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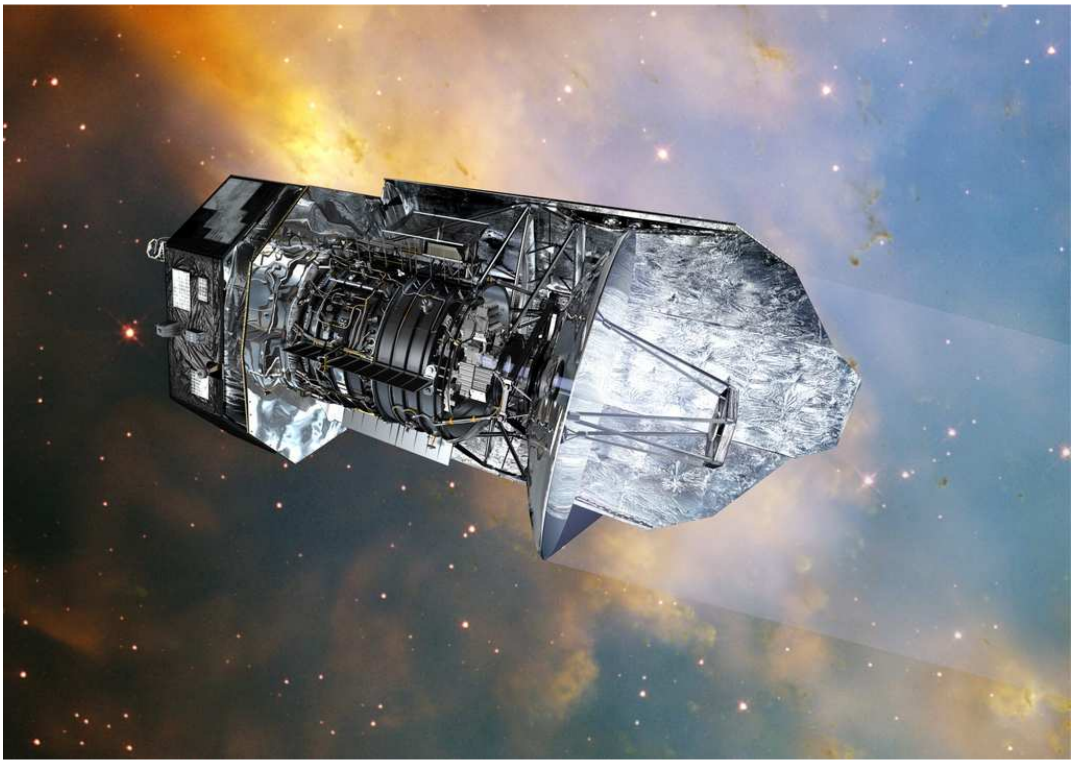

European Space Agency
Agence spatiale européenne

Abstract

This document contains the minutes of the 22nd European Workshop on Thermal and ECLS Software held at ESA/ESTEC, Noordwijk, The Netherlands on 28–29 October 2008. It is intended to reflect all of the additional comments and questions of the participants. In this way, progress (past and future) can be monitored and the views of the user community represented. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.
Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under 'Workshops'.

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Day 1

Tuesday 28th October 2008

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 the tools, and for the presentation of new methodologies. He reminded everyone about the 2008-11-14 deadline for the submission of papers to next year's ICES conference to be held in Savannah, Georgia, USA. (See appendix A)

1.2 Columbus Thermal Control System On-Orbit Performance

J. Persson (ESA/ESTEC) presented details of an analysis of the Columbus thermal control system that he had performed to investigate unexpected power readings in the pre-launch period. He described the results for two different configurations of the water loop on different days and the verification against in-flight data. (See appendix B)

H. Rathjen (Astrium GmbH) had noticed the use of GFs on the slides and asked whether the water loop had been modelled using `FHTS`. J. Persson said that the water loop submodel was an `FHTS` model that had come from industry, and maybe they could also explain the issue about the pump speed. S. de Palo (Thales Alenia Space) confirmed that they had worked on the `FHTS` model. He suspected that the problem was due to the fact that in the model the maximum pressure drop across the heat exchangers was a constant, and that this did not correspond to the real pressure drop seen in flight. He thought that this would explain the differences in the pump speeds.

M. Molina (Carlo Gavazzi Space) had noticed that J. Persson had not included the EUTEF in the model. He said that in the cases when the ISS orbit gave a high beta angle, the EUTEF shadow on Columbus could affect the absorbed flux and therefore the temperatures. For the -XVV orientation with positive beta angle there would be no shadow from the EUTEF and so there would be a lot of sun on the port side. J. Persson said that this could explain the effect locally. The EUTEF was at the 'top' so he could always check if there were differences between the port and aft overhead zones.

M. Molina added that when the shuttle docked with the ISS, there was a complete 180° change around the yaw-axis, and this would be a great opportunity for the model correlation. J. Persson acknowledged that this would provide better confidence in the model, but wondered whether the potential benefits justified the cost of the work, especially when the existing model already provided results that gave a good-enough match with the flight data.

1.3 Experience of High Accuracy Thermal Modelling from the LISA Pathfinder Thermal Noise Analysis

N. Fishwick (Astrium UK) described the stringent thermal stability requirements for LISA Pathfinder. He presented new methods that had been developed to structure the ESATAN model in order to have confidence that numerical variation had been reduced sufficiently to show that the thermal stability requirements had been met. (See appendix C)

E. Overbosch (Dutch Space) asked how they intended to verify such an accurate model. He said it was always possible to make a prediction, but how could they ever know how the hardware would react because they could never test it to this level of accuracy. N. Fishwick admitted that this was a very good question. They could not measure to that accuracy, but they could see whether the instrument worked. O. Pin (ESA/ESTEC) said that this was a case of verification by analysis, although he admitted that a test would be better. S. Price (Astrium UK) commented that there was such a high uncertainty because it wasn't possible to verify by test. E. Overbosch said that there were so many details and wondered how you could ever be convinced that the TMM was of a high enough standard.

M. Molina (Carlo Gavazzi Space) argued that in reality it might be possible to make a more positive statement by considering the linear model behind everything. If it were possible to demonstrate that the linear model gave good results, and could verify the linear model for different inputs, then it would be possible to have confidence. Once it had been demonstrated that the model fitted reality in the linear domain using some step function or wave equation, then you could have more confidence in the results.

M. Molina commented that the name 'PSD' had been inherited from the structural analysis world, and felt it was not appropriate to use it for the thermal analysis. In a previous workshop he had already proposed the terms *Temperature Spectral Density* (kelvin per root hertz) and *Power Spectral Density* (watt per root hertz) to avoid any confusion. N. Fishwick agreed that this was a good idea. M. Molina asked that the function name in ESATAN should be changed to reflect this. H. Brouquet (ALSTOM) replied that it was already called the *Linear Spectral Density* in ESATAN.

P. Poinas (ESA/ESTEC) wanted to return to slide 4. He had noticed that N. Fishwick had said that the solution would converge to the level of the model. What had he meant? That if the dimension was given as 10e-6 that the solution would converge to 10e-6? N. Fishwick said that the solution depended on the number of digits given to the MATLAB routine. If the initial state were given with 6 decimal digits, then the result would vary by 10e-6. P. Poinas commented that this variation was independent of the model size and complexity itself.

O. Pin admitted that the fact that ESATAN executed the solver using double precision was clearly something to look at, but he was interested to know whether the different ways of specifying the initial conditions had an effect on the PSD results. He asked whether they had produced a clear curve showing the results of starting in single precision and then comparing with results obtained with the double precision 'tricks' that had been presented. If the results were the same, he wondered whether there was any advantage in doing all of the work to convert the model to double precision. N. Fishwick said that he did have such a graph, but had not included it in the presentation. The graph showed that there was not much difference between using single and double precision, but they could not have known that in advance. M. Molina commented that it was not the actual number produced that was important, but the variation in the result. O. Pin agreed, but said he would need to see the single-precision graph to see whether it would be really necessary to invest.

H. Brouquet had some comments to make on work that been performed by ALSTOM to investigate the numerical drift in ESATAN following Ulrich Rauscher's presentation at the previous workshop. The first point to note was that the model had only used the RELXCA control constant, and they had shown that using ENBALA as well would give a better solution. The second point was that there was no difference in the PSD results when using single or double precision. However, this issue had become such a source of concern for users that ALSTOM had already decided to convert all of ESATAN to use double precision. The next version of ESATAN would store all model data in the MDB file in double precision. This had been due for announcement in the ESATAN presentation later anyway. The third point was that there was no inherent limit in the number of nodes that could be handled by the SLFRTF routine. However, there was a limit on the size of the model that could be stored in memory on a particular machine. Users were advised that the more performant the machine they had, the more nodes they could handle. C. Kirtley (ALSTOM) explained that the SLFRTF routine used a matrix method, so it did need a lot of memory to handle a large number of nodes.

1.4 New Technology for Modeling and Solving Radiative Heat Transfer using TMG

C. Ruel (MAYA) presented two major developments within TMG. The first was the support for non-grey body radiation analysis using multi-band optical properties. The second was the introduction of parallelization into various parts of the calculation chain to allow simultaneous solution on multiple processors. (See appendix D)

H. Rooijackers (ESA/ESTEC) asked how Maya intended to parallelize the solvers. C. Ruel replied that they would not be introducing new software but would instead be modifying their own solvers to do the parallelization in their own code.

1.5 The ESATAN Thermal Suite

C. Kirtley (ALSTOM) presented a brief history of the different releases of the tools over the past few years and the new features that had appeared with each release, and how this history fitted into ALSTOM's vision for the tools in the future. It had become clearer to ALSTOM that the tools had become more closely coupled over time and that it now made sense to integrate them further. He then introduced the ESATAN-TMS workbench framework that would be available to users at the start of 2009. (See appendix E)

P. Poinas (ESA/ESTEC) said that he was a new user to the current versions of ESARAD and ESATAN. He wanted to know whether the new version would remove the conflicting options for running analyses. It was confusing to be offered options that applied to running within the different mission, radiative and analysis cases as well as running outside the cases. Would the new version clean these options? Would it be backward compatible? C. Kirtley said that the changes would be backward compatible, so it would still be possible to import old models. The menu system in the new version had been significantly cleaned up. He said this would be clearer in the demonstration later.

P. Poinas asked whether ALSTOM were sure that industry were actually using the analysis case and mission definitions, or were they using the functions independently. For example, the user could define mission and analysis cases in a simple way, but there were lots of other options available in the GUI. Were these options used or not? C. Kirtley said that the simple

answer was Yes. People were mainly using the radiative case and analysis case method of working. H. Brouquet (ALSTOM) said that people often ended up using some of the low-level functions by mistake, rather than the high-level features of the radiative and analysis cases, and he agreed that it was confusing, especially for new users. He asked for everyone to wait for the demonstrations later.
S. de Palo (Thales Alenia Space) asked whether the CAD interface was included in `ESATAN-TMS`. C. Kirtley said that the `CADconverter` was still a separate tool but that it could be added to the command menu in the GUI. The `CADconverter` was not a standard utility within the workbench at the moment and required a separate licence.
M. Gorlani (Blue Engineering) asked whether it was still possible to import CAD/STEP models into `ESARAD`. H. Brouquet said that in `ESATAN-TMS` the process had not changed at the moment. The user needed to use the `CADconverter` to generate an `ESARAD` geometry file that could be imported. He pointed out that `STEP-TAS` files were different.
M. Gorlani asked whether it was possible to do this directly from `ESARAD`. H. Brouquet said that it was not possible to import them directly. The user first needed to convert the STEP AP203 file using the `CADconverter`, but the user could launch the `CADconverter` from the workbench. He said that ALSTOM were looking at ways of merging the tools in the future, but for the moment the `CADconverter` was still a separate program.

1.6 Stability Analysis in the Columbus Active Thermal Control System

T. Klingberg (ESA/ESTEC) presented details of an investigation into the stability of the PID controllers used in the water loop of the Columbus thermal control system. He described a variation on the Nyquist criterion and its use in determining the sensitivity of the controllers to changes in their operating parameters. (See appendix F)

S. de Palo (Thales Alenia Space) wondered about the heat exchanger model. He said that if you relied on the `ESATAN/FHTS` element then there was no way to model the efficiency of the heat exchanger. He wondered whether it had been possible to model this in some other way. He also wondered whether any thought had been given to modelling other types of controller. For a hypothetical Columbus-2 and other future applications it might be possible to have something better than a simple PID controller. T. Klingberg said that it would be interesting to look at applications where it would be necessary to analyze how two controllers could affect each other. It could be that a PID controller was not really good for this application and that it might be better to have a state controller, or a nested [cascade] controller if one had more effect than the other. However the PID controller was the classical industry standard. For the heat exchanger, the `FHTS` model assumed that the exchange was perfect and that the temperature of the ammonia would become the temperature of the water. The equation for the heat exchanger had been given on one of the slides: epsilon was the efficiency of the heat exchanger. T. Klingberg had used the equation that had come from Alenia, but as far as he was aware it was the same one that NASA was using.

J. Etchells (ESA/ESTEC) had noticed that the analysis had required the linearization around the mass flow rate. He asked whether the results from the model were available. When asked what the range of applicability of the linearisation was, T. Klingberg said that the model was valid near a working point, and further from that point provided that the system was near linear. The big potential non-linearity here was the control valve, but the valve never

went beyond 80% non-linear. There were other non-linearities so more research would be needed.
S. de Palo commented on the non-linearity. He said that he had given a presentation at the previous workshop describing the linearization of all working points that the system could have, with lots of configurations. Simply changing five parameters would need lots of changes elsewhere just to see the changes for the heat exchanger. The system described today was much more linear. T. Klingberg admitted that he had to give a lot of credit to TAS-I for their work on nodes two and three, but these used a different linearization. So far he had only looked at simple configurations.

1.7 THERMICA — On-going research and developments

T. Soriano (Astrium Satellites) described some new features that had been developed in SYSTEMA and more particularly in THERMICA since the previous workshop. He demonstrated boolean geometry and cutting operations and the video playback feature that also showed the kinematics and trajectory cabapilities. He also gave a brief description of the Reduced Conductive Network method for calculating linear conductive couplings. (See appendix G)
HP. de Koning (ESA/ESTEC) asked whether a white paper was available that described the RCN method. T. Soriano said that they had not published it yet, but would do in the future.

1.8 A Software Tool Applying Linear Control Methods to Satellite Thermal Analysis

M. Altenburg (EADS Astrium) presented the development of TransFAST, a software tool to help transfer results from a classical thermal network to a standard linear control system and to solve this system in the frequency domain. (See appendix H)

S. de Palo (Thales Alenia Space) asked what software had been used for the solver. Was it MATLAB? He also wanted to know more about the format used for the ESATAN import.
M. Altenburg said that MATLAB had been used for everything. He said that they had used the option with ESATAN-10.2 to output to CSV format from the steady state. This was easy to read in MATLAB.

M. Molina (Carlo Gavazzi Space) asked whether it was possible to combine different types of disturbances, and if so, how did they ensure that they were dimensionally consistent.
M. Altenburg said that boundary nodes only were used for subsystems and that single sources were used for power as a first phase. The transfer function included both gain and phase shift information, but it was not easy to scale both at the same time, and this allowed them to use a state space model where the user could define two or three inputs and summarize the effect. In the other approach it was only possible to sum the inputs without considering the phase.

M. Molina said that in LISA Pathfinder, there were some disturbances that were internal and some that were external. There were temperature fluctuations in the skin, and power fluctuations in the diodes. Would it be possible to handle both of these in TransFAST?
M. Altenburg said that the user needed to take separate sources and create a single input vector: TransFAST did not handle 'real' inputs.

M. Molina commented that everyone had seen that there were different requirements at the satellite, payload, and instrument levels and wondered how the different groups superimposed the margins. Was everyone using the same approach? Was everyone superimposing the margins, or using the same calculations?
S. de Palo asked about the maximum number

of nodes that TransFAST could handle. M. Altenburg said that there was no limit for the DIT [Direct Inversion of the Transformed] matrix but there was a limit of 2000 nodes for the CEF [Conditioned Evaluation of the Frequency response] matrix. S. de Palo then asked whether the tool was used on a 64-bit machine. M. Altenburg said that the tool worked on a normal PC. He said that the difference between the two approaches was that for one they conditioned the vectors before the calculations and this made it fast to calculate the frequency gain between nodes. For the other approach they used the gain between all nodes and then did the calculation.

M. Molina asked how the disturbances were defined. M. Altenburg said that they used a vector containing a series of zero or one unit steps. The next version would have the possibility to have a real value between zero and one and then calculate the direct power dissipation.

M. Molina asked whether TransFAST would be available to subcontractors. M. Altenburg said that he did not know, he had only been involved on the programming side.

1.9 ALSTOM Product Developments

H. Brouquet (ALSTOM) presented the different aspects of the new ESATAN-TMS workbench and highlighted the new simpler and integrated user interface, the possibility to run non-orbit cases for the analysis of instruments in test chambers, the ability to define and visualize time- and temperature-dependent properties, and the performance and scalability improvements that would allow larger geometrical models such as those imported from CAD. He gave a demonstration of ESATAN-TMS and also showed how existing PcESATAN users could easily transfer their models into the new workbench. (See appendix I)

S. de Palo (Thales Alenia Space) asked how the licences would work for the different menu options and how they applied to batch processing on Linux clusters. H. Brouquet said that if the tools already worked on the same platform then they would also work within the workbench on that platform. S. de Palo asked how it would work if he only wanted to use ESATAN. H. Brouquet said that as soon as the model was opened in the GUI it would take whichever licence was appropriate. When running in batch mode there would be no need to take an ESATAN-TMS-GUI licence. M. Gorlani (Blue Engineering) asked whether this meant that each user now needed three licences. H. Brouquet answered that the user would require one licence for the GUI, one for the ESARAD part if an ESARAD model was open, and one for the ESATAN part if an ESATAN model was open, but this didn't really change how the user would work. All that would happen was that the new licence file would contain an entry for an ESATAN-TMS-SPACE licence instead of an ESARAD_PRO licence. S. de Palo asked what would happen if you opened as many GUIs as you had licences. H. Brouquet said that it would work the same way as it did now. Using ESATAN required an ESATAN licence, and using ESATAN from within ESARAD required both an ESATAN and an ESARAD licence. He said that the new licence system meant that a user who did not work in a space environment did not need to have a licence to run the mission calculations. The new licences had different levels. The ESATAN user currently had a combined licence that allowed use of both the GUI and ESATAN, and current users would automatically receive the separate GUI licence as well. S. de Palo said that they were running from Linux, and therefore did not use PcESATAN, and did not want to occupy licences just because the GUI was open on the screen. H. Brouquet assured him that the ESATAN user would get a GUI licence on top of what they had now.

G. Tonellotto (ESA/ESTEC) asked whether the new variable property feature was only available as a function of temperature. H. Brouquet said

that the new feature offered time dependent boundary conditions *and* temperature dependent material properties.
M. Bernard (Astrium) asked whether the new system allowed the user to interface in-house subroutine libraries that had already been developed for `ESATAN`. H. Brouquet showed that the Analysis Case dialog provided an area where the user could define additional files to be compiled or linked into the executable and said that he could demonstrate the full functionality outside the presentation. The GUI support capabilities were already there. M. Bernard asked whether arrays and constants could be defined in a separate file. H. Brouquet assured him that the $INCLUDE file option still worked as before. The user could also create a directory and include it in the model tree. M. Bernard asked about templates. H. Brouquet replied that the user could define a template model file that could be used for all analysis cases.
P. Poinas (ESA/ESTEC) commented that `ESARAD` had capabilities for working with variables, and wondered whether these variables could not be passed to `ESATAN` instead of their computed values as this would improve traceability and parameterisation.
R. Nadalini (Active Space Technologies) asked about the availability of the new interface on Windows XP and Vista. H. Brouquet said that the workbench would be available on the same platforms as the current version, so Vista would be supported with the new compiler.
R. Nadalini commented that the user often needed to select a property or shell from a list, but in the current version these lists appeared to be in random order. He wondered whether it would be possible to sort these lists to make it easier to find things. H. Brouquet admitted that this could be improved. He said that there was a search option already, but they would look at sorting these lists in the future.

1.10 Innovative Ray Tracing Algorithms for Space Thermal Analysis

P. Vueghs (University of Liége) presented the main thrust of his PhD thesis, which looked at speeding up raytracing by replacing multiple calls to Monte Carlo ray-tracing by using a modified ray-tracing hemisphere method. He also described how the raytracing results could be applied to both geometrical primitives and finite element meshes with a new approach to statistical accuracy control. (See appendix J)
T. Soriano (Astrium Satellites) asked how the new algorithm handled specularity. Did it use a combination of view factors instead of ray propagation? P. Vueghs said that the system could handle specularity by including it in the so-called ‘extended’ view factor. The raytracing in this system was a light operation because it only followed the specularly reflected rays, so it did not add much to the overall computation.
T. Soriano asked whether the direct view and specular reflections were handled in a single pass. If so, how did this relate to the extended view factor calculations? HP. de Koning (ESA/ESTEC) answered that more than one set of extended view factors were calculated when specular reflection needed to be considered, one for each spectral band.

1.11 THERMISOL — New features and demonstration

T. Soriano (Astrium Satellites) gave a brief overview of the module structure within `THERMISOL` and described the modifications that had been made to the `MORTRAN` syntax to simplify some operations for the user, especially event handling, and to support the separation of time and temperature dependent variable updates during the solution run, and to allow adaptive code based on the results at each iteration step. (See appendix K)

M. Bernard (Astrium) asked about the $VTEMPERATURE blocks. Could the user adapt values to have temperature dependent GLs, and GRs? What about heater powers? Would this not be dangerous because the user could not know whether the solution had converged yet. T. Soriano said that this is why the optimisations were needed in order to leave some time for the solution to adapt to the modifications and allow convergence that way.

M. Bernard had a suggestion for the name of the syntax presented in the GUI. The 'New' option should be renamed as 'v431 syntax'. He said that the 'Old' and 'New' distinction was clear in this version, but as new versions were released, maybe with additional changes, the terms would become confusing. The GUI should not use 'Old' and 'New' but should be more explicit.

HP. de Koning (ESA/ESTEC) said that there was a big issue with the language changes here. He felt that this was a repeat of the ESABASE and SYSBAS language situation of 15 years ago. The fact that the ESATAN and THERMISOL languages were now branching could lead to incompatible models in the future. This needed to be addressed. He said that part of the STEP-TAS work had been looking at a neutral representation of models in SINDA, ESATAN and THERMISOL. T. Soriano said that he was also concerned and wanted to keep the differences within strict boundaries. He did not plan to remove the old syntax, so there would still be two ways of doing the analysis within THERMISOL. He said it was important that the time needed to convert a model from ESATAN to THERMISOL should be kept as short as possible, so he wanted to keep these differences within limits.

O. Pin (ESA/ESTEC) asked whether the THERMISOL team planned to provide a means to export these changes to ESATAN. He recalled that the THERMISOL team had been clear at the beginning that the original THERMISOL would never deviate from the ESATAN language. He conceded that for the major changes it was possible that they provided added values, but questioned whether changing the syntax to provide an equivalent form was really useful, e.g. the MORTRAN STATST call. He asked why the THERMISOL team did not provide converters so that the THERMISOL models could be converted to run in ESATAN. T. Soriano said that the STATST change was just more convenient for the users. He argued that ALSTOM had also added new features to the ESATAN language. O. Pin admitted that they had, but argued that it was ALSTOM's language and that ALSTOM had no obligation to implement changes made by other people. C. Theroude (Astrium Satellites) argued that they could not commit to follow ALSTOM's developments to the language for the next 20 years because they didn't know what ALSTOM would do in the future. T. Soriano repeated that they wanted to keep the differences in the language to certain limits so that it would not be time consuming for the user to convert. O. Pin emphasized that ALSTOM had committed that, in principle, models would always be backwards compatible. THERMISOL had now introduced the new VTIME, VTEMPERATURE and VRESULT blocks. Would there be new blocks next year? C. Theroude said that after the discussion at the previous workshop they had kept the old VARIABLES blocks definitions from ALSTOM and had provided new blocks. O. Pin said that all he was asking for was a THERMISOL to ESATAN converter to save the user from making the changes by hand. The tools were not compatible. C. Theroude argued that THERMISOL models were compatible with ESATAN. HP. de Koning said he did not agree and that the issue was black or white, either the tools were compatible or they were not. C. Theroude said that Astrium could not commit to following any ALSTOM changes. He would really prefer to work with a neutral language that also supported other thermal modelling tools such as SINDA. HP. de Koning admitted that this would be better and that STEP-TAS had been designed to make this possible in the future. Exchanging the structure of an ESATAN model ($NODES,

$CONDUCTORS, etc.) was already done in the ESATAP STEP-TAS files, but exchanging the user-defined MORTRAN would be a big challenge. The THERMISOL language was now effectively a branch of the ESATAN language. As long as this situation was clear to the end-users problems would be avoided. The community would speak by using the tools that they liked. He just wanted the situation to be clear: the THERMISOL language was no longer compatible with ESATAN.

1.12 Correlation of ESATAN TMM with Ice Sublimation Test

A. Schubert (Astrium GmbH) presented results of an investigation into the unexpected build up of ice on the stage separation structure during an Ariane-5 launch, and how the sublimation of the ice in flight had cooled the structure below its qualification limit. She described a simple experimental test and a one-dimensional representation of the set-up in ESATAN. (See appendix L)

S. de Palo (Thales Alenia Space) asked whether other software had been considered. Had they considered using a multi-physics software tool to check the results. A. Schubert said that they had not looked at other software yet.

M. Molina (Carlo Gavazzi Space) asked about the slide where the test with the perspex substrate showed a thickness variation that was 3-4 times more than the aluminium. Was there a reason for this? A. Schubert said that she had anticipated this question in a previous version of the presentation, but had not included it here. The reason was that they had measured the water level during filling, and had assumed an uncertainty in the model of +/- 2mm, with a variation of 0.4mm due to the expansion of the ice layer as the water froze. After the first calculation, the ice layer on the aluminium substrate had been reduced by 0.6mm, but they had to increase it in order to keep the thermocouple covered. Therefore the test run had been filled to a higher level, so the minimum thickness was higher. M. Molina asked whether the change in thickness was different for the aluminium and the perspex. A. Schubert said that in the aluminium test there had been a much larger change in thickness.

HP. de Koning (ESA/ESTEC) asked whether they had considered using ice supports for the thermocouples to be prepared in a separate chamber. A. Schubert confirmed that they had thought about this agreed that this could be applied for future tests.

H. Rathjen (Astrium GmbH) said that ESATAN had been used because they had wanted to include it in a stage level model, which was already written in ESATAN.

G. Tonellotto (ESA/ESTEC) asked whether it was only the low temperatures that had been unexpected for the Ariane flight, or was it just the appearance of the ice. A. Schubert answered that they had been expecting temperatures below 0°C, but not the ice sublimation and the colder temperatures that resulted from it as the flight progressed. H. Rathjen said that the ice sublimation had contributed to temperatures 25°C below those expected at the stage separation. HP. de Koning observed that they had been lucky to have sensors there to measure the temperature during flight, otherwise they would never have known about the problem.

Day 2

Wednesday 29th October 2008

2.1 Improved Handling of Thermal Test Results

HP. de Koning (ESA/ESTEC) presented details of work completed since the previous workshop relating to processing thermal test data and analysis predictions using `DynaWorks`. The sensor data was imported in near real-time using simple annotated comma separated value files from the ground based test environment (EGSE) via an FTP server. The `ESATAN` analysis predictions were imported via `STEP-TAS` files. He concluded by announcing a competitive ITT that would open on a similar subject shortly after the workshop. (See appendix M)

S. de Palo (Thales Alenia Space) asked whether the annotated CSV format could be made available for the Herschel test campaign. HP. de Koning answered that, in principle, yes, the format could be made available. People should contact him in order to get help on how to get the activity going. This was standard technology that could be made available to the community. He said that this work had been been shown to be very useful in solving what was a very common problem. He felt it strange that it had not been solved with a common tool or software before now.

J. Persson (ESA/ESTEC) remarked on the 'near real-time' import, and asked whether this was a requirement that had come as a result of Alenia's presentation at a previous workshop. HP. de Koning said that the work had not been targeted at any particular project. The ITT had been used as a way to solicit ideas. Many companies had already looked at this problem and had developed their own systems and procedures. Now it was time to take all of this effort to the next level. There were too many individuals trying to solve the same problem over and over again. He agreed that the work done by Alenia would be useful input.
M. Gorlani (Blue Engineering) asked whether this work related only to mechanical testing. He noted that if someone wanted to include model correlation in the procedure, it might involve a lot of computation time. Was there a need to use reduced or simplified models? HP. de Koning said that reduced models could be one approach. Another would be to just use lots of compute power via a computer cluster. Lots of different solutions were possible, depending on the exact test requirements. The reduced model approach had its advantages, but in reality the goal was to correlate the complete model with the tool. The disadvantage was determining how well the reduced model matched the complete model.

2.2 ESATAP — Distribution and maintenance process

F. Brunetti (DOREA) described the process of registering with the ESATAP support website in order to download the software and access the information there. He encouraged users to file software problem reports via the dedicated forms so that any issues with ESATAP could be addressed and the software improved. Videos on using ESATAP would appear on the website shortly. He informed everyone that training could also be arranged on site as well as in Cannes. (See appendix N)

E. Overbosch (Dutch Space) asked whether DOREA would be able to help with providing the DMPTAS routine on Sun Solaris. F. Brunetti said yes, because although they did not have a binary version available for Solaris, it was just a question of recompiling. DMPTAS was written in C++ and had been designed to be highly portable. On the PC, they had used the MinGW environment. He did not foresee any problem with providing a version for Solaris.

R. Patricio (Active Space Technologies) asked whether the following day's training was open to all. F. Brunetti said he should contact DOREA in order to arrange training. He could offer training at the customer's site, or the customer could have the training in Cannes. O. Pin (ESA/ESTEC) said that ESA would pay for the training in the end from the maintenance budget. O. Pin supposed that F. Brunetti might be more than happy to come to Portugal to give a training to Active Space Technologies. But he felt it might be better to arrange for training for a larger group, at Astrium in Toulouse for example, so that industry would only have to pay for engineering time. In this way the training would remain free for the user. Sdp asked whether the training would be available at all companies. O. Pin said that maybe it would be better for some people to combine their training with that of other companies.

S. de Palo (Thales Alenia Space) remarked that he had already tried to work through some of the small training examples, but had encountered problems when using the Linux version on their servers. It had not been possible to run ESATAP, load the HDF5 file and then save the task. So far they had not been able to solve this problem on Linux, and would probably move to the PC Windows version. F. Brunetti said that this could either be a problem in the licence handling, or a problem with how the tool was being used, and asked him to send a software problem report. He stressed that ESATAP was still a very young product, that had just been released in February, and although they were doing their best it was possible that some things still needed to be fixed. S. de Palo asked whether ESATAP had also been tested as a server distribution. F. Brunetti admitted that this had not been tested at the beginning when ESATAP had been released, but DOREA were working on this in collaboration with ESA. He asked everyone to send software problem reports if they discovered issues so that DOREA would know the exact problems that needed to be fixed.

M. Bernard (Astrium) asked how the licencing worked. Did the user need more than one licence if more than one ESATAP was being run at a time? F. Brunetti answered that one licence meant one machine could run multiple ESATAP sessions in parallel. He said that they were already looking at the issue of having the licence information on a central server for ESA. The central server would still need to have a licence file that contained the host identifiers of all of the machines that needed to run to run ESATAP, so the user would have to register all of those machines. There was no licence server as such: just a file available at some central location that ESATAP could read. M. Bernard asked whether it would be possible to have two ESATAP sessions running on the same machine. F. Brunetti said that would be possible. O. Pin explained that there was no real limitation on the number of licences within a company. ESA only really needed to know who was using ESATAP because of the way the ESA funding rules worked, and to avoid problems with unauthorised users.

2.3 Implementation of the Equation of Time in Sun Synchronous Orbit Modelling and ESARAD Planet Temperature Mapping Error at the Poles

A. Sauer (EADS-Astrium) described the orbital effects that resulted in changes to the solar reference vector, and how these changes could result in significant differences in the environmental heat fluxes calculated. He presented a workaround, using the Equation of Time, that had been applied to the analysis of the MIPAS instrument on Envisat. He then went on to describe a problem that had been discovered in `ESARAD` for the analysis of spacecraft models in low Earth orbit over the poles, resulting in lower planet fluxes than expected in the polar regions. (See appendix O)

S. Price (Astrium UK) commented that for their Envisat analysis, they had used an ascending node that corresponded to 22:00 $\pm$ 15 minutes. Was the variation that had been present in addition to this 15 minutes or was it encompassed in the 15 minutes? A. Sauer said that they had looked at the timing of the node line plus the equation of time. They had started with the 22:00 $\pm$ 15 requirement but had then needed to add the extra variation.

S. Cuylle (Verhaert Space) asked about the influence of the variation on the solar constant. A. Sauer replied that the solar constant was calculated using the distance of the Earth from the Sun, so it had been calculated correctly.

P. Poinas (ESA/ESTEC) commented on the workaround to the polar temperature mapping problem, and said that the same behaviour could be achieved by imposing the temperatures on the planet instead of allowing `ESARAD` to calculate the temperatures for a smaller mesh. A. Sauer said he did not know whether this had been investigated because a colleague had done the analysis. P. Poinas said that the planet flux depended on the mesh used and the interpolation of the temperature of the elements. The problem could be solved by using a finer mesh and by adjusting the temperature of the polar element to take the polar singularity into account.

S. Höfner (Max Planck Institute) asked whether the incorrect planet flux calulation over the poles had been observed in orbits higher than 50km. A. Sauer said that they had only looked at the low Earth orbit case.

S. Price asked which version of `ESARAD` had this problem. H. Beaumont (ALSTOM) said that it had been discovered in `ESARAD`-6.2.1. H. Brouquet (ALSTOM) noted that the problem would be corrected in the release at the end of the year.

2.4 TCDT — New Features

M. Gorlani (Blue Engineering) presented the background to the Thermal Concept Design Tool, a brief overview of the types of companies that had requested to download the `TCDT`, and their locations. He said that they had conducted the first user survey, and he listed some of the enhancements that had been suggested. He gave a demonstration of some of the improvements that had already been made to correct the problems where the different worksheets were not updated automatically as changes were made. (See appendix P)

C. Kirtley (ALSTOM) asked about the data loaded back into the `TCDT` after the `ESARAD` or `ESATAN` analysis runs. M. Gorlani said that after the `ESARAD` run, the `TCDT` extracted the GRs in order to build the model that could be used with either `ThermXL` or `ESATAN`. After the `ESATAN` run, the `TCDT` extracted the temperatures from the comma separated value output file. The user could copy them from the data sheet directly into `ThermXL`.

O. Pin (ESA/ESTEC) announced that ESA had published ARTIFIS and TOPIC on the exchange web site free of charge. They had been made available, but had never been announced. The TCDT made use of ARTIFIS and TOPIC, and that was the reason why he was announcing their availability now. D. Gibson (ESA/ESTEC) reminded everyone that ARTIFIS and TOPIC were available 'as is' but were not supported or under active development.

2.5 Applicability of EcosimPro to simulate a Life Support System

V. Guirado (NTE) outlined work carried out in his previous job at NTE on the preliminary design of a life support system for a future Moon base. The three main sub-systems were the MELISSA waste recycling and food production compartments, the air revitalization system (ARES), and the grey water treatment unit (GWTU). These systems were modelled using EcosimPro. (See appendix Q)
V. Guirado had created the component library himself, and J. Etchells (ESA/ESTEC) asked him whether he was aware that an ECLSS library already existed, or had he developed his own library because he needed additional components? V. Guirado said that the standard ECLSS library was mainly concerned with dynamic analysis, and it would have been difficult to use them for a steady state analysis case, so he had created his own components.

2.6 ALSTOM Product Demonstration

I. Guest (ALSTOM) presented further information about the new ESATAN-TMS workbench. He skipped over the basic features that had already been shown in earlier presentations. He described how the different tools had been brought together under a utilities menu, how to generate the results files in HDF5 format and the benefits that the new format gave, improvements to the Crank-Nicolson solver, error reporting and post-processing using ThermNV. (See appendix R)

The computer had needed to be restarted in the middle of the demonstration, so S. Cuylle (Verhaert Space) commented that such problems were not new, and expressed his concern that stability still seemed to be an issue. I. Guest countered by saying that he was demonstrating a beta version of the software, and that he had been through this demonstration at least twenty times previously, and that this was the first time he had experienced such a problem. H. Brouquet (ALSTOM) explained that the Windows blue screen problem was due to memory problems with the laptop, and not with the software. S. Cuylle argued that the problems he had witnessed, both yesterday and today, were just like the problems that he experienced on a regular basis. H. Brouquet argued that the demonstration involved the development version of the software. He said that most users would agree that the stability of the tools had improved greatly over the past few years and that they did not normally see crashes like the one they had just observed.

R. Patricio (Active Space Technologies) observed that the previous day P. Poinas (ESA/ESTEC) had asked about parameterised properties in ESARAD and whether it was possible to propagate them into the ESATAN model. When the user did a parametric analysis, were alpha and epsilon also handled? I. Guest said that they were. C. Kirtley (ALSTOM) explained that the parametric analysis worked with the ESATAN model, so the user could always vary the parameters withing the ESATAN model.

R. Nadalini (Active Space Technologies) assumed that the new ESATAN-TMS system required less intervention in the ESATAN model. I. Guest agreed. R. Nadalini noted that in the current version of ESARAD, the automatic conductor generation could create conductive lines that were not always accepted by ESATAN. He had observed this problem in ESARAD-6.2 and ESATAN-10.2. H. Brouquet said that this was a known problem, and that ALSTOM had changed the way that the GL statement was generated, so this problem should be solved in the new release.

R. Patricio asked whether the cross comparison feature in ThermXL allowed the user to select root sum squares, and if not, whether the user could program something to handle them. C. Kirtley said that in the cross comparison report the user could do that. R. Patricio supposed that if he had five different cases he could get a report with a single root sum square value. C. Kirtley confirmed that it should be possible.

2.7 Implementation of a Mars thermal environment model using standard spacecraft analysis tools

A. Quinn (Astrium UK) described the methods that had been developed to use ESARAD for the analysis of a model of a Mars rover on the surface of the planet. They had used an external tool to calculate various aspects of the Martian atmosphere and environment. The geometrical model consisted of the rover and the immediate surface, and was rotated and positioned to correspond to the appropriate Martian latitude and longitude. Additional work had been needed to handle the effects of the atmosphere and the ground under the rover. (See appendix S)

J. Etchells (ESA/ESTEC) asked about the convection correlations that had been mentioned. The Mars atmosphere contained a lot of carbon dioxide and was at a much lower pressure than the correlations he had seen, which were all derived from terrestrial applications. He wondered whether current values of the Grashof number, etc. were still valid on Mars. A. Quinn said that they were using the numbers from the terrestrial applications. J. Etchells asked whether they had considered calculating the heat transfer coefficients using CFD analysis. A. Quinn replied that they had considered it, but did not currently have either the tools or the expertise in-house.

HP. de Koning (ESA/ESTEC) observed that the real Mars environment experts where the people at NASA/JPL. He wondered whether there had been any contact with them as it could prove to be useful because they might have very useful data that could be used to validate the model.

R. Nadalini (Active Space Technologies) asked whether the LMD tool[1] had been integrated into ESATAN. A. Quinn said they used the tool to output values for the day of interest, and then integrated these values into ESATAN as arrays. He was asked why they had not used the Mars Climate Database. A. Quinn explained that the Mars Climate Database was really intended for supercomputing applications for dynamic climate modelling, and that they had only needed a small amount of data for specific locations and conditions, and to be able to run within ESATAN on a normal PC or workstation. R. Nadalini asked whether it would be possible for other groups to have access to the tool. A. Quinn said that he did not see any reason why not, but it was an ESA tool so the question should really be directed at ESA.

S. de Palo (Thales Alenia Space) asked whether the tool was also available for modelling the Earth. HP. de Koning said that he was not sure, but the person to ask in ESA would be Eamonn Daly of the Space Environment and Effects group.

[1]Tool created at the Laboratoire de Météororologie Dynamique in Paris under ESA contract

2.8 Thermal Design and Analysis of the BroadBand Radiometer

O. Poyntz-Wright (RAL) presented details of the BroadBand Radiometer, a British-built instrument that would fly on ESA's EarthCARE mission. He explained the requirements and the thermal model that had been developed for the analysis. He described enhancements to the tools that would have simplified the analysis, and outlined the future plans for a more detailed instrument model and further analysis work. (See appendix T)

E. Overbosch (Dutch Space) asked about the stability control of the heaters. Was it a simple on/off system or was it based on PID controllers? O. Poyntz-Wright said that so far they had only used a simple system where the heaters were either completely on, or were completely off. E. Overbosch expressed surprise that they had been able to achieve that level of stability with such a simple system. That was very good.

M. Gorlani (Blue Engineering) asked why they had decided to create the `ESARAD` and `ESATAN` models by hand rather than use a CAD tool. O. Poyntz-Wright said that it was basically down to personal preference, and admitted that he had no experience of importing a CAD model and so had preferred to build a simple model and add detail to it as required.

2.9 STEP-TAS Activities

E. Lèbegue (CSTB) presented the goals and progress of the IITAS project to provide an industrial implementation of the `STEP-TAS` protocols in the main European thermal tools, and the real world models that would be made publically available for use in validation. His company provided the `C++` software development kit and the graphical validation tool `BagheraView`. (See appendix U.1)

A. Fagot (DOREA) described the `TASTMM` project and its goals to provide an interface to thermal mathematical model data using `STEP-TAS` in both the ASCII Part-21 format and in the binary HDF5 format as this was much more compact and efficient. (See appendix U.2)

HP. de Koning (ESA/ESTEC) gave a brief overview of the other `STEP-TAS` developments that were in progress and the plan for 2009, including work on kinematics and mission aspects, representation of thermal mathematical models, standardisation, and foreseen `STEP-TAS` interfaces in `TMG` and some of the US tools. (See appendix U.3)

M. Gorlani (Blue Engineering) asked whether the real models that would be used to test the converters would be made public [they would] and asked whether it would be possible to obtain the beta versions of the converters. HP. de Koning said that it was still too early to release the beta versions, but said that if companies were interested to help in the testing, then it would probably be possible within a few months. All test models would indeed become available for public access. He said that validation would involve a `THERMICA` model produced by EADS Astrium in Friedrichshafen, an `ESARAD` model produced by RAL, and a `CIGAL2` model produced by Thales Alenia Space in Cannes. The idea was that every partner developed one model that would be made public, with no issues about IPR. These models could also be useful for testing other software.

S. de Palo (Thales Alenia Space) remarked about the screenshot that had shown `BagheraView` and `TASverter`. E. Lèbegue said that the release schedule for `BagheraView` was the same as for the converters. They were still validating and consolidating all of the work done, and the release would probably take place in the middle of next year. He said that a beta release of `BagheraView` that used the old version of `STEP-TAS` was available for anyone who was prepared to search on Google for it. HP. de Koning observed that one interesting point about this version of BagheraView was that it was also able to import both STEP AP-203 and AP-214 files, and could be used to compare models and to do a visual overlay inspection of a model.

2.10 Thales Alenia Space thermal software suite — Presentation of the tools and current policy

T. Basset (Thales Alenia Space) gave a brief history of the thermal tool development in Cannes, and the evolution of the different tools over the past 30 years. F. Brunetti (DOREA) narrated an animation showing the process of building a simple model using CIGAL2. JP. Dudon (Thales Alenia Space) described the background to the 3D conductive tool, the computation of elementary conductive couplings, the reduction of a finite element model and the generation of the equivalent thermal model. F. Brunetti narrated another animation showing the visualisation of temperatures on both the finite element, and lumped parameter representations of the same model. T. Basset then announced that they were making the tool available for free to anyone who wanted to use it, and that CDs were available with a two month trial licence so that people could evaluate the tool for themselves. (See appendix V)

HP. de Koning (ESA/ESTEC) had noted that they intended to release the 3D conductor calculation tool, and asked whether this would also support all of the STEP-TAS conductor links as well. T. Basset said that it was possible to export the links to ESATAN. JP. Dudon said that it was possible to output in a format suitable for ESATAN, but they had not considered STEP-TAS.

P. Vueghs (University of Liége) had noted that description of the finite element mesh and how it was possible to fuse a finite element to a geometrical element. He wondered whether they had access to the real geometry. JP. Dudon explained that CORATHERM only considered the facetted geometry mesh. However, the mesh was parameterised so that it was possible to adapt it.

S. de Palo (Thales Alenia Space) asked whether IGES import was available as part of CIGAL2. And how were the temperature mappings handled? JP. Dudon said that CIGAL2 was just a pre- and post-processor with modules from OpenCASCADE providing the IGES import facilities. S. de Palo asked whether it was possible to export to FEM. JP. Dudon said that there was an export to STEP-TAS. S. de Palo asked how they were able to export the temperatures for the lumped parameter model and then convert back to the finite element model. JP. Dudon explained that they used a very simple format, an internal FORTRAN format, that was used specifically for CIGAL2.

H. Rooijackers (ESA/ESTEC) asked about the platforms on which CIGAL2 could be run. F. Brunetti said that the CD contained a version that would run on Windows Vista and XP. Everything had been implemented so that it could be compiled on Unix, so it would not be a big effort to compile a version for Unix if required.

2.11 Workshop Close

H. Rooijackers (ESA/ESTEC) remarked that this year there had been an increase in the number of presentations, and also an increase in the quality of presentations. He wanted to thank all of the authors and presenters, and all of the other participants, and hoped to see everyone at the following workshop.

Appendix A

Welcome and Introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

esa

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Thermal and Structures Division

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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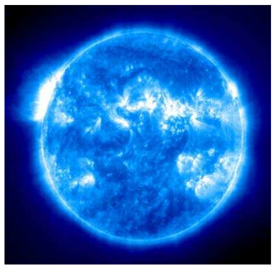

Programme

- 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

28-29 Oct 2008 22nd European Workshop on Thermal and ECLS Software 4

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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

- in “La Galleria", Koningin Wilhelmina Boulevard 18, 2202 GT Noordwijk, tel +31(0)1719 17196
- fixed menu with choice of main course (fish, meat or vegetarian) for €28,50 p.p. *Drinks are charged individually.*
- Restaurant booked today for 19:30
- Please arrange your own transport
- "Dutch" dinner == to be paid by yourself
- If you would like to join,
  then contact the registration desk today **before 13:00**,
  to let the restaurant know what to expect

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Restaurant “La Galleria"

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Menu CAPRI

(€ 28,50 p.p. excluding drinks)

INSALATA DI MEGLIO
Fresh salad with grilled chicken breast,
pine kernel nuts and crispy bacon with pesto dressing
or
INSALATA CAPRESE
Tomato salad with buffalo mozzarella cheese and fresh basil
~~~~~~~~~~~~
SALMONE ALLA GRIGLIA CON FINOCCHIO E LIMONE
Grilled salmon with fennel and a lemongrass vinaigrette
or
SALTIMBOCCA ALLA ROMANA
Sautéed veal covered with San Daniele ham in a white wine sauce with sage
~~~~~~~~~~~~
TORTA PISTACCHIO
Italian Pistacchio cake

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ICES 2009

- The 39th International Conference on Environmental Systems (ICES) will be held July 12 – July 16, 2009, Savannah, Georgia, USA.
- Deadline for submitting abstracts: Friday 14 November, 2008
- 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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Appendix B

Columbus Thermal Control System On-Orbit Performance

Jan Persson
(ESA/ESTEC, The Netherlands)

Zoltan Szigetvari
(EADS Astrium, Germany)

Gaetano Bufano
(Thales Alenia Space, Italy)

Abstract

The Columbus laboratory module, a major European contribution to the International Space Station, was launched onboard the Space Shuttle Atlantis on 7 February 2008. The presentation will present some early data on the performance of the Columbus thermal control, both active and passive, after start of on-orbit operations. The data will be compared to a set of analysis results from the Columbus Integrated Overall Thermal Mathematical Model (IOTMM), which have been produced with the observed ISS on-orbit conditions as input.

