ground-based, and admitted that if it had been space-based then modelling the ray tracing through the lenses would be important because even small heat loads could be significant.

[1] http://exchange.esa.int/restricted/sinas

2.3 Thermal analysis for re-entry vehicles - Software needs and expectations

S. de Palo (Thales Alenia Space) presented two study cases for re-entry vehicles that required using more than the standard ESARAD and ESATAN type analysis. The first involved a semi-real time thermal control monitoring system that interfaced to MATLAB/Simulink. The second involved integrating multi-physics models, with the specific example of using FHTS to model water cooling pipes in the leading edge of a wing section during re-entry. (See appendix N)
M. Huchler (EADS Astrium) asked whether the thermal mathematical model was maintained in Simulink in the first example. S. de Palo said that Simulink was used as the equation solver. He had not needed a linear system. The problem had been how to translate the capacity matrix into Simulink, and also the radiative and linear conductor matrices. It would have been better if there had been a direct method of extracting the information from ESARAD and ESATAN into Simulink. M. Huchler asked whether radiative heat exchange had been included. S. de Palo said that if they considered passive cooling then they only needed to handle radiation for the heat rejection. However, if they wanted to have an accurate model then they would need to consider radiative exchange, but he did not think it was fast enough to be able to make a linearisation for several time-steps in real time. He had not needed to consider radiative heat exchange so he was able to use linearisation in this case.
J. Etchells (ESA/ESTEC) said that it would be possible to use EcosimPro and create a thermal model similar to that used in ESARAD and ESATAN and then create C++ classes and objects which could be wrapped in Simulink. S. de Palo said that it would have been possible, but he had not wanted to be tied to any particular topology because it was difficult to update. He admitted that EcosimPro could be useful.
J. Persson (ESA/ESTEC) asked why EcosimPro had not been considered. S. de Palo said that partly because the study had been an exercise, and also because he did not want to be forced to create schematic layouts of all nodes and conductors. He felt that it would be better to use a smart method that involved matrices that could be generated automatically. He did not want to add an extra step into the modelling process.
J. Etchells asked about the second example study, of the wing section, and how the cooling ducts had been modelled in ANSYS. S. de Palo said that the ducts had been modelled as boundary nodes, and he had then created a less detailed model in FHTS to provide the boundary data. ANSYS could perform both CAD with a lumped-parameter-like approach for the fluidic problems inside. He said that there was someone trying to do something similar with Thermal Desktop for the fluidic part within a PATRAN model.

2.4 Use of ThermXL for rapid evolution of ExoMars rover vehicle design

A. Quinn (Astrium UK) presented the background for the ExoMars rover design and the reasons for the decision to use ThermXL for investigating the thermal response of the initial design. He described how the original requirements were not as established as he had at first thought, resulting in a lot of redesign of the geometry, and also changes to the landing dates and hence thermal environment. He highlighted the strengths of ThermXL for simple models, and explained the difficulties of maintaining a single analysis file relating to multiple analysis cases, the lack of a thermostat element and problems exporting the logic for a thermostat into the ESATAN model. (See appendix O)

C. Kirtley (ALSTOM) asked whether the use of ESARAD had been considered. ESARAD analysis cases could have been used for the separate mission cases. A. Quinn said that he had not considered it. It might have been possible, but he thought that some parts of the network could not be modelled in ESARAD, so ThermXL would still have been needed.
R. Nadalini (Active Space Technologies) had noted the difficulties trying to handle multiple cases within a single analysis file, and the problems with nested IF states, and asked whether any macros had been used. A. Quinn said that they had used Visual Basic, which had simplified some parts, but it really depended on what you were trying to do, and they had still had some problems. R. Nadalini suggested that it would be possible to have a single model sheet with a switch or button that called the appropriate logic. A. Quinn agreed, but said that there was always the question of knowing when it was appropriate to move on and convert the model to a more complex tool. They had expected to be doing a “simple” analysis and had chosen ThermXL for that reason.
B. Shaughnessy (RAL) asked about the ranges of latitude and the seasons for the landing sites. A. Quinn said that they had considered a range between 45°N and 15°S and the mission included contingency cases between LS0 and LS180, i.e. from equinox to equinox.
J. Etchells (ESA/ESTEC) asked about the effect of the Martian atmosphere and how they had handled the attenuation of the solar fluxes. A. Quinn said that they had used information from the European Martian Database to get the correct optical depth, but they had found some limitations. They were now looking at different interpolation strategies.
H. Rooijackers (ESA/ESTEC) suggested that for configuration control they might be interested to know that there was now a Subversion plug-in for Microsoft Office.

2.5 Thermal Concept Design Tool

M. Gorlani (Blue Engineering) presented a brief summary of the development phase of the TCDT and an overview of the functionality. He went on to describe the TCDT web site that had been established for registration for use and download of the software, problem reporting, etc. He explained what was available in the TCDT download package and for which platforms it was intended. (See appendix P)
U. Rauscher (Astrium GmbH) asked whether it would be possible to have a summary of the features. He felt that the presentation had been a bit short. Was there a limit to the size of model for instance? M. Gorlani replied that there had been a full demonstration of the TCDT at the previous year’s workshop, so he had not wanted to go into too much detail. The TCDT allowed the user to build a full geometrical mathematical model by defining surfaces in the graphical user interface and providing dimensions, number of nodes, meshing details and thermal node numbers and then assigning thermo-optical properties. When the surface is added to the database it is also added to the Excel worksheet. All parts of the GMM could be visualised using the 3D viewer available in the Excel environment. The GMM could be exported as an ESARAD model. The user could then define an orbit. The logic of the orbit construction in the GUI was similar to geometry construction. The orbit parameters were similar to what was available in ESARAD. When the orbit was saved to the database it was also downloaded to an orbit worksheet and could be checked with a 3D orbit viewer. It was possible to define multiple orbits for different cases. The user could create a thermal mathematical model from the GMM via a worksheet, and all data would be available in the ESATAN $NODES block.
U. Rauscher wanted to know whether the TCDT could run ESARAD on the file that it had created. M. Gorlani said that the Thermal Simulation Manager within TCDT could be used to start the calculation on either the local or a remote machine. He said that the user could perform high level

analysis using the TCDT. He suggested that it would probably be better for users to download the TCDT for themselves because it contained a lot of functionality and they could then see what was available.

M. Gorlani said that the TCDT also handle parametric analysis and was able to launch external cases. The user needed to define the parametric cases within a worksheet and ask the TCDT to vary the parameter within limits. The user could then get a matrix of test cases. If the Native mode had been chosen in the Thermal Simulation Manager the user could run the cases using a stochastic approach with a Latin Hypercube. The user could also change the matrix as required and then launch the parametric cases.

R. Patricio (Active Space Technologies) asked for some clarification of the linear conductor calculations. Were they derived from a geometry built around STEP-TAS? M. Gorlani said that the linear conductors were calculated using a primitive grid using the surface information provided by the user in the worksheet. There was no possibility to import models into the TCDT but there was a facility to export the models in ESARAD and ESATAN format.

H. Pasquier (CNES) noted that there was a clear link from the TCDT to ESARAD and ESATAN. She wanted to know about the possibility of export to THERMICA and THERMISOL. M. Gorlani said that there had been no work in that area. O. Pin (ESA/ESTEC) explained that the history of the TCDT was to provide a tool specifically for the Concurrent Design Facility at ESA. The CDF infrastructure involved sharing data via Excel spreadsheets, and this was the reason why the TCDT was based on Excel. It had not been based on Excel to work with ThermXL as such, so the link to ThermXL was a bonus. The CDF used ESARAD and ESATAN, and this was why the TCDT exported to these formats. The tool had been developed explicitly with the CDF requirements in mind, so the decision to distribute the tool to the rest of the European thermal community was simply an added bonus. ESA had foreseen that there were unlikely to be many paying customers for this sort of tool, and had decided to make it available anyway. The maintenance budget that had been allocated would be insufficient to provide compatibility with other tools. This was simply not a priority for ESA and the CDF. If someone wanted to use the TCDT, then the tool was available to them, as is. Of course, if someone decided to provide direct funding for new functionality or interfaces, then O. Pin was not against capitalizing on the framework provided by the TCDT.

HP. de Koning (ESA/ESTEC) reminded everyone that they could use TASverter to convert the ESARAD model produced by the TCDT into another format, so the building blocks were available.

O. Pin said that THERMISOL was supposed to be compatible with ESATAN (with the possible exception of the $VARIABLES1 and $VARIABLES2 blocks) so in principle there should be no problem with importing an ESATAN model produced by the TCDT into THERMISOL. He repeated what HP. de Koning had said: to get a THERMICA model, simply export an ESARAD model from the TCDT and then use TASverter to convert it. This was the approach that was already being used within Blue Engineering.

C. Stroom (retired) asked for a statement from ESA on the availability of ARTIFIS and TOPIC. O. Pin stated that ARTIFIS and TOPIC had been developed by a young graduate several years previously, and although there had been some minor changes there had been no further development. A binary release was available but it had never really been made visible. He said that ESA would take an action to make the tools available.

2.6 ESATAP - Handling large thermal results data with HDF5

F. Brunetti (DOREA) gave only a brief overview of ESATAP because it had been demonstrated at the previous year's workshop, and went on to describe the challenges that ESATAP had faced in working with the STEP-TAS Part-21 files written in ASCII. The process of reading the ASCII file was slow, and it also used a lot of memory because the complete file needed to be read. This had led to the development of an implementation of the STEP-TAS Part-21 file using HDF5, which allowed storing the data in a hierarchical binary format that would be portable across platforms. Dorea were also working to provide an ESATAN output routine for dumping results data into STEP-TAS format using HDF5. A. Fagot (DOREA) described the results of running test cases using both the ASCII and HDF5 versions of the STEP-TAS data and demonstrated importing the HDF5 data files in real time. (See appendix Q)
R. Patricio (Active Space Technologies) asked whether the HDF5 format would spread to the other tools, such as ThermNV. J. Thomas (ALSTOM) answered that when the development toolkit became available ALSTOM would be looking at how to use HDF5 format data within ThermNV. He said that the toolkit had not yet been delivered, so they could not make immediate plans and could only consider it as a long term option.

2.7 ThermNV - Post-processing multiple results sets

As H. Brouquet (ALSTOM) was unable to speak because of a cold, J. Thomas (ALSTOM) took over the talking while H. Brouquet gave a live demonstration of the improvements to ThermNV that had been released since the previous workshop. Most of the features were a direct result of user feedback on the previous versions. The first major improvement related to large models, where a dialog containing the list of available nodes was automatically presented to the user so that a selection could be made of the nodes of interest. H. Brouquet demonstrated how this could be used, along with the automatic grouping and layout tools to create a meaningful schematic of the network. The next improvement was the comparison of results data against two levels of maximum and minimum limits which could be used to highlight whether the results exceeded qualification and design requirements. The final feature shown was the ability to define and save the layout of all of the schematics, tables and charts and then apply these to multiple data sets, and to display the min/max values over all data sets. This functionality could be driven via a batch method as well as from the graphical user interface. (See appendix R)
There were no questions.

2.8 Closure

H. Rooijackers (ESA/ESTEC) thanked all of the contributors for taking the time and trouble to put together the presentations on the development of their tools, or on the experiences of using the tools. He thanked all of the attendees for taking part in another stimulating and successful workshop. He hoped to see everyone again at the next workshop in a year's time.

Appendix A

Welcome and Introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

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Workshop objectives

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

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ESA Workshop Team

Harrie Rooijackers   Organiser
Duncan Gibson   Software Support & Workshop Secretary

with help from the ESA Conference Bureau

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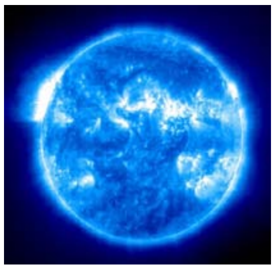

Programme

- Two-day programme
- Presentations of 30 min, including 5 minutes for questions and discussions
- Cocktails today after the workshop in the Foyer
- Dinner (optional) tonight in Noordwijk

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Practical information

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

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Practical information

- Lunch: 13:00 - 14:00
- Cocktail today at 17:30 in the Foyer
- Check your details on the list of participants and inform the Conference Bureau of any modifications.
  Leave your email address!
- Workshop dinner tonight!

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Dinner

- "Dutch" dinner == to be paid by yourself
- in “Paul's Recept", Huis Ter Duinstraat 27,
  2202 CS Noordwijk a/Z, tel (+31)-071 - 361 55 98
- fixed menu with choice of main course (fish, meat or vegetarian) for 36,50 euro p.p., including a drink
  Suggestion: calculate extra drinks bill per table and share equally
- Restaurant booked today for 20:00
- Please arrange your own transport
- If you would like to join,
  then contact the registration desk today **before 13:00**,
  to let the restaurant know what to expect

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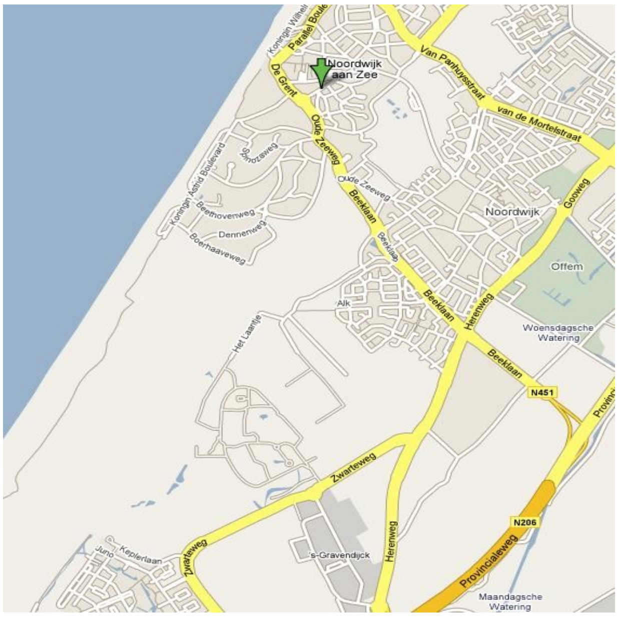
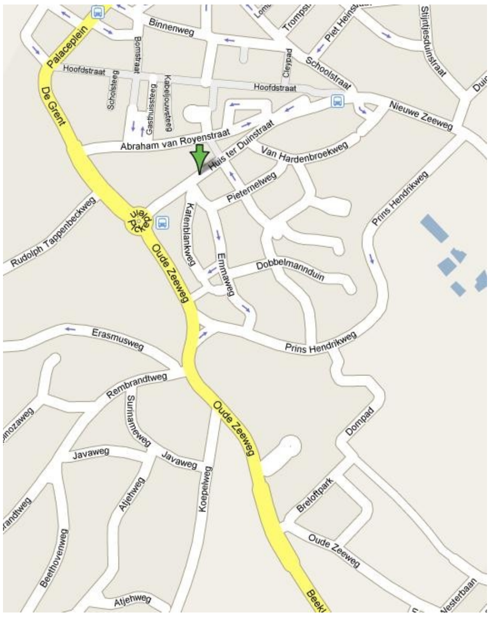
Restaurant “Paul's Recept"





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Menu
(€ 36,50 p.p. including a drink)

Sautéed quail with mushroom risotto and chips of parsnips

*****

Fried on the skin cod filet with spinach and pistou of tomato

or

Sautéed venison steak with potato mousseline, red cabbage and sauce of gingerbread and red port

*****

Creamy parfait of caramel with hazelnut caramel sauce

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ICES 2008

- The 38th International Conference on Environmental Systems will be held June 29 - July 3, 2008, Hyatt Regency, San Francisco, California, USA
- Deadline for submitting abstracts: Friday 9 November, 2007
- abstracts may be submitted online at http://www.sae.org/ices (preferred)
- or sent to: Olivier Pin, email olivier.pin@esa.int
- Abstracts must include paper title, author(s) name(s), mailing and e-mail addresses, phone and fax numbers

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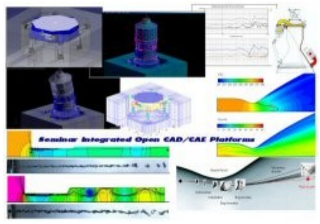
ESA/NAFEMS Seminar



- ESA/NAFEMS seminar on
  Engineering Analysis Quality and
  Verification and Validation

  6 December 2007

  ESA/ESTEC
  Noordwijk, The Netherlands

  see http://www.congrex.nl/07m29/
  or Olivier Pin, email olivier.pin@esa.int

- Deadline for submitting abstracts: Friday 2 November, 2007
  (probably extended 1 week)

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Appendix B

Parallel thermal analysis with Linux clusters

Duncan Gibson
(ESA/ESTEC, The Netherlands)

Parallel analysis using Linux clusters

Transfer of knowledge

Duncan Gibson
Analysis and Verification Section
ESA/ESTEC D/TEC-MCV

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Parallel analysis using Linux clusters
30-Oct-2007
sheet 1

Objectives

- Why talk about parallel computing on Linux clusters?
  - Thermal software and processor speed improvements are matched by complexity of thermal models and analysis campaigns
  - Need to consider other methods of improving analysis throughput
- What does this presentation describe?
  - Experience of Thermal division at ESTEC
  - Using existing, non-specialist hardware
  - Using existing, off-the-shelf software
- What this presentation does not describe:
  - Supercomputers
  - GRID computing
  - Any low-level technical details

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sheet 2

Previous workshops have discussed model reduction techniques to speed up analysis, but nobody seems to be using them. In fact the trend is the opposite with bigger models, perhaps from CAD systems, that soak up any software or processor speed improvements. Parallel computing provides another approach to improving analysis throughput. To support it properly, thermal managers need to consider their infrastructure, and tool developers need to design for parallel use.

ESTEC has maybe a little more freedom to explore some areas because we don't have the same drivers as industry. This is one area in which we have some experience, and it is worth sharing that experience. We have just scratched the surface, but what we have done might also be possible for everyone, without major capital investment, today.

Discussion aimed at typical thermal departments using local hardware. Not aimed at supercomputers for weather forecasting or nuclear reactor simulations, nor at remote execution or grid computing used in some climate studies and SETI@home

This presentation is just an overview to get people thinking. Don't want to go into any really detailed technical descriptions because everyone's environment will be different.

Thermal analysis environment

- “20” years ago
  - Analysis using ESTEC’s IBM office automation mainframe or VAX/VMS
  - Desktop access using IBM 3270 terminals or DEC VT100
- “15” years ago
  - Analysis using dedicated Unix minicomputer (HP) as compute server, with one graphics workstation (HP/Sun)
  - Desktop access using VT100 terminals (and IBM 3270 to mainframe)
- “10” years ago
  - Analysis using dedicated Unix (HP/SGI) compute servers
  - Desktop access with graphics using thin-client X-terminals (x3270, SoftWindows)
- “5” years ago
  - Analysis using dedicated Unix (SGI/Sun) compute servers
  - Desktop access with graphics using “individual” Linux systems (Terminal Server access to Lotus Notes)
- “0” years ago
  - Analysis using dedicated Unix (Sun) server and Linux cluster
  - Desktop are “synchronized” Linux systems also used for analysis (Terminal Server access to Lotus Notes)

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sheet 3

This is a very rough guide to the evolution of the thermal analysis environment available to the engineers at ESTEC. The timeline and system details are approximate because new systems were phased in, and old systems were phased out, so there was a much more gradual evolution or metamorphosis than appears above.

Move to a dedicated analysis facility in order to have some control and autonomy because thermal users had different (additional) requirements to office automation users . HP chosen because of positive experience of HP instrumentation and monitoring in the Mechanical System Laboratory. Only one graphics workstation for visualization. Later added Sun workstations, which were cheaper than HP, but also created compatibility problems.

Thin client X-terminals provide cheap access to graphical interfaces with central system administration compared to PCs or Unix workstations.

Mass purchase of cheaper PC hardware, with graphics, means users can use local processor for desktop work, leaving the central servers free for analysis. Initial Linux systems require installation and update on an individual basis.

Switch from HP to SGI servers due to harmonization with Structures group to streamline system administration. Switch from SGI to Sun after SGI’s future looked uncertain and their big servers were significantly more expensive than Sun. New systems are multi-processor.

“Unassigned” Linux desktops are put to use in an Linux cluster. Cluster grows and is renewed.

Thermal analysis software

- “20” years ago
  - SINDA, CBTS, VWHEAT, ESABASE, ESATAN
  - Radiative analysis using the matrix method
- “15” years ago
  - ESATAN, MATRAD, VuVu, ESARAD, ESABASE, Thermica in industry
  - Radiative analysis using Monte-Carlo ray tracing
- “10” years ago
  - ESATAN, ESARAD, ESABASE, Thermica in industry
- “5” years ago
  - ESATAN, ESARAD, CFDRC, Thermica in industry
- “0” years ago
  - ESATAN, ESARAD, TASverter, Thermica, NASTRAN, PATRAN, TRASYS

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sheet 4

20 years ago, all tools – mostly text based - available on IBM mainframe or VAX/VMS.

Own environment more tailored for thermal analysis. Less rigid and more dynamic. More responsive to local users.

VuVu was an in-house tool for visualizing MATRAD geometry files. Tightly coupled to HP graphics accelerator hardware. Obsoleted by introduction of ESARAD on Sun workstations.

ESABASE used for “conversion” of Thermica models to ESARAD, but ran on VAX elsewhere in ESTEC.

Research Fellow joins the thermal division, who uses CFDRC to calculate convective air flows within ATV. Mesh adjusted so that various calculated values can be fed into ESATAN model.

In-house requirements for Thermica, NASTRAN, PATRAN and TRASYS as experience of data exchange for TASverter increases.

Interesting to note: 15 years ago 30 users shared 400Mb of disk space. Relatively simple ESARAD and ESATAN models. Typical ESARAD analysis runs all night. Now each user has 10Gb disk quota plus 50Gb of scratch space. Analysis requirements, ESARAD models and ESATAN models have become much more complex. Cryogenic models. High stability models. Typical ESARAD analysis still runs all night.

Limitations in the past

- Before "5" years ago
  - Local scripts used with limited success for a while for crude load balancing across HP compute servers
  - Infrastructure too limited for real parallel computing
    - Single processor systems
    - Different processor architectures
    - Incompatible binary data formats
    - Slow inter-machine networking
    - Hardware specific software licences
  - Thermal software not designed for parallel computing

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sheet 5

With 20 thermal engineers sharing the main compute server for their office automation work, each analysis job had a noticeable effect on system load and response times. Migrating one CPU intensive analysis job to the more lightly loaded graphics machine made a noticeable difference to performance.

But this requires having identical, or at least compatible systems, and/or using system independent data files, and having licences available on each system. Initial load balancing involved 2 HP800 series machines. Additional SUN systems could not be incorporated. Later 3 HP700 systems could run HP800 executables, but not the other way round. Much confusion among users about where jobs could and could not be run. Too much effort to maintain scripts to reflect differences and limitations on each machine.

Improvements in the present

- What enables parallel computing now?
  - Multi-processor machines
  - Many cheap single processor machines
  - Fast inter-machine network
  - Floating network licences
- Two key events
  - CFDRC as first "parallel-enabled" application in TEC-MC
  - Arrival of "spare" identical office automation machines

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sheet 6

The rise in computer power has been matched by the increased complexity of the analysis but there are now other factors at play.

Multi-processor systems allow automatic load balancing by the system, so a single analysis job doesn't overload the system and users can still work.

Mass produced standard PC hardware is much cheaper to buy than traditional minicomputers or workstations.

Faster networks allow much better data sharing between systems. Intelligent network switches provide better use of bandwidth.

Floating network licence managers mean that software can be made available across more systems without additional administration and configuration. Systems can be swapped in and out of the computing environment easily.

CFDRC was already geared up to work in a multi-processor environment. CFDRC software is computationally intensive and would be in constant use as each run could take days or even weeks. The ESARAD and ESATAN thermal analysis was not as intensive, with peaks of activity and periods of inactivity. The CFDRC user was keen to make maximum use of the system if the thermal analysis didn't require it, but this proved difficult to organise. A turnkey system, with Linux and CFDRC on it was purchased. An experimental cluster was set up using "surplus" office automation PCs reconfigured for Linux.

Now CFDRC is being used in the Propulsions section on a dedicated 250-node Linux Cluster.

Examples of clusters in ESTEC

- Propulsion

- Thermal
  - 2005: 20 x Dell Precision
  - 2007: 20 x rack-mounted

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Partitioning the problem space

- For Monte Carlo ray tracing applications, such as ESARAD, the problem space could be decomposed at various levels
  - By individual rays
  - By individual surfaces
  - By orbit position
  - By parametric case
- For iterative solvers, such as ESATAN, the choice may be limited
  - By parametric case

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It might be possible, at a conceptual level, to divide the problem space into different levels, but in reality to do so might require additional support from the application itself. If the level is too detailed, the overhead of running each smaller analysis might outweigh any benefits.

An ESATAN model could also be partitioned by splitting it into submodels or components that could be solved separately and having a management layer that handles communication of input/output values between the components. However, this presentation is about running models without major changes.

Note that tools that enable Stochastic analysis might provide a framework for running jobs in parallel across multiple processors but this is outside my experience. I haven’t looked into it, but I am also curious whether the new ESATAN parametric case handling can be used in a parallel mode.

Improving analysis throughput (1)

- The “system” could partition each analysis into chunks that could run in parallel on several machines or processors
  - Process existing code with parallelizing compiler?
    - Not all applications are suitable for parallelization without modification
    - Developers must also supply compatible parallelized libraries
  - (Re)design algorithm to use multiple-processes?
    - Data structure access and integrity issues
    - Assumes “system” can allocate chunks to processors
  - CFDRC subdivides the problem space and then uses the operating system to run different parts on different processors

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The ideal scenario for the user is for the “system” to do everything automatically: break the analysis into chunks, identify processors on which to run those chunks, and allocate chunks to processors. Unfortunately such a “system” does not really exist. Such a system can be broken down into three aspects: the multiple hardware processors, operating system support for job management on those processors, software support to work with the job management system.

Work may be required to rearrange algorithms and data flow in order to benefit from a parallelizing compiler.

Redesigning an algorithm to be multi-threaded can be a major task because there are critical issues with shared memory access and synchronization. Changing to use multiple processes involves additional effort in re-reading of input files and state information, inter-processor communication, and updating state information and integrating results. Care needs to be taken with data integrity in the event that a process is interrupted or fails.

A multi-processor system might provide automatic allocation of different chunks of analysis to the different local processors. Allocation of chunks across the network to remote processors requires some infrastructure support and configuration.

CFDRC provides most of the “system” for partitioning the complete analysis. The user needs to specify which processors are available for the computation. The CFDRC software allocates chunks of work to each processor. CFDRC is able to restart from a previous state if one of the processes fails or is interrupted.

Improving analysis throughput (2a)

- The user(s) could partition a single analysis case into chunks that could run in parallel on several machines or processors
  - Data structure access and integrity issues
  - Detailed knowledge of analysis dataflow needed

  - ESARAD Parallel Kernel facility (introduced in 5.7.5)
    - Usually define single batch file
      - Definition of radiative case, mission, accuracy, etc.
      - FOR loop calling CALCULATE(REF, SAF, PAF, ALBEDO_PAF) at each orbit position
    - For Parallel Kernel runs
      - Definition of radiative case, mission, accuracy, etc. as usual.
      - Ask ESARAD to Save [Multiple] Analysis Files (*_VREF.erk, *_HF.erk)
      - User can manually run these Analysis Files in parallel

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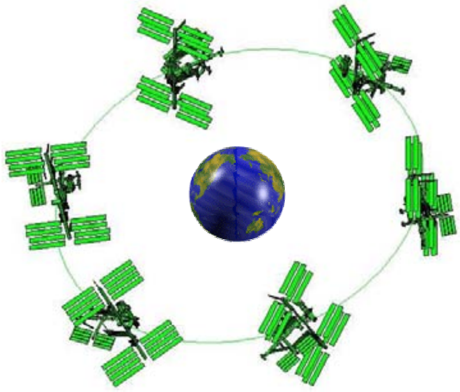
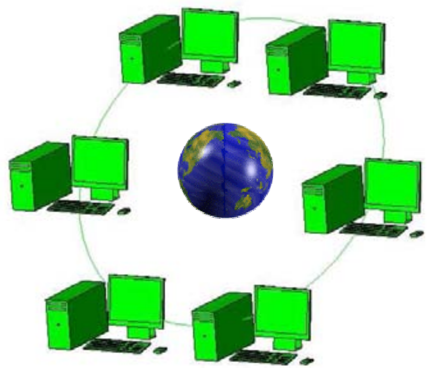
Once the user has defined a satellite geometry and specified an orbit and other analysis parameters in a radiative case, Esarad's Parallel Kernel facility can be used to output individual kernel batch files that relate to calculating view factors or radiative exchange factors at one or more orbit positions and others for calculating the heat fluxes at those positions.

Improving analysis throughput (2b)

- ESARAD Parallel Kernel facility
  - ISS_COLD, 7 orbit positions, 90000 rays (using ESARAD 5.7.5 in 2005)
    - Normal run took 21938 seconds 6:05:38
    - Parallel run took 5272 seconds 1:27:52





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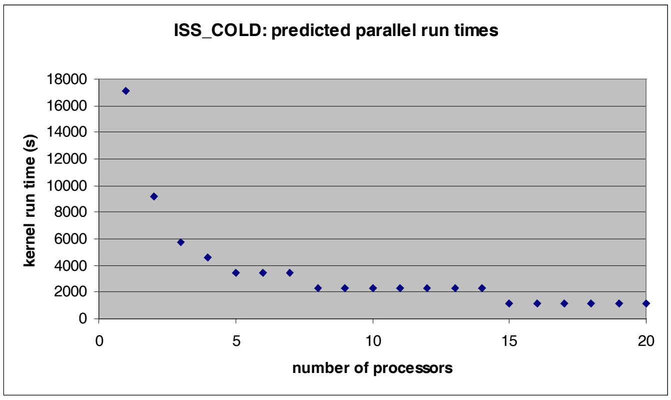
In the example, the accumulated orientation of all of the surfaces in the ISS is different at each orbit position, so each position requires both a VF/REF calculation and a heat flux calculation. All machines share a networked file system and a shell script managed allocating and running each job using a remote shell command line and then waiting for the creation of a file showing that the batch job had completed. Synchronization was crude, with delays of 60 seconds between each job and while waiting for jobs to complete. Can see that there is some overhead because total time for parallel runs is greater than time for normal run divided by number of processors.

Improving analysis throughput (2c)

- ESARAD Parallel Kernel facility
  - ISS_COLD: predicted parallel run times (using ESARAD 6.0.1 in 2007)
    - 15 orbit positions, REF 50000 rays, HF 3000 rays
    - Single processor timings of VREF and HF files “extrapolated” across processors



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Parallel analysis using Linux clusters
30-Oct-2007
sheet 12

Unexpected interruptions in plans to upgrade hardware and software on the Linux cluster result in NFS problems that prevent using cluster machines to get up-to-date timing information for this presentation. The other option was a shared multi-processor server but this was already in heavy use for real project work using CFDRC. Therefore only able to predict parallel execution times based on results of running parallel jobs sequentially on one machine using a reduced number of rays. These are optimistic predictions because queue management and synchronisation overheads are not taken into account.

What is interesting is that it only takes a few processors to make a significant difference to the analysis time. So an engineer waiting for a job that would run overnight on a single processor could get results within the same working day if using 2, 3 or 4 processors. This is within the standard block of licences provided by Alstom, i.e. there is no need to buy additional licences to achieve a big improvement on turnaround time for a single analysis case.

Improving analysis throughput (3)

- For larger analysis campaigns, the user(s) could run several analyses in parallel on multiple machines or processors
  - Each analysis job runs "as is"
  - Care needed to isolate each job from others
  - Scripting required to generate input files
  - Really need intelligent queue management system to run jobs

  - ISS / ATV / Columbus
    - Shell / Python scripts generate jobs for beta angles from -70.0° to +70.0° in 5.0° steps and submit to queue management system for 20 machine Linux cluster. Each job runs both ESARAD and ESATAN.

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Parallel analysis using Linux clusters
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A set of template files created from original batch files.

A shell or python script used to read parametric data from file, and copy the template files to a new directory, substituting the parametric data in the process, and then generating another script to set the appropriate environment (ESARAD_HOME, etc) and then submit this second script to the queue management system. The advantage of the queue management system is that it handles all allocation and synchronization. The disadvantage is that you need to manage disk space so your second script needs to tidy up after itself. Queue management system needs to be configured so that the first user with 100s of jobs doesn't block anyone else.

Management need to decide policy before it can be configured into such a system, i.e. number of simultaneous jobs per user, who has priority, etc.

Queue management system used was commercial tool called PBSPro. PBS stands for Portable Batch System. The original version was developed for NASA in the mid 1990s. An open source version called OpenPBS is also available, but is no longer under development. Details of both tools can be found via http://www.pbspro.com/openpbs.html

Conclusions

- Parallel thermal analysis is available today
  - But you may have to roll your own infrastructure
- Identical cheap hardware and floating licences help
  - Homogeneous machines not required, but make it easier in practice
- Some form of queue management needed for running complete analyses in parallel
  - Better use of "idle" hardware, but need to consider multiple users submitting jobs
  - Large number of licences required for large parametric studies
- ESARAD Parallel Kernel Facility can reduce elapsed time for a single case
  - Requires careful planning
  - Standard block of 4 licences enough to make significant throughput gains
- Support needed at application level to make parallel computing easier (CFDRC)

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Parallel analysis using Linux clusters
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Appendix C

New technology for modelling and solving radiative heat transfer using TMG

Kevin Duffy
(MAYA, Canada)

21st European Workshop on Thermal and ECLS Software

New Technology for Modeling and Solving Radiative Heat Transfer using TMG

October 30, 2007

Introduction

MAYA has undertaken development of two major new technologies for radiative heat transfer simulation:

- Enable treatment of wavelength dependence in radiative exchange
- New solver technology to enable faster processing of high definition models
- Projects co-sponsored by the Canadian Space Agency

Nongray radiative exchange

- Gray approximation is widely used in spacecraft thermal analysis
- Treatment of nongray effects become important at cryogenic temperatures

Parallelization

- Target software modules which use the most CPU
- Provide a parallel solution which is deployable to most client sites today
- View factor computations are "inherently parallel," so have been targeted as the first candidates for parallelization

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The Gray Approximation

Common to most spacecraft thermal tools

- The approximation is that surfaces radiate with an emissivity which is independent of wavelength
- Often reasonable when the absolute temperatures of radiating surfaces do not vary much relative to one another
- Accommodated by averaging the fundamental wavelength-dependent thermo-optical properties over the spectrum, e.g.:

$$\varepsilon_{eff} \equiv \frac{\int \varepsilon(\lambda) P(\lambda,T) d\lambda}{\int P(\lambda,T) d\lambda}$$

- The gray approximation makes thermal radiation analysis a relatively simple problem, i.e., simple radiative conductance networks

Could the gray approximation be called a necessary approximation to facilitate a numerical solution?

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Nongray Analysis

What?

- Nongray analysis must capture the effects of $\varepsilon(\lambda)$: a surface can absorb with an absorptivity at λ_1 and radiate with a different value of emissivity at λ_2
- Similar in concept to the common S/C thermal distinction between solar and IR radiation, except that a surface absorbs *and radiates* across the whole spectrum.

Why?

- While the gray approximation is reasonably acceptable in many scenarios, thermal radiative analysis of cryogenic systems often *requires* a nongray approach
- Depending on wavelength-dependent emissivity, The gray approximation becomes increasingly inaccurate as the ratio of absolute temperatures diverge from unity.

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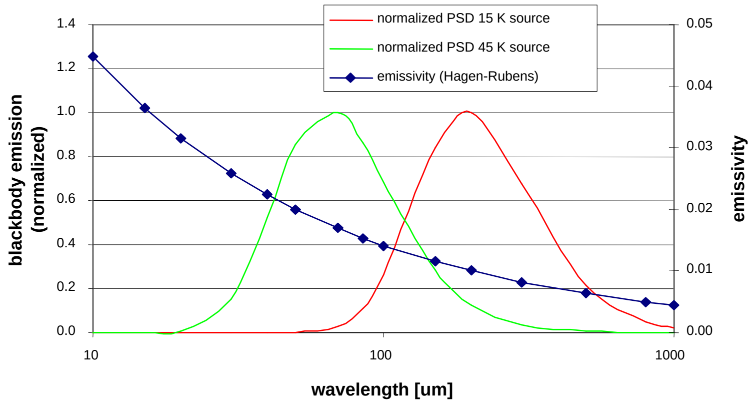
Nongray: really, why? (1)

- Consider two surfaces, one at 15K and one at 45K: graph shows the normalized power spectra of the surfaces
- Emissivity follows the Hagen-Rubens formula (proportional to $\lambda^{-1/2}$)



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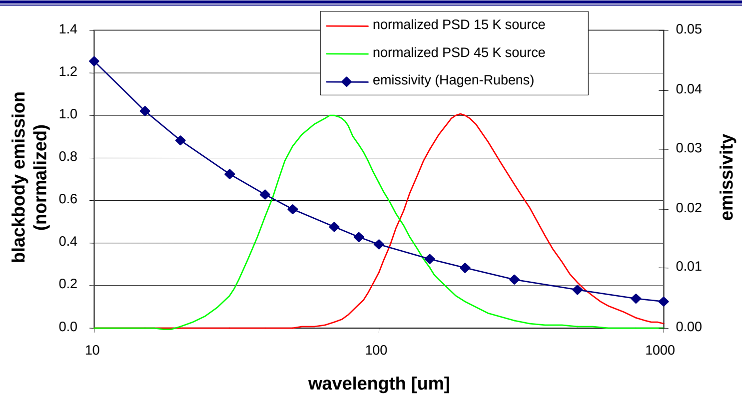
Nongray: really, why? (2)



- while reasonable to use ε_{eff} as the average emissivity for a surface at a certain temperature, it is not a good approximation to use ε_{eff} as the average absorption for that surface unless the incoming radiation was also radiated at around the same temperature
- With the gray approximation, the absorptivity of the 15K surface is **under-predicted** by about **a factor of 1.7**

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Nongray Analysis in TMG

Discretization

- The fundamental equations for radiative exchange between surfaces are discretized in terms of wavelength
- The discretization takes the form of *N wavelength bands*
- Thermo-optical properties are now defined band-wise:

$$\varepsilon_{kg} \equiv \frac{\int_{\lambda_{g-1}}^{\lambda_g} \varepsilon(\lambda) P(\lambda,T)\, d\lambda}{\int_{\lambda_{g-1}}^{\lambda_g} P(\lambda,T)\, d\lambda} \approx \frac{\int_{\lambda_{g-1}}^{\lambda_g} \varepsilon(\lambda)\, d\lambda}{\int_{\lambda_{g-1}}^{\lambda_g} d\lambda} = \frac{1}{\Delta\lambda} \int_{\lambda_{g-1}}^{\lambda_g} \varepsilon(\lambda)\, d\lambda$$

- *g* is the band number
- number of bands and band spacing is user-input

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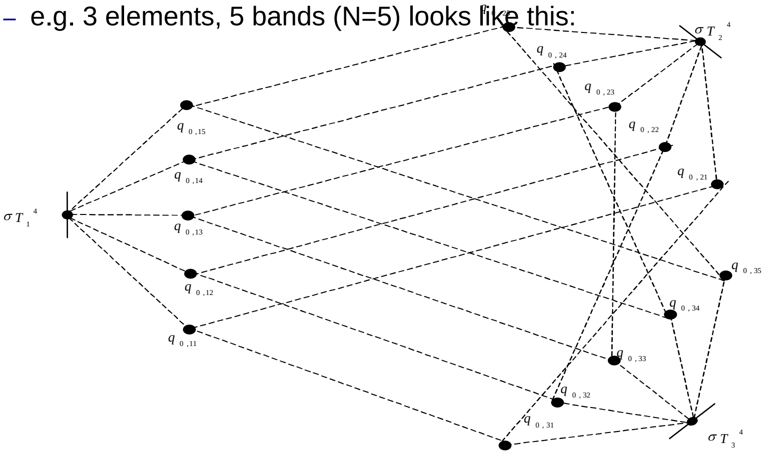
Nongray Analysis in TMG

Multiband Radiosity Method

- The radiosity method has been rederived using the band structure
- Each radiating element takes N radiosity (‘Oppenheim’) elements
- A distinct radiative conductance network is created in each band
  - e.g. 3 elements, 5 bands (N=5) looks like this:



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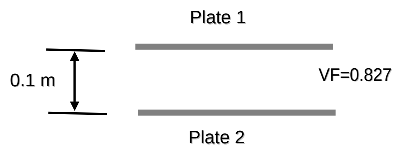
Nongray Validation

Two Plates in space

- Plate 1:
  area = 1 m^2, Sink @ T_1, ε_{1g}, g=1..N
- Plate 2:
  area = 1 m^2, ε_{2g}, g=1..N



- Total heat emitted and absorbed by plate 2 can be derived analytically:

$$Q_{2,emit} = \sum_{g=1}^{N} \varepsilon_{2,g}\, p_g(T_2) A \sigma T_2^4$$

$$Q_{2,abs} = \sigma \sum_{g=1}^{N} \left\{ \left[\varepsilon_{1g} A_1 p_g(T_1) T_1^4 VF_{12} \varepsilon_{2g} + \left(\varepsilon_{2g}\right)^2 A_2 p_g(T_2) T_2^4 VF_{21} (1-\varepsilon_{1g}) VF_{12} \right] \times \left[\frac{1}{1 - VF_{12} VF_{21} (1-\varepsilon_{1g})(1-\varepsilon_{2g})} \right] \right\}$$

- 4 test cases varying T_1, N, ε_{1g} and ε_{2g}

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Nongray Validation

Two Plates in Space: Test Matrix

Test Case	Number of Bands	Band limits (micrometers)					T_1 = Element 1 Temperature (sink)
		λ_0	λ_1	λ_2	λ_3	λ_4	
2.0	1	-	-	-	-	-	100 K
2.1	2	0	40.0	4.E3	-	-	100 K
2.2	2	0	40.0	4.E3	-		100 K
2.3	2	0	40	4.E3	6.E3		50 K
2.4	4	0	40.0	80.0	120.0	1.2E5	60 K

Test Case	Number of Bands	Band Emissivities (element 1)				Band Emissivities (element 2)			
		ε_1	ε_2	ε_3	ε_4	ε_1	ε_2	ε_3	ε_4
2.0	1	0.5	-	-	-	0.5	-	-	-
2.1	2	0.1	0.25	-	-	0.1	0.2	-	-
2.2	2	0.5	0.05	-	-	0.1	0.2	-	-
2.3	2	0.1	0.25	-	-	0.1	0.2	-	-
2.4	4	0.1	0.25	0.15	.05	0.3	0.25	0.2	0.18

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Nongray Validation

Two Plates in Space: Results

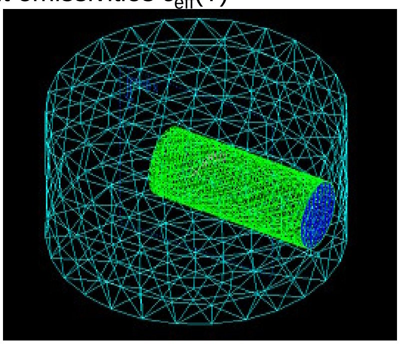
- T_2 is temperature computed with nongray method
- $Q_{2,abs}$ and $Q_{2,emit}$ are computed analytically from T2
- Method should yield $Q_{2,emit}=Q_{2,abs}$

Test Case	T_1 (input)	T_2 (result)	$Q_{2,emit}(T_2)$ (analytic)	$Q_{2,abs}(T_2)$ (analytic)	% error
2.0	100 K	77.95 K	0.419 W	0.415 W	0.9%
2.1	100 K	88.91 K	0.911 W	0.904 W	0.8 %
2.2	100 K	73.19 K	0.284 W	0.280 W	1.2%
2.3	50 K	40.05 K	0.0289 W	0.0286 W	0.8%
2.4	60 K	46.17 K	0.0559 W	0.0547 W	2.2%

Nongray: Sample Application

Simplified model of telescope instrument with cryogenic optics

- $\varepsilon(\lambda)$ for the three materials in the model were used to determine emissivities for three separate analyses :
  - classical gray analysis with constant ε_{eff}
  - gray model with temperature dependent emissivities $\varepsilon_{eff}(T)$
  - two-band nongray model



- Cryocooler modeled as a 31 K nongeometric sink coupled to the end of the telescope
- Critical design issue is how much heat load goes into the cryocooler

Nongray: Sample Application

Comparison of Heat Loads into Cryocooler

Case	Heat Load into 31K Cryocooler
Classical Gray Analysis	0.168 W
Gray with ε(T)	0.159 W
Nongray 2 bands	**0.209 W**

Remarks:

- The 2 band nongray calculation shows the cryocooler needs to draw about 24% more heat than that shown by the gray analysis.
- Temperature dependent emissivity gives worse results!

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Nongray Analysis

Work in Progress

- Support of wavelength dependent specularity & transmissivity: this yields different conductance networks in each band;
- Ray tracing of environmental radiative fluxes in multiple bands;
- Extension beyond radiosity method: Gebhardt's method and Monte-Carlo determined RAD-K's;
- Improved numerical convergence, and increase in solution accuracy with many bands (presently heat leaks occur between bands);
- Deployment of feature to graphical user interfaces.

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Parallel Computing

Motivation

- Analysts are consistently building bigger, higher fidelity models, and still want faster throughput
- Improvement in processor clock rates is becoming asymptotic
- Multi-core processors are becoming more predominant
- Many users wish to make use of networked computers and/or clusters

Possible Approaches

- Shared memory
  - Parallel processes or threads share same data space
- Distributed memory
  - Parallel processes each have dedicated memory and communicate via message passing.