Columbus Thermal Control System On-Orbit Performance

22nd European Workshop on Thermal and ECLS Software
28&29 October 2008

Jan Persson European Space Agency
Zoltan Szigetvari EADS Astrium
Gaetana Bufano Thales Alenia Space

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ESTEC Thermal & Structure Division

Content

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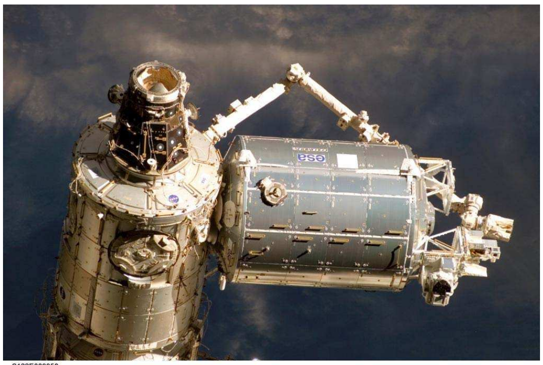
Introduction

- Mission
  - ESA microgravity laboratory for the ISS
  - Launch on STS-122/F1E on 7 February 2008
- Design
  - Cylindrical pressurized compartment, diameter 4.5 m, length 6.4 m
  - Accommodates 10 payload racks internally and 4 attached payloads externally
  - Supports a shirtsleeve environment for 3 crew members



S122E009958

ISS016E028524

- Thermal control
  - Combination of passive and active
  - MLI (beta cloth top layer on exposed blankets)
  - Chromic acid anodization on MDPS panels
  - Aluminium shell with external heater foils
  - Internal cooling by water loop, with interface to Condensing Heat Exchanger for cabin temperature and humidity control and heat exchangers for heat rejection to the ISS

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Objective

- Due to practical constraints, the Columbus module has never been subjected to a thermal balance test
- The Columbus thermal design has been verified by applying a validated Integrated Overall Thermal Mathematical Model (IOTMM) for the flight predictions. The Columbus System Requirements Document, COL-ESA-RQ-001, specifies

5. 4. 3.
ID.219 AT
The thermal design of the APM shall be consistent with all specified operational scenarios and derived contingency modes without causing heat soak back, undercooling, condensation or other adverse effects.
Note : (Requirement Clarification): Qualification on FC level is via analysis supported by test on PFM (to validate analysis). Test is performed at system level in the frame of the integrated system test. ATCS is tested at S/S level during the water loop step 4 to validate the TCS TMM. THG is tested at section level to validate the THG TMM. Unit Thermal design is tested at unit level. (THG – Temperature and Humidity Grid)

- The purpose of the current simulation is to gain insight into how well the chosen method of verification has managed to produce an IOTMM which is able to reproduce the observed on-orbit TCS performance

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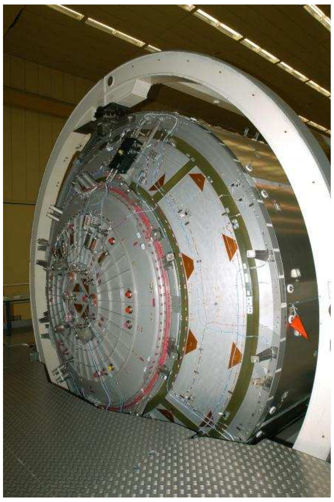
Thermal control overview
1. Shell heater design architecture (1)



- Main and redundant heater chains have 78 heaters each
- Each chain has 6 circuits with 13 heaters
- Main heater chain is powered and controlled by HCU 1
- Redundant heater chain is powered and controlled by HCU 2
- Three redundant thermistors are implemented for the HCU to control each individual circuit
- Heater elements are trapezoid-shaped Kapton foils (1249 +/-3% ohms)
- With 120 VDC, it produces around 146 W per circuit and almost 900W per chain

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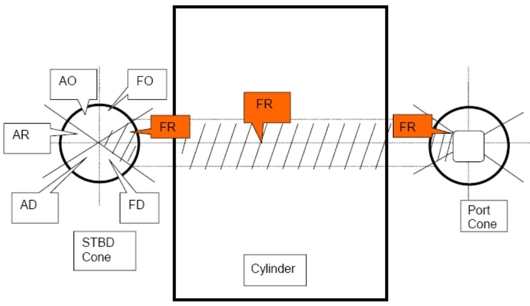
Thermal control overview
1. Shell heater design architecture (2)

- The shell, i.e. the Port Cone, the Cylinder and the STBD Cone, is subdivided into 6 zones (AD, AR, AO, FO, FR, FD) in the longitudinal direction, each covered by one main and one redundant heater circuit
- The 3 main and the 3 redundant thermistors are located at the two cones and in the middle ring of the shell
- Each heater circuit is activated when at least one of the three thermistors detects a temperature < = 20 °C and is switched off when all the three thermistors detect a temperature > = 23 °C *(valid for the default temperature setting)**

*) The default control set points have been selected in order to keep a comfortable margin w.r.t. the maximum dewpoint (15.5 °C) permitted in manned modes



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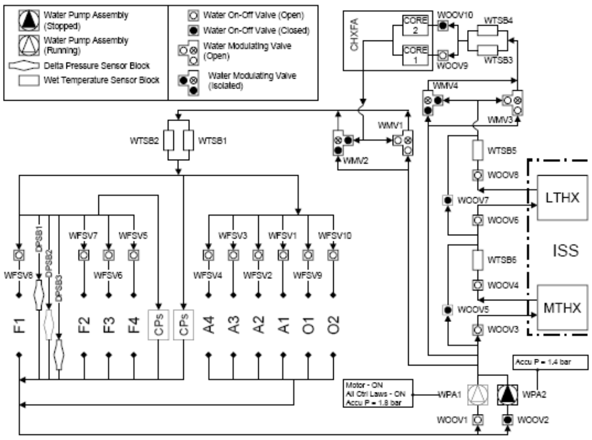
Thermal control overview
2. Water loop design architecture (1)

- Active Thermal Control data
  - Single-loop architecture
    - 22-kW heat rejection capability (14.5 kW from payloads)
  - Service to
    - 10 payload racks
    - 24 cold-plate mounted avionics boxes
    - 1 condensing heat exchanger
  - Components
    - Redundant water pumps
    - Redundant pair of three-way water modulating valves
    - Water on-off valves
    - Payload water flow selection valves
    - Wet temperature sensor blocks
    - Delta pressure sensor blocks
  - Operational boundaries and control set-points
    - Water from ISS in the range 1.1 to 6.1°C
    - CHX inlet temperature control at 5±1°C
    - Plenum inlet temperature control at 17±1°C
    - Plenum delta pressure control in the range 40 to 44 kPa
    - Operating WPA at 1.8±0.15 kPa



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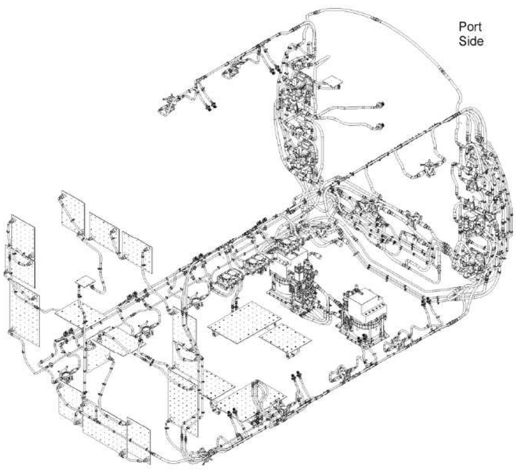
Thermal control overview
2. Water loop design architecture (2)

- Hardware configuration
  - Water lines
    - ¾" titanium hard lines for the main water lines
    - ½" titanium hard lines for the ISPR and cold plate branches
    - wire-braid restrained Teflon flex lines for ATCS equipment and payload rack connections
    - Low temperature section of ATCS, from the ISS to the three-way modulating valve after the CHX, insulated with Armaflex foam insulation to avoid condensation
  - Cold plates
    - 14 1.5 ATR cold plates (Spacelab heritage)
    - 5 Standard cold plates (Spacelab heritage)
    - 2 Allied Signal -4 cold plates
  - Connections
    - Standard hydraulic screw fittings between water lines and between water lines and cold plates
    - Quick Disconnects between water lines and ATCS equipment and payload racks
  - Volume
    - 208 litres with the maximum allowed payload volume of 80 litres
    - The F1E payload configuration has had a total volume of 120.5 litres



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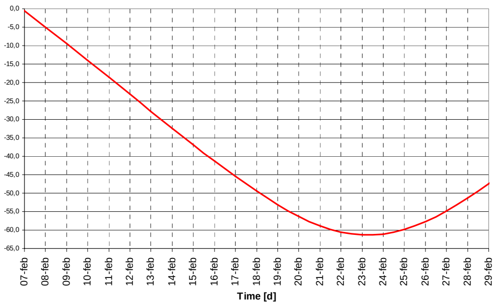
22 and 28 February operational configuration

- Internal configuration
  - No payload in operation except for FSL being activated on 22 February
- External configuration
  - SOLAR and EuTEF external payloads in commissioning phase

Rack Location	Facility	Sub Rack Facilities
A1	Not Used	N/A
A2	Biological Laboratory (BLB)	WAICO
A3	European Physiology Module (EPM)	MEEMM, CARDIOLAB, NASA-Drawer
A4	Not Used	N/A
F1	European Drawer Rack (EDR)	PCDF EU
F2	Not Used	N/A
F3	Not Used	N/A
F4	Not Used	N/A
O1	Fluid Science Laboratory (FSL)	Geoflow
O2	Not used	N/A
O3	Zero-g Stowage Rack	N/A
O4	Zero-g Stowage Rack	N/A
D4	European Transport Carrier (ETC)	N/A

EPF Location	Facility	Sub Facilities
SOZ	Solar Monitoring Observatory (SOLAR)	SOVIM, SOLSPEC, SOLACES
SOX	European Technology Exposure Facility (EuTEF)	DOSTEL,EXPOSE,DEBIE-2 , FIPEX, MEDET, PLEGPAY, TRIBOLAB, EuTEMP, EVC
SDX	Not used	
SDN	Not used	



- Thermal environment
  - ISS flying in +XVV Z-Nadir attitude
  - Beta angle around -60°, representing a hot case, with high starboard solar flux

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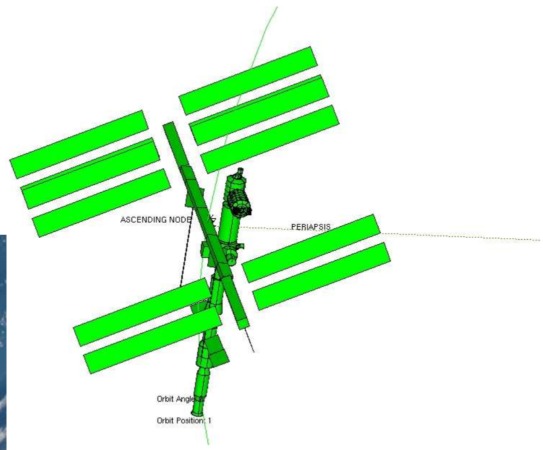
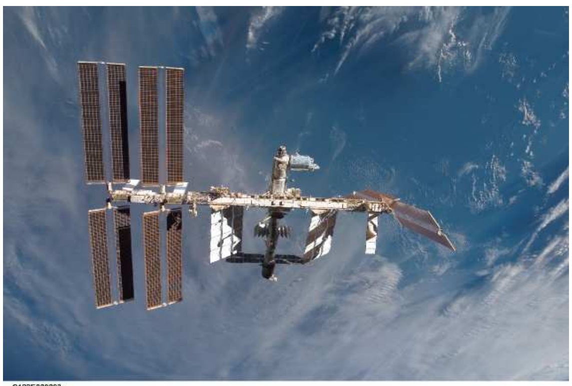
ISS and Columbus sun exposure

- The photo shows the ISS at the time of Space Shuttle Atlantis departure on 18 February 2008
- The ESARAD image shows a sun view of the ISS and the Columbus IOTMM on 22 February 2008





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Thermal modelling details

- The TASI ESATAN/FHTS modelling from 2004, which is available at ESTEC, forms the basis for the simulation. However, the ESARAD modeling has been augmented with a 2-D automatic sun orientation for pointing the solar panels to the sun and rotating the radiators out of the sun for each orbit position. The input has been adapted in order to correspond to the operating conditions on 22 February, with, in terms of geometry, two important exceptions
  - The Starboard SARJ is modelled as articulating and not fixed
  - The presence of SOLAR and EuTEF is not modelled
- The utilized thermal software and model sizes are
  - ESARAD 6.2.1 – 1232 basic shells
  - ESATAN 10.2 – 2606 thermal nodes
    - 9 level 1 submodels, 1 level 2 submodel
    - 1628 GL conductors
    - 87350 GR conductors
    - 49 GF conductors

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Comparison between shell heater on-orbit and analysis data 22 and 28 February HCU operations

- During the Launch-to-Activation (LTA) phase, with Columbus in the Space Shuttle cargo-bay, it had been noticed that power was drawn predominantly from APCU 1, powering HCU 1, which could be an indication of a problem on HCU 2. While it was found that the difference in part could be attributed to an off-set in the power telemetry, a characterization was still regarded as important.
- On 22 February, HCU 2 was switched off and HCU 1 was operating with a steady current draw of about 5 A. With the measured voltage it corresponds to about 600 W or 4 heater circuits. By shifting the HCU 1 temperature set-points to 18 and 20°C, the heaters were powered off and the Columbus shell started to cool down slowly.
- On 28 February, HCU 1 was switched off and HCU 2 was operating with a steady current draw of about 5 A and, similar to HCU 1 on 22 February, the HCU 2 temperature set-points were shifted to 18 and 20°C.

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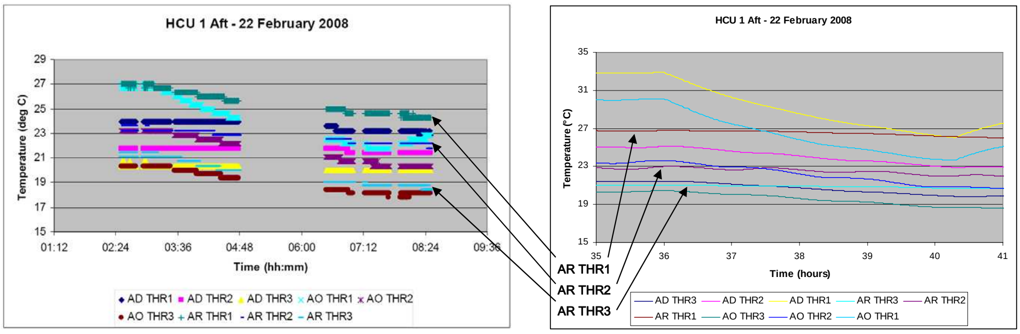
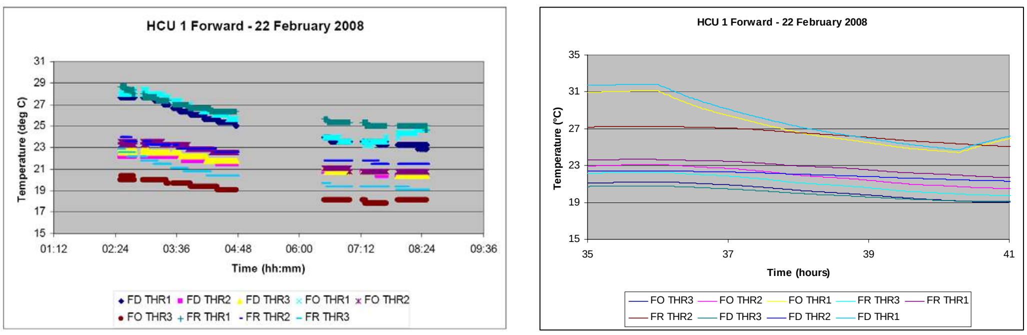
Comparison between shell heater on-orbit and analysis data
22 February results – Aft shell

- Thermistors with number 1 are on the starboard side, with number 2 are at the centre and with number 3 are on the port side. It is clear that the starboard thermistors are at a higher temperature and there is a rather significant temperature gradient in the axial direction. Considering how the heaters are distributed and the heater switching logic, it leads to heaters on the starboard side being powered together with heaters on the port side, due to the relative cool-down of the Port Cone.
- The simulation starts the power outage with the AR zone heaters switched off
- The on-orbit data indicate that the AD and FD zone heaters, are switched off



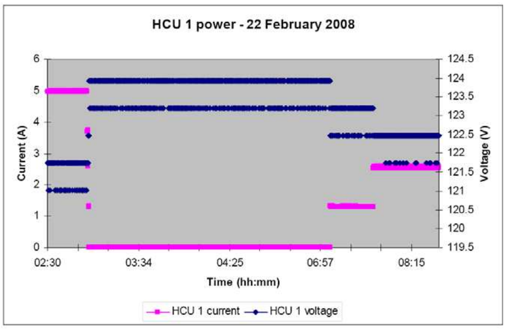
Comparison between shell heater on-orbit and analysis data
22 February results – Forward shell

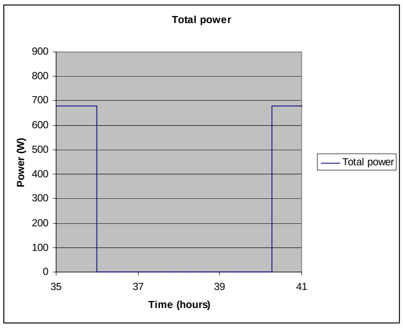
- Not surprisingly, both aft and forward shell heater zones show the same behaviour and, with some variation, steady-state and transient behaviour is similar both for flight data and simulation results
- The maximum temperatures from the on-orbit data for the starboard cone are lower than for the simulation. The maximum on-orbit temperature gradient from starboard to port sides is 8°C (FO), while the simulation produces a maximum temperature gradient of 13.9°C (AD) on the shell (in steady-state)
- In the circumferential direction, the starboard cone on-orbit data show a maximum temperature gradient of 4.8°C (FR to AD) to be compared to 11.5°C (AD to FR) in the simulation results



Comparison between shell heater on-orbit and analysis data
22 February results – Heater power consumption

- The simulation was performed completely cutting the power to the heaters, while the on-orbit operation was based on changing the temperature set-point. Consequently the on-orbit power data show a gradual increase in current draw from HCU 1, which also explains the difference in the transient temperature profiles in the two previous viewgraphs
- It has to be noted that the simulation is based on a fixed voltage of 116 VDC from the HCU 1 and the maximum resistance per heater. It translates to 136 W per circuit, to be compared to about 150 W per circuit with the measured values. The on-orbit data present voltage and current to the HCU 1 and the data are not corrected for internal losses





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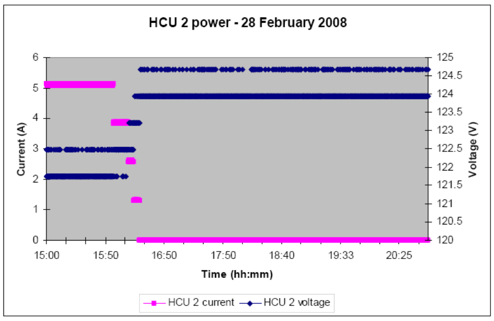
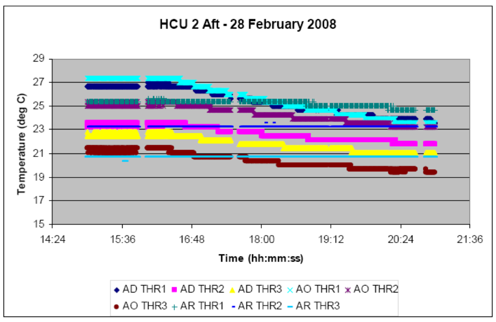
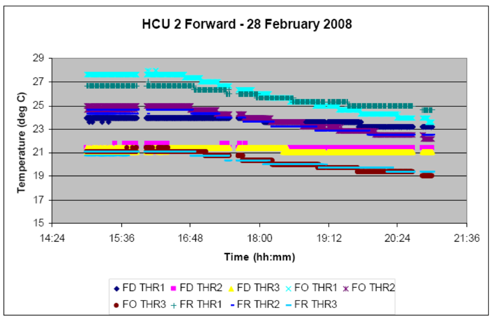
Comparison between shell heater on-orbit and analysis data
22 February versus 28 February results

- The results for HCU 2 on 28 February resemble very strongly the results for HCU 1 on 22 February. None of the thermistors reach the lower threshold of 18°C in the observed period
- The on-orbit data indicate that the AR and FD zone heaters, are switched off at the start of the cool-down transient
- FD THR2 and THR3 readings are very close
- Maximum gradients are 6.3°C (FO) in axial direction and 3.7°C in the circumferential direction (FO to FD)







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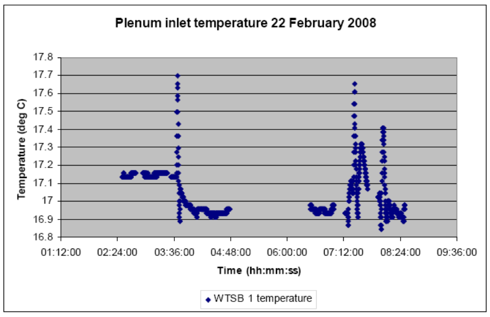
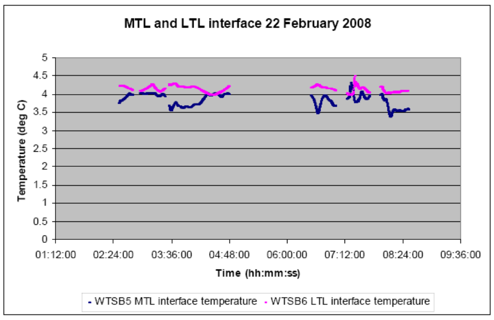
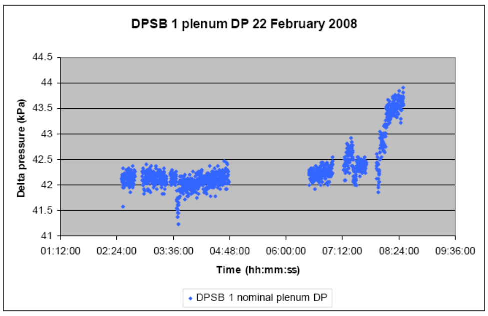
Comparison between water loop on-orbit and analysis data 22 February – ATCS performance

- The measured LTL interface temperature of 4°C has been used as input for the simulation
- The effect of the TCV kick operation is clearly shown in the on-orbit data for the DPSB 1 and WTSB 1. The TCV kick operation, every 1 ¼ hour, has to prevent condensate carry-over in the CHXFA. For high by-pass ratio, it moves the TCV to achieve 70% air flow through the active core
- The resulting higher water temperature produces a brief upset of the plenum inlet temperature







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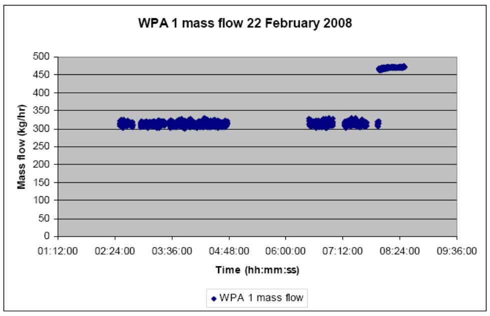
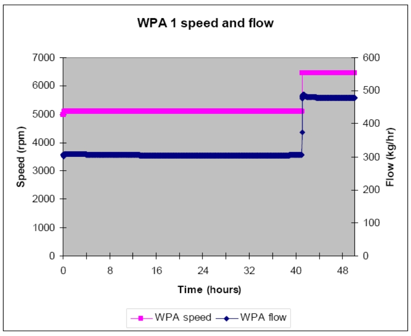
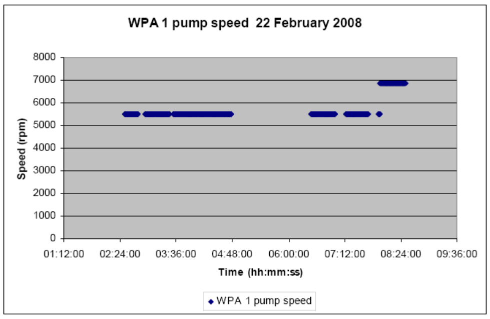
Comparison between water loop on-orbit and analysis data 22 February – Pump flow rate and speed

- The increase in flow rate and speed on 22 February is caused by the activation of FSL in ISPR location O1. FSL is calibrated for a flow rate of 170 kg/hr at 40 kPa
- From a comparison between the plot below and the plots to the right, it is obvious that the IOTMM is able to reproduce, with good fidelity, the on-orbit data
- The simulated pump speed is somewhat lower than the measured one, but that is fully in line with the finding during the IOTMM correlation







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Conclusions

- Generally the IOTMM results correlate well with the on-orbit data
- A significant longitudinal temperature gradient is created on the Columbus shell for negative beta angles due to the heater implementation
- Most likely the heater power consumption could be reduced by optimization of the heater control algorithm, e.g. by lowering the upper threshold to below 23°C or by using a scheme based on the average shell temperature to control the heaters. Further investigation would be needed, but there is limited overwrite capability of the HCU EPROM on-orbit
- The simulated water loop behaviour corresponds closely to what is observed during flight

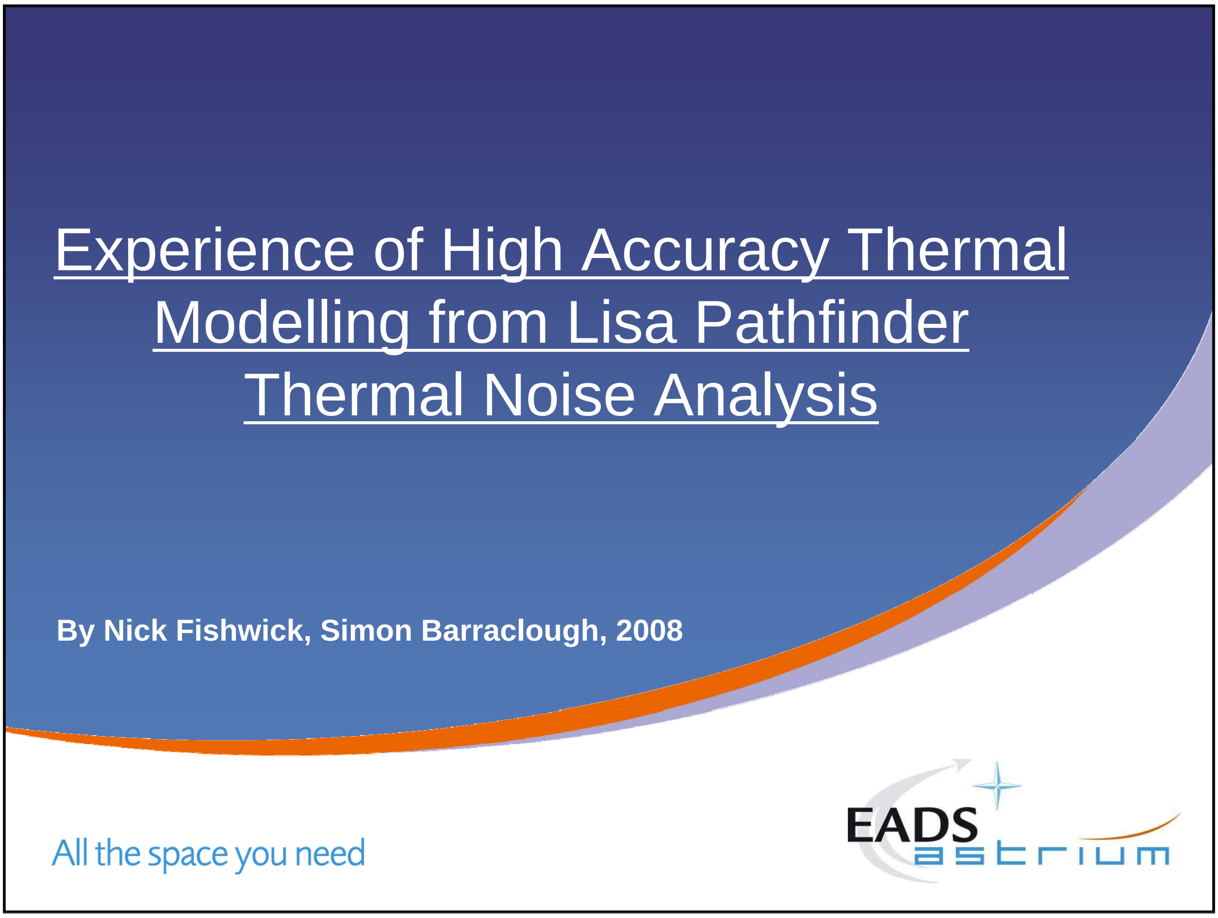
Appendix C

Experience of High Accuracy Thermal Modelling from the LISA Pathfinder Thermal Noise Analysis

Nick Fishwick Simon Barraclough
(EADS Astrium, United Kingdom)

Abstract

The increasing accuracies of the thermal stability of space science missions requires that thermal models of the instrument payloads need to have higher stability requirements. The Lisa Pathfinder technology demonstration mission for detecting gravity waves is one such sensitive mission with changes in temperature of 10^{-6} K being significant to the payload. Following on from the work by Ulrich Rauscher on Guidelines for High Accuracy Thermal Modelling (presented at the 21st Workshop last year) the implementation of Double Precision values in ESATAN has been investigated with Lisa Pathfinder. The study of the variations on temperature convergence and the Power Spectral Density analysis of the identified Thermal Noise sources on the mission have shown that the payload meets the temperature requirements of 10^{-3} K Hz$^{-1/2}$.


Experience of High Accuracy Thermal Modelling from Lisa Pathfinder Thermal Noise Analysis
By Nick Fishwick, Simon Barraclough, 2008
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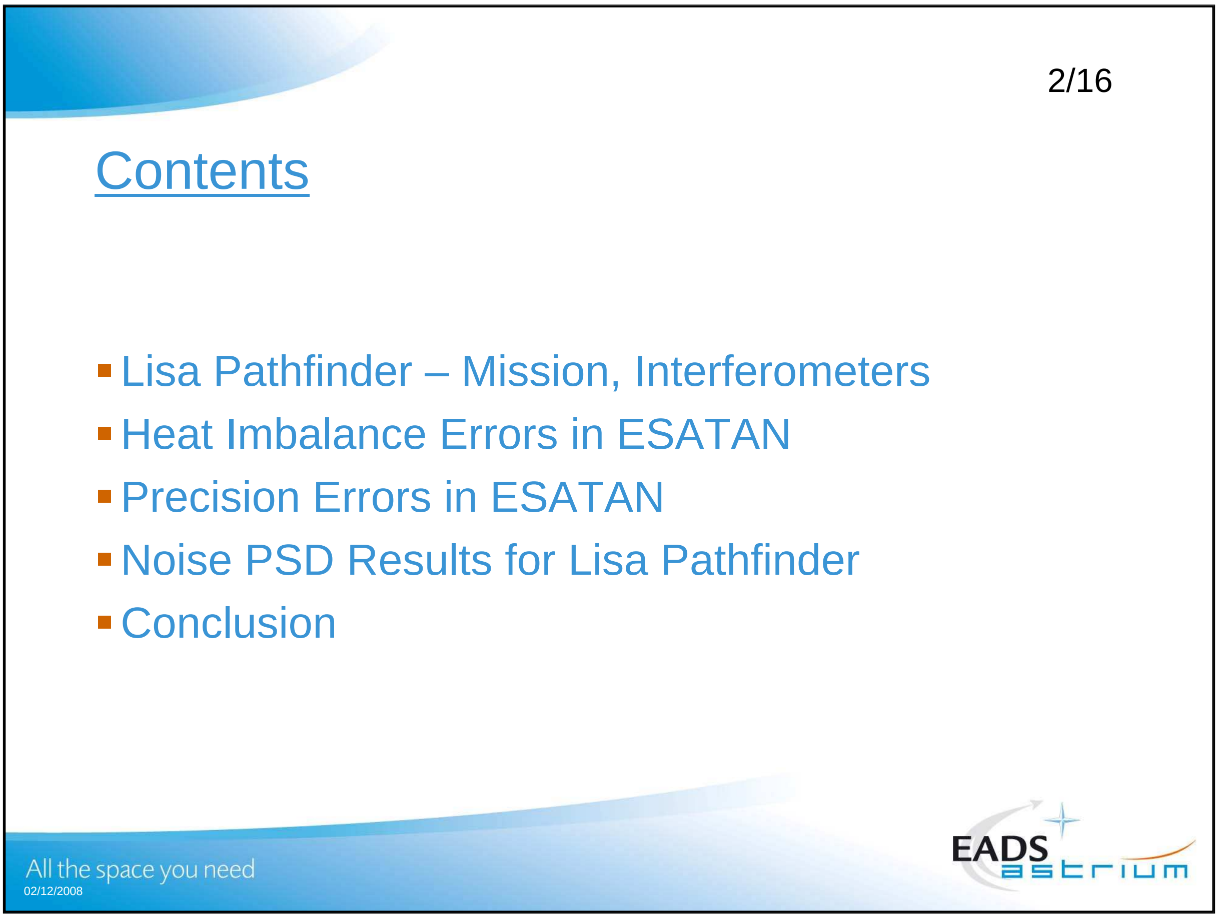
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Contents
Lisa Pathfinder – Mission, Interferometers
Heat Imbalance Errors in ESATAN
Precision Errors in ESATAN
Noise PSD Results for Lisa Pathfinder
Conclusion
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Lisa Pathfinder - Mission

- Technology Demonstration Mission for LISA
- Searching for Gravity Waves
- Lissajous Orbit at Lagrange L1
- NASA / ESA Co-op Program
- Test Lisa Technology Package (LTP) and Micro-Propulsion

Supplied by ESA Images and Videos

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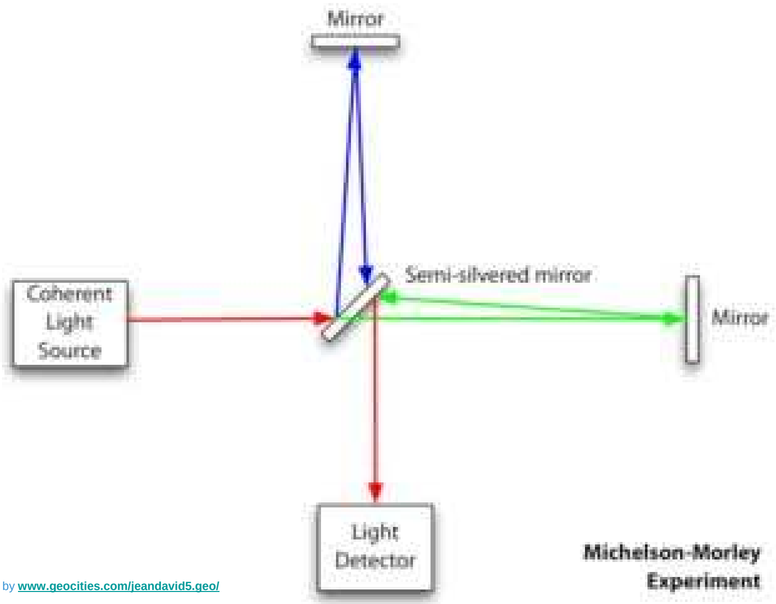
Lisa Pathfinder - Interferometer



Michelson-Morley Experiment

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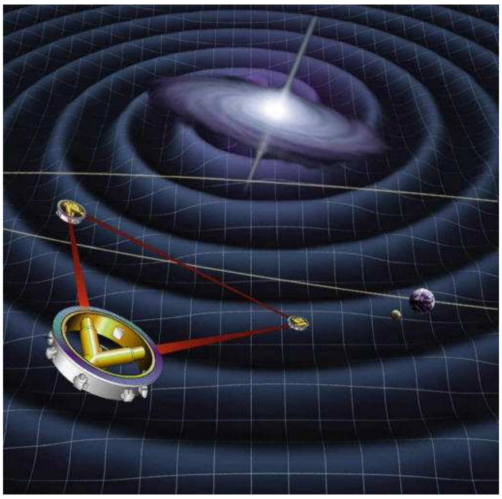
Lisa - Interferometer



Supplied by EADS Astrium

Distance between each spacecraft ≈ 5 million km

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Lisa Pathfinder – Interferometer Requirements

- Objective: “Free-Floating” Test Mass
- Very Sensitive: 10^{-12} m (atom = 10^{-10} m)
- Temperature Stability: 10^{-3} K / √Hz from 0.001 to 0.1 Hz

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Inaccuracies in Thermal Modelling

- ESATAN can be accurate to temperatures of order **10^{-6} K**
  (Ulrich Rauscher, 21st European Workshop on Thermal and ECLS Software)
- **Inaccurate modelling of the system is caused by:**
  - Discretization errors
  - Material data inaccuracy
  - Boundary conditions, dissipation assumptions
  - Human error from hand calculations and model definition
  - Simplified radiative modelling.
- ***Inaccuracy in the solving process***
  - *Heat imbalance errors (Model Convergence)*
  - *Influence of different solvers on the iteration process*
  - *Truncation and rounding errors in the calculation process*

Supplied by Ulrich Rauscher

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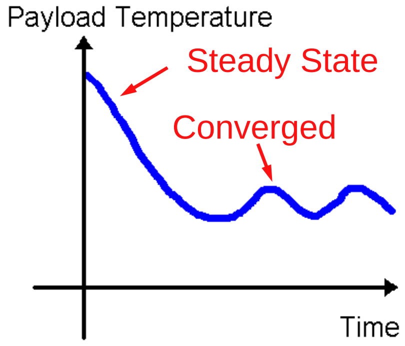
ESATAN Model Convergence

- Model needs to converge to order 10^{-6} K accuracy
- Major Sources of Thermal Noise Identified:
  - Solar Flux
  - Thruster Power Supplies
  - Power Control and Distribution Unit (PCDU)
  - Computer (OBC)
- Noise Profiles Generated
  - Determined from Solar Flux Measurements
  - Worst case where one thruster has failed
  - White Noise at 0.5% of Total Unit Dissipation
- Due to addition of Noise Profiles (external heat flux variation) during Transient calculation, there is a drift in the overall temperature level
  - Needs a Steady State pre-calculation with a very low heat imbalance to minimise temperature drift
  - Need to run the Transient Analysis until convergence



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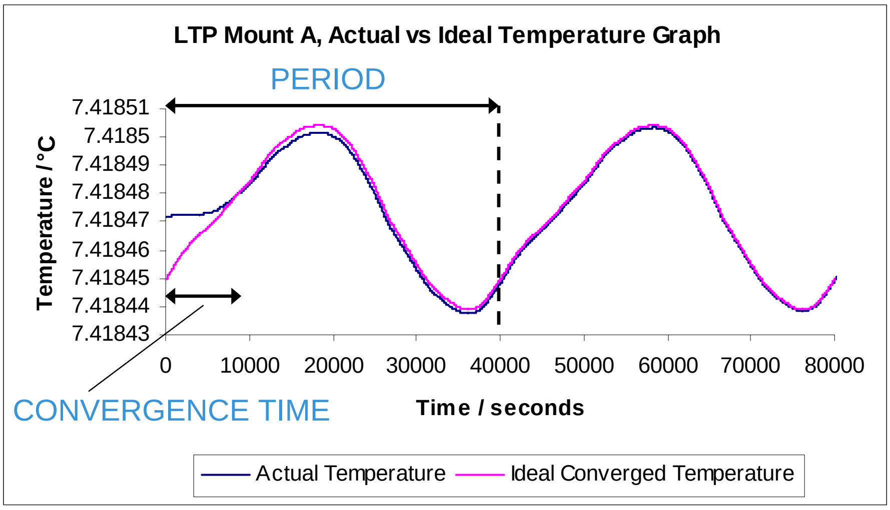
ESATAN Convergence Results



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ESATAN Model Settings

- Steady State Relaxation Convergence Criterion (RELXCA) = 10^{-10}
- Transient Relaxation Convergence Criterion (RELXCA) = 10^{-6}
- Node starting temperatures = 10.0 ºC
- Solvers used = SOLVIT
  = SLCRNC
- Output Interval = 5.0 seconds
- Most other settings at default values
  (e.g. Temperature Damping (DAMPT) = 1.0)
- Noise Profiles with no discontinuities over repeated cycles
- Real computational time takes six hours every Noise Period

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Double Precision in ESATAN

- Every value can be declared at double precision in ESATAN
- However the variable precision is changed in ESATAN from input file to executable file

  (Ulrich Rauscher, 21st European Workshop on Thermal and ECLS Software)
- For certain data blocks, the pre-processor truncates the variables down to single precision and then extends them back to double precision in the executable program file:
  - $NODES - Truncated and Extended
  - $CONDUCTORS - Truncated and Extended
  - $CONSTANTS - Truncated and Extended
  - $ARRAY - Truncated and Extended
  - $INITIAL - Remains at Double Precision

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Double Precision Workaround in ESATAN

- Declare all data in $DATA blocks as normal (initialise)
- Declare all data again in the $INITIAL block to Double Precision as Subroutines

- Problem: Limited Number of Subroutines due to Memory
  - Solution: Use ESATAN v10.2
- Problem: Limit on Size of Very Large Subroutines
  - Solution: Split up the Large Subroutines into Little Ones
- Problem: Double Precision Workaround does not allow for two separate coupling references to the same pair of nodes
  - Solution: Rewrite all multiple coupling references into one reference

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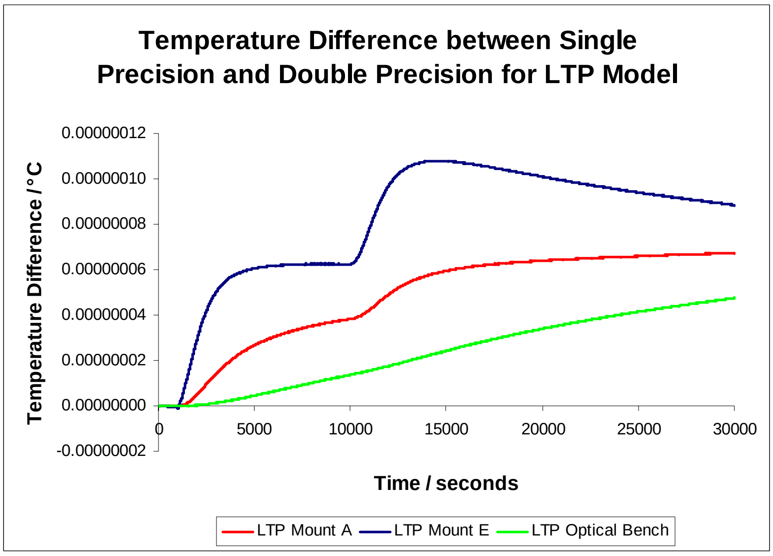
Double Precision Results



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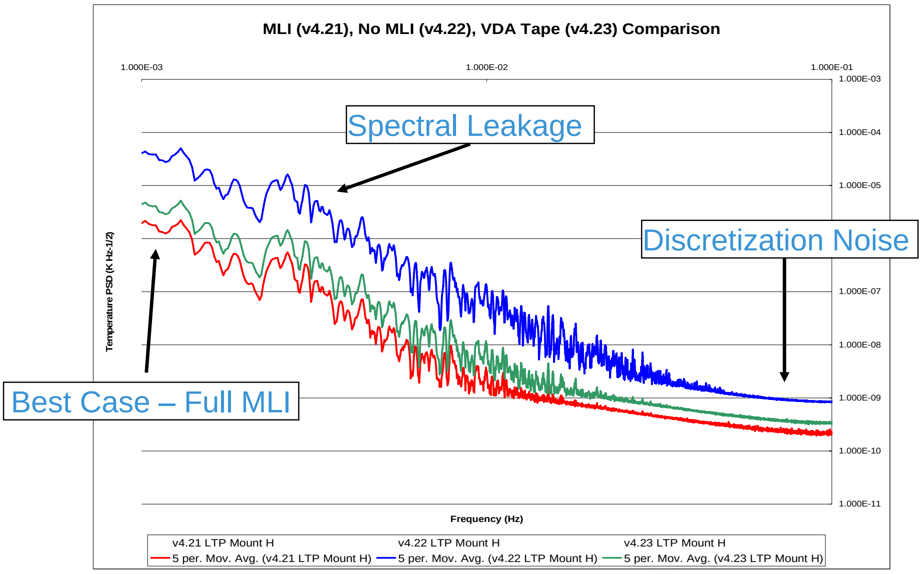
PSD Results



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Conclusion

- LTP Thermal Model meets the Requirements
- LTP Model converges to within 10^{-5} K within 1st Period
- ESATAN Double Precision Workaround Possible
- PSD Analysis Works

- Suggestions on ESATAN Improvements:
  - Make sure that data blocks in ESATAN are kept as double precision during the Pre-processor stage
  - Increase the model maximum node number capacity for the ESATAN Frequency Response Transfer Function (SLFRTF) [from 1,500 nodes to greater than 6,000 nodes]

- Next Steps:
  - Investigate Improved Noise Profiles
  - Review Alternative Transfer Functions

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Any Questions?

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Appendix D

New Technology for Modeling and Solving Radiative Heat Transfer using TMG

Christian Ruel
(MAYA, Canada)

Abstract

As engineers increasingly rely on numerical models within the framework of a collaborative development process, demands on solution performance are becoming much more severe. In order to effectively address these demands, we believe that a massive, quantum improvement in the solution speed of spacecraft thermal analysis systems is required. To achieve such a breakthrough, MAYA has undertaken the parallelization of the TMG software system, enabling full exploitation of multiprocessing computer environments (consisting of multiprocessor servers or networked workstations or clusters).
Maya is also developing an innovative numerical method for the simulation of radiative heat transfer in cryogenic systems, based on the radiosity method, in which the radiating spectrum is discretized into spectral bands. A surface at a given temperature will radiate and absorb in all the bands, but the coefficients of emissivity and absorptivity - while equal to each other in a given band - will vary from one band to the next.

22st European Workshop on Thermal and ECLS Software

New Technology for Modeling and Solving Radiative Heat Transfer using TMG

October 28, 2008

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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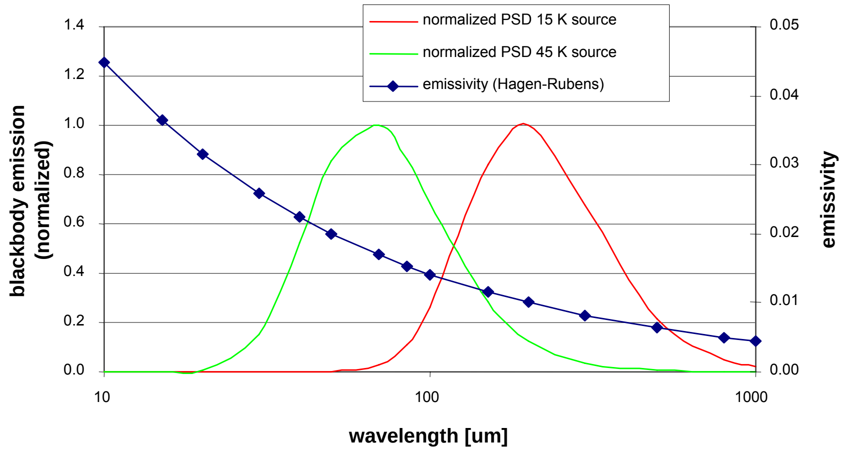
Nongray: really, why? (1)

- 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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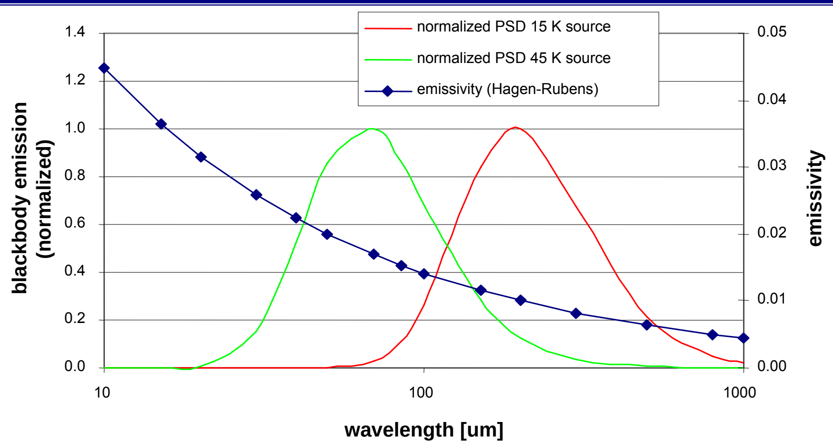
Nongray: really, why? (2)



- 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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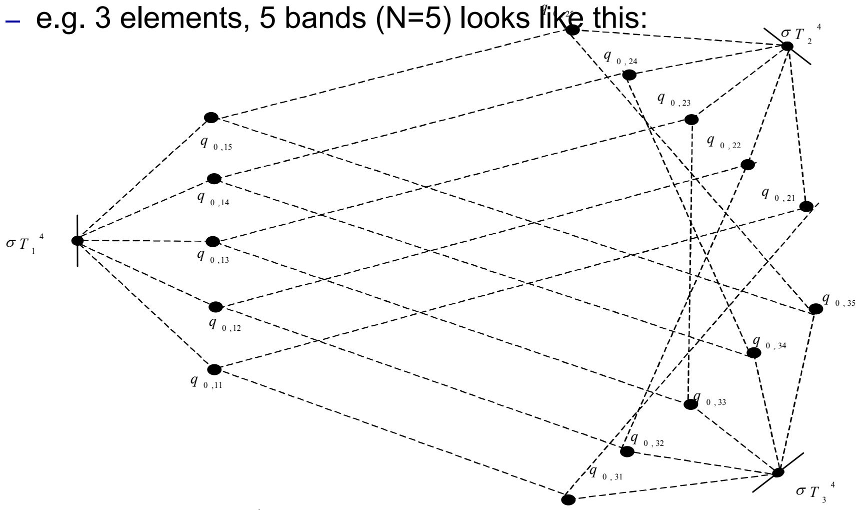
Nongray Analysis in TMG

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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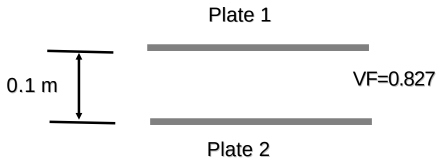
Nongray Validation

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:

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

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

- 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) λ_0	λ_1	λ_2	λ_3	λ_4	T_1 = Element 1 Temperature (sink)
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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Flat Plate Radiating to Space

Test Case	Number of Bands	Target T	number of iterations	Computed T
1.0	2	1000 K	40	1000.03 K
1.1	2	1000 K	93	1000.03 K
1.2	2	1000 K	34	1000.06 K
1.3	3	1000 K	42	999.99 K
1.4	3	40 K	39	40.003 K
1.5	4	25 K	58	24.998 K

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Two Flat Plates and Space

Two Plates in Space: Results

- T2 is temperature computed with nongray method
- Q2,abs and Q2,emit are computed analytically from T2
- Method should yield Q2,emit=Q2,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	0.281 W	-0.8%
2.3	50 K	40.05 K	0.0289 W	0.0286 W	0.8%
2.4	60 K	46.17 K	0.0555 W	0.0560 W	-0.85%

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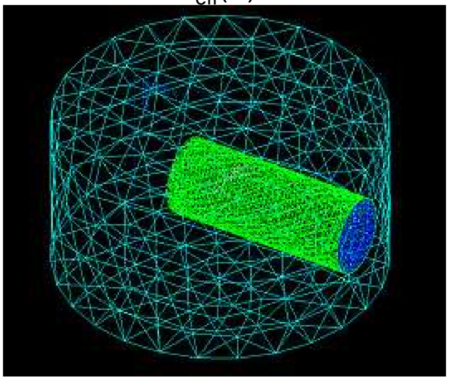
Nongray: Sample Application

Simplified model of telescope instrument with cryogenic optics

- ε(λ) 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

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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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Extension to Ray-Traced View Factors

Specular and Transparent surfaces imply that Oppenheim's method cannot be used alone for all reflections/transmissions

Ray-traced view factors are employed

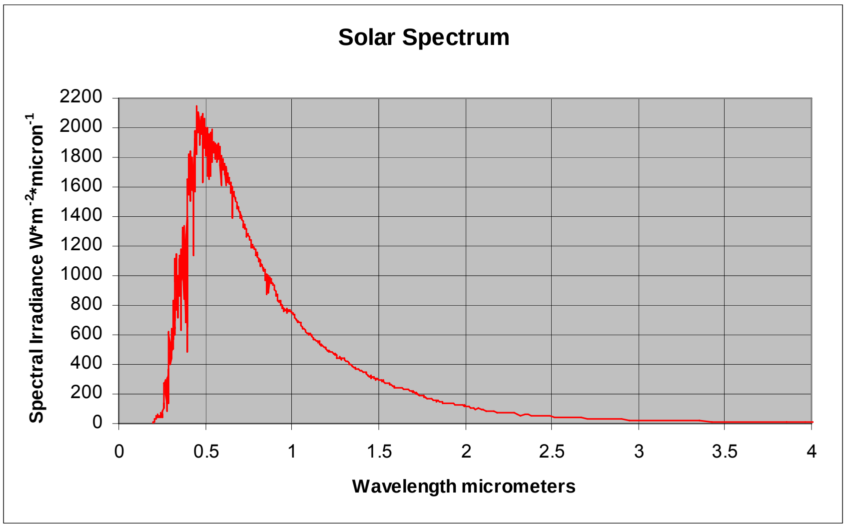
View factors become band dependent

Test Series 3: Two Specular Plates Radiating to Space

Test Case	Number of Bands	T_1 (input)	T_2 (result)	$Q_{2,emit}(T_2)$ (analytic)	$Q_{2,abs}(T_2)$ (analytic)	% error
3.0	1	100 K	79.29 K	1.34 W	1.34 W	-0.2E-3 %
3.1	2	60 K	31.37 K	1.08E-2 W	1.08E-2 W	-0.6E-2 %
3.2	4	60 K	34.09 K	1.54E-2 W	1.54E-2 W	-0.02%
3.3	11	80 K	44.18 K	7.20E-2 W	7.21E-2 W	-0.07%

Solar Spectrum

For multi-band analysis, the solar spectrum is integrated over bands defined by the user. Can also be input.



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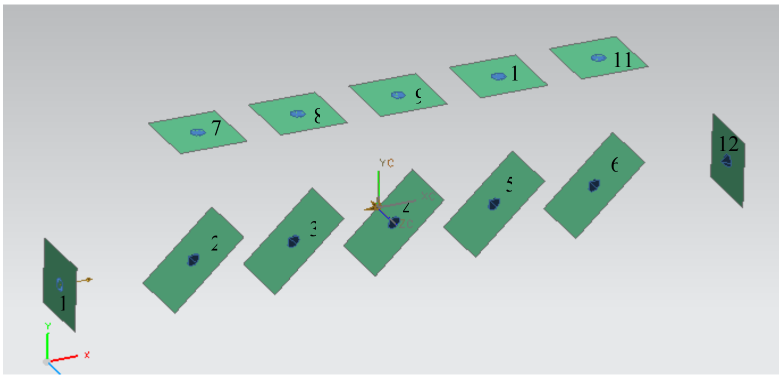
Wavelength dependent heat sources



11 bands used, each intermediate plate able to reflect & transmit energy in various bands

One simple and one more complicated set of material properties

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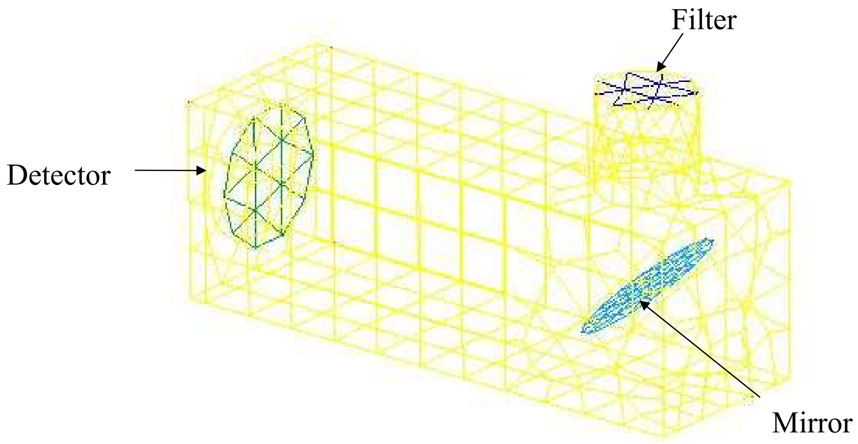
Cryogenic Optics with Radiative Heating



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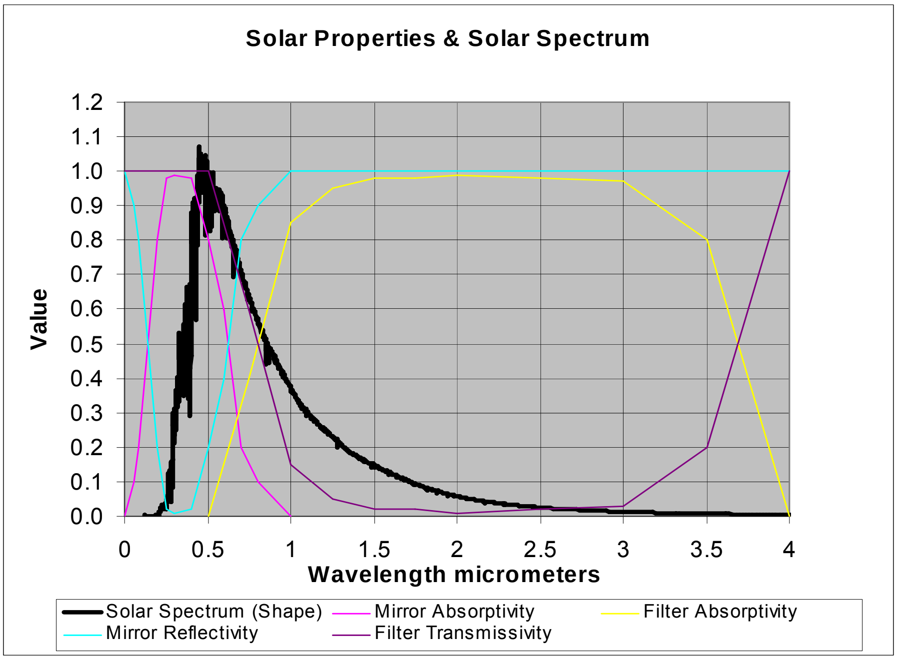
Cryogenic Optics with Radiative Heating



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Cryogenic Optics with Radiative Heating

Case	Solar Bands	Solar Load on Lens (W)	Solar Load on Mirror (W)	Solar Load on Sample (W)	Heat Flow into Cryocooler (W)
Gray	1	1.29	0.515	0.915	0.958
3 bands	2	1.47	0.404	0.860	0.903
4 bands	3	1.24	0.698	0.780	0.823
5 bands	4	1.29	0.788	0.639	0.683
9 bands	8	1.32	0.748	0.650	0.693
17 bands	16	1.30	0.854	0.570	0.613
33 bands	32	1.29	0.872	0.559	0.603

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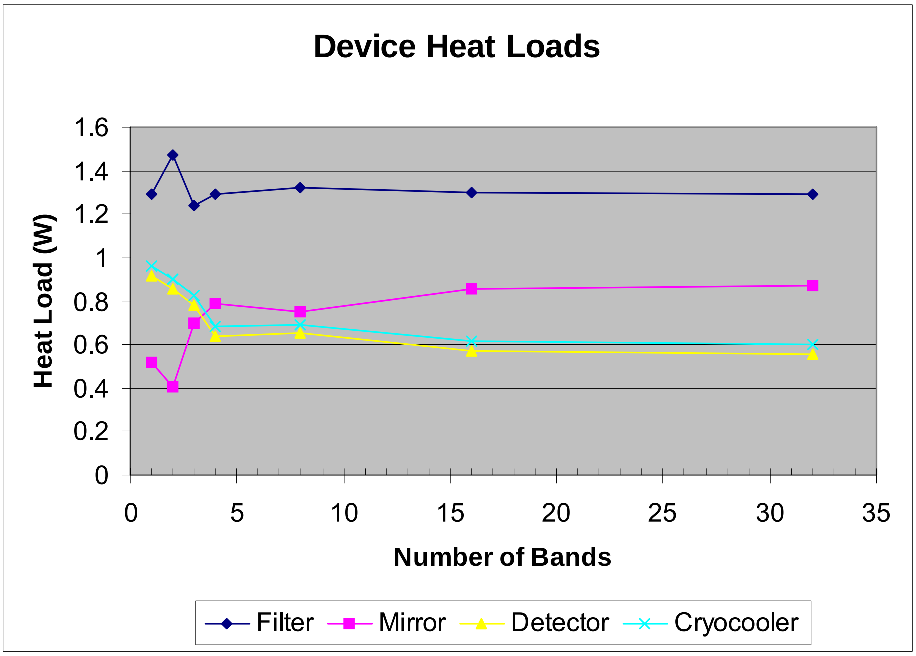
Cryogenic Optics with Radiative Heating



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Parallelization

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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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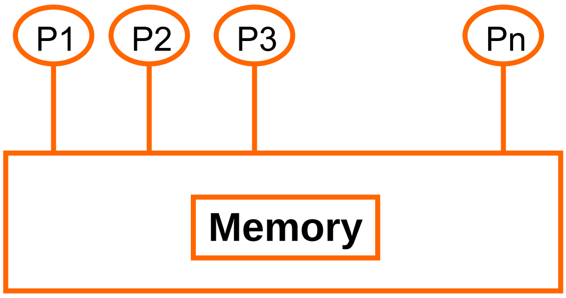
Parallel Computing

Shared Memory Parallelization

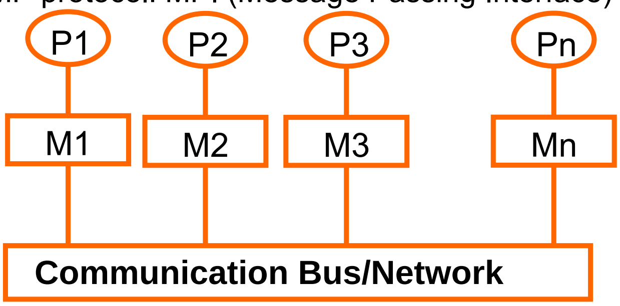
- Same memory usage as the serial run
- Multiple processes use the same memory and I/O
  - Synchronization of tasks is the key for implementation
  - Deadlocks and memory overwrites must be avoided!
- Scalability is determined by the hardware
- Popular Open SMP protocol: OpenMP



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)



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

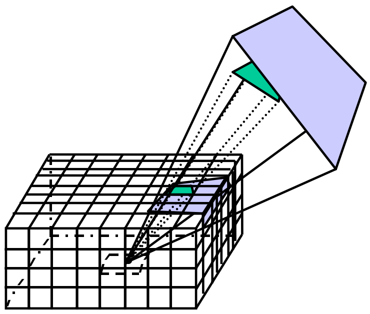
DMP Parallelization of the Hemicube Method

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

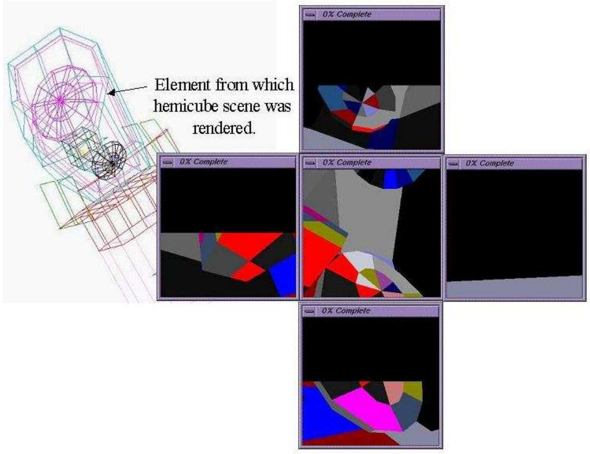
- variant of the Nusselt sphere method
- each face of the cube is divided into pixels: each pixel has a known view factor contribution
- hemicube is centered on a receiver element and the image of surrounding “emitter” elements are projected onto the hemicube
- view factors are tallied through pixel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



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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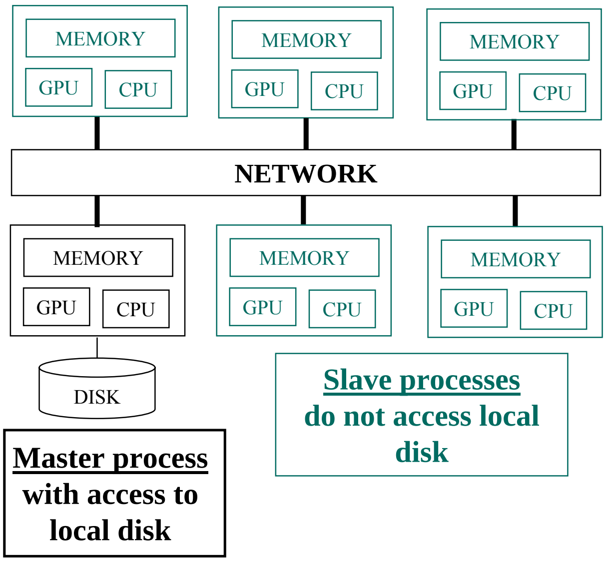
DMP Parallelization of the Hemicube Method

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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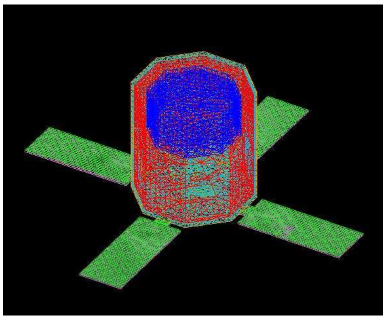
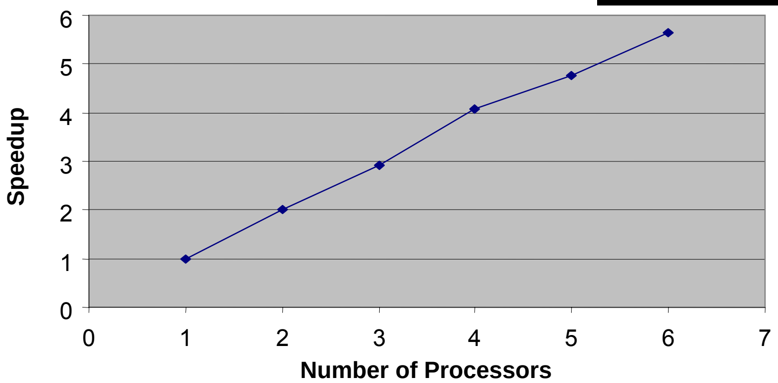
DMP Parallelization of the Hemicube Method

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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Parallelization of the View Factor Module

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

VUFAC module

- Contour integral method
- Shadowed View Factors using element subdivision
- Orbit Calculations
- Radiative Heat Loads
- Ray Tracing: deterministic and Monte-Carlo
- Thermal Coupling Calculations

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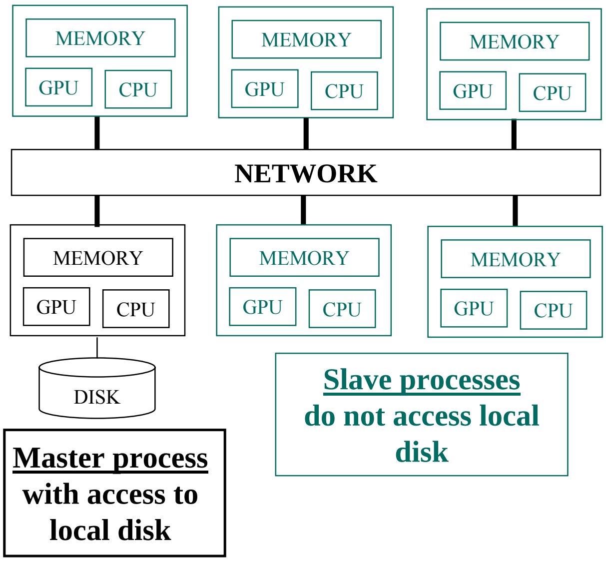
DMP Parallelization of the VUFAC Module

Vufac Parallel Architecture

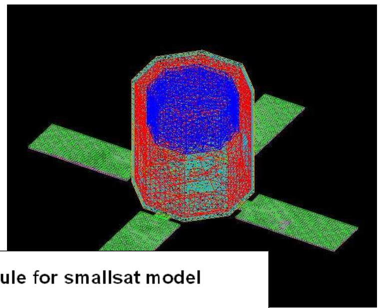
- Master/Slave system
- Master:
  - Performs all I/O
  - Sends model to slaves
  - Instructs slaves which VFs to compute
  - Receives VFs from slaves and writes results to single file
  - Computes some VFs when it has time
- Slave
  - Receives model, instructions
  - Computes VF's
  - Sends VF's to Master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

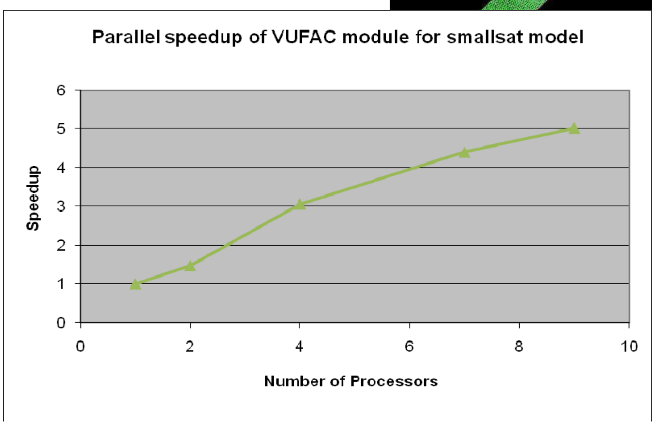


DMP Parallelization of the VUFAC Module

Finely meshed satellite model

- 21,058 shell elements
- 4.04×10^6 view factors
- 27.8 minutes on 1 core (Intel Quad running Linux)
- 5.5 minutes on 9 cores (3 Intel Quads running Linux)





DMP Parallelization of View Factor Calculations

- Technology already commercialized !
  - **NX Advanced Thermal**
  - **NX Space Systems Thermal**
- Requires installation of MPI on all machines
  - MPICH2 is open source library
- Only a single installation of NX Thermal is necessary
- Parallelization of solver is in progress

"What took about 7 days of CPU time on the single CPU system only took 2 days when running 4 processors (on two machines)...I almost cried."

User from NASA GSFC

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Thank you

Appendix E

The ESATAN Thermal Suite

Chris Kirtley
(ALSTOM, United Kingdom)

Abstract

Overview of the status of the ESATAN Thermal Suite including user support and development plans.

Thermal & ECLS Software Workshop

ESATAN Thermal Modelling Suite

Author: Chris Kirtley
Date: 28th Oct 2008

POWER SYSTEMS
Aerospace

ALSTOM

Introduction

- Product Development
  - Development framework
  - Overview of development history
  - Key milestones & developments
- Our Vision & how we are getting there
- Current product suite
  - Announce the forthcoming release
  - Overview of the product

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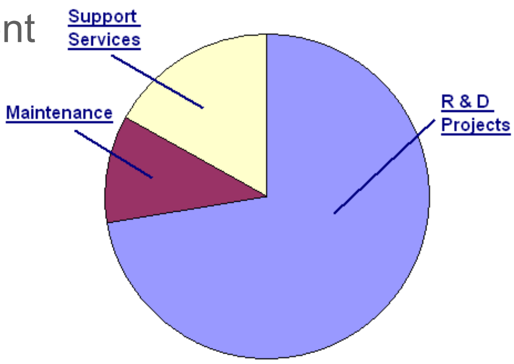
POWER SYSTEMS ALSTOM

Our Commitment to the Space Community

- Continue to invest in the products
- Year after year we invest heavily in R & D activities
  - New functionality
  - Algorithm/Solver development
  - User interface development



2008/2009 Development Breakdown

ESA Thermal & ECLS Software Workshop 2008, 28-29 Oct 2008 - P 3/25

POWER SYSTEMS ALSTOM

Our Commitment to the Space Community

….but it's not just R & D,

- Invest in the maintenance of the tools & infrastructure
  - Support multi-platforms / test infrastructure
  - Porting to new platforms / operating systems
  - Bug fixing & minor enhancements
  - Invest in the architecture of the software
    - Performance & scalability

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POWER SYSTEMS ALSTOM

Our Commitment to the Space Community

….but it's not just R & D and maintenance,

- We consider support a vital part of the business
- Provision of high-quality user support infrastructure
  - Web and e-mail support interface
  - Support engineers work closely with the developers
- Work closely with customers
  - Talking to you and visiting your sites
  - Bringing requirements to the project team
- Strong team at this workshop

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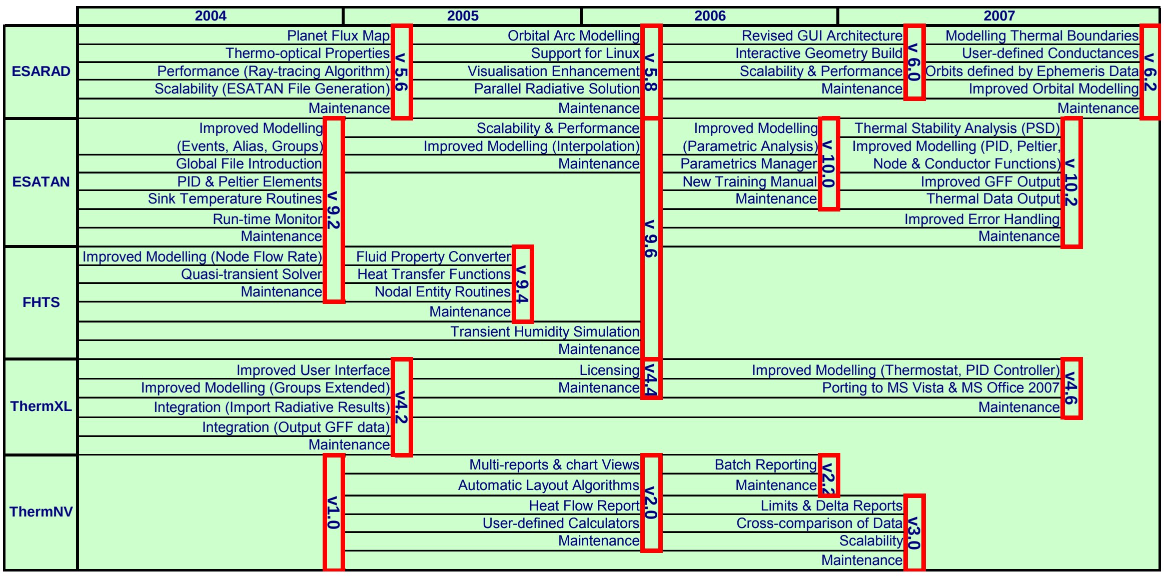
POWER SYSTEMS ALSTOM

Product Development History

Product Releases 2004 - 2007



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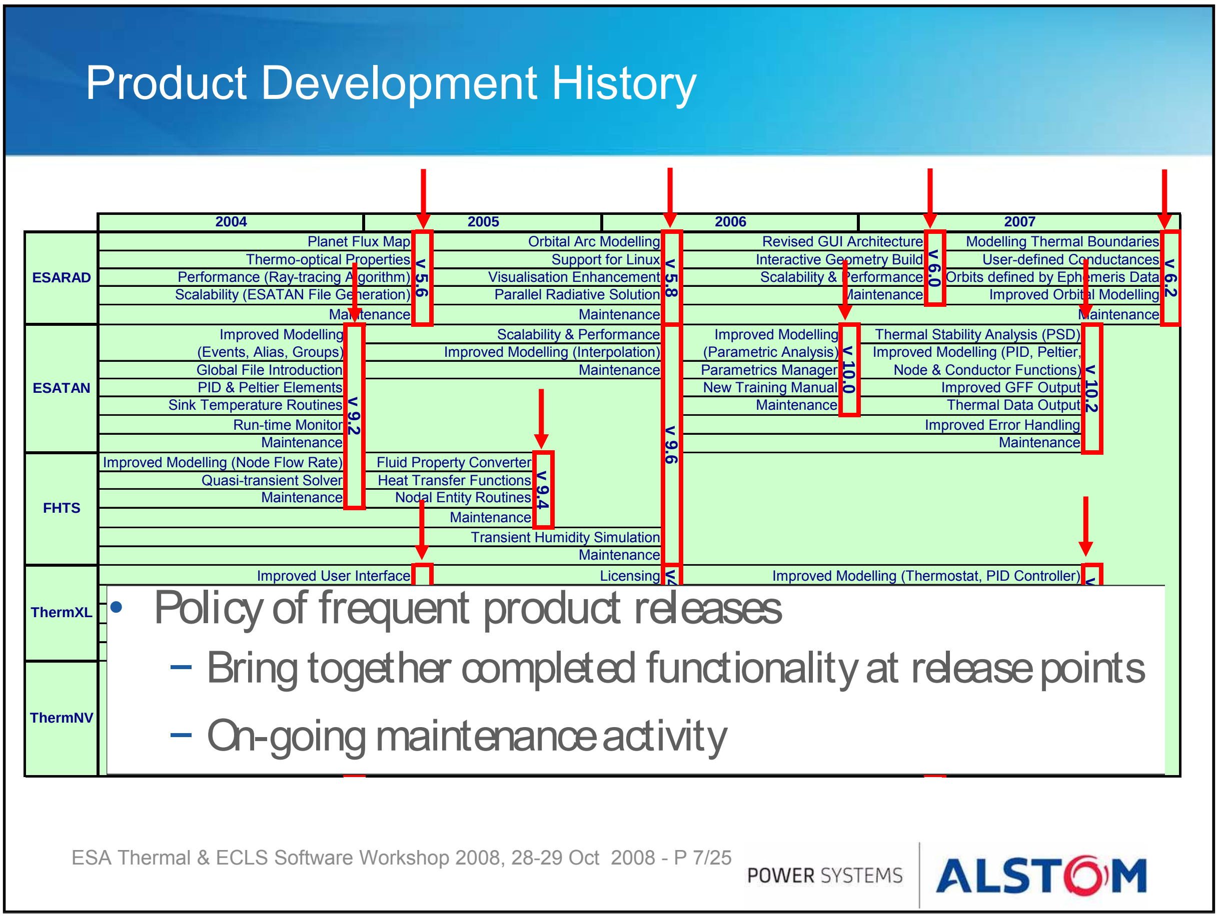
POWER SYSTEMS ALSTOM


Product Development History
2004
2005
2006
2007
ESARAD
ESATAN
FHTS
ThermXL
ThermNV
Planet Flux Map
Thermo-optical Properties
Performance (Ray-tracing Algorithm)
Scalability (ESATAN File Generation)
Maintenance
Orbital Arc Modelling
Support for Linux
Visualisation Enhancement
Parallel Radiative Solution
Revised GUI Architecture
Interactive Geometry Build
Scalability & Performance
Modelling Thermal Boundaries
User-defined Conductances
Orbits defined by Ephemeris Data
Improved Orbital Modelling
Improved Modelling
(Events, Alias, Groups)
Global File Introduction
PID & Peltier Elements
Sink Temperature Routines
Run-time Monitor
Improved Modelling (Interpolation)
(Parametric Analysis)
Parametrics Manager
New Training Manual
Thermal Stability Analysis (PSD)
Improved Modelling (PID, Peltier,
Node & Conductor Functions)
Improved GFF Output
Thermal Data Output
Improved Error Handling
Improved Modelling (Node Flow Rate)
Quasi-transient Solver
Fluid Property Converter
Heat Transfer Functions
Nodal Entity Routines
Transient Humidity Simulation
Improved User Interface
Licensing
Improved Modelling (Thermostat, PID Controller)
v 5.6
v 5.8
v 6.0
v 6.2
v 9.2
v 9.6
v 9.4
v 10.0
v 10.2
• Policy of frequent product releases
– Bring together completed functionality at release points
– On-going maintenance activity
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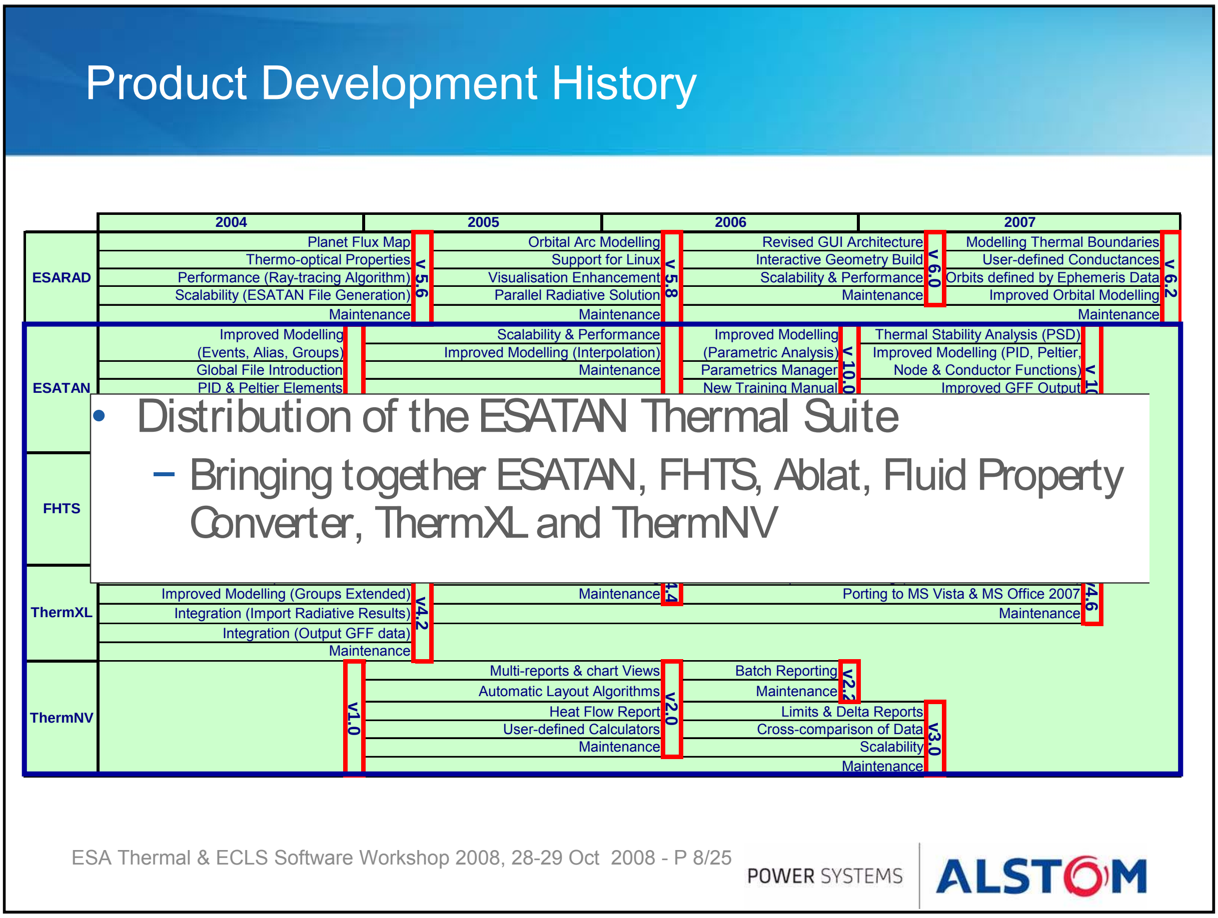
Product Development History
2004
2005
2006
2007
ESARAD
ESATAN
FHTS
ThermXL
ThermNV
Planet Flux Map
Thermo-optical Properties
Performance (Ray-tracing Algorithm)
Scalability (ESATAN File Generation)
Maintenance
Orbital Arc Modelling
Support for Linux
Visualisation Enhancement
Parallel Radiative Solution
Revised GUI Architecture
Interactive Geometry Build
Scalability & Performance
Modelling Thermal Boundaries
User-defined Conductances
Orbits defined by Ephemeris Data
Improved Orbital Modelling
• Distribution of the ESATAN Thermal Suite
– Bringing together ESATAN, FHTS, Ablat, Fluid Property Converter, ThermXL and ThermNV
Improved Modelling (Groups Extended)
Integration (Import Radiative Results)
Integration (Output GFF data)
Porting to MS Vista & MS Office 2007
Multi-reports & chart Views
Automatic Layout Algorithms
Heat Flow Report
User-defined Calculators
Batch Reporting
Limits & Delta Reports
Cross-comparison of Data
Scalability
v4.2
v4.6
v1.0
v2.0
v2.2
v3.0
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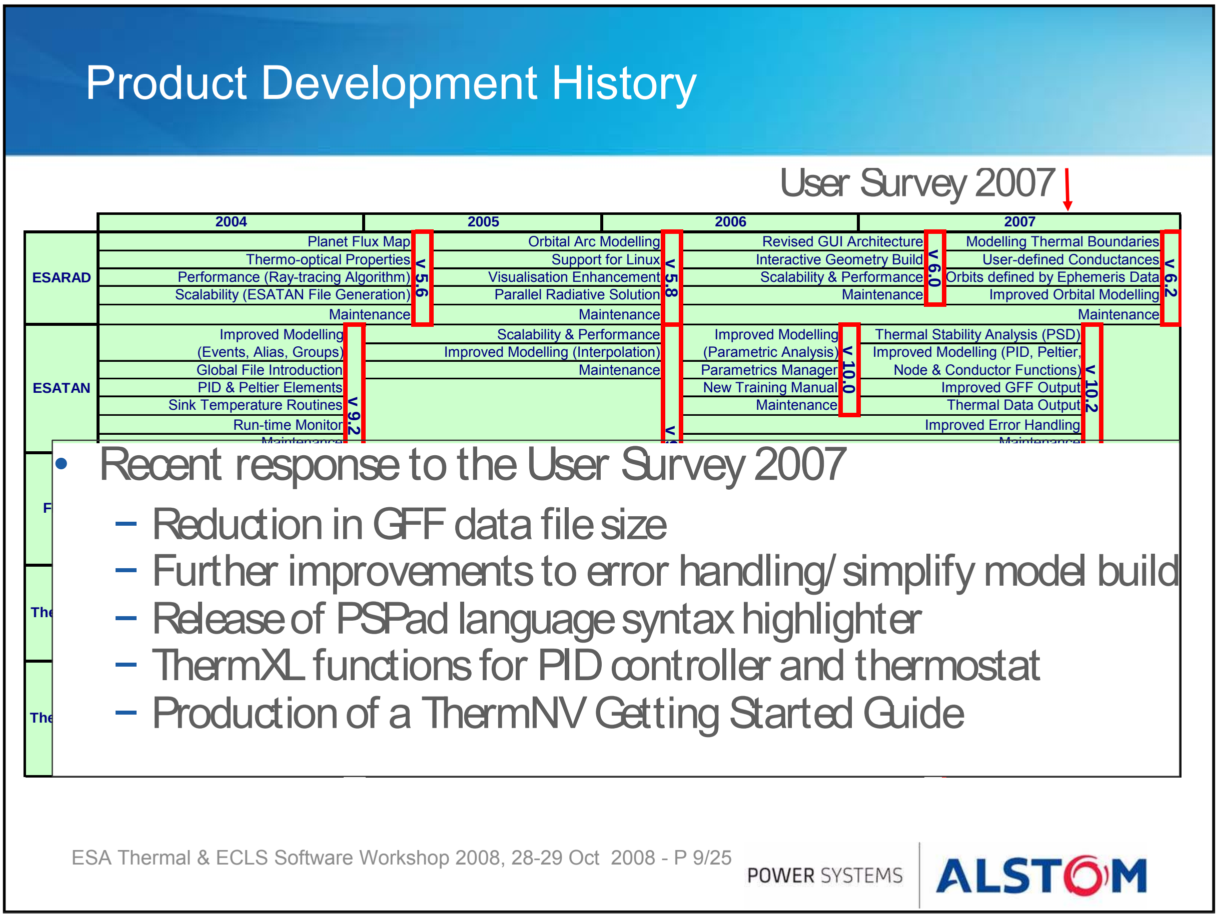
Product Development History
User Survey 2007
2004
2005
2006
2007
ESARAD
Planet Flux Map
Thermo-optical Properties
Performance (Ray-tracing Algorithm)
Scalability (ESATAN File Generation)
Maintenance
V5.6
Orbital Arc Modelling
Support for Linux
Visualisation Enhancement
Parallel Radiative Solution
Maintenance
V5.8
Revised GUI Architecture
Interactive Geometry Build
Scalability & Performance
Maintenance
V6.0
Modelling Thermal Boundaries
User-defined Conductances
Orbits defined by Ephemeris Data
Improved Orbital Modelling
Maintenance
V6.2
ESATAN
Improved Modelling
(Events, Alias, Groups)
Global File Introduction
PID & Peltier Elements
Sink Temperature Routines
Run-time Monitor
V9.2
Scalability & Performance
Improved Modelling (Interpolation)
Maintenance
Improved Modelling
(Parametric Analysis)
Parametrics Manager
New Training Manual
Maintenance
V10.0
Thermal Stability Analysis (PSD)
Improved Modelling (PID, Peltier,
Node & Conductor Functions)
Improved GFF Output
Thermal Data Output
Improved Error Handling
V10.2
• Recent response to the User Survey 2007
– Reduction in GFF data file size
– Further improvements to error handling/ simplify model build
– Release of PSPad language syntax highlighter
– ThermXL functions for PID controller and thermostat
– Production of a ThermNV Getting Started Guide
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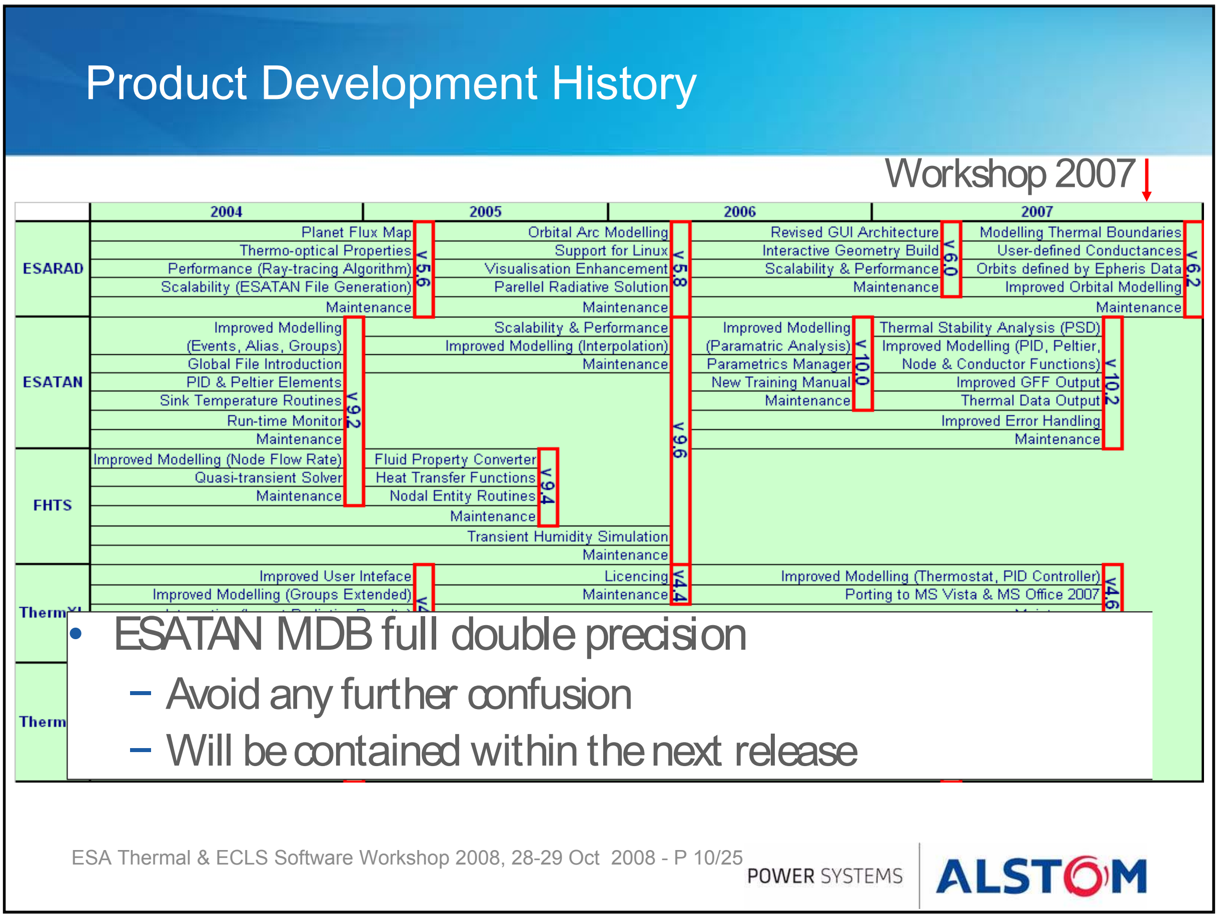
Product Development History
Workshop 2007
2004
2005
2006
2007
ESARAD
Planet Flux Map
Thermo-optical Properties
Performance (Ray-tracing Algorithm)
Scalability (ESATAN File Generation)
Maintenance
V5.6
Orbital Arc Modelling
Support for Linux
Visualisation Enhancement
Parellel Radiative Solution
Maintenance
V5.8
Revised GUI Architecture
Interactive Geometry Build
Scalability & Performance
Maintenance
V6.0
Modelling Thermal Boundaries
User-defined Conductances
Orbits defined by Epheris Data
Improved Orbital Modelling
Maintenance
V6.2
ESATAN
Improved Modelling
(Events, Alias, Groups)
Global File Introduction
PID & Peltier Elements
Sink Temperature Routines
Run-time Monitor
Maintenance
V9.2
Scalability & Performance
Improved Modelling (Interpolation)
Maintenance
V9.6
Improved Modelling
(Paramatric Analysis)
Parametrics Manager
New Training Manual
Maintenance
V10.0
Thermal Stability Analysis (PSD)
Improved Modelling (PID, Peltier,
Node & Conductor Functions)
Improved GFF Output
Thermal Data Output
Improved Error Handling
Maintenance
V10.2
FHTS
Improved Modelling (Node Flow Rate)
Quasi-transient Solver
Maintenance
Fluid Property Converter
Heat Transfer Functions
Nodal Entity Routines
Maintenance
V9.4
Transient Humidity Simulation
Maintenance
ThermXL
Improved User Inteface
Improved Modelling (Groups Extended)
Licencing
Maintenance
V4.4
Improved Modelling (Thermostat, PID Controller)
Porting to MS Vista & MS Office 2007
V4.6
Therm
• ESATAN MDB full double precision
– Avoid any further confusion
– Will be contained within the next release
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Product Development History

- Recent focus of development has been on integration
  - Extending support for the thermal definition of the model
    - Non-geometric nodes
    - User-defined conductors
    - Thermal boundary conditions
  - Enhancing the product as a thermal analysis environment
  - Developments moving the products closer together

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Product Development History

- Our business is thermal software development,
  - Committed to investing in R & D of the products
  - Committed to the continual maintenance of the products
  - Making regular releases
    - Functionality available to users in timely fashion
  - ISO 9000 TickIT accredited
    - regularly assessed by external auditors
- Our development history demonstrates this commitment

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Product Vision

Our vision,

- Provide a complete and efficient thermal modelling environment
  - Functionality to meet the current modelling needs of projects
  - High-quality, fully validated products
- Efficient end-to-end integration within multi-disciplinary engineering environment
- Backing this up with professional customer support services

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Product Vision

To achieve the vision,

- Integration of our products
  - Recent developments have moved the products closer
    - We recognise that the process is not a one shot process
    - Bringing the products closer makes iterations more efficient
  - Efficient environment/less error prone/avoid learning multiple interfaces

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Product Vision

- Move the modelling to a higher level
  - but retaining the text model representation
  - retain the flexibility of the tools
  - retain the power of the batch processes
  - Retain compatibility
- Integration with other processes
  - Integration with CAD/FEM continues to be a key driver
  - Our CAD Converter is already in use and well received

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Product Vision

- Supporting CAD/FEM puts requirements on the product infrastructure
  - Significant architectural work completed in support of envisaged process
    - Performance & scalability requirements
    - Enhanced geometry modelling
    - We have now moved the result data store to HDF (compressed binary format)

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Product Vision

- Maintain customer confidence
  - Continue to provide high-quality, validated products
  - Provide effective customer support services
    - On-line reporting system, visiting customers
    - Attending workshops & conferences
    - Provide formal training courses
  - Responsive to customers needs
    - Continual assessment and prioritisation of user requests
    - As shown, releasing functionality in a timely manner

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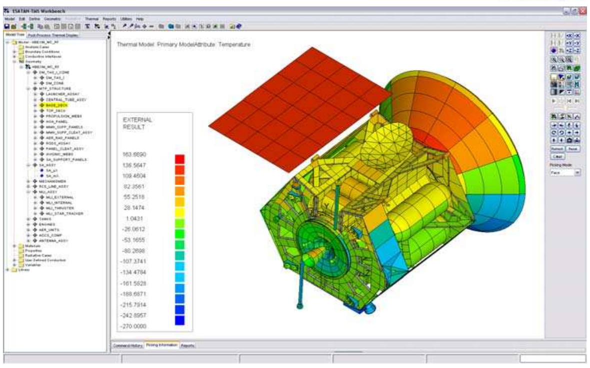
What Next?

ESATAN Thermal Modelling Suite now in beta test phase

ESATAN-TMS Thermal Modelling Suite



Model courtesy of Thales Alenia Space & OHB Systems

- Brings together ESARAD & the ESATAN Thermal Suite
- Logical progression of ESARAD
- Full interface to ESATAN
- Replaces the PC ESATAN interface

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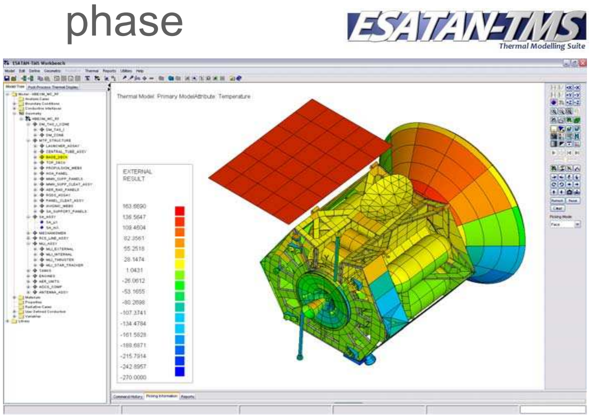
What Next?

ESATAN Thermal Modelling Suite now in beta test phase



Model courtesy of Thales Alenia Space & OHB Systems

- Interface referred to as ESATAN-TMS Workbench
- All customers will receive the product
- Functionality available through the licence
- Full demonstrations will be given by Henri & Ian

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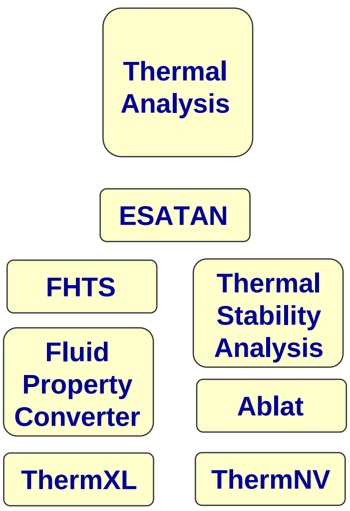
ESATAN Thermal Modelling Suite

How will this effect you?