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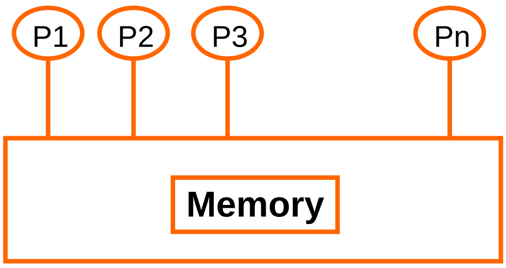
Parallel Computing

Shared Memory Parallelization

- Same memory usage as the serial run
- Multiple processes use the same memory and I/O
  - Synchronization of tasks is the key for implementation
  - Deadlocks and memory overwrites must be avoided!
- Scalability is determined by the hardware
- Popular Open SMP protocol: OpenMP



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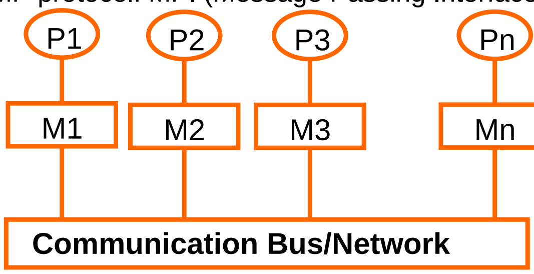
Parallel Computing

Distributed Memory Parallelization

- Each process has its own dedicated memory
  - Possibility of both duplication and/or splitting of memory use, depending on application
- Inter-process communication usually required
  - No synchronization required for memory access
- Scalability is determined by the algorithm being parallelized as well as the communication speed
- Popular DMP protocol: MPI (Message Passing Interface)



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Parallel Computing

MAYA has begun parallelizing its solvers using the *Distributed Memory* paradigm

- The DMP approach accommodates user's existing hardware
  - With DMP, parallelization is achievable with multicore, multi-processor, network, and ***cluster*** architectures; SMP requires multicore or multi-CPU boxes (excludes networks and clusters)
  - All users with a network could in principle use DMP today; not so with SMP
- DMP scalability not as limited by available hardware
  - With SMP, if the best machine available is a quadcore processor, no more than 4 processors can be used
  - Given a scalable algorithm and a good network or hub, more than 4 processors can easily be brought to bear on a solve
- DMP is more cost effective to implement in existing code
  - SMP often requires paradigm shift & re-architecture, DMP not as much

We are still keeping our eye on new developments

- e.g., racks of programmable graphics processors (stream processing)
  - early prototyping of new algorithms for this kind of hardware (R&D)

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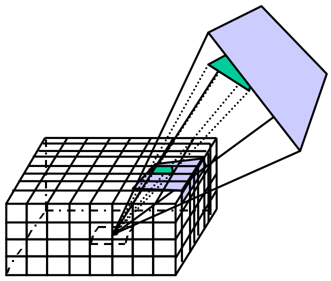
DMP Parallelization of the Hemicube Method

Parallelization of View Factor Computation

- View factor algorithms are *inherently parallel*, because view factors do not depend on one another
- Each process holds the model of the entire radiation environment, which independently computes a subset of the view factors

Hemicube Method: TMG *Hemiview* module

- variant of the Nusselt sphere method
- each face of the cube is divided into pixels: each pixel has a known view factor contribution
- hemicube is centered on a receiver element and the image of surrounding "emitter" elements are projected onto the hemicube
- view factors are tallied through pixel contributions



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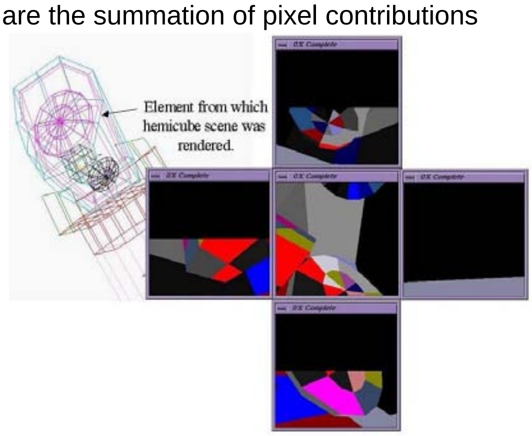
DMP Parallelization of the Hemicube Method

MAYA's Hemicube Technology

- MAYA uses the standard graphics processor to accelerate computation of the hemicube method
- the OpenGL library is used to render a scene of elements onto faces of the hemicube, view factors are the summation of pixel contributions
- Background rendering is used to increase reliability at little more computational cost
- Parallel run requires one graphics processor per process



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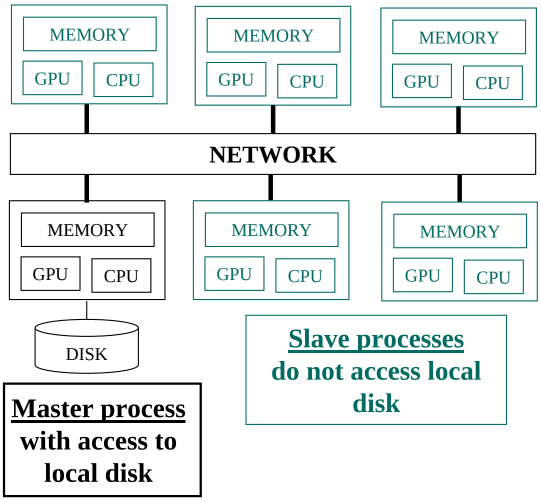
DMP Parallelization of the Hemicube Method

Hemiview Parallel Architecture

- Master/Slave system
- Master:
  - Performs all I/O
  - Sends model to slaves
  - Instructs slaves which VFs to compute
  - Receives VFs from slaves and writes results to single file
  - Computes some VFs when it has time
- Slave
  - Receives model, instructions
  - Computes VF's
  - Sends VF's to Master
- Load balancing is performed, assuring all processes are busy



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DMP Parallelization of the Hemicube Method

Parallel Hemiview: user/analyst issues

- Recently available as beta version (depending on license)
- Requires installation of MPI on all machines
  - MPICH2 is open source library
- Only a single installation of TMG is necessary
- Analyst presently needs to do some manual set-up on all machines to prepare for parallel run
  - We aim to automate this process
- Single parameter toggle to activate parallel hemiview
  - Serial and parallel versions are the same executable
  - Any model which runs in serial should produce same results in parallel
  - Windows runs require additional “machine file” which specifies where processes run

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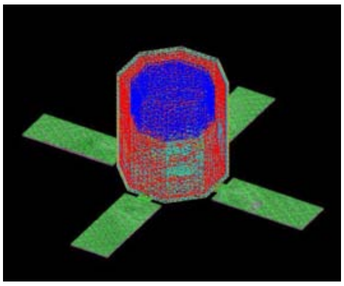
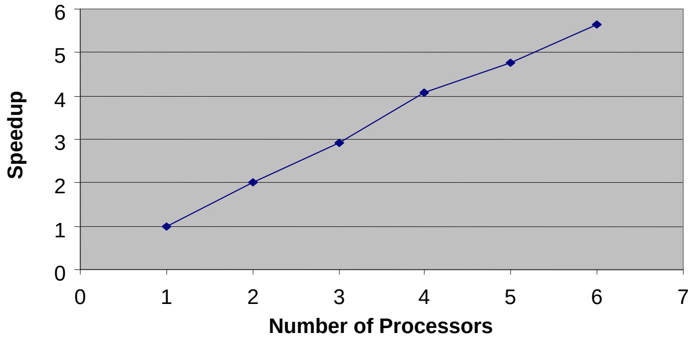
DMP Parallelization of the Hemicube Method

Sample Results

- **Finely meshed satellite model**
  - 21,058 shell elements
  - 4.04×10^6 view factors
  - 50.6 minutes on 1 opteron running Linux
  - 8.9 minutes on 6 networked opterons





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More Parallelization

Work-in-progress and future work includes:

- Parallelization of linear conjugate gradient solver and matrix assembly (domain decomposition)
  - prototyping work indicates speedups of 2-3 on 4 processors for large models
  - ‘non-sparse’ radiation matrix complicates domain decomposition strategies
- Parallelization of ray-tracing and general view factor module (VUFAC)
- Parallelization of other key computational bottlenecks in the TMG solve
- Investigation of new hardware, especially programmable graphics processors

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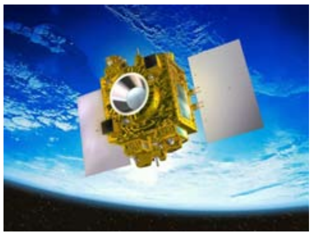
MAYA

Appendix D

GAETAN V5: a Global Analysis Environment for Thermal Analysis Network

Hélène Pasquier
(CNES, France)



GAETAN V5 :

A Global Analysis Environment for Thermal Analysis Network

PASQUIER Hélène, *Thermal Engineer, CNES*

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Agenda

- **Presentation of GAETAN V5**
- **Demonstration of the new friendly interface**
- **Focus on dimensioning case research modules**

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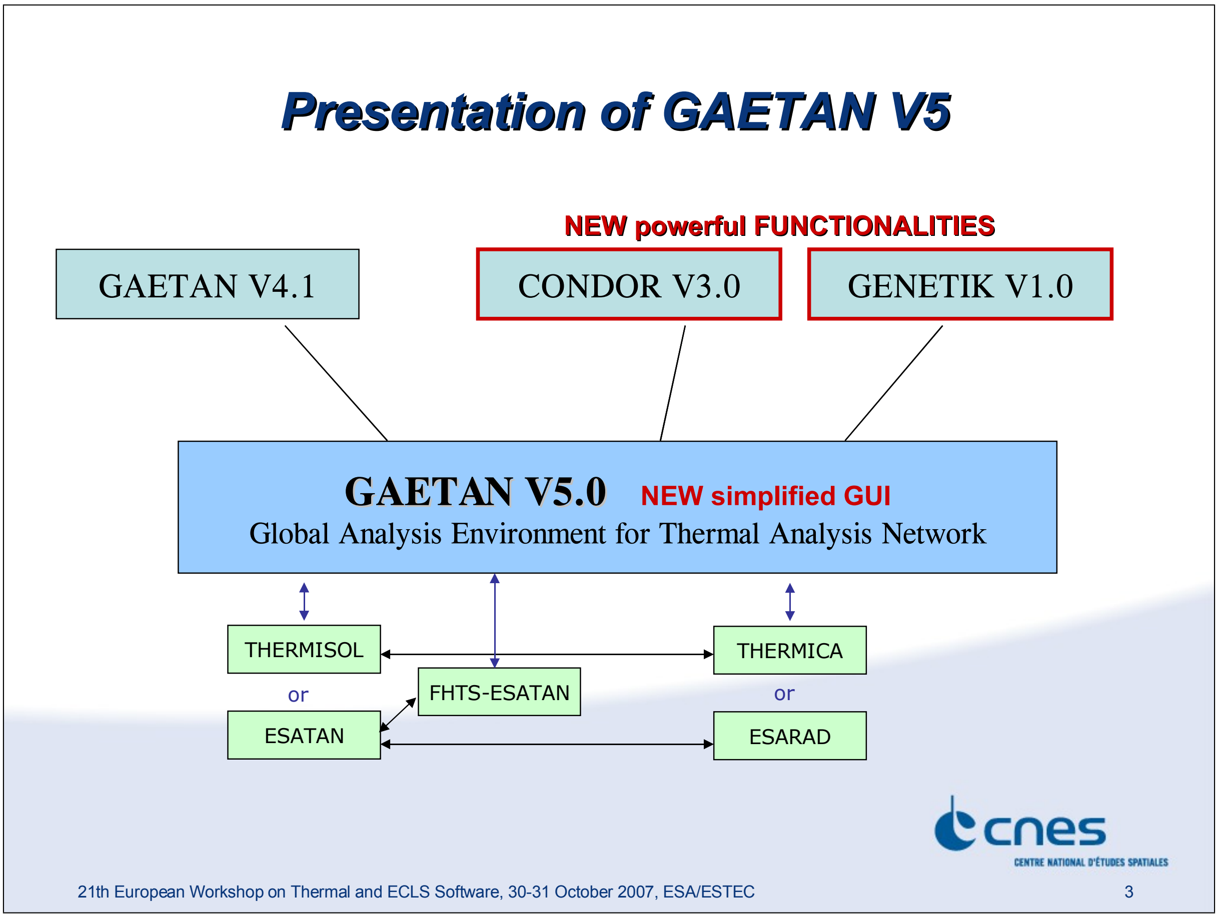
Presentation of GAETAN V5
NEW powerful FUNCTIONALITIES
GAETAN V4.1
CONDOR V3.0
GENETIK V1.0
GAETAN V5.0
NEW simplified GUI
Global Analysis Environment for Thermal Analysis Network
THERMISOL
or
ESATAN
FHTS-ESATAN
THERMICA
or
ESARAD
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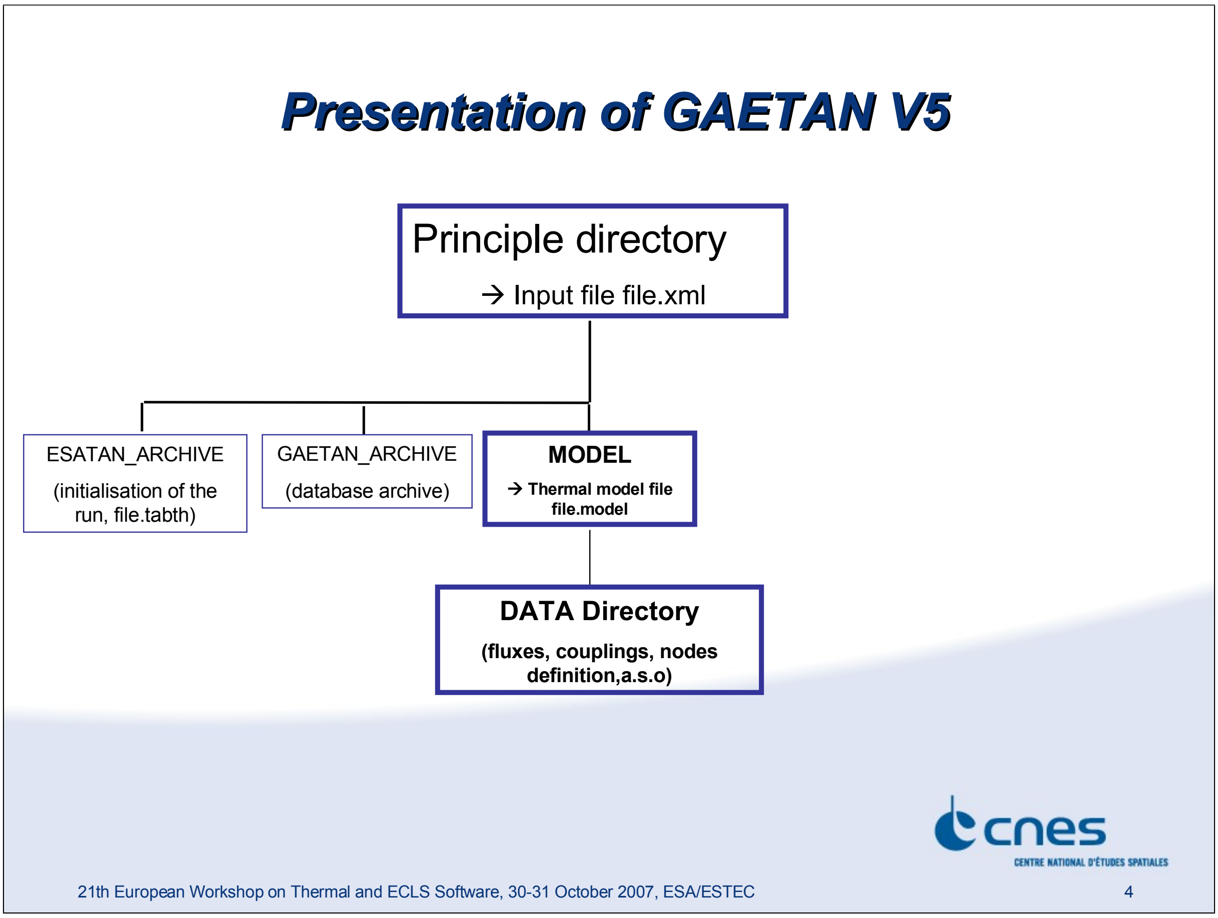
Presentation of GAETAN V5
Principle directory
→ Input file file.xml
ESATAN_ARCHIVE
(initialisation of the run, file.tabth)
GAETAN_ARCHIVE
(database archive)
MODEL
→ Thermal model file file.model
DATA Directory
(fluxes, couplings, nodes definition,a.s.o)
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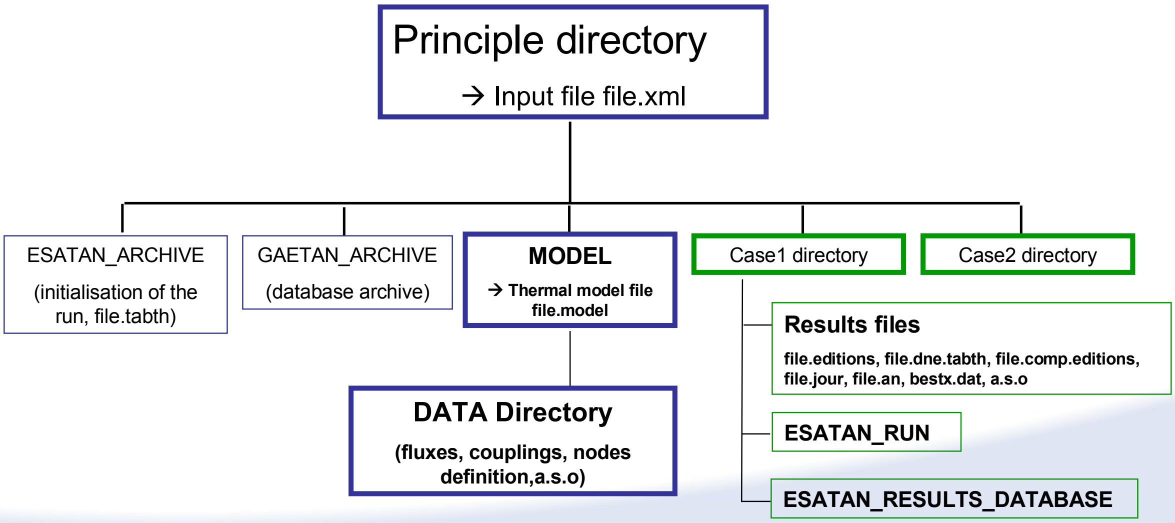
Presentation of GAETAN V5



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Presentation of GAETAN V5
- Main functionalities of GAETAN -

→ PRE PROCESSING FUNCTIONS

- Thermal model configuration and studies management

- Practical use of names for calculation cases, heat load cases, groups of nodes, heat balance, calculation times, a.s.o.

- Complementary entities helpful for thermal study management (i.e. : groups of nodes, condensed nodes, boundary fluxes, instantaneous thermal slopes, a.s.o.)

- Thermal coupling and sensitivity cases analyses

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Presentation of GAETAN V5
- Main functionalities of GAETAN -

→ **POST PROCESSING FUNCTIONS**

- Heat balance analysis : detailed exchanged heat flows diagnostic and extrema
- Radiator / Heat sink analysis (Sink temperature, heat rejection, heat power on simulated heat sink during thermal test …)
  → Useful for thermal balance test engineering
- Automatic results comparison
  - -With specification, with test results, between several calculation cases
  - -Between nodes, groups of nodes
  - -Using mapping table

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Presentation of GAETAN V5
- Main functionalities of GAETAN -

→ **MIXTE FUNCTIONS**

- Help for model reduction (energetic approach)
- Data archived : for later initialization (ESATAN_ARCHIVE), for later post processing (ESATAN_RESULTS_DATABASE) or for comparison (GAETAN_ARCHIVE)
- Dimensioning case research with the CONDOR and the GENETIK modules

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Presentation of GAETAN V5
- Main functionalities of GAETAN -

The aim of the new GUI is to make the software easier to use.

➡ DEMONSTRATION

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Focus on dimensioning case research modules
- CONDOR Module -

- Why CONDOR ?
  - **New project → complex orbit and many possible attitude (random attitude for example)**

➡ **More complicated to determine the dimensioning case for thermal analysis**

- What is CONDOR ?
  - **This aim of the module is the evaluation of external orbital conditions for simple geometries, classical orbits and attitude conditions**
  - **Condor can also be used with Thermica/Esarad – GAETAN – Thermisol/Esatan to obtain data (fluxes, temperature, a.s.o) for many complex geometries, orbital and attitude conditions**

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Focus on dimensioning case research modules
- GENETIK Module -

- Why GENETIK ?
  - **More exhaustive research with GENETIK (variation of many parameters can be tested) – optimized research (Genetic Algorithm → Darwin theory)**

	CONDOR	GENETIK
Geometry	fixed by user (simple or complex)	
Orbit	Parameters fixed by user Ex. : albedo = 0.25 / altitude = 800 km	Discrete variation or range defined by user Ex. : albedo Є [0.25,0.35] / altitude = 800 km or 900 km
Attitude	Parameters fixed by user Ex. : X_{SAT} = Earth direction	Discrete variation or range defined by user Ex. : X_{SAT} = Earth direction or Azimut = 100° / Zenith = 20°
Day of the year	Between 0 and 365 with a fixed time step	Between 0 and 365
Results	Worth day (hot or cold) of the year	Worth case (ex . : albedo = 0.22 - altitude = 900 km - Azimut = 100° / Zenith = 20° - day 272)

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21th European Workshop on Thermal and ECLS Software, 30-31 October 2007, ESA/ESTEC 11

GAETAN V5 – Future Activities

- Improvements on the software are in course today
- First semester of 2008 → operational use of GAETAN V5 in CNES and TAS Toulouse
- Second semester of 2008 → implementation of the users back and finale validation of the tool
- End of 2008 – beginning of 2009 : tool available for the European community

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cnes
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Appendix E

ESARAD radiative analyser - development status

Julian Thomas
(ALSTOM, United Kingdom)

ESARAD Development Status

Author: Julian Thomas
Date: 30th Oct 2007

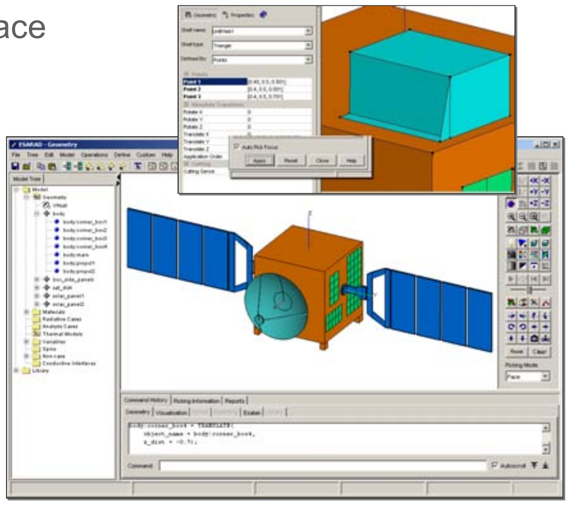
POWER SYSTEMS
Aerospace

ALSTOM

ESARAD 6.0

Released as promised in March 2007;

- Improved layout of User Interface
- Interactive model construction
- Performance improvements

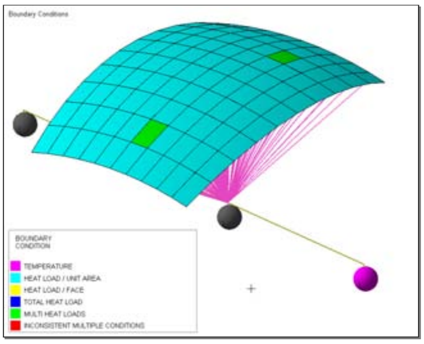


ESARAD Status - 27 Oct 2007 - P 2

POWER SYSTEMS ALSTOM

ESARAD 6.2

Release November 2007



- Non-geometric thermal node elements
- User defined (non-geometric) conductors
- Boundary Conditions
- Improved Analysis Case mechanism and interface
- Orbital ephemeris support (incl. import from STK)
- Option for compatibility with Sinda/G
- Automated database upgrade for 6.0 models

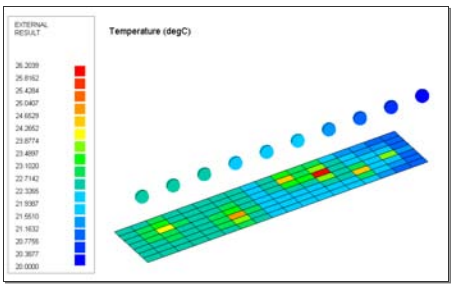
ESARAD Status - 27 Oct 2007 - P 3

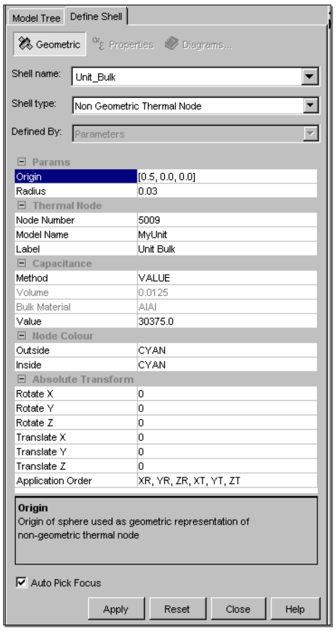
POWER SYSTEMS ALSTOM

ESARAD 6.2

Non-geometric thermal nodes

- New shell type
- Option to visualise nodes
  - Included in pre/post displays





ESARAD Status - 27 Oct 2007 - P 4

POWER SYSTEMS ALSTOM

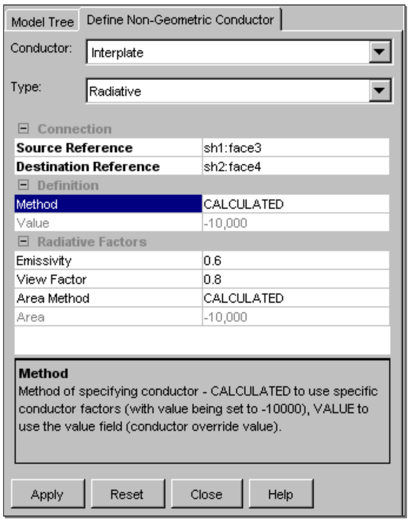
ESARAD 6.2

User defined (non-geometric) conductors;

- Conductive
- Convective
- Radiative
- Advective

Source–Destination defined with;

- Node number
- Face
- Shell side
- Non-geometric node shell

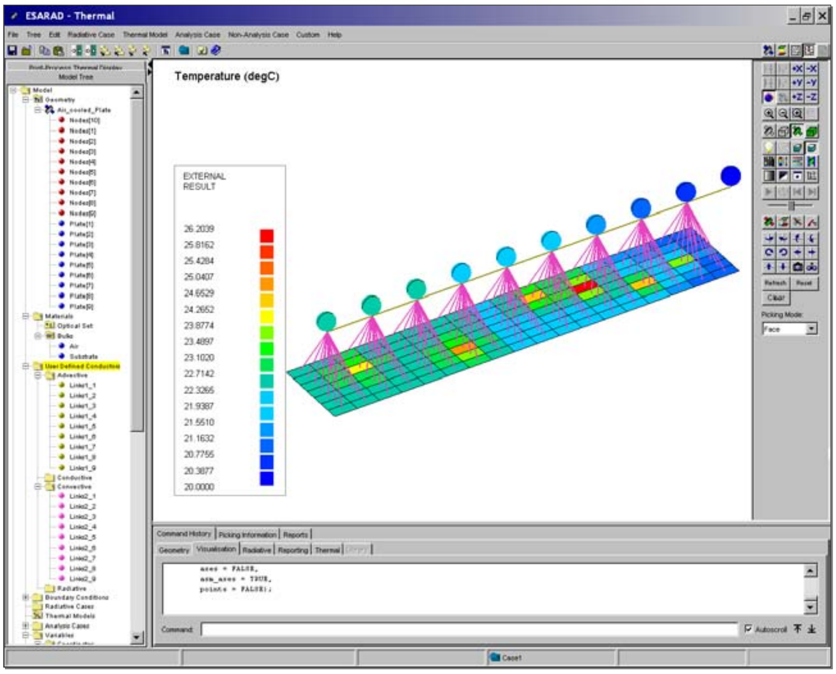


ESARAD Status - 27 Oct 2007 - P 5

POWER SYSTEMS ALSTOM

ESARAD 6.2

Visualisation of user defined conductors



ESARAD Status - 27 Oct 2007 - P 6

POWER SYSTEMS ALSTOM

ESARAD 6.2

Format of user defined links in generated model;

- Conductive (GL = K.A/l)
  GL(1001,1003) = 180.00 * 0.10; # from conductor Doubler
- Convective (GL = h.A)
  GL(2110,1007) = 1.00 * 0.00143; # from conductor Links2_6
- Radiative (GR = A.Eps.vf)
  GR(1001,2001) = 0.25 * 0.60 * 0.80; # from conductor Inter_plate
- Advective (GF = m.Cp)
  GF(1001,1002) = 1.005 * 0.240; # from conductor Links1_1

Easier validation/modification

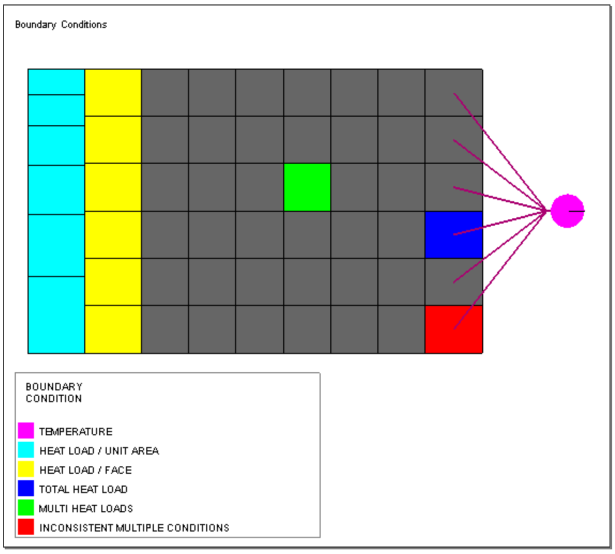
ESARAD Status - 27 Oct 2007 - P 7

POWER SYSTEMS ALSTOM

ESARAD 6.2

Boundary Conditions

- Initial Temperature
- (Fixed) Temperature
- Heat Load
  - per unit area
  - per face
  - Total
- Pre-processing
  - Values
  - Types



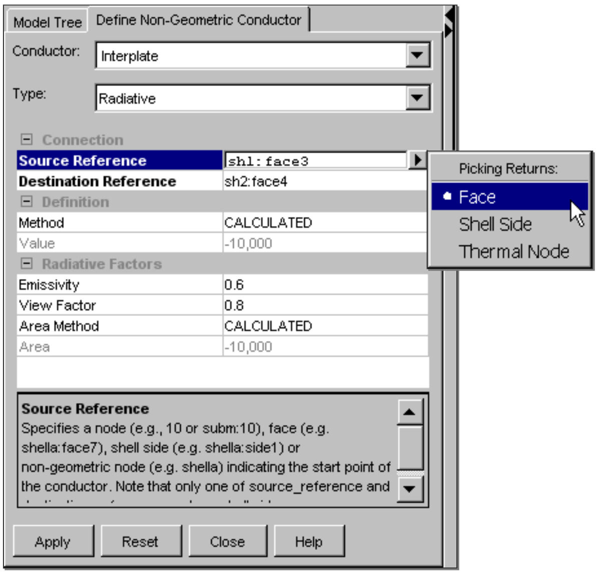
ESARAD Status - 27 Oct 2007 - P 8

POWER SYSTEMS ALSTOM

ESARAD 6.2

Picking mode selection

- User defined conductors
  - Thermal Node (number)
  - Face
  - Shell side
- Boundary conditions add
  - Shell



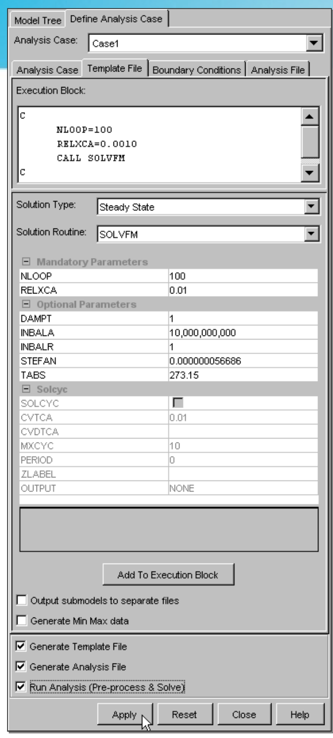
ESARAD Status - 27 Oct 2007 - P 9

POWER SYSTEMS ALSTOM

ESARAD 6.2

Improvements to Analysis Case and interface

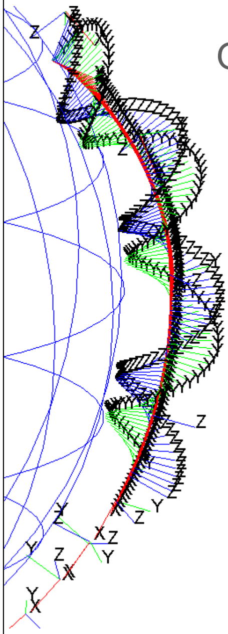
- Replaced multiple forms and “wizard” with single tabbed interface
- Improved work-flow
- Improved control of template file
- Analysis file options saved



ESARAD Status - 27 Oct 2007 - P 10

POWER SYSTEMS ALSTOM

ESARAD 6.2



Orbital ephemeris support

- Two formats supported
  - Time, position & orientation (Yaw, Pitch, Roll)
  - Time, position & velocity
- Import from external “csv” file
  - from Satellite Tool Kit (STK) report
  - from in-house tools
- Adds support for solar vector & precession

video

ESARAD Status - 27 Oct 2007 - P 11

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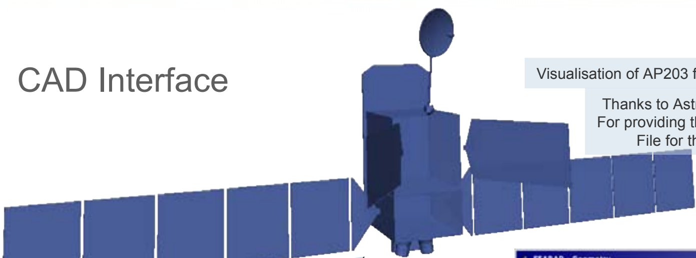
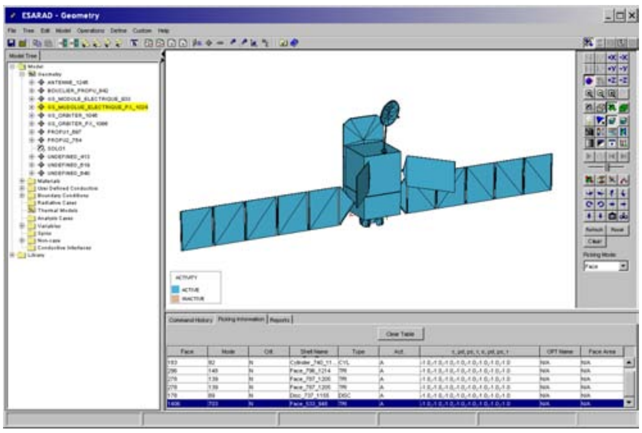
ESARAD 6.2

CAD Interface



Visualisation of AP203 file in BagheraView 3.3

Thanks to Astrium Toulouse
For providing the Step AP203
File for this model



Automatic translation of
STEP AP203/209/214
to ESARAD “erg”

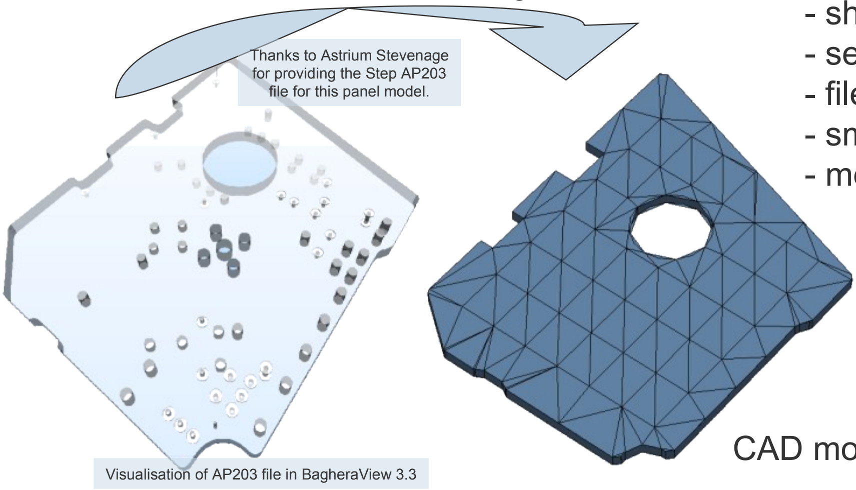
ESARAD Status - 27 Oct 2007 - P 12

POWER SYSTEMS ALSTOM

ESARAD 6.2

CAD Interface

Automatic translation
STEP AP203 to ESARAD “erg”



Automated;
- shape recognition
- selective hole removal
- filet removal
- small element removal
- meshing

CAD model hierarchy retained

ESARAD Status - 27 Oct 2007 - P 13

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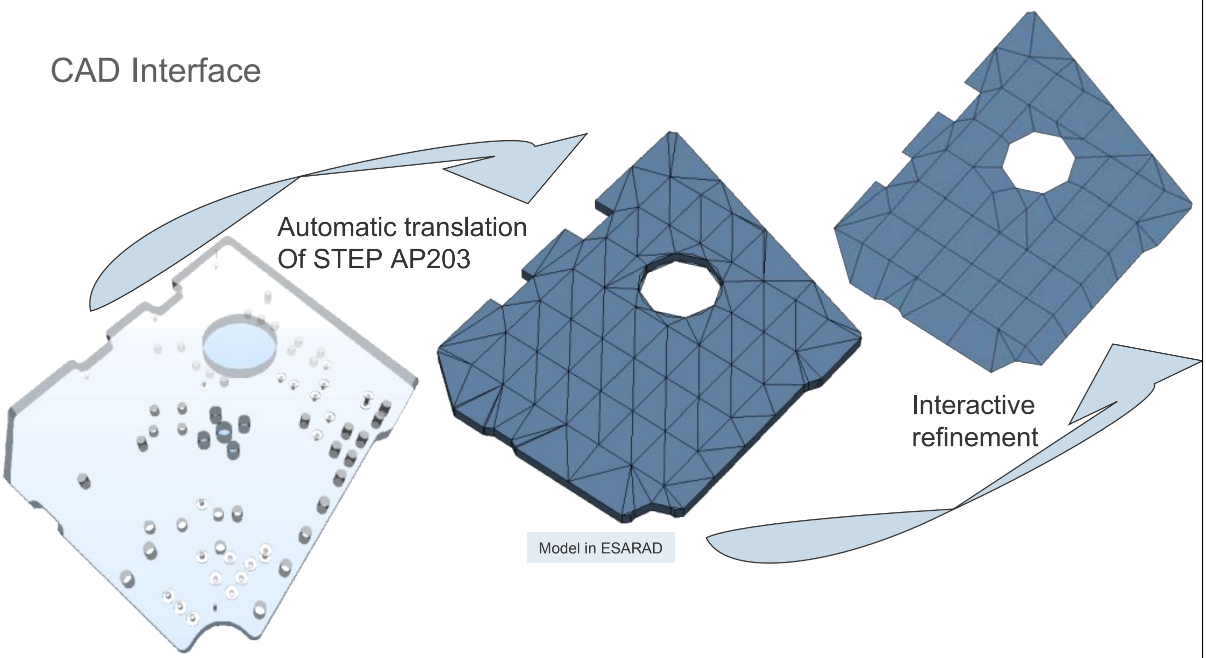
ESARAD 6.2

CAD Interface



ESARAD Status - 27 Oct 2007 - P 14

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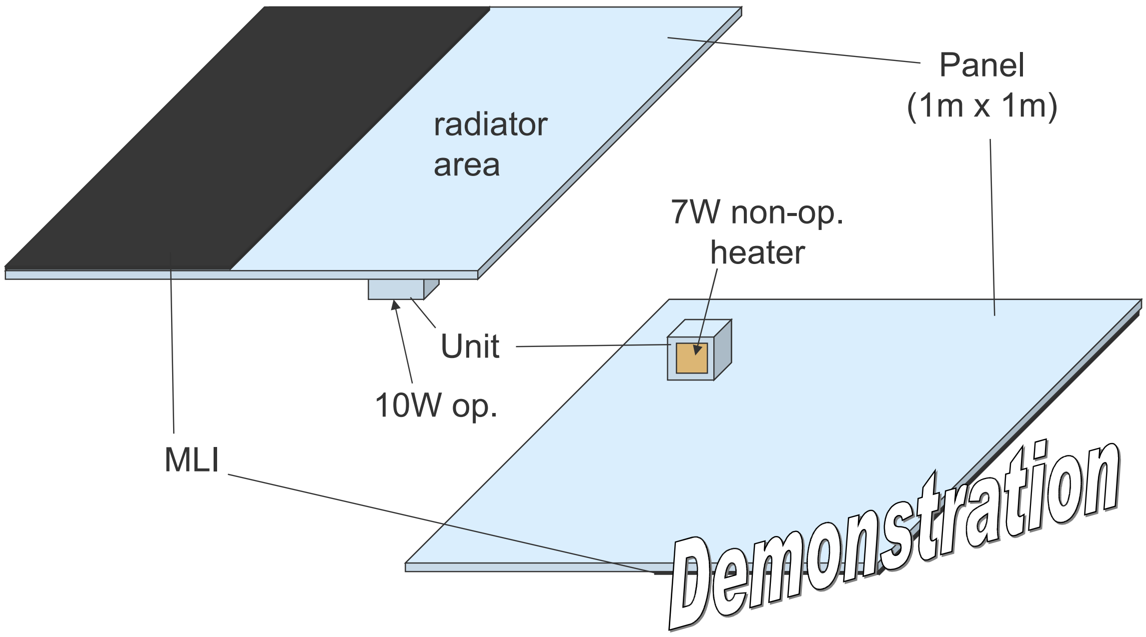
Example Model



TGN IS Presentation - 05/02/2007 - P 15

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www.alstom.com

www.aerospace.power.alstom.com

ALSTOM

Appendix F

Guidelines for high accuracy thermal modelling. Experiences and results from ESA study: Improvement of thermal analysis accuracy

Ulrich Rauscher
(EADS Astrium, Germany)

Guidelines for High Accuracy Thermal Modelling, Experiences and Results from the ESA Study: Improvement of Thermal Analysis Accuracy

Ulrich Rauscher, Astrium GmbH

30th / 31st October 2007

21st European Workshop on Thermal and ECLS Software

All the space you need

EADS astrium

Astrium GmbH

Overview

1. Introduction
2. The Accuracy Aspect in Thermal Modeling
3. The Accuracy in the Solving Process
4. Guidelines in order to improve the accuracy
5. Future Investigations and Next Steps

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Oct. 2007 — p2

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Introduction

- Current and planned scientific Space Missions go constantly to higher accuracy of the instrument payload.
- This higher accuracy of the instruments causes high stability requirements for the instrument structures and instrument I/Fs.
- The stability of the instruments during in orbit operation is disturbed mainly by temperature changes caused by changing external and internal heat loads. These temperature changes induce thermo-elastic deformations of the structure, which influence the alignment of such an instrument structure and leads therefore to a degraded performance of the instrument.
- In order to minimize these effects, the sensible structures are de-coupled from the sources of disturbance by mechanical and thermal means whenever possible. Moreover thermo-stable structures are used to minimize the mechanical deformations.
- However, instruments have reached now a level of stability requirement, where de-coupling and mechanical design means come to border. The remaining influences are in the order of mK down to microK of variation in the structures, which leads to performance influencing deformations of the structures.

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Oct. 2007 — p3

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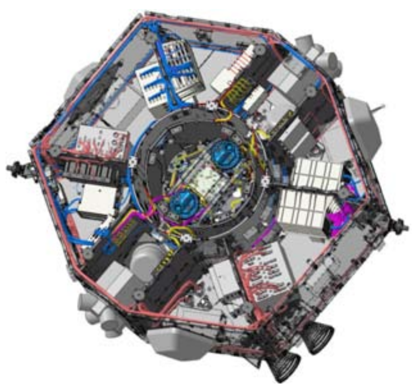
Introduction

Currently investigated missions, in which such phenomena play a role are the LISA pathfinder Mission and Gaia.

In Lisa pathfinder, (launch planned 2009) the sensitive component is a free flying mass in the center of the instrument, which is used for measuring gravitational wave effects. Disturbances are unwanted acceleration of this mass.



This basic requirement on acceleration is broken down to the different types of disturbance sources such as

- gravitational,
- (electro-)magnetic, etc.,
- Thermo-elastic induced accelerations
- and further subsystem and / or discipline specific requirements have been derived.

According to the acceleration requirement, which is expressed in the form of [quantity] / √ Hz the thermal requirement is formulated in the form [K / √ Hz]

The investigated ΔT at the sensors is in the range of 10^{-5} K

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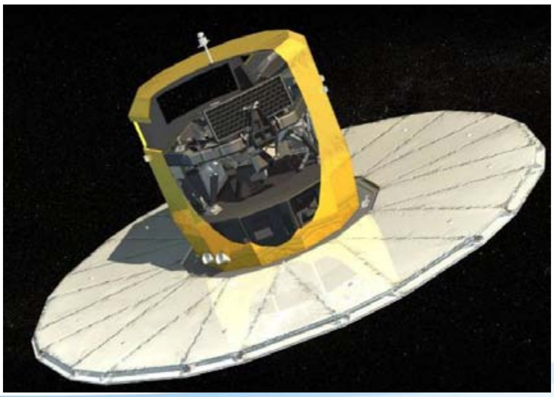
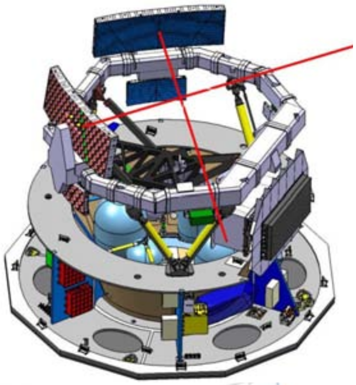
Introduction

- **Gaia** is an optical Telescope positioned at L2 with launch date begin of 2012, currently at end of Project Phase B. Gaia will provide positional, radial velocity and photometric measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars throughout our galaxy. The survey aims for completeness down to magnitude 20, with accuracies of 10 micro arcs second at magnitude 15
- The satellite consists of the SVM, a large deployable sun-shield (diameter 10 m), the telescope with its focal plane assembly mounted on a circular structure made from SiC and a protecting cover, the so-called thermal tent.
- The satellite is pointing with it's –X side to the sun with a solar aspect angle of 45° and performs a rotation about the x-axis in 6h in order to scan the starfield.





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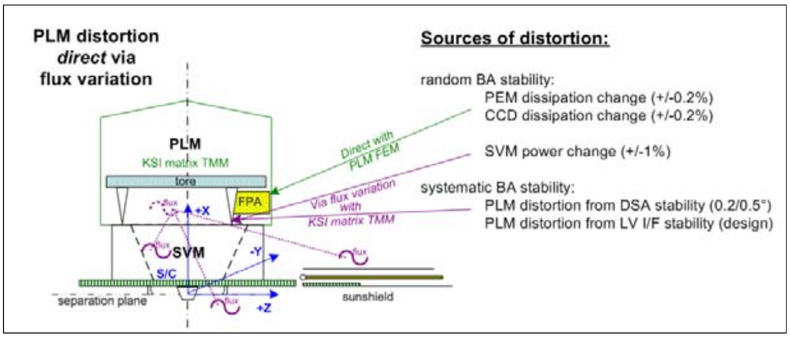
Introduction

The PLM structure is highly de-coupled from the SVM by insulating bipods to the SVM and high performance MLI at the structure itself and at the interface to the PLM enclosure.

The temperature fluctuations which are induced and which have to be analyzed are in the range of several micro K.

The resulting deformation leads to a variation of the basic angle between the 2 line of sights of the telescope in the order of several picorad.



The figure shows an example for the sources of distortion which act on the PLM. The sources can be differentiated in

- direct thermal variations in the telescope structure itself and
- temperature variations in the SVM structure, which cause a deformation of the mechanical interfaces of the PLM.

The distortion sources can moreover be separated in

- systematic distortions, which are coming e.g. from the geometrical configuration in conjunction with the rotation and the sun aspect angle of the satellite, and
- random effects like dissipation variation in components

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Introduction

From the temperature ranges it can be seen that major problem for such instruments is

the Analysis and the Verification of the Performance

in the spacecraft design process.

- Distortion sources and the transfer of these distortions can be verified only by scaling the distortions to higher levels.
- For a big structure like for example at Gaia this verification has to be done for each subsystem separately. With this testing only a characterization of the components can be achieved.
- The final end to end verification of the performance can then only be done with a final thermal and mechanical model.

In order to perform this design and verification process, the analysis tools must be able to reproduce the accuracy in temperature resolution as it will be during operation in Space, in order to validate the performance of the instrument and spacecraft.

For the current projects this means: Reproduction of temperature variations with the analysis tools in the order of 10^{-7} K at the Payload modules. On the other side of the heat transfer chain at the source of distortion the investigated temperature variations are in the range from several K up to 10K.

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The Accuracy Aspect in Thermal Modelling

Accuracy of a Thermal Model can be divided in 2 major field

3. Model Representation

Inaccurate modelling of the system is caused by:

- Discretization errors
- Material data inaccuracy
- Boundary conditions, dissipation assumptions
- For the linear coupling part the modelling uncertainty is still mainly caused by errors and inaccuracies in the, more or less, hand calculations and engineering judgement in the model.
- Simplified radiative modelling.

4. Solving Process

Inaccuracy in the solving process

- Heat imbalance errors
- Truncation and rounding errors in the calculation process, conversion between different number formats
- Influence of different solvers on the iteration process

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The Accuracy Aspect in Thermal Modelling

- Inaccurate modelling errors are user induced errors.
  - Errors from lack of information on configuration or degree of detail and operational boundary conditions in an early project phase.
  - Simplifications in order to keep model at controllable level of nodes and to limit computation time
  - Simplifications in modelling of material data
  - Coupling values which depend highly on configuration and workmanship (MLI)
  - Errors from worst case assumptions
  - The "human" factor: Undetected coupling calculation errors
  - These errors are not necessarily wrong calculations but are also normal steps in the evolution of a design
- Errors in numerical computation cannot be avoided to a certain degree and the user must be aware of them and must know the parameters and rules in the solvers to minimise them.

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The Accuracy in the Solving Process

In the ESA study : Improvement of Thermal Analysis Accuracy mainly the solver related accuracy aspects have been investigated, as in present projects the question arose whether the ESA tools ESARAD and ESATAN are able to resolve these small temperature variations with sufficient accuracy.

The investigations concentrated on:

- Mesh sizing
- ESATAN parameters:
  - Data handling in ESATAN
  - Solver performance steady state and transient solvers
- ESARAD parameters:
  - Number of Rays, Random seed
  - Calculation of External loads and the implementation in ESATAN
- Comparison to the Astrium solver THERMISOL (SYSTEMA)
- A first comparison to the heat transfer approach in the frequency domain

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The Accuracy in the Solving Process

Mesh Sizing

- Mesh sizing has been investigated at the elements of the heat transfer path between distortion source and the interface of the instrument.
- Mesh refinement is useful at locations next to interfaces or changing boundary conditions and at locations where changing temperatures for radiative exchange play an important role in the heat transfer path.
- The results in the study showed, that higher mesh refinement resulted in a damping of the temperature variation at the sensitive location (coming from a coarse model to finer meshing)
- Attention has to be paid to the geometrical representation of sensitive parts: The geometrical model must not be driven by the capabilities of the geometrical representation in the analysis Tool (ESARAD/THERMICA) but on the expected heat flow.
- In order to have useful mesh refinement a pre-analysis with a coarser model should be done, which is used to analyze the heat flow paths from distortion source to sensitive item. The mesh refinement can then concentrate on this path.
- Is a sufficient low heat imbalance and temperature relaxation reached in the model a sufficient mesh refinement can only be checked by variation of the mesh refinement at sensitive locations and comparison of the temperature variation or derived performance parameters of the instrument.

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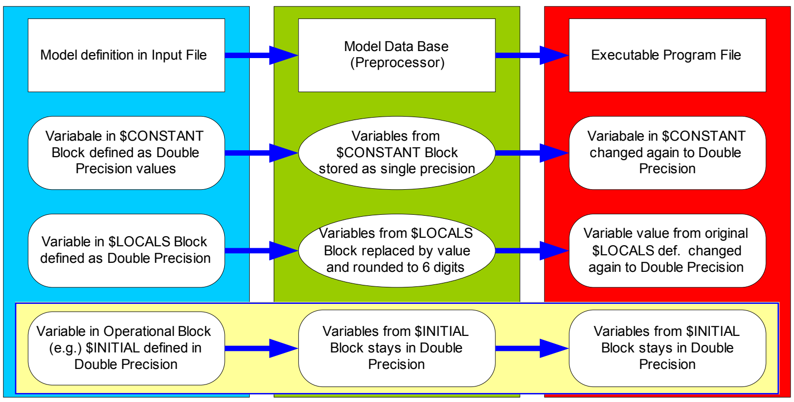
The Accuracy in the Solving Process

ESATAN related Investigations

- Data Handling in ESATAN: Defined Variable Format is changed in ESATAN from input file to executable file



- Values of LOCAL variables are rounded to 6 significant digits
- Value of LOCAL variable defined in D format appears in FORTRAN code in E format
- The only correct output is got for variables defined in operational blocks (e.g. $INITIAL)

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The Accuracy in the Solving Process

- ESATAN Data Handling

Item	defined in	Input Value	Output (in Source Code or via $OUTPUTS)
user variable	$LOCALS	1.123456789	.112346E+01
user variable	$LOCALS	1.123456789D0	.112346E+01
user variable	$LOCALS	1.12345D0	.112345E+01
T	$NODES	123.56	.123559997559E+03
C	$NODES	521.2D0	.521200012207E+03
C	$NODES	751.23	.751229980469E+03
QI	$NODES	5.123D0	.512300014496E+01
QI	$NODES	1.123	.112300002575E+01
GL	$CONDUCTORS	3.1234	.312339997292E+01
GL	$CONDUCTORS	0.01234D0	.123399998993E-01
GR	$CONDUCTORS	0.1051	.105099998415E+00
GR	$CONDUCTORS	0.1051D0	.105099998415E+00
STEFAN	$CONSTANTS	5.6686D-8	.566860016704E-07
user variable	$CONSTANTS	1.23456E-08	.123456000978E-07
user variable	$CONSTANTS	1.23456D-08	.123456000978E-07
user variable	$INITIAL	1.23456E-08	.123456000978E-07
user variable	$INITIAL	1.23456D-08	.123456000000E-07
user variable	$INITIAL	1.23456	.123456001282E+01
array(1)	$ARRAYS	1.123456	.112345600128E+01
array(2)	$ARRAYS	2.123456D0	.212345600128E+01

- This means: If high accuracy is needed for a variable value the definition has to be done in an operational block. This includes also all data, which is normally defined in $NODES, $CONDUCTORS, $CONSTANTS and $ARRAY blocks, like the area, capacitance values, boundary temperatures, Dissipation.

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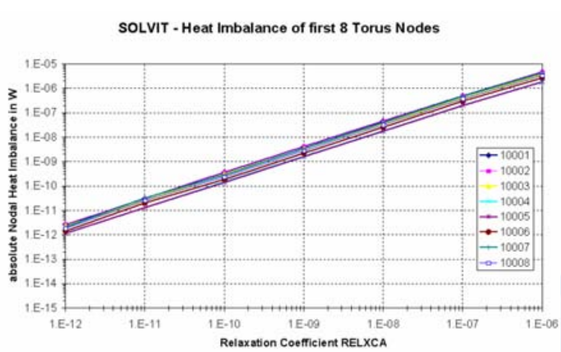
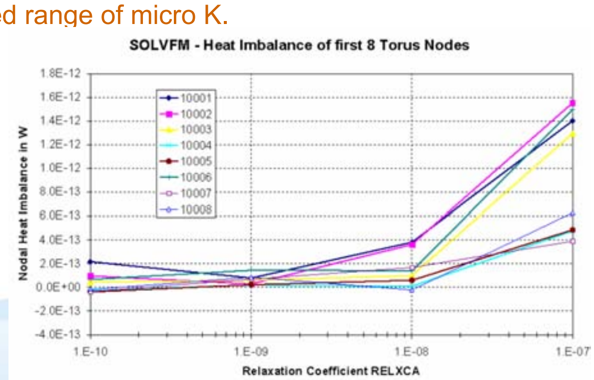
The Accuracy in the Solving Process

- ESATAN Steady State Solvers SOLVIT and SOLVFM

Investigations in the present study showed:

- The matrix invert solver SOLVFM is faster and delivers lower heat imbalance at comparable relaxation coefficient as the successive point iteration solver SOLVIT.
- However: SOLVFM convergence is much more critical than SOLVIT.
- Therefore: If very low heat imbalance and relaxation coefficient is needed SOLVIT is more practical. Proposed way is: set relaxation coefficient to sufficient low value and check then heat imbalance values.
- The temperature level depends highly on reached heat imbalance and relaxation coefficient even in a relaxation range, which is much lower than the investigated temperature accuracy: Example GAIA: investigation in micro K range. RELXCA was varied between 10E-8 and 10E-12. All these calculations lead to different results in the considered range of micro K.





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The Accuracy in the Solving Process

- ESATAN Transient Solvers SLFWBK and SLCRNC
  - Both solvers are in principle identical solvers using the Crank Nicholson forward backward differencing method and a Newton Raphson iteration scheme for solving the equation system.
  - SLCRNC using always the actual temperatures during the iteration process for updating all temperature dependent variable values. SLFWBK uses for the whole iteration the temperature at the begin of the time step. > Advantage for SLCRNC if such couplings (e.g. MLI couplings, temp dependent material values) are used in the coupling definition
  - Main control parameters for the transient calculation is the relaxation coefficient RELXCA and the time step size DTIME. In order to guarantee convergence, the general rule exists to keep the time step at 95% of the time constant CSGMIN of the system. These parameters have been investigated in the present study.
  - Investigation concentrated hereby on the analysis of temperature fluctuations caused by a periodical variation at the boundary of the model (caused by external loads or dissipation variations

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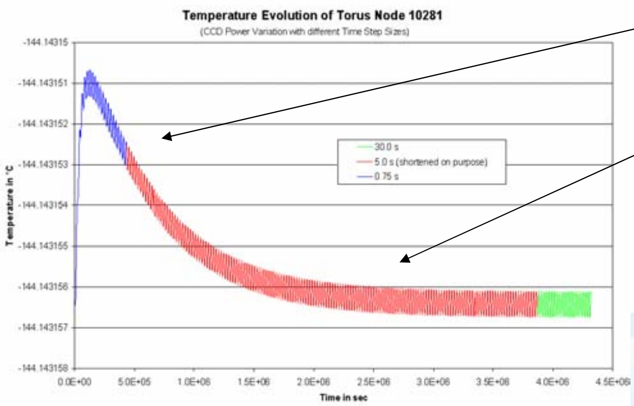
The Accuracy in the Solving Process

- ESATAN Transient Solvers SLFWBK and SLCRNC Results:
  - As expected both solvers are suitable for the high accuracy investigation
  - The results showed that not necessarily such a small time step has to be used as 95% of CSGMIN would mean.
  - Example GAIA: 95% of CSGMIN for the GAIA model means 0.75 sec at a period of 21600 sec. All results for other time steps up to 30 sec came to exactly the same results.
  - A steady state pre-calculation with very low heat in-balance is very important for an effective transient analysis in order to avoid drifting of overall temperature level

Each period in the graph is 6 h



Problem of Drift in the Transient Calculation leads to long simulation time !

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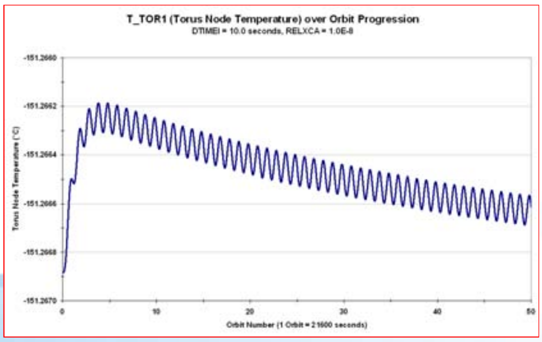
The Accuracy in the Solving Process

- ### ESATAN Transient Solvers SLFWBK and SLCRNC Results DRIFTING Problem:
  - For the drifting of the overall temperature level at sensitive locations 2 different effects could be seen in the analyses
    1. Drift in transient calculation which can be deleted by sufficient low relaxation coefficient
       - Main reason is here the difference between heat imbalance in steady state and final balance in transient.
    2. Drift which could not be removed
       - For the cases where variation was induced by external heat flux variation the drifting could not be removed.
  - However: The transient calculation showed very stable behavior in the temperature answer at sensitive locations. The drift was superimposed to this variation at considered period. -> Therefore a De-Trending of the results has been performed in a region of the result, where constant drifting could be seen.



All the space you need
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The Accuracy in the Solving Process

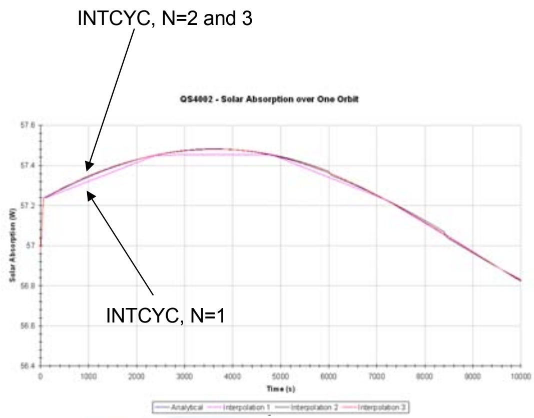
- ### ESATAN Transient Solvers SLFWBK and SLCRNC Results Implementation of External Loads
- With Respect to previous Problem the implementation of the External Loads, received by ESARAD have been investigated.
- Result here is that interpolation routines in ESATAN delivers sufficient possibilities to adapt the external loads interpolation, depending on
  - Sudden changes in illumination
  - Multi-reflections

By adapting:
- Angle gap and Eclipse offset parameter in ESARAD
- Number of independent variable pairs in the cyclic interpolation routine INTCYC

Shadowing of special parts can not be automatically detected but may not be neglected.

Such effects have to be overcome by analytical investigations of such points in time or a sufficient small number for the angle gap.

In the example of GAIA, where sun comes only from the –X side of the satellite and the variation is induced by the rotation of the satellite no difference could be seen in the results between the interpolation degree between 1 to 3 and an angle gap of 40°
(no eclipse)



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The Accuracy in the Solving Process

ESARAD Aspects

- For the ESARAD modeling mainly the points are important, which have been discussed for the meshing of the item an the loads implementation above:
  - Nodal breakdown shall be oriented on heat flow path
  - Calculation points have to be critically assessed in order to calculate really at extreme points of irradiation and changes of irradiation
- Number of Rays for REF calculation / Random Seed for REF calculation
  - Investigation in number of rays and the check on consistency with different numbers for the random seed showed, that only very high number of rays of > 50000 leads to such a confidence in the REF, that also different random seed values lead to the same temperature results at the sensitive locations of high accuracy models.
  - In the GAIA example different random seed values at 20000 rays lead to a difference in temperature of up to 0.15 K at the sensitive parts. For 50000 rays this value goes down to 0.015K One can see here again that absolute temperatures cannot be investigated with high accuracy.
  - It is clear that higher number of rays means a strong increase in computation time.

Gaia example

Number of rays	Angle gap (°)	CPU time (mins)
5,000	10	34
15,000	10	67
15,000	15	67
15,000	20	59
20,000	5	174
20,000	10	114
20,000	15	85
20,000	20	75
20,000	30	64
20,000	40	58
50,000	10	259
100,000	10	500
200,000	20	698

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The Accuracy in the Solving Process

Comparison to THERMISOL

- The comparison to the Astrium Solver THERMISOL V4.0.34 was done with 2 load cases for different distortion sources. The solver is in principle able to read ESATAN input files with small changes in variable definition and solver routines.
- THERMISOL has not the problem with the variable data format conversion as the solver is able to handle double precision data at every stage from input file to executable program.
- The Steady State solver performance of THERMISOL reaches lower heat imbalance at same relaxation coefficient compared to ESATAN. Therefore the drifting in transient disappeared at higher relaxation coefficient than in ESATAN. For the case, where in ESATAN the drifting could not be removed, THERMISOL showed the same behavior.
- Therefore THERMISOL is an alternative solver, which is useful for high accuracy problems. Any redefinition of variables or constants on operational blocks is not necessary.

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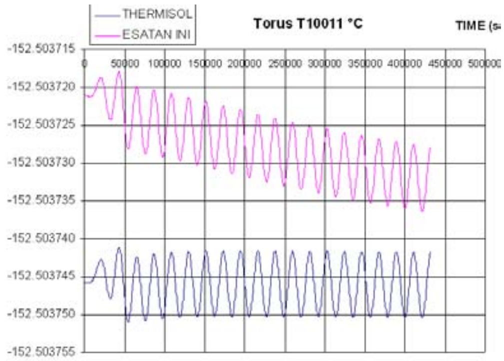
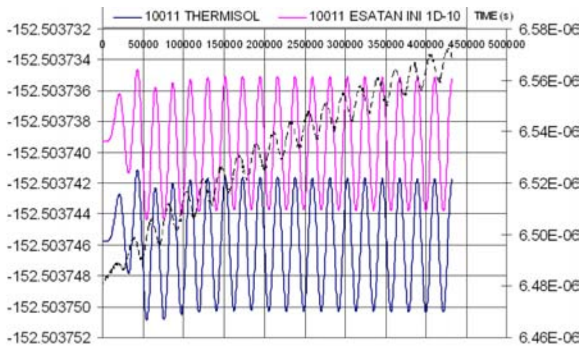
The Accuracy in the Solving Process

- Comparison to THERMISOL

ESATAN vs THERMISOL at RELXCA = 1.0E-8



ESATAN vs THERMISOL at RELXCA = 1.0E-10



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Guidelines in order to Improve the Accuracy

- MESH Size: Perform coarse model analysis for identification of heat flow paths in the investigated item then perform mesh refinement along heat flow path. Check result with heat imbalance /Relaxation of model and change of performance.
- ESATAN data handling: Define all sensitive values in Double Precision in $INITIAL in order to guarantee same value in Input and Executable program file, adapt output format to a format where relevant changes can sufficiently be resolved.
- ESATAN Solvers Steady State
  - SOLVIT and SOLVFM can both be used for high accuracy analysis
  - SOLVFM is faster and achieves small heat imbalances at larger RELXCA values than SOLVIT, but requires a DAMPT value less than 1.0 (e.g. 0.5)
  - For an investigated temperature resolution of 10 µK it is necessary to achieve very small heat imbalances (i.e. to work with RELXCA values as low as possible) in order to avoid small temperature drifting of the transient solution to a final temperature level.

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Guidelines in order to Improve the Accuracy

- ESATAN Solvers Transient
  - The solvers showed very stable results for temperature variations in the range of 10^{-6}K.
  - SLCRNC is the recommended solver because of the update of temperature dependent variables during the iteration process
  - Time step size must not necessarily be 0.95 x CSGMIN. With respect to calculation time it has been found that the optimum is at a value, which is about 10 times larger. In order to optimize this the loop count in the *.MON file can be checked.
  - The drifting of the transient solution can be diminished by minimizing the heat flux balance in the steady state pre-calculation. If this is not possible a de-trending of the results have to be used in a time period, where a constant drift of the results can be clearly identified.

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Guidelines in order to Improve the Accuracy

- ESARAD Parameters
  - Modeling and Mesh density shall be oriented at heat flow in the model. Minimum one loop has to be expected for optimization of the mesh.
  - In order to achieve stable REF calculation results the number of rays has to be so big, that different random seed values lead not to a significant temperature change in the considered range of analyzed temperature. Ray number > 50000 is proposed.
  - Angle gap and additional calculation points shall consider all expected extremes and sudden changes in illumination of an investigated item.

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Future Investigations and Next Steps

- Comparison to other Approach: Investigation in the Frequency Domain with a Heat Transfer Function
  - For the Study a comparison has also be performed between ESATAN results to a linearised version of the ESATAN model. This model could then be treated in MATLAB with an Ordinary Differential Equation Solver (ODE) From this model a heat transfer function could be evaluated, which was used for analysis in the frequency domain, based on a steady state temperature distribution calculated with ESATAN.
  - With the heat transfer function it is possible to get information in the form of

    GAIN = Output / Input

    The Input is the amplitude of variation for a parameter or a set of parameters of the model. The output is the amplitude of the variation of temperatures at a set of nodes. The gain is the amplification /damping between Input and Output
  - First comparison runs with the Gaia model (with about 1900 nodes) showed good compliance between the ODE solver results in the time domain and the HTF in the frequency domain but big differences to the ESATAN results. (ESATAN temperature variation was about factor 4 to 10 larger)
  - It is planned to continue the investigation in this area and to identify the differences between ESATAN results and HTF results. For this validity of the linearization of the model, especially at locations with bigger temperature changes, has to be checked

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Appendix G

ESATAN Thermal Suite - development status

Chris Kirtley
(ALSTOM, United Kingdom)

Thermal & ECLS Software Workshop

ESATAN™ Thermal Suite

Product Development 2007

Author: Chris Kirtley
Date: 30th Oct 2007

POWER SYSTEMS
Aerospace

ALSTOM

Introduction

ESATAN™ Thermal Suite.

- Outline the current status of the suite.
- Present developments performed over the last year.
  - Resulting in a new release of the suite.
- Strong team available for you over the next 2 days.
  - Workshop is a major event for us.
  - Time for us to listen to what you want.
  - Reassess & update our development plans.

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ESATAN Thermal Analyser

Jun 2003	Dec 2004	Jun 2005	Dec 2005	Oct 2006
v8.9	v9.2	v9.4	v9.6	ESATAN™ 10

Release of ESATAN™ 10 announced at last years workshop.

- Included a completely re-written Training Guide.
  - Models defined by a Space Thermal Engineer.
  - All models provided with the installation.
- On request, ported the software to SUSE Linux.
  - SUSE & CentOS now supported.
- Implemented feature requests.
- Completely new parametric analysis architecture.
  - Easily run multiple solutions, varying parameters.
  - Re-run an analysis using different control parameters.
  - Supported by Parametrics Manager Interface.

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ESATAN Thermal Analyser

Jun 2003	Dec 2004	Jun 2005	Dec 2005	Oct 2006
v8.9	v9.2	v9.4	v9.6	ESATAN™ 10

Release of ESATAN™ 10 announced at last years workshop.

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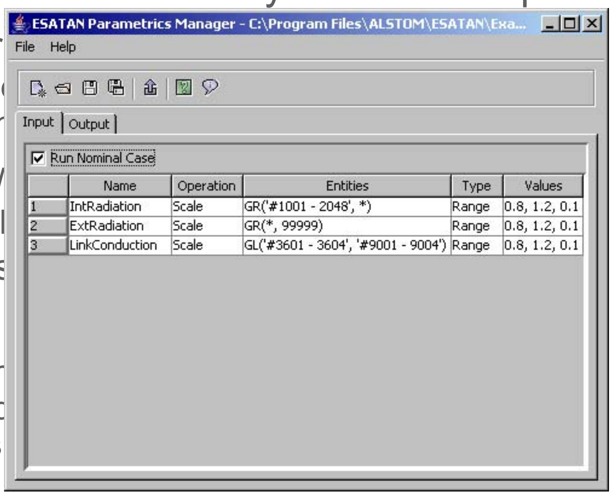
- Completely new parametric
  - Easily run multiple solutior
  - Re-run an analysis using c
  - Supported by Parametrics



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POWER SYSTEMS ALSTOM

Thermal Network Pre- & Post-processor

Mar 2006 — v2.0
Jul 2006 — v2.2
Apr 2007 — v3.0

ThermNV 3 Beta demonstrated at the 2006 workshop.

- Very positive feedback received.
  - In response, extended development to implement your requests.
- Released April 2007.
- Provided new reports types.
  - Delta reports.
  - Limits reports.
- Graphical representation of limits report.
- Analysis across results from multiple sets.

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POWER SYSTEMS ALSTOM

ESATAN™ Thermal Suite

Jun 2003 — v8.9
Dec 2004 — v9.2
Jun 2005 — v9.4
Dec 2005 — v9.6
Oct 2006 — ESATAN™ 10
Oct 2007 — ESATAN™ 10.2

ESATAN 10.2 is now available

- Thermal stability analysis
- PID Controller extended
- Peltier element extended
- Easy assess to internal data
- Export thermal data
- Extended control of GFF output
- Improved error messaging
- Address user reported issues

ThermXL 4.6 is now available

- Thermostat function
- PID Controller function
- Extended link to ESARAD
- Port to Microsoft® Office 2007
- Port to Microsoft® Vista®
- Address user reported issues

- These releases in direct response to your requests.
  - User survey 2007; Thank You for your support.

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 Release

ESATAN 10.2
- PID Controller extended
- Peltier element extended
- Improved error messaging
- Easy assess to internal data
- Thermal stability analysis
- Extended control of GFF output
- Export thermal data

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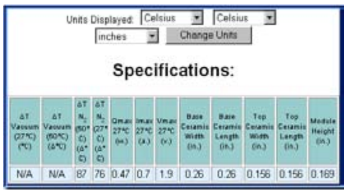
ESATAN™ 10.2 (PID/Peltier)

- Extension of Peltier Device system element.
  - Original element defined by low-level design parameters.
    - Defined by number of couples & geometric factor.
    - Data not always easily available from manufactures.
  - Extended to higher-level parameters.
    - Defined by.
      - Maximum INTENSITY => geometric factor.

        +
      - Maximum POWER => number of couples.

        OR
      - Maximum VOLTAGE => number of couples.



Marlow Peltier Device

- Extension of PID Controller system element.
  - Allow negative response (optional).

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Error Handling)

- Enhancement of Error Messaging.
  - Format & content of error message improved.

```
@
@---------------------------------------------------- | MESSAGE    1 |-
@
@@@@  FATAL ERROR
@
@      Problem.............: Insufficient dynamic storage
@      Current action......: Reading node pairs for inter-model links
@      Info................: Need at least 1682 storage locations.
@                             Set DYSTOR on the $EXECUTION line of the
@                             main model:
@                                $EXECUTION, DYSTOR = 10000
@      Context.............: Initialising model before solution
@
@      Reference...........: (LOADI ,    1)
@
@-------------------------------------------------------------------
@
```

  - Close-out user-reported issues.

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Data Access)

- Requirement to access ESATAN data structures.
  - Full set of node GET & SET routines.
    - e.g. `GETC(1)` [get capacitance of node 1].
    - e.g. `SETT(1, 20.0D0)` [set capacitance of node 1 = 20.0D0].
  - Full set of conductor GET & SET routines.
    - e.g `GETGL(CURRENT, 1, 2)` [get value of GL(1, 2)].
    - e.g `SETGL(CURRENT, 1, 2, 120.0D0)` [set GL(1, 2) = 120.0].
  - Facilitates accessing internal data from external routines.
  - Simplifies constructing loops within operation blocks.

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Stability)

- Thermal Stability Analysis.
  - Stringent requirements coming from projects, Lisa Pathfinder.
    - Critical to isolate components against thermal disturbances.
    - Interested over a specified frequency range.
  - Can use a traditional approach to analysis stability.
    - Transient runs, time consuming.
    - Associated issues related to sampling & analysing response.
  - ESATAN 10.2 launches its new Thermal Stability Analysis capability.
    - Provided as a new solver, `SLFRTF`.
    - Dump Gain & Phase to CSV for a given frequency range, `DMPFR`.
    - During a solution, get Gain & Phase at given frequency, `EVALFR`.

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Stability)

- Stability analysis performed around steady state condition.
- Analysis of complete model.

```
$EXECUTION
      CALL SOLVIT # Calculate steady state
#
      CALL SLFRTF # Stability analysis
```

- … and then, output gain and phase for specified input / output pairs over a given range of frequencies.

```
# Output gain/phase between radiator and unit1
      CALL DMPFR(‘input’, RADIATOR, ‘output’, UNIT1,
                 f_start, f_end, n_freq, ‘ ‘)
```

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Stability)

- Gain and Phase dump (CSV) files generated.
  - Data easy to post-process, for example with MS® Excel.
  - Files generated, $\underbrace{\textit{model}\text{.fr\_gain.csv and }\textit{model}\text{.fr\_phase.csv}}$.

	A	B	C	D
1	# Frequency Response - Gains			
2	# LISA_PF	24 OCTOBER 2007 15:45:00		
3	# ESATAN 10.2			
4	#			
5	# Frequency	gain(Q27010, T21501)	gain(Q27020, T21501)	gain(Q27030, T21501)
6	1.00E-08	0.174623	0.147859	0.171879
7	1.17E-08	0.174622	0.147859	0.171878
8	1.38E-08	0.174621	0.147858	0.171877
9	1.62E-08	0.174619	0.147857	0.171875
10	1.91E-08	0.174617	0.147855	0.171873
11	2.24E-08	0.174614	0.147852	0.17187
12	2.63E-08	0.17461	0.147849	0.171866
13	3.09E-08	0.174604	0.147844	0.171861
14	3.63E-08	0.174596	0.147838	0.171853
15	4.27E-08	0.174586	0.147828	0.171843
16	5.01E-08	0.174571	0.147816	0.171828
17	5.89E-08	0.17455	0.147799	0.171809
18	6.92E-08	0.174522	0.147775	0.171781
19	8.13E-08	0.174482	0.147742	0.171743
20	9.55E-08	0.174428	0.147697	0.171691
21	1.12E-07	0.174354	0.147635	0.171619
22	1.32E-07	0.174251	0.147549	0.17152
23	1.55E-07	0.174109	0.14743	0.171384
24	1.82E-07	0.173915	0.147268	0.171196
25	2.14E-07	0.173647	0.147044	0.170938

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ESATAN™ 10.2 (Thermal Stability)

- Gain and Phase dump (CSV) files generated.
  - Data easy to post-process, for example with MS® Excel.
  - Files generated, $\underbrace{\textit{model}\text{.fr\_gain.csv and }\textit{model}\text{.fr\_phase.csv}}$.

	A	B	C	D
1	# Frequency Response - Gains			
2	#	OCTOBER 2007 15:45:00		
5	# Frequency	ga T21501)	gain(Q27020, T21501)	gain(Q27030, T21501)
6	1.00E-08	0.174623	0.147859	0.171879
7		0.174622	0.147859	0.171878
8	1.38E-08	0.174621	0.147858	0.171877
9	1.62E-08	0.174619	0.147857	0.171875
10	1.91E-08	0.174617	0.147855	0.171873
11	2.24E-08	0.174614	0.147852	0.17187
12	2.63E-08	0.17461	0.147849	0.171866
13	3.09E-08	0.174604	0.147844	0.171861
14	3.63E-08	0.174596	0.147838	0.171853
15	4.27E-08	0.174586	0.147828	0.171843
16	5.01E-08	0.174571	0.147816	0.171828
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ESA Thermal & SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Stability)

- Gain and Phase dump (CSV) files generated.
  - Data easy to post-process, for example with MS® Excel.
  - Files generated, *model*.fr_gain.csv and *model*.fr_phase.csv.

	A	B	C	D
1	# Frequency Response - Gains			
		gain(Q27010, T21501)	g	(Q27030, T21501)
		0.174623		0.171879
				0.171878
8	1.38E-08	0.174621	0.147858	0.171877
9	1.62E-08	0.174619	0.147857	0.171875
10	1.91E-08	0.174617	0.147855	0.171873
11	2.24E-08	0.174614	0.147852	0.17187
12	2.63E-08	0.17461	0.147849	0.171866
13	3.09E-08	0.174604	0.147844	0.171861
14	3.63E-08	0.174596	0.147838	0.171853
15	4.27E-08	0.174586	0.147828	0.171843
16	5.01E-08	0.174571	0.147816	0.171828
17	5.89E-08	0.17455	0.147799	0.171809
18	6.92E-08	0.174522	0.147775	0.171781
19	8.13E-08	0.174482	0.147742	0.171743
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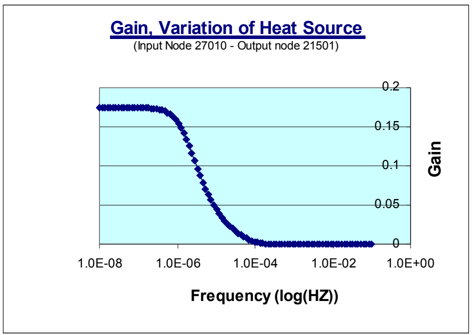
25	2.14E-07	0.173647	0.147044	0.170938

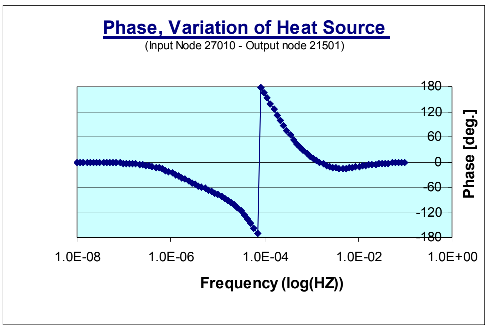
ESA Thermal &

R SYSTEMS

ESATAN™ 10.2 (Thermal Stability)

- Gain and Phase dump (CSV) files generated.
  - Data easy to post-process, for example with MS® Excel.
  - Files generated, *model*.fr_gain.csv and *model*.fr_phase.csv.
- Provides plots of gain/phase against frequency.





- … or easily plot output PSD versus frequency.

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POWER SYSTEMS

ESATAN™ 10.2 (Thermal Data Output)

Thermal data output.

- Provide finer control of data stored within the GFF file.
  - Select individual nodes, groups, alias.
  - Select specific nodal entities, T, QI, QE, …
  - Select conductor types, GL, GR, GF, …

```
CALL DMPGFF('#10-110','NODES(T) CONDUCTORS(GL)',CURRENT, ' ')
```

  - Easier pre- and post-processing within ThermNV.
  - ESARAD 6.2 supports extended routine.

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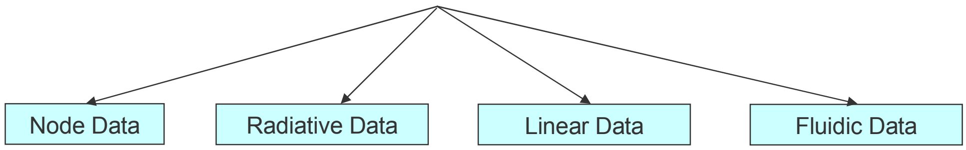
POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Data Output)

Thermal Data Output.

- Export basic thermal model data to CSV format, `DMPTHM`.
  - Direct request from users.
  - Dumps data at given point in time.
  - Output in vector / matrix format.



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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Data Output)

Thermal Data Output.

- Export basic thermal model data to CSV format, `DMPTHM.`

	A	B	C	D	E
1	# Basic Thermal Model Data - Nodes				
2	# H_SECTION		27 OCTOBER 2007		14:27:13
3	# ESATAN 10.2				
4	#				
5	# T	C	Q		
6	138.101	170.834	0		
7	144.792	41.7591	52.753		
8	142.218	82.5482	0		
9	139.887	81.6699	0		
10	139.287	81.4437	0		
11	138.964	40.661	0		
12	-273.15	0	0		
13	135.295	55.318	0		
14	135.66	110.826	0		
15	136.298	111.159	0		
16	135.705	110.85	0		
17	135.386	55.3417	0		
18	-273.15	0	0		

s.

nt in time.

format.

Linear Data

Fluidic Data

ıg in third-party tools, e.g. MATLAB

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POWER SYSTEMS ALSTOM

ESATAN™ 10.2 (Thermal Data Output)

Thermal Data Output.

- Export basic thermal model data to CSV format, `DMPTHM.`
  - Direct request from users.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	# Basic Thermal Model Data - Linear Conductances												
2	# H_SECTION			27 OCTOBER 2007	14:27:13								
3	# ESATAN 10.2												
4	#												
5	# GL												
6	0	0	0	14.5954	0	0	0	0	0	14.4568	0	0	0
7	0	0	18.1443	0	0	0	0	0	0	0	0	0	0
8	0	18.1443	0	17.8684	0	0	0	0	0	0	0	0	0
9	14.5954	0	17.8684	0	17.7035	0	0	0	0	0	0	0	0
10	0	0	0	17.7035	0	17.6516	0	0	0	0	0	0	0
11	0	0	0	0	17.6516	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	17.2412	0	0	0	0
14	0	0	0	0	0	0	0	17.2412	0	17.2976	0	0	0
15	14.4568	0	0	0	0	0	0	0	17.2976	0	17.3001	0	0
16	0	0	0	0	0	0	0	0	0	17.3001	0	17.2489	0
17	0	0	0	0	0	0	0	0	0	0	17.2489	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0

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ESATAN™ 10.2 (Thermal Data Output)

Thermal Data Output.

- Export basic thermal model data to CSV format, `DMPTHM`.
  - Direct request from users.
  - Dumps data at given point in time.
  - Output in vector / matrix format.

Node Data	Radiative Data	Linear Data	Fluidic Data

  - Useful for post-processing in third-party tools, e.g. MATLAB

POWER SYSTEMS ALSTOM

ThermXL 4.6 Release

<u>ThermXL 4.6 is now available</u>
- Port to Microsoft® Office 2007
- Port to Microsoft® Vista®
- Extended link to ESARAD
- Thermostat function
- PID Controller function

POWER SYSTEMS ALSTOM

ThermXL 4.6

- ThermXL 4.6 aimed at responding to user requests.
  - Now compatible with MS® Office 2007.
  - Now compatible with MS® Vista®.
    - Validated with Office XP & 2007 and Vista & 2007 configurations.
  - Extension of import model from ESARAD v6.2.
    - Imports complete network, including non-geometric nodes/conductors.
    - Imports boundary conditions (temperature / heat load).

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ThermXL 4.6, continued

- User survey requests.
  - Modelling a thermostat => `STMThermostat.`
    - Implemented as a user-callable function.
    - Corresponds to ESATAN THRMST routine.
  - Modelling a PID Controller => `STMPIDController.`
    - User-callable function.
    - Corresponds to ESATAN PID Controller system element.

example

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ThermXL 4.6 (Example)

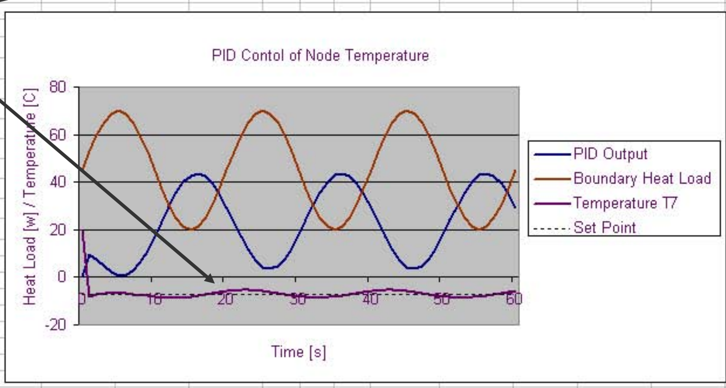
L7 = =STMPIDController(Nodes!D16,Nodes!D17,Nodes!D15,Nodes!D18,Nodes!D19,Nodes!D20,Nodes!D21,Nodes!D22,Nodes!D23,Nodes!D24)

ThermXL Nodes TRANSIENT

ThermXL — ESATAN FHTS ESARAD ThermNV thermal analysis tools from ALSTOM Power

Group	Number	Label	Type	mC	α	ε	Area	QS	QA	QE	QI	T0 [C]	T [C]	RCTime	Imbalance
	10	Wall 1	D	1.00E-01	0.00	0.00	1.00E+00					20.00	4.79	2.78E-03	2.10E-01
	12	Interm 1	D	1.00E-01	0.00	0.00	1.00E+00					20.00	1.99	3.45E-03	1.72E-01
	14	Interm 2	D	1.00E-01	0.00	0.00	1.00E+00					20.00	-1.44	4.35E-03	1.12E-01
	16	Interm 3	D	0.00E+00	0.00	0.00	1.00E+00				2.94E+01	20.00	-5.89	0.00E+00	-1.90E-03
	18	Interm 4	D	0.00E+00	0.00	0.00	1.00E+00					20.00	-11.62	0.00E+00	-1.04E-03
	20	Wall 2	D	0.00E+00	0.00	0.00	1.00E+00					20.00	-16.28	0.00E+00	4.55E-13
	100	Hot End	D	0.00E+00	0.00	0.00	0.00E+00				4.50E+01	20.00	7.04	0.00E+00	-5.47E-13
	200	Cold End	B	0.00E+00	0.00	0.00	0.00E+00					-20.00	-20.00	0.00E+00	7.45E+01

PID Controller	PID1
Temperature of Node 7	-5.89
Set Point Temperature	-7
Proportional Term (P)	6
Integral Term (I)	3.5
Differential Term (D)	0.1
PID Maximum Output	60
PID Minimum Output	0
Minimum Error	0
Allow Negative Response	OFF



back

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Conclusion

- ESATAN 10.2 is now available for download.
  - Implements features requested by users.
  - New Thermal Stability Analysis solver.
- ThermXL 4.6 is now available for download.
  - As for ESATAN, implements features requested by users.
  - Now available on MS Vista & Office 2007.
- ESATAN is a powerful tool integrated within the ESARAD graphical user interface.
- Strong team available for you over the next 2 days.
  - Workshop is a major event for us.
  - Time for us to listen to what you want.

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www.aerospace.power.alstom.com
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Appendix H

LISA Pathfinder thermal stability analysis

Denis Fertin
(ESA/ESTEC, The Netherlands)


esa SCIENCE
LISA Pathfinder
LISA Pathfinder
thermal stability
analysis
D. Fertin
European Workshop Thermal
& ECLS Software
ESA-ESTEC, Noordwijk,
30-31 2t October 2007


LISA Pathfinder
esa SCIENCE
Lpf thermal stability analysis

LISA Pathfinder

Table of contents

LISA Pathfinder

LISA Pathfinder

- First fundamental physics science mission.
- To prepare for the Lisa mission by testing the concept of gravitational wave detection:
  - Demonstrating that the required force noise floor can be achieved (appropriate S/N ratio will be reached for LISA).
- To validate in flight technologies not fully testable on ground:
  - Inertial sensor: test mass cannot be free floating on the ground,
  - FEEPs: microNewton force is difficult to measured.