ESATAN Thermal Suite

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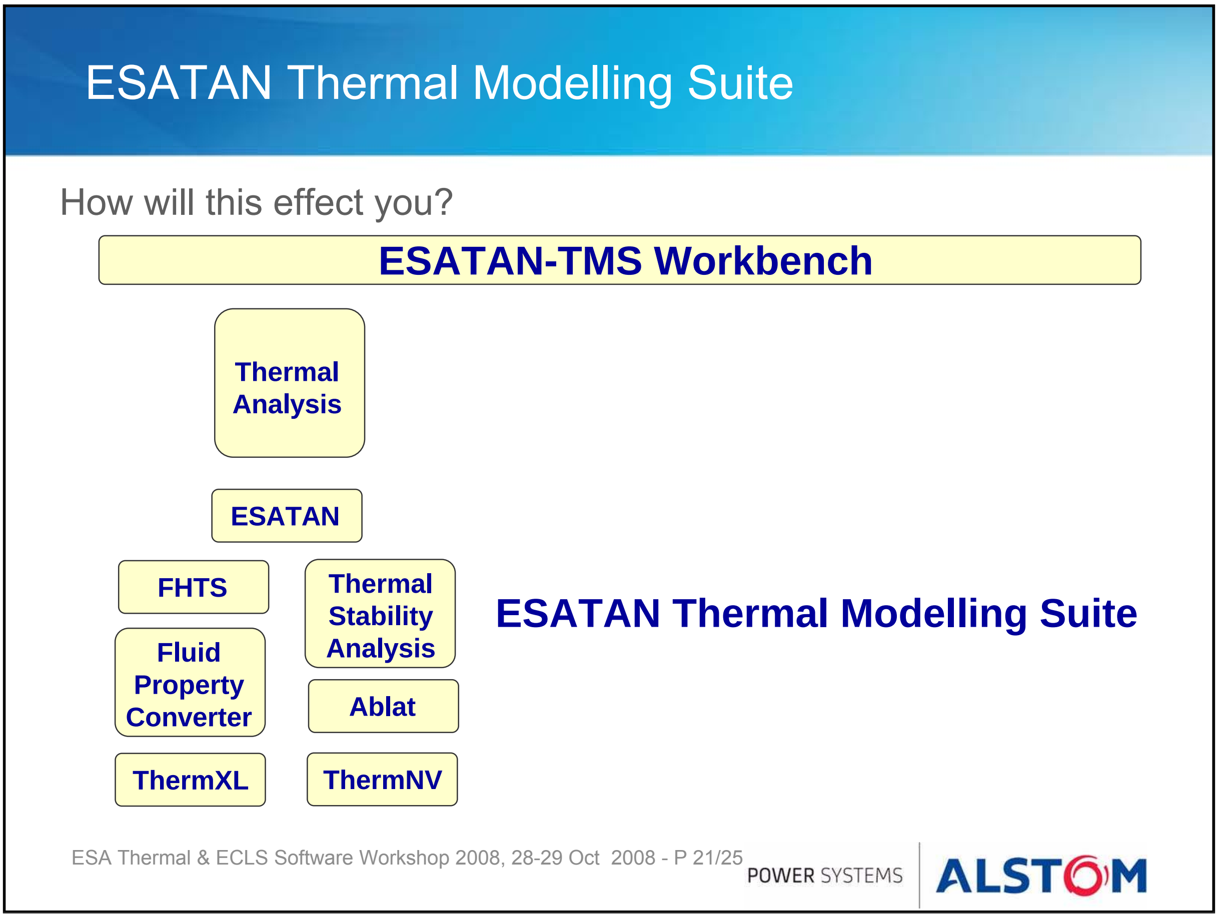
ESATAN Thermal Modelling Suite
How will this effect you?
ESATAN-TMS Workbench
Thermal Analysis
ESATAN
FHTS
Thermal Stability Analysis
Fluid Property Converter
Ablat
ThermXL
ThermNV
ESATAN Thermal Modelling Suite
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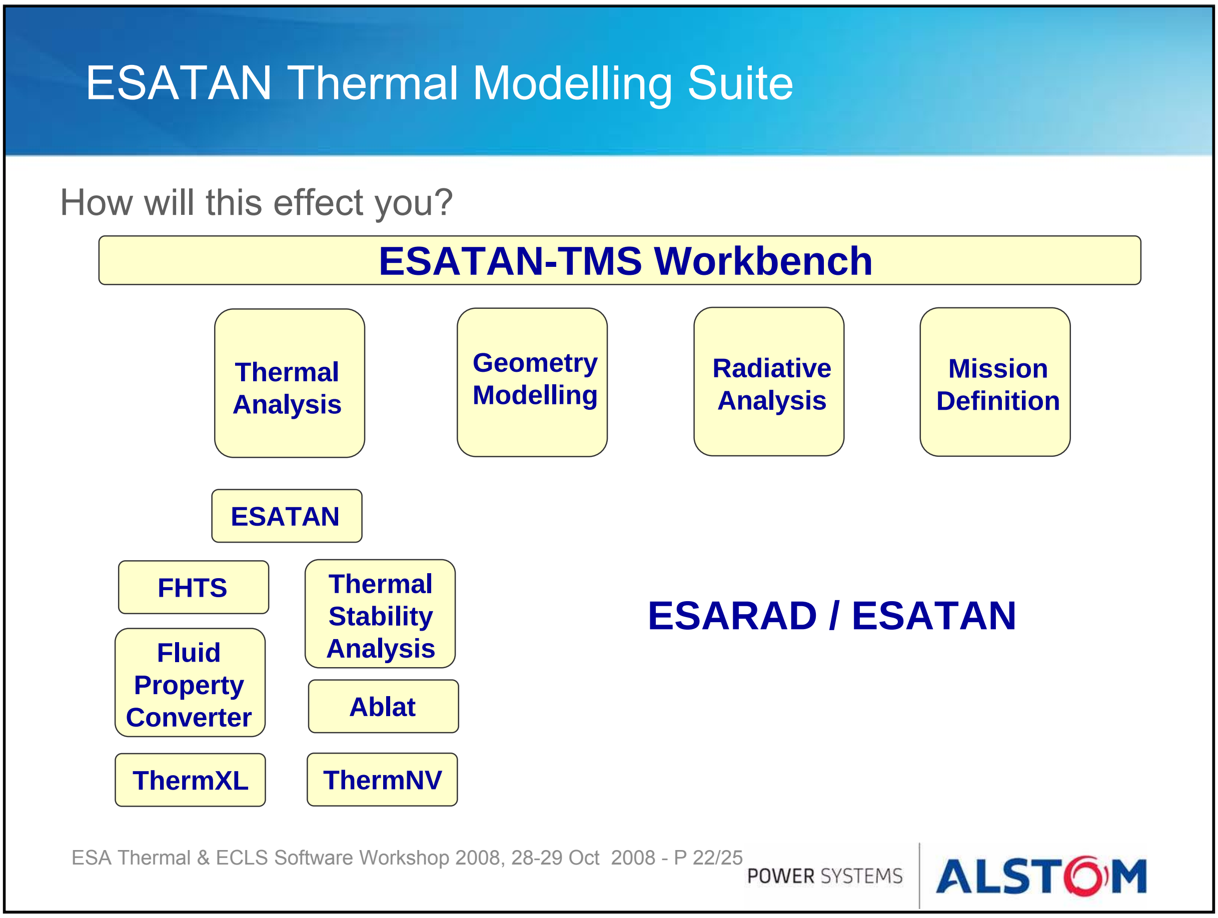
ESATAN Thermal Modelling Suite
How will this effect you?
ESATAN-TMS Workbench
Thermal Analysis
Geometry Modelling
Radiative Analysis
Mission Definition
ESATAN
FHTS
Thermal Stability Analysis
Fluid Property Converter
Ablat
ThermXL
ThermNV
ESARAD / ESATAN
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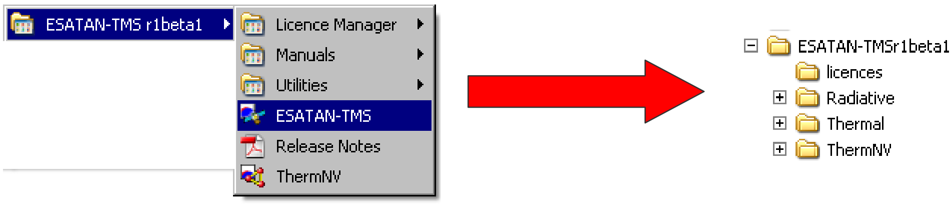
ESATAN Thermal Modelling Suite

- One product, one installer
  - Simplify installation, rationalise common components
  - On Windows,



  - The same structure on Unix/Linux

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Conclusion

- Committed to continued investment in the products
- Announce release of ESATAN Thermal Modelling Suite
- Why ESATAN-TMS
  - Logical development step, not a surprise
  - Product developments coming together
  - Fits with our vision of integration of the products/processes
  - Clearer product definition for our customers
  - Common interface (Workbench)

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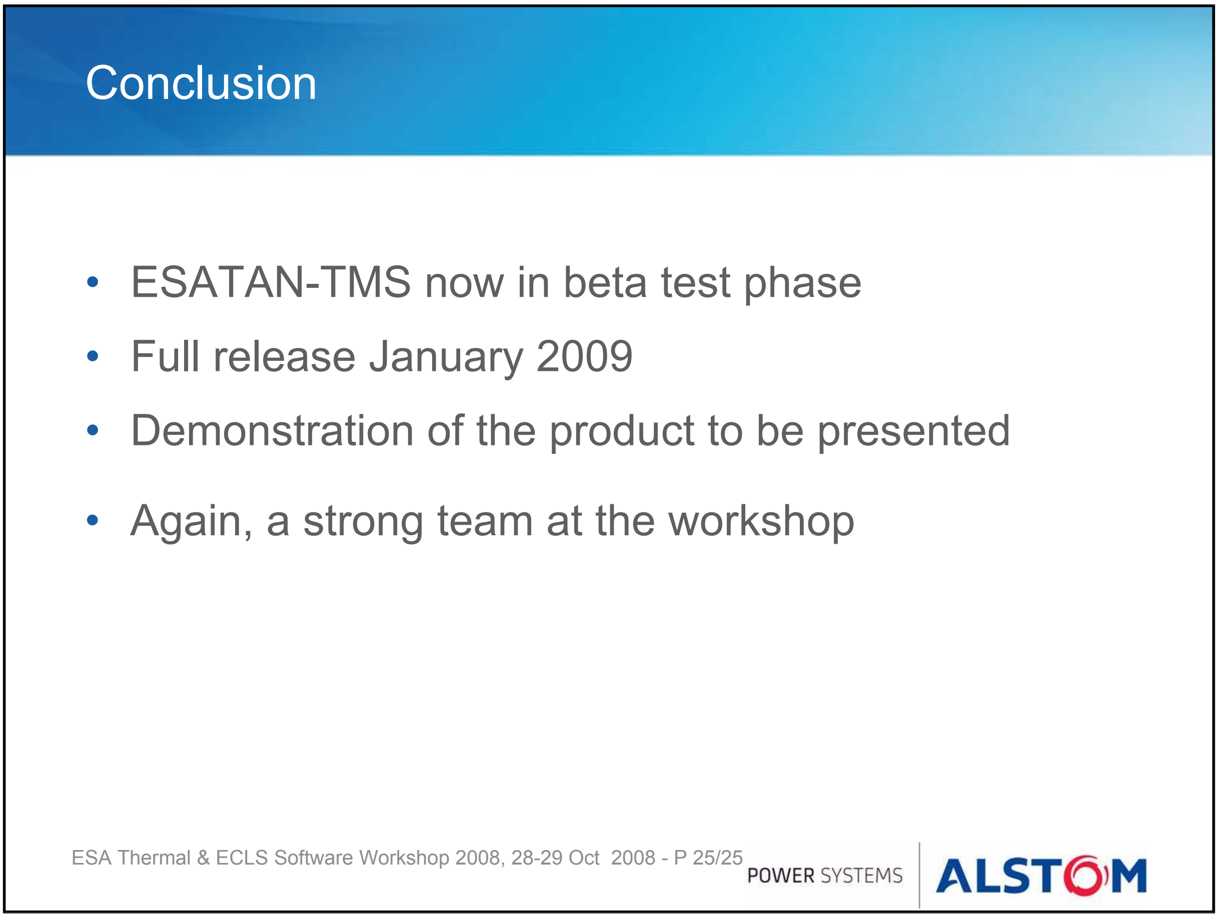
Conclusion
• ESATAN-TMS now in beta test phase
• Full release January 2009
• Demonstration of the product to be presented
• Again, a strong team at the workshop
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www.esatan-tms.com
Support@esatan-tms.com
ALSTOM

Appendix F

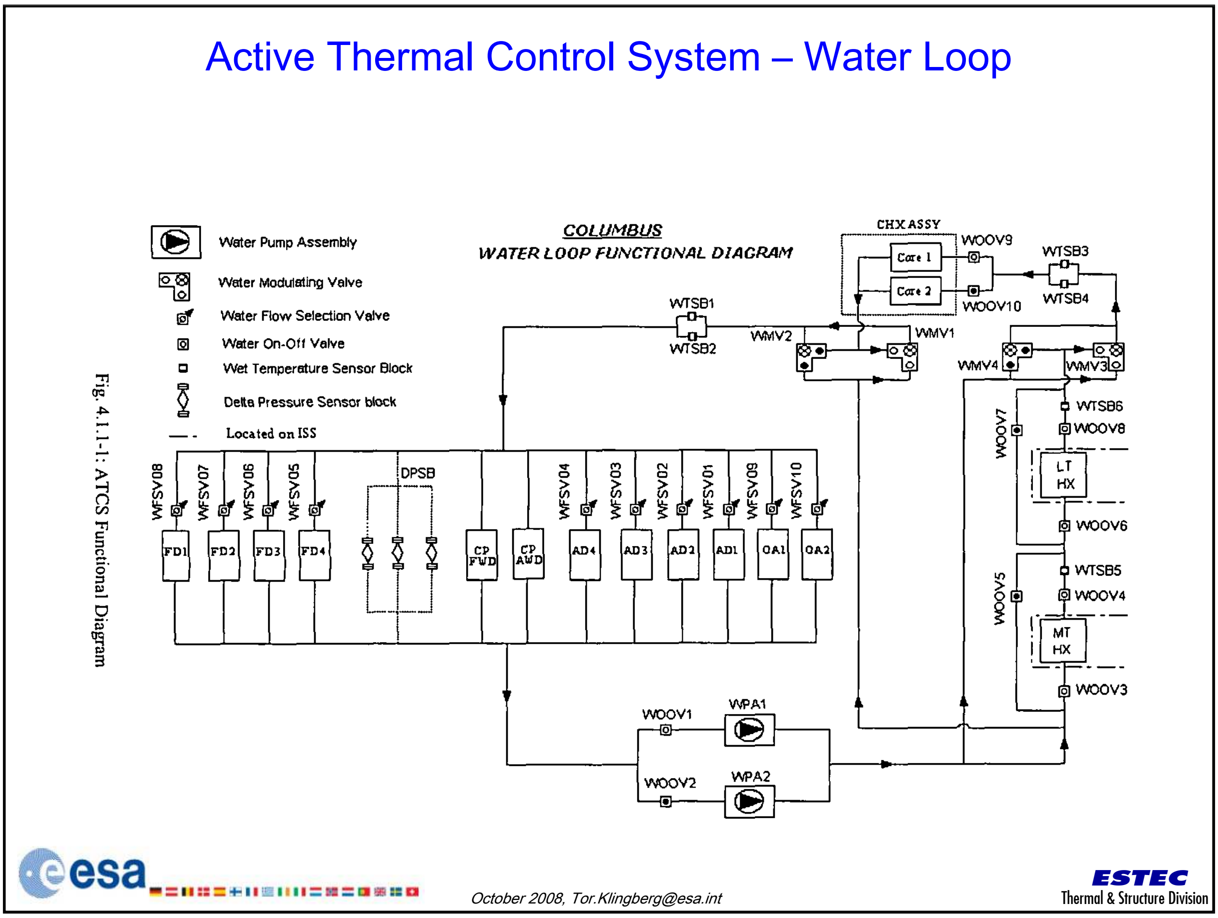
Stability Analysis in the Columbus Active Thermal Control System

Tor Klingberg
(ESA/ESTEC, The Netherlands)

Abstract

Using analytical control theory and ESATAN simulation to analyze the stability margin of the Columbus ATCS under different conditions.


Stability Analysis of the Columbus
Active Thermal Control System
Tor Klingberg


Active Thermal Control System – Water Loop
Water Pump Assembly
Water Modulating Valve
Water Flow Selection Valve
Water On-Off Valve
Wet Temperature Sensor Block
Delta Pressure Sensor block
Located on ISS
COLUMBUS
WATER LOOP FUNCTIONAL DIAGRAM
CHX ASSY
Core 1
Core 2
WOOV9
WOOV10
WTSB3
WTSB4
WTSB1
WTSB2
WMV2
WMV1
WMV4
WMV3
WTSB6
WOOV8
WOOV7
LT HX
WOOV6
WTSB5
WOOV4
WOOV5
MT HX
WOOV3
WFSV08
WFSV07
WFSV06
WFSV05
DPSB
WFSV04
WFSV03
WFSV02
WFSV01
WFSV09
WFSV10
FD1
FD2
FD3
FD4
CP FWD
CP AWD
AD4
AD3
AD2
AD1
OA1
OA2
WOOV1
WPA1
WOOV2
WPA2
Fig. 4.1.1-1: ATCS Functional Diagram
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ESTEC
Thermal & Structure Division

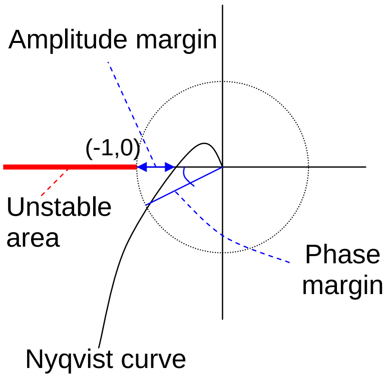
Verification

- The Columbus ATCS has been verified by simulation using ESATAN/FHTS and physical testing.
- However, no theoretical analysis of the stability has been performed.
- Using control theory, the stability of a (simplified) system can be verified analytically.
- This analysis can also show what control parameters are most stable.

Stability analysis

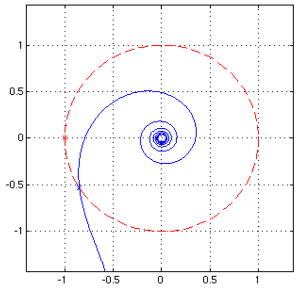
- Make a simplified model of the system
- Mathematical description of relations between variables
- Linear transfer function description
- Calculate stability and stability margin using Nyquist criterion.

Stability criterions



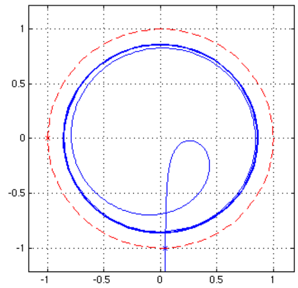
- Amplitude margin: Distance between where the Nyqvist curve crosses the real axis and the point (-1,0).

  Problem: There may be several crossings.



- Phase margin: Angle between the real axis and where the Nyqvist curve crosses the unit circle.

  Problem: With a high derivative (D) control constant, the Nyqvist curve will go into a large circle. Not as stable as the phase margin indicates



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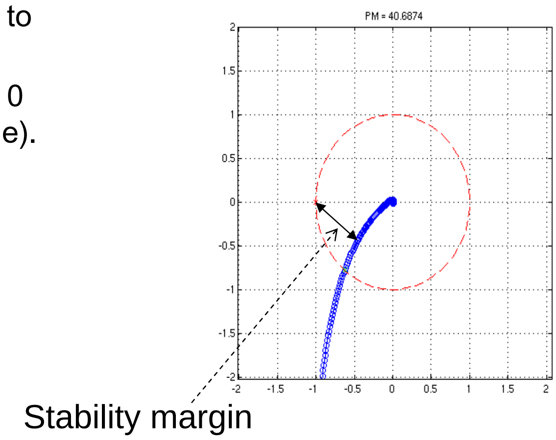
Stability criterions

- Instead, use the shortest distance between the Nyqvist curve and the point (-1,0) to measure stability margin.
- The value will range from 0 (unstable) to 1 (very stable).



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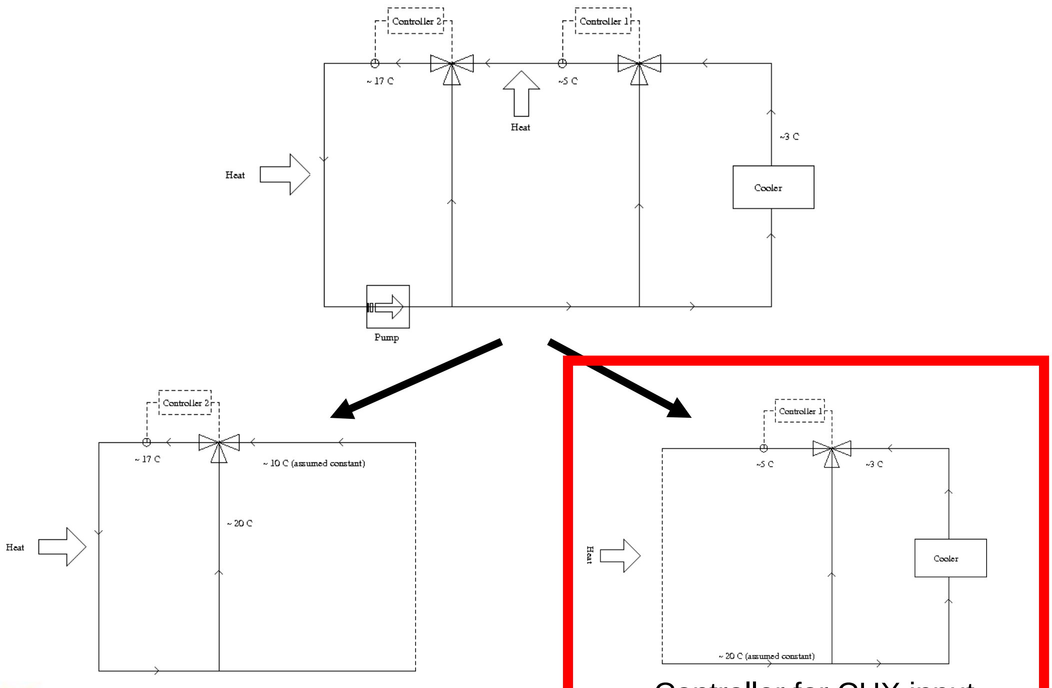
Separate into two parts



Controller for plenum input

Controller for CHX input

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Mathematical model

- Each of the two loops is described by a simplified mathematical model.
- A system of differential equations connecting valve position, hydraulic resistances, water flow rates and temperatures.

Hydraulic resistance:

$$K_{hx}(\alpha) = K_{hx}^{pipe} + K_{hx}^{valve}(\alpha)$$
$$K_{by}(\alpha) = K_{by}^{pipe} + K_{by}^{valve}(\alpha)$$

Water flow speed:

$$K_{hx}\dot{m}_{hx}^2 = K_{by}\dot{m}_{by}^2$$
$$\dot{m}_{hx} + \dot{m}_{by} = \dot{m}_0$$

Water mixing in valve:

$$\dot{m}_{hx}T_{LT}(t-\tau_{ltv}) + \dot{m}_{by}T_0(t-\tau_{iv}) = \dot{m}_0 T_{out}(t)$$

MT and LT heat exchangers:

$$M_{MT}\frac{dT_{MT}}{dt} + \dot{m}_{hx}T_{MT} = \varepsilon_{MT}\dot{m}_{hx}T_{NH_3MT} + (1-\varepsilon_{MT})\dot{m}_{hx}T_0$$
$$M_{LT}\frac{dT_{LT}}{dt} + \dot{m}_{hx}T_{LT} = \varepsilon_{LT}\dot{m}_{hx}T_{NH_3LT} + (1-\varepsilon_{LT})\dot{m}_{hx}T_{MT}$$

Temperature sensor:

$$\tau_s\frac{dT_s(t)}{dt} + T(t)_s = T_{LT}(t-\tau_{vs})$$

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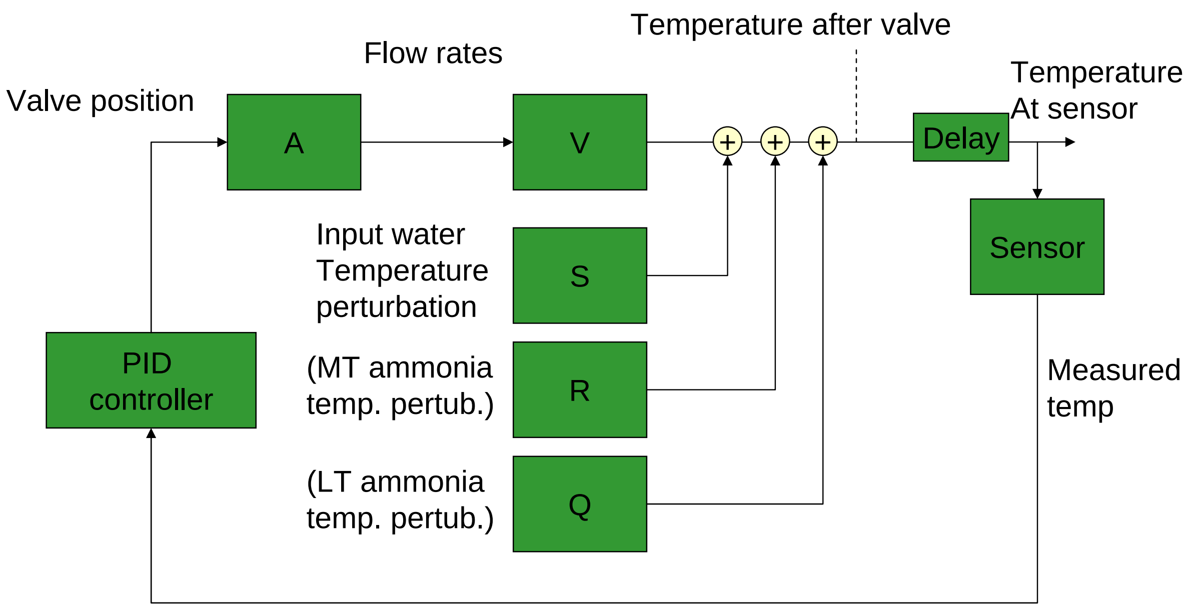
Linearization

- The differential equations are linearized around a working point and Laplace transformed into a system of transfer functions.
- Example: Heat exchanger temperature equation:

$$M\frac{dy}{dt} + \dot{m}y = \varepsilon\dot{m}u \quad \longrightarrow \quad Y(s) = \underbrace{\frac{\varepsilon\dot{m}}{Ms+\dot{m}}}_{G(s)} U(s)$$

System of transfer functions



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Implementation

- A program using MATLAB to vary the control parameters and analyze the system stability in each case, making a map of possible control parameters.
- Loop through various PID parameters and determine stability margin in each case.

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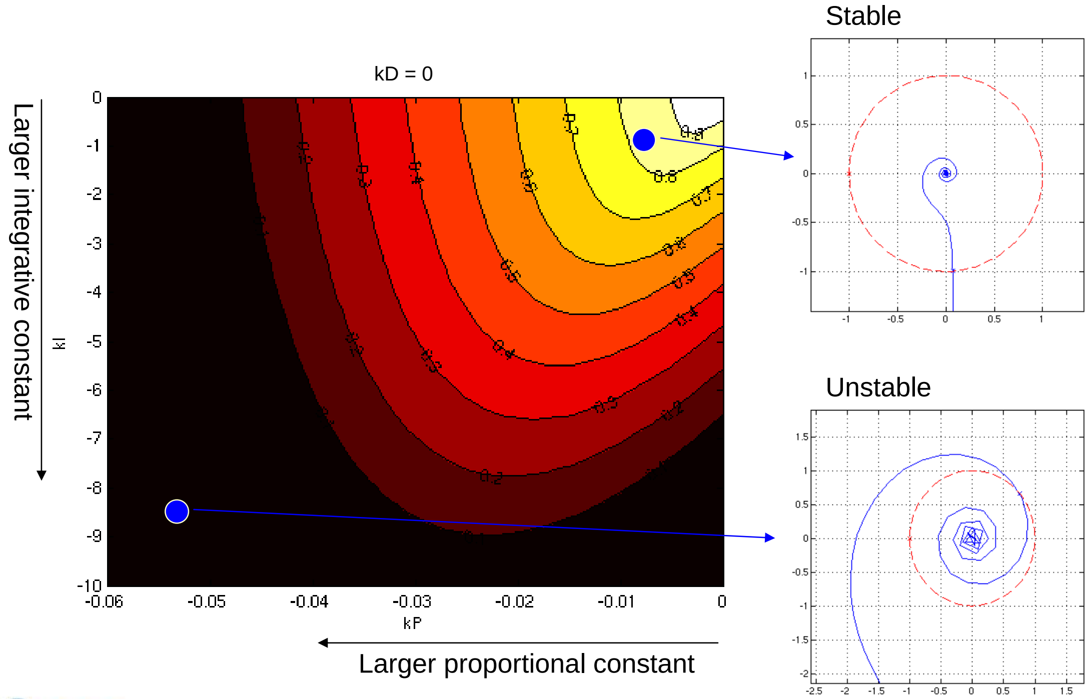
Example results



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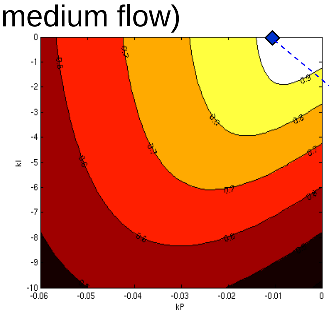
Test cases

- Payload racks flow rate: high/low
- Racks heat load: high/low
- Temperature set-point at 5 or 10 °C
- Most likely to be unstable: low flow – high load – high setpoint.

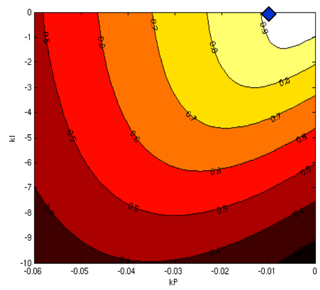
Results

Normal case (setpoint 5°C, medium flow)

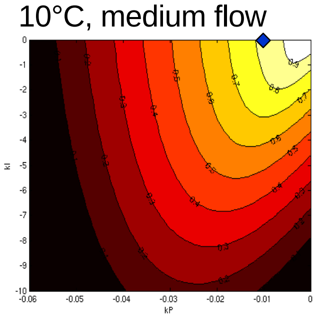


Current control parameters
kP = -0.011
kI = -0.00165
kD = 0

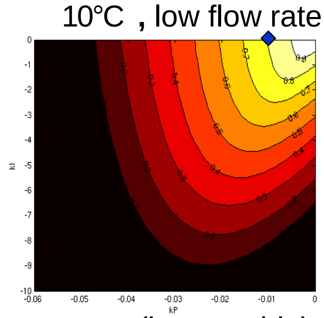
5°C, lower flow rate



10°C, medium flow



10°C , low flow rate



(least stable)

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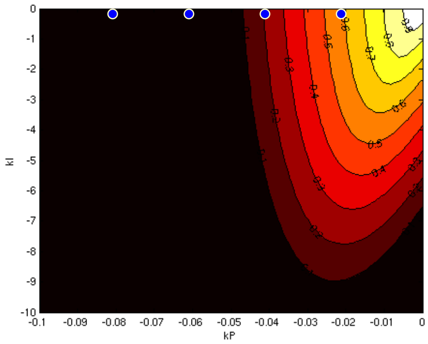
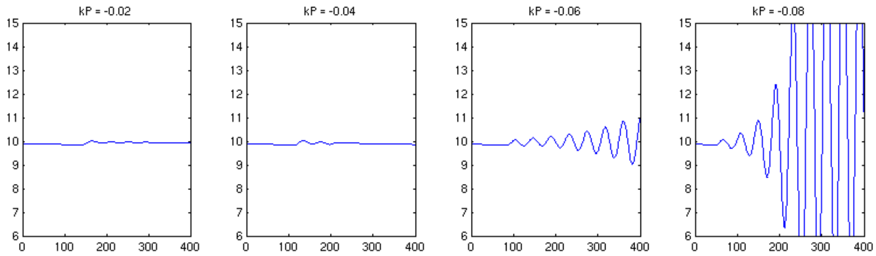
Comparison with simulation

MATLAB stability analysis result



ESATAN/FHTS transient simulation result



stable stable unstable unstable

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Comments

- To the first order, the system is very simple:
  - A delay between the valve and sensor
  - The slowness of the sensor
- A delay is problematic for regulation. It can lead to oscillations with frequency matching the delay time.

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Further work

- Analyse the plenum input temperature controller.
- Investigate interactions between the two systems using a 2x2 matrix of transfer functions.
- Add temperature disturbances
  - Sine wave and ramp

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Appendix G

THERMICA
On-going research and developments

Timothée Soriano
(EADS Astrium, France)

Abstract

SYSTEMA: The THERMICA framework
Since the version available last year (4.2.3), the current release offers new functionalities:

- New framework based on QT technology
- Boolean Shapes
- Multi-kinematics and sequences management
- Video recording

+ Presentation of some on-going developments for the next release.

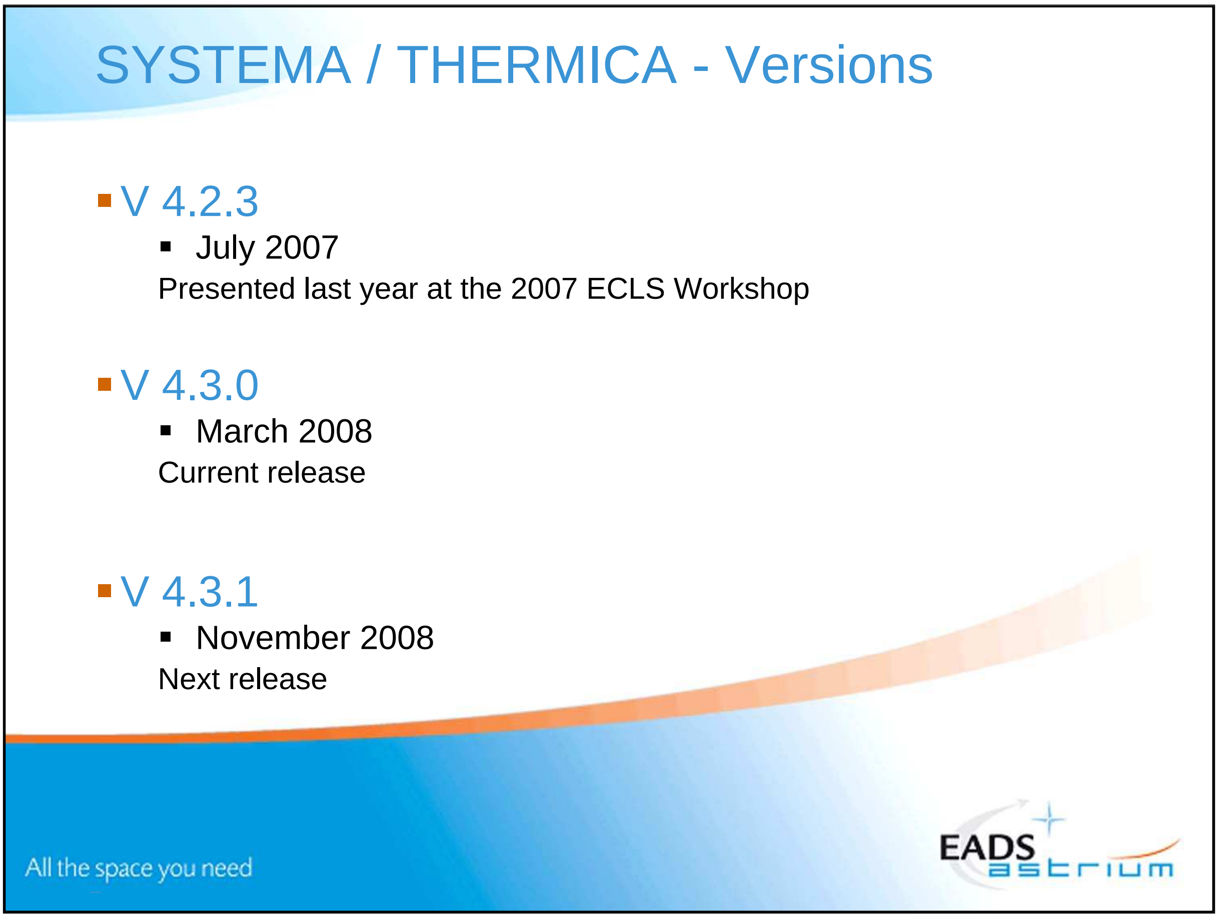
THERMICA 4.3.1

- Extended for the new SYSTEMA functionalities
- Integrate maps for planet properties and/or night/day temperatures definition for the IR flux
- Integrate the new conductive method: the RCN

  The Reduced Conductive Network is a new method compatible with the radiative mesh and can also be used for better convergence finite elements methods as well.
  The main idea of the RCN method is to determine a sub-space of linearly equivalent results and to find a particular solution from this sub-space. This solution provides some particular properties which make it compatible with radiative aspects and is given by the limit of a specific function.

+ Presentation of some on-going developments for the next release.


THERMICA
V4.3.1 Presentation
On-Going Researches & Developments
Demonstration
All the space you need
EADS
astrium


SYSTEMA / THERMICA - Versions
V 4.2.3
July 2007
Presented last year at the 2007 ECLS Workshop
V 4.3.0
March 2008
Current release
V 4.3.1
November 2008
Next release
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SYSTEMA v4.3.1 / 4.2.3

- Framework based on QT technology
  - **Intuitive**, **User Friendly** and **Ergonomic**
- Boolean shapes
  - Cutting operations **flexible** and **easy to handle**
- Multi-kinematics and sequences management
  - Helps creating **complex mission scenarios**
- Video recording for multimedia presentation
  - **Realistic rendering** with textures and display properties
  - **Smart camera** following satellites or planets

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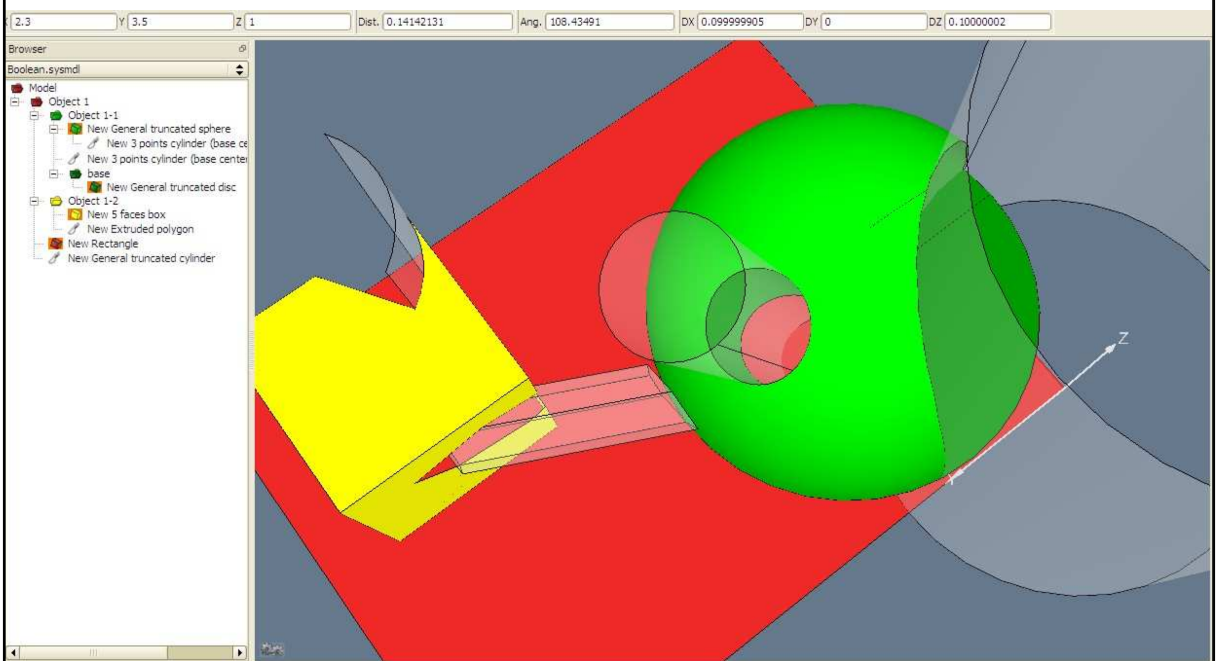
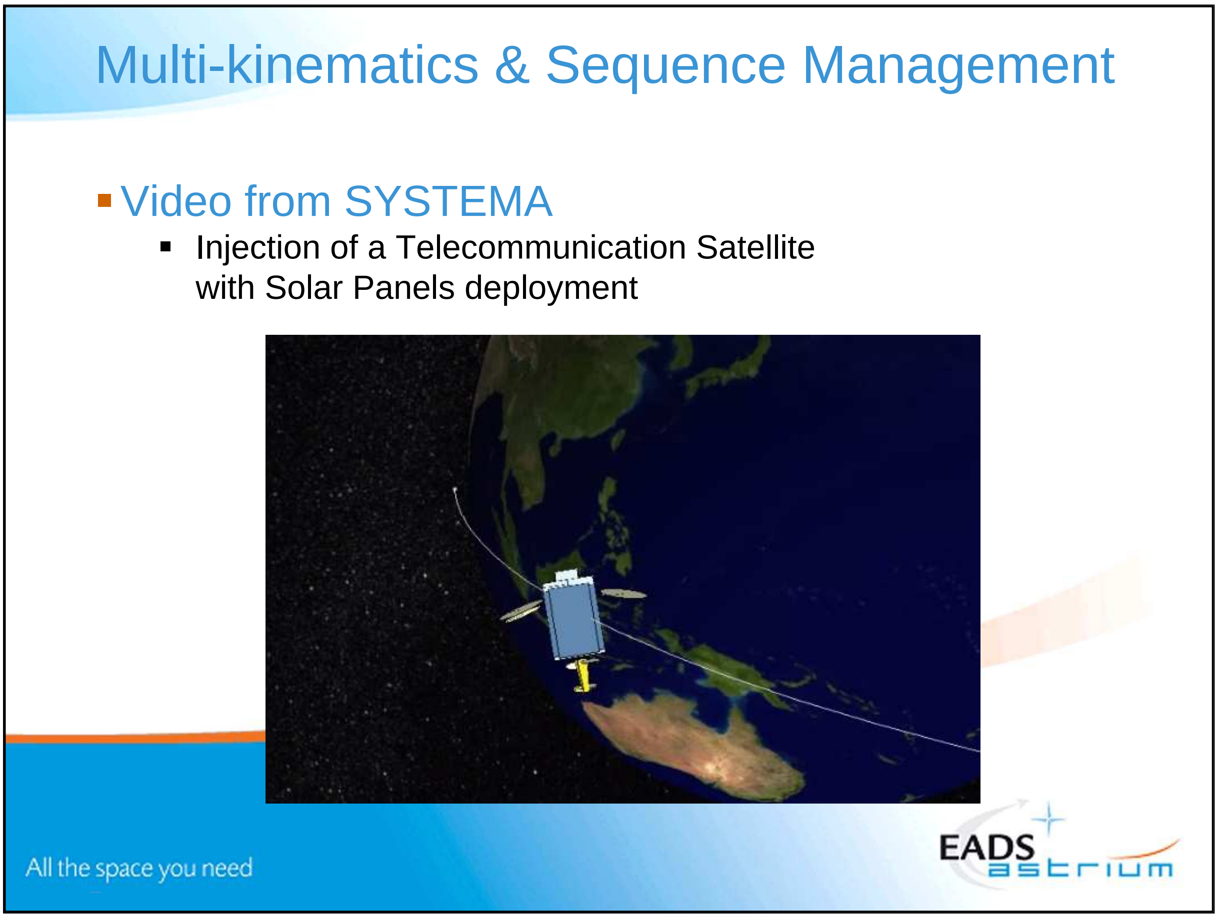
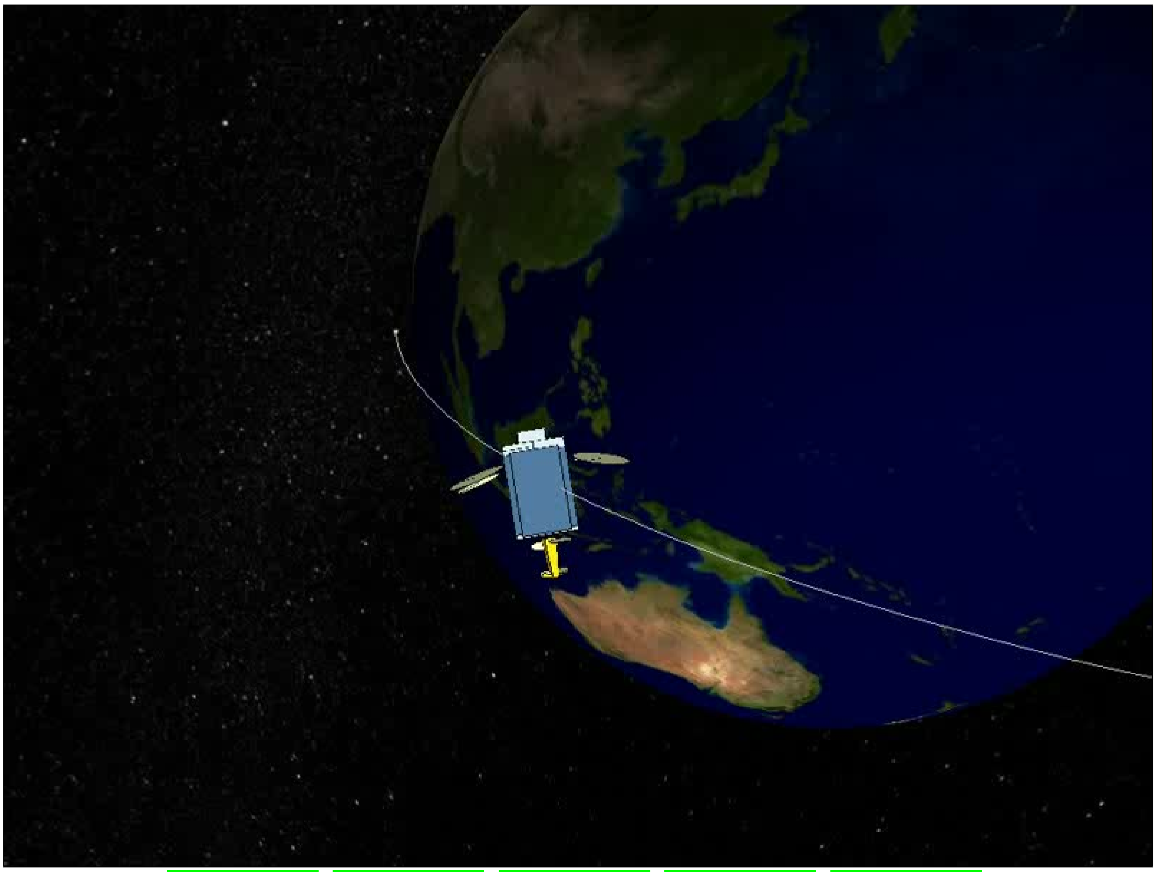
Boolean shapes

- Demonstration



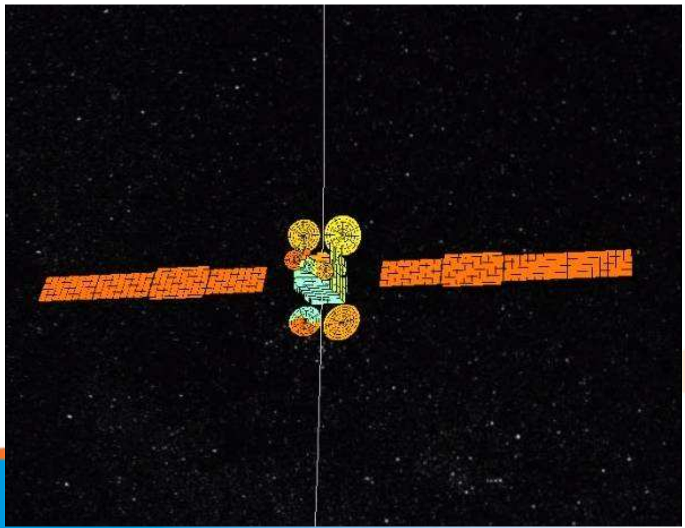




Slow Normal Fast Play/Pause Stop

Multi-kinematics & Sequence Management

- Video from SYSTEMA
  - Results of Solar Fluxes on a Telecommunication Satellite



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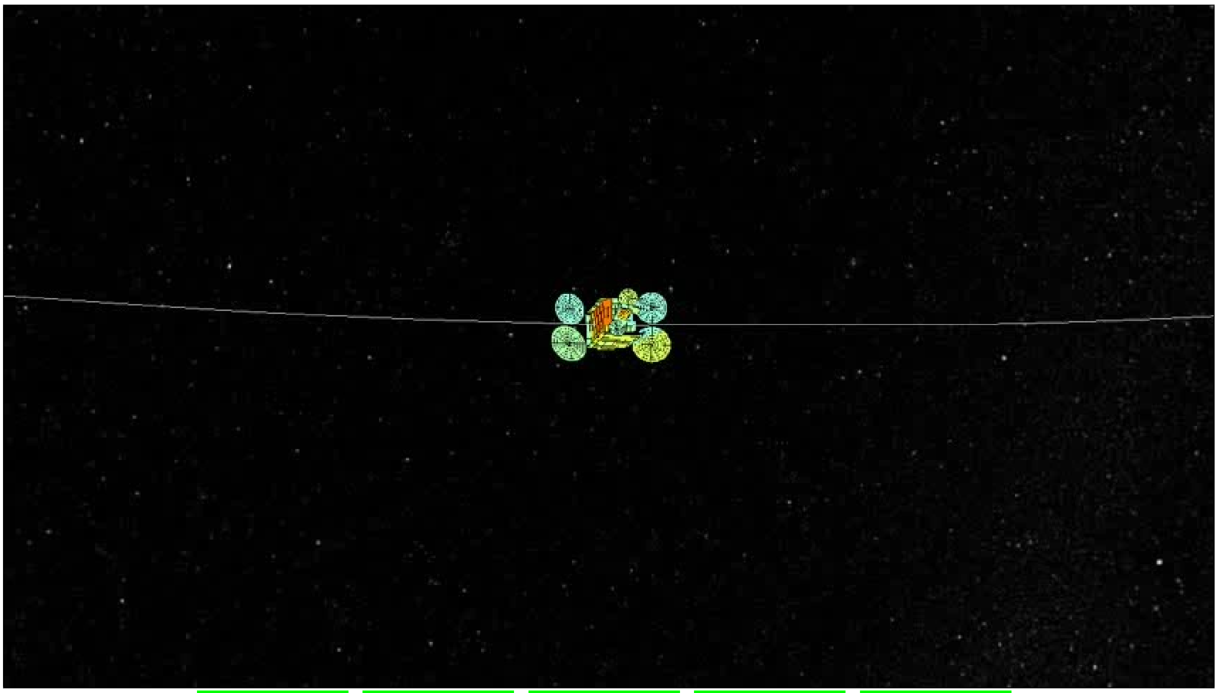
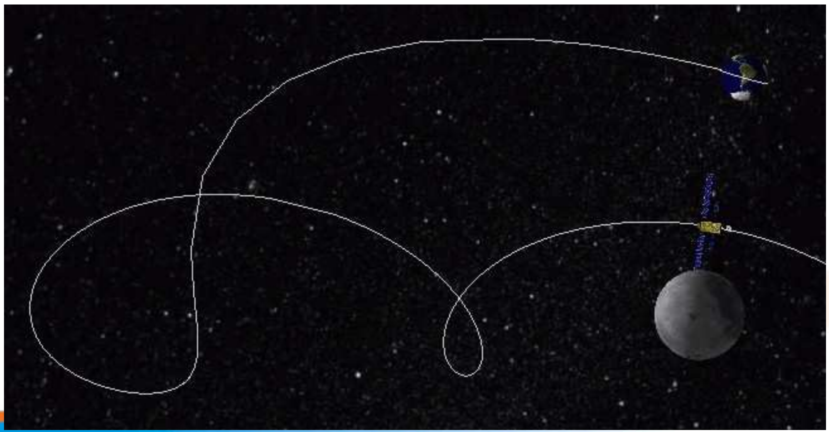