LISA Pathfinder

Mission objective

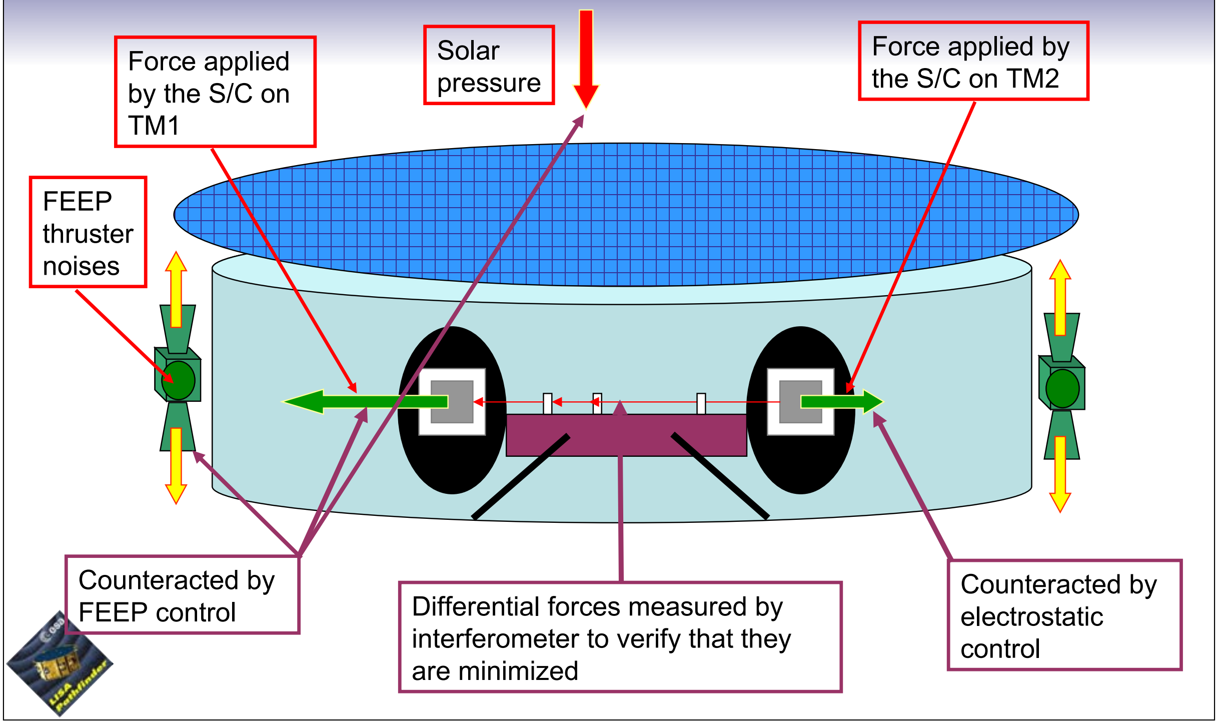
- Mission objective: verify that a test-mass can be put in pure gravitational free-fall within 3×10^{-14} m/s²/√Hz between 1 mHz and 30 mHz

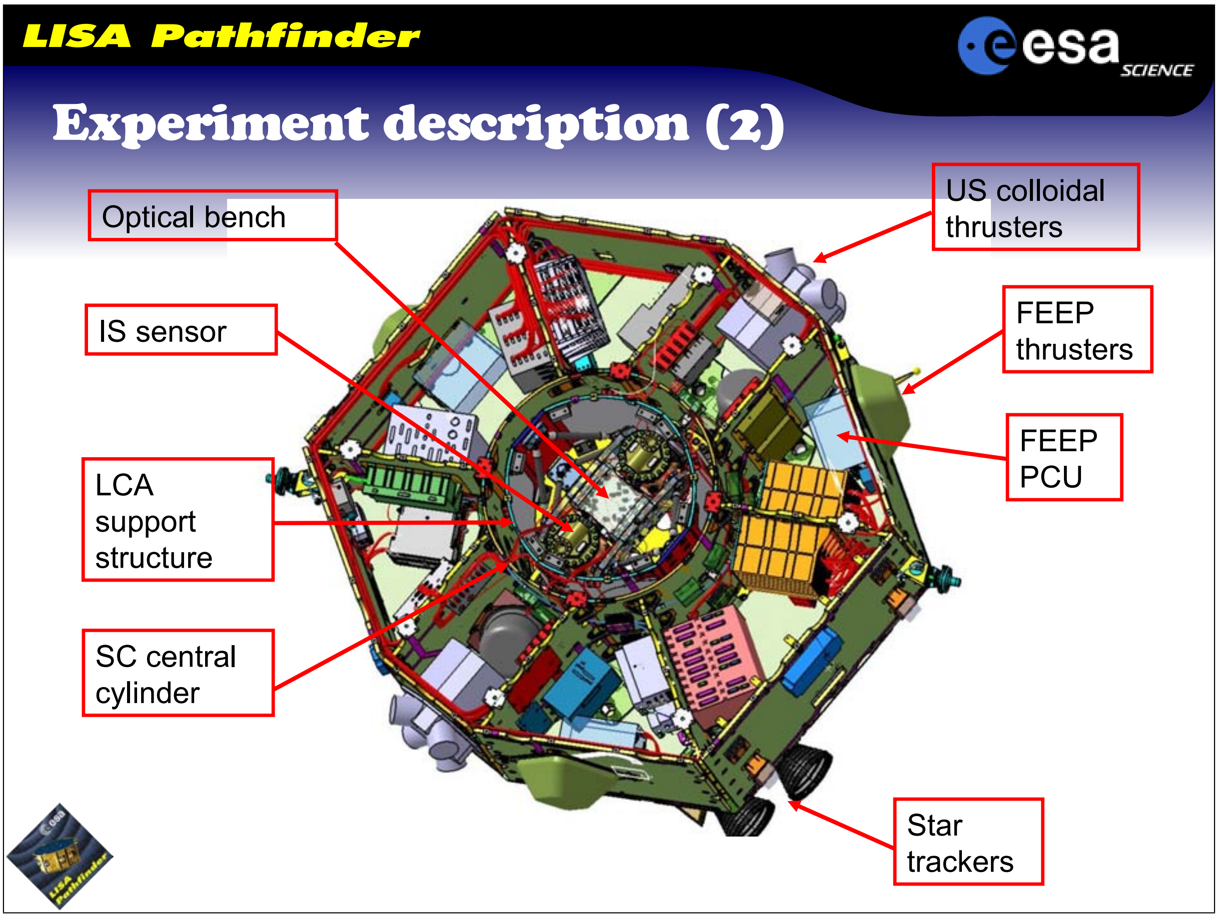
$$S_a^{1/2}(f) \leq 3\times10^{-14}\left[1+\left(\frac{f}{3mHz}\right)^2\right] ms^{-2}/\sqrt{Hz}$$

- Sources of force noise must be minimized:
  - ⇨No pressure force or mechanical contact force: “drag-free” mission.
  - ⇨No electromagnetic forces.
  - ⇨No self-gravity forces from SC and instrument itself.
- Differential acceleration measurement must be one order of magnitude better:
  - ⇨ Measurement by interferometry with accuracy better than 9 [pm/√Hz].

LISA Pathfinder

Experiment description (1)




LISA Pathfinder
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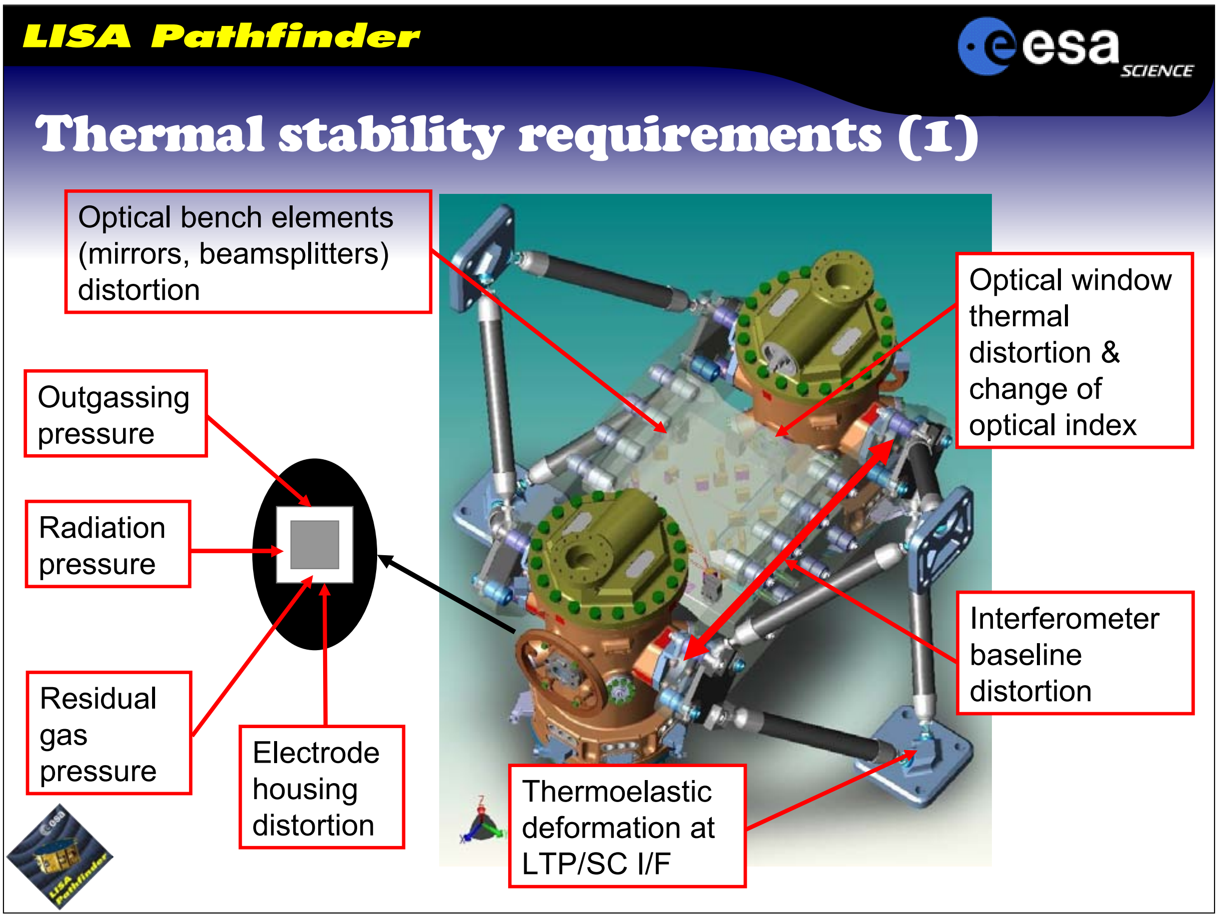
Experiment description (2)
Optical bench
IS sensor
LCA support structure
SC central cylinder
US colloidal thrusters
FEEP thrusters
FEEP PCU
Star trackers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Thermal stability requirements (1)
Optical bench elements (mirrors, beamsplitters) distortion
Outgassing pressure
Radiation pressure
Residual gas pressure
Electrode housing distortion
Thermoelastic deformation at LTP/SC I/F
Optical window thermal distortion & change of optical index
Interferometer baseline distortion

LISA Pathfinder

Thermal stability requirements (2)

- Mission performance requirements expressed as power spectrum density:

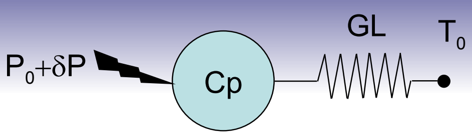
  ⇒ all thermal requirements are also expressed as power spectrum density.

- What is power spectral density function?

  ⇒ Power spectral density function (PSD) shows the strength of the variations (energy) as a function of frequency. In other words, it shows at which frequencies variations are strong and at which frequencies variations are weak.

LISA Pathfinder

A simple thermal filter (1)



$$C_p\left[\frac{dT_1}{dt}\right] = GL\times(T_0 - T_1) + (P_0 + \delta P)$$

- Steady-state: $\left[\frac{dT_1}{dt}\right] = 0 \text{ and } \delta P = 0 \Rightarrow T_1 = T_0 + \frac{P_0}{GL}$

- Transient: $C_p\left[\frac{\delta T_1}{dt}\right] + GL\times\delta T_1 = \delta P$

ω=0

- Sinusoidal power variation:

$$\delta P_1(t) = P_{10}\times e^{j\omega t}$$
$$\delta T_1(t) = T_{10}\times e^{j\omega t}$$
$$(C_p j\omega + GL)T_{10}\times e^{j\omega t} = P_{10}\times e^{j\omega t}$$

⇒ $$\delta T_1(j\omega) = \frac{\delta P_1}{GL}\times\frac{1}{\left(1 + j\omega\times\frac{C_p}{GL}\right)}$$

LISA Pathfinder

A simple thermal filter (2)

- From the linearized thermal model, the thermal filter gain and phase plot can be derived. They express how a power or temperature boundary fluctuation is attenuated at another node by the thermal network.

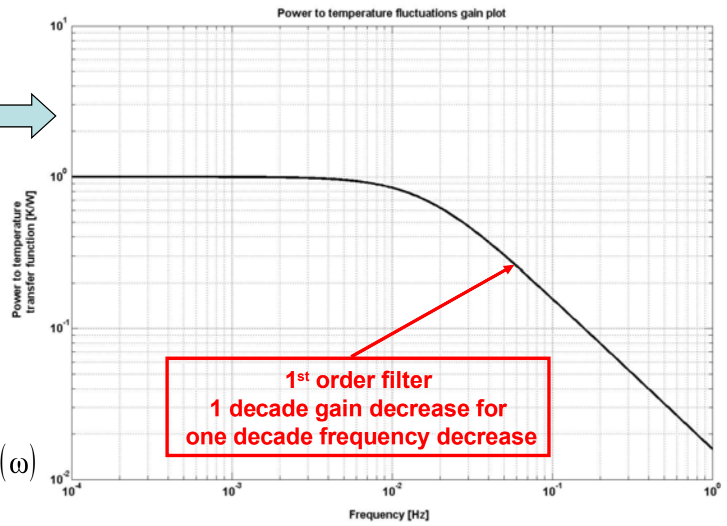
- For example for the previous system with Cp=10 and GL =1.

- Power spectrum density is related to transfer function:

$$\delta T(j\omega) = H(j\omega) \times \delta P(j\omega)$$

$$\Rightarrow$$

$$PSD_{\delta T}(\omega) = |H(j\omega)|^2 \times PSD_{\delta P}(\omega)$$



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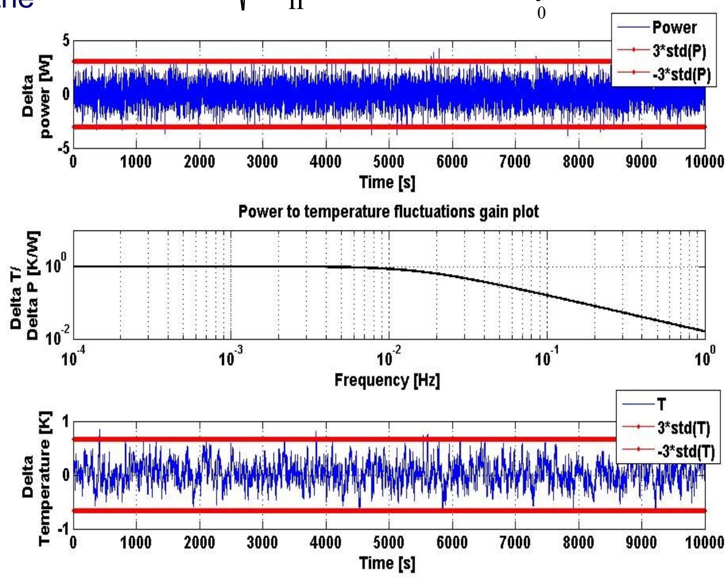
Time and Frequency domain analysis

- Root Mean Square (and standard deviation) of input or output signal is related to the integral of the power spectrum density:

$$\delta T_{RMS} = \sqrt{\frac{\sum_{k=1}^{n} \delta T_k^2}{n}} \quad \text{and} \quad \delta T_{RMS}^2 = \int_0^{f_{MAX}} PSD_{\delta T}(\omega)\, d\omega$$

- If power spectrum density is constant, standard deviation is directly related to the square root of the psd:

$$\delta T_{RMS} = \sqrt{PSD_{\delta T}} \times f_{MAX}$$



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Proposed ESATAN add-on

- ESATAN includes the non-linear thermal model:

$$C_{N\times N}\left[\frac{dT}{dt}\right]_{N\times 1} = K_{N\times N}\times[T]_{N\times 1} + F_{N\times N}\times\left[T^4\right]_{N\times 1} + B_{N\times q}\times P_{q\times 1}$$

Add-On 1: Extraction of matrices

- C (size N×N) matrix of thermal capacitances of the nodes (diagonal).
- K (size N×N) matrix of thermal conductances between the nodes.
- F (size N×N) matrix of radiative couplings between the nodes.
- P (size N×q) matrix of input power dissipation (and external fluxes).

- Linearize the thermal model: $C\times\left[\frac{d\delta T}{dt}\right] = \left(K + F\times 4\times T_e^3\right)\times\delta T + B\times\delta P$

- Derive the thermal filter transfer function:

Add-On 2: Computation of gain & phase plots

$$\delta T(j\omega) = \left\{Cj\omega - \left(K + F\times 4\times T_e^3\right)\right\}^{-1} B\times\delta P(j\omega)$$

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Thermal disturbances

- During science phase:
  - The spacecraft is constantly facing the sun at L1,
  - No equipments are switched on or off.

⇒ Major sources of thermal disturbances:
  - FEEP power control units (3 PCU),
  - On-board computer (1 OBC),
  - Power Control and Distribution Unit (PCDU),
  - Solar flux variation.

- FEEP PCU is the leading source of disturbances in the Lisapathfinder measurement bandwidth:
  - The applied thermal disturbances can be derived of the control system commands (thrust is going up and down therefore PCU power dissipation goes up and down).

LISA Pathfinder

Numerical performance assessment

- Alternative way to determine the thermal stability is to estimate numerically the power spectrum density:
  1. Define time series of inputs for FEEP PCU, OBC, PCDU and solar flux fluctuations.
  2. Perform a transient simulation with ESATAN detailed thermal model.
  3. Estimate numerically the power spectrum density of the outputs using fast-Fourier transform techniques.
- Problems:
  - Simulations needs to be very long without step transient in input power,
  - Numerical estimate of power spectrum density is intrinsically limited,
  - Results are difficult to interpret.

⇒ Both analytical and numerical performance needs to be done and compared to provide confidence in the results and enable interpretation.

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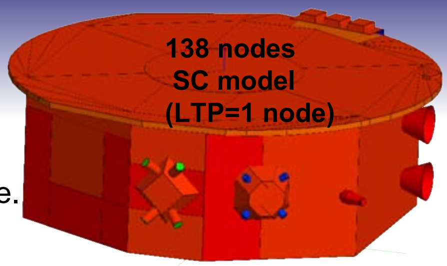
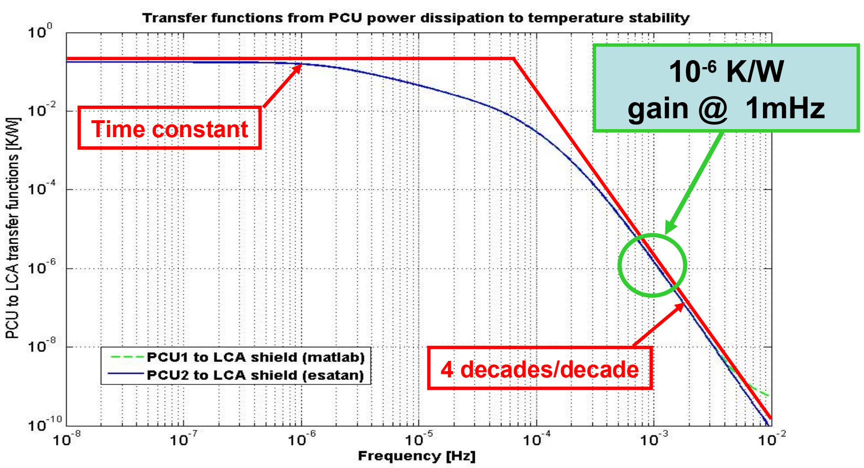
Results (1): analytical

- Performed with PDR reduced S/C model (CLA model without convection):
  1. Extracting matrices from ESATAN model,
  2. Using beta version of ESATAN new release.
  - Enable only assessment of SC/LCA I/F structure thermal stability.





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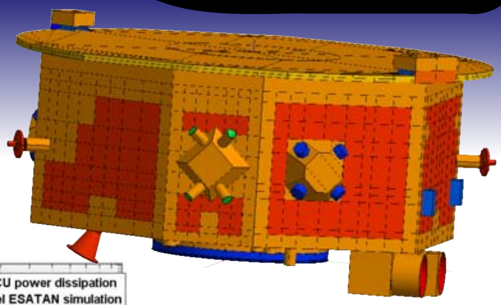
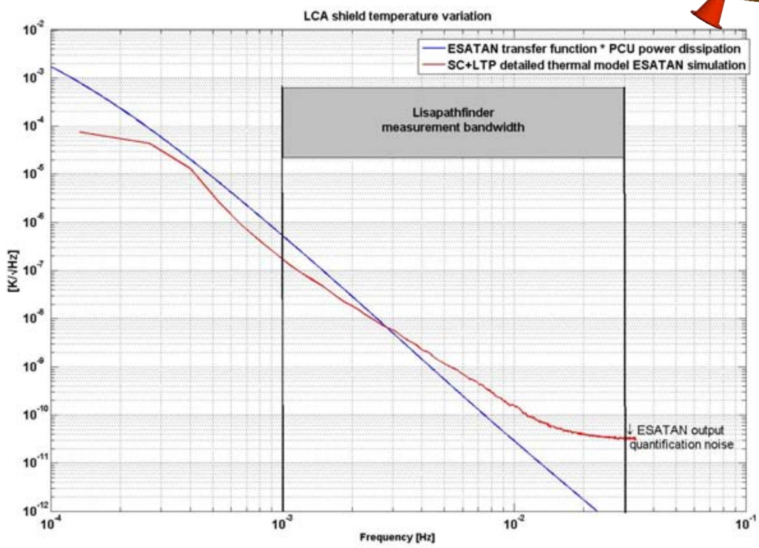
Results (2): numerical

- Performed with post PDR detailed S/C model.
  - Enable assessment of all thermal stability requirements.



SC + LTP model
detailed model
> 6000 nodes



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Follow-on

- Evaluate all thermal performance requirements with a reduced LTP+SC model with sufficient discretization for LTP.
- Extract the reduced (condensed) linear dynamic system of thermoelastic behaviour from Nastran and obtain analytically the transfer function between power dissipation and deformation.
- Insert thermoelastic model (and optical model?) into Lpf End To End performance simulator.

LISA Pathfinder

References

- Use of Spectral Analysis in Thermal Stability Verification, ICES 2002 (2002-01-2373)

  G. Barbagallo and D. Stramaccioni, ESA-ESTEC
- LISA PathFinder Thermal Design and Micro-Disturbance Considerations

  S. Barraclough, A. Robson, K. Smith, Astrium UK, England.J.A. Romera Perez ESA ESTEC
- Thermal Analysis for Systems Perturbed in the Linear Domain Method development and Numerical Validation

  Marco Molina, Alberto Franzoso and Matteo Giacomazzo, Carlo Gavazzi Space SpA
- Probability, Random variables and Stochastic Processes

  Athanasios Papoulis, S. Unnikrishna Pillai, Mc Graw Hill

Appendix I

Thermal model correlation using Genetic Algorithms

Frédéric Jouffroy
(EADS Astrium, France)

THERMAL MODEL CORRELATION USING GENETIC ALGORITHMS

21st European Workshop on Thermal and ECLS Software

ESTEC, 30-31 Octobre 2007

Frédéric JOUFFROY, EADS Astrium

Nicolas DURAND, DSNA/DTI/R&D/POM

All the space you need

Contents

- Study context
- Basics about genetic algorithm
- Test plan definition
- Test results
- conclusion

All the space you need
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Thermal Model Correlation Using Genetic Algorithms
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Study context

- ESA contract number: 19840/06/NL/PA
- **Goal**: Evaluate feasibility of using **Genetic Algorithms** (GAs) to address the general issue of **post- test thermal model correlation.**
- Thermal model correlation = An optimization problem
  Reduce difference between model predictions and test measurements
- Thermal background: problem is complex***:***

⇒ *Collaboration with optimization specialized researchers to find/perfect a method appropriate to our problem.*

Nicolas DURAND: DSNA/DTI/R&D/POM (*ENAC Toulouse*)
Use of GAs to solve Air Traffic Control problems

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Description of Thermal model correlation problem

A complex problem…

- Many variables to be simultaneously correlated
- Function shape is very hilly ⇒ Many different local minimums
- No analytical expression of the function.

Use of a global method to explore the whole domain and identify the global solution.

- Deterministic methods: Restricted to reduced number of parameters and specific problems.
- Stochastic methods (GAs, etc): Results depend from previous data computed but also random seeds. Suitable to many problems

Note: Thermal model correlation process specificity:

Fitness function computation cost very high compared to usual optimization problems

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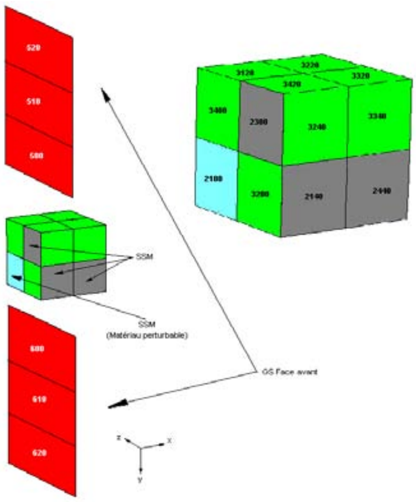
Chosen approach: Method testing rationale

- Use of a ***"theoretical" numerical based only approach***
  - Models are perturbed by changing parameter values.
  - 'Test measurements' temperatures used for correlation correspond to model predictions, before introducing perturbation.
- **Simultaneous** correlation for two test cases (hot + cold), steady-state conditions only.
- Test Cases definition
  - Tested on small size TMM models only (up to 280 Nodes)
  - Test first the method for a reduced number of correlation parameters (5).
  - Then extend it to a larger number of parameters representative of future industrial problems (up to 20 parameters).

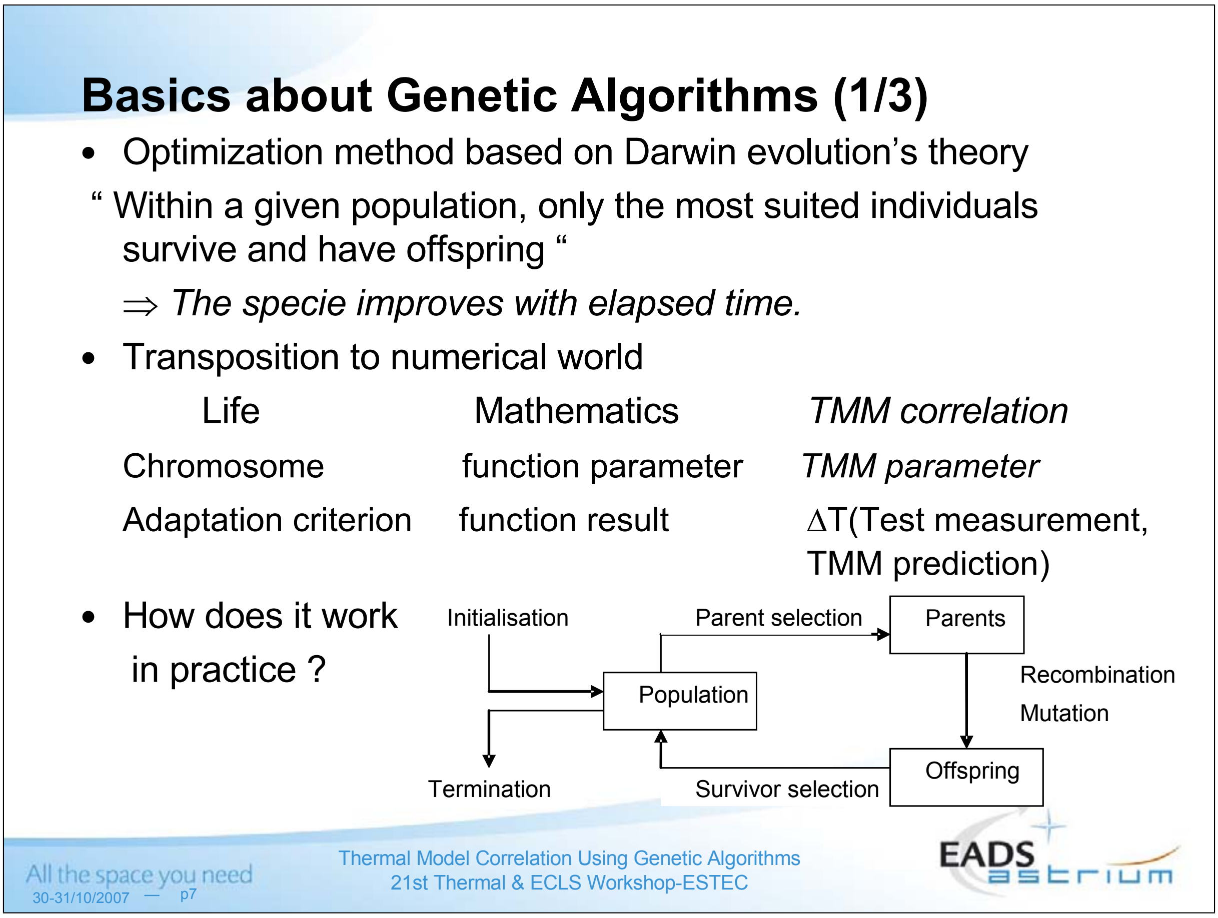
Tested models



- Model1: Studybook case model
  - 100 nodes, usual modelling situations (dissip. unit in enclosure+ radiator, MLI, structural panels , solar array
  - 21 TMM parameters: Dissipation and conductive aspects (λ longi & transverse, thickness, Contact and MLI eficiciency.
    - 2 measurement point sets ⇒ *Evaluate impact of instrumentation*
- Model 2: instrument phase B model

  280 nodes,17 TMM parameters (dissipation & conductive aspects).

<u>Note:</u> Model computation speed increased by directly running executable file (correlation parameters values read from input file)


Basics about Genetic Algorithms (1/3)
• Optimization method based on Darwin evolution's theory
" Within a given population, only the most suited individuals survive and have offspring "
⇒ The specie improves with elapsed time.
• Transposition to numerical world
Life
Mathematics
TMM correlation
Chromosome
function parameter
TMM parameter
Adaptation criterion
function result
ΔT(Test measurement, TMM prediction)
• How does it work in practice ?
Initialisation
Parent selection
Parents
Population
Recombination
Mutation
Termination
Survivor selection
Offspring
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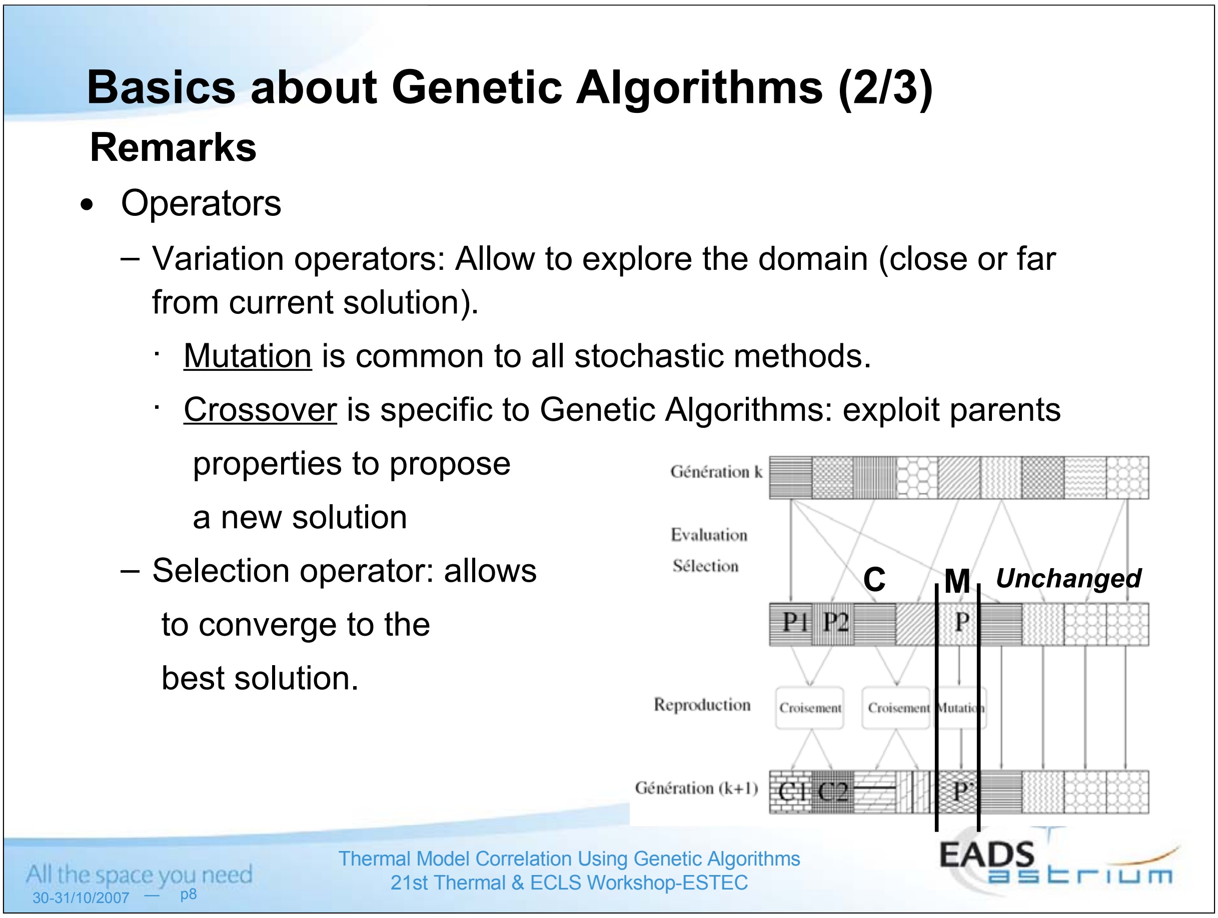
Basics about Genetic Algorithms (2/3)
Remarks
• Operators
– Variation operators: Allow to explore the domain (close or far from current solution).
· Mutation is common to all stochastic methods.
· Crossover is specific to Genetic Algorithms: exploit parents properties to propose a new solution
– Selection operator: allows to converge to the best solution.
Génération k
Evaluation
Sélection
C
M
Unchanged
P1 P2
P
Reproduction
Croisement
Croisement
Mutation
Génération (k+1)
C1 C2
P'
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Basics about Genetic Algorithms (3/3)

Remarks (end)

- Good GA operation = Balance between domain exploration and fast convergence
- GA Implementation
  - Many possible technical solutions for the elementary bricks
  - Many associated GA parameters may be tuned to get a better behaviour

  GA kernel good programming is a matter of experience

  GA optimization itself is problem specific and also a matter of experience

Practical applicability of GA to thermal model correlation

- **Any change in correlation problem definition generate a new optimization problem**
  - TMM used
  - Modelling change in TMM
  - Correlation parameters used
  - Measurement points used

- **Thermal engineers are not optimization / GA specialists**

  Questions to be answered by the study:

  - Does GA allow to find the solution to the thermal problem ?
  - Is there a given (≈frozen) simple GA parameterization globally suitable to thermal correlation problem ?

  ⇒To be evaluated in this study for two small models only

Test plan definition (1/3)

- Evaluate which value(s) of three most important GA parameters should be suited to thermal problem :
  - Population size
  - Crossover rate
  - Mutation
- Evaluate robustness of GA to different thermal model problems
  - Change of TMM
  - Change of correlation parameter set used
  - Change of measurement point set used

Test plan definition (2/3)

For each model

- 4 to 5 different values of population size

  values defined based on number of correlation parameters used
- 10 different (Crossover rate x Mutation rate) configurations

	Crossover rate			
Mutation rate	0	0,2	0,4	0,6
0,2	x	x	x	x
0,4	x	x	x	
0,6	x	x		
0,8	x			

- Tested TMM correlation parameter configurations
  - 8 different reduced configurations (5 parameters)
  - 1 large configuration (~ 20 parameters)
- Two different measurement point sets
- For a given test case, 4 to 5 different runs with different random seeds

Test plan definition (3/3)

Stop criterion

- Fitness function definition

$$FF = \sum_{thcases} \sum_{measnodes} (T_{pred} - T_{meas})^2$$

Note: Standardized measurement of model discrepancy

Average Model Correlation Accuracy (AMCA) in °C:

$$AMCA = \sqrt{\frac{\sum_{thcases} \sum_{measnodes} (T_{pred} - T_{meas})^2}{nbcases.nbmeasnodes}}$$

- Success definition
  - FF<0.01 ⇒Max discrepancy on any point<0.1°C
  - Max nb of computed generations = 500

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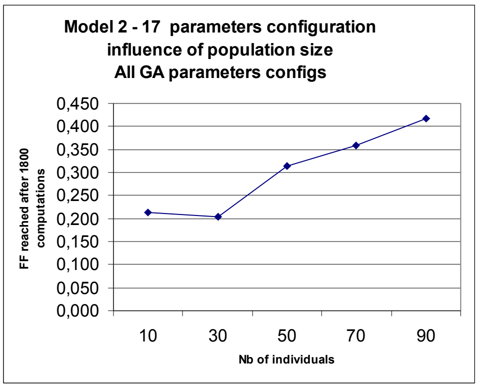
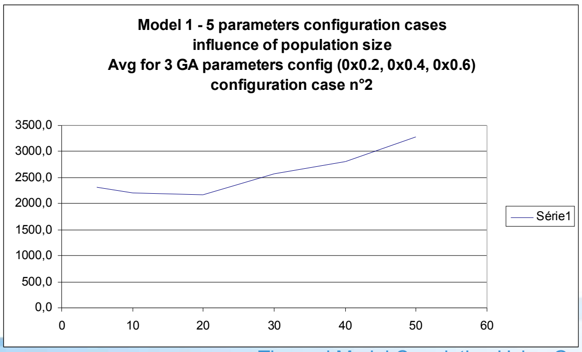
Tests results : Sensitivity to population size

better results with small values

Optimum seems to be between nb correl. parameter & 2 x nb.correl. parameter

Note: Never go lower than 10 to still have a GA.





⇒ Are GA a suited method ?

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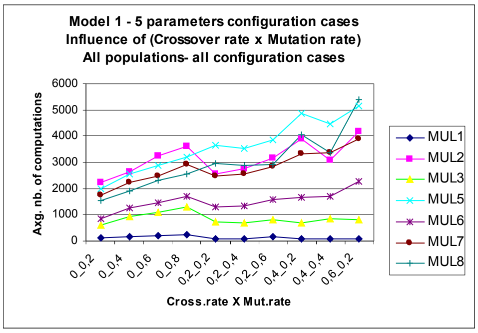
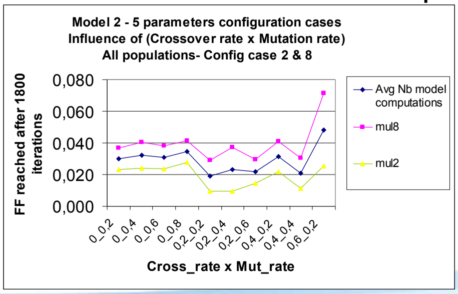
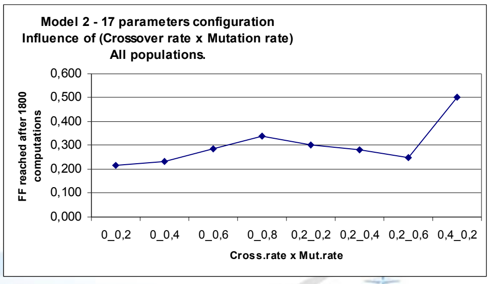
Tests results : Crossover rate x Mutation rate

- Easy situations
  - No crossover needed
  - Mutation should be low (0.2)
- Difficult situations
  - A bit of crossover may be used (0.2)
    - Mutation should be kept low



Note: Crossover is the GA specific feature ⇒ Are GA a suited method ?





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Tests results: Influence of parameter set used for correlation

- Simulation duration increases with number of involved parameters.

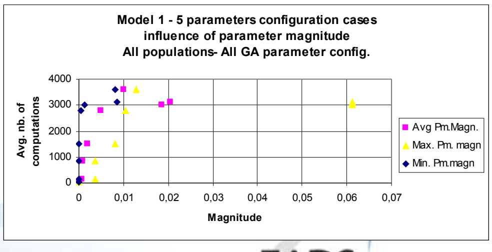
Test cases	Avg nb.Comp.
5 param.config. Population: 20 to 40 individuals Easy configuration Hard configuration	 843 3208
21 param.config Population: 60 to 100 individuals	 33072

- GA operation depends on parameter configuration
- Simulation duration increases with magnitude of parameters.

Magnitude= Potential impact of parameter on FF value when varying in its allowed domain.

Note: Only main magnitude params. are initially taken into account by the optimization process

⇒ *Incremental correlation approach?*



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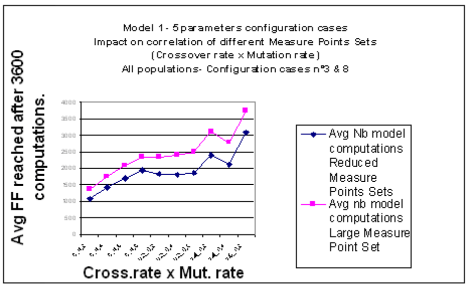
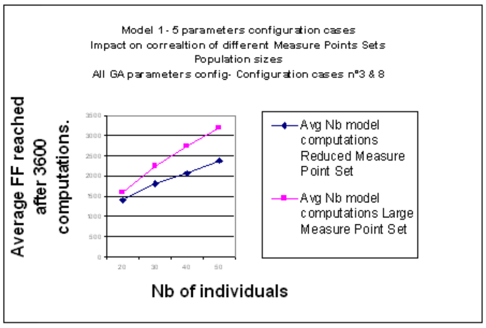
Tests results :
Influence of Measurement set used.

- Tested on model1
  - 1st Measurement set used (standard): 22 points
  - 2nd Measurement set used: 35 points

    FF success criterion trimmed to get comparable results.
- Similar results obtained for 2ns measurement point sets.
  - Model more difficult to correlate: More constraints to be solved

  Due to more points involved ?





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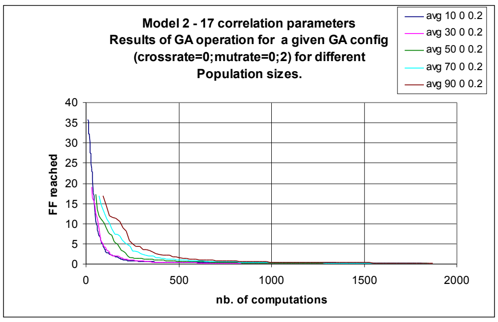
Tests results : Convergence speed

- GA has a fast initial convergence (to find areas where are solutions) but a slow finishing

$\Rightarrow$ No interest of insisting with GA operation



Note: Results obtained with GA are already interesting.
Example
Model 1 – 21 parameters
AMCA ≈ 0.1°C after 1000 computations
But problem (model, nb of measure points) remains simple

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Tests results :
Comparison with random search

Fitness obtained for a given number of model computations = 4000 in random search

Tested for 5 parameters configuration from model 1

	GA results		Random search	
	nb. Runs	end FF	Nb runs	end FF
MUL2	2471	0,01	4000	0,1
MUL8	1991	0,01	4000	0,56

GA is much better than a random search !

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Conclusion (1/3)

- GA allows to identify areas where the best correlation solution is … but not to converge finely on it.
  - This convergence may be sufficient.

    The whole allowed domain has been explored

  → *The order of magnitude of correlation reachable with this model has been found.*

  ⇒ For additional correlation improvement, need to change model:
    - Correlation parameter choice
    - Variation domain for parameters
    - TMM modelling
- Capacity to correlate several cases in one shot (fitness function definition)

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Conclusion (2/3)

- GA parameterization:

  Some simple preliminary guide lines for thermal model correlation may be proposed

  (TBC, for DSNA/POM GA implementation only)
- Computation cost is a key issue.

Estimated –minimum-: Run of 500 to 1000 cases for just one correlation simulation.

⇒Needs to drastically increase computation power available to address industrial cases: (large model, transient conditions).

Clusters + parallelization …

⇒Optimization process to be improved**:**

- Evaluation of alternative global methods.
- Couple local method to initial global method step.

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Conclusion (3/3)

GAs Evaluated on 2 small models only

Results need to be confirmed by much more tests on different models.

- Thermal model correlation is a complex problem requiring complementary skills:

  Thermal engineering/ Numerical optimization/ Software engineering
- Fruitful collaboration achieved with DSNA/DTI/R&D/POM team have allowed to really progress on the matter

Great thanks to Nicolas DURAND for its 1st class support all along this project !

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Appendix J

SYSTEMA V4 - New framework for THERMICA

Christophe Theroude
(EADS Astrium, France)

SYSTEMA V4

New framework of THERMICA

Christophe THEROUDE, ASTRIUM Satellites

21st European Workshop on Thermal and ECLS Software

30 October 2007

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ASTRIUM Satellites

Agenda

- SYSTEMA overview
- SYSTEMA framework presentation
  - Geometry
  - Trajectory
  - Kinematics
  - Mission
  - Processing
- On-going evolutions
- SYSTEMA V4 demonstration

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SYSTEMA Overview

- Description
  - SYSTEMA permits satellite system analyses with detailed applications intended for specialists (AOCS, thermal, power …)
  - SYSTEMA embeds applications requiring: a 3D surface model of the spacecraft, the spacecraft orientation in space, space environment models.
- History
  - System analysis software development with ESA and CNES for more than15 years
  - SYSTEMA development company funding for more than 10 years
  - Software distribution (THERMICA, DOSRAD …) for 10 years
  - Experience on observation and scientific spacecraft (HELIOS, SOHO, Mars-Express…) and telecommunication spacecraft (NILESAT, ASTRA, Intelsat, Inmost...)

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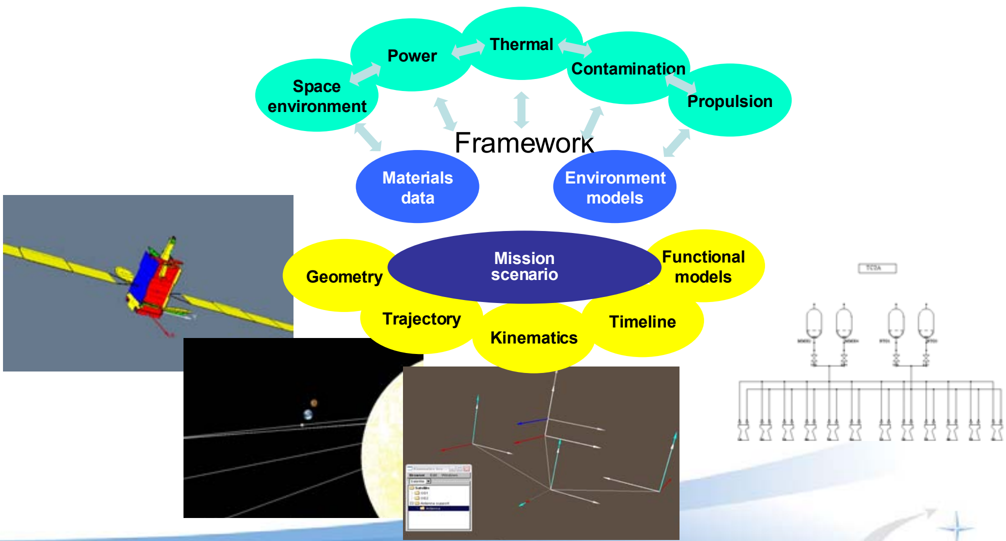
SYSTEMA: an interdisciplinary tool suite



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Current status of SYSTEMA

- SYSTEMA V3
  - Developed 10 years ago
  - Integrated framework
  - Embeds a large set of applications
  - Some applications (THERMICA) of SYSTEMA are sold
- SYSTEMA V4
  - Development initiated 3 years ago
  - New software technology + increased capabilities
  - Integrated framework
  - Application integration as a plug-in
  - SYSTEMA 4.2.2 released in 07/07
  - THERMICA 4.2.2 released in 07/07
  - DOSRAD 4.3 development planed by end of 2007

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SYSTEMA: The key features

- Clear separation between framework and applications
  - Easy to develop new applications for specific use
  - Easy to maintain and make evolutions
- Software standards based
  - Helps exchanges between tools (XML for all input/output files, HDF5 for large computation results)
- Modularity
- Rich platform support
  - PC, Linux, SUN, HP
- Modern and intuitive ergonomics

OpenGL

XML

UML

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SYSTEMA framework

- SYSTEMA framework embeds in a generic environment a large suite of engineering applications
- It provides a set of basic functionalities required to make an analysis:
  - CAD import / model generation / meshing / properties / results display
  - Trajectory definition (Keplerian or general)
  - Kinematics description (pointing laws or general)
  - Mission scenario description / results display / animation
  - Processing: defining the computation case and the run parameters
- Applications are plug-in package described by XML files
- SYSTEMA framework is also a powerful stand-alone application to perform mission and kinematics analysis.

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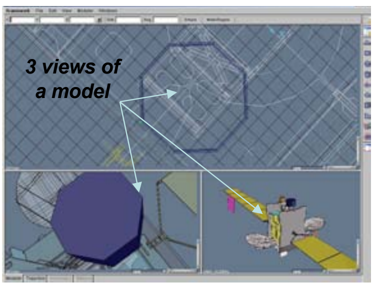
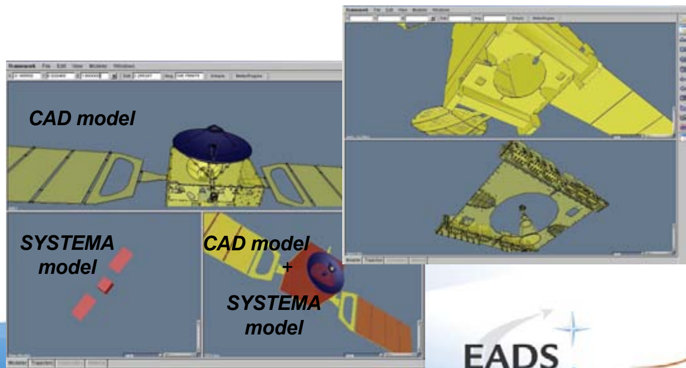
SYSTEMA Modeler

- Interfaced with several standard formats
  - STEP (CAD), unv, Nastran, IGES
- Easy model creation
  - Hierarchical description
  - Interactive shapes creation
- Easy 3D manipulation
  - Standard mouse zoom, pan, rotate
- Multi-viewers / multi-models management
  - Simultaneous points of view over a model
  - Several models can be loaded





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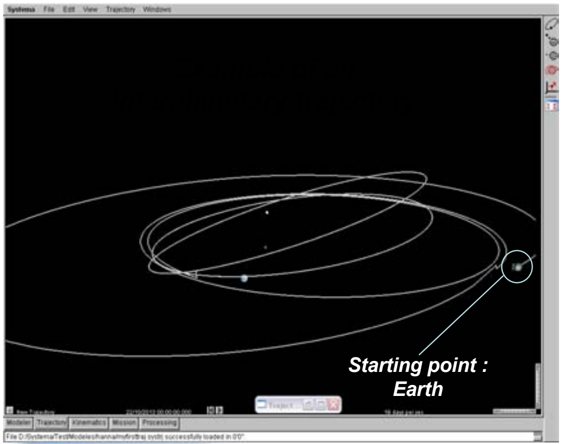
SYSTEMA Trajectory

- Management of every planets of the solar system, Sun and moon with the real ephemerid
- Complex trajectories as a structured assembly of orbital arcs
- Arc defined either as a Keplerian arc or as a general trajectory (position, velocity)
- Functionalities in each viewport: zoom, pan, rotate, fit
- Selection of arcs in the browser or in the 3D viewer
- Animation of the spacecraft trajectory including the planets



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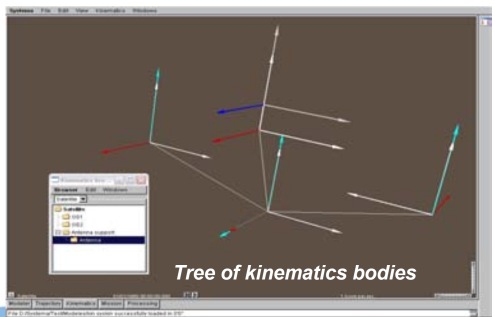
SYSTEMA Kinematics

- General definition of kinematics without the support of a geometry
- Tree of rigid moving bodies linked by degrees of freedom (and constraints)
- Compatibility with kinematics tools
- Definition of pointing laws of each moving bodies
- Definition of general kinematics laws



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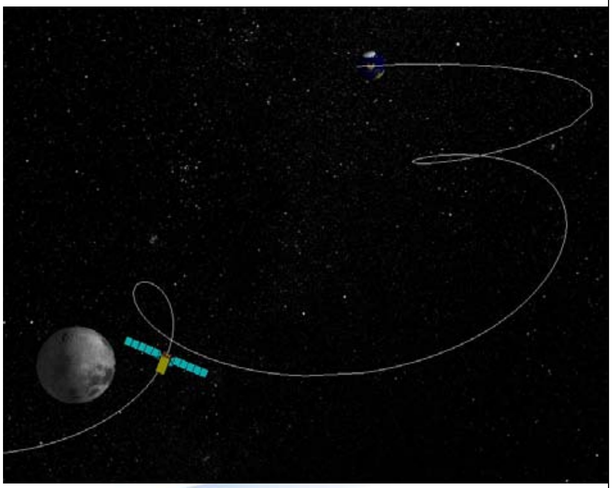
SYSTEMA Mission scenario

- The SYSTEMA mission scenario concept allows the user to define the whole system and the connection between the different aspects:
  - Geometrical model
  - Trajectories
  - Sequences of kinematics and pointing
- Management of a timeline, of events (eclipse…)
- Animation of the whole system
- In the future management of spacecraft modes (platform / payload usage…)



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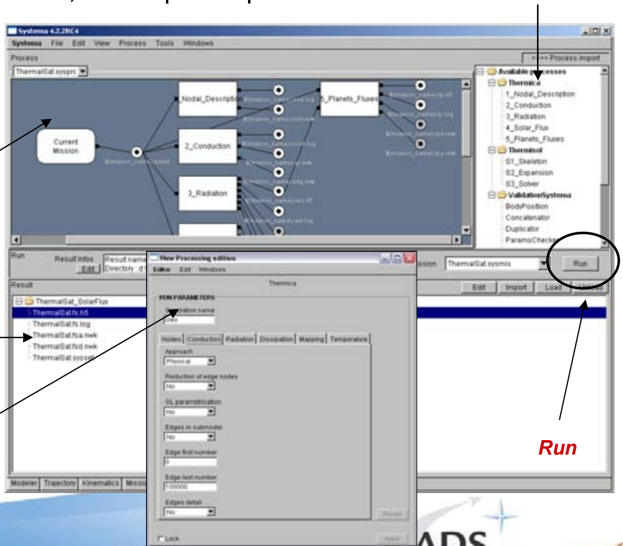
SYSTEMA Processing

- Interactive processing
  - Sets the applications and their properties, their input/output files…
  - A processing schematics created
  - Any mission can be chosen from this module
  - Results management

Available applications



Process management

Result management

Process parameters

Run

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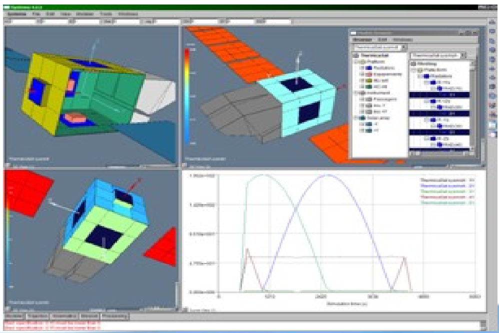
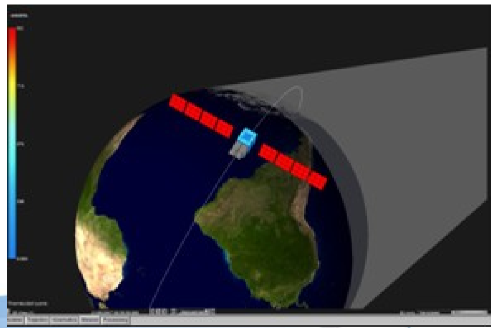
SYSTEMA Processing Results

- Analysis results can be displayed:
  - Text file
  - 2D table
  - 3D on animated model





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On-going evolutions

- New Graphical User Interface under QT → more user interaction (12/07)
- Sophisticated camera scenario support and video recording (12/07)
  - Creation of a working/demonstration movie
- More complex shapes support (boolean cuts) (12/07)

- Integration of DOSRAD application in V4 environment
- Enhancement of mission scenario definition
  - Mission sequence
  - Improved timeline management
- And more…

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http://www.systema.astrium.eads.net/
SYSTEMA

Appendix K

THERMICA Suite - Complete thermal analysis package

Timothée Soriano
(EADS Astrium, France)

THERMICA Suite

Complete thermal analysis package

Timothée SORIANO, ASTRIUM Satellites

21st European Workshop on Thermal and ECLS Software
30 October 2007

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THERMICA V4

21st Thermal and ECLS Software Workshop

Content

- THERMICA
  - A SYSTEMA V4 Plug-In Application
  - New Conduction Module
- THERMISOL
  - Linked to SYSTEMA v4
  - Recent evolutions
  - Recent projects
- POSTHER
  - A post-processing tool for THERMISOL

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THERMICA
A SYSTEMA V4 Plug-In Application

- Input Model =
  - SYSTEMA v4 geometry
    - Easy model creation
  - + THERMICA properties
    - Inheritance of properties
    - Use of materials
    - New meshing and numbering concepts
  - + SYSTEMA v4 trajectory
    - Interplanetary mission taken into account
  - + SYSTEMA v4 kinematics
    - Easy kinematics creation

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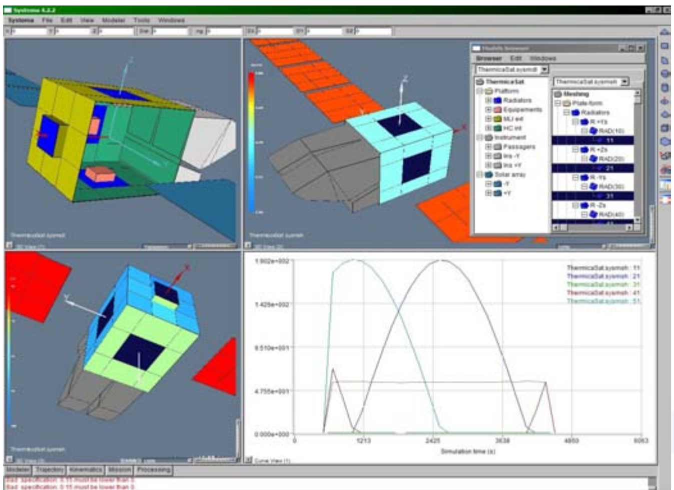
THERMICA
A SYSTEMA V4 Plug-In Application

- Pre and Post-Processing features



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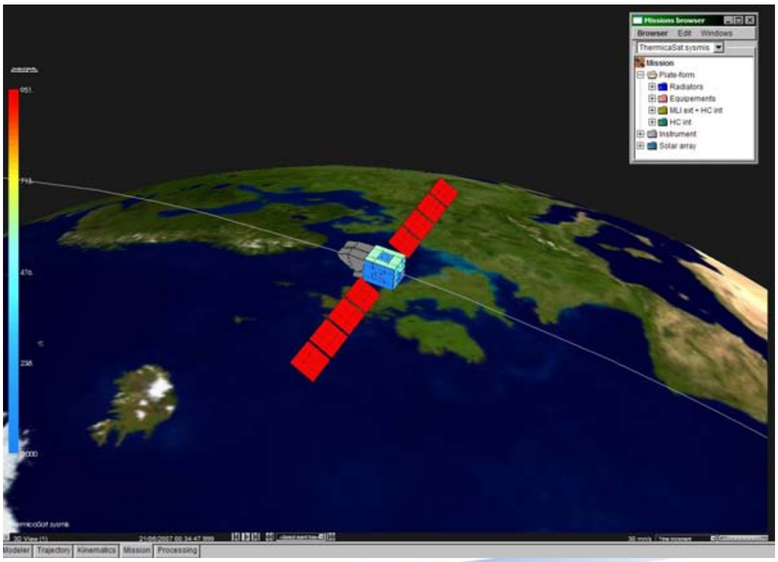
THERMICA
A SYSTEMA V4 Plug-In Application



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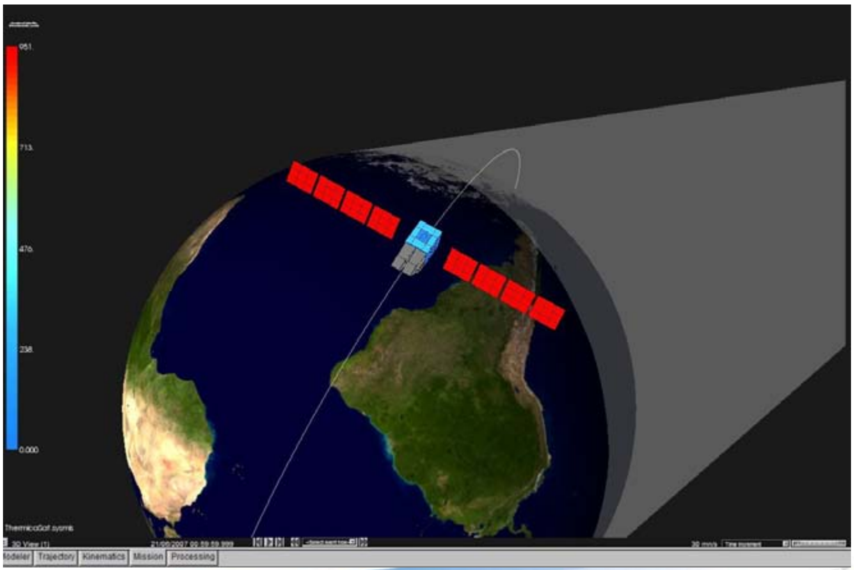
THERMICA
A SYSTEMA V4 Plug-In Application



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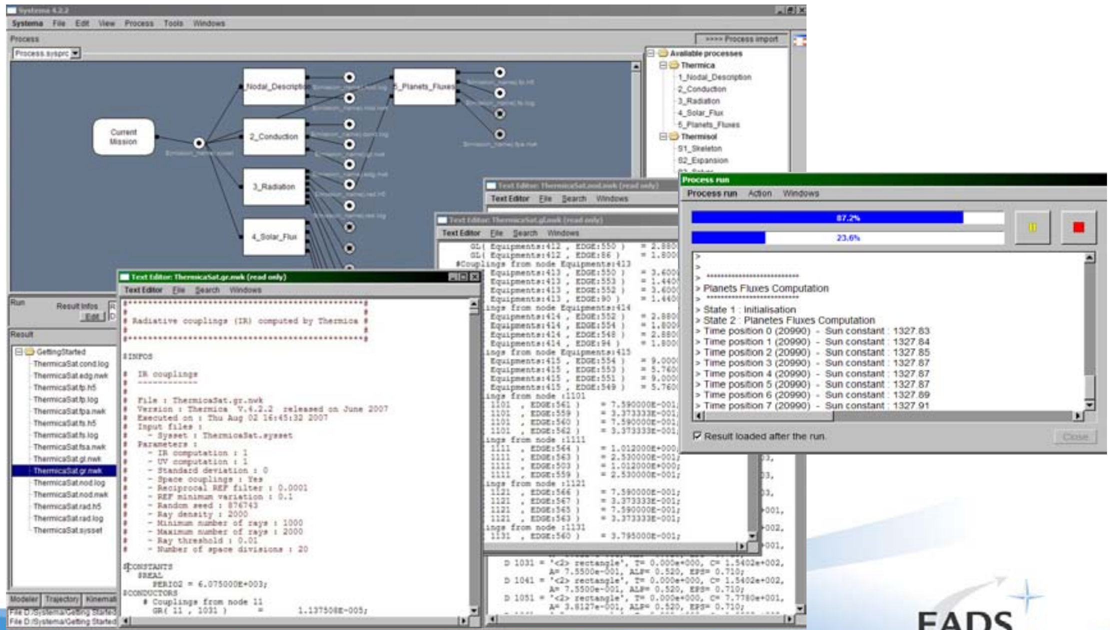
THERMICA

A SYSTEMA V4 Plug-In Application



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THERMICA

A SYSTEMA V4 Plug-In Application

- Open for New Evolutions
  - SYSTEMA V4 platform allows new possibilities to THERMICA
    - Planet Properties
    - Mission Sequences
    - Boolean Shapes
    - New Ray Display
    - … Dual Geometry/Schematic representation

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THERMICA
New Conduction module

- Context
  - History
    - Conduction was added by hand
    - Automatic generation of conductors using empirical formulas
    - Finite Elements method
  - Need for an updated method
    - For non-conformance management (without lose of accuracy)
    - For boolean shapes (to come next year)

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THERMICA
New Conduction module

- Why a new method is needed
  - Finite elements methods are good using a fine mesh…

    … usually much finer than a mesh designed for radiation

    … and we need one set of variables for both radiation and conduction
  - When searching to update the actual finite element method…

    … limitations where found to the FEM

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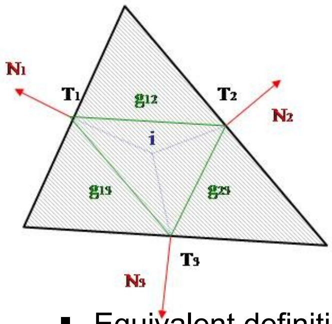
THERMICA
New Conduction module

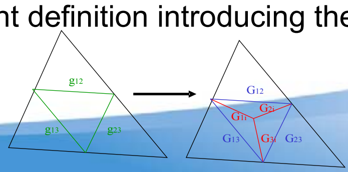
- Review of the Finite Element approach
  - Computation of Edge Couplings using the Fourier's law



$$\int_C e\lambda\nabla T.n\ ds = 0$$

$$\longrightarrow q_k = -e.l_k.\lambda.\nabla T.N_k$$

  - Equivalent definition introducing the shape centre



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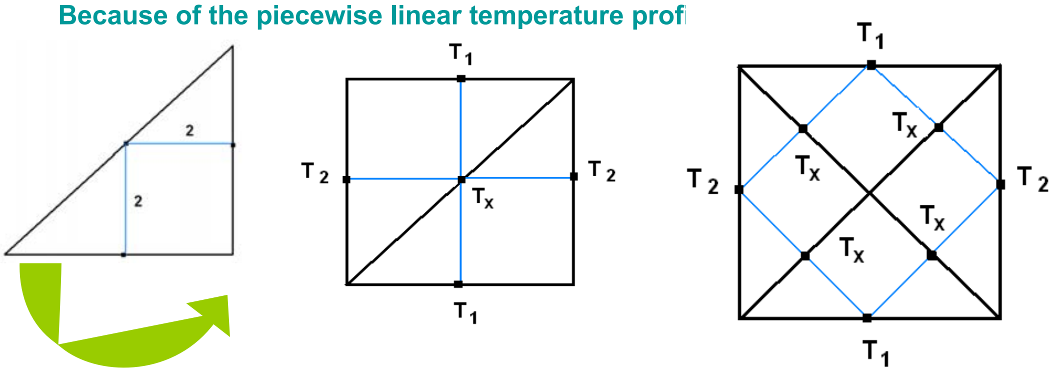
THERMICA
New Conduction module

- Flux computation using the FEM
  - On a non-linear temperature field, calculation of the flux through a border vary depending on the mesh

Because of the piecewise linear temperature profi



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New Conduction module

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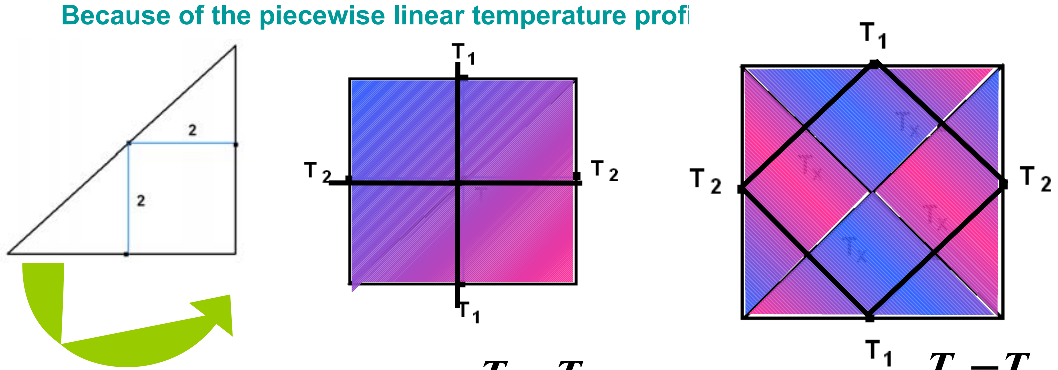
Because of the piecewise linear temperature profi



$$Q_2 = GL \cdot \left(\frac{T_1 - T_2}{2}\right) \qquad Q_2' = 2.GL \cdot \left(\frac{T_1 - T_2}{2}\right)$$

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THERMICA

New Conduction module

- The New Module was designed so
  - It is independent from the mesh
  - It guaranties a good flux through edges
  - It has a surface node representing the mean temperature of the surface
  - It can manage non-conformance without approximations
  - It can deal with boolean shapes
- This was given by a **Volume Element** approach

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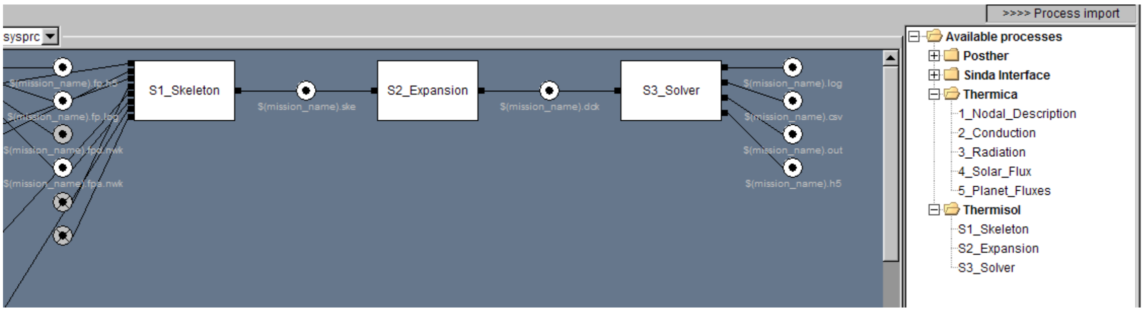
THERMISOL

A SYSTEMA V4 Plug-In Application

- Composed of the three classical modules



- SYSTEMA Post-Processing features are also available

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THERMISOL

Recent Evolutions

- Use of “Constants” and “Locals” paragraphs
  - The “Locals” definitions can be used in the entire Input File
    - No more restricted to declaration paragraphs
    - Do not create GENMOR code (for automatic updates)
    - Cannot be changed
    - **Guaranty a full double precision compatibility**
  - The “Constants” definitions are unchanged from previous version
    - Can be used in the entire input file
    - Generate a GENMOR code for automatic updates
    - Can be updated by the user
    - **Guaranty a full double precision compatibility**

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THERMISOL

Recent Evolutions

- Use of “Variables1” and “Variables2”
  - Status has not always be cleared
    - Does V1 should be called at each iteration of one transient step
    - If V1 is called at the beginning of one time-step and V2 at the end, since the time-steps are solved one after the other, what really makes the difference…
  - But some needs where clearly defined
    - Temperature dependant coefficients, when resolving the implicit part of one time-step, should be updated as the temperature evolutes
    - Time dependant phenomena should be only updated when time varies
- …So, in Thermisol, the scope of V1 and V2 was re-defined as
  - Variables1: Temperature dependant code
  - Variables2: Time dependant code

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THERMISOL

Recent Evolutions

- Variables 1 and 2 optimisations
  - The clear definition of V1 and V2 allows advanced optimizations for more accurate and faster convergence
- Example of call sequence using a Crank-Nicholson scheme

At $t = t^0$

- Update of time dependencies at t^0 (V2 call)
- Update of temperature dependences (V1 call)

→ Evaluation of φ^0

t^{n+1}

t^n

- Update of temperature dependences (V1 call)
- ♦ *Explicit resolution*
- Update of time dependencies at t^{n+1} (V2 call)
- ♦ *Implicit resolution loops*
  - Update of temperature dependences (V1 call)
  - → Evaluation of φ^{n+1}
  - Computation of temperatures

$$C \,.\, (T^{n+1} - T^n) = \Delta t \,.\, (\varphi^n + \varphi^{n+1}) / 2$$

Call to V2 not at the end but at the middle of one time step

Calls to V1 to update temperature data

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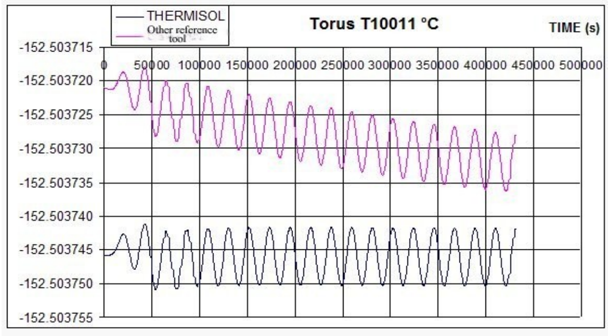
THERMISOL
Recent Projects

- GAIA
  - Steady-State convergence reached micro-Kelvin



  - … but at first, it needed more than 40.000 iterations
  - With the newly V1 optimisations, it converged in less than 2.000 iterations

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THERMISOL
Recent Projects

- COMS
  - Ability to manage very large models
    - Newly updates of Thermisol suppress limitations on the number of variables to be used or on the number of variable couplings
    - On the COMS projects, tests were made using more than a million variables and more than a million variable couplings

Thanks to more extensive use on different projects
THERMISOL evolutes to converge faster and more accurately

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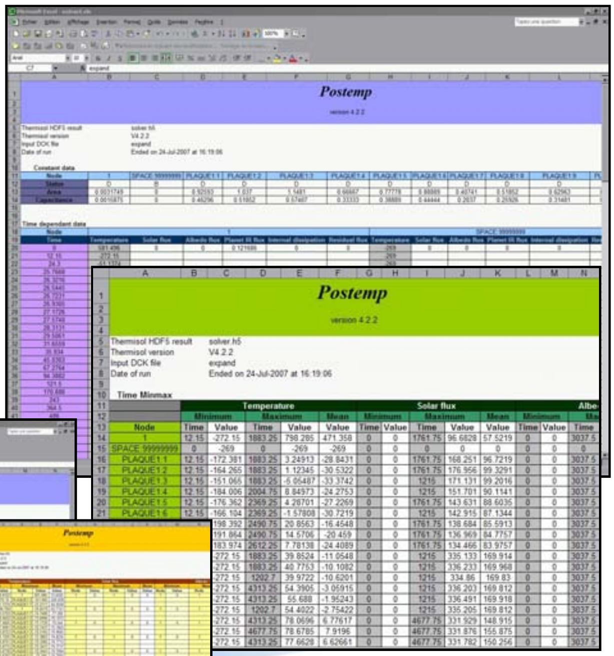
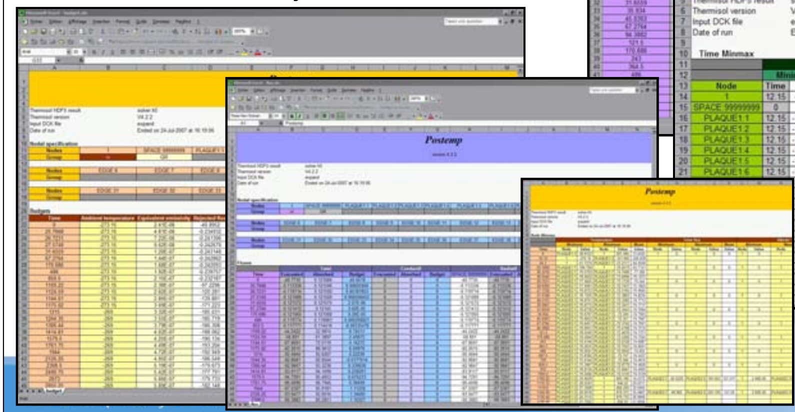
POSTHER

Post-Processing Tool for Thermal Results

- Generates Excel files
  - Extracts data from results
  - Performs Min/Max analysis over nodes
  - Performs Min/Max analysis over times
  - Gives Flux balances
  - Exports Ambient Temperature, Equivalent emissivity, Rejected flux and Thermal rejection





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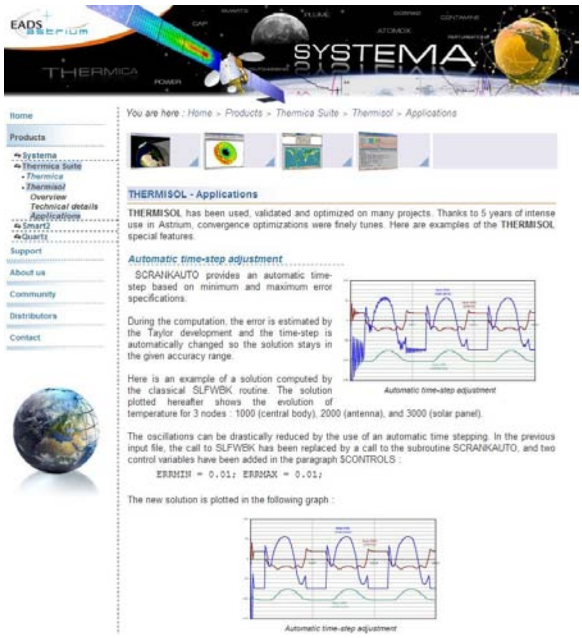

Contact:

timothee.soriano@astrium.eads.net

All the space you need

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Appendix L

Thermo-elastic analysis of the LISA Pathfinder spacecraft

James Etchells
(ESA/ESTEC, The Netherlands)

LISA Pathfinder Thermo-Elastic Analysis

Presented by: J. Etchells

Contributors: S. Appel, G. Chirulli, E. Koekkoek, J.A. Romera Perez,

21st European Workshop on Thermal and ECLS Software
30th – 31st October 2007

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Overview of Presentation

1. Background
2. Objectives of the Analysis
3. Thermal Analysis
4. Thermal to Structural Mapping – including demo
5. Structural Analysis
6. Results and Discussion

Focusing on methodologies

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31st October 2007
Sheet 2

Background to the LPF Mission (1)

- LISA Pathfinder (LPF) is a pre-cursor mission for the LISA (Laser Interferometer Space Antenna) mission
- S/C will detect gravitational waves generated by massive objects (e.g. black holes)
- Objective is to demonstrate critical technologies for LISA such as:
  - Drag free and attitude control in S/C using two test masses
  - Test feasibility of laser interferometry at the level of accuracy envisaged for LISA
- LISA Technology Package (LTP) capable of measuring tiny movements of the test masses:
  - 1 nano-meters relative to the S/C ($1\text{x}10^{-9}$ m)
  - 10 pico-meters relative motion between test masses ($1\text{x}10^{-11}$ m)
- Direct consequence of this is that an extremely stable S/C structure is required
  - Thermo-elastic distortions are potentially very important

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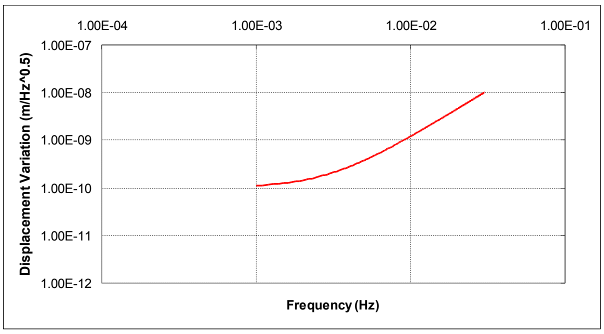
Background to the LPF Mission (2)

- Requirements for thermo-elastic stability are expressed as Power Spectral Density (PSD) or Linear Spectral Density (LSD)
- Example : Variation in distance between electrode housings (in x direction):

$$x_{dist} \leq 100 \times 10^{-12} \left(1 + \left(\frac{f}{0.003}\right)^2\right) \frac{m}{\sqrt{Hz}} \quad \text{for} \quad 1 \times 10^{-3} \leq f \leq 3 \times 10^{-2}\, Hz$$



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Objectives of the Analysis

- Objective to carry out a thermo-elastic analysis of the full LPF S/C in order to verify the stability requirements
  - Some questions existed about the analysis methodology used in industry
  - Typical kind of "shadow engineering" task carried out at ESTEC
  - Verify the results/predictions produced by industry
- Analysis was originally envisaged as an ***analysis*** task not a ***modelling*** task
  - Re-use of industrial thermal models meant minimal modelling
    - Just combine industrial models into single S/C model
  - Main task was to be the thermal to structural mapping
- Analysis would be carried out using standard ESA tools:
  - ESARAD, ESATAN, SINAS, NASTRAN

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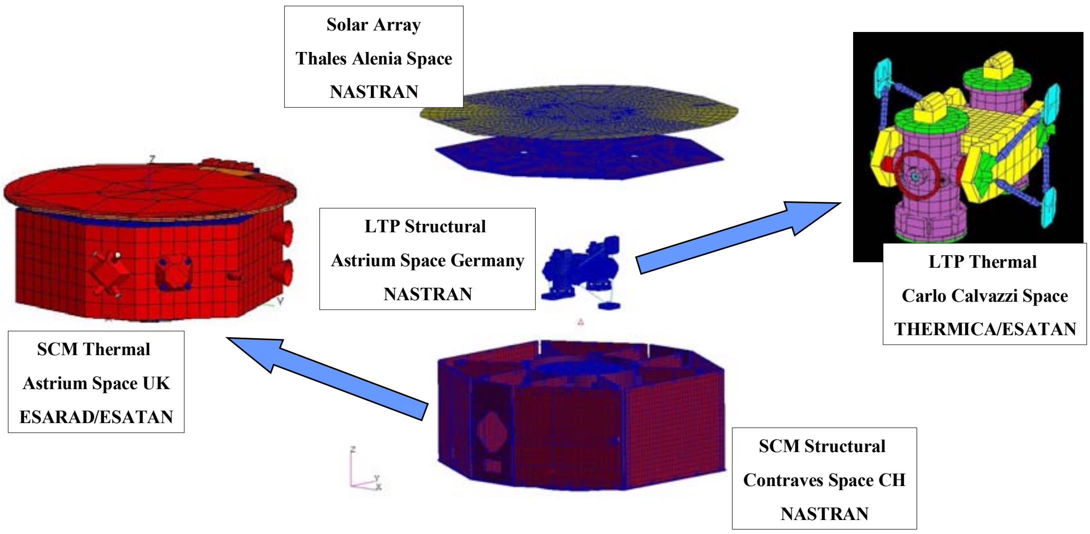
Industrial Consortium and Models Used



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Update of Thermal Models

- Originally minimal modelling was envisaged – analysis not modelling
  - thermal models already developed by industry
- Generally industrial models were of a high standard – but not up to date
  - in many cases industrial thermal models were still at PDR level
  - actual design baseline had evolved considerably
- Structural FEM models were generally more up-to-date than thermal models
  - FEM models can be produced mush more quickly from CAD
  - Structural analysis used in design process mush more – even driving it
- Therefore, two problems:
  - Thermal models out of sync with current design baseline
  - Thermal models out of sync with structural FEM
- Therefore much more modelling was required than initially expected
  - Thermal model updates represented the single largest effort expended

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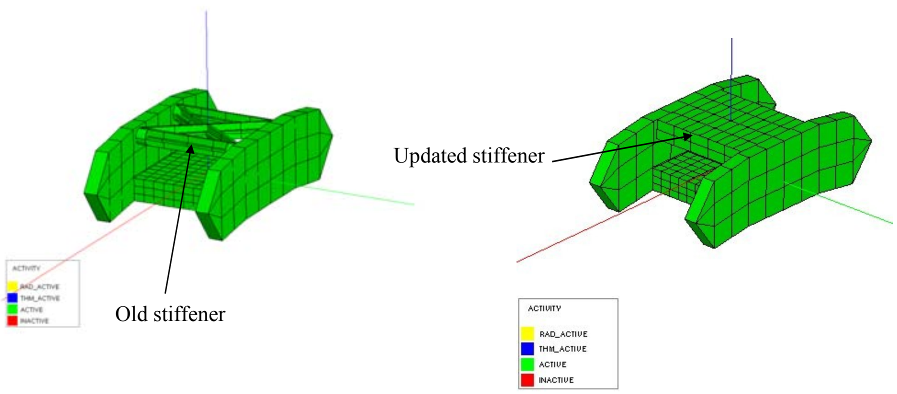
Update of Thermal Models
Example 1 : Optical Bench Stiffener



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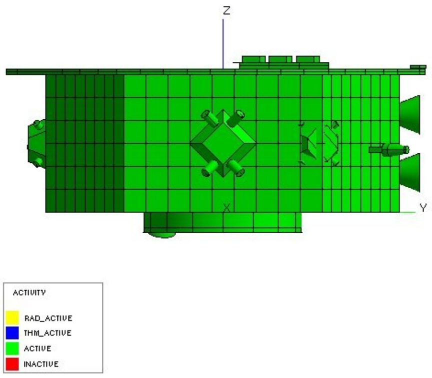
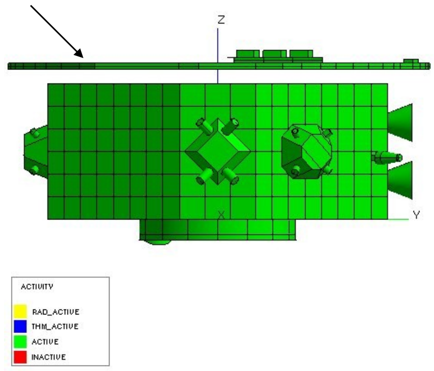
Update of Thermal Models
Example 2 : Solar Array/Sunshield Position



New “raised” sunshield position



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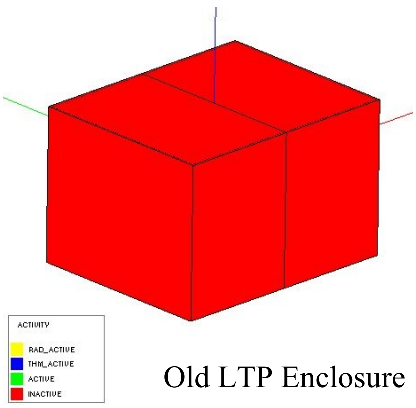
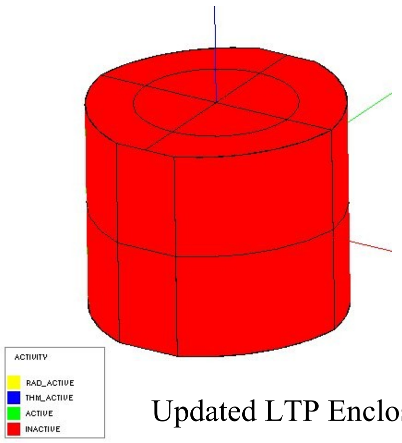
Update of Thermal Models
Example 3 : LTP Enclosure



Old LTP Enclosure



Updated LTP Enclosure

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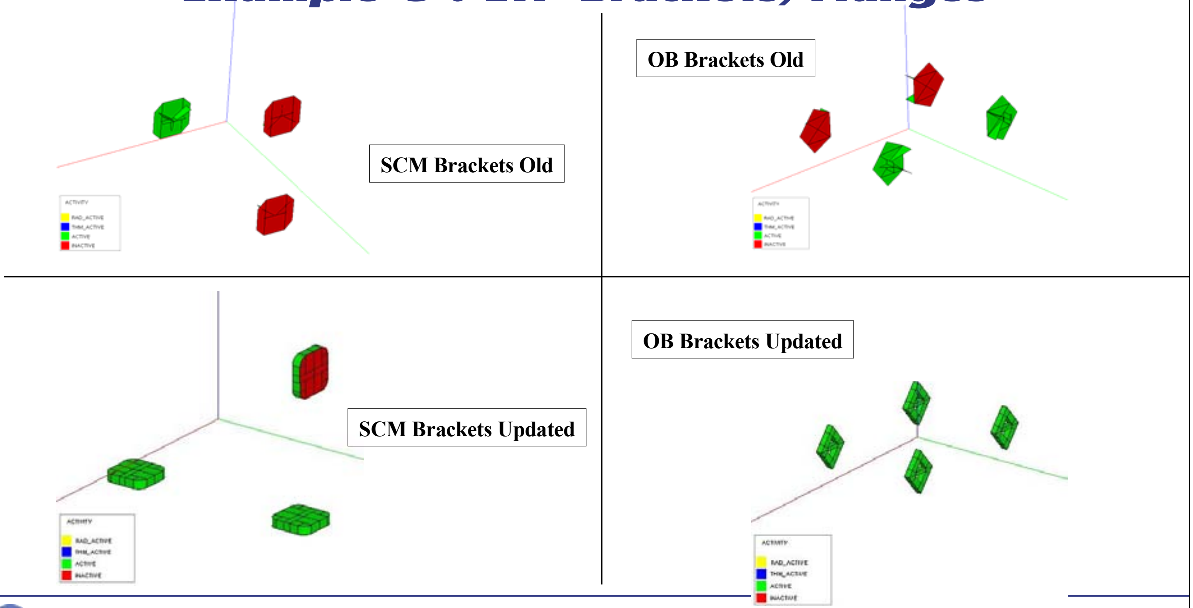
Update of Thermal Models
Example 3 : LTP Brackets/Flanges



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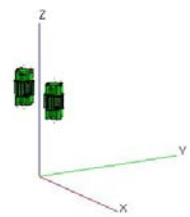
Integration of Thermal Models

TMM

- Integration of ESATAN models of LTP and SCM was simple
  - Conductive interface through LTP enclosure support cleats
  - Existing harness/fibre optic conductances from existing LTP model
  - ESARAD GRs

GMM

- Position updated LTP model inside updated SCM model
- Split into several (6) enclosures - like a Russian doll
  - Reduces computation time for raytracing



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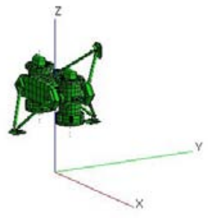

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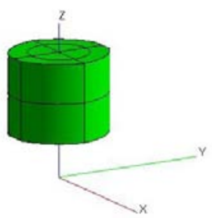

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Integration of Thermal Models

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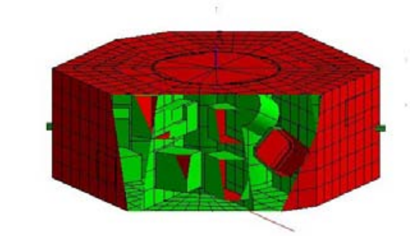

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Integration of Thermal Models

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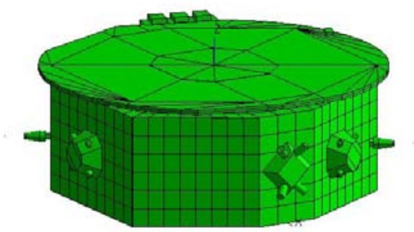

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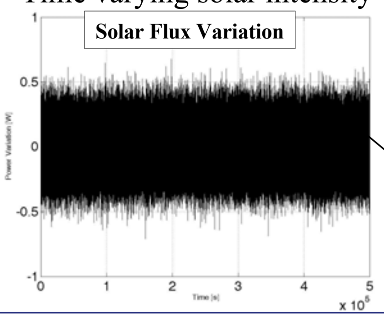
Thermal Loads and Boundary Conditions

Boundary Conditions

- BCs in industrial models replaced with single deep space node
  - Industrial LTP model had extra boundary nodes for conductive/radiative interfaces

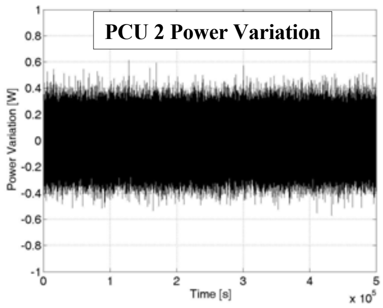
Thermal Loads (Provided by ASU)