Slow Normal Fast Play/Pause Stop

Interplanetary Missions

- Video from SYSTEMA
  - Lunar Mission



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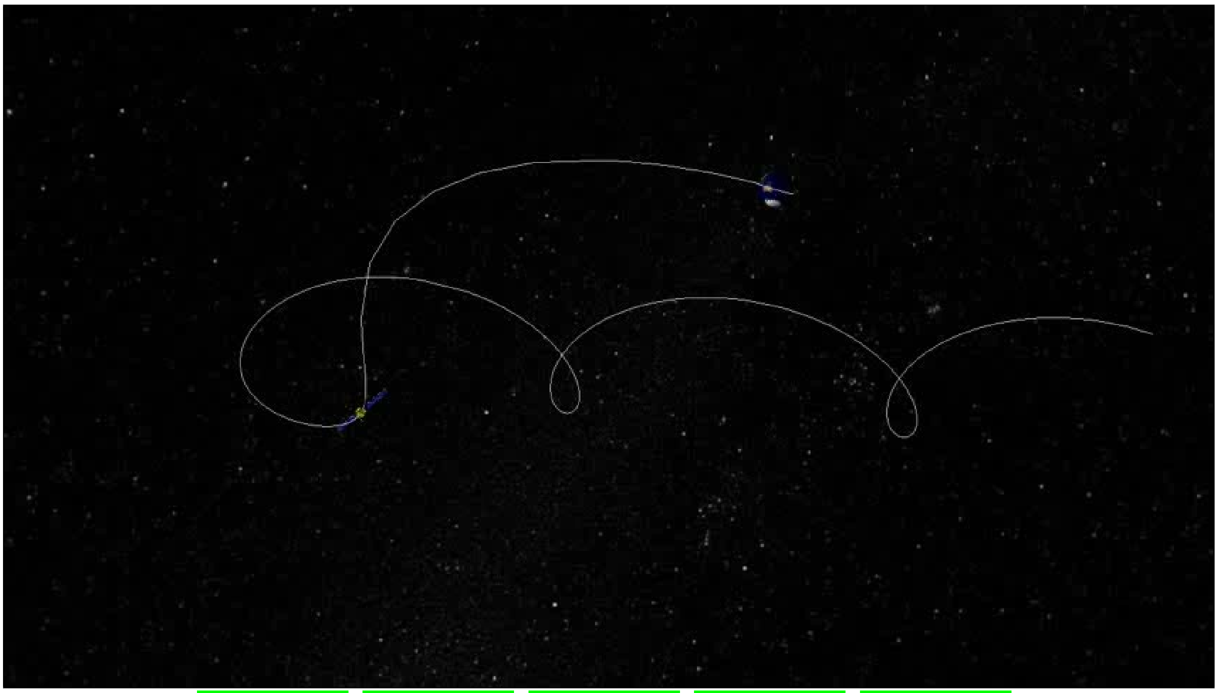
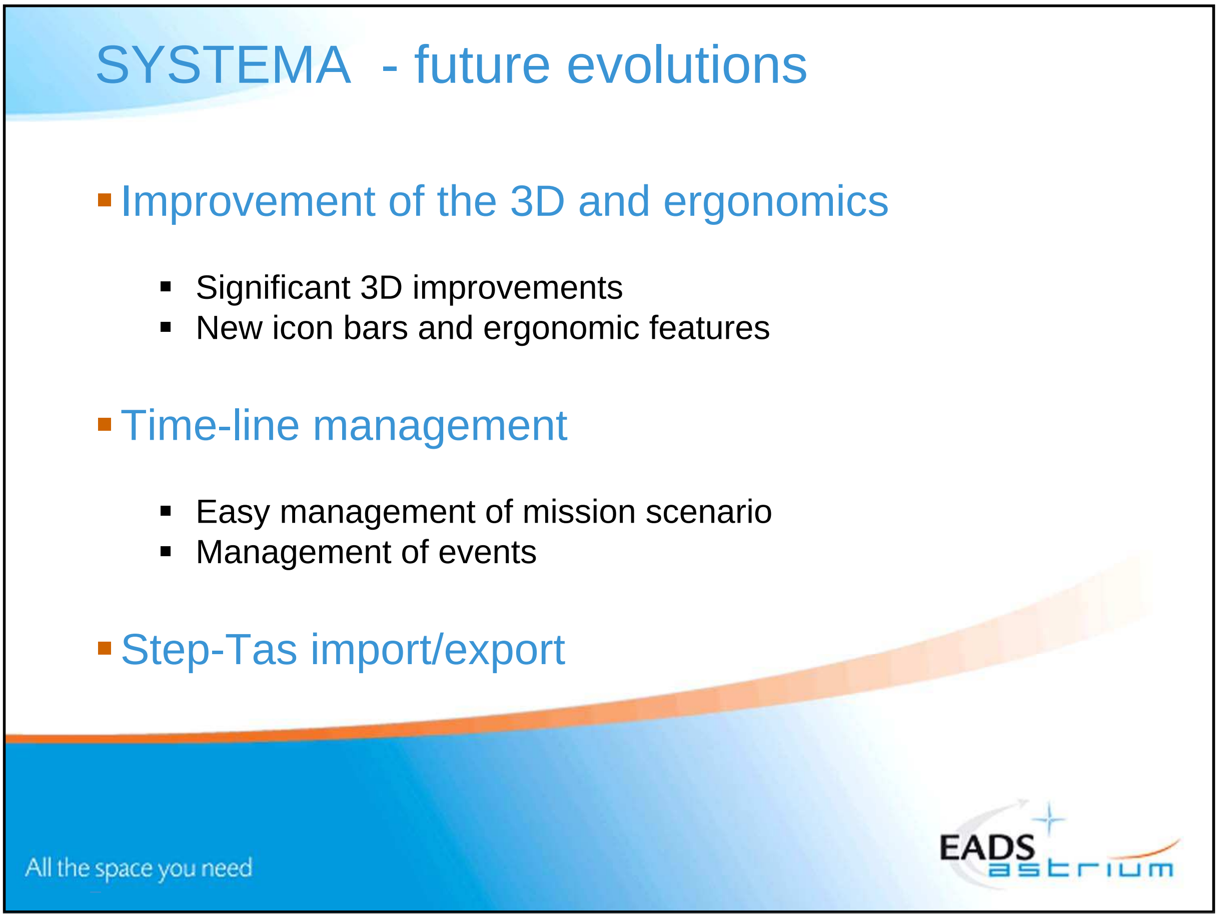


Slow | Normal | Fast | Play/Pause | Stop


SYSTEMA - future evolutions
Improvement of the 3D and ergonomics
Significant 3D improvements
New icon bars and ergonomic features
Time-line management
Easy management of mission scenario
Management of events
Step-Tas import/export
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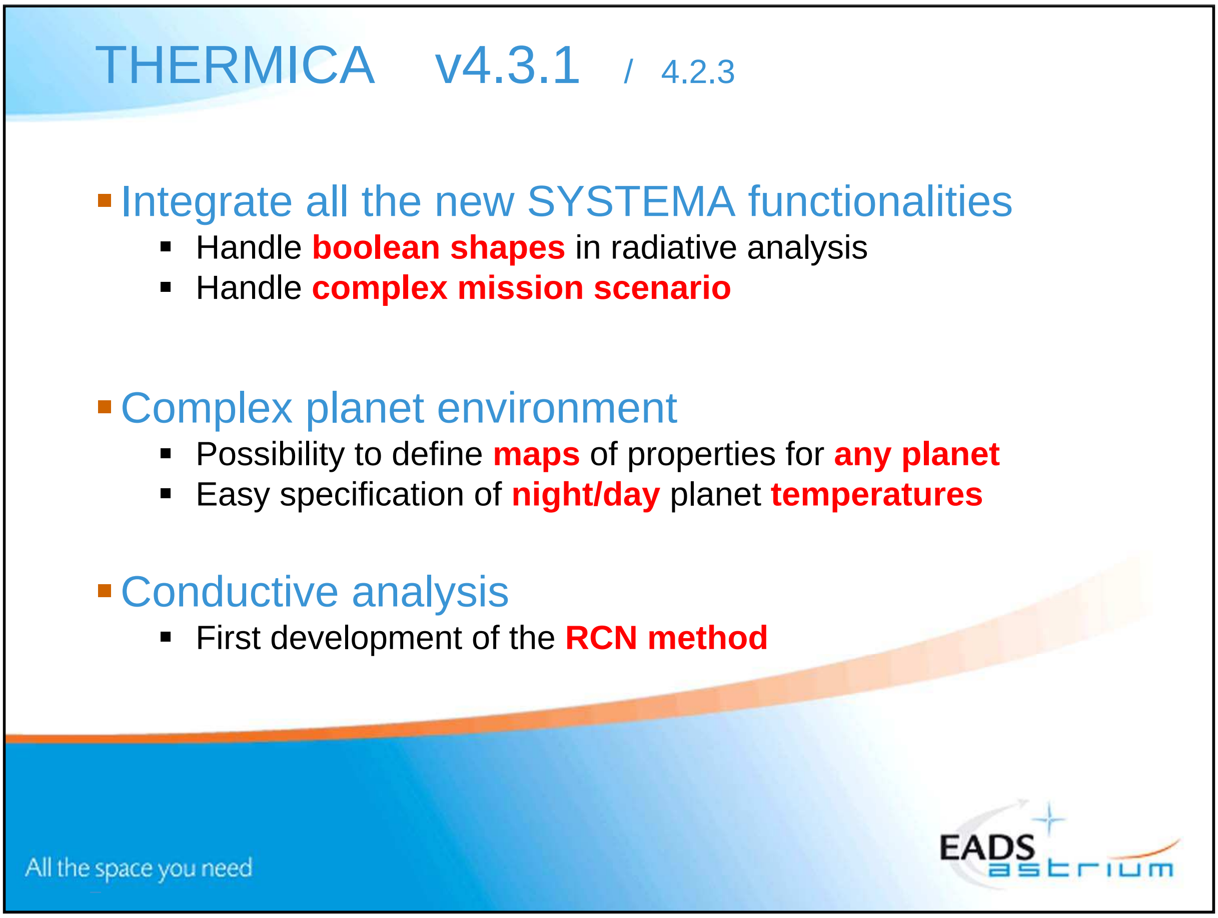
THERMICA v4.3.1 / 4.2.3
Integrate all the new SYSTEMA functionalities
Handle boolean shapes in radiative analysis
Handle complex mission scenario
Complex planet environment
Possibility to define maps of properties for any planet
Easy specification of night/day planet temperatures
Conductive analysis
First development of the RCN method
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Conductive analyses: the RCN method

- The ***Reduced Conductive Network*** method
  - Compatible with **Radiative Mesh**
  - Compatible with **not conformant meshes**
  - Compatible with **boolean shapes** *(not implemented in v4.3.1)*
  - **Integrates** the fluxes on the edges

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Conductive analyses: the RCN method

- Principle of the RCN approach
  - It defines a sub-space of linearly exact results
  - It searches within this sub-space a particular solution for which
    - The nodes (edges/surface) correspond to **mean temperatures** (and not geometrically localized temperatures)
    - The couplings **do not depend on a temperature profile**

The RCN solution can be reached analytically or by a process integrating the fluxes on the edges

(to deal with not conformant meshes and boolean shapes)

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New Mapping Module

- Based on the RCN method
  - Load of **FEM model** & **Visualization** of both Thermal/FEM model
  - Definition of **associations** *(optional)*
  - **Mapping** of temperature results based on a **detailed** recalculated **temperature profile** *(thanks to a backward RCN approach)*
  - **Export** of the temperatures on the mechanical mesh

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On-going researches on Radiative Analyses

- Needs for a new method for Radiative Analyses
  - To get **more accuracy** and **faster**
  - To deal **more efficiently** with **larger model**
- Main idea of the new method

  Re-use of some information of the classical ray-tracing algorithm in order **to increase the accuracy** of the Radiative Exchange Factors and **to optimize the ray-tracing** process itself

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New Radiative Analyses Method

- Actual status
  - **Fundamental aspects** have been mathematically **consolidated**
  - Major **algorithms aspects** have been **implemented**
  - Tests are being made to

    - Validate the method
    - Optimize it (accuracy and performances)

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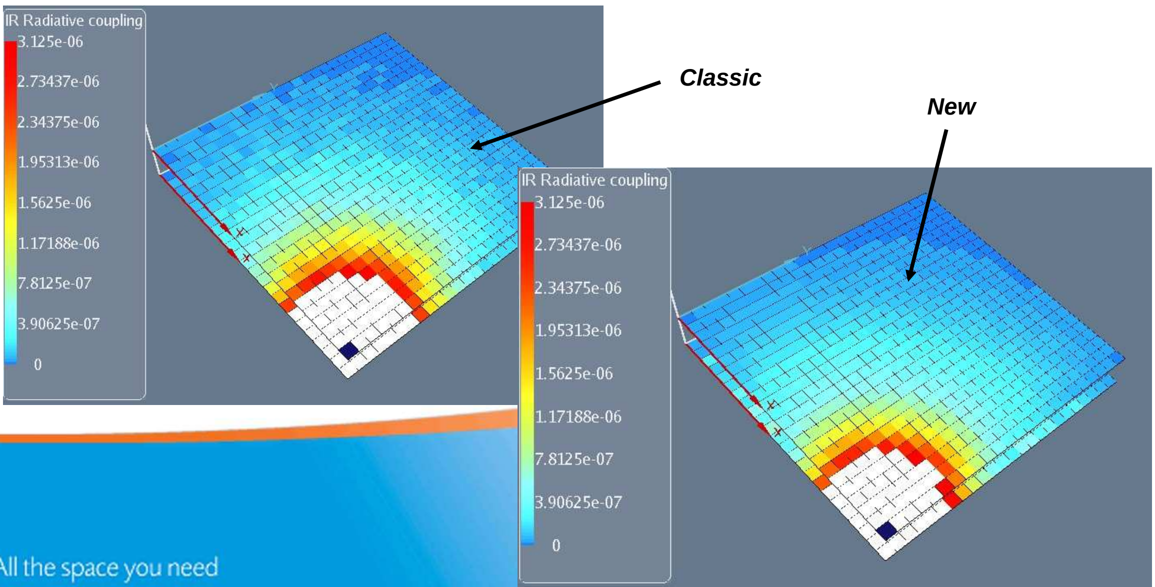
New Radiative Analyses Method

- Preliminary results
  - Test of 2 plane surfaces seeing one each other



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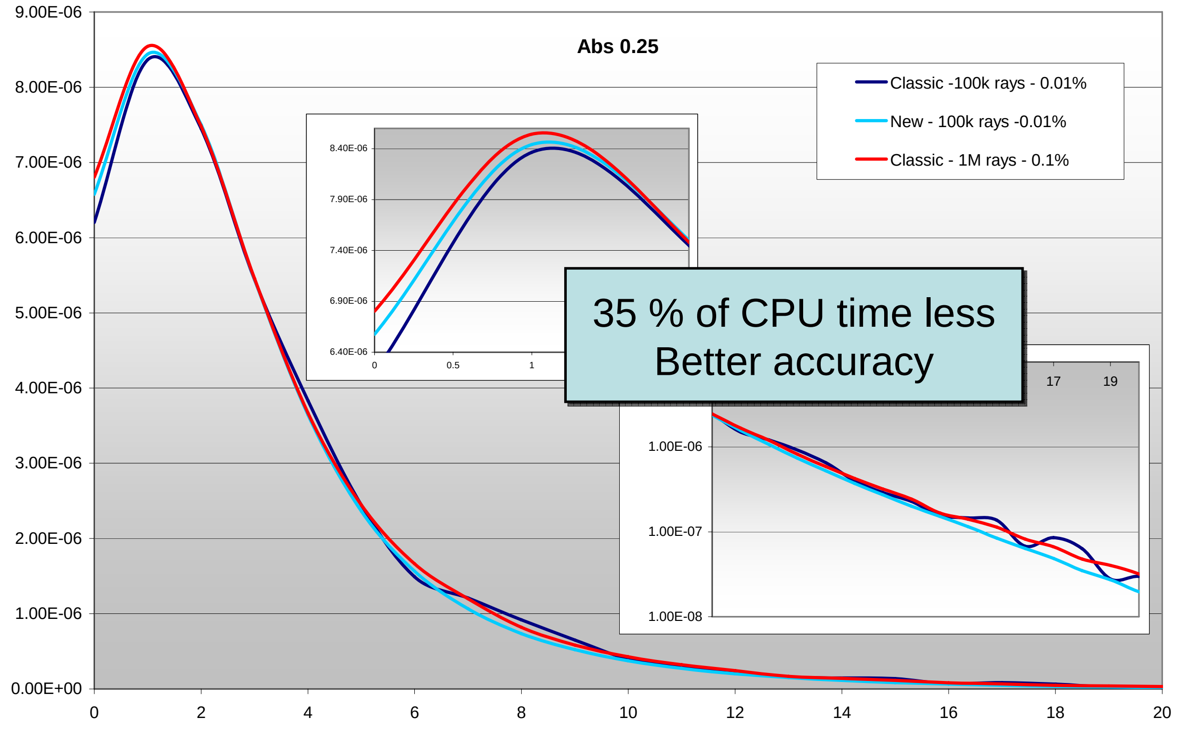
New Radiative Analyses Method



New Radiative Analyses Method

Preliminary conclusions

- The method seems to **converge correctly** to the exact results
- The **gain of CPU time** is significant when a good accuracy is required

Further developments

- Many other tests are necessary to confirm the expectations of the method and to consolidate its implementation
- Final integration to the Radiative and Solar fluxes analyses to be done

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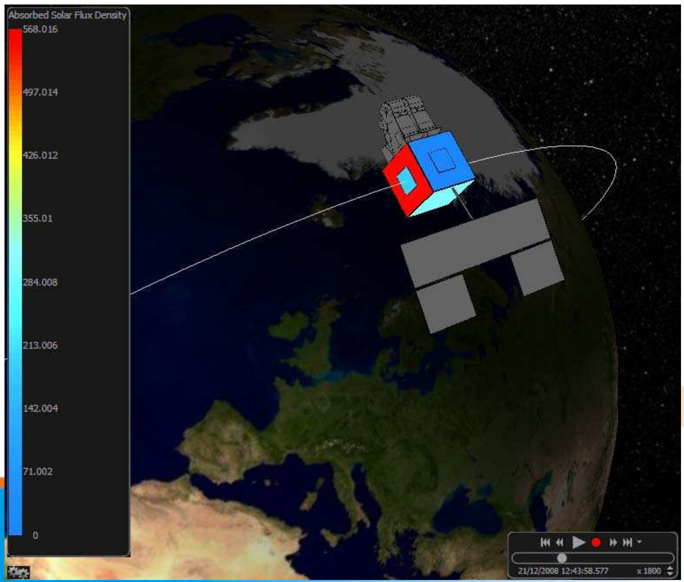
THERMICA v4.3.1 - Demonstration

- Spot : Radiative and Fluxes Analysis



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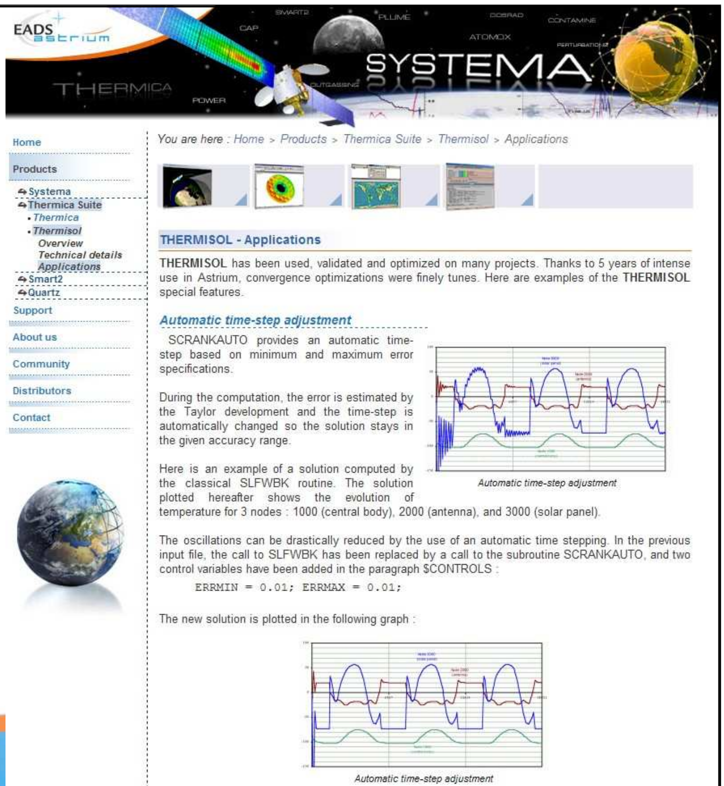
SYSTEMA
THERMICA
THERMISOL

Visit our new Web site :
www.systema.astrium.eads.net

Contact :
timothee.soriano@astrium.eads.net



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Appendix H

A Software Tool Applying Linear Control Methods to Satellite Thermal Analysis

Martin Altenburg Johannes Burkhardt
(EADS Astrium, Germany)

Abstract

The presentation discusses the development of the software tool TransFAST, which firstly transfers the classical thermal network to a standard linear control system, and subsequently solves this system in the frequency domain. Application of this type of analysis becomes more and more important for missions, where extremely demanding requirements on geometrical and thus thermo-elastic stability are involved. In such cases the deviations from a certain steady-state are small enough for performing thermal analysis on linearized systems. As a major advantage, thermal stability analyses can be performed without running extensive transient thermal analysis, delivering reasonable and even more accurate results, compared to the classical approach, and in general with significantly less effort.

For solving one key issue, the inversion of the system matrix, the presentation discusses two different numerical approaches, the direct inversion of the transformed system matrix (DIT) and the conditioned evaluation of the frequency response (CEF). A comparison of the different methods is provided for the application example LISA. For this mission, requirements imposed on the satellite system design and/or on the scientific payload design are defined in the frequency domain because these requirements have to be met for a certain measurement bandwidth only. Mission specific requirements are typically expressed in terms of $quantity/\sqrt{Hz}$, the so-called linear spectral density, in analogy to the power spectral density, i.e. $quantity^2/Hz$.

TransFAST also comprises powerful post-processing features for graphical output, which allows checking the analysis results directly after the calculation is performed. As a further feature of this software the user can import also results from external sources like ESATAN for further post- processing.

A Software Tool Applying Linear Control Methods to Satellite Thermal Analysis

Martin Altenburg // 28.10.2008
martin.altenburg@astrium.eads.net

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Motivation

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

All the space you need
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Linearization Approach (1)

1) Heat transport equation (conduction & radiation)

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

2) Re-arrangement of thermal network matrices

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

3) Linearization of radiative terms around equilibrium state

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

$$\left[\delta \dot{T} \right] = \left(diag[C]^{-1} \cdot [K] + diag[C]^{-1} \cdot [F] \cdot 4 \cdot diag\left[T_e^3 \right] \right) \cdot [\delta T] + diag[C]^{-1} \cdot [\delta Q]$$

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Linearization Approach (2)

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

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

→ $[\bar{A}]$

Node Property
- Heat capacity (CP)

→ $[\bar{B}]$

[A]	system matrix
[B]	input matrix
[C]	measurement matrix
[D]	input/output coupling matrix
[u]	input/control vector
[x]	state vector
[y]	output vector

Distinguish node types:
boundaries are no state variables

$$\begin{bmatrix} \delta \dot{T}_D \\ \delta \dot{T}_B \end{bmatrix} = \begin{bmatrix} \bar{A}_{DD} & \bar{A}_{DB} \\ \bar{A}_{BD} & \bar{A}_{BB} \end{bmatrix} \cdot \begin{bmatrix} \delta T_D \\ \delta T_B \end{bmatrix} + \left[\bar{B} \right] \cdot \begin{bmatrix} \delta Q_D \\ \delta Q_B \end{bmatrix}$$

$$[\dot{x}] = [A] \cdot [x] + [B] \cdot [u] \qquad [y] = [C] \cdot [x] + [D] \cdot [u]$$

Linear Control System

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Linear Control Methods for Thermal Systems

- **Frequency domain analysis (Transfer Function Approach):**
  Apply Laplace Transform on the Linear Control System

$$[G(s)] = \left[\frac{Y(s)}{U(s)}\right] = [C]\cdot[sI - A]^{-1}\cdot[B] + [D]$$

  → G(s) includes gain and phase shift information
  → G(s) provides the complete thermal system characterization

- Two different numerical approaches:
  → direct inversion of the transformed system matrix (DIT)
  → conditioned evaluation of the frequency response (CEF)

- Post processing possibility

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Frequency Domain Analysis

- Inputs (from external and internal noise sources), e.g. solar, S/C equipment:
  → Power Dissipation Input
  → Temperature Fluctuation Input

- Evaluation of these inputs at all or selected thermal nodes
  (system characterization)
- In terms of linear control system: SISO … MIMO

- Many options for visualization of the results:
  → Gain vs. frequency for all nodes, 3d-plot
  → Gain vs. frequency (for selected nodes), 2d-plot
  → Gain for all nodes for one selected frequency, gain vs. nodes, 2d-plot

- Tool capabilities are presented exemplary for LISA S/C (payload), see next slides

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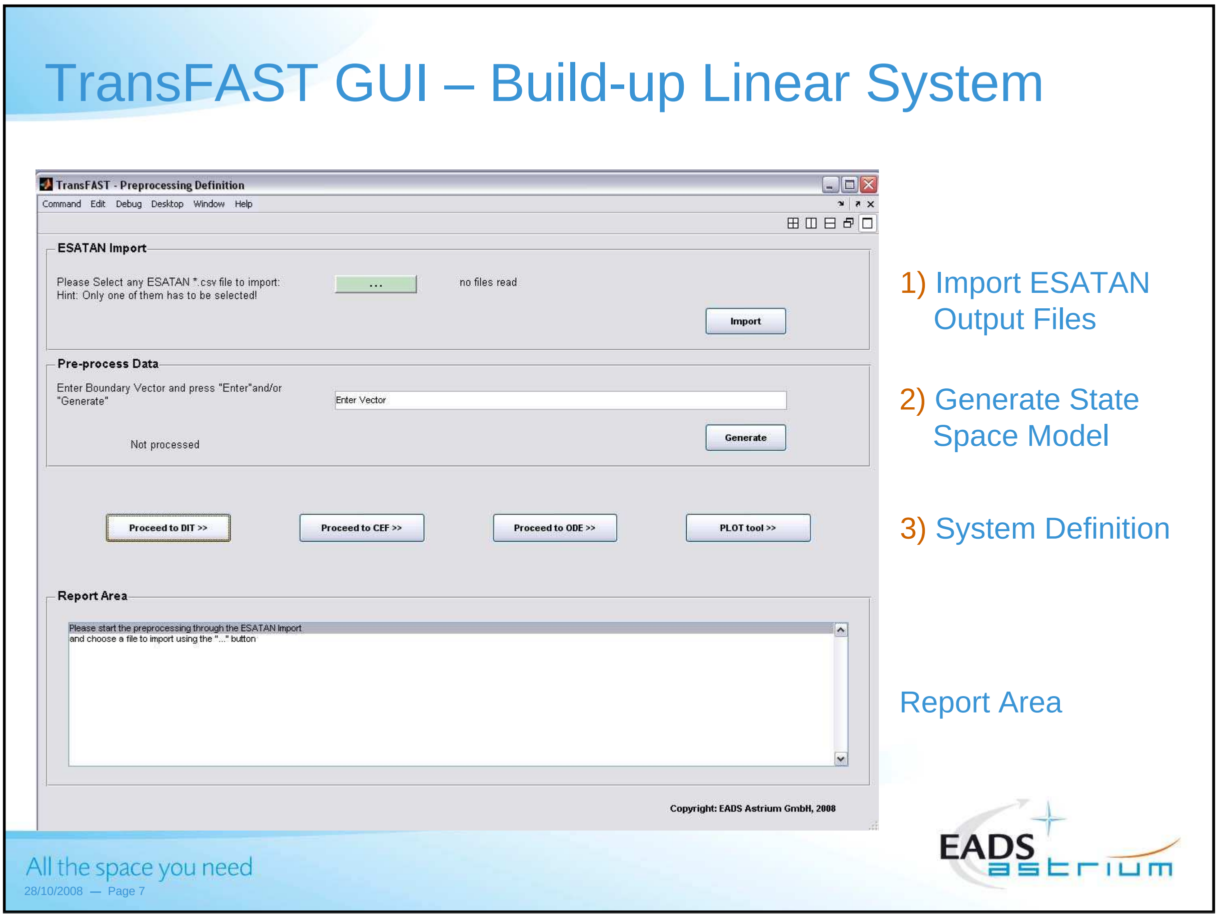
TransFAST GUI – Build-up Linear System
TransFAST - Preprocessing Definition
Command Edit Debug Desktop Window Help
ESATAN Import
Please Select any ESATAN *.csv file to import:
Hint: Only one of them has to be selected!
...
no files read
Import
Pre-process Data
Enter Boundary Vector and press "Enter"and/or "Generate"
Enter Vector
Not processed
Generate
Proceed to DIT >>
Proceed to CEF >>
Proceed to ODE >>
PLOT tool >>
Report Area
Please start the preprocessing through the ESATAN import
and choose a file to import using the "..." button
Copyright: EADS Astrium GmbH, 2008
1) Import ESATAN Output Files
2) Generate State Space Model
3) System Definition
Report Area
All the space you need
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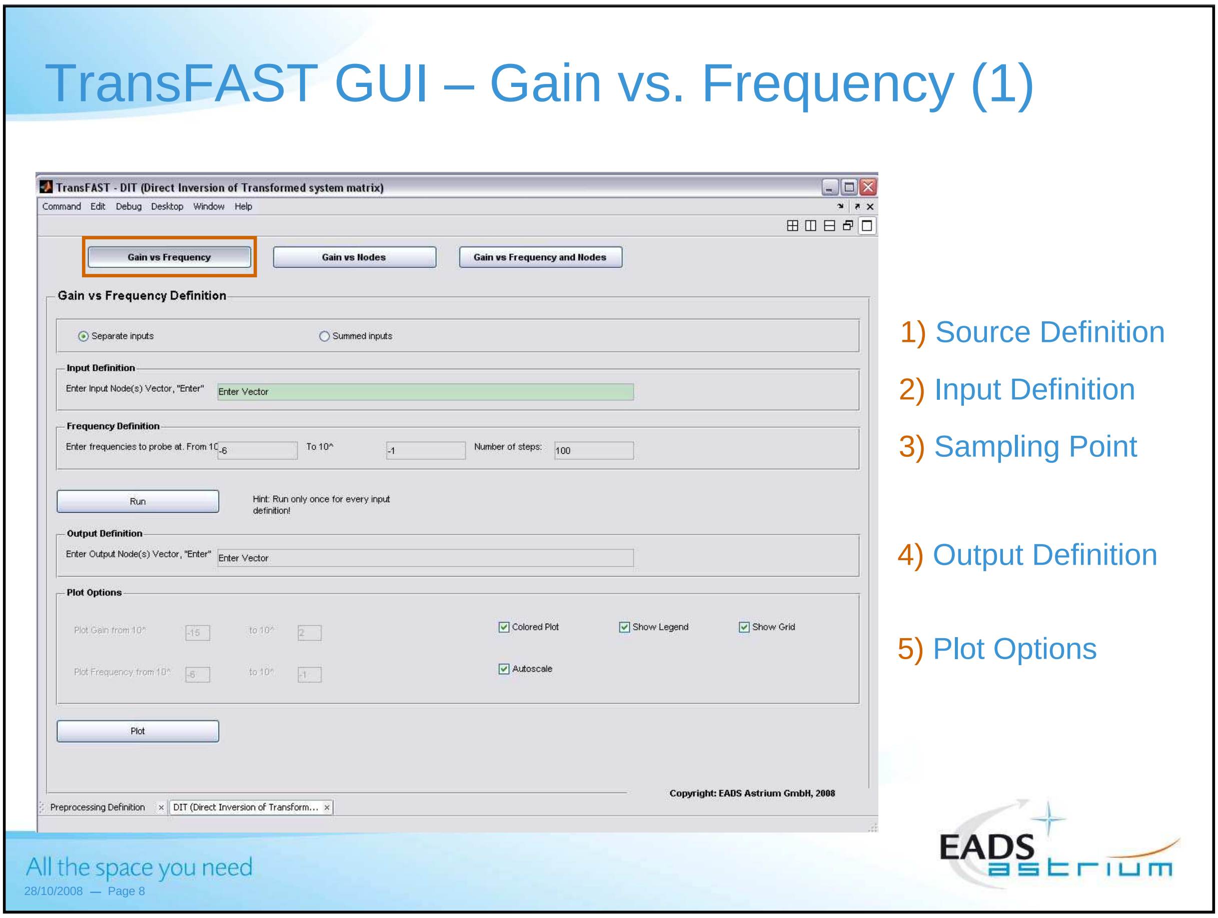
TransFAST GUI – Gain vs. Frequency (1)
TransFAST - DIT (Direct Inversion of Transformed system matrix)
Command Edit Debug Desktop Window Help
Gain vs Frequency
Gain vs Nodes
Gain vs Frequency and Nodes
Gain vs Frequency Definition
Separate inputs
Summed inputs
Input Definition
Enter Input Node(s) Vector, "Enter"
Enter Vector
Frequency Definition
Enter frequencies to probe at. From 10^
-6
To 10^
-1
Number of steps:
100
Run
Hint: Run only once for every input definition!
Output Definition
Enter Output Node(s) Vector, "Enter"
Enter Vector
Plot Options
Plot Gain from 10^
-15
to 10^
2
Plot Frequency from 10^
-6
to 10^
-1
Colored Plot
Show Legend
Show Grid
Autoscale
Plot
Copyright: EADS Astrium GmbH, 2008
Preprocessing Definition
DIT (Direct Inversion of Transform...
1) Source Definition
2) Input Definition
3) Sampling Point
4) Output Definition
5) Plot Options
All the space you need
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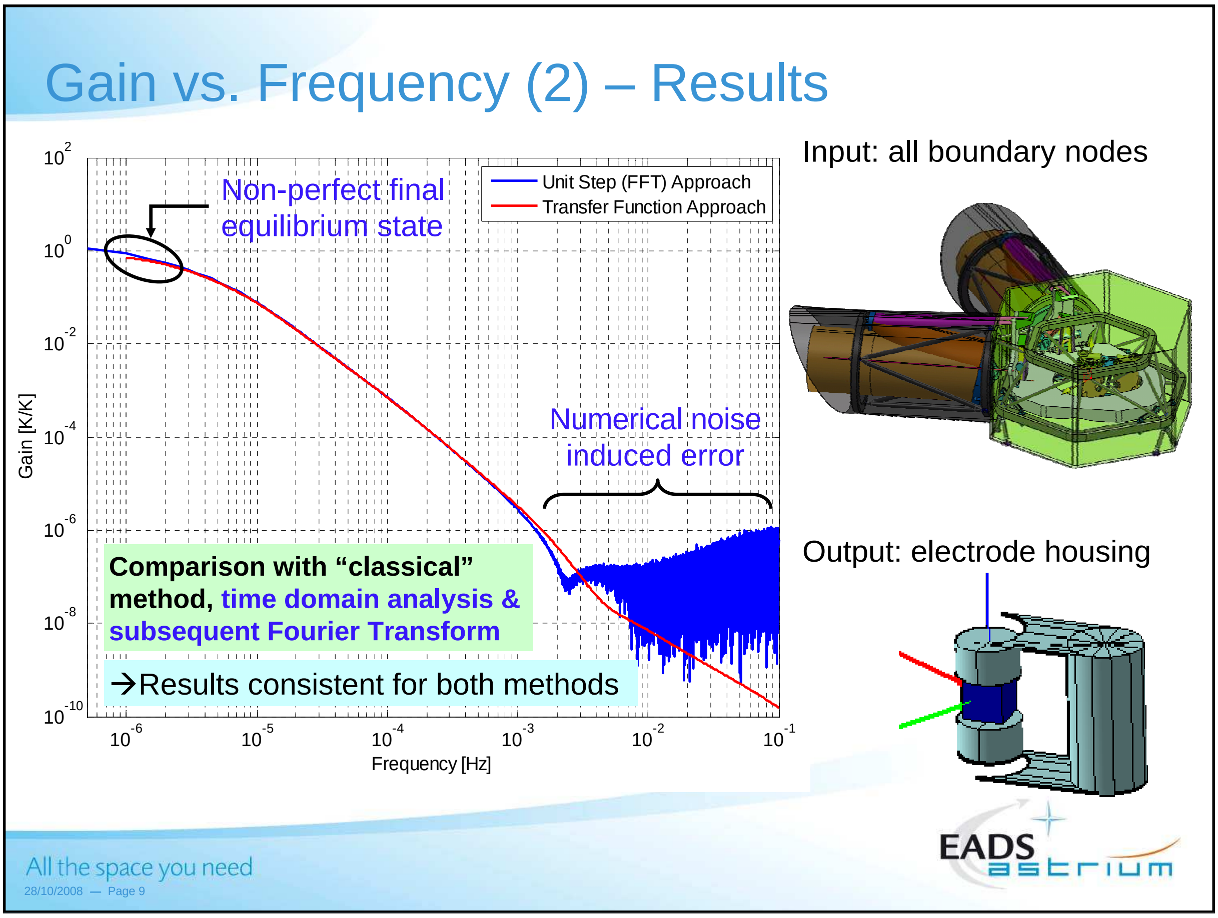
Gain vs. Frequency (2) – Results
Input: all boundary nodes
Output: electrode housing
Unit Step (FFT) Approach
Transfer Function Approach
Non-perfect final equilibrium state
Numerical noise induced error
Comparison with "classical" method, time domain analysis & subsequent Fourier Transform
→Results consistent for both methods
Gain [K/K]
Frequency [Hz]
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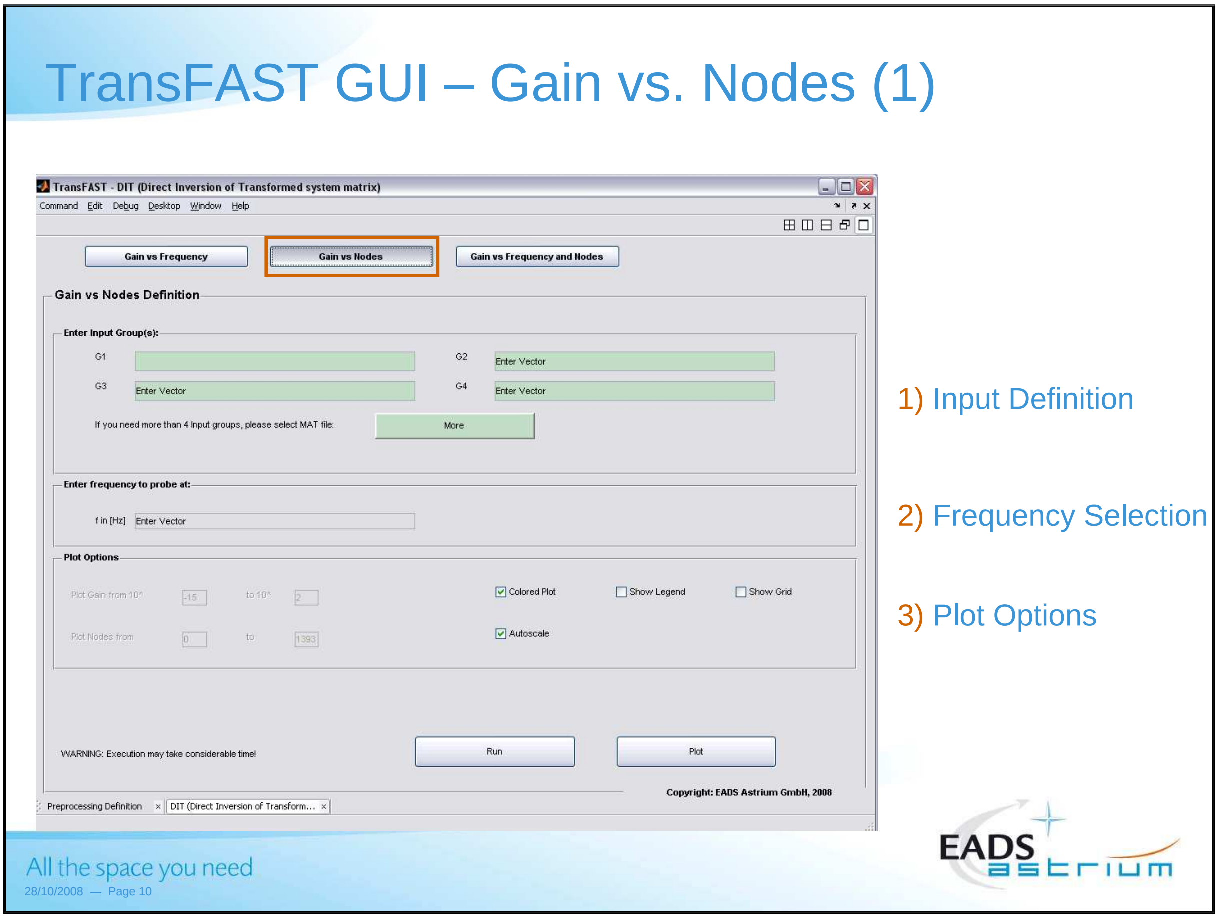
TransFAST GUI – Gain vs. Nodes (1)
TransFAST - DIT (Direct Inversion of Transformed system matrix)
Command Edit Debug Desktop Window Help
Gain vs Frequency
Gain vs Nodes
Gain vs Frequency and Nodes
Gain vs Nodes Definition
Enter Input Group(s):
G1
G2
G3
G4
Enter Vector
If you need more than 4 input groups, please select MAT file:
More
Enter frequency to probe at:
f in [Hz]
Plot Options
Colored Plot
Show Legend
Show Grid
Autoscale
WARNING: Execution may take considerable time!
Run
Plot
Copyright: EADS Astrium GmbH, 2008
Preprocessing Definition
DIT (Direct Inversion of Transform...
1) Input Definition
2) Frequency Selection
3) Plot Options
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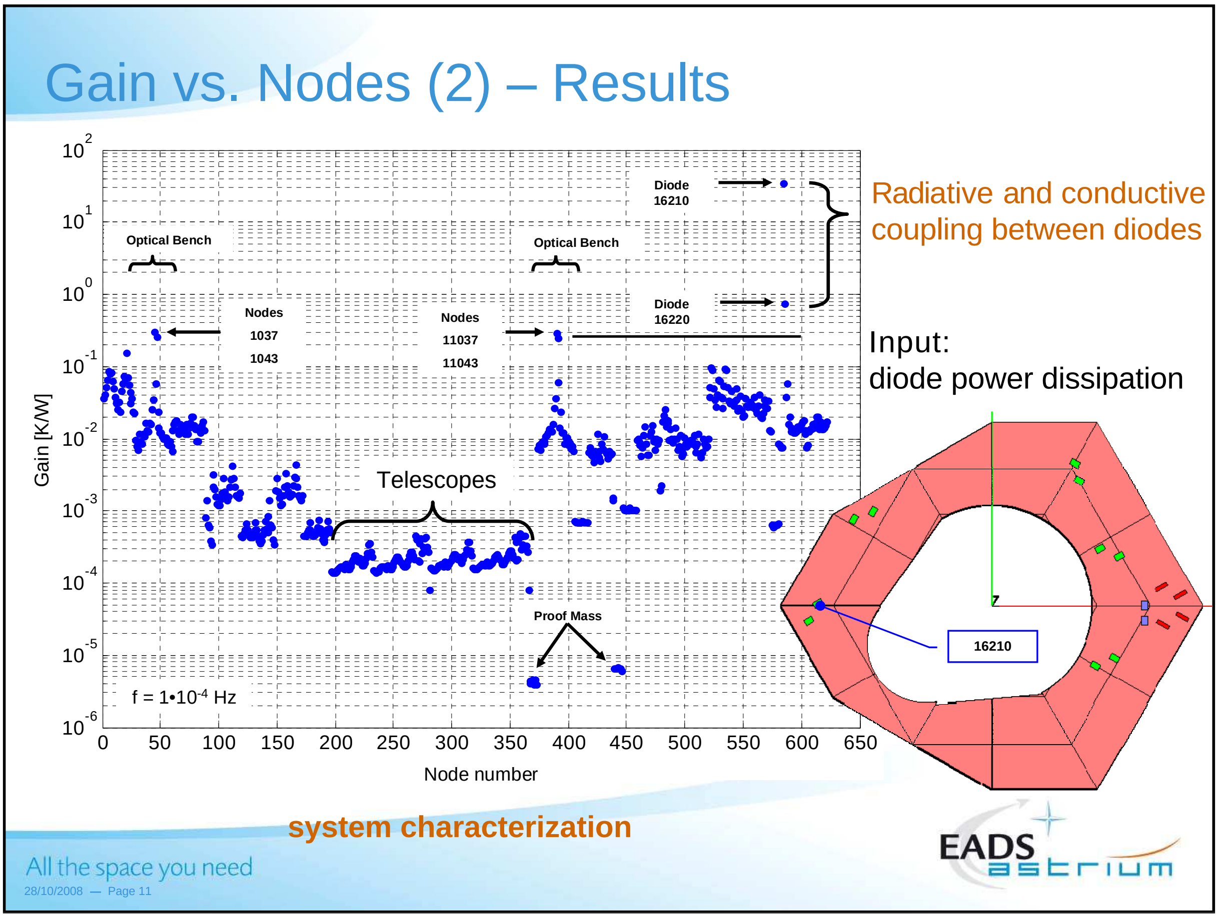

Gain vs. Nodes (2) – Results
Gain [K/W]
Node number
Optical Bench
Optical Bench
Nodes 1037 1043
Nodes 11037 11043
Diode 16210
Diode 16220
Telescopes
Proof Mass
f = 1•10-4 Hz
Radiative and conductive coupling between diodes
Input: diode power dissipation
16210
system characterization
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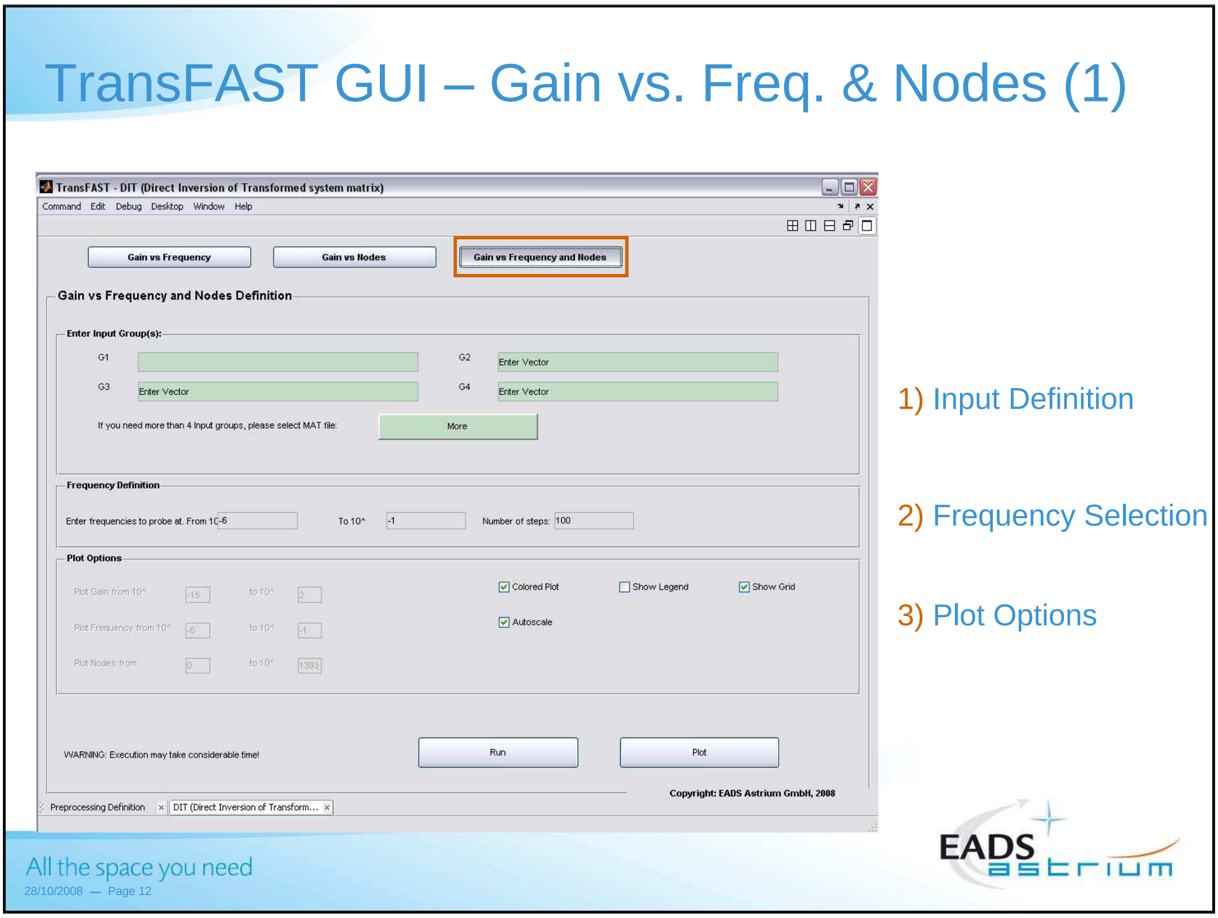

TransFAST GUI – Gain vs. Freq. & Nodes (1)
TransFAST - DIT (Direct Inversion of Transformed system matrix)
Gain vs Frequency
Gain vs Nodes
Gain vs Frequency and Nodes
Gain vs Frequency and Nodes Definition
Enter Input Group(s):
If you need more than 4 Input groups, please select MAT file:
More
Frequency Definition
Enter frequencies to probe at. From 10^
To 10^
Number of steps:
Plot Options
Colored Plot
Show Legend
Show Grid
Autoscale
WARNING: Execution may take considerable time!
Run
Plot
Copyright: EADS Astrium GmbH, 2008
1) Input Definition
2) Frequency Selection
3) Plot Options
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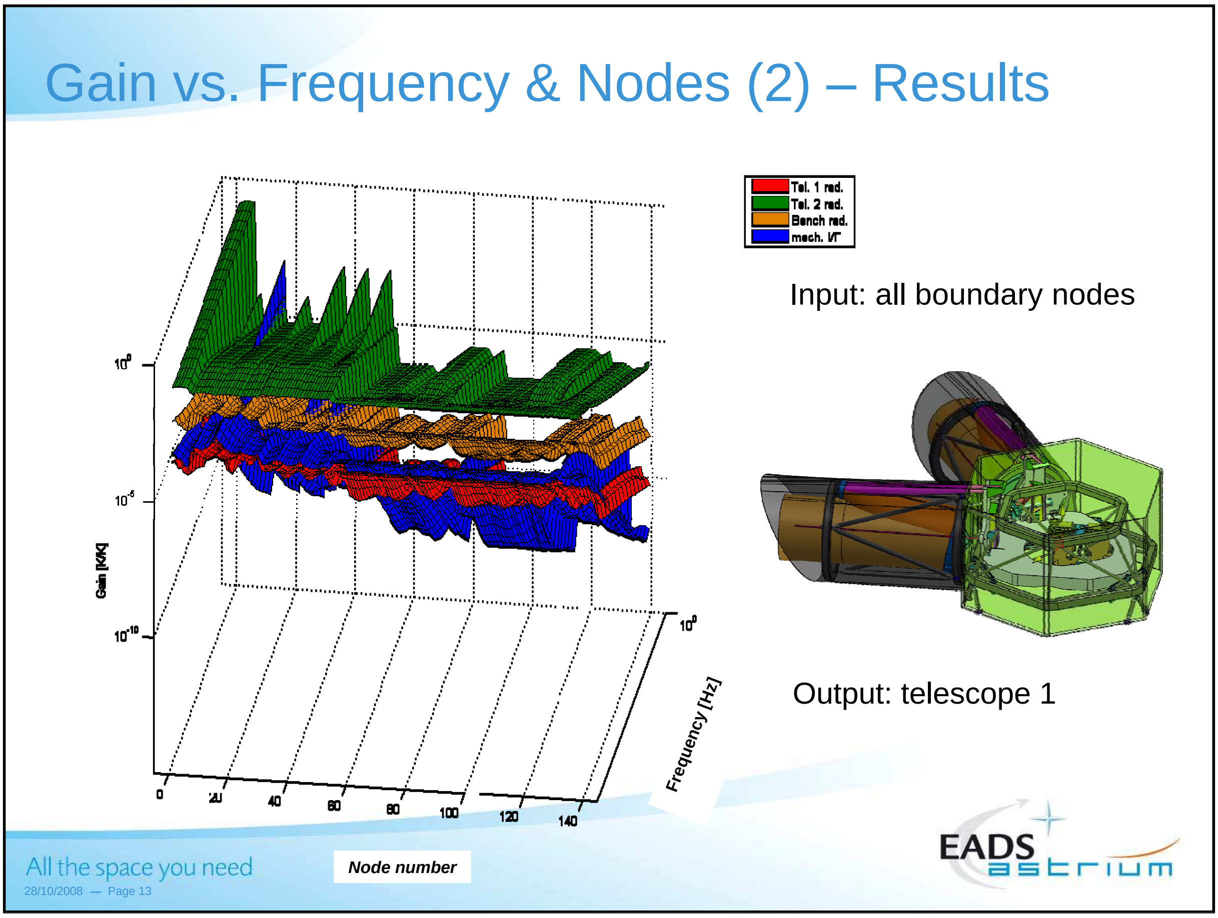
Gain vs. Frequency & Nodes (2) – Results
Tel. 1 rad.
Tel. 2 rad.
Bench rad.
mech. I/F
Input: all boundary nodes
Output: telescope 1
Gain [K/K]
10^0
10^{-5}
10^{-10}
Frequency [Hz]
Node number
0
20
40
60
80
100
120
140
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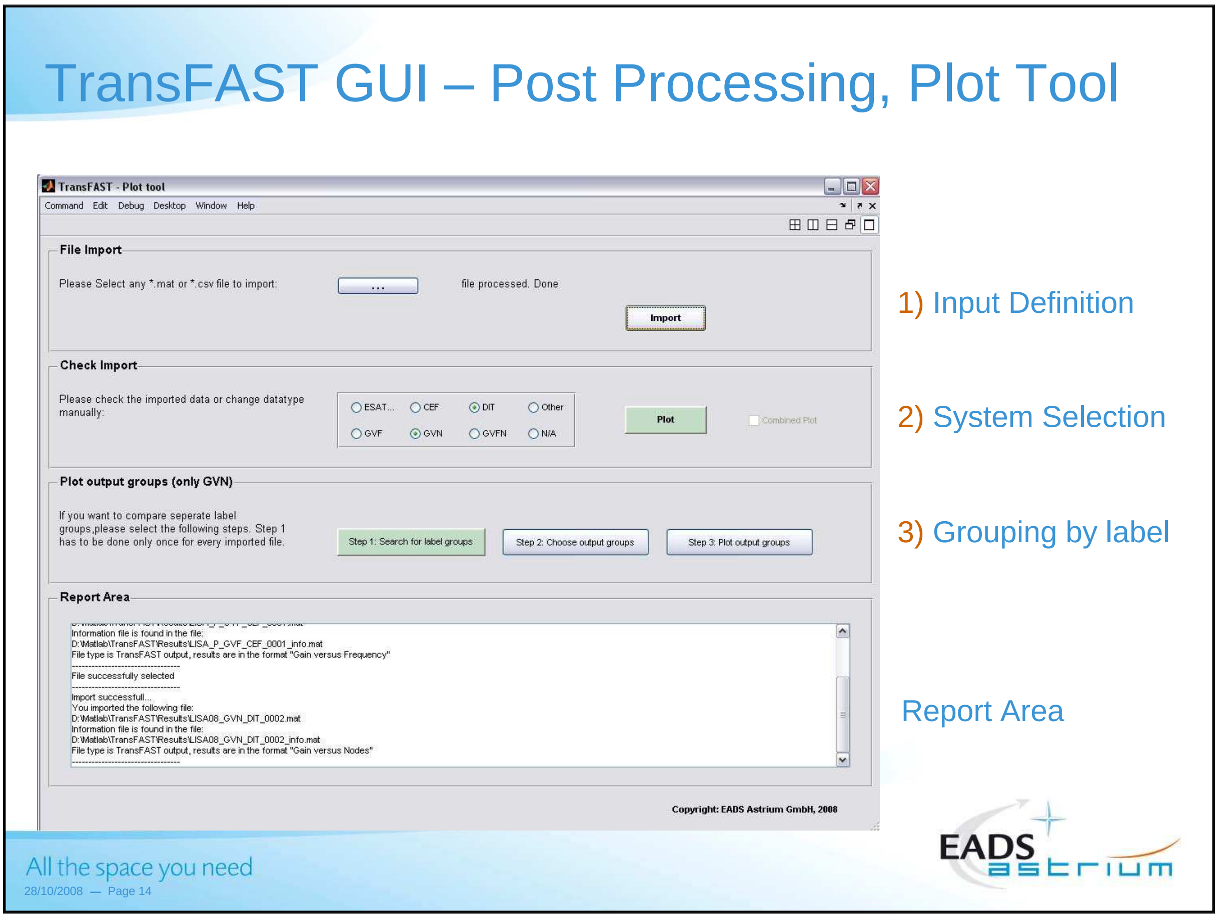
TransFAST GUI – Post Processing, Plot Tool
TransFAST - Plot tool
Command Edit Debug Desktop Window Help
File Import
Please Select any *.mat or *.csv file to import:
file processed. Done
Import
Check Import
Please check the imported data or change datatype manually:
ESAT... CEF DIT Other
GVF GVN GVFN N/A
Plot
Combined Plot
Plot output groups (only GVN)
If you want to compare seperate label groups,please select the following steps. Step 1 has to be done only once for every imported file.
Step 1: Search for label groups
Step 2: Choose output groups
Step 3: Plot output groups
Report Area
Information file is found in the file:
D:\Matlab\TransFAST\Results\LISA_P_GVF_CEF_0001_info.mat
File type is TransFAST output, results are in the format "Gain versus Frequency"
File successfully selected
Import successfull...
You imported the following file:
D:\Matlab\TransFAST\Results\LISA08_GVN_DIT_0002.mat
Information file is found in the file:
D:\Matlab\TransFAST\Results\LISA08_GVN_DIT_0002_info.mat
File type is TransFAST output, results are in the format "Gain versus Nodes"
Copyright: EADS Astrium GmbH, 2008
1) Input Definition
2) System Selection
3) Grouping by label
Report Area
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Summary

- Methods for Application of Linear Control Methods established & verified in a standard S/W environment, MATLAB
  - → Linearization, Laplace Transform, Post-processing
- Powerful S/W tool available for
  - → system characterization
  - → derivation of stability requirements for (sub)systems
  - → requirement verification by analysis
- Significant advantages compared to standard methods:
  - → Promises higher accuracy
  - → Reduced computational & memory effort
- Application on present and future missions whenever high thermal (thermo-elastic) stability is required
  (not necessarily limited to LISA pathfinder & LISA missions!)

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Outlook

- Extend S/W tool by implementation of linear system solver in the time domain (ODE)
- Implementation of project-specific post processing options (frequency domain)
- Improve user friendliness (GUI)
- …

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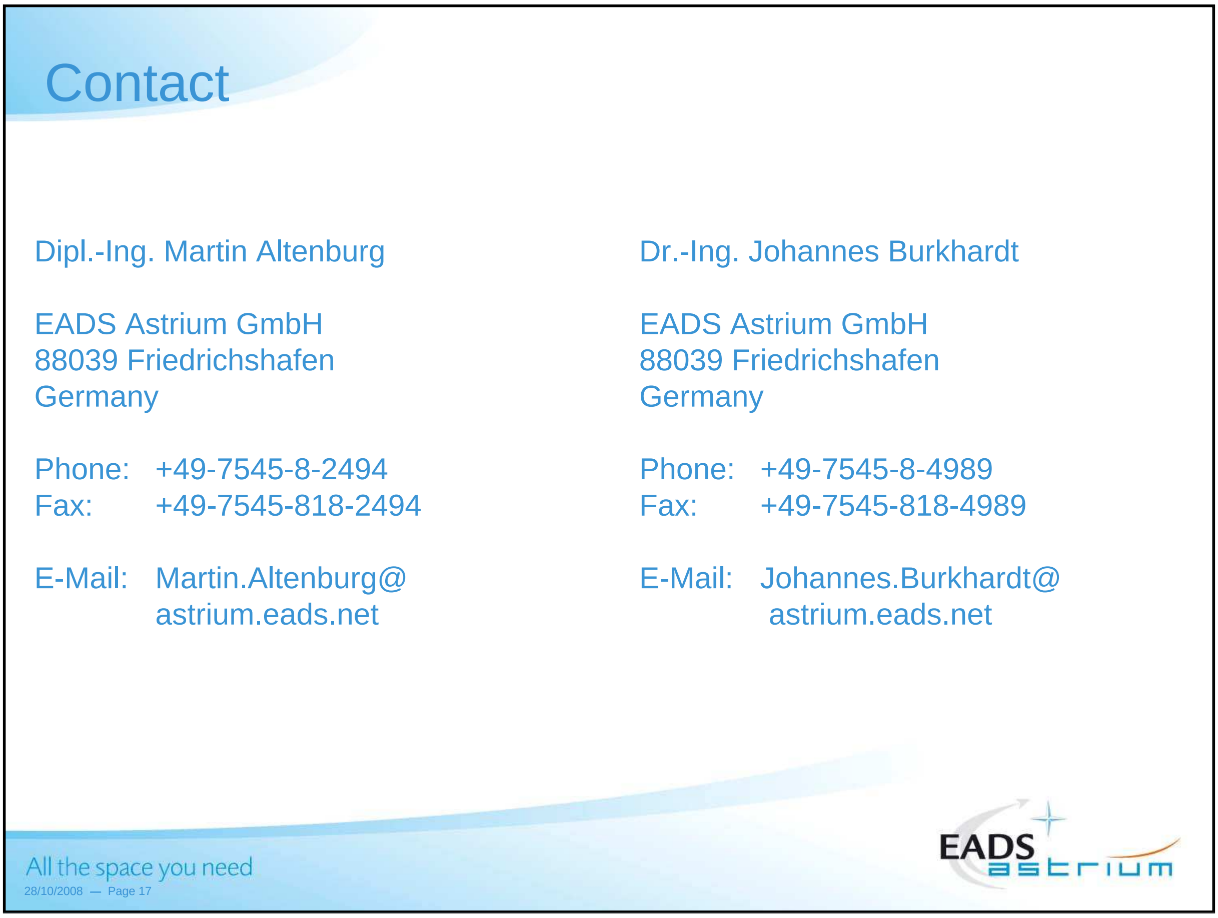
Contact
Dipl.-Ing. Martin Altenburg
EADS Astrium GmbH
88039 Friedrichshafen
Germany
Phone: +49-7545-8-2494
Fax: +49-7545-818-2494
E-Mail: Martin.Altenburg@astrium.eads.net
Dr.-Ing. Johannes Burkhardt
EADS Astrium GmbH
88039 Friedrichshafen
Germany
Phone: +49-7545-8-4989
Fax: +49-7545-818-4989
E-Mail: Johannes.Burkhardt@astrium.eads.net
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Appendix I

ALSTOM Product Developments

Henri Brouquet
(ALSTOM, United Kingdom)

Abstract

Overview of new features introduced in the latest versions of the products.

Thermal & ECLS Software Workshop

ESATAN-TMS Development Status

2008

Author: Henri Brouquet
Date: 28h Oct 2008

POWER SYSTEMS
Aerospace

ALSTOM

Introduction

Presentation of recent developments

- New layout for the ESATAN-TMS workbench
  - Permanent set of menus now available
- Additional Geometry Building Capabilities
  - Shell Assignment
- Modelling Time & Temperature Dependency
  - Support for boundary condition & thermal properties
- Non-Orbital (ground-based) Analysis support
  - Extended support of the Radiative case
- Extended Analysis Case Tree Menu Options
  - Fast and efficient way of performing operations

ESA Thermal & ECLS Software Worksop 2007, 28-29 Oct 08 - P 2

POWER SYSTEMS ALSTOM

Introduction

Presentation of recent developments

- New Utility Menu for complete thermal tool integration
  - Direct launch of ThermNV, Parametric Manager…
- Support for new HDF result data file
  - Compatible with all of ESATAN-TMS
  - More scalable and smaller file
- Improvement for transient solver SLCRNC
- Maintenance and Enhancement
  - Pre-processor error message improvement
- ThermNV new display label
  - Units, etc

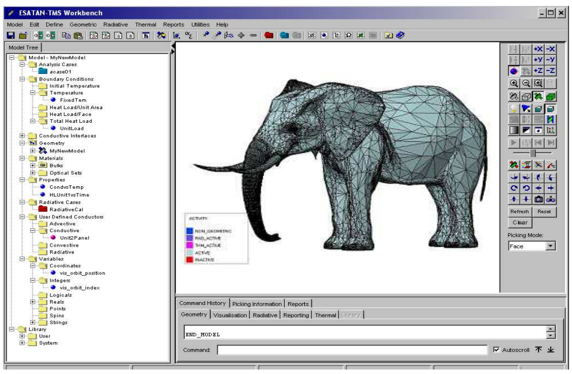
ESA Thermal & ECLS Software Worksop 2007, 28-29 Oct 08 - P 3

POWER SYSTEMS ALSTOM

Introduction

Live Demonstration

- Importing an ESATAN Thermal Model into ESATAN-TMS Workbench
- Non-orbital (ground-based) Thermal Analysis Example

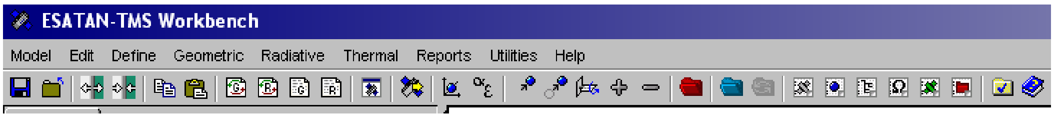


ESA Thermal & ECLS Software Worksop 2007, 28-29 Oct 08 - P 4

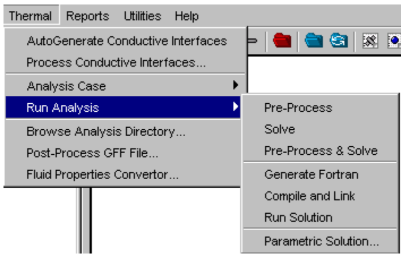
POWER SYSTEMS ALSTOM

ESATAN-TMS Workbench – New Layout

- Focus to Streamline the complete thermal modelling process
  - Efficient environment/less error prone
  - avoid learning multiple interfaces
- New set of permanent menus
  - Model, Geometric, Radiative, Thermal



- Dedicated Thermal menu with special care for our PcESATAN users



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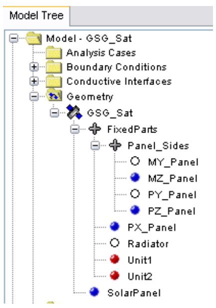
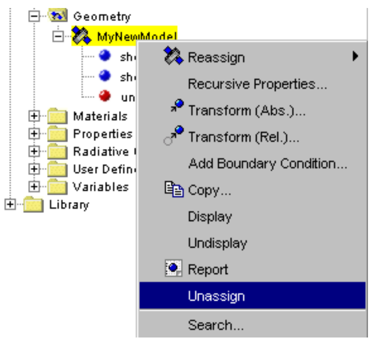
ESATAN-TMS Workbench – Shell Assignment

- Development to support CAD and FEM model
  - Removal of some modelling restriction



- Top-down geometry building approach
  - Shell can now be defined as placeholder



- Overall Model unassign facility
  - Following user request on easing the process of model building

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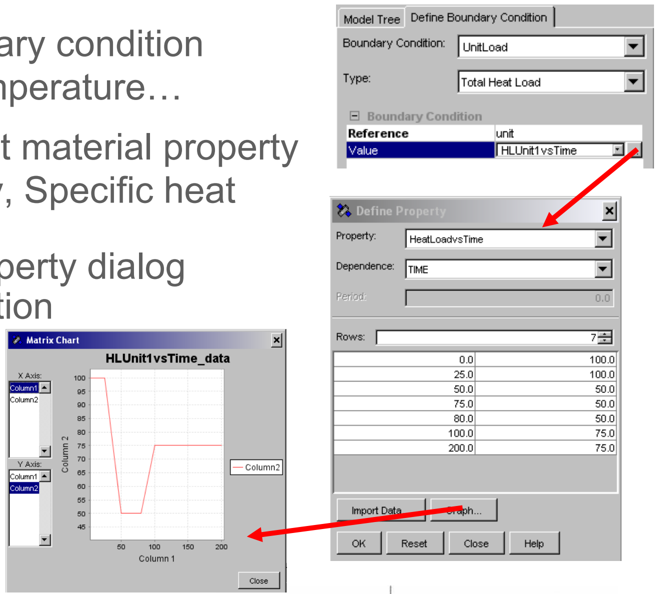
ESATAN-TMS Workbench – Modelling Time & Temperature Dependency

- Direct extension of work released in last version as part of ESARAD 6.2
- Time dependent boundary condition
  - Heat load, Fixed temperature…
- Temperature dependant material property
  - Density, conductivity, Specific heat
- Definition through a property dialog with quick visual inspection



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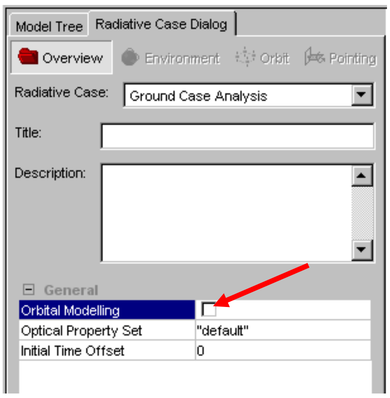
ESATAN-TMS Workbench – Non-Orbital Analysis

- Non-orbital radiative analysis requirement
  - Satellite in test chamber
  - Component in casing
  - Internal parts of engine
- Extended Radiative Case support
  - Orbital modelling flag
  - Disable mission related dialogs
- Easy generation of the thermal model using the analysis case functionalities
  - Template file
  - Chaining of radiative case results



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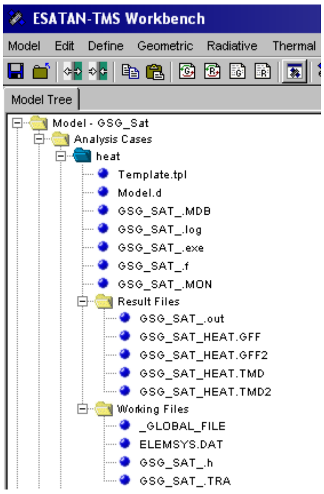
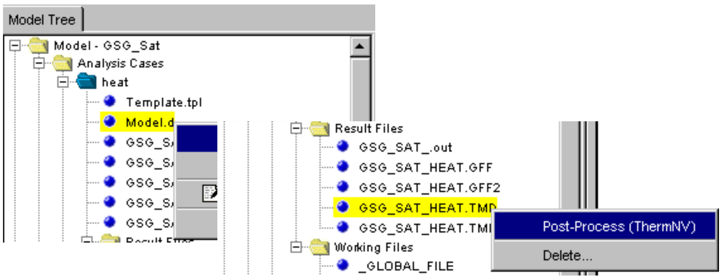
ESATAN-TMS Workbench – Analysis Case Tree Menu Options

- Implementation of a fast and efficient way of performing operation
  - User model files sorted in dedicated order
- Extended interactive model tree options
  - Dedicated Right click menu on specific files
  - Double click option on opening text file





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Conclusion

- ESATAN-TMS streamlines the complete thermal modelling process
- Enhanced functionalities of PcESATAN
- ESATAN-TMS Workbench is a fully integrated solution for thermal analysis

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www.esatan-tms.com
ALSTOM

Appendix J

Innovative Ray Tracing Algorithms for Space Thermal Analysis

Pierre Vueghs
(University of Liége, Belgium)

Abstract

The objective of the presentation is to give a short overview of the Ph.D. thesis entitled Innovative Ray Tracing Algorithms for Space Thermal Analysis, performed at the University of Liège in Belgium, with the support of ESA and the Belgian National Fund for Scientific Research (FNRS). In this presentation, we will mention the requirements that the final algorithm must fulfil; we will briefly present some key elements of the developed method, such as the hemisphere method, the combination of geometrical primitives with finite element meshes, statistical accuracy control and report. The validation aspects are then covered with comparison with analytical cases and industrial-ESARAD type models.

Innovative Ray Tracing Algorithms for Space Thermal Analysis

P. Vueghs (ULg/LTAS)

Supervisors:
Prof. P. Beckers (ULg/LTAS)
H.P. de Koning & O. Pin (ESA/ESTEC)
PhD thesis supported by the Belgian National Fund for Scientific Research (FNRS) under ESA Contract 20180/06/NL/PA

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Objectives

- Design a new ray tracing algorithm
  - that combines the advantages of *Esarad*–type tools and finite element formalism
  - that is still compatible with common software for space thermal engineering
- Obtain a faster ray tracing for comparable accuracy, mesh, …
- Develop an efficient and intuitive statistical accuracy control

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Innovative Ray Tracing Algorithms for Space Thermal Analysis 2008-10-28 sheet 2

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References to measure results

- *Esarad*
- *Samcef Bacon / Mecano Thermal*
- Simple test cases with analytical solution

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Innovative Ray Tracing Algorithms for Space Thermal Analysis

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Characteristics of *Esarad*

- Geometry based on primitive surfaces
  - triangle, quad, disc, sphere, cylinder, …
- Robust ray tracing
  - used for almost 20 years in industry
- Statistical accuracy control
  - although not fully implemented
- Thermal equations written in terms of REFs (GRs for solution with *Esatan*)

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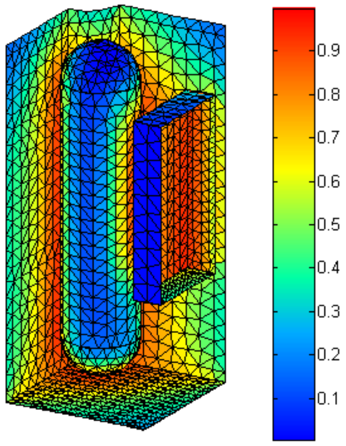
Characteristics of *Samcef* (1/2)

- Finite element model and formulation
- No geometrical primitives, but geometry approximated by triangular and/or quadrilateral facets
  - ⇒ Fast ray tracing on simple elements
- Gradient of the VFs on the FE mesh
- Possibility to treat multiple (more than two) wavelength bands



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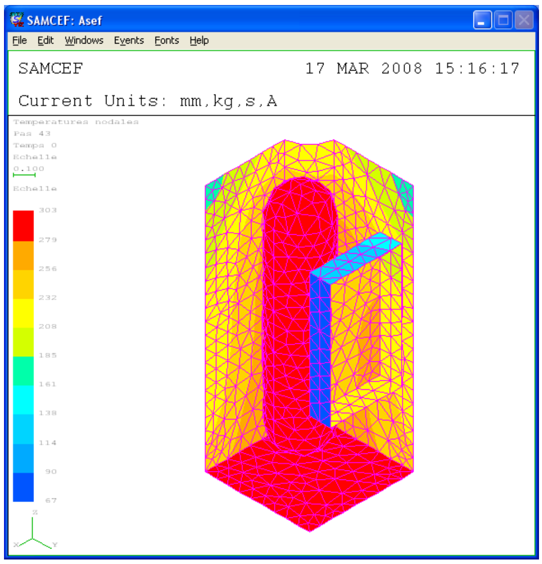
Characteristics of *Samcef* (2/2)

- Thermal equations written in terms of either VFs or REFs
  - Radiosity equations (VFs)
  - Gebhart equations (REFs)
- Smooth integration with heat conduction (directly on the FE mesh)
- Linear or quadratic temperature profile



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Common aspects

- VFs / REFs computed with purely random ray tracing
  – Random emission points on the faces
  – Random directions
- Uniform VF or REF per elementary surface patch
  – *Esarad* active face
  – *Samcef* finite element

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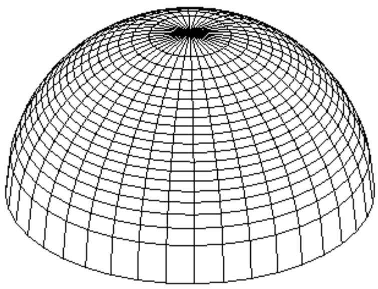
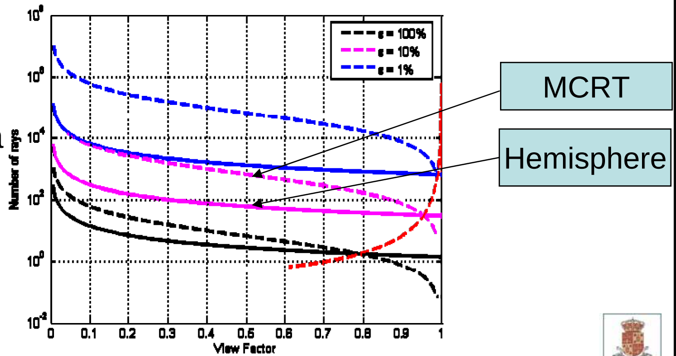
Solutions (1/4)

- Optimized generation of rays: *Hemisphere*
  – Better convergence
    - error α $1/N^{3/4}$
    - error α $1/N^{1/2}$ for MCRT
  – Adapted statistical accuracy control
  – Better than MCRT at handling large surface area differences





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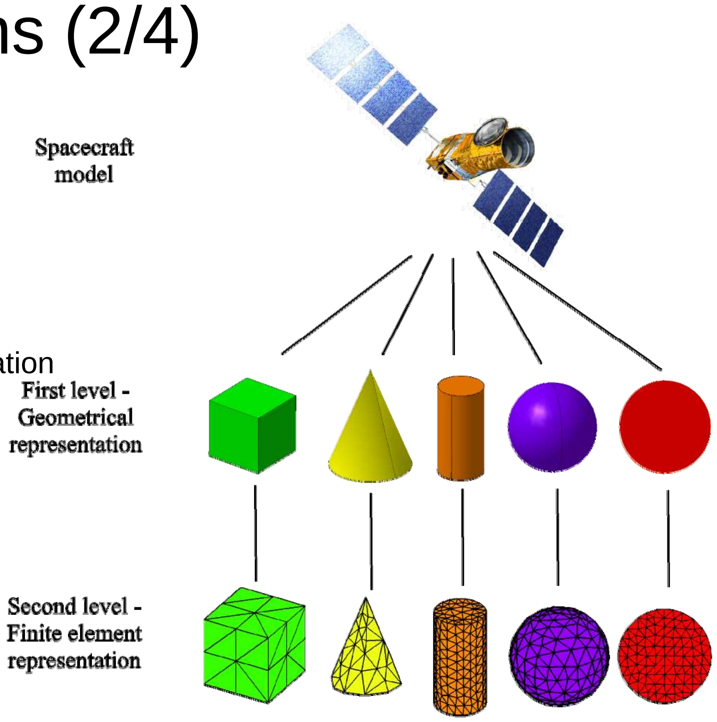
Solutions (2/4)

- Geometrical method
  - Geometrical model
  - Finite element mesh
  - ⇒ Combination
  - ⇒ Two level RT-acceleration method
- Geometrical model
  - ⇒ Radiation
- Finite element mesh
  - ⇒ Conduction



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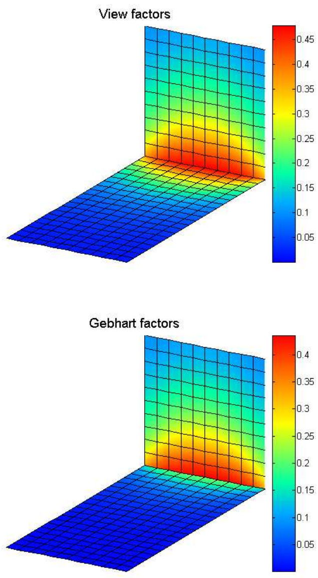
Solutions (3/4)

- Computation of VFs
  - And Extended VFs (EVFs) in case of specular reflection or transmission
- Use of the Gebhart's matrix method for REF's
  - Also in case of non-diffuse surfaces
  - Also in case of non-isothermal surfaces
  - Adaptive mesh for non-uniform mutual irradiation
- Complete ray tracing for absorbed heat fluxes



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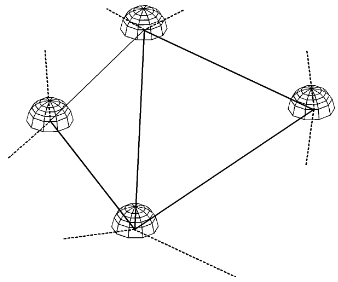
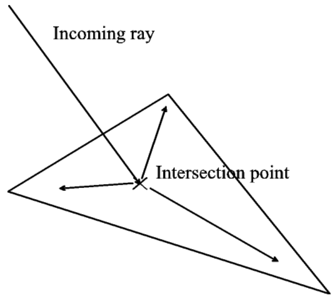
Solutions (4/4)

- Finite Element based VFs
  - Linear (or quadratic) VF field
  - Emission of the rays from the FE nodes
    - using the hemisphere method
  - Interpolation with the shape function
    - at the impact of each ray
  - Access to a detailed gradient of VF over each FE
  - Computation of temperatures on the FE nodes
    - Computation of extreme temperatures on auto generated mesh possible (e.g. identification of “hot spots”)





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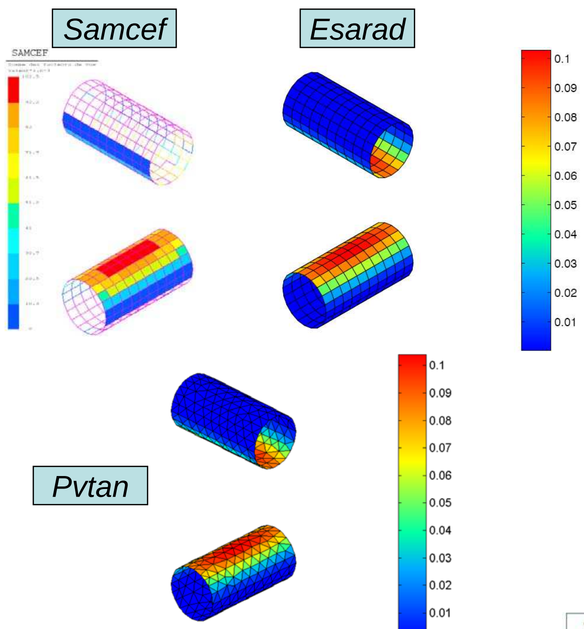
Validation (1/8)

- Small test cases
  - with analytical solutions
  - Convergence of the error with the number of rays
  - New method is well-behaved



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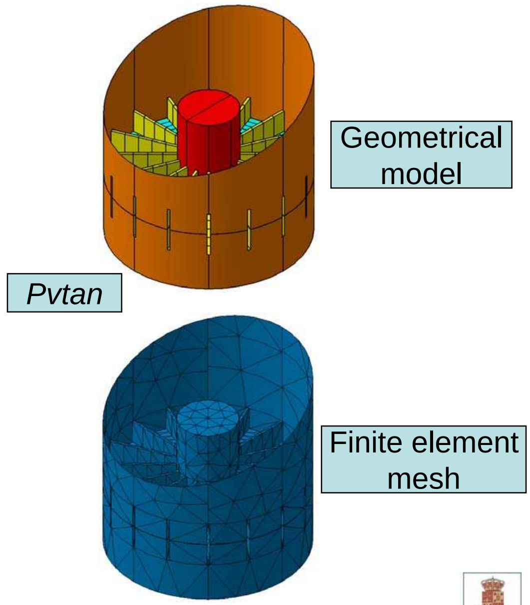
Validation (2/8)

- XEUS model
  - 1156 surfaces
  - Different primitives
  - Obstacles
  - Contains large and small surfaces
  - Large and small VF to deep space



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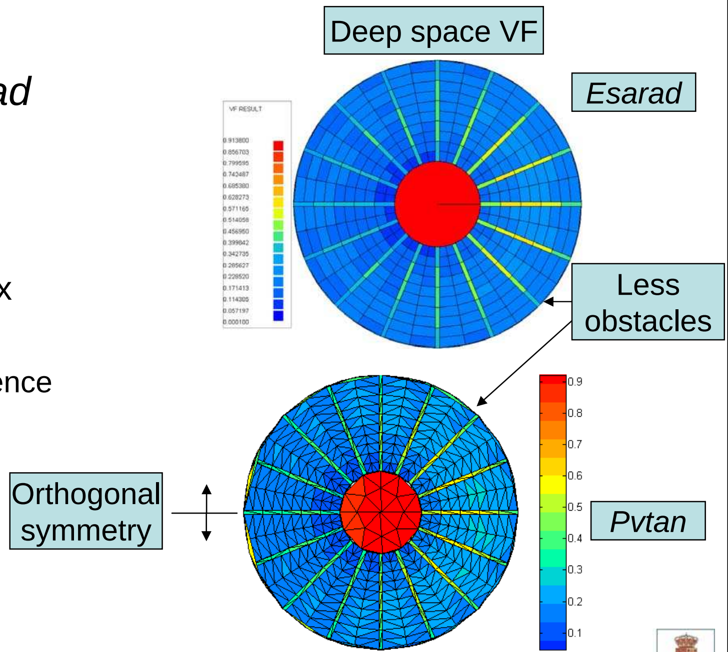
Validation (3/8)

- Comparison with *Esarad* and *Samcef*
  - Deep space VF & REF
  - Global VF & REF
  - Absorbed solar heat flux
  - Temperature field
    - First computed in absence of conduction, i.e. only radiative heat transfer taken into account



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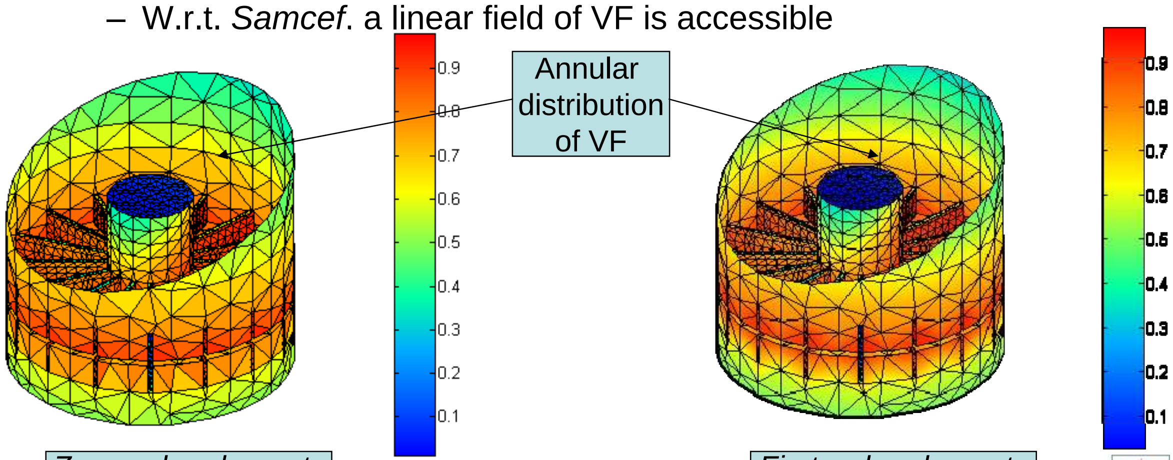
Validation (4/8)

- Finite element view factors
  - W.r.t. *Esarad*, a gradient is computed
  - W.r.t. *Samcef*. a linear field of VF is accessible



Zero order elements *First order elements*

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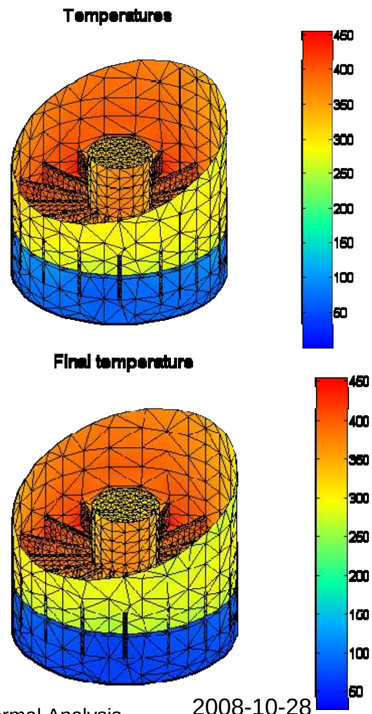
Validation (5/8)

- Second step: inclusion of conductive heat transfer in the shells
  - iterative scheme initiated with a first solution based on radiation only
- Temperature smoothing due to conduction



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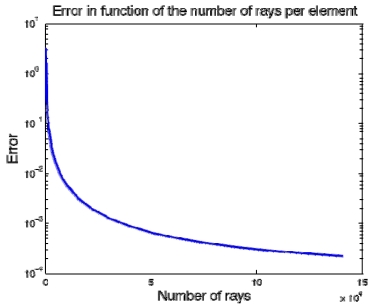
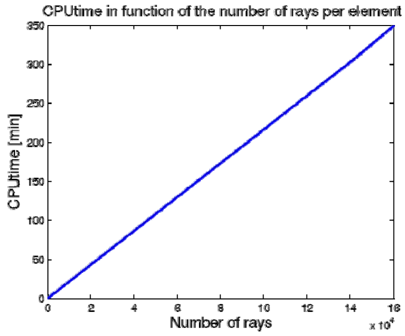
Validation (6/8)

- Mathematical behaviour



- CPU time
  - Linear with number of rays



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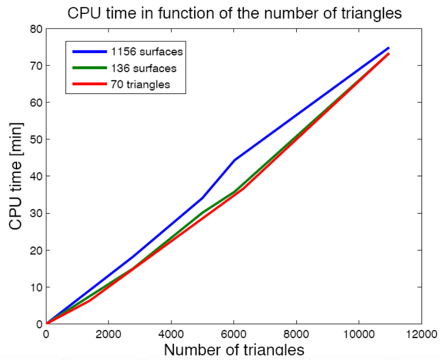
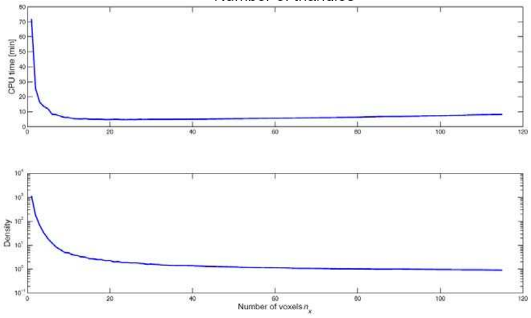
Validation (7/8)

- CPU time in function
  - Of the number of surfaces
  - Of the number of elements



- Acceleration of the ray tracing (voxels)



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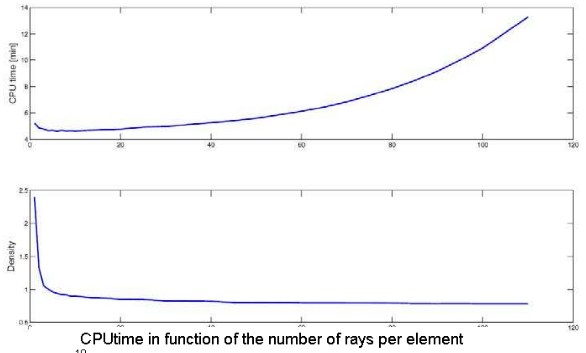
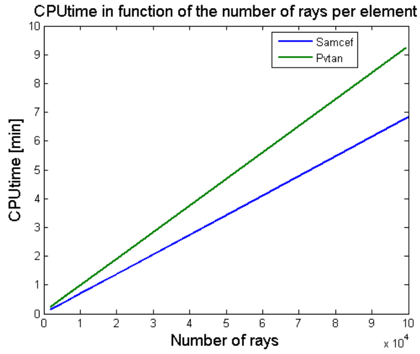
Validation (8/8)

- Acceleration of the ray tracing (geometrical method)



- Comparison CPU time *Samcef* and new algorithm
  - Currently *Pvtan* is about 1.25 times slower
  - But no performance tuning / profiling yet



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Perspectives (1/3)

- Optimal combination of the new algorithm's modules shows very promising potential for reduction of CPU time and memory usage for full orbit analysis
- (E)VFs could be used in place of REFs to avoid many multiple-reflection MCRT steps
  - In particular also for multiple wavelength bands
- Hemisphere Method can be extended to efficiently compute planet IR and albedo fluxes
  - Limit ray casting within solid angle from spacecraft to planet
  - Support for planet albedo and temperature (lat, long) maps

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Perspectives (2/3)

- Optimal combination of the new algorithm's modules enables CPU time and storage reduction
- for orbital simulations
  - Multi-reflection for each of the M spectral bands (cryogenics applications)
  - ⇒M ray tracings
  - Heat flux for each of the N orbit positions
  - ⇒ 3*N ray tracings
- We could reduce the number of RT
  - ⇒1 ray tracing for the couplings
  - Heat flux for each of the N orbit positions
  - ⇒ 2*N ray tracings for the heat fluxes

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Perspectives (2/3)

- N orbit positions
- M wavelength bands
- No moving geometry
- HM = Hemisphere Method

	Current *Esarad* & *Thermica*-like tools	New algorithm
VFs / REFs	• M * MCRT to compute REFs	• 1 * HM to compute (diffuse) VFs • M * ray-tracing for specular and/or transmission EVFs or 1 RT with M simultaneous updates
Planet fluxes	• 2N * MCRT to compute absorbed albedo and planet IR	• N * HM to compute planet VF • N * step to compute incident albedo and planet IR
Solar fluxes	• N * MCRT to compute absorbed solar	• N * ray-tracing to compute incident solar
Temperatures	• Solve REF (GR) based thermal equations (*Esatan*)	• Solve VF based thermal equations (radiosity, flux and temperature) • Solve REF based thermal equations

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Perspectives (3/3)

- New approach can support full accuracy control in all steps (VFs and fluxes)
- Integrates well with auto-generated FE meshes
- Supports radiative and conductive gradients over FE elements
- Has similar order of magnitude ray-tracing performance (per ray) as existing methods but needs significantly less rays for overall analysis case (e.g. one whole orbit)
- Thesis published in 2009

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Appendix K

THERMISOL
New features and demonstration

Timothée Soriano
(EADS Astrium, France)

Abstract

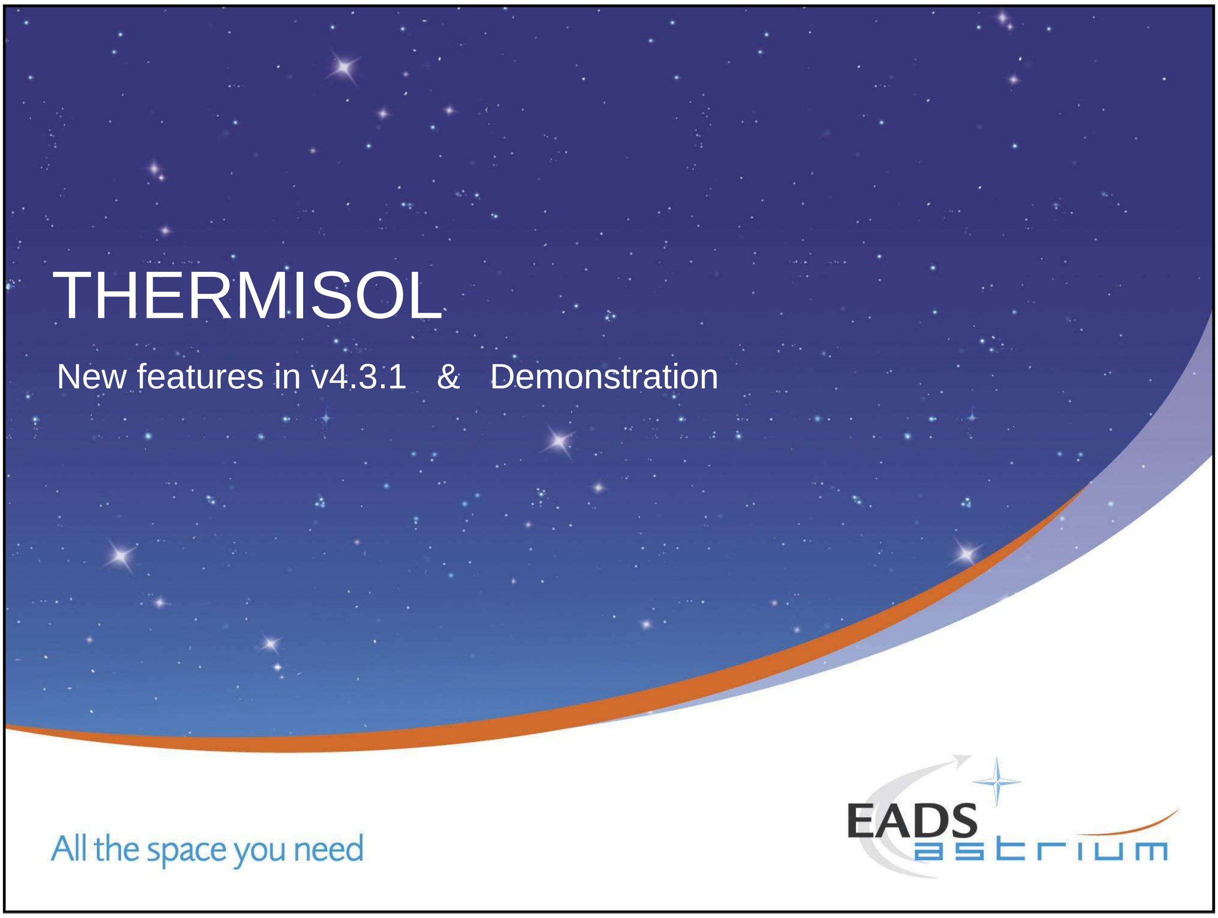
Brief presentation of THERMISOL modules:

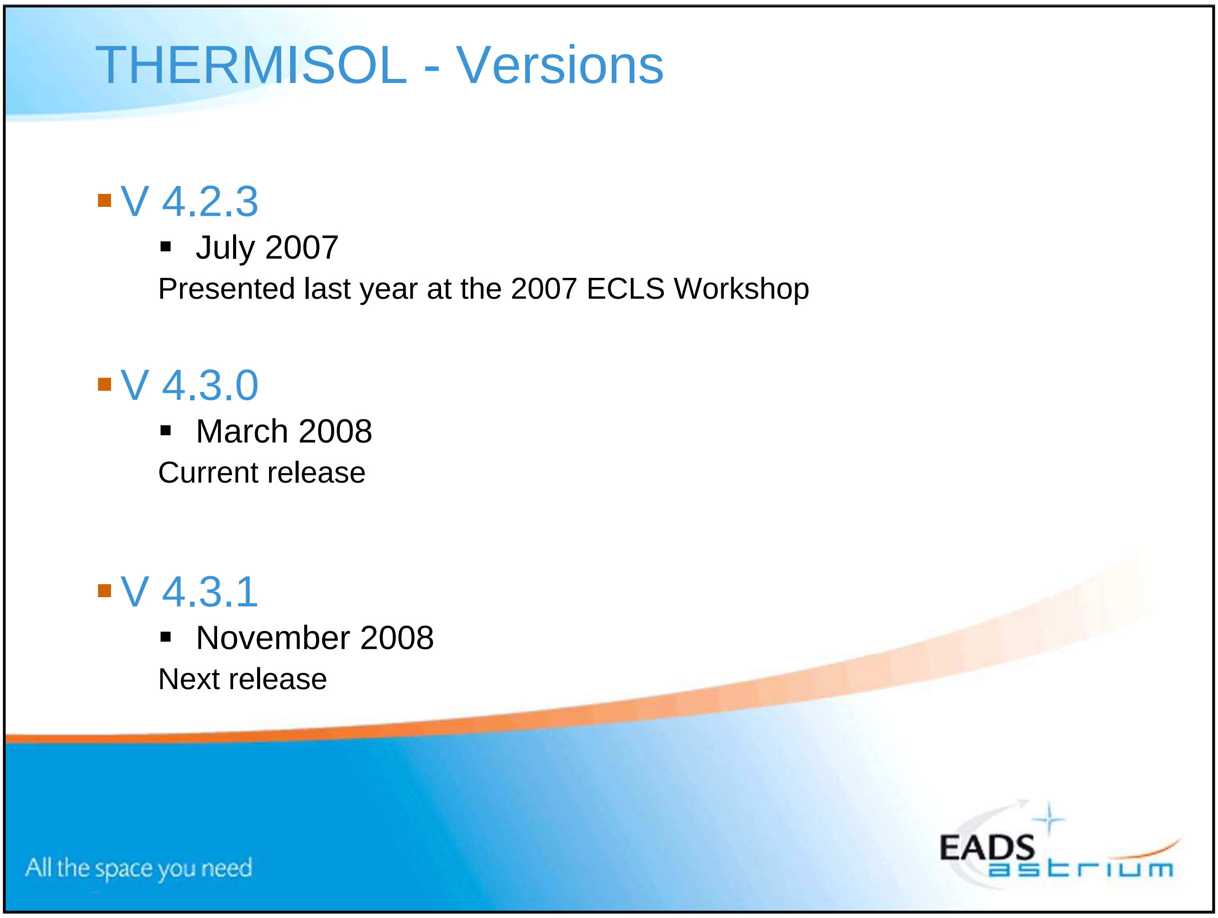
- Skeleton generator and expander
- Input file pre-processor (reader)
- Solver library
- Post-processing tools: Posther & B-Plot

Brief presentation of new features in THERMISOL 4.3.1

- Extension of implicit Mortran syntax
- Extension of the node specifications of output subroutines
- Automatic conversions of single floats to double precision floats
- New executive blocks: $VTEMPERATURE / $VTIME / $VRESULT
- Management of time events

Demonstration: Example of cold/hot cases study
Using a simplified model of a satellite, we will compute the temperatures in cold and hot case.