- Time varying (white noise) power dissipation from 5 units (PCUx3, PCDU, OBC)
- Time varying solar intensity



500,000 sec data

1 sec intervals



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TMM Issues (1): Convergence

- Using full S/C model SS solver could not converge beyond RELXCA < 10^{-5} K
- Observation of monitor file revealed good convergence followed by sudden instability
  - Different solvers tried (SOLVIT, SOLVFM) but to no avail
  - Temperature damping helped but still had instability + very slow convergence
- Eventually problem identified as energy imbalance in the test masses
  - TMs are very well isolated so residual energy is slow to “dissipate”
  - Dummy GLs were introduced between TMs and housings to speed up convergence – then removed for final “clean” steady state run
  - Allowed convergence to RELXCA < 10^{-8} K in steady state

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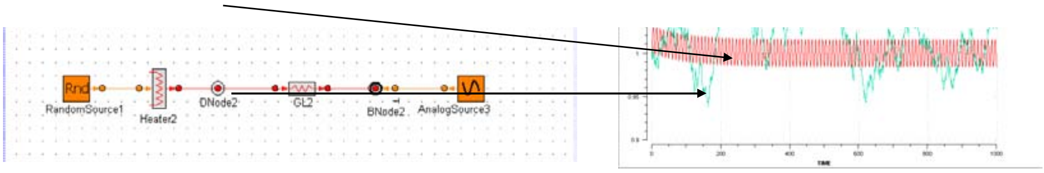
TMM Issues (2): Drift

- After steady state run, temperature drift observed in transient solution using same “mean” power dissipations
- Two different kinds of drift can be identified
  - Drift due to a systematic heat load such as a sine wave
  - Drift due to residual energy imbalance after the steady state solution



- In the LPF model only random power variations were considered therefore drift must be due to residual energy imbalance : three solutions identified
  - Obtain a better convergence (↓ RELXCA, ↓ INBALA) – Difficult due to convergence
  - Obtain a quasi-steady state using transient run with average heat load - Implemented
  - De-trend output temperatures to remove drift - Implemented

Final Analysis Case

- After overcoming convergence and drift problems the following analysis case was used:

SOLVIT
Dummy conductors ON
Mean power

→ **SOLVIT**
Dummy conductors OFF
Mean power

→ **SLFWBK**
Dummy conductors OFF
Mean power
500,000 sec
Large(er) time step

→ **SLFWBK**
Dummy conductors OFF
Power variation
500,000 sec
time step <= 1sec

Helps convergence

Reduces drift

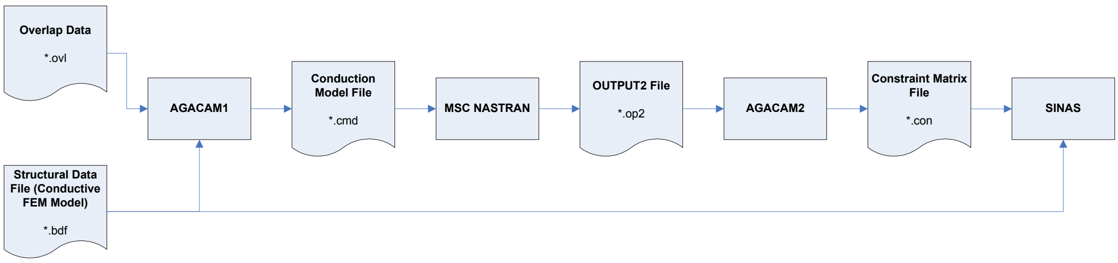
Thermal to Structural Mapping

Objective

- To build up correspondence (***overlap data***) between thermal nodes and structural FEM nodes
  - Allows temperatures to be applied as loads in structural model

Chosen Method

- Use SINAS and GMM geometry to map thermal nodes to structural FEM
  - SINAS presented at 2006 workshop (see proceedings)
    - http://mechanical-engineering.esa.int/thermal/tools/attachments/workshop2006/



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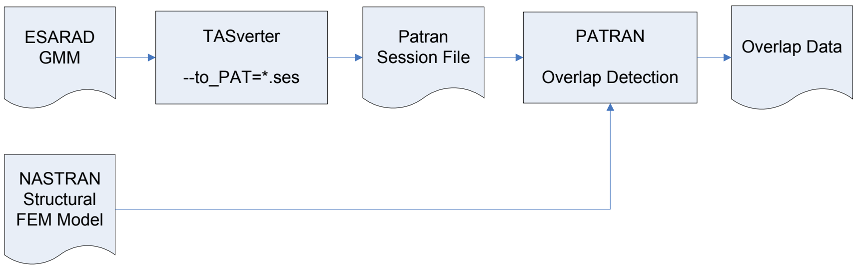
SINAS : Building Overlap Data



- Building overlap data is most time consuming part of the process
- It is the process of finding correspondence between thermal nodes and finite elements
- For LPF analysis overlap data was needed for entire S/C
  - huge task approx. 6800 thermal nodes 120,000 grids, 140,000 elems.– impossible to do the whole S/C at once

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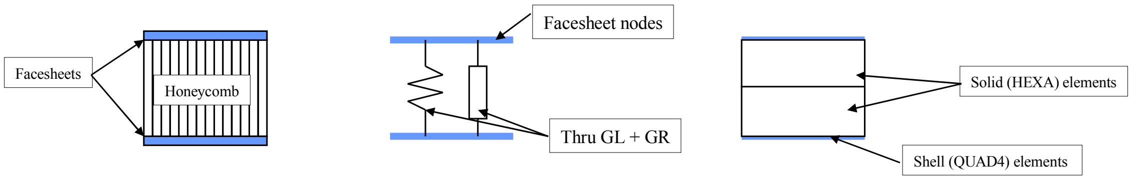
SINAS : Building Overlap Data

- ESARAD GMM was split up into total of 14 zones e.g. shear panels, outer panels, optical bench, LTP enclosure…
- Corresponding FEM topology extracted from the full NASTRAN model
  - Heavy use of Patran utilities such as the invaluable "***Group Extend***"
- Overlap data built up on a zone-by-zone basis using SINAS Patran interface
  - Combined at the end using text editor
- Gradient areas not required for sandwich panels due to modelling approach used
  - Panels modelled in FEM : 2 facesheets (shells elements) and honycomb (solid elements)
  - Temperatures from ESATAN facesheet node mapped to shells elements only



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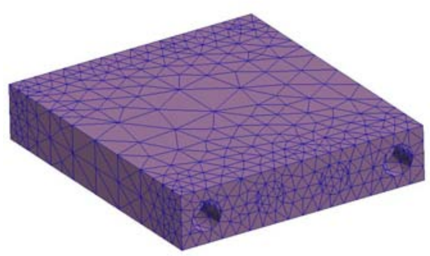
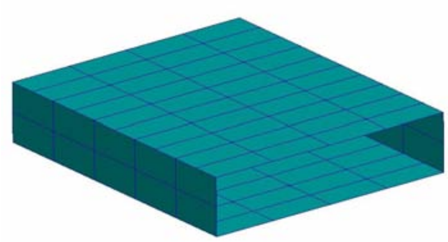
SINAS : Building Overlap Data

- Mapping process is complicated when solid elements are used in the structural FEM
  - Shells used for thermal GMMs representing "surfaces"
  - Further complicated when unstructured FEM meshes are used (e.g. tet mesh)
- Luckily SINAS uses ***FEM Topology*** for interpolation so adequate mapping can be built up



Optical Bench Stiffener FEM



Optical Bench Stiffener TLP

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SINAS : The Rest of the Process

- In order for SINAS to carry out interpolation user must build a conductive representation of the structural FEM model
  - So called "Structural Data File"
  - Typically replace MAT1 cards with MAT4 cards, PCOMP with PSHELL etc
  - Replace RBEx/MPC with CELAS elements – but not always obvious what value to use
- Using overlap data and conductive FEM model run through other SINAS modules
  - Max memory limits were hit in a few places – had to increase array sizes
  - Problems with gradient areas were identified due to changes in MSC NASTRAN DMAP

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Temperature Post-Processing

- Variations in temperature are extremely small + CTEs are also very small
  - Leads to tiny structural displacements - possible issues with NASTRAN numerical precision
  - Therefore decided to process temperatures before FEA
- Structural model is completely linear – no temperature dependent CTE
  - Therefore temperatures deltas were scaled to avoid numerical problems
- Temperature vector at each time step offset to give variations (deltas) around a nominal temperature vector $\{T_0\}$ (chosen to be start of final transient analysis)

$$\{\Delta T\} = \{T\} - \{T_0\}$$

- Temperature deltas then scaled up and provided for structural analysis
  - Equilibrium (zero strain temperature) for FEA is then 0ºC

$$\{\Delta T'\} = \{\Delta T\}.f$$

f = 1x10^6 for LPF analysis

- Must remember to scale down structural displacements by factor f !!

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Structural Analysis

- Carried out by E. Koekkoek (formally) from ESTEC TEC-MCS section
- Output of SINAS was provided
  - 600 time steps of 15 seconds - sufficient for the freq. range of interest
- Standard model checks carried out for thermo-elastic analysis
  - e.g. free eigenmodes, strain energy, free expansion
  - Some problems identified in the strain energy & free-expansion checks but we proceeded anyway
- Quasi static run carried out for each time step
  - Balance between administration time for NASTRAN and matrix decomposition
  - 25 subcases per run chosen as good compromise

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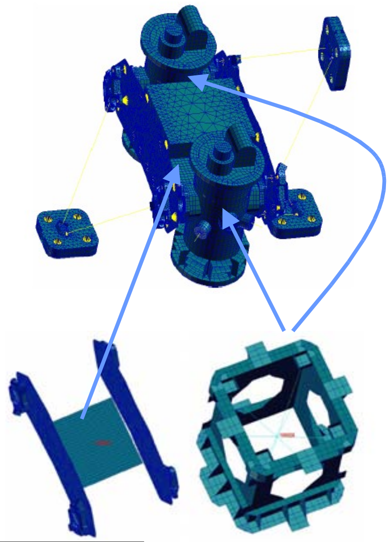
Post-processing to PSD/LSD

- Requirements for displacement are given in terms of Linear Spectral Density (LSD)
- Existing Matlab script (from ASD) was used to produce LSD plots of results
  - Results are de-trended using linear least square fit – removes some drift
  - Welch algorithm used for LSD
    - Blackman-Harris window
    - 7 segments (smoothing factor of 4)
    - 50% overlap between segments
- Output nodes on the optical bench, S/C interface flanges and electrode housings were chosen



Optical Bench Output Node

Electrode Housing Output Nodes

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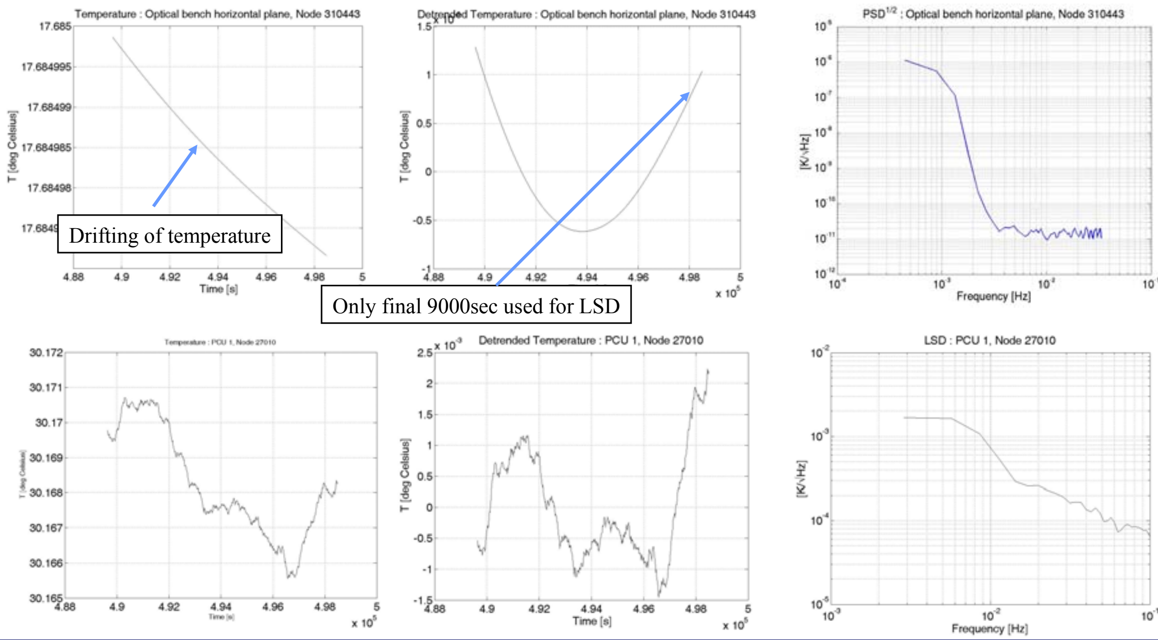
Sample Results: Temperatures



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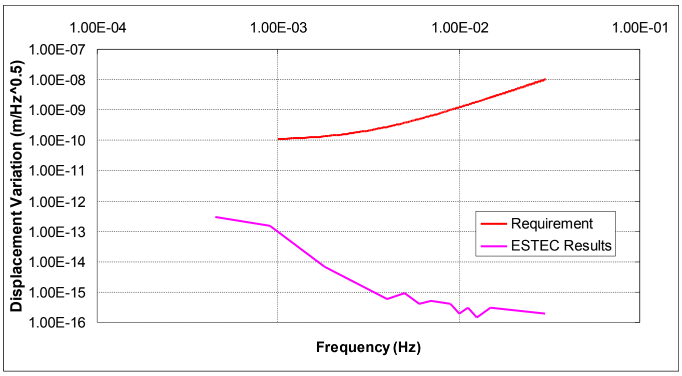
Sample Results: Electrode Housing Displacement Variation

- ESTEC results displayed smaller displacements than industrial analysis
  - Possible reasons for differences are different input data, different methodology used etc.



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Conclusions (1)

- Results of the ESTEC Analysis confirmed that LPF thermo-elastic distortions were within requirements
  - ESTEC analysis produced much ***smaller*** distortions than the industrial analysis predicted
  - Industrial methodology could be considered conservative
- Significant challenges overcome in terms of thermal analysis
  - High accuracy analysis required – presented many challenges
  - Many lessons learned which mirror experiences in industry (e.g. GAIA analysis)
    - One of the motivations for starting the ITAA with ASG
- SINAS used for an entire S/C
  - Use of TASverter module (link with Patran) was essential – available to all of you free!!
- Single biggest headache / time consuming operation was update of thermal model configurations – followed by mapping
  - Use of a common FEM model would have many advantages
    - Might take a few days to run – but it took weeks for modelling + mapping

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Conclusions (2)

- Self criticism – always important!:
  - Choice of solver (SFLWBK) – possible not the best
  - Smaller values of RELXCA/ENBALA should have been used

  Both addressed in ITAA activity
    - Convergence problems prevented this – but problem now seems to be solved
- Use of transfer function type methods could be very interesting
  - As presented by D. Fertin (ESA), M. Molina at past workshop
    - Work on-going at ESTEC with trainee
  - Considering thermal-structural model as an I/O system is very useful for stability analysis
  - Model fidelity can be maintained but without numerical issues encountered with traditional tools

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Appendix M

Thermal design and analysis of the FMOS IR Camera

Allan Dowell
(Rutherford Appleton Laboratory, UK)

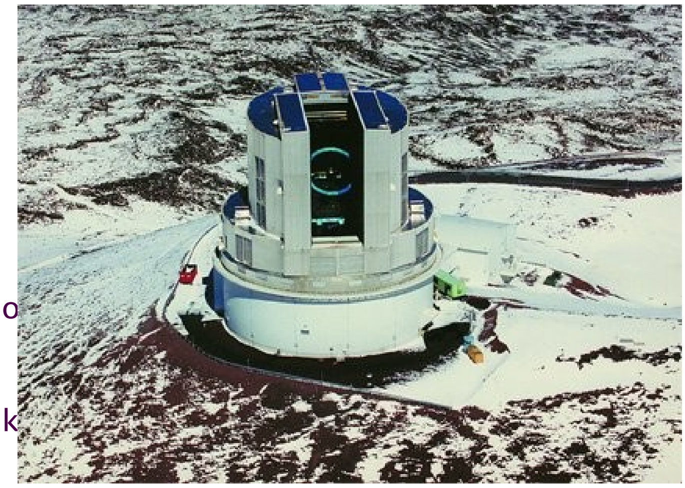
Science & Technology Facilities Council

Thermal Design and Analysis of the FMOS IR Camera

Allan Dowell
Thermal Engineering Group, RAL
Email: A.Dowell@rl.ac.uk
www.sstd.rl.ac.uk/thermal

Overview

1. Title
2. Introduction
3. Requirements
4. Thermal Design & ESARAD
5. ESATAN
6. RAL AIT
7. Results
8. Oxford and Hawaii Integratio
9. TEG RAL Ground Projects – VISTA Camera
10. Contact details & further link

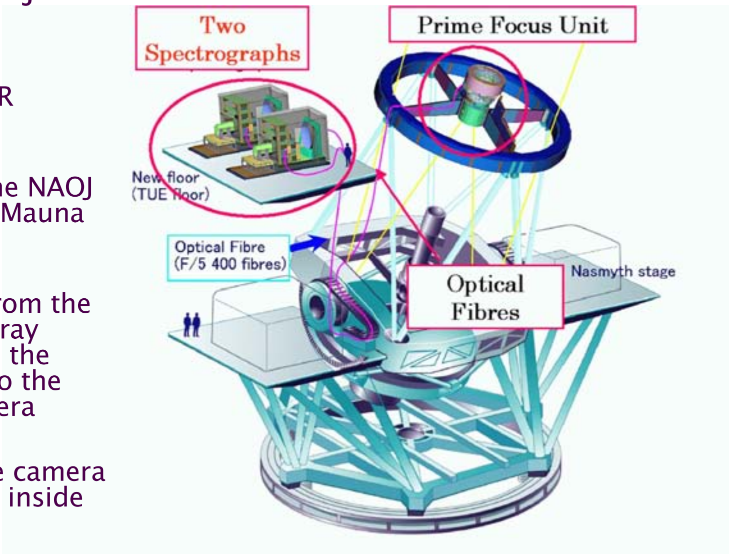


Thermal Engineering Group
Space Science and Technology Department

Science & Technology Facilities Council

Introduction

- FMOS – Fibre-fed Multi-Object Spectrograph
  - New ground-based near-IR instrument
  - Sept '07 - integrated in the NAOJ Subaru 8 m Telescope at Mauna Kea, Hawaii
  - The FMOS name comes from the "ECHIDNA" fibre optics array which transmit light from the telescope's prime focus to the spectrograph and IR camera
  - RAL is responsible for the camera dewar which sits partially inside the spectrograph



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Requirements (1)

Parameter	Spectrograph	Camera	Detector
Life	10 years	10 years	
Absolute temperature	**190 K–200 K**	**<77 K**	**Controllable within range 70 K<T<77 K to accuracy of 0.1K**
Temperature stability	1 K/5mins	1K/min	0.1 K/hr
Temperature drift over life	+/-2.5K	N/A	2K
Temperature gradient	N/A stability: stable to 1K/5mins	200 K – 77K (TBC) stability: N/A	0.1 K stability: stable to 0.01 K/min
Maximum cooling rate for lenses	10 K/hr	10 K/hr	N/A
Maximum cold-warm-cold cycle time	48 hrs	<1week	<1week

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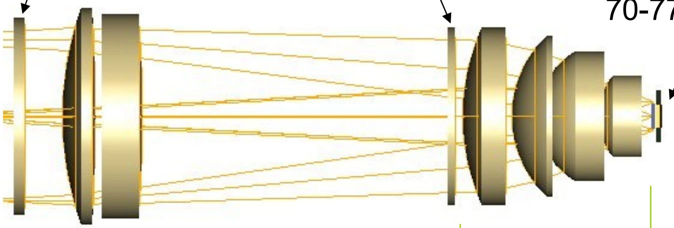
Requirements (2) - Optics Temperatures

These derived requirements are all to limit the background IR loads from camera into the detector

Camera Window 200 K

IR Filter <148 K

Detector 70-77 K



Components in direct view of the detector $<T_{Detector}+10$ K

L1 & L2

Front Lenses

L3 L4 L5 L6

Rear Lenses <118 K

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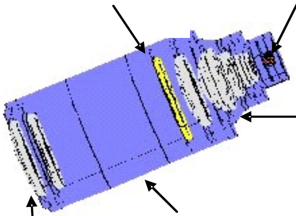
Thermal Design / ESARAD Geometric Model

Detector (70K to 77K). Actively controlled. Mounted on Copper block for isothermalisation and attachment of controlling heaters and thermometry

Filter <125K



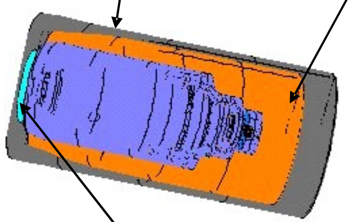
Rear Lens Group (90K to 125K)

Front Lens Group

Camera Barrel, Stainless Steel, polished outer finish (? =0.03) Black on inside. Low conductance mounts. Electrical resistance

Vacuum Vessel, Stainless Steel GN_2 fill during warm up

Thermal Shroud, Copper – Bare outer surface & black on inside (?=0.9). LN_2 cooled for faster 24 hour cooldowns



Window mainly operating in 200K environment

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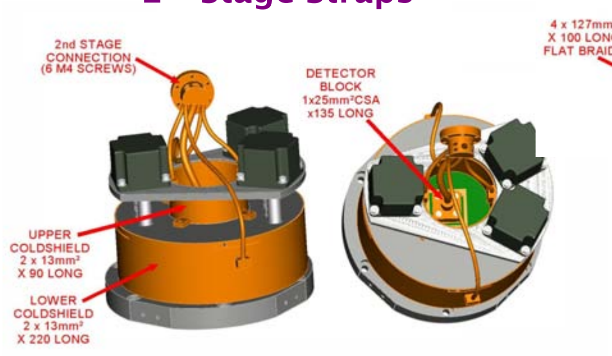
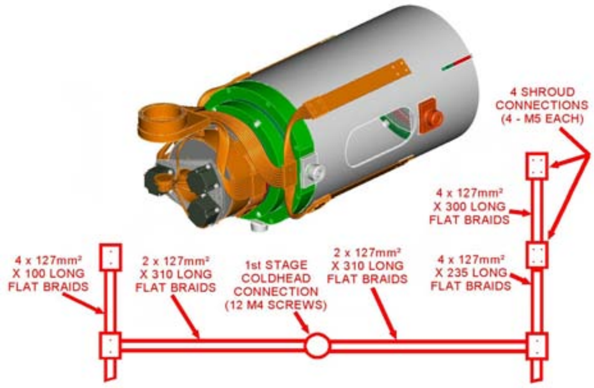
Thermal Design – Copper Thermal Straps

2-stage Sumitomo CH-210 Cryocooler (not shown) has a set of copper thermal straps from each stage to cool the CCD and lens barrel

2nd Stage Straps





1st Stage Straps

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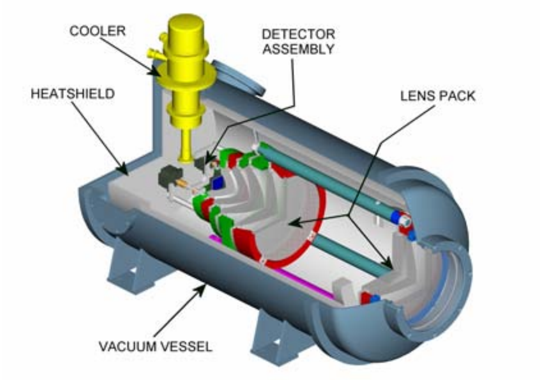
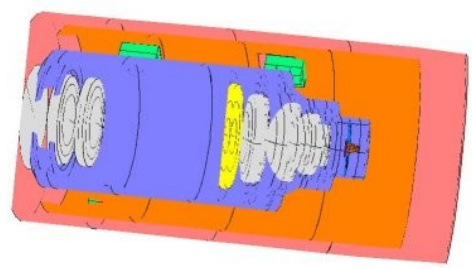
ESARAD Geometric Model (Cross-Section)





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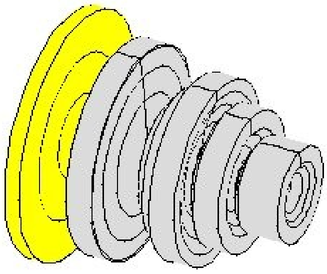
ESARAD Geometric Model – Lens Shells

Rear Lens Pack – Spherical Shells (defined by points)



- Real life surface follows a parabolic equation rather than a spherical section

- Not often critical in projects but perhaps shell surface definition by equation could be a useful addition to ESARAD

Rear Lens Pack – Assembly

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ESATAN Thermal Math Model

- 2003 - ESATAN v. 8.8.5 and ESARAD v. 5.6.1
- 2005 - ESARAD v. 5.6.1 and ESATAN v. 9.4.0

- 250 nodes (2001 version had 900)
- 16,000 GRs and 800 GLs
- Temperature dependent material properties used from TEG thermal database.

- Cooler heat lift and temperatures set boundary nodes from arrays representing the 2 stages of the CH-210 Sumitomo cryocooler.

- ESARAD treats lenses as thermally opaque.
  - Lens shells are active outside and inactive inside. Rays stop at that surface.

    ∴ Lens transmission modelling in ESATAN following:

$$QR_{Ln} = \tau_{Ln-1}\ \sigma\ .\ \varepsilon\ .(Te_{Ln}{}^{4}.Te_{Ln-1}{}^{4})\ /\ A_{Ln}$$

- 3 annular ring nodes used for temperature gradient across lens.
- Approximation used for GL node for centre node to second ring node as this shape is difficult to derive.

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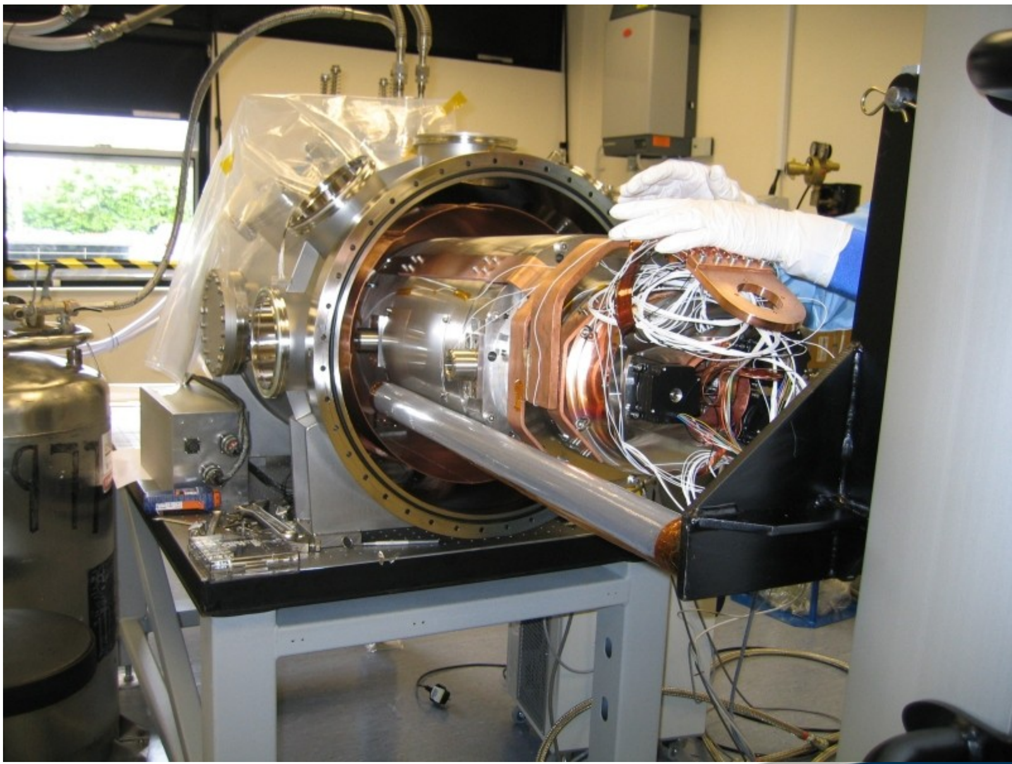

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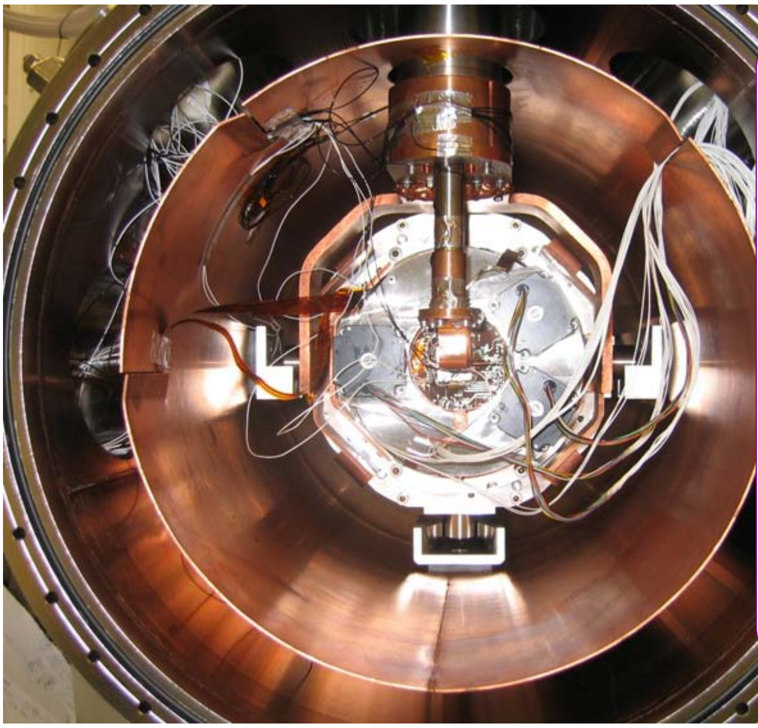
RAL AIT (2)



Testing of the Camera without Spectrograph in room temperature at RAL

LN2 pre-cooling

GN2 + heater warm-up

Detector overheating from feedback sensor error

Strap/sensor attachment

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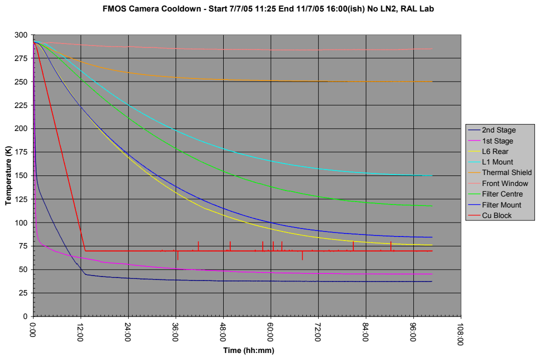
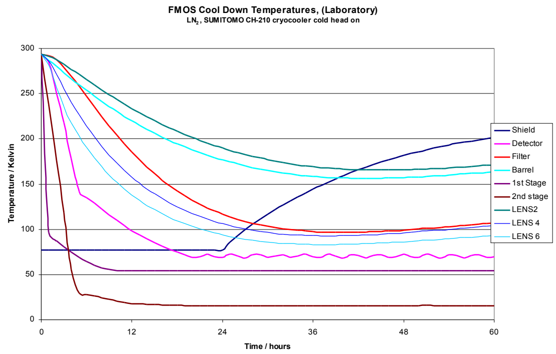
Results – RAL Lab Cooldown

Cooldown Actual Without LN_2 pre-cool



Faster Cooldown Predicted With LN_2



(Detector unstable because heater control unmodelled)

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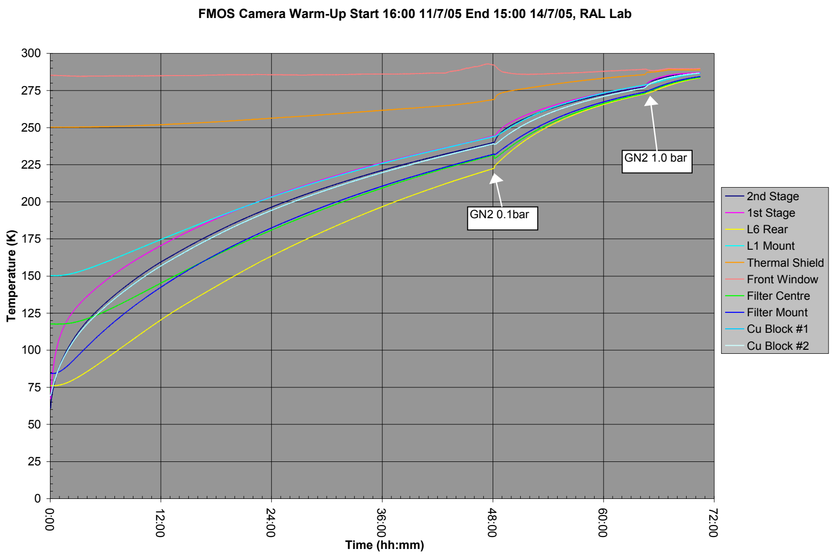
Results – Lab Warm Up



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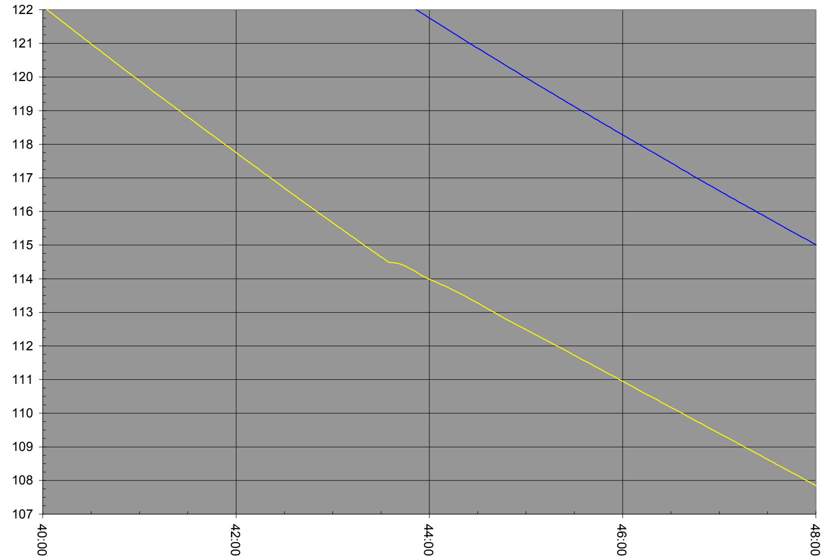
Results – Lens 6 Cool down



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Cryogenic Testing - RAL Results

Steady State

Part	Requirement / K	Lab (Room Temperature) Actual / K
Front Window	200	284.9
Lens 1 Centre	190	(Estimate) 180
Lens 1 Mount		150
Filter Centre	<148	117.7
Filter Mount	–	84.4
Lens 6	< 87	76.1
Detector	70-77	70.0
Copper Block	70-77	70.0
Coldhead 1st stage	–	45.2
Coldhead 2nd stage	–	37.4

Transient

Cooldown with LN2 = 24 hrs
(without predicted 60 hrs)

Warmup with GN2 = 65 hrs

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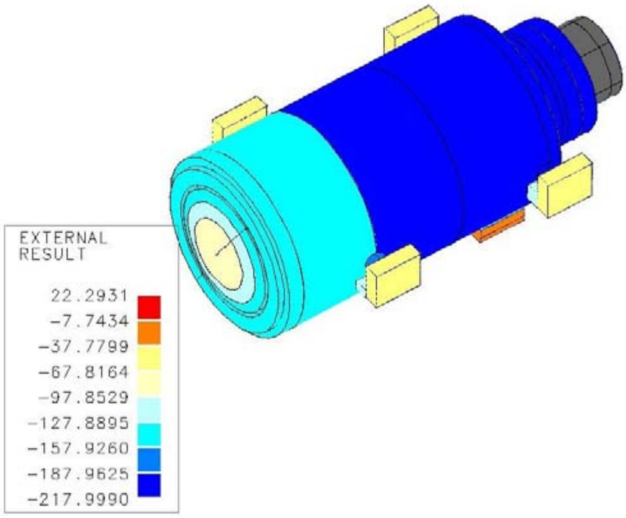
Lens Barrel GFF Temperature Overlay



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Oxford University - In Spectrograph

After testing at RAL, Front of the camera placed into the spectrograph at Oxford University

The back of camera is in a 273 K room whilst the front lies in the 200 K spectrograph

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Subaru Telescope Integration (1)

Camera and Spectrograph shipped and fitted into Spectrograph Room in 8 m Subaru Telescope, Mauna Kea, Hawaii.

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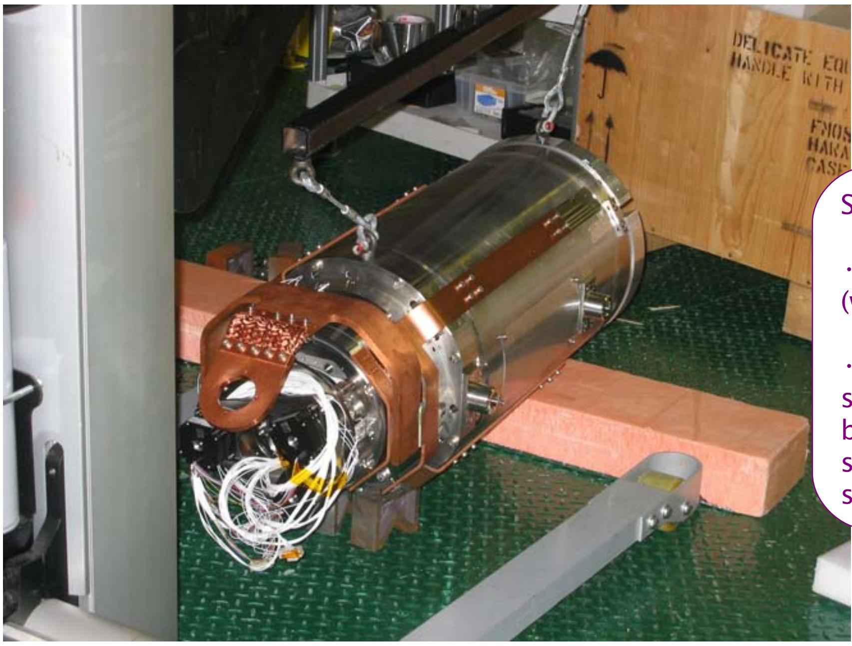
Subaru Telescope Integration (2)



St. steel lens barrel:

- Motor harnesses (white cables)
- 1st Stage copper straps with flexi-braid cooling the stainless steel structure

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Subaru Telescope Integration (3)

Spectrograph Structure with Main Mirror

Camera Dewar

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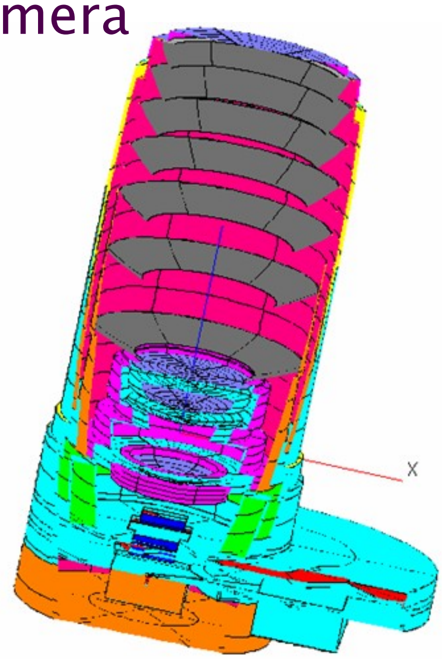
TEG RAL Ground Projects – VISTA Camera



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Contact Details and Further Reading

Allan Dowell

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/thermal

Email: A.Dowell@rl.ac.uk

Websites:
RAL FMOS Project: www.sstd.rl.ac.uk/FMOS
Subaru Telescope: www.naoj.org/
Durham University: www.cfai.dur.ac.uk/fix/projects/fmos/fmos.html
AAO: www.aao.gov.au/local/www/echidna/
Oxford University: http://www-astro.physics.ox.ac.uk/research/

Papers
Lens 6 etc: SPIE, 6273, 76, 2006, Froud et al.
IRS2 integration: SPIE, 6269, 136, 2006, Dalton et al.
FMOS overview: SPIE 6269, 43, 2006, Iwamuro et al.
VISTA Camera: SPIE 6269, 30, 2006, Dalton et al.

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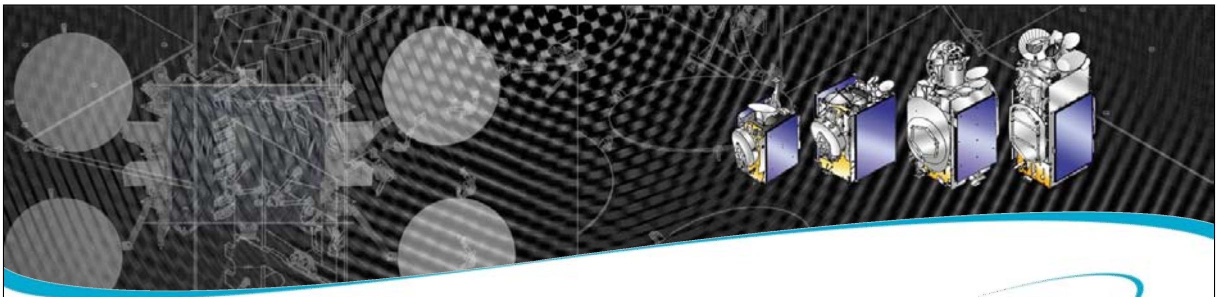
Appendix N

Thermal analysis for re-entry vehicles - software needs and expectations

Savino De Palo
(Thales Alenia Space, Italy)



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Thermal Analysis for Re-Entry Vehicles - S/W Needs and Expectations

Savino De Palo - *Thermal Systems*
Federico Maretto - *Advanced Projects*

Template reference : 100182079N-EN

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THERMAL ANALYSIS FOR RE-ENTRY VEHICLES

Page 2

- INTRODUCTION
- STUDY CASE 1 : THERMAL ANALYSIS FOR HMS
- CONCLUSIONS AND PERSPECTIVE
- STUDY CASE 2 : THERMAL ANALYSIS FOR HOT- STRUCTURES
- CONCLUSIONS AND PERSPECTIVE

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INTRODUCTION

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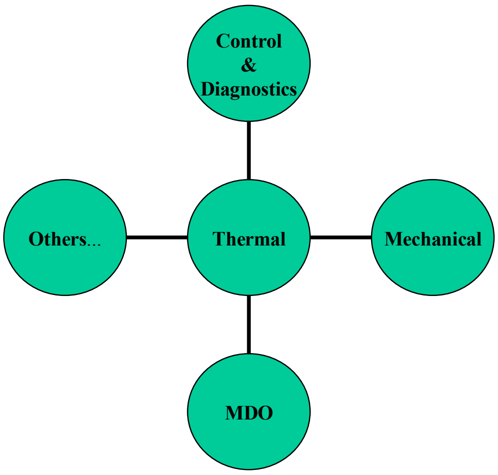
INTRODUCTION



In the field of Re-Entry Vehicles there is a growing need for Thermal Analysis (TA) not only for Thermal Design needs but also to support other disciplines as Mechanical, Control, etc..

In some cases data exchange and coupling among disciplines are so critical that the TA must be performed with tools different from the standard ones (e.g. ESATAN- ESARAD) even for ESA programs !