THERMISOL
New features in v4.3.1 & Demonstration
All the space you need
EADS
astrium


THERMISOL - Versions
V 4.2.3
July 2007
Presented last year at the 2007 ECLS Workshop
V 4.3.0
March 2008
Current release
V 4.3.1
November 2008
Next release
All the space you need
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THERMISOL modules

- Skeleton generator & expander
  - **Easy management** of THERMICA **outputs** for THERMISOL
  - Creation of **generic** skeleton and/or input files for THERMISOL
  - Use of **powerful** `#READ` **instructions** (including parametric reading instructions in batch mode)

THERMISOL modules

- THERMISOL pre-processor
  - **Fast** and **Robust** Pre-processor
  - Handle **very huge input files** in a few minutes (with more than a million couplings plus many variables)
  - **Automatic split** of **large Subroutines** for compilation optimization
  - Guaranty of **Double Precision**
  - Handle **complex MORTRAN syntax**

THERMISOL modules

- Solver Library
  - **Complete set of routines** for network management, outputs, mathematical functions and more
  - **Fast and Robust Solving routines** for Steady-State & Transient analyses (with many optimizations to prevent from divergence)
- POSTHER
  - Extract and Post-process Thermal Results (fluxes analyses, min/max studies…)
  - Export of Excel files
- B-Plot
  - Automatic graph generator (ps format)

All the space you need

EADS astrium

THERMISOL v4.3.1

- Extension of MORTRAN syntaxes
  - Node Data

T 1000		T:SUBMODEL:1000
Tvariable	T:variable	T:SUBMODEL:variable
T:(mathematical expression)		T:SUBMODEL:(mathematical expression)

  - New MORTRAN syntaxes

N	internal node number	
NS	node status	ex: NS 100 = ‘B’
GLS/GRS/GFS	coupling status	ex: GLS(1,2) = ‘X’

All the space you need

EADS astrium

THERMISOL v4.3.1

- Nodal entities
  - A **new block** can be declared before the $NODES one instead of the USERNOD.DAT:
    $ENTITIES
  - This block is **local** to a model
    - A model using user's defined nodal entities can be included as a sub-model without any modification of the model itself or the new main model
    - User's nodal entities are available in all the model concerned
  - **Output routines** can be called with user's nodal entities
    - For the nodes not concerned by the nodal entities will have no value ('-')

All the space you need

EADS astrium

THERMISOL v4.3.1 - ENTITIES

```
$MODEL TOTO

  $ENTITIES
     INTEGER       STATUS
     REAL          HEAT_DISSIP
     CHARACTER     POSITION

  $NODES
     D 100 = 'Equip +Z', T = 0,   STATUS = 0, HEAT_DISSIP = 120,  POSITION = 'ON' ;
     D 110 = 'Equip -Z',  T = 0,   STATUS = 0, HEAT_DISSIP =   70,  POSITION = 'ON' ;
     …

  $INITIAL [or $VTEMPERATURE or $VTIME or $VRESULT or $EXECUTION or $OUTPUTS]
    … STATUS100 = …
    … STATUS:100 …
    INODE = 100
    … STATUS:INODE …

  $OUTPUTS
    CALL PRNDTB(' ', 'T,QI,QR,STATUS,HEAT_DISSIP,POSITION', CURRENT)
```

Easy declaration

Easy initialization

Easy to use

Compatible with outputs

All the space you need

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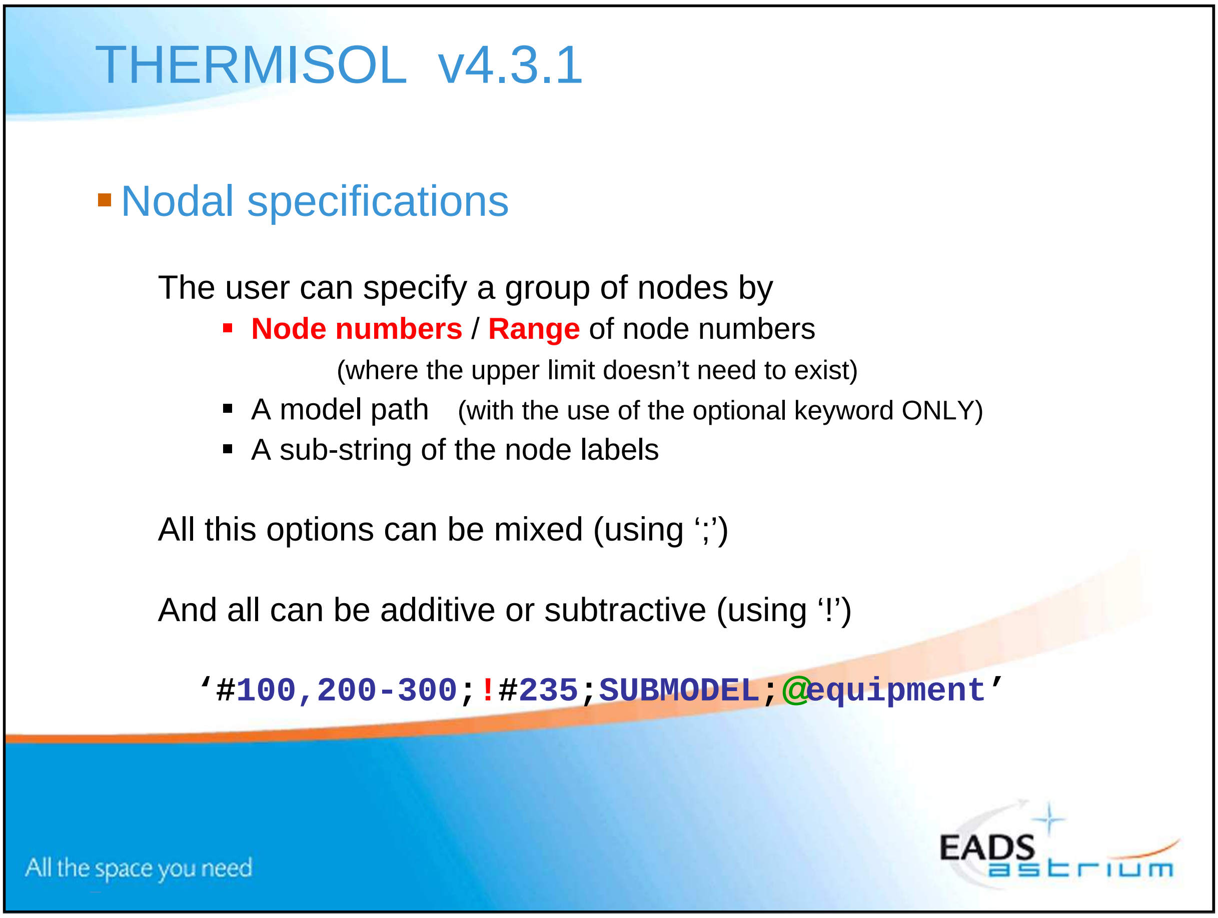
THERMISOL v4.3.1
Nodal specifications
The user can specify a group of nodes by
Node numbers / Range of node numbers
(where the upper limit doesn't need to exist)
A model path (with the use of the optional keyword ONLY)
A sub-string of the node labels
All this options can be mixed (using ';')
And all can be additive or subtractive (using '!')
'#100,200-300;!#235;SUBMODEL;@equipment'
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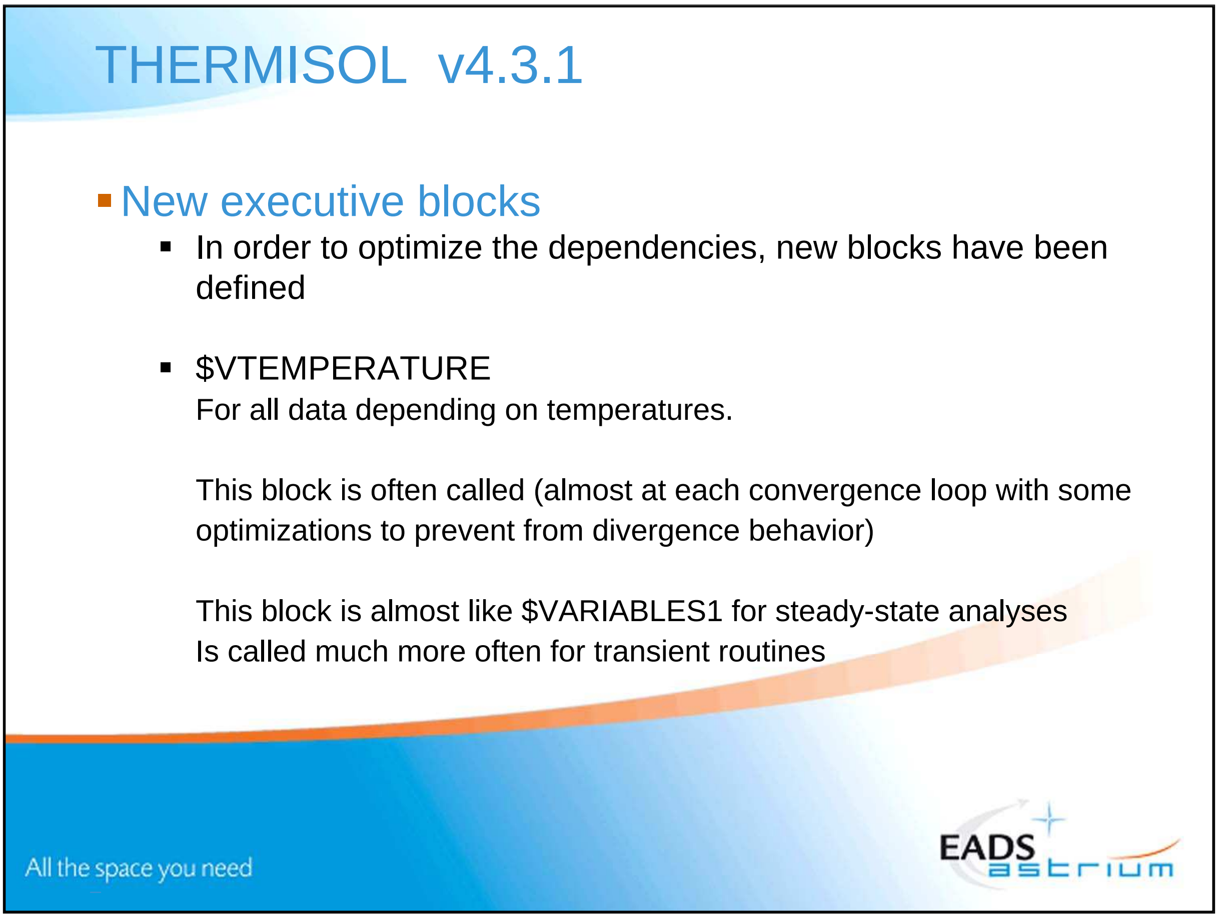
THERMISOL v4.3.1
New executive blocks
In order to optimize the dependencies, new blocks have been defined
$VTEMPERATURE
For all data depending on temperatures.
This block is often called (almost at each convergence loop with some optimizations to prevent from divergence behavior)
This block is almost like $VARIABLES1 for steady-state analyses
Is called much more often for transient routines
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THERMISOL v4.3.1

- $VTIME
  For all data depending on the simulation time

  This block is suitable for
  continuous time dependant phenomena
  (like external fluxes interpolations)
  and for time discrete phenomena
  (may require a use of an EVENT for a better numerical integration)

- $VRESULT
  For data that need to be updated after the temperatures have converged

  This block behaves exactly like $VARIABLES2

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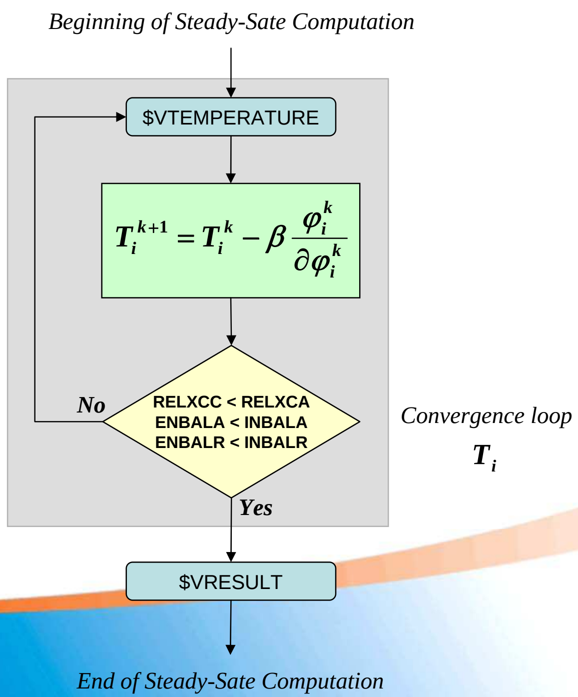
THERMISOL v4.3.1 – Steady State Process



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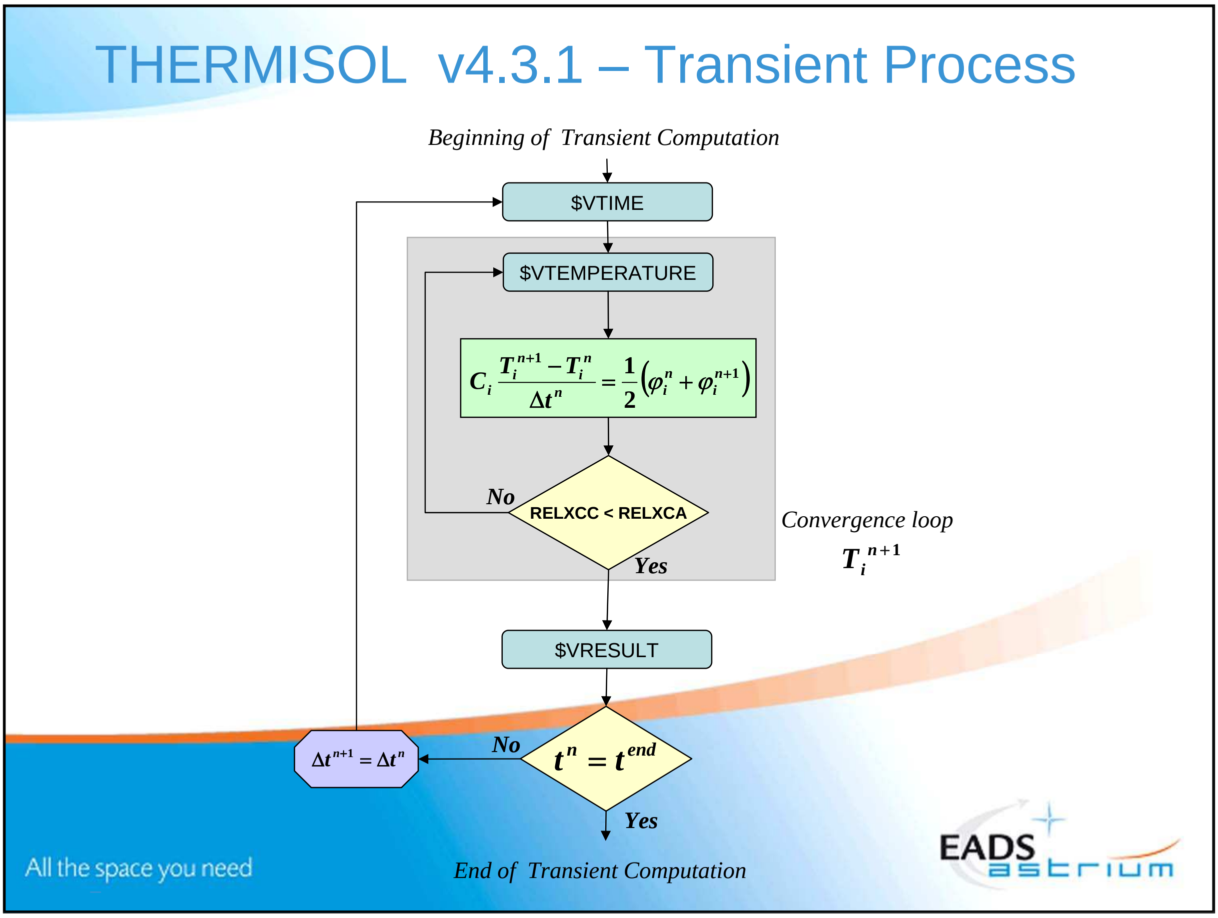
THERMISOL v4.3.1 – Transient Process
Beginning of Transient Computation
$VTIME
$VTEMPERATURE
$C_i \frac{T_i^{n+1} - T_i^n}{\Delta t^n} = \frac{1}{2}(\varphi_i^n + \varphi_i^{n+1})$
No
RELXCC < RELXCA
Yes
Convergence loop
T_i^{n+1}
$VRESULT
$\Delta t^{n+1} = \Delta t^n$
No
$t^n = t^{end}$
Yes
End of Transient Computation
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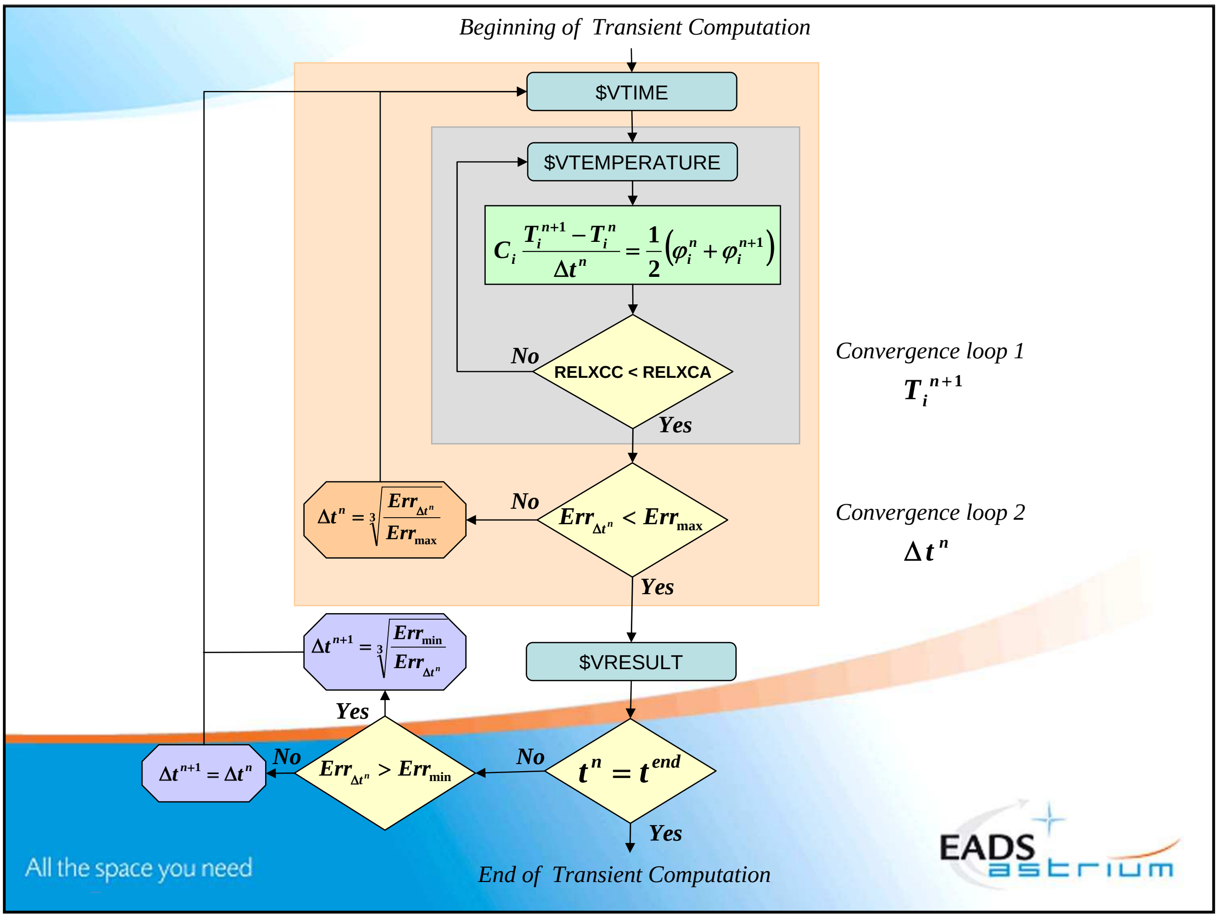
Beginning of Transient Computation
$VTIME
$VTEMPERATURE
$C_i \frac{T_i^{n+1} - T_i^n}{\Delta t^n} = \frac{1}{2}(\varphi_i^n + \varphi_i^{n+1})$
No
RELXCC < RELXCA
Yes
Convergence loop 1
T_i^{n+1}
$\Delta t^n = \sqrt[3]{\frac{Err_{\Delta t^n}}{Err_{max}}}$
No
$Err_{\Delta t^n} < Err_{max}$
Yes
Convergence loop 2
Δt^n
$\Delta t^{n+1} = \sqrt[3]{\frac{Err_{min}}{Err_{\Delta t^n}}}$
$VRESULT
Yes
$\Delta t^{n+1} = \Delta t^n$
No
$Err_{\Delta t^n} > Err_{min}$
No
$t^n = t^{end}$
Yes
End of Transient Computation
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THERMISOL v4.3.1

$EVENTS:

There are 2 types of EVENTS:

- $TIMESTEP
  Useful for discrete time phenomena
  Forces an update of fluxes in order to immediately take into account the discrete phenomena (no numerical inertia)

- $OUTPUT
  To add specific output times
  Forces a call to $OUTPUTS at that time

THERMISOL v4.3.1

$EVENTS declarations

```
$EVENTS
  $PERIOD                                  # Those are a real local constants
    ORBITAL_PERIOD = 5250.4;
    P_EQUIP = ORBITAL_PERIOD / 20;

  $TIMESTEP
    My_event = 123.45;                     # A time-step event
    New_event = My_event + 300;            # Another time event
    SWITCH_EQUIP = 32.0 [P_EQUIP1];        # A periodic time-step event

  $OUTPUT
    Out_event = 680.0;                     # A output event
    Periodic_out = 500.0 [500.0];
```

THERMISOL v4.3.1

▪ Use of EVENTS

```
AT My_event DO                     # The instructions will be executed only
   [instructions]                  #    if the current time is after the event
ENDDO

BEFORE SWITCH_EQUIP DO             # The instruction will be executed only
   [instructions]                  #    if the current time is before any odd
ENDDO                              #    occurrence of the periodic event

AFTER (SWITCH_EQUIP,2) DO          # The instruction will be executed only
   [instructions]                  #    if the current time is after the 2nd
ENDDO                              #    occurrence of the periodic event

BETWEEN My_event & New_event DO    # The instructions will be
   [instructions]                  # executed between the two
ENDDO                              # events
```

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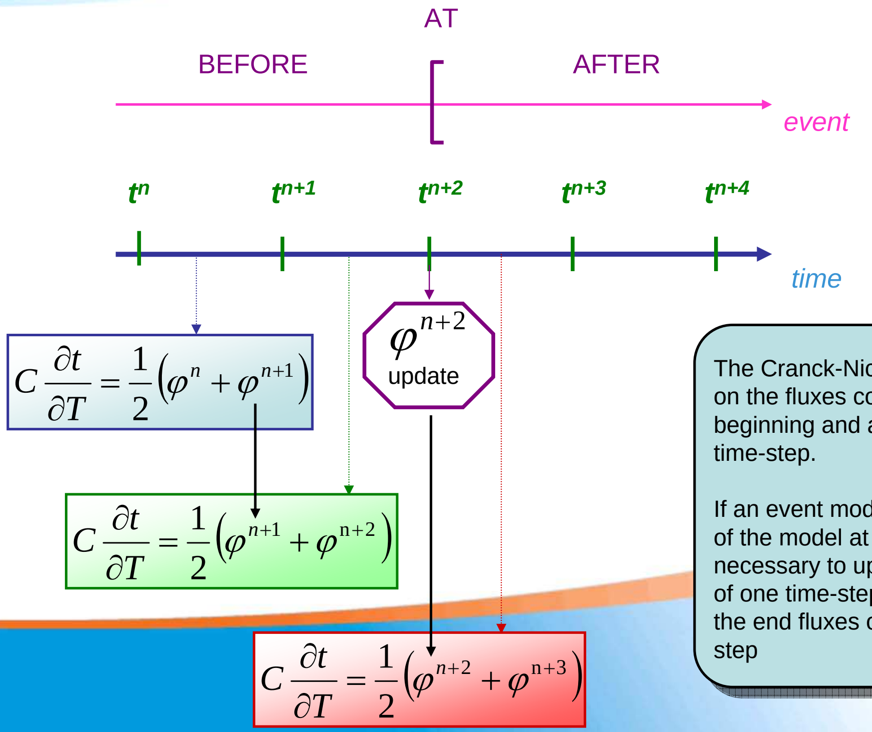
Crank-Nicholson with TIMESTEP events



The Cranck-Nicholson scheme lies on the fluxes computed at the beginning and at the end of one time-step.

If an event modifies the environment of the model at a specific time, it is necessary to update the initial fluxes of one time-step instead of re-using the end fluxes of the previous time-step

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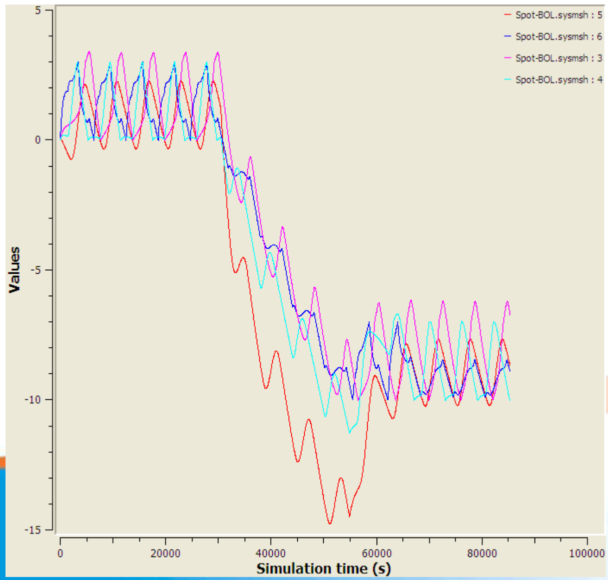
THERMISOL v4.3.1 - Demonstration

- Spot – Cold Case Study



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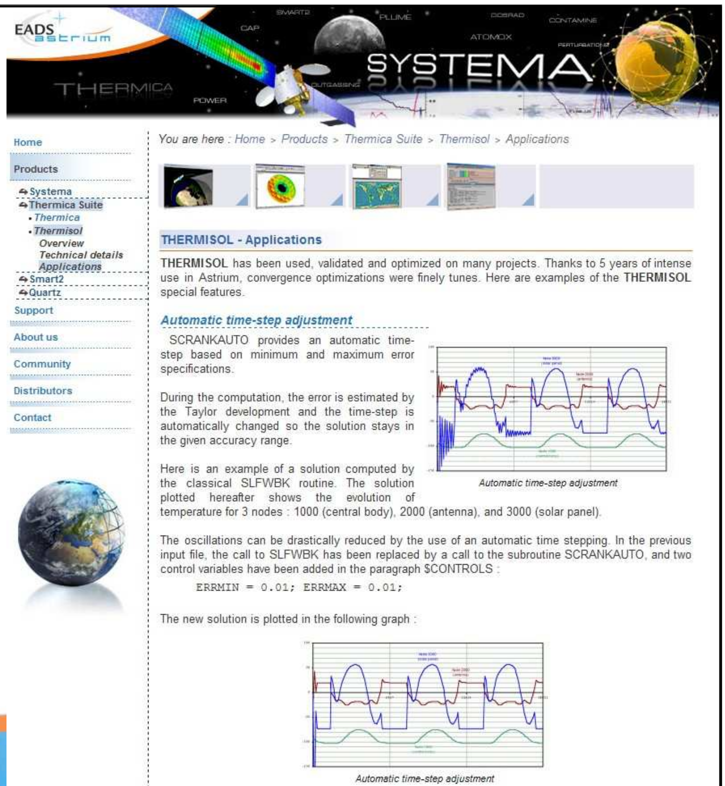
Contact :
timothee.soriano@astrium.eads.net



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Appendix L

Correlation of ESATAN TMM with Ice Sublimation Test

Anna Schubert
(EADS Astrium, Germany)

Abstract

During ascent of a previous ARIANE 5 launcher, the stage separation system (SSS) of the cryogenic upper stage (ESCA) exceeded its qualified lower temperature limit at the event of stage separation. Although a proper stage separation could be achieved for that flight, detailed studies followed this unexpected cold temperature drop. These investigations identified the formation of frost/ice on ground and its subsequent sublimation during ascent as the important contribution to the observed phenomenon. Consequently, counteractive measures have been successfully applied for subsequent flights, where up to now a temperature limit violation of the SSS has never been encountered again. For a better understanding of the sublimation effects which were caused by the ice layer on the launcher structure, sublimation tests have been performed. In these tests, an ice layer was applied on two different substrates, one of Plexiglas and one of Aluminium, which were equipped with thermocouples. The test setup was then placed in a vacuum chamber, which was evacuated, causing sublimation of the upper ice layer. During the evacuation, the pressure in the chamber was recorded, and the temperatures were measured in different positions in the ice layer and on both substrate surfaces.

In order to establish a correlation of thermal analyses with the results of the a.m. tests, two small thermal mathematical models (TMMs) were established with ESATAN, one for ice on Aluminium and one for ice on Plexiglas. They represent both the substrate and the ice layer and regard the sublimation heat flux through both, based on the pressure dependent sublimation mass flow rate. Both for the ice on Plexiglas and the ice on Aluminium, the results of the calculations show a very good overall accordance with the measured test results. The applied model, which is the focus of this presentation, is based on the Hertz-Knudsen relation with an evaporation coefficient of $\gamma = 0.3$, where the temperature dependent vapour pressure of ice is respected according to the Goff-Gratch-Equation.


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Correlation of ESATAN TMM with Ice Sublimation Test
Anna Schubert // October 28, 2008
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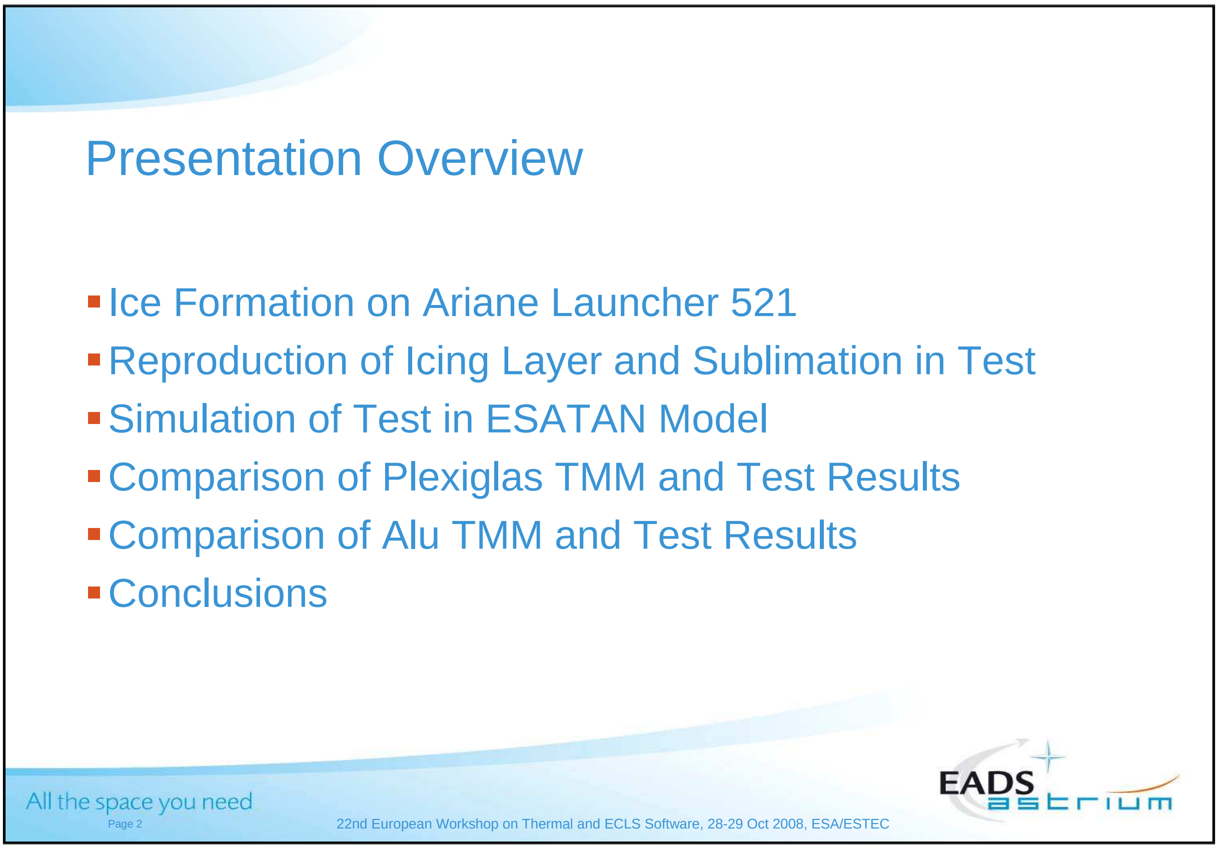
Presentation Overview
Ice Formation on Ariane Launcher 521
Reproduction of Icing Layer and Sublimation in Test
Simulation of Test in ESATAN Model
Comparison of Plexiglas TMM and Test Results
Comparison of Alu TMM and Test Results
Conclusions
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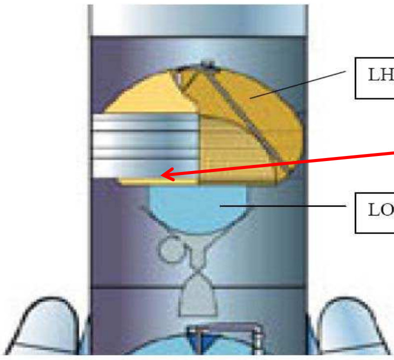
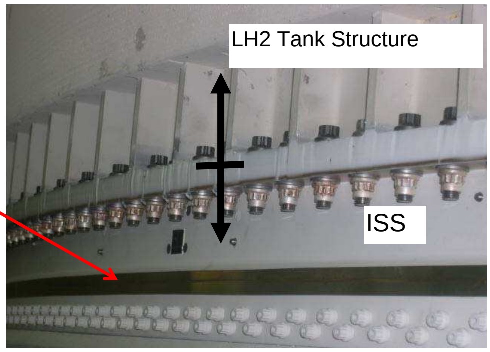
Ice Formation on Ariane 5 Launcher 521 (1/2)

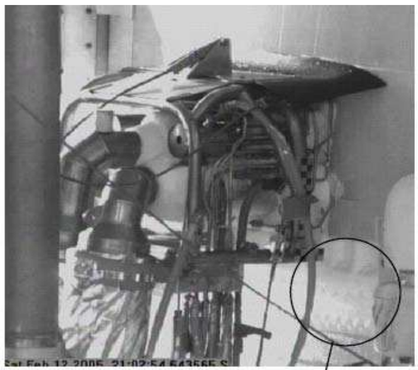
- Description of A5 ESC-A and Stage Separation System (SSS)





Ice Formation on Ariane 5 Launcher 521 (2/2)

- Below LH2 fill and drain coupling, the structure temperature reached values below 0°C.
- Ice layer formed due to humid environment
- During flight, the ice sublimated, and the adjacent structures temperatures dropped even further.
- Countermeasures for following flights: Flushed cover below LH2 and LOX fill and drain coupling and heater system on whole SSS (Stage Separation System) circumference to avoid ice layer formation



Reproduction of Icing Layer and Sublimation in Test (1/4)

- For better understanding of ice formation and sublimation during launcher ascent, the following tests were performed:
  - Frost formation test
  - Sublimation test with ice layer (2mm) on Plexiglas substrate
    - Plexiglas substrate: 70mm x 70mm x 2mm
    - Thermocouple within ice layer at 1.5mm above Plexiglas
  - Sublimation test with ice layer (5mm) on Aluminium substrate
    - Aluminium substrate: 60mm diameter, 5mm thickness
    - Thermocouples within ice layer in different heights, relevant for model correlation: 2mm and 4.5mm
    - Thermocouples on upper and lower side of Aluminium substrate

To be reproduced with ESATAN TMM

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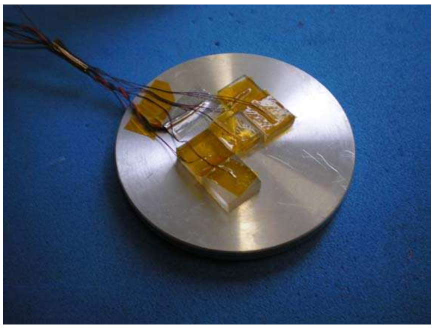
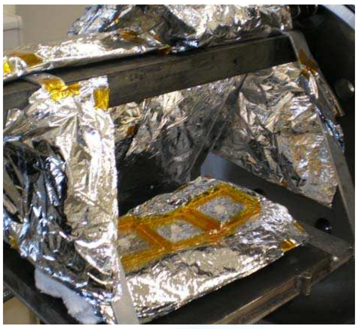
Reproduction of Icing Layer and Sublimation in Test (2/4)

- Sublimation Test Procedure:
  - Substrates equipped with thermocouples and prepared with ice layers were placed in a small chamber, which was evacuated. During evacuation, local temperatures and ambient pressure were measured.





Plexiglas substrates placed in vacuum chamber

Aluminium substrate equipped with thermocouples

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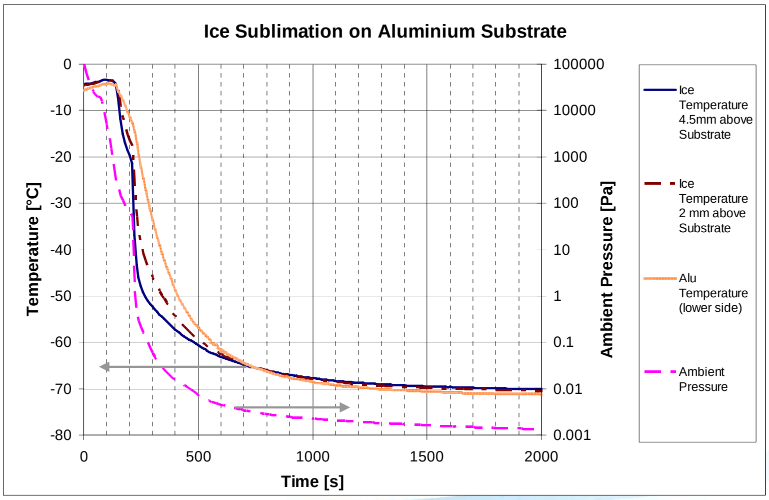
Reproduction of Icing Layer and Sublimation in Test (3/4)

- Test Results with Ice on Aluminium



- Ice temperature 4.5mm above substrate is decreasing until the end. This leads to the conclusion that the thermocouple is covered with ice until the end.

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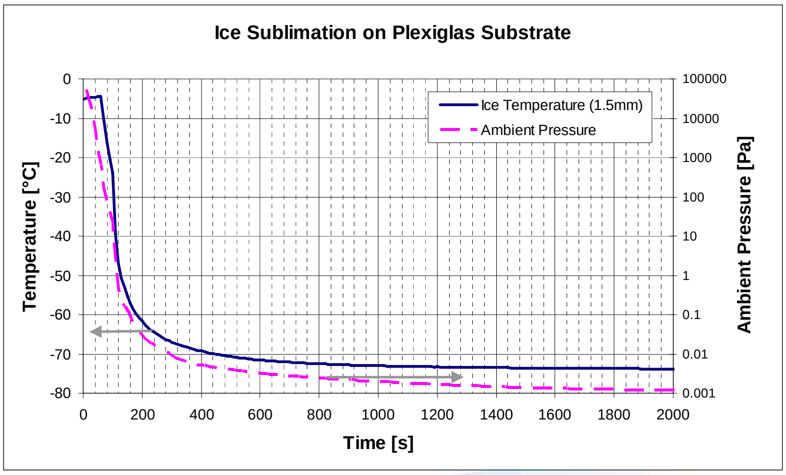
Reproduction of Icing Layer and Sublimation in Test (4/4)

- Test Results with Ice on Plexiglas



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Simulation of Test in ESATAN Model (1/4)

- How can the observed effects of ice layer sublimation be implemeted into a TMM?
  - Establishment of Model in ESATAN
  - Correlation of Test and Model Simulation

- Assumptions and Simplifications (1/3)
  - 1-dimensional heat transfer
  - Lower side of substrate is adiabatic
  - Plexiglas supports for thermocouples neglected
  - Radiation neglected
  - Convection due to evacuation neglected
  - Vaporized ice / water has no impact on vapor concentration

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Simulation of Test in ESATAN Model (2/4)

- Assumptions and Simplifications (2/3)
  - Only heat flux caused by ice sublimation: $\dot{q} = \dot{m} \cdot H_{sub}$
  - Mass flow rate (per m²) based on Hertz-Knudsen relation: $\dot{m} = \dfrac{\gamma \cdot (p_{vap} - p_{amb})}{\sqrt{\dfrac{2 \cdot \pi \cdot \Re \cdot T_S}{M_{H_2O}}}}$
  - Consequential decrease of ice layer thickness: $\dot{t} = \dfrac{\dot{m}}{\rho_{ice} \cdot A}$

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Simulation of Test in ESATAN Model (3/4)

- Assumptions and Simplifications (3/3)
  - Temperature dependent vapour pressure of ice [in hPa] from Goff-Gratch Equation:

$$\left.\begin{aligned}\log_{10}(p_{vap}) = &- 9.09718 \cdot (273.16 / T_S - 1)\\ &- 3.56654 \cdot \log_{10}(273.16 / T_S)\\ &+ 0.876793 \cdot (1 - T_S / 273.16)\\ &+ \log_{10}(6.1071)\end{aligned}\right\} \rightarrow p_{vap} \text{ in hPa}$$

  - Sublimation enthalpy calculated from melting and vaporising enthalpies:

$$H_{sub} = H_{melt}(T_S) + H_{vap}(T_S)$$
$$= -2.13 \frac{J}{kg \cdot K} \cdot T_S + 248.5 \frac{J}{kg} + 2.33 \frac{J}{kg \cdot K} \cdot T_S - 3134 \frac{J}{kg}$$

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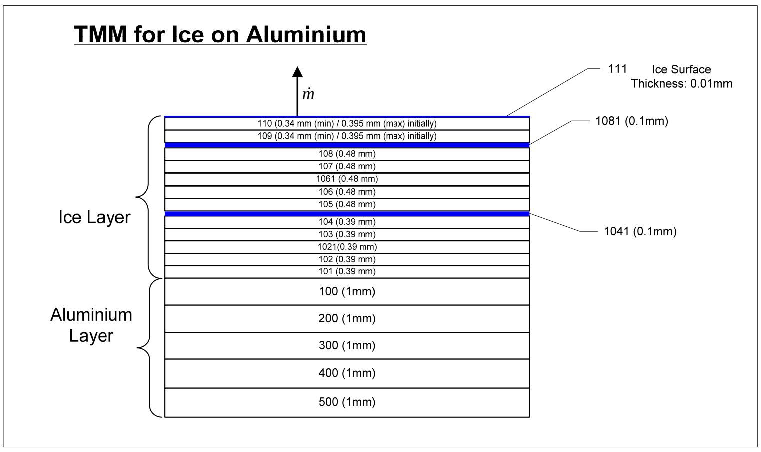
Simulation of Test in ESATAN Model (4/4)



- One very thin ice surface layer (0.01mm)
- Two thin ice layers representing the thermocouple locations (0.1mm each)
- Two ice layers with variable thickness (initially 0.34mm (min.) and 0.395mm (max.) each)
- All other ice layers with fixed thickness of 0.39mm / 0.48mm each
- Five Aluminium layers (1mm each)

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Simulation of Test in ESATAN Model

- Further assumptions for TMM
  - Filling uncertainty for ice layer: ±0.2 mm
  - Ice layer thickness increased by 3% due to expansion
    - → + 0.06 mm for ice on Plexiglas
    - → + 0.15 mm for ice on Aluminium
  - Ice on Aluminium: Min. thickness constraint, because thermocouple at 4.5 mm is constantly covered with ice → $t_{ini,min}$= 5.24mm instead of 4.95mm
  - **Ice on Alu** initial thicknesses: $t_{ini,min}$ = 5.24 mm; $t_{ini,max}$ = 5.35 mm
  - **Ice on Plexiglas** initial thicknesses: $t_{ini,min}$ = 1.86 mm; $t_{ini,max}$ = 2.26 mm

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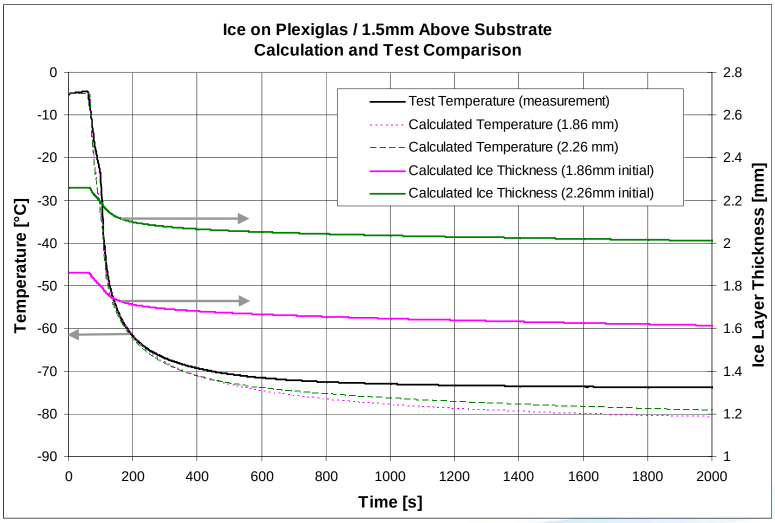
Comparison of Plexiglas TMM and Test Results



- Evaporation coefficient: **γ = 0.3**
- Sensitivity on ice thickness: Min. and max. ice layer thickness, taking into account filling uncertainty
- Good accordance in the beginning, but after 200s, TMM and test results drift apart constantly
- In test, temperature rises during the first 100s. This is not reflected in the simulation, because lateral effects (like radiation, convection, etc.) were neglected

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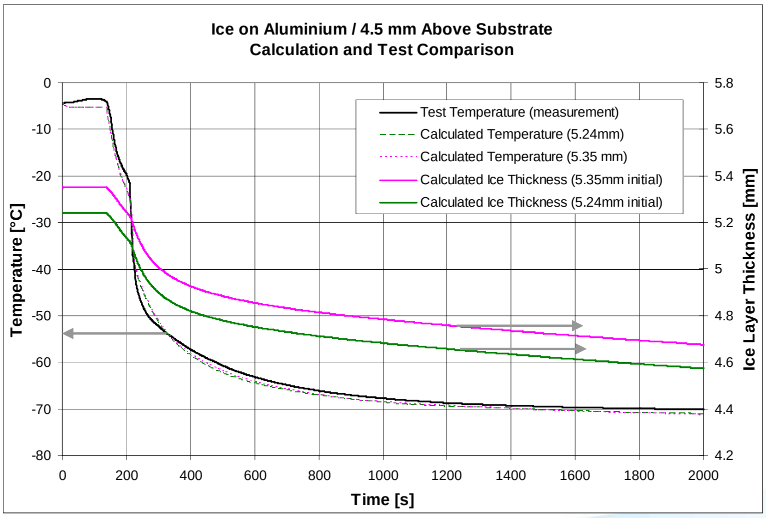
Comparison of Alu TMM and Test Results (1/3)



- Evaporation coefficient: **γ = 0.3**
- Sensitivity on ice thickness: Min. and max. ice layer thickness, taking into account filling uncertainty
- Good accordance, especially regarding the „bends“ in the temperature evolution
- In test, temperature rises during the first 100s. This is not reflected in the simulation, because lateral effects (like radiation, convection, etc.) were neglected

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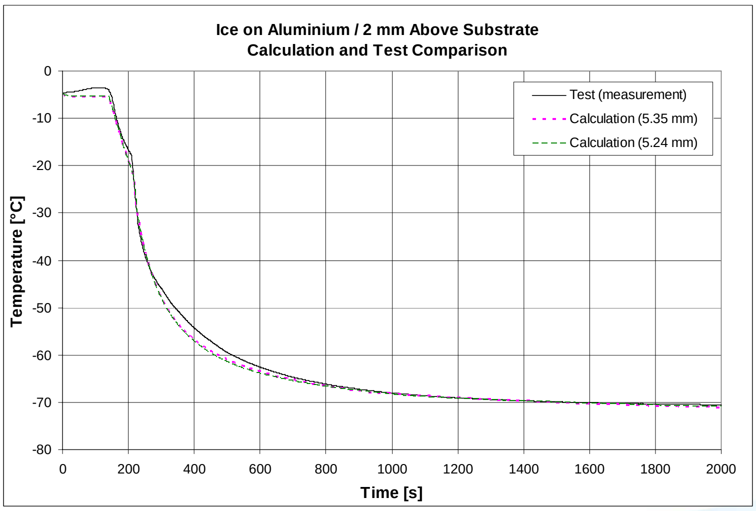
Comparison of Alu TMM and Test Results (2/3)



- Evaporation coefficient: **γ = 0.3**
- Good accordance, especially regarding the „bends“ in the temperature evolution
- In test, temperature rises during the first 100s. This is not reflected in the simulation, because lateral effects (like radiation, convection, etc.) were neglected

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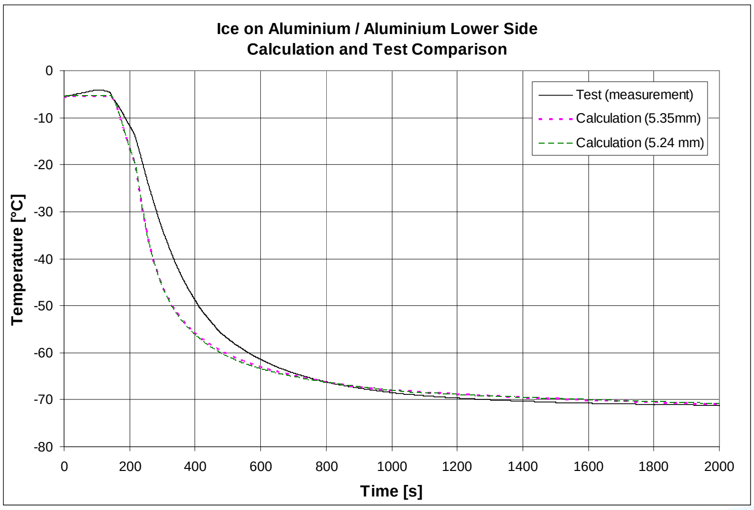
Comparison of Alu TMM and Test Results (3/3)



- Slower temperature drop in reality compared to simulation
- Possible reason: Plexiglas supports for thermocouples constrain heat flux through ice layer

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Conclusions

- Good overall accordance between test results and simulation results
- Evaporation coefficient used in the Hertz-Knudsen relation:

  γ **= 0.3**

- TMM for Ice on Aluminium : Slower temperature drop observed for lower thermocouples (esp. Alu lower side) compared to calculations. Possible reason: Impact of plexiglas supports not negligible
- Refined model extended from 1D to 3D, which regards thermocouple supports, would be favourable.
- New tests, with emphasis on improvement of thermocouple supports and prescision of ice layer thickness would be favourable.