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STUDY CASE 1 – TA FOR HMS

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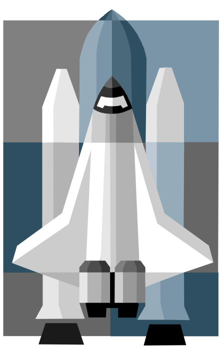
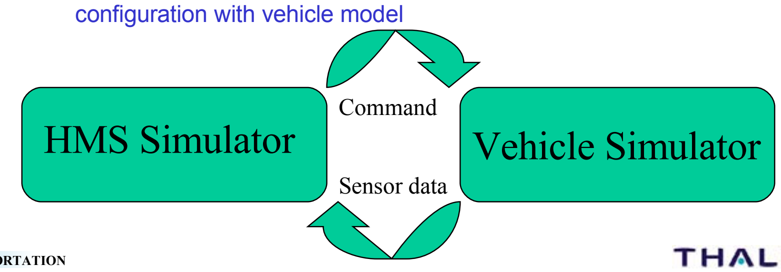
STUDY CASE 1 : THERMAL ANALYSIS FOR HEALTH MONITORING SYSTEMS



• HMS for RSTS is an ESA Program dedicated to next generation re-usable Re-Entry vehicles:

- On-board and off-board monitoring systems :
  - healt status check
  - corrective actions during flight
  - maintenance planning / optimization between flights
  - Go/No Go for next flight
- HMS real time simulator to be defined and tested in working configuration with vehicle model



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STUDY CASE 1 – TA FOR HMS

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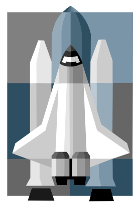
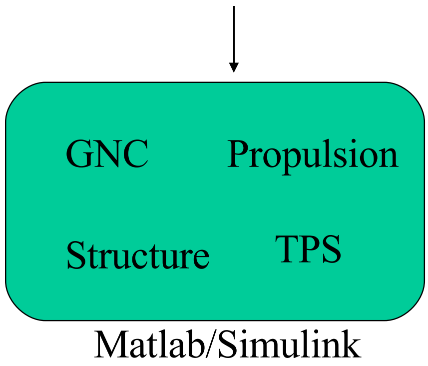
VEHICLE SIMULATOR

- **Baseline is Hopper vehicle concept (Astrium)**
- **Physical models of the following subsystems:**
  - GNC
  - Propulsion
  - Structure
  - TPS
- **Simulator to be developed with Matlab/Simulink**
  - Model-Based Design tool
  - Standard tool for Control System design
  - Able to model any type of Dynamic System
  - Several add-ons available but no one dedicated to Thermal →develop internal models





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STUDY CASE 1 – TA FOR HMS

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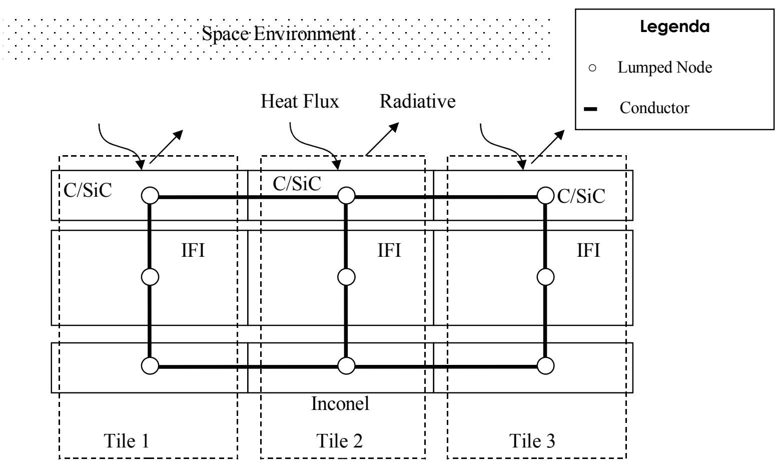
TPS THERMAL MODEL (1)

- Lumped Parameter approach : physical modelling based on 1° principle
- Full non-linearity implemented (radiative heat exchange, material performance vs T ...)
- Ageing/failure modes/degradations can be switched on/off or tuned on demand



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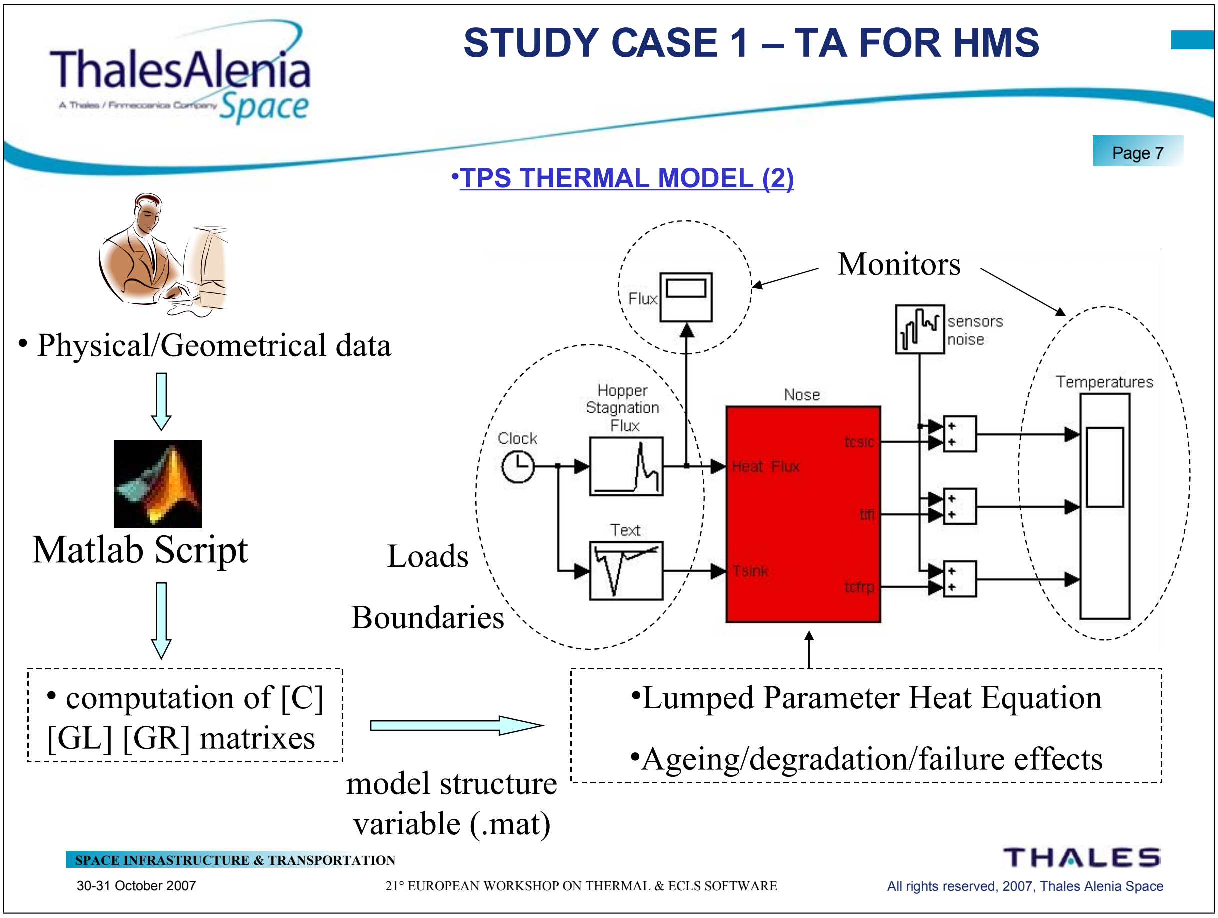
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STUDY CASE 1 – TA FOR HMS
Page 7
•TPS THERMAL MODEL (2)
• Physical/Geometrical data
Matlab Script
• computation of [C] [GL] [GR] matrixes
model structure variable (.mat)
Loads
Boundaries
Monitors
Flux
sensors noise
Hopper Stagnation Flux
Clock
Text
Nose
Heat Flux
Tsink
tcsic
tifi
tcfrp
Temperatures
•Lumped Parameter Heat Equation
•Ageing/degradation/failure effects
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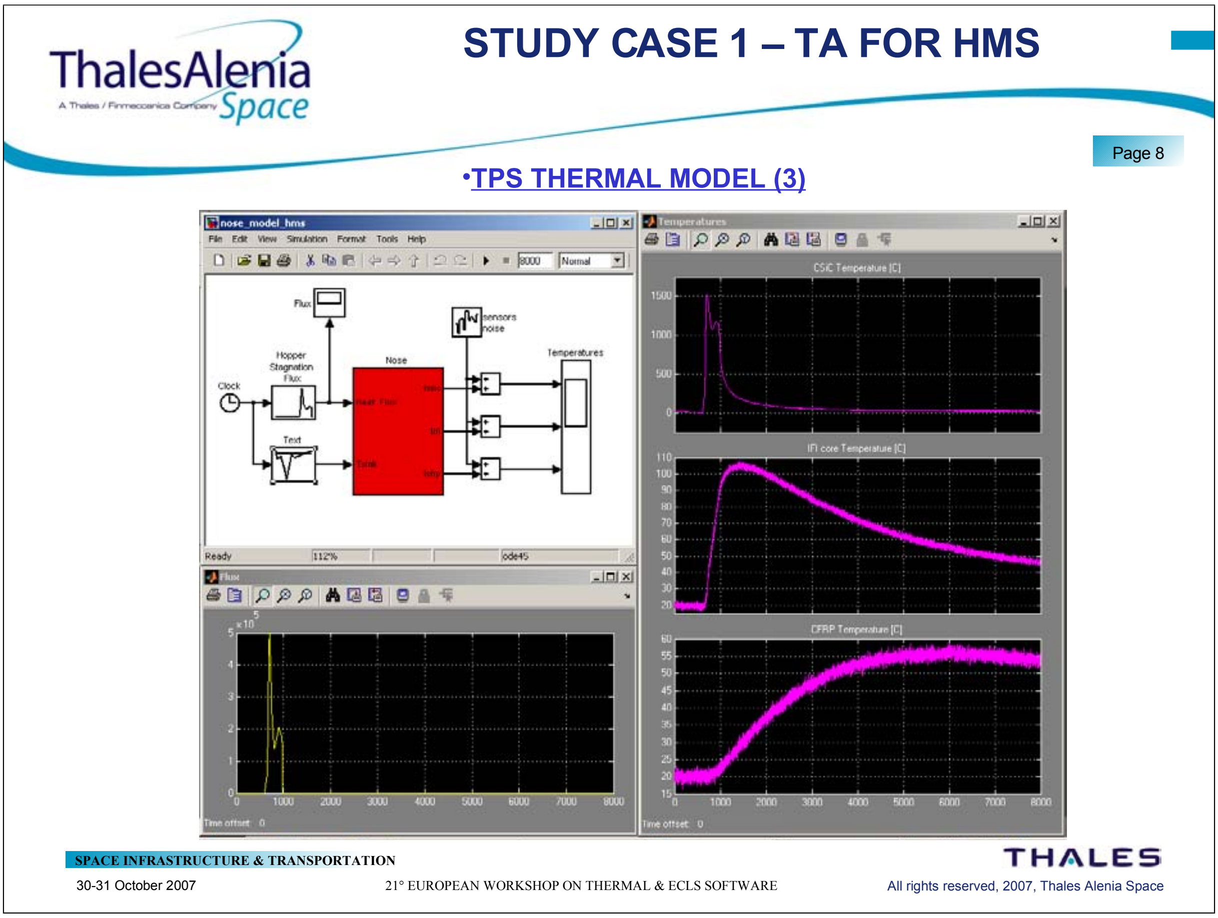
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STUDY CASE 1 – TA FOR HMS
Page 8
•TPS THERMAL MODEL (3)
nose_model_hms
Temperatures
CSiC Temperature [C]
IFI core Temperature [C]
CFRP Temperature [C]
Flux
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STUDY CASE 1 – TA FOR HMS

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CONCLUSIONS ON STUDY CASE 1 (1)

WHY SIMULINK THERMAL MODELS ?

Thermal models in MATLAB / SIMULINK can be useful for the following tasks (other than Re-Entry vehicles applications...)

- Control Systems developement (e.g., PID), providing also a clear link between Thermal Dept. & Avionic Dept.
- Real Time simulator for real time applications (flight operations, tests ...)
- Integrated analysis with any type of system (HMS like, multiphysics)

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STUDY CASE 1 – TA FOR HMS

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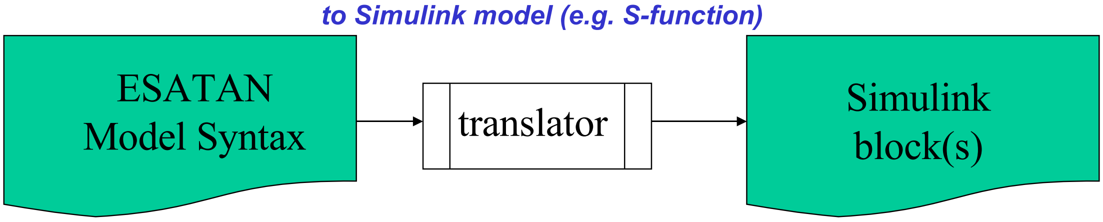
CONCLUSIONS ON STUDY CASE 1 (2)

THERMAL S/W INTERFACING WITH MATLAB / SIMULINK ?

- Comsol MultiPhysics (export FEM models to S-functions)
- SINDA models can be run/stop from Matlab command lines

Need for automatic translator from Lumped Parameter model (e.g. ESATAN like syntax) to Simulink model (e.g. S-function)



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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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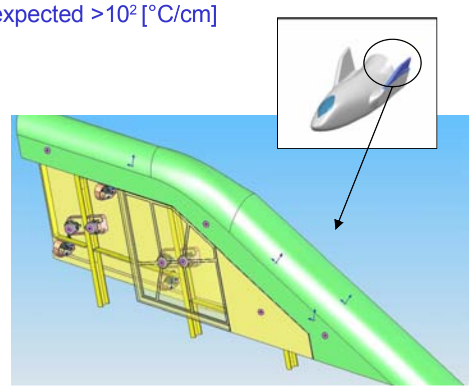
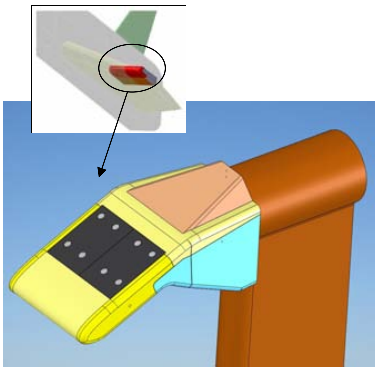
STUDY CASE 2 : THERMAL ANALYSIS FOR HOT-STRUCTURES

- Hot-Structures are key components for next generation Re-Entry vehicles
  - 5°European WorkShop on TPS & Hot Structures
- Thermal-Mechanical interactions is the core problem
  - Reduce deformations to the minimum (plasma injection must be avoided)
  - Thermal gradients expected >10² [°C/cm]
  - Bolts pre-loading
  - Contact
- Thermal analysis must be :
  - Accurate
  - Detailed
  - Good interpolation with FEM
- Other aspects
  - CAD I/F



Hybrid Structures



ASA experiment

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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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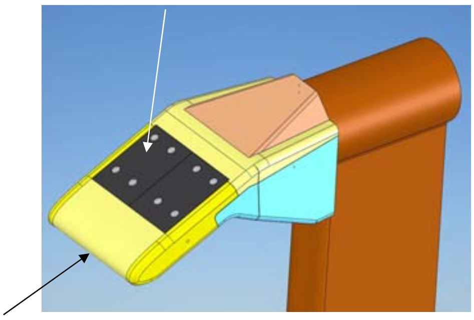
ADVANCED STRUCTURE ASSEMBLY (ASA)

- **Research financed by the Italian Space Agency (ASI)**
- **Goal: use new technologies, test at material and wing assembly levels (Scirocco PWT)**
- **Wing Leading Edge**
  - Actively Cooled (Thales Alenia Space)
  - UHTC (CIRA)
- **Closure Panels**
  - Hybrid Panels (Univ. La Sapienza)
  - Metal Matrix Composite (CSM)
- **Thermal- Mechanical design developed with MultiPhysics approach by using Ansys 10**
- **ESATAN-FHTS used for hydraulic elements only**

Closure Panel



Wing Leading Edge

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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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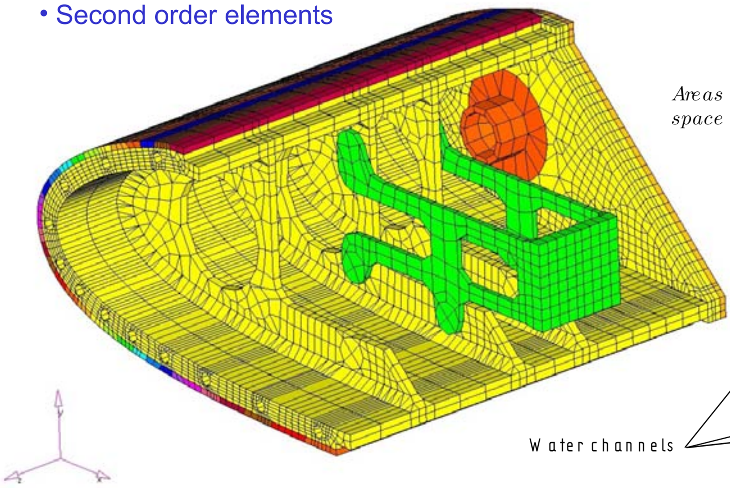
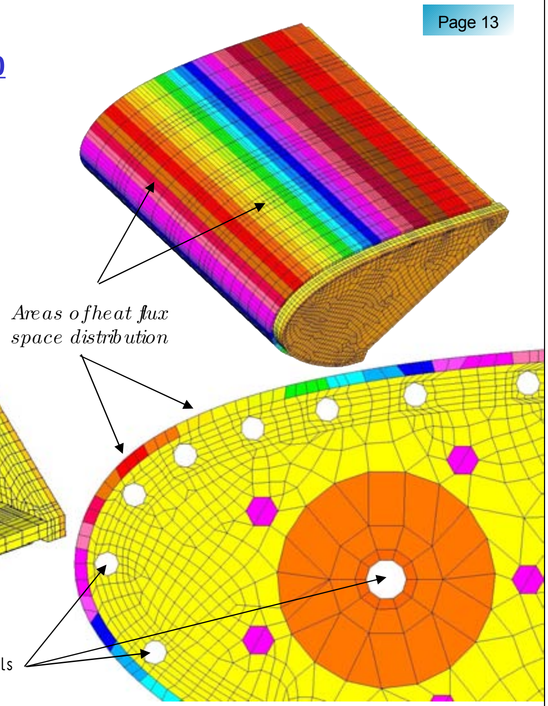
ACWLE MESH overview - Hyper mesh 7.0

- Fully detailed manual structured grid
- 63’000 nodes
- 50’500 elements (46’000 hex + 4’500 penta/tetra)
- Second order elements





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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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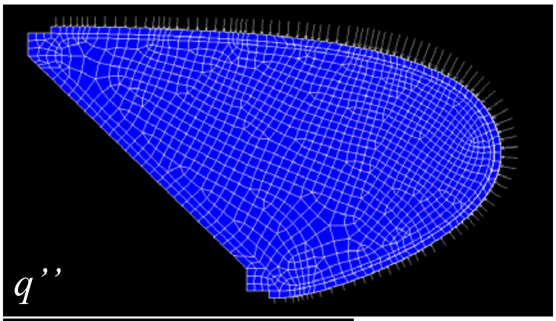
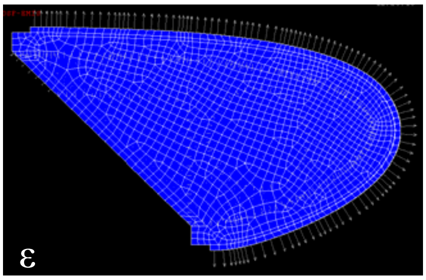
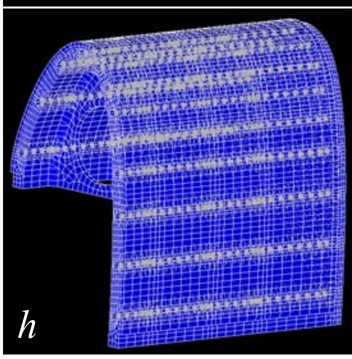
THERMAL ANALYSIS overview Ansys 10.0

- Transient non-linear thermal analysis, 4000s
- Material properties temperature dependent
- Heat fluxes distributed in time and space
- Convection distributed along ACWLE channels lenght and manifolds computed with FHTS
- External radiation







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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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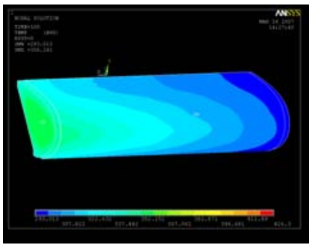
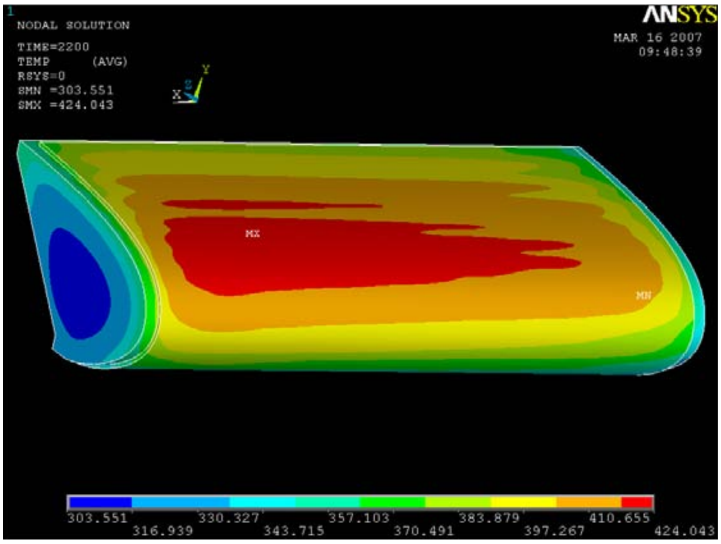
Page 15

THERMAL ANALYSIS - Temperature

Max Temperature raised :
@ 2400s → 426°K (153°C)



Animation 0÷4000s



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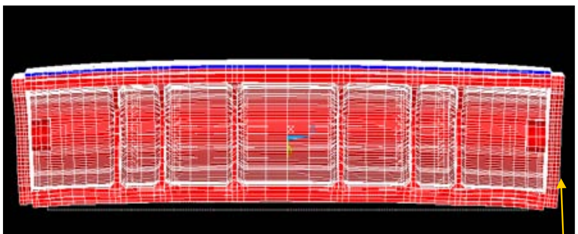
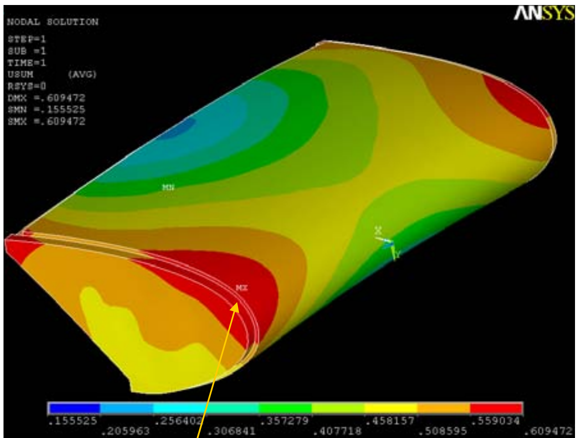
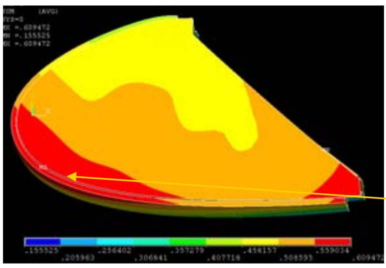
MECHANICAL ANALYSIS - temperature effects (1)

Displacement





Max temperature:153°C



Max displacement: 0.61mm

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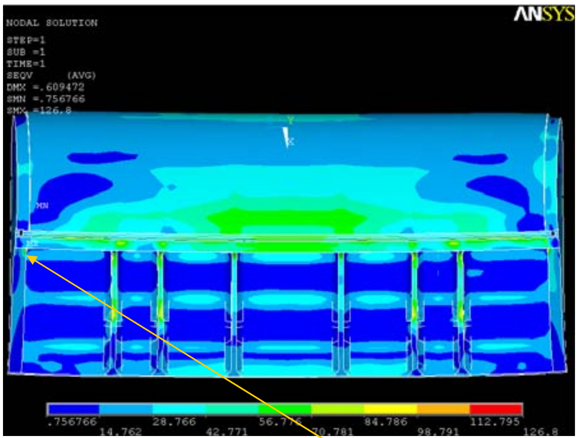
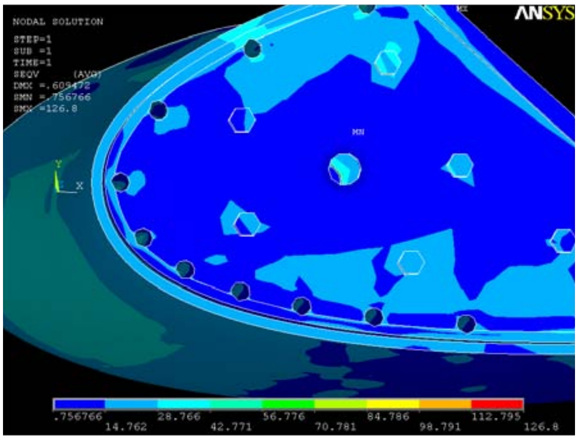
MECHANICAL ANALYSIS - Temperature Effects (1)

Von Mises stress





Max: 140MPa@117°C

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STUDY CASE 2 – TA FOR HOT-STRUCTURES

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CONCLUSIONS ON STUDY CASE 2

- Hot-Structures is one of the “natural” application of Multiphysics analysis
- Huge FEM models → System size limitations (not for complete vehicle models!)
- Several COTS S/W are available for MultiPhysics analysis (Ansys, Abaqus ...) which allow:
  - direct coupling with Mechanical (and not only) FEM models
  - rapid implementation of design modifications with CAD models
- These tools are already the standard S/W for Re-Entry vehicle applications
- Interfaces with CFD codes is another key point. Also in this case COTS tools (e.g. MpCCI) are already the standard

To have a clear idea of the market status, COTS MultiPhysics FEM tools developers should be invited at the WorkShop to discuss / present / make demonstrations on thermal applications

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Appendix O

Use of ThermXL for rapid evolution of ExoMars rover vehicle design

Andy Quinn
(EADS Astrium, UK)

"Use of ThermXL for Rapid Evolution of ExoMars Rover Vehicle Design".

Presented by
Andy Quinn, ExoMars Rover Thermal Engineer
Astrium UK

All the space you need

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Central Engineering

Introduction

- EXOMARS
  - Mission Info
  - Mission Objectives
- Thermal Modelling
  - Surface environment
  - On board Hardware
- Model evolution
  - Mission
  - Thermal design
- ThermXL use
  - Reasons for selection
  - Model control
  - Issues
- Conclusions

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EXOMARS

- ESA project
- Prime Contractor Alcatel Alenia in Turin
- Astrium UK Rover Vehicle lead
- Nominal launch in 2013 with backup in 2015
- Landing in 2015/16
- Currently working on an extension to the Phase B1

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Rover Mission Objectives

- The Science Objectives
  - Search for signs of past and present life on Mars
  - Identify and characterise possible hazards to human exploration
  - Enhance knowledge of the Mars environment
- The Mission Goals
  - To deliver to the surface of Mars a large lander incorporating a mobile exobiology package
  - To develop and operate a complex Exobiology package, mounted on a Rover, able to perform at different locations on the surface
  - To implement on-board an Orbiter the communications links for the Rover, and a rendezvous package

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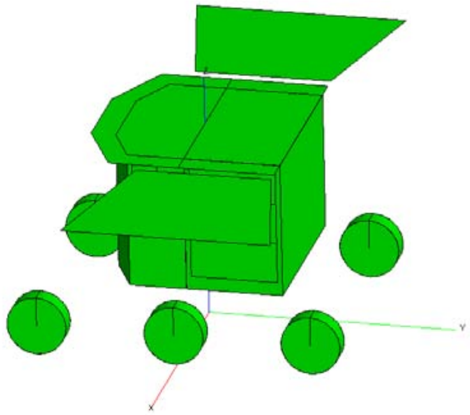
Thermal Modelling

- Mars environment
  - Solar Flux
  - Atmosphere
  - Diurnal period
- Thermostatic heaters
- Loop Heat pipes



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Model Evolution

Mission

- Uncertainty over launcher & consequent configuration
- Mission start date variation
- Landing latitude range
- Large number of cases required to envelope possible missions

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Thermal Design

- Initial design concept from Phase A complex
- Reduced to LHP's and thermal switch
- Discrete switch removed
- Service module equipments coupled together in conductive frame
- Reduced RHU power

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Reasons for ThermXL

- Ease of generating network using excel functionality
- Formulas can be simply implemented
- Quick to change with small model
- ESARAD integration
- Real time output display

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Model Control

- Attempted to maintain all cases in one sheet
- Initially simple with only 2 cases
- Added Control Sheet to Excel when more added
- Case switching in excel difficult
- Eventually used 1 sheet per case

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ThermXL Issues

- Difficult to add multiple switches

  Nested IF statements in Excel can become very unwieldy. This makes switching cases, adding power profiles and other switching logic difficult to control.
- Run time
- Export to ESATAN loses all logic/routines etc

  The ESATAN export does not take any Excel formulae into account. This makes implementing more complex models in ESATAN very time consuming
- Configuration management becomes hard with more complex models

  It is not practically possible to contain everything in one workbook. Multiple case workbooks can diverge if not properly controlled.

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In Conclusion

- Excellent tool for simple early analysis
- Rapid model updating useful
- Configuration management difficult
- Time consuming to convert more complex models to ESATAN

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Any Questions?

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Appendix P

Thermal Concept Design Tool

Matteo Gorlani
(Blue Engineering, Italy)

Thermal Concept Design Tool Distribution & Maintenance

Matteo Gorlani
Blue Engineering, Torino, Italy

Harrie Rooijackers
European Space Agency, Noordwijk, The Netherlands

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Sheet 1

Overview

- Background
- TCDT Overview
- TCDT Web Pages
- TCDT Package
- TCDT Team

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Sheet 2

Background (1/2)

BLUE ENGINEERING & THALES ALENIA SPACE TORINO developed for ESA THE THERMAL CONCEPT DESIGN TOOL (TCDT)

- Provide a flexible and easy environment to investigate a large number of different configurations and TCS options
- Increase the integration between the TCS discipline and other disciplines, in order to speed-up the S/C optimisation
- Support a change of method in the S/C and in particular TCS design, moving toward a design oriented approach
- Exploit the functionalities of ESATAN, ESARAD, ThermXL, ARTIFIS and TOPIC by allowing the user to use them at an higher level

Activity
- started in 2004
- closed in 2007

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Sheet 3

Background (2/2)

ESA awarded to BLUE ENGINEERING the contract to DISTRIBUTE & MAINTAIN the TCDT:

- Distribution will start after the WorkShop
- TCDT Web Pages are available for
  - Registration/TCDT licence request
  - Problem Reporting
  - New Feature request
- TCDT Support by TCDT Team at BLUE

Activity
- started in 2007
- foreseen up to 2011

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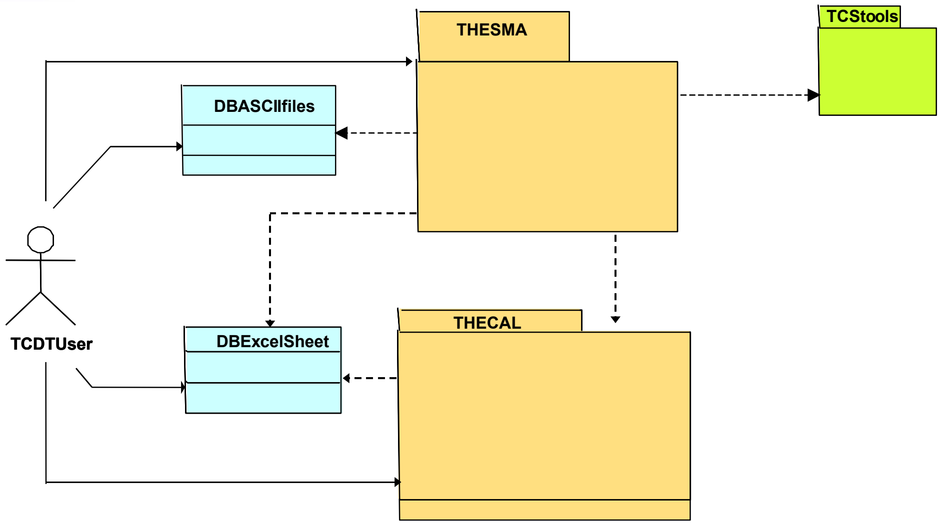
Sheet 4

TCDT Overview (1/5)



TCDTdatabases TCDTaddin TCStools

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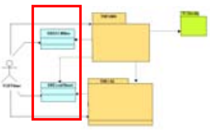
Sheet 5

TCDT Overview (2/5)

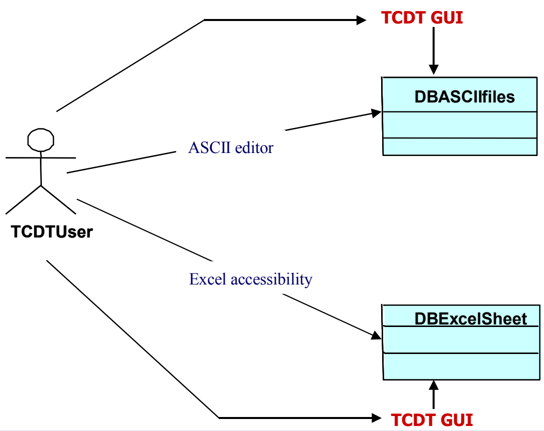


DATABASES

Two types of databases:

- An Excel workbook (DbSheet): geometry, thermal characteristics, analyses and results
- An ASCII file (DBASCIIFile): TCDT configuration and planets database.

User Access to Databases



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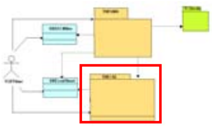
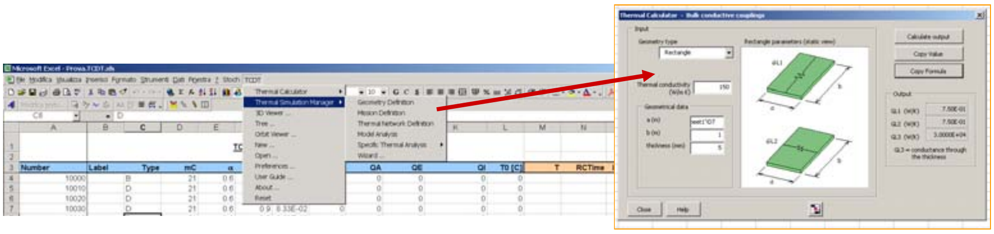
TCDT Overview (3/5)



THERMAL CALCULATOR

- Calculate Mass (M), Centre of Gravity, Moments of Inertia and thermal capacitances
- Calculate conductive couplings and contact conductance
- Calculate radiative conductors and external fluxes
- Calculate sink temperatures, heat exchanged for nodes and group of nodes according to data in the DBsheet
- Select among possible Insulation and thermal interface



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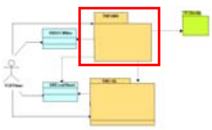
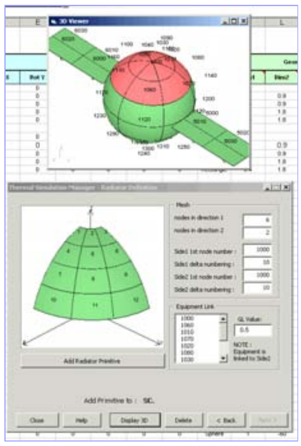
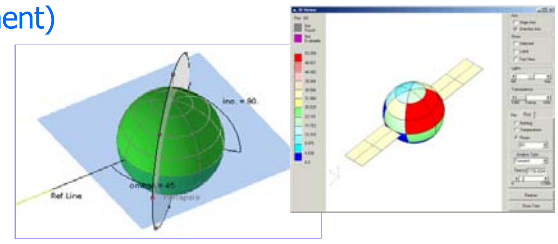
TCDT Overview (4/5)



THERMAL SIMULATION MANAGER

- Build geometrical and thermal mathematical models
- Create input files for the external tools
- Define missions, radiative and thermal analysis cases
- Run analysis cases with the external tools
- Retrieve the results of analysis cases Perform specific analysis and design tasks on pre-built geometrical/thermal typical configurations
- Perform parametric analyses (e.g. for extreme cases assessment)





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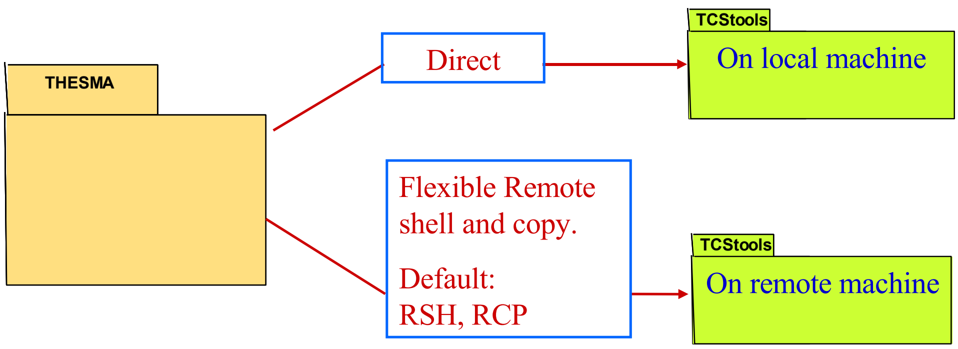
TCDT Overview (5/5)

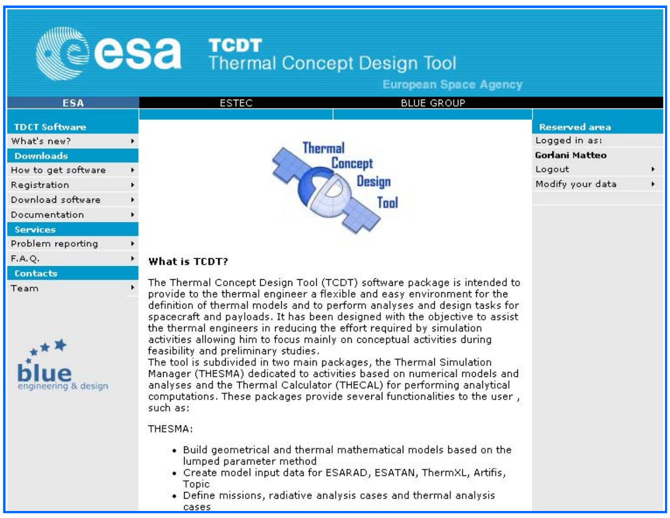
TCS TOOLS

- TCS TOOLS are not distributed within the TCDT package.
- ESATAN, ESARAD and ThermXL are commercial tools, contact the manufacturer for more information.
- Artifis and Topic are tools in use at ESTEC, contact ESA for more information and availability.



TCDT Web Pages (1/4)

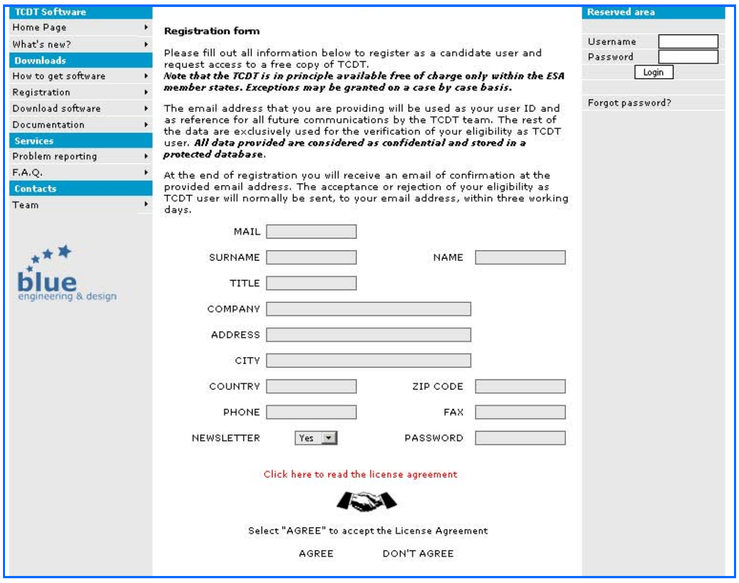
INTRODUCTION TO THE TCDT AND NEWS (Public Area)



http://www.blue-group.it/TCDT/

TCDT Web Pages (2/4)

REGISTRATION (Public Area)



The TCDT is in principle available free of charge only within the ESA member states. Exceptions may be granted on a case by case basis.

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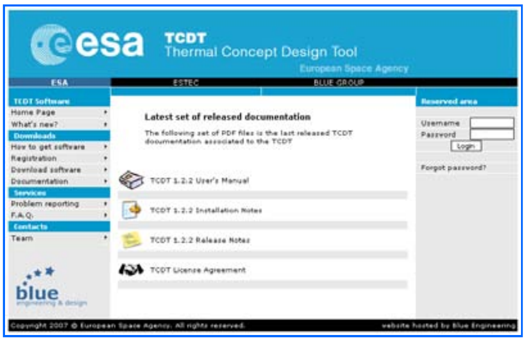
TCDT Web Pages (3/4)

TCDT PACKAGE DOWNLOAD

TCDT Package download page (Private Area)



TCDT Documentation download page (Public Area)

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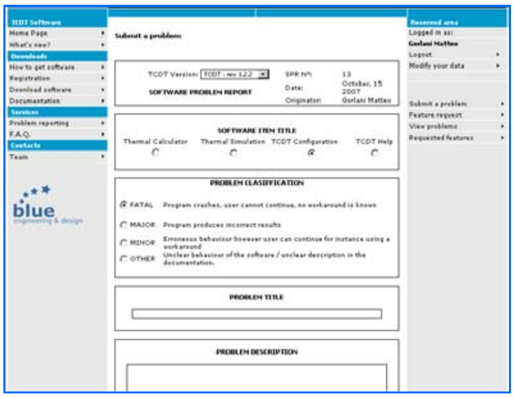
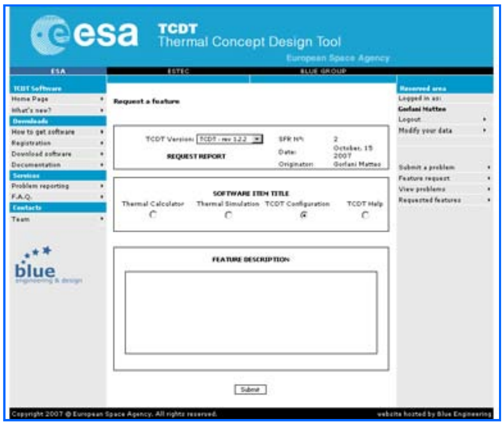
TCDT Web Pages (4/4)

PROBLEM REPORTING AND FEATURE REQUEST (Private Area)

Each TCDT User can:

- Open a SPR (Public or Private)
- Check SPR resolutions for all public SPRs





Each TCDT User can:

- Add a new FR
- View all added FRs

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TCDT Package (1/2)

PACKAGE CONTENTS

TCDT: the main programs

- ThermXL Version
- Non ThermXL Version

TCDTuseraddin: a user customizable addin based upon TCDT

- ThermXL Version
- Non ThermXL Version

TCDT Help

- User Manual
- Programmers reference manual
- Theoretical manual
- Tutorials
- Release notes
- Installing notes

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TCDT Package (2/2)

PLATFORMS AND HARDWARE

Component	Minimum requirements
Computer and processor	Personal computer with a 1000-MHz Pentium III Processor
Operating System and additional software	• Microsoft Windows 2000 with Microsoft Excel 2000 • Microsoft Windows XP with Microsoft Excel 2003
Memory	256 Mb
Hard disk	100 MB of available hard-disk space
Drive	CD-ROM drive
Display	Super VGA (1280 x 1024)
Local Area Network (LAN)	A local network connection is required for certain functionalities (I/F and exchange data with external software installed on other platforms)

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TCDT Team (1/2)

DEVELOPMENT

BLUE ENGINEERING S.R.L.	THALES ALENIA SPACE TORINO
Matteo Gorlani - Project Manager **Andrea Tosetto** - Software Development	**Valter Perotto** - Project Manager **Luca Tentoni** - Software Development

ESA - ESTEC

Dr. Olivier Pin - Head of Thermal Analysis and Verification Section
Dr. Harrie Rooijackers - Project Manager

Many THANKS to ThalesAlenia Space Team

A Thales / Finmeccanica Company

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TCDT Team (2/2)

DISTRIBUTION & MAINTENANCE

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

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Appendix Q

ESATAP - Handling large thermal results data with HDF5

François Brunetti
(Dorea, France)

esa Mechanical Engineering Department
Thermal and Structures Division

DOREA TECHNOLOGY

ESATAP

Handling Large Thermal Results Data with HDF5

ESA/ESTEC project managers:

Harrie ROOIJACKERS Hans Peter DE KONING

Authors:
alain.fagot@dorea.fr
francois.brunetti@dorea.fr

DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00

ESATAP Quick Presentation

- **ESATAP is a flexible post-processing tool of STEP-TAS/STEP-NRF data files.**
- **Main features:**
  - Handle the standard STEP-NRF thermal results data files.
  - Allow to implement own post processing scripts (components)
  - Provide a toolbox of around 40 basic components for statistical, thermal, mathematical calculation, heatflow, etc.
  - Provide interfaces with MS Word, MS Excel, OpenOffice, GnuPlot, etc.
  - Provide a graphical user interface for non-programmers allowing to easily implement/maintain/improve/enrich the Toolbox and/or own Local components or structured complex tasks.

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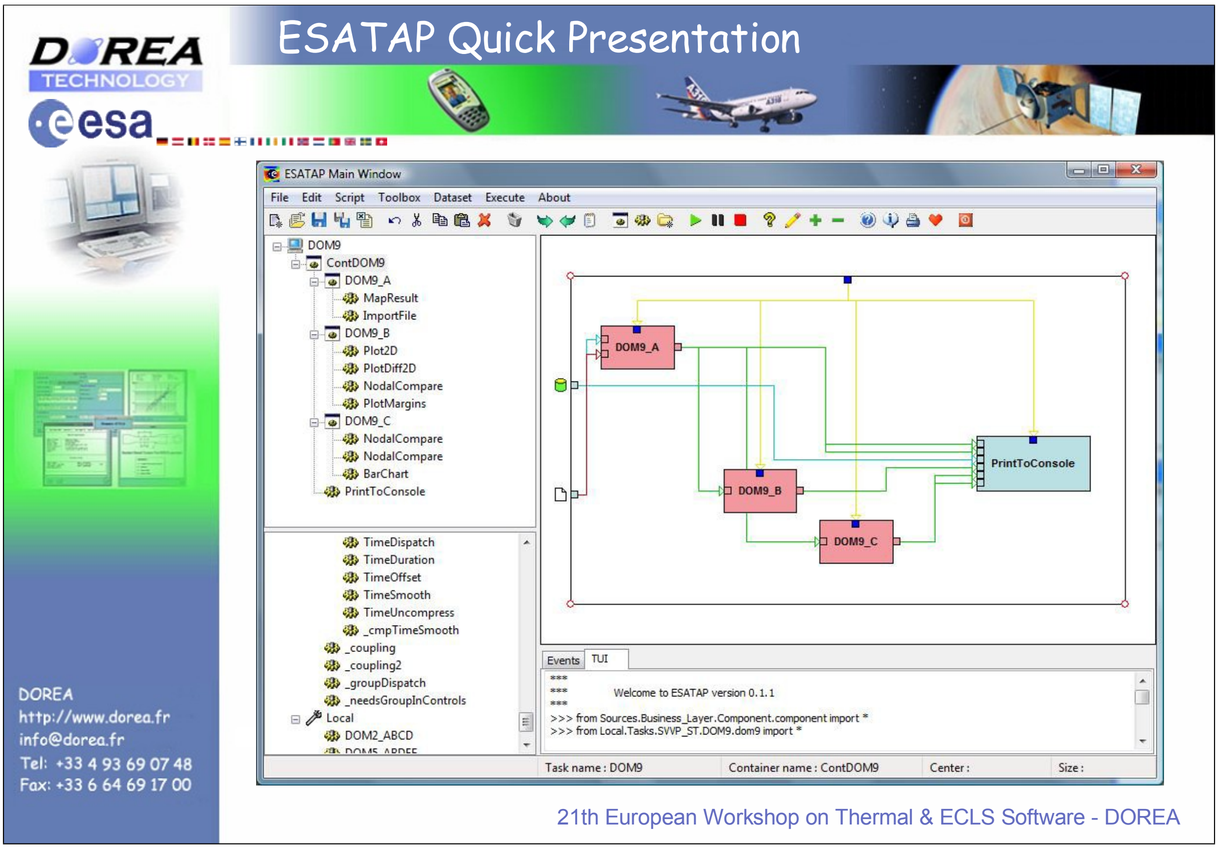
ESATAP Quick Presentation
DOREA TECHNOLOGY
esa
ESATAP Main Window
File Edit Script Toolbox Dataset Execute About
DOM9
ContDOM9
DOM9_A
MapResult
ImportFile
DOM9_B
Plot2D
PlotDiff2D
NodalCompare
PlotMargins
DOM9_C
NodalCompare
NodalCompare
BarChart
PrintToConsole
TimeDispatch
TimeDuration
TimeOffset
TimeSmooth
TimeUncompress
_cmpTimeSmooth
_coupling
_coupling2
_groupDispatch
_needsGroupInControls
Local
DOM2_ABCD
DOM9_A
DOM9_B
DOM9_C
PrintToConsole
Events TUI
Welcome to ESATAP version 0.1.1
>>> from Sources.Business_Layer.Component.component import *
>>> from Local.Tasks.SVVP_ST.DOM9.dom9 import *
Task name : DOM9
Container name : ContDOM9
Center :
Size :
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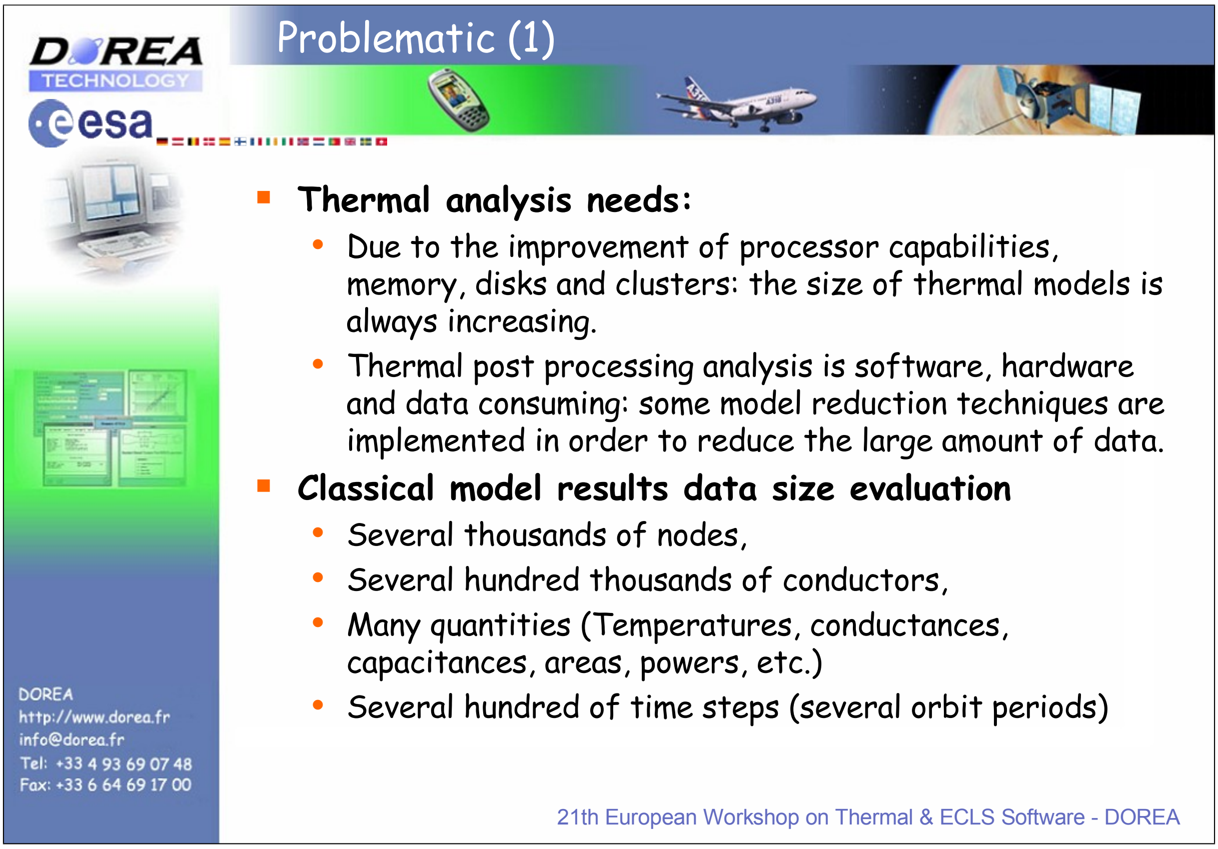
Problematic (1)
DOREA TECHNOLOGY
esa
Thermal analysis needs:
Due to the improvement of processor capabilities, memory, disks and clusters: the size of thermal models is always increasing.
Thermal post processing analysis is software, hardware and data consuming: some model reduction techniques are implemented in order to reduce the large amount of data.
Classical model results data size evaluation
Several thousands of nodes,
Several hundred thousands of conductors,
Many quantities (Temperatures, conductances, capacitances, areas, powers, etc.)
Several hundred of time steps (several orbit periods)
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Problematic (2)

- **Raw data size:**
  - Minimum results data array size order:
    - 100000 x 100 x 10 = 10 Mega of doubles
    - > 80 Mbytes for conductors
  - Model data size:
    - 1000 x 100 x 10 = 8 Mbytes
- **Data exchange format overhead:**
  - STEP-TAS part 21 (ASCII):
    - NRF datacube : 99% of the size, model 1 %
    - > 80 Mbytes of raw data ⇔ > 300 Mbytes
  - GFF : > 500 Mbytes
- **Objectives:**
  - An operational model issued from solvers generates a large amount of data, difficult to exchange. Improve the thermal data exchanges,
  - To reduce the time response as much as possible on results data access read to anticipate the needs.

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Fax: +33 6 64 69 17 00

Studied solution

- **Solution:**
  - Use of a standard binary format, portable with indexing facilities,
  - I/O libraries allow to have the both archiving Part 21 ASCII format and HDF5 binary format for operational use.
  - Implement a generator able to provide the STEP-TAS (thermal) API for both part 21 and HDF5 data format.
  - Provide an efficient and optimized API able to quickly access slices of data within a large set of result values.

=> Adapt STEP-TAS SDK to HDF5

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Topics

- STEP-TAS and HDF5

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STEP-TAS and HDF5

- **One of the main requirements for STEP-NRF & STEP-TAS is: exchange and archiving of large amounts of results data (from analysis, simulation, test or operation)**
  - Central ENTITY: nrf_datacube
  - Huge number of nrf_network_node and nrf_network_node_relationship
- **HDF5 selected long time ago as most appropriate binary data transport / storage**
- **Now using PyTables 2.0 and HDF5 1.6.5 as most efficient means to do fast implementation**
  - Easy to use high level API – integrates very well with existing pyExpress toolkit

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Forseen Advantages of using HDF5

- **HDF5 retrieves data on demand from disk**
  - Contrary to Part 21 format where one must load the whole dataset in memory
  - HDF5 allows real time compression and chunking of Data
- **Forseen advantages on huge models**
  - Run time memory is maintained at reasonable level
  - HDF5 Dataset files are much smaller due to compression.
  - STEP-TAS HDF5 API allows to handle huge datasets where Part21 API failed.

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Topics

- **STEP-TAS and HDF5**
- **STEP-TAS SDK**

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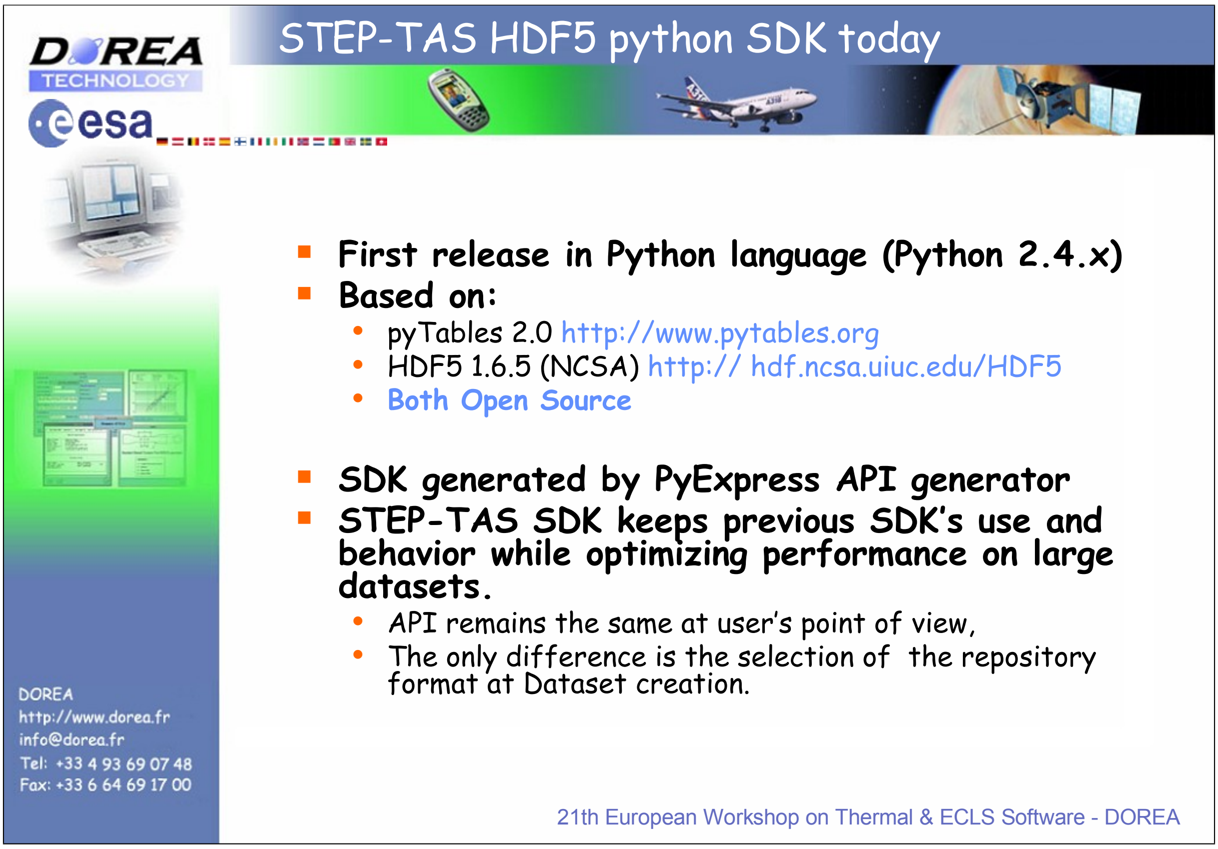

STEP-TAS HDF5 python SDK today
DOREA TECHNOLOGY
esa
First release in Python language (Python 2.4.x)
Based on:
pyTables 2.0 http://www.pytables.org
HDF5 1.6.5 (NCSA) http:// hdf.ncsa.uiuc.edu/HDF5
Both Open Source
SDK generated by PyExpress API generator
STEP-TAS SDK keeps previous SDK's use and behavior while optimizing performance on large datasets.
API remains the same at user's point of view,
The only difference is the selection of the repository format at Dataset creation.
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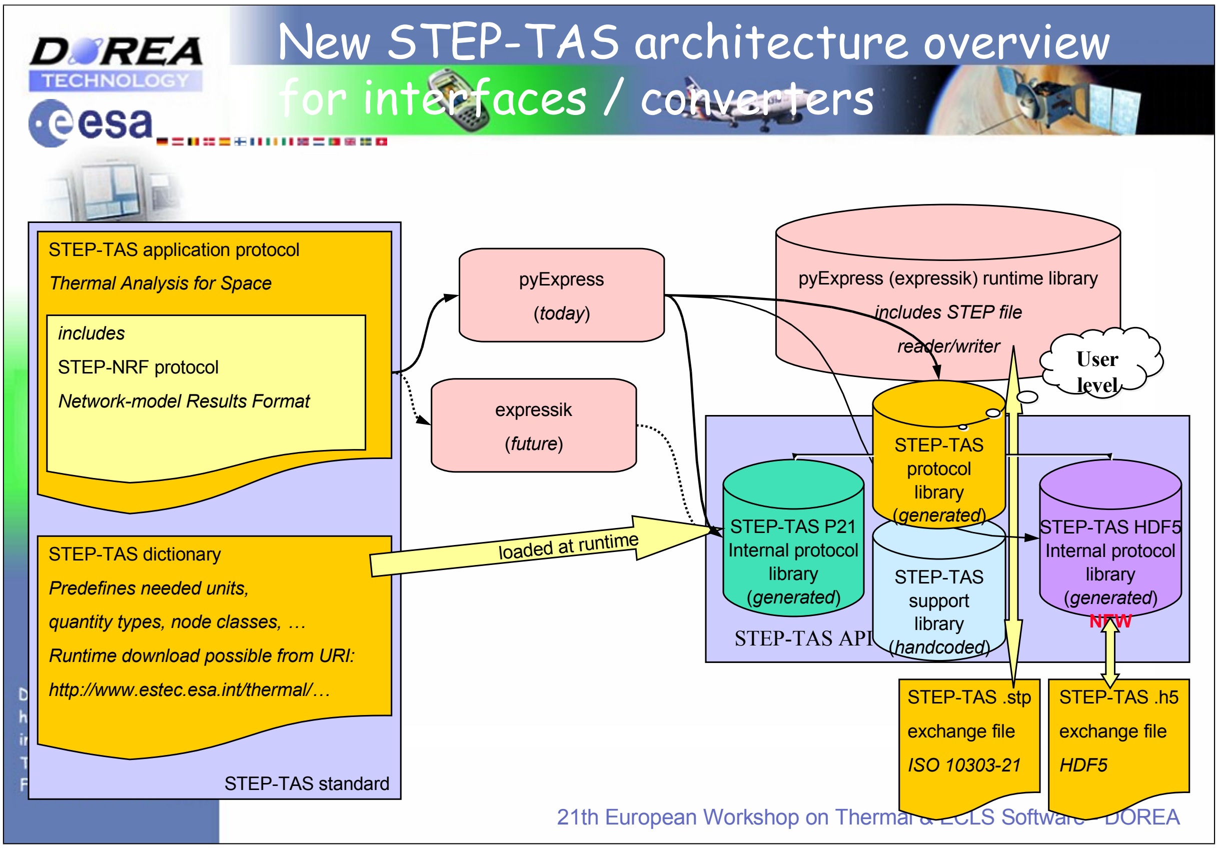

New STEP-TAS architecture overview for interfaces / converters
DOREA TECHNOLOGY
esa
STEP-TAS application protocol
Thermal Analysis for Space
includes
STEP-NRF protocol
Network-model Results Format
STEP-TAS dictionary
Predefines needed units,
quantity types, node classes, …
Runtime download possible from URI:
http://www.estec.esa.int/thermal/…
STEP-TAS standard
pyExpress
(today)
expressik
(future)
loaded at runtime
pyExpress (expressik) runtime library
includes STEP file
reader/writer
User level
STEP-TAS protocol library (generated)
STEP-TAS P21 Internal protocol library (generated)
STEP-TAS support library (handcoded)
STEP-TAS HDF5 Internal protocol library (generated)
NEW
STEP-TAS API
STEP-TAS .stp exchange file ISO 10303-21
STEP-TAS .h5 exchange file HDF5
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STEP-TAS HDF5 python SDK - tuning

- **HDF5 offers a low memory consumption for large models**
- **But data access to HDF5 data can be time consuming**
  - HDF5 representation of an EXPRESS model consists in consequent number of tables (similar to Relational Databases Tables) and arrays.
  - Reading data of an Express instance means reading data in several HDF5 tables/arrays
- **As to provide best execution time/Memory management, STEP-TAS generated SDK implements a fine handling of data between run-time memory and HDF5 datasets.**

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Topics

- STEP-TAS and HDF5
- STEP-TAS API
- **Some Benchmarks**

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Benchmark 1

- **Model contents**
  - 1112 thermal nodes,
  - Datacube 1: 1111 Observable item x 14 quantities x 576 states => **895 104** values
  - Datacube 2: 1 Observable item x 14 quantities x 576 states => 8 064 values
- **size of dataset in P21 file : 93,6 Mb**
- **size of dataset in HDF5 file : 30,3 Mb**
- **Objective of the bench**
  - The benchmark is executed twice with P21 and with HDF5 files
  - Opening dataset
  - Display lists of dataset content (Models, Nodes, conductors, quantities, results, ….)
  - Execute 4 « ReadObservableItemData » on first datacube (retrieve values for defined quantities, nodes, times)
  - Make a copy of input dataset

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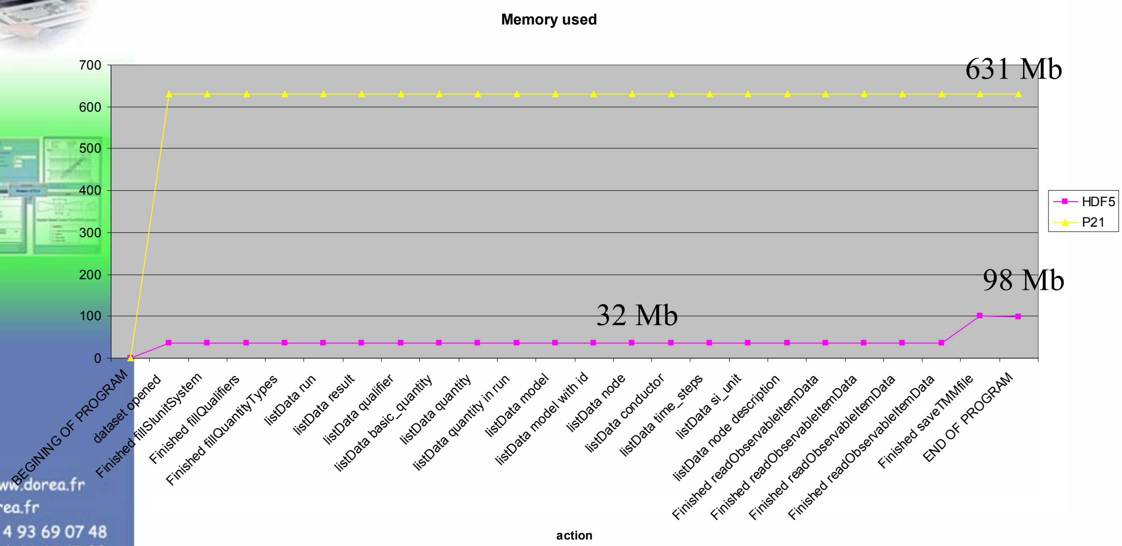
Benchmark 1 – Memory usage



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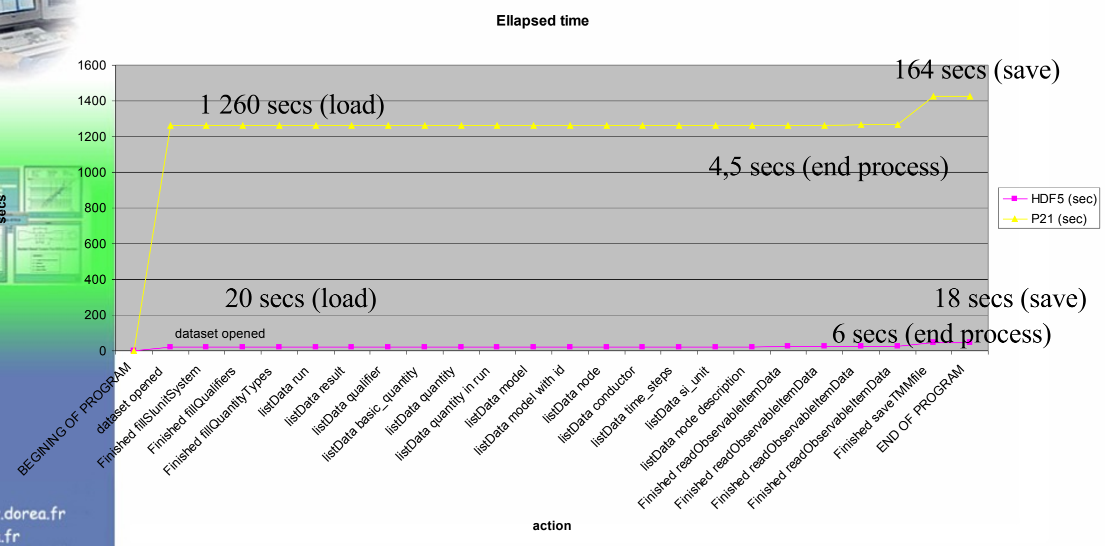
Benchmark 1 – Execution time



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Benchmark 2

- **size of dataset in P21 file : 12 Mb**
- **size of dataset in HDF5 file : 5,9 Mb**
- **Model contents**
  - 1112 thermal nodes, **106 959** conductors
  - Datacubes with 15554 values to **210016** values
- **Objective of the bench**
  - The benchmark is executed twice with P21 and with HDF5 files
  - Opening dataset
  - Execute 4 « ReadObservableItemData » on first datacube (retrieve values for defined quantities, nodes, times)

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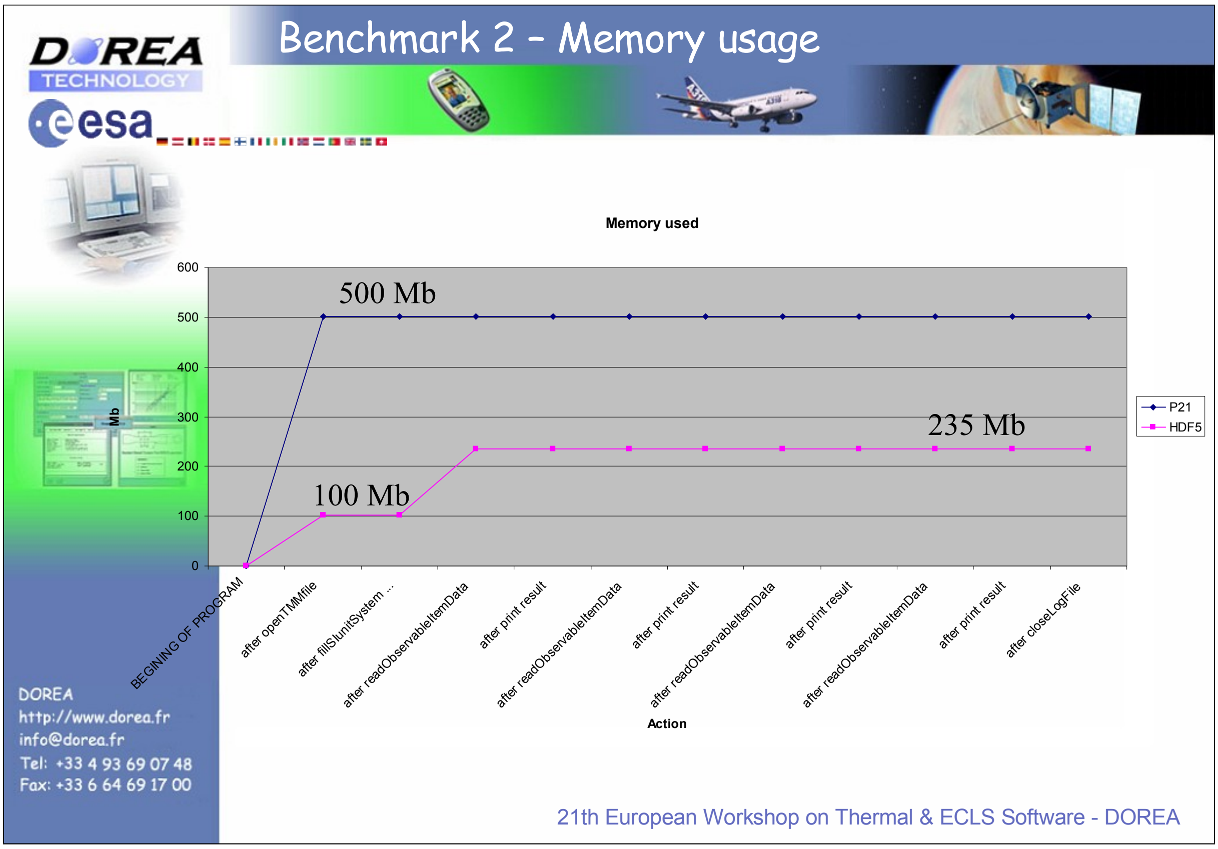
Benchmark 2 – Memory usage
DOREA TECHNOLOGY
esa
Memory used
Mb
Action
500 Mb
100 Mb
235 Mb
P21
HDF5
BEGINING OF PROGRAM
after openTMMfile
after fillSIunitSystem ...
after readObservableItemData
after print result
after closeLogFile
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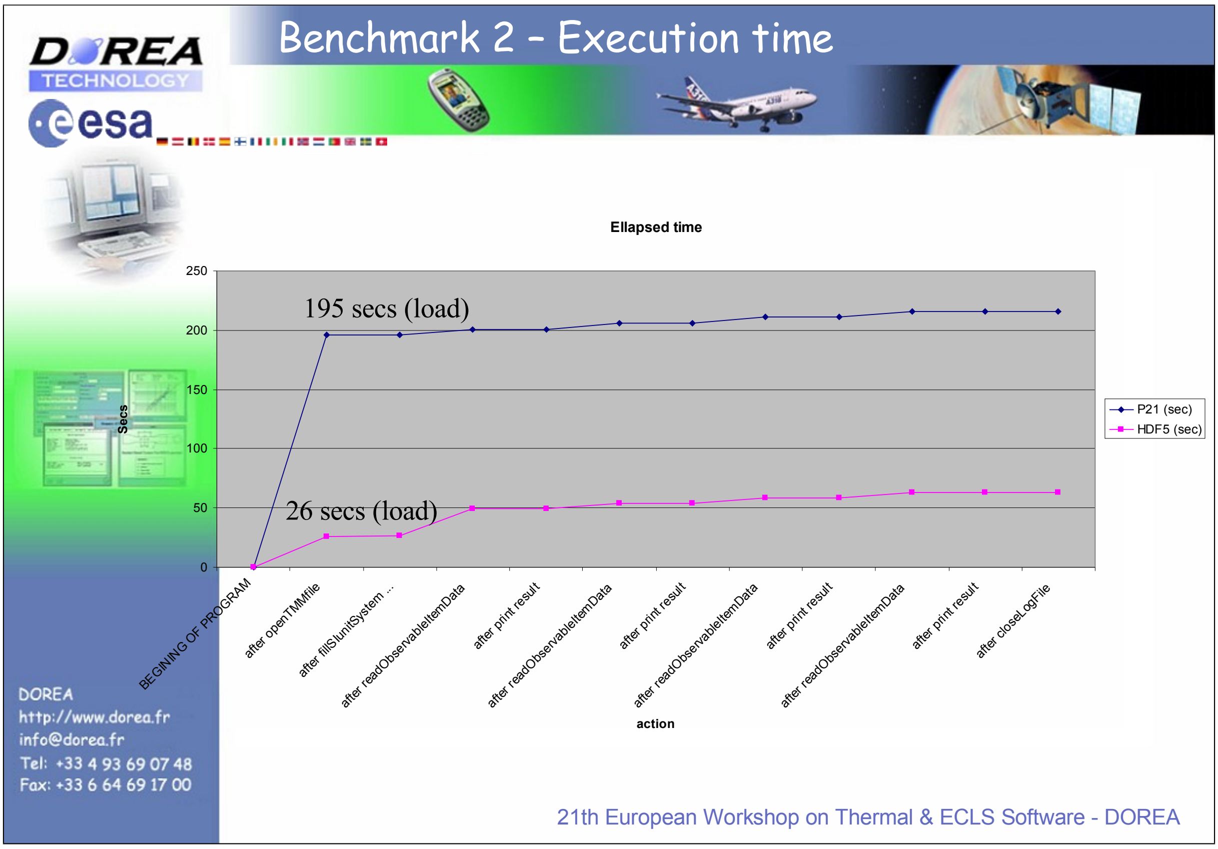
Benchmark 2 – Execution time
DOREA TECHNOLOGY
esa
Ellapsed time
Secs
action
195 secs (load)
26 secs (load)
P21 (sec)
HDF5 (sec)
BEGINING OF PROGRAM
after openTMMfile
after fillSIunitSystem ...
after readObservableItemData
after print result
after closeLogFile
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Demo

- **Data size:**
  - Extracting and handling 2 periods of temperatures from a group of 30 nodes within 1000 nodes, 20 quantities.
- **Extracting data:**
  - Part 21 or other ASCII results formats:
    - Around 1h30 (with 1h28 of data loading)
  - HDF5:
    - < 30 s (20 s of data table structure preload when opening)
- **Simple post processing calculation**
  - Part 21 or other ASCII results formats:
    - Same order than for extraction.
  - HDF5:
    - < 60 s (20 s of data table structure preload when opening)

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Conclusion

- **STEP-TAS 5.2 SDK for HDF5:**
  - Actually under system validation
  - Availability : December 2007
- **ESATAP HDF5:**
  - Distribution process is being finalized
  - Availability : January 2008
  - Platforms: Windows XP/Vista, Linux
- **ESATAN (DUMPTAS HDF5):**
  - Availability : December 2007

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Appendix R

ThermNV - Post-processing multiple results sets

Henri Brouquet
(ALSTOM, United Kingdom)

ThermNV

Post-Processing of Multiple Results Sets

Author: Henri Brouquet

Date: 31st Oct 2007

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Aerospace

ALSTOM

ThermNV Status Summary

ThermNV is part of the ESATAN Thermal Suite

ThermNV 2.0 : released Mar. 2006

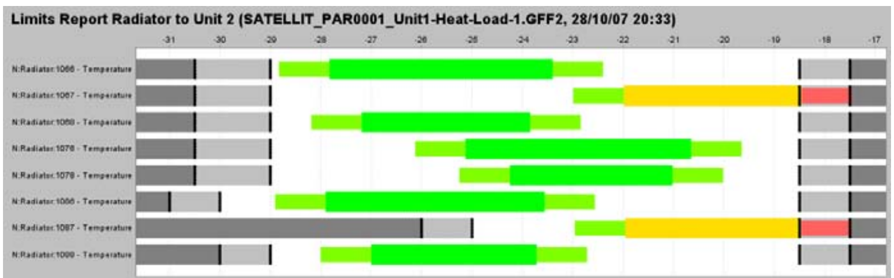
- enhanced post-processing & larger models

ThermNV 2.2 : released Aug. 2006

- Added "batch" capability

ThermNV 3.0 : released April 2007

- Cross comparison of multiple result sets



ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 2

POWER SYSTEMS ALSTOM

ThermNV 3.0 – New Features

- Handling large models
  - Display list available for nodes, conductors and sub-models
- Comparison of model data against specified limits
  - Representation of limit data via a bar chart and/or a data report
- Comparison of model data against reference data
  - Support for sensitivity analysis and test correlation
- Support for cross-comparison between data sets
  - Cross-comparison available on Limits and Delta report

Limits Report Radiator to Unit 1 (Unit_polar_limits.csv, 28/10/07 20:59)

Temperature

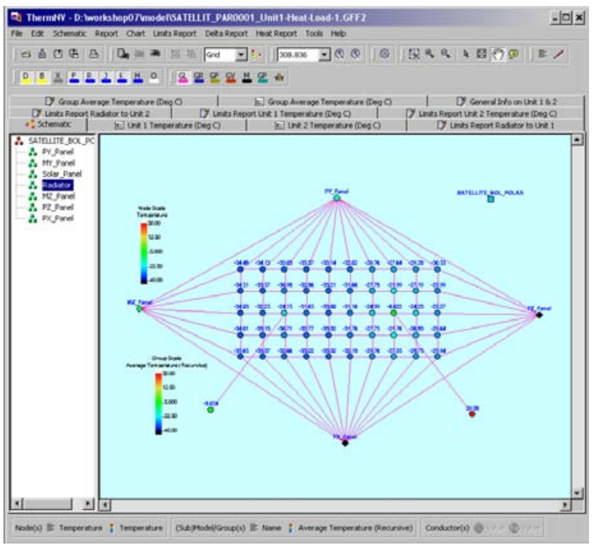
ID	Label	Tmin Qualif (Deg C)	Tmin guarantee (Deg C)	Min - uncertainty	Case of Min	Min	Max	Case of Max	Max + uncertainty	Tmax guarantee (Deg C)	Tmax Qualif (Deg C)
N.Radiator.1061	Radiator	-37.00	-34.50	-34.96	SAT.PAR0001.GFF2	-33.96	-23.35	SAT.PAR0003.GFF2	-22.35	-10.000	-9.000
N.Radiator.1062	Radiator	-37.00	-34.50	-32.45	SAT.PAR0001.GFF2	-31.45	-19.54	SAT.PAR0003.GFF2	-18.54	-10.000	-9.000
N.Radiator.1063	Radiator	-37.00	-34.50	-34.42	SAT.PAR0001.GFF2	-33.42	-22.63	SAT.PAR0003.GFF2	-21.63	-10.000	-9.000
N.Radiator.1071	Radiator	-37.00	-34.50	-33.88	SAT.PAR0001.GFF2	-32.88	-21.27	SAT.PAR0003.GFF2	-20.27	-10.000	-9.000
N.Radiator.1072	Radiator	-37.00	-34.50	-25.65	SAT.PAR0001.GFF2	-24.65	-9.699	SAT.PAR0003.GFF2	-8.699	-10.000	-9.000
N.Radiator.1073	Radiator	-37.00	-34.50	-33.42	SAT.PAR0001.GFF2	-32.42	-20.65	SAT.PAR0003.GFF2	-19.65	-10.000	-9.000
N.Radiator.1081	Radiator	-37.00	-34.50	-35.04	SAT.PAR0001.GFF2	-34.04	-22.93	SAT.PAR0003.GFF2	-21.93	-10.000	-9.000
N.Radiator.1082	Radiator	-37.00	-34.50	-32.65	SAT.PAR0001.GFF2	-31.65	-19.26	SAT.PAR0003.GFF2	-18.26	-10.000	-9.000
N.Radiator.1083	Radiator	-37.00	-34.50	-34.68	SAT.PAR0001.GFF2	-33.68	-22.58	SAT.PAR0003.GFF2	-21.58	-10.000	-9.000

ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 3

POWER SYSTEMS ALSTOM

ThermNV – Display List

- Handling large models
  - Display list available for nodes, conductors and sub-models
  - Used to switch on/off the display of any entity in the schematic
  - User preference for maximum number of nodes

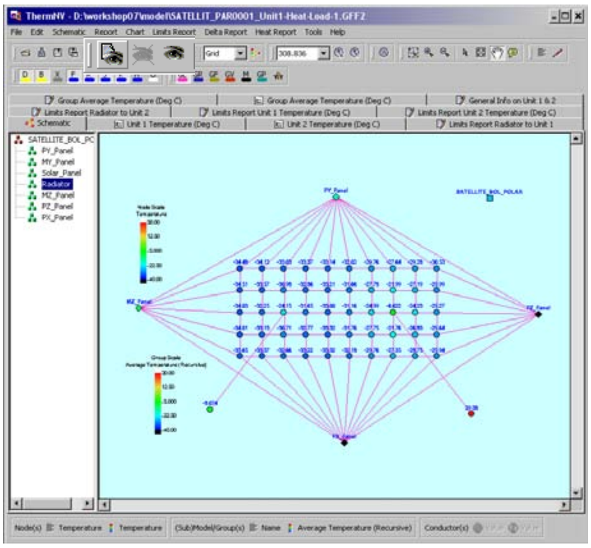


ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 4

POWER SYSTEMS ALSTOM

ThermNV – Display List

- Handling large models
  - Display list available for nodes, conductors and sub-models
  - Used to switch on/off the display of any entity in the schematic
  - User preference for maximum number of nodes

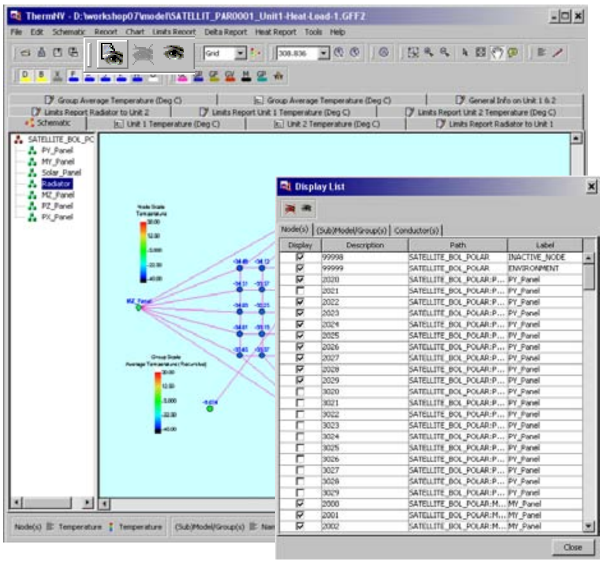


ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 5

POWER SYSTEMS ALSTOM

ThermNV – Display List

- Handling large models
  - Display list available for nodes, conductors and sub-models
  - Used to switch on/off the display of any entity in the schematic
  - User preference for maximum number of nodes



ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 6

POWER SYSTEMS ALSTOM

ThermNV – Limits Report

- Comparison of model data against specified limits
  - Available for any attribute for nodes, conductors and sub-models
  - Representation of limit data via a bar chart and/or a data report
  - Lower (**LoLo, Lo**) and upper **(Hi, HiHi)** limits for minimum & maximum specifications
  - Limits data are either imported from a csv format file or entered in the GUI

Limits Report Radiator to Unit 1 (SAT_PAR0003.GFF2, 28/10/07 20:59)

Temperature

ID	Label	Tmin Qualif (Deg C)	Tmin Guarantee (Deg C)	Min - uncertainty	Time of min (s)	Min Temp (Deg C)	Max Temp (Deg C)	Time of max (s)	Max + uncertainty	Tmax Guarantee (Deg C)	Tmax Qualif (Deg C)
N.Radiator:1061	Radiator	-37.00	-34.50	-29.75	4324	-28.75	-23.35	2162	-22.35	-10.000	-9.000
N.Radiator:1062	Radiator	-37.00	-34.50	-25.83	4324	-24.83	-19.54	2162	-18.54	-10.000	-9.000
N.Radiator:1063	Radiator	-37.00	-34.50	-29.53	4324	-28.53	-22.63	2162	-21.63	-10.000	-9.000
N.Radiator:1071	Radiator	-37.00	-34.50	-27.87	4324	-26.87	-21.27	2162	-20.27	-10.000	-9.000
N.Radiator:1072	Radiator	-37.00	-34.50	-14.78	4324	-13.78	-9.699	2162	-8.699	-10.000	-9.000
N.Radiator:1073	Radiator	-37.00	-34.50	-27.73	4324	-26.73	-20.65	2162	-19.65	-10.000	-9.000
N.Radiator:1081	Radiator	-37.00	-34.50	-29.84	4324	-28.84	-22.93	2162	-21.93	-10.000	-9.000
N.Radiator:1082	Radiator	-37.00	-34.50	-26.05	4324	-25.05	-19.26	2162	-18.26	-10.000	-9.000
N.Radiator:1083	Radiator	-37.00	-34.50	-29.80	4324	-28.80	-22.58	2162	-21.58	-10.000	-9.000

ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 7

POWER SYSTEMS

ThermNV – Limits Report

- Comparison of model data against specified limits
  - Available for any attribute for nodes, conductors and sub-models
  - Representation of limit data via a bar chart and/or a data report
  - Lower (**LoLo, Lo**) and upper **(Hi, HiHi)** limits for minimum & maximum specifications
  - Limits data are either imported from a csv format file or entered in the GUI

Limits Report Radiator to Unit 1 (SAT_PAR0003.GFF2, 28/10/07 20:59)

Temperature

Tmin Qualif (Deg C)	Tmin Guarantee (Deg C)	Min - uncertainty	Time of min (s)	Min Temp (Deg C)	Max Temp (Deg C)	Time of max (s)	Max + uncertainty	Tmax Guarantee (Deg C)	Tmax Qualif (Deg C)
-37.00	-34.50	-29.75	4324	-28.75	-23.35	2162	-22.35	-10.000	-9.000
-37.00	-34.50	-25.83	4324	-24.83	-19.54	2162	-18.54	-10.000	-9.000
-37.00	-34.50	-29.53	4324	-28.53	-22.63	2162	-21.63	-10.000	-9.000
-37.00	-34.50	-27.87	4324	-26.87	-21.27	2162	-20.27	-10.000	-9.000
-37.00	-34.50	-14.78	4324	-13.78	-9.699	2162	-8.699	-10.000	-9.000
-37.00	-34.50	-27.73	4324	-26.73	-20.65	2162	-19.65	-10.000	-9.000
-37.00	-34.50	-29.84	4324	-28.84	-22.93	2162	-21.93	-10.000	-9.000
-37.00	-34.50	-26.05	4324	-25.05	-19.26	2162	-18.26	-10.000	-9.000
-37.00	-34.50	-29.80	4324	-28.80	-22.58	2162	-21.58	-10.000	-9.000

ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 8

POWER SYSTEMS

ThermNV – Delta Report

- Comparison of model data against reference data
  - Support for sensitivity analysis and test correlation
  - Deviation (delta) from the reference available
  - RSS automatically calculated on selected nodes
  - Available for any attribute (T, QI, conductor heat flow…) and any user calculator.

Temperature

ID	Label	Result	Nominal	Delta Nominal
N:PCB_1:1001	PCB 1	28.11	22.41	**5.699**
N:PCB_1:1002	PCB 1	28.99	23.26	**5.727**
N:PCB_1:1003	PCB 1	30.32	24.55	**5.770**
N:PCB_1:1004	PCB 1	32.23	26.39	**5.838**
N:PCB_1:1005	PCB 1	35.48	29.50	**5.980**
N:PCB_1:1006	PCB 1	35.40	29.44	**5.965**
			RSS	**14.28**

ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 9

POWER SYSTEMS ALSTOM

ThermNV – Cross Comparison of Data Sets

- Support for cross-comparison between data sets
  - Cross-comparison available on Limits and Delta report
  - Automatic cross-comparison report generated using ThermNV batch

Limits Report Radiator to Unit 1 (Unit_polar_limits.csv, 29/10/07 18:55)

Temperature

ID	Label	Tmin Qualif (Deg C)	Tmin guarantee (Deg C)	Min - uncertainty	Case of Min	Min	Max	Case of Max	Max + uncertainty	Tmax guarantee (Deg C)	Tmax Qualif (Deg C)
N:Radiator:1061	Radiator	-37.00	-34.50	**-32.24**	SAT.PAR0001.Unit1-1.GFF2	-31.24	-16.06	SAT.PAR0003.Unit1-3.GFF2	-15.06	-1.0000	0.000
N:Radiator:1062	Radiator	-37.00	-34.50	**-29.02**	SAT.PAR0001.Unit1-1.GFF2	-28.02	-10.18	SAT.PAR0003.Unit1-3.GFF2	-9.183	-1.0000	2.000
N:Radiator:1063	Radiator	-37.00	-34.50	**-31.84**	SAT.PAR0001.Unit1-1.GFF2	-30.84	-15.81	SAT.PAR0003.Unit1-3.GFF2	-14.81	-1.0000	2.000
N:Radiator:1071	Radiator	-37.00	-34.50	**-30.76**	SAT.PAR0001.Unit1-1.GFF2	-29.76	-12.81	SAT.PAR0003.Unit1-3.GFF2	-11.81	-1.0000	2.000
N:Radiator:1072	Radiator	-37.00	-34.50	**-20.13**	SAT.PAR0001.Unit1-1.GFF2	-19.13	5.996	SAT.PAR0003.Unit1-3.GFF2	6.996	-1.0000	2.000
N:Radiator:1073	Radiator	-37.00	-34.50	**-30.43**							
N:Radiator:1081	Radiator	-37.00	-34.50	**-32.32**							
N:Radiator:1082	Radiator	-37.00	-34.50	**-29.23**							
N:Radiator:1083	Radiator	-37.00	-34.50	**-32.10**							

Temperature

ID	Label	Nominal	Min	Min Delta	Case of Min	Max	Max Delta	Case of Max	Delta RSS
N:PCB_1:1001	PCB 1	22.41	**9.778**	**-12.63**	NonOp.GFF1	**28.11**	**5.699**	Hot.GFF1	**13.86**
N:PCB_1:1002	PCB 1	23.26	**9.777**	**-13.49**	NonOp.GFF1	**28.99**	**5.727**	Hot.GFF1	**14.65**
N:PCB_1:1003	PCB 1	24.55	**9.775**	**-14.77**	NonOp.GFF1	**30.32**	**5.770**	Hot.GFF1	**15.86**
N:PCB_1:1004	PCB 1	26.39	**9.774**	**-16.62**	NonOp.GFF1	**32.23**	**5.838**	Hot.GFF1	**17.61**
N:PCB_1:1005	PCB 1	29.50	**9.774**	**-19.73**	NonOp.GFF1	**35.48**	**5.980**	Hot.GFF1	**20.61**
N:PCB_1:1006	PCB 1	29.44	**9.773**	**-19.66**	NonOp.GFF1	**35.40**	**5.965**	Hot.GFF1	**20.55**
								RSS	**42.61**

ThermNV – Post-Processing of Multiple Results Sets – 31/10/2007 - P 10

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Appendix S

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