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Appendix M

Improved Handling of Thermal Test Results

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

Etiènne Cavro
(Intespace, France)

Abstract

Last year Intespace implemented under ESA contract in DynaWorks a number of features to improve the processing of thermal test results. This presentation will show what they were and discuss further work in this area.
The improvements focussed on:

- Simple, near-realtime import of EGSE sensor data;
- Import of ESATAN analysis predictions into DynaWorks, so that predictions and life test results could be compared interactively;
- Archiving of complete thermal test campaigns for future post-test consultation.

The improvements will be illustrated at hand of real test campaigns in which the new features were validated.

Improved Handling of Thermal Test Results

Hans Peter de Koning (ESA/ESTEC, Noordwijk, The Netherlands)
Etiènne Cavro (Intespace, Toulouse, France)

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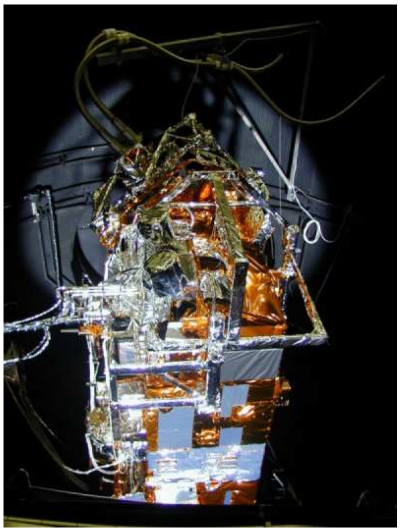
Mechanical Engineering Department
Thermal and Structures Division

Background

- Thermal testing is an essential activity in the development of a space system
- It is also very costly
- Need to improve process with good ICT
  - Main users are thermal engineers from customer and supplier (e.g. ESA and prime contractor)
  - Both during test and post-test
- Although many advances over the years quite a number of bottlenecks remain
- Main thermal test tools in use in ESTEC (LSS): DynaWorks® and STAMP



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Activity "Improved access to thermal test data"

- CCN to an existing ESA contract with Intespace
- Performed mainly by Etiènne Cavro
- Developed as part of DynaWorks®
- Started January 2007
- Completed January 2008

Objectives for "Improved access to thermal test data"

Increase effectivity and efficiency of thermal engineer performing thermal tests by:

1. Collecting all relevant test data in near-real time in a single database
   - so that simultaneous and synthesized monitoring, viewing, processing and analysis of such data can be performed in a single test data processing tool
   - in particular sensor readings coming from other sources than the test facility itself, e.g. flight sensors in spacecraft or instruments through EGSE, ...
2. Providing on-line access to an archive of thermal tests performed in the past
   - which can be browsed through user level queries
   - from which past test information and results data can be retrieved in a format that can be processed readily in the same data processing tool
3. Providing real-time access to relevant thermal analysis predictions
   - which can be loaded and viewed in the same data processing tool

Collecting all relevant test data in near-real time in a single database (1/4)

- Test facility sensor data and EGSE mission/instrument specific sensor data
  - Test facility sensor data is routinely provided
- Original idea was to do an import interface with SCOS2000 EGSE
  - SCOS2000 is the ground station software platform used by ESOC on majority of ESA missions for TMTC, and therefore also for EGSE
- The SCOS2000 CORBA interface documentation and API turned out to be too complex
  - Too complex to implement within the frame of this limited activity
  - Also no "dry run" environment available out-of-the-box (e.g. test data server simulating EGSE)
- General problem: EGSE in isolated network – no external connection allowed
- Decided on simple fallback solution using an enhanced CSV format and FTP connection

CSV = Comma Separated Value

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Collecting all relevant test data in near-real time in a single database (2/4)

- Proof of concept with SMOS thermal balance test April 2007 in ESTEC LSS
  - Prime contractor: CASA
- Proof of concept importing from SMOS EGSE sensor data successful
  - Also thanks to simple CSV format file made available by CASA
  - Actual data file transfer using USB stick approximately two times per hour
  - DynaWorks CSV import handles a-sychronous import of sensors scans well
    - Performs bookkeeping w.r.t .timestamp of scan
    - Handles duplicate scans gracefully – warns for differences for already imported timestamp
    - Can catch up with large import intervals
- Went on to generalise the CSV format in pragmatic manner

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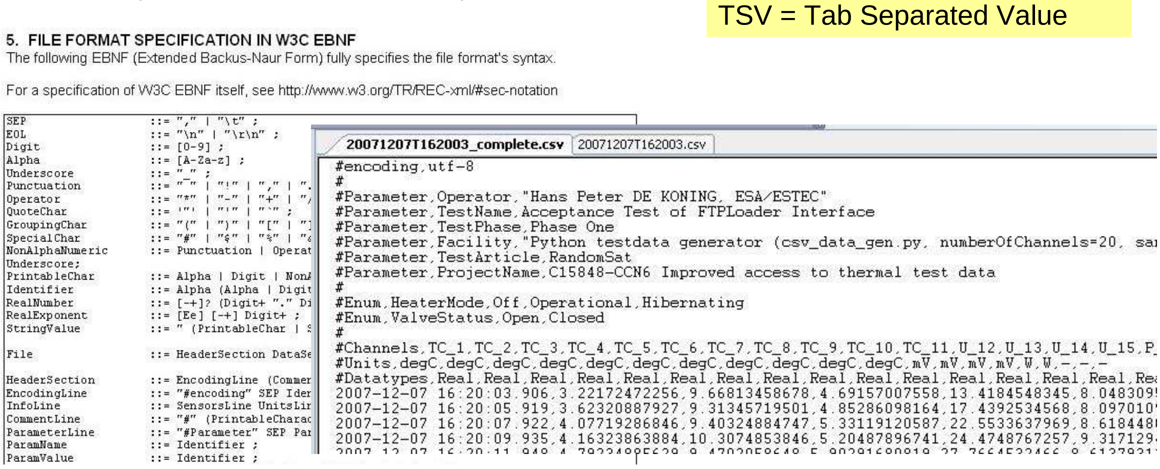
Sheet 6

Collecting all relevant test data in near-real time in a single database (3/4)

- Extended CSV or TSV format with formal specification
  - Compatible with Excel .csv or tab-separated .txt

CSV = Comma Separated Value
TSV = Tab Separated Value



5. FILE FORMAT SPECIFICATION IN W3C EBNF

The following EBNF (Extended Backus-Naur Form) fully specifies the file format's syntax.

For a specification of W3C EBNF itself, see http://www.w3.org/TR/REC-xml/#sec-notation

```
SEP              ::= "," | "\t" ;
EOL              ::= "\n" | "\r\n" ;
Digit            ::= [0-9] ;
Alpha            ::= [A-Za-z] ;
Underscore       ::= "_" ;
Punctuation      ::= " " | "!" | "," | ".
Operator         ::= "*" | "-" | "+" | "/
QuoteChar        ::= '"' | "'" | "`" ;
GroupingChar     ::= "(" | ")" | "[" | "]
SpecialChar      ::= "#" | "$" | "%" | "&
NonAlphaNumeric  ::= Punctuation | Operat
Underscore;
PrintableChar    ::= Alpha | Digit | NonA
Identifier       ::= Alpha (Alpha | Digit
RealNumber       ::= [-+]? (Digit+ "." Di
RealExponent     ::= [Ee] [-+] Digit+ ;
StringValue      ::= " (PrintableChar | S

File             ::= HeaderSection DataSe

HeaderSection    ::= EncodingLine (Commer
EncodingLine     ::= "#encoding" SEP Ider
InfoLine         ::= SensorsLine UnitsLir
CommentLine      ::= "#" (PrintableCharac
ParameterLine    ::= "#Parameter" SEP Par
ParamName        ::= Identifier ;
ParamValue       ::= Identifier ;
```

20071207T162003_complete.csv | 20071207T162003.csv

```
#encoding,utf-8
#
#Parameter,Operator,"Hans Peter DE KONING, ESA/ESTEC"
#Parameter,TestName,Acceptance Test of FTPLoader Interface
#Parameter,TestPhase,Phase One
#Parameter,Facility,"Python testdata generator (csv_data_gen.py, numberOfChannels=20, sa
#Parameter,TestArticle,RandomSat
#Parameter,ProjectName,C15848-CCN6 Improved access to thermal test data
#
#Enum,HeaterMode,Off,Operational,Hibernating
#Enum,ValveStatus,Open,Closed
#
#Channels,TC_1,TC_2,TC_3,TC_4,TC_5,TC_6,TC_7,TC_8,TC_9,TC_10,TC_11,U_12,U_13,U_14,U_15,P_
#Units,degC,degC,degC,degC,degC,degC,degC,degC,degC,degC,degC,mV,mV,mV,mV,W,W,-,-,-
#Datatypes,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Real,Re
2007-12-07 16:20:03.906,3.22172472256,9.66813458678,4.69157007558,13.4184548345,8.048309
2007-12-07 16:20:05.919,3.62320887927,9.31345719501,4.85286098164,17.4392534568,8.097010
2007-12-07 16:20:07.922,4.07719286846,9.40324884747,5.33119120587,22.5533637969,8.618448
2007-12-07 16:20:09.935,4.16323863884,10.3074853846,5.20487896741,24.4748767257,9.317129
```

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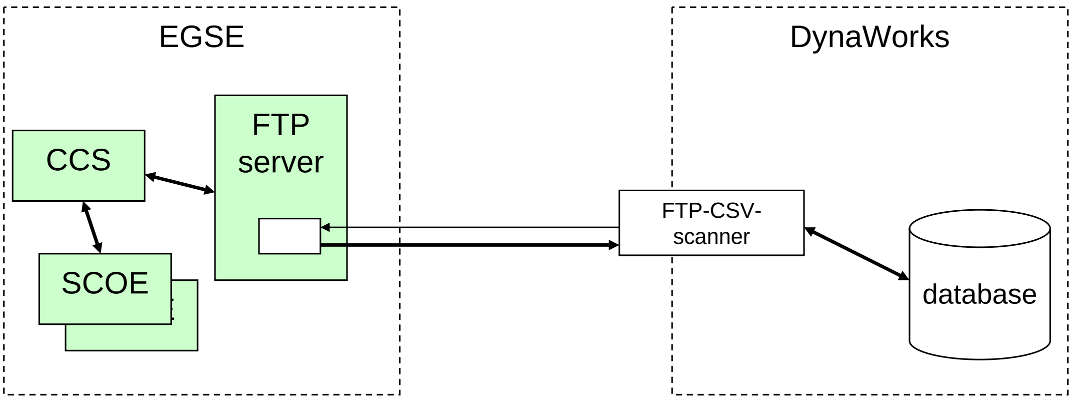
Sheet 7

Collecting all relevant test data in near-real time in a single database (4/4)

- Simple FTP transfer using "directory polling handshake"



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Sheet 8

Providing on-line access to an archive of thermal tests performed in the past

- Basically this is using existing functionality in DynaWorks
- Procedure written how to perform import of existing DynaWorks post-test databases
  - Including details on "Thermal" database schema
- Can browse over a number of projects / tests / testphases
- Trials performed with Rosetta, Venus Express and SMOS data
- Should be developed into an ESA archive of tests performed
  - Not done yet due to lack of time on ESA's side
- In future should be possible to consult results from past test campaigns through a network connection to the archive server while performing a test
  - E.g. useful in anomaly investigations

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Sheet 9

Providing real-time access to relevant thermal analysis predictions (1/2)

- Goal: test predictions from analysis (e.g. ESATAN) available during test
  - In same database and display as actual live test results
- Analysis predictions loaded before test begins
- Provide time shift function to match transients
- Implemented proof-of-concept STEP-TAS import interface in DynaWorks
  - Uses same STEP-TAS results files as ESATAP
  - Created new DynaWorks Thermal database schema to accommodate STEP-TAS concepts
  - Shows interesting future capability to connect analysis and testing
  - Pre-cursor to component for near-real-time test correlation
- As quick intermediate solution can also use adapted ESATAN CSV format
  - For ad-hoc CSV "quick-and-dirty" converter development
    the csv module that comes with the free Python environment proved to be excellent

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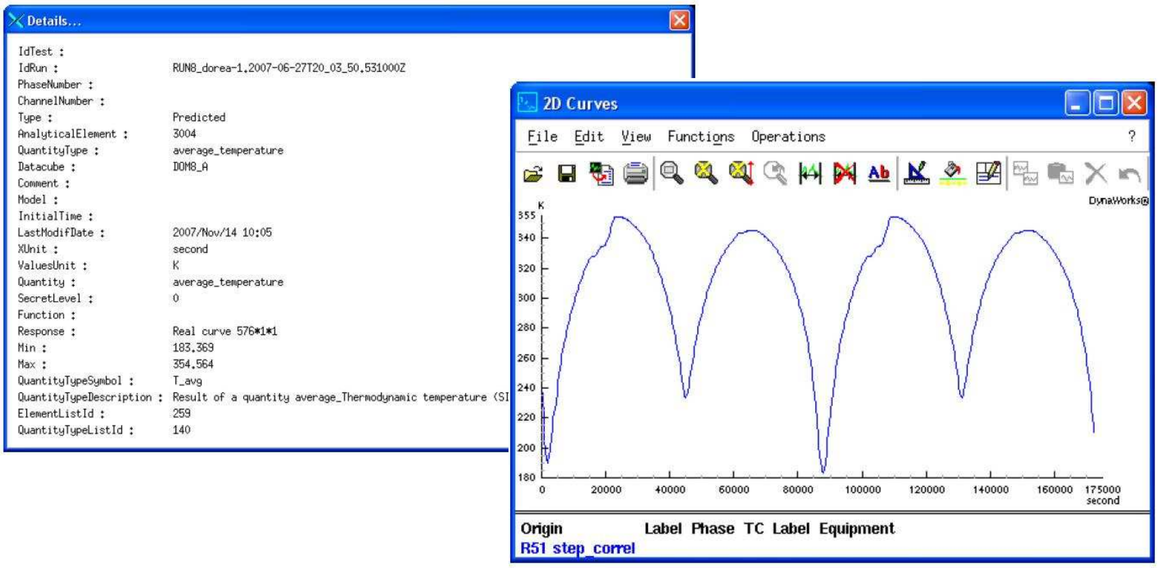
Providing real-time access to relevant thermal analysis predictions (2/2)



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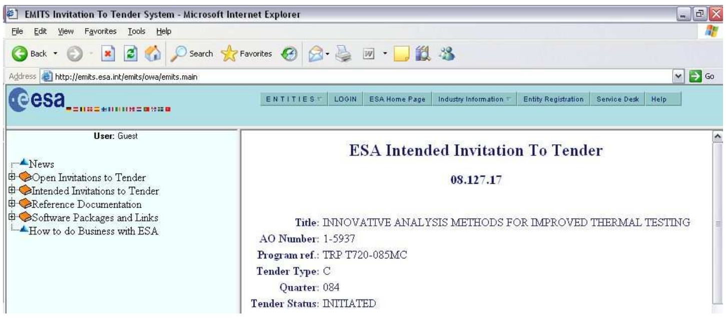
Sheet 11

New TRP ITT (AO 1-5937) "Innovative Analysis Methods for Improved Thermal Testing"

- ITT open this week – 300kEuro earmarked
- Critical assessment of bottlenecks in thermal testing – propose innovative solutions
  - E.g. near-real-time test correlation, sensor locations and results in 3D visualisation, early prediction of thermal equilibrium
- Implementation and validation in beta release software



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Sheet 12

Appendix N

ESATAP
Distribution and maintenance process

François Brunetti
(DOREA, France)

Abstract

After having finalized the first industrial version of ESATAP early 2008, the Thermal Post Processing tool funded by ESA and developed by DOREA, a dedicated website is now available. This presentation shows the distribution procedures and online materials: hot-line, bug tracking system, FAQ, training courses and videos are now available for thermal users.

DOREA TECHNOLOGY

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ESATAP

Distribution & Maintenance

ESA/ESTEC project managers:

Harrie ROOIJACKERS Hans Peter DE KONING

Authors:

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

DOREA TECHNOLOGY

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- **ESATAP has been developed by SILOGIC, TAS & DOREA and 100% funded by ESA.**
- **DOREA is in charge of the maintenance and distribution since 2008.**
- **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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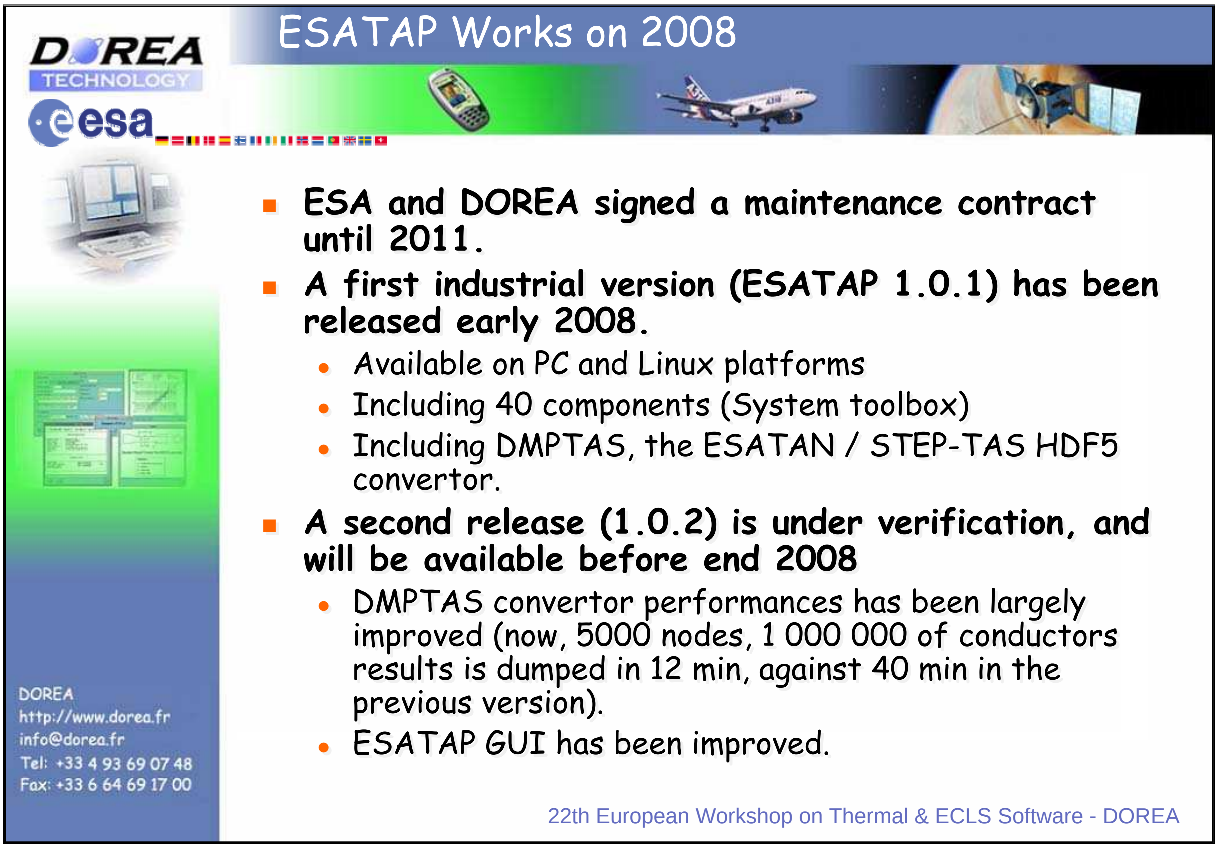

DOREA TECHNOLOGY
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ESATAP Works on 2008
ESA and DOREA signed a maintenance contract until 2011.
A first industrial version (ESATAP 1.0.1) has been released early 2008.
Available on PC and Linux platforms
Including 40 components (System toolbox)
Including DMPTAS, the ESATAN / STEP-TAS HDF5 convertor.
A second release (1.0.2) is under verification, and will be available before end 2008
DMPTAS convertor performances has been largely improved (now, 5000 nodes, 1 000 000 of conductors results is dumped in 12 min, against 40 min in the previous version).
ESATAP GUI has been improved.
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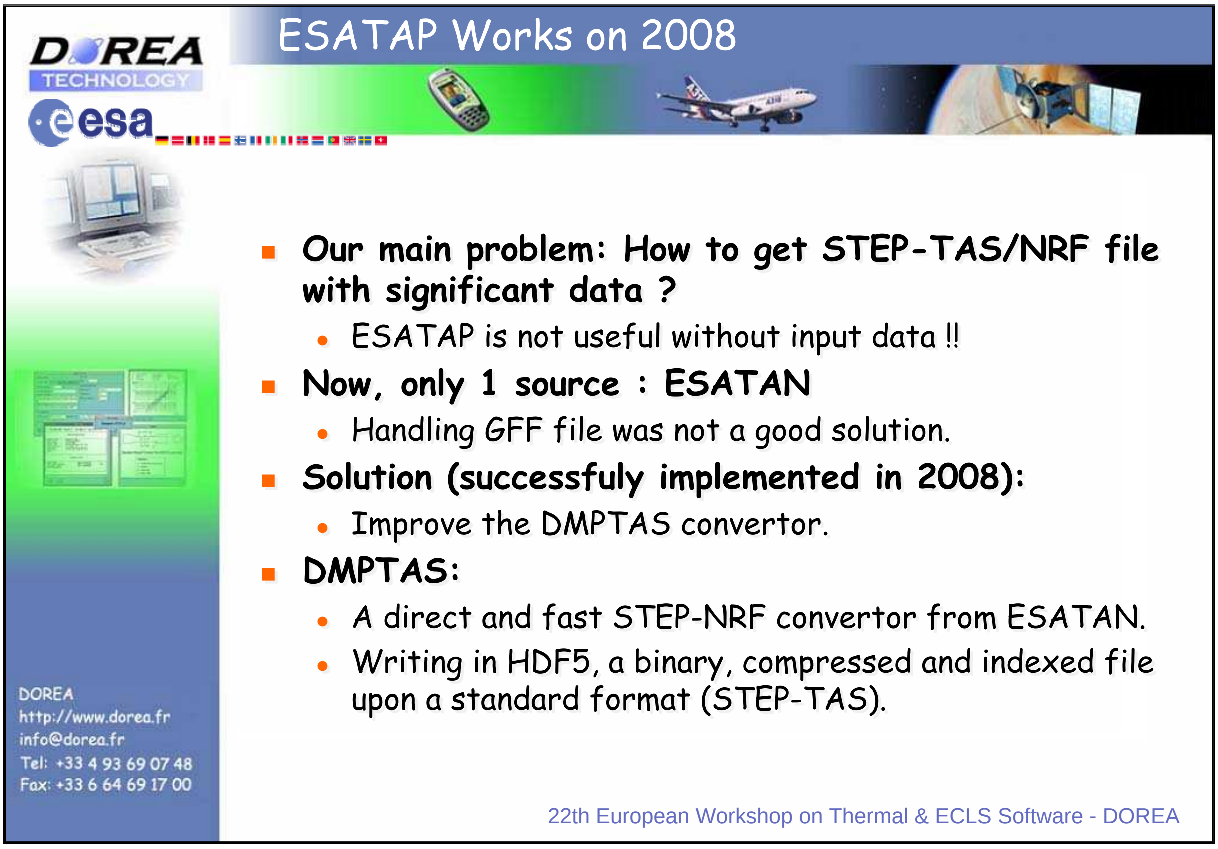

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ESATAP Works on 2008
Our main problem: How to get STEP-TAS/NRF file with significant data ?
ESATAP is not useful without input data !!
Now, only 1 source : ESATAN
Handling GFF file was not a good solution.
Solution (successfuly implemented in 2008):
Improve the DMPTAS convertor.
DMPTAS:
A direct and fast STEP-NRF convertor from ESATAN.
Writing in HDF5, a binary, compressed and indexed file upon a standard format (STEP-TAS).
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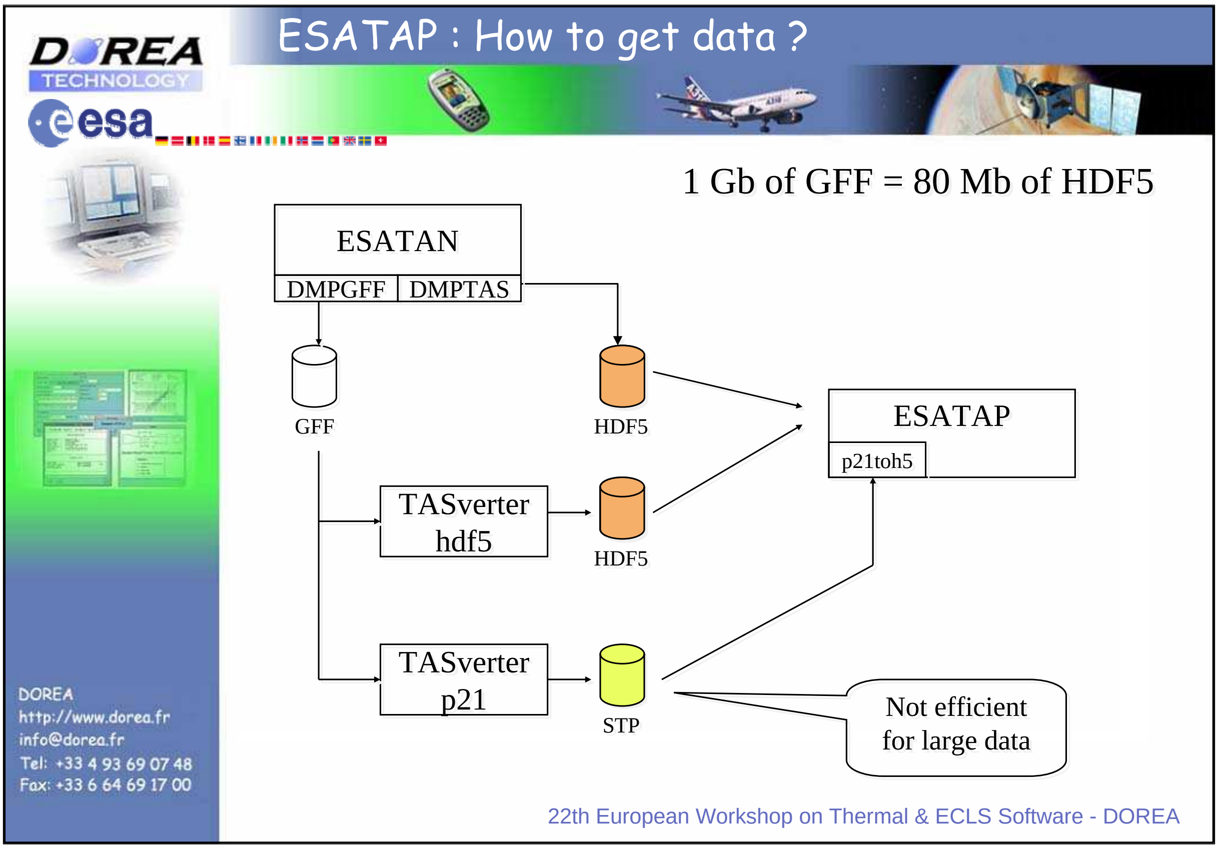
ESATAP : How to get data ?
1 Gb of GFF = 80 Mb of HDF5
ESATAN
DMPGFF
DMPTAS
GFF
HDF5
ESATAP
p21toh5
TASverter hdf5
HDF5
TASverter p21
STP
Not efficient for large data
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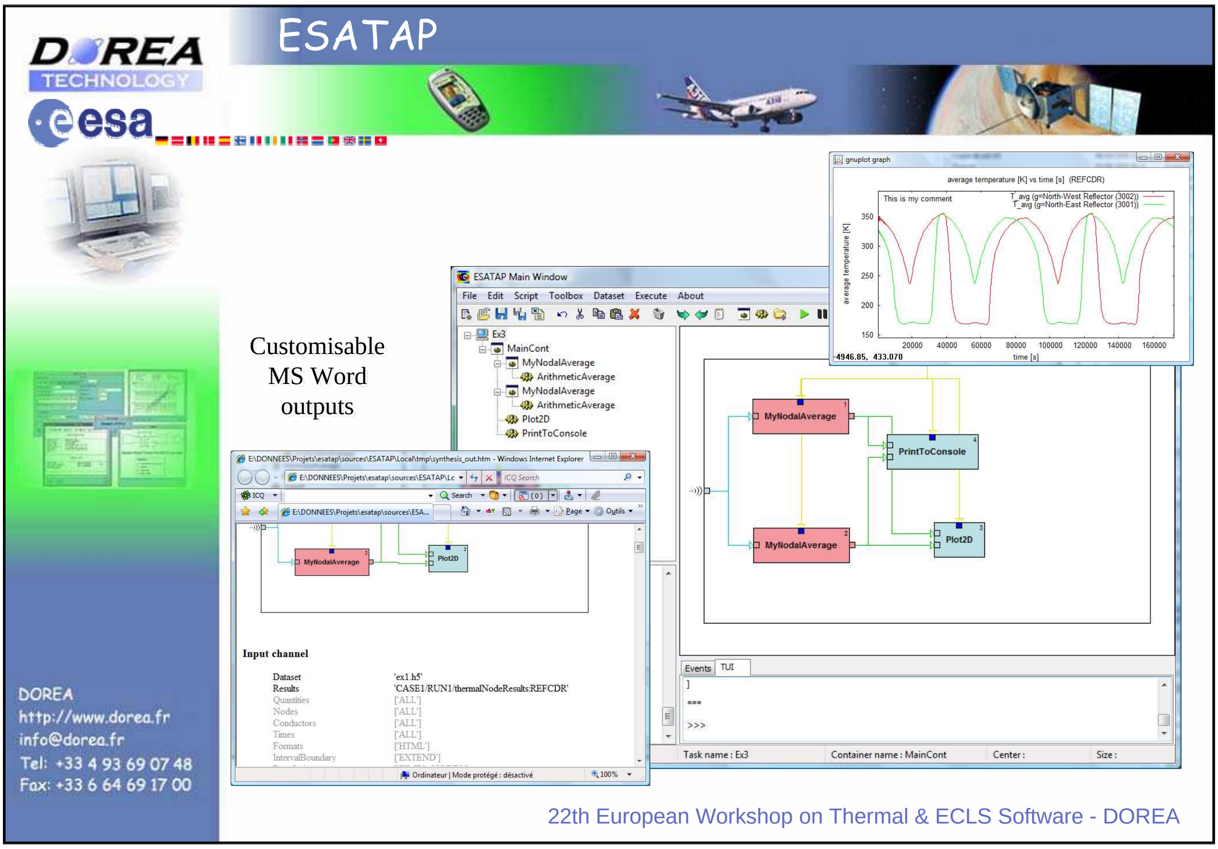
ESATAP
Customisable MS Word outputs
ESATAP Main Window
MyNodalAverage
PrintToConsole
Plot2D
Input channel
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Announcements
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Problems reporting
Contacts
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support@esatap.com
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ESATAP
Website and mail system hosted by DOREA
What is ESATAP?
ESATAP is a post-processing tool for thermal analysis data using the STEP-TAS and STEP-NRF data exchange standards. The main objective of the tool is to evaluate the results of the solution steps and to verify the quality of the input model and data. The results of operations performed by ESATAP can be used as input to other analysis tasks.
ESATAP:
Handles the standard STEP-TAS/NRF (v5.2) thermal results data files.
Allows the implementation of your own post processing scripts (components),
Provides a toolbox of around 40 basic components for statistical, thermal, mathematical calculation, heatflow, etc.,
Provides interfaces with MS Word, MS Excel, OpenOffice, GnuPlot, etc.,
Provides 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.
Package content
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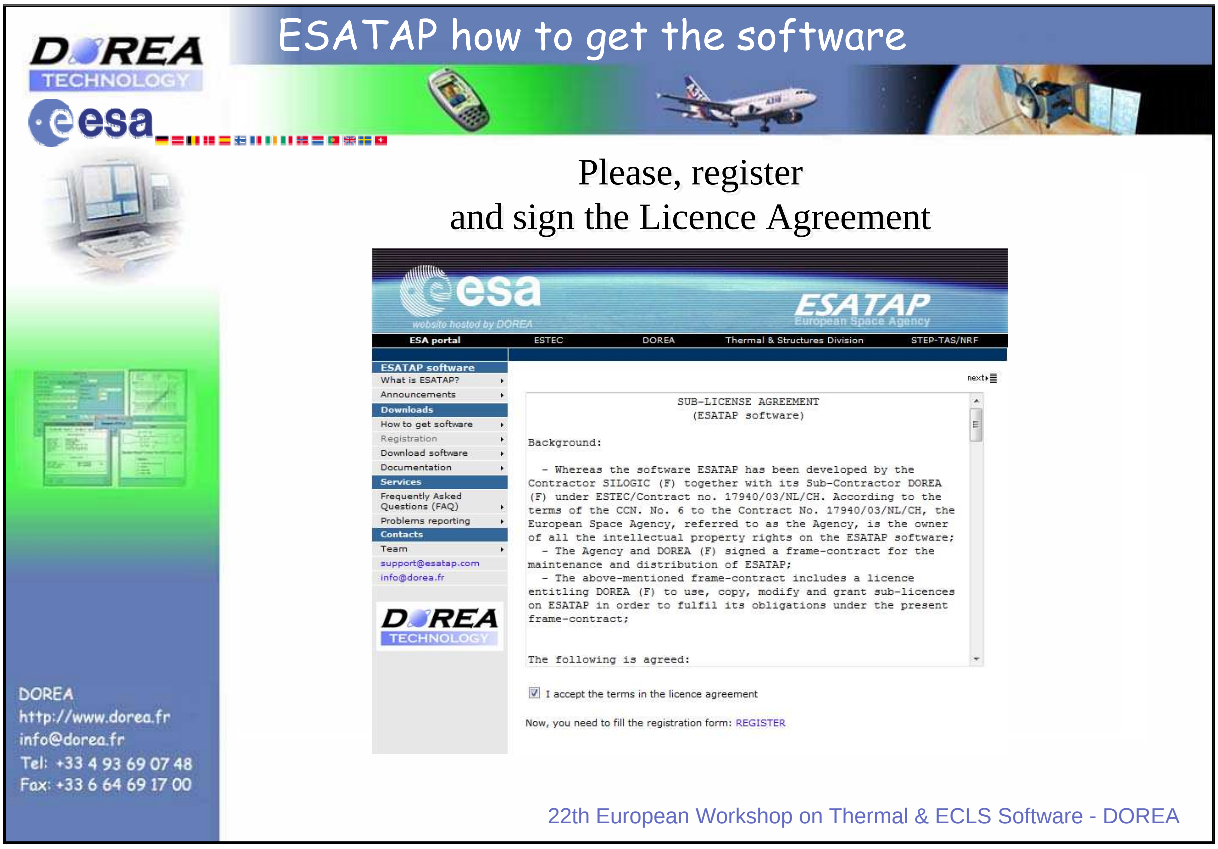
ESATAP how to get the software
DOREA TECHNOLOGY
esa
Please, register
and sign the Licence Agreement
esa
website hosted by DOREA
ESATAP
European Space Agency
ESA portal
ESTEC
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STEP-TAS/NRF
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What is ESATAP?
Announcements
Downloads
How to get software
Registration
Download software
Documentation
Services
Frequently Asked Questions (FAQ)
Problems reporting
Contacts
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info@dorea.fr
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SUB-LICENSE AGREEMENT
(ESATAP software)
Background:
- Whereas the software ESATAP has been developed by the Contractor SILOGIC (F) together with its Sub-Contractor DOREA (F) under ESTEC/Contract no. 17940/03/NL/CH. According to the terms of the CCN. No. 6 to the Contract No. 17940/03/NL/CH, the European Space Agency, referred to as the Agency, is the owner of all the intellectual property rights on the ESATAP software;
- The Agency and DOREA (F) signed a frame-contract for the maintenance and distribution of ESATAP;
- The above-mentioned frame-contract includes a licence entitling DOREA (F) to use, copy, modify and grant sub-licences on ESATAP in order to fulfil its obligations under the present frame-contract;
The following is agreed:
I accept the terms in the licence agreement
Now, you need to fill the registration form: REGISTER
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Fax: +33 6 64 69 17 00
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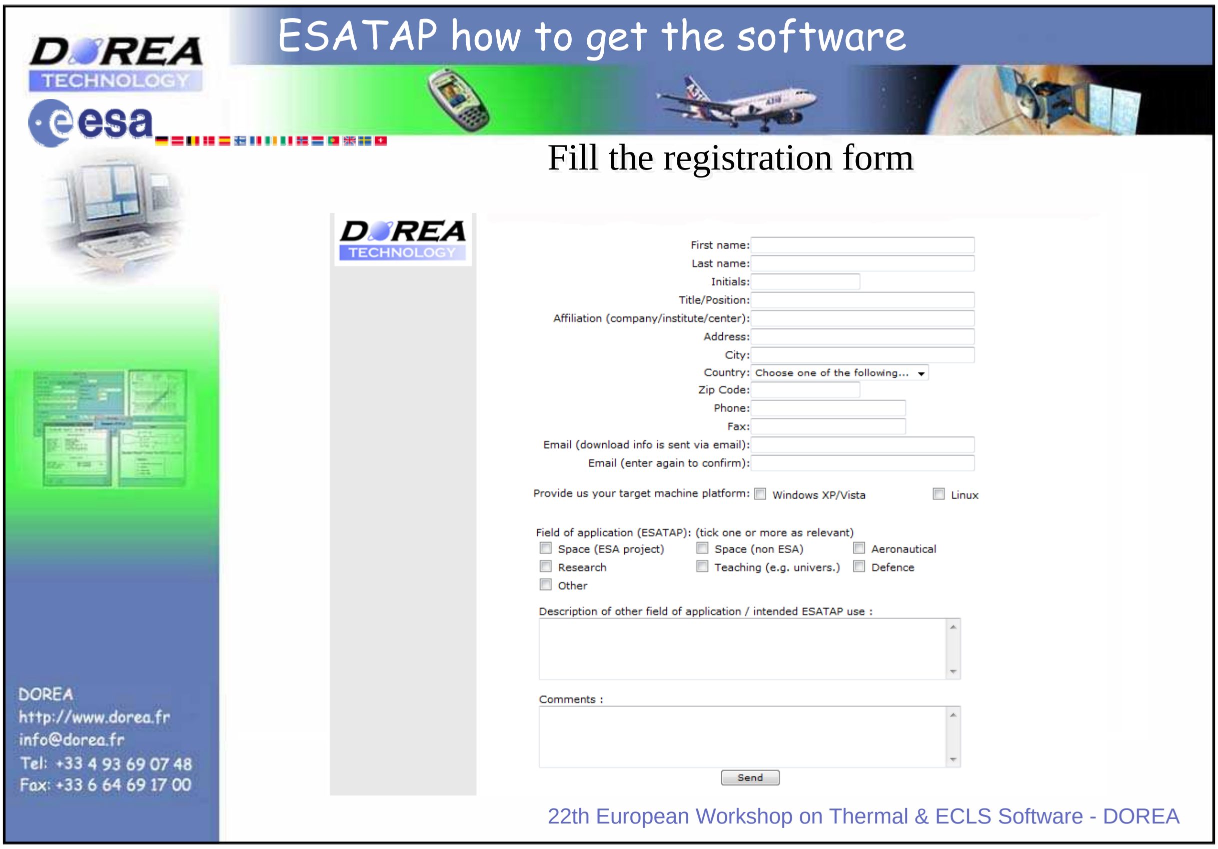

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ESATAP how to get the software
Fill the registration form
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First name:
Last name:
Initials:
Title/Position:
Affiliation (company/institute/center):
Address:
City:
Country: Choose one of the following...
Zip Code:
Phone:
Fax:
Email (download info is sent via email):
Email (enter again to confirm):
Provide us your target machine platform: Windows XP/Vista Linux
Field of application (ESATAP): (tick one or more as relevant)
Space (ESA project) Space (non ESA) Aeronautical
Research Teaching (e.g. univers.) Defence
Other
Description of other field of application / intended ESATAP use :
Comments :
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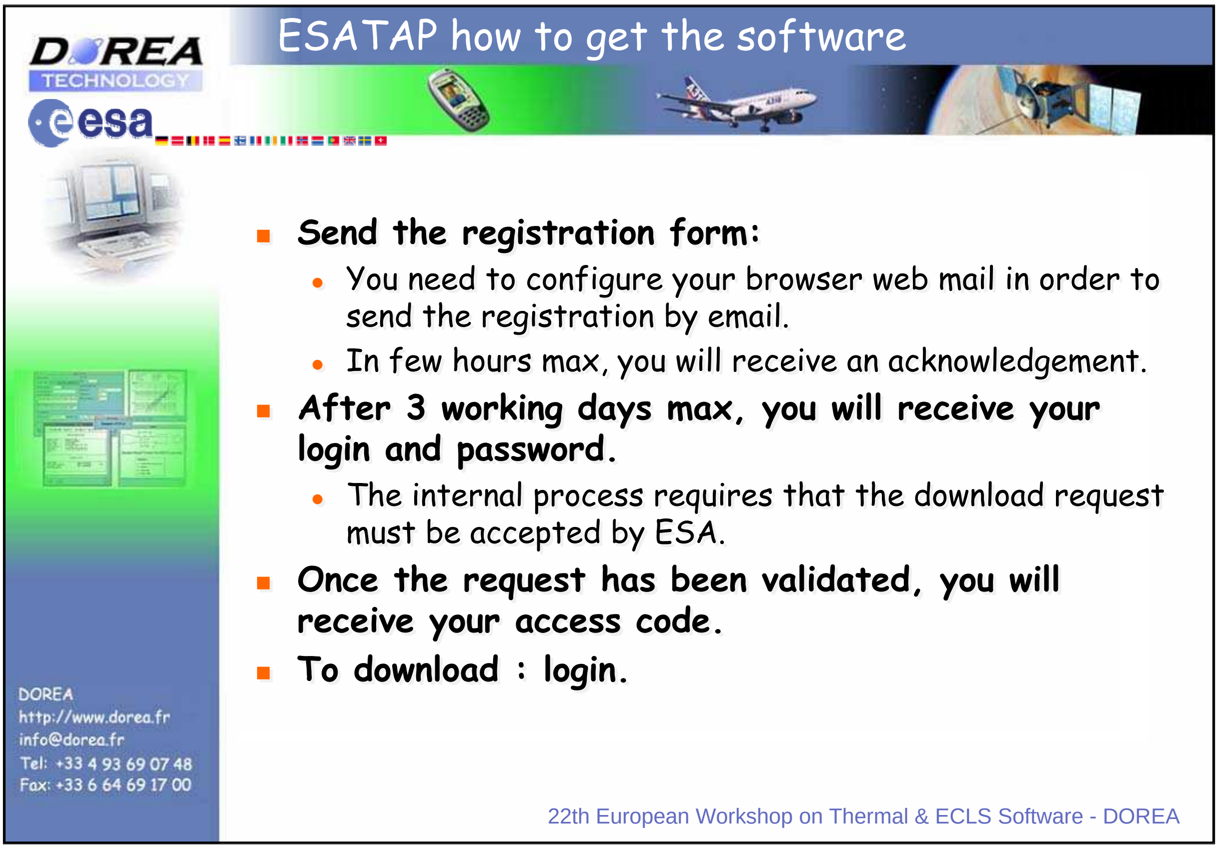

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ESATAP how to get the software
Send the registration form:
You need to configure your browser web mail in order to send the registration by email.
In few hours max, you will receive an acknowledgement.
After 3 working days max, you will receive your login and password.
The internal process requires that the download request must be accepted by ESA.
Once the request has been validated, you will receive your access code.
To download : login.
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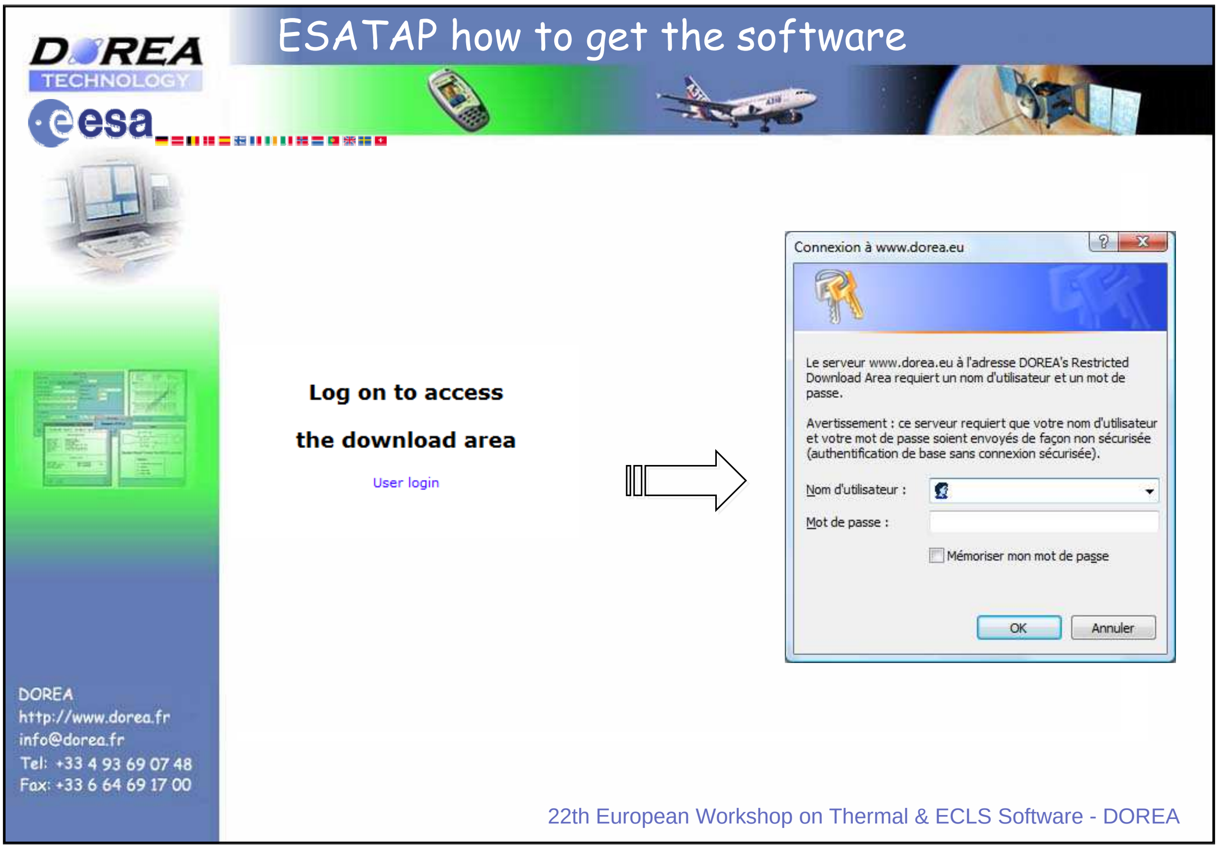
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Connexion à www.dorea.eu
Le serveur www.dorea.eu à l'adresse DOREA's Restricted Download Area requiert un nom d'utilisateur et un mot de passe.
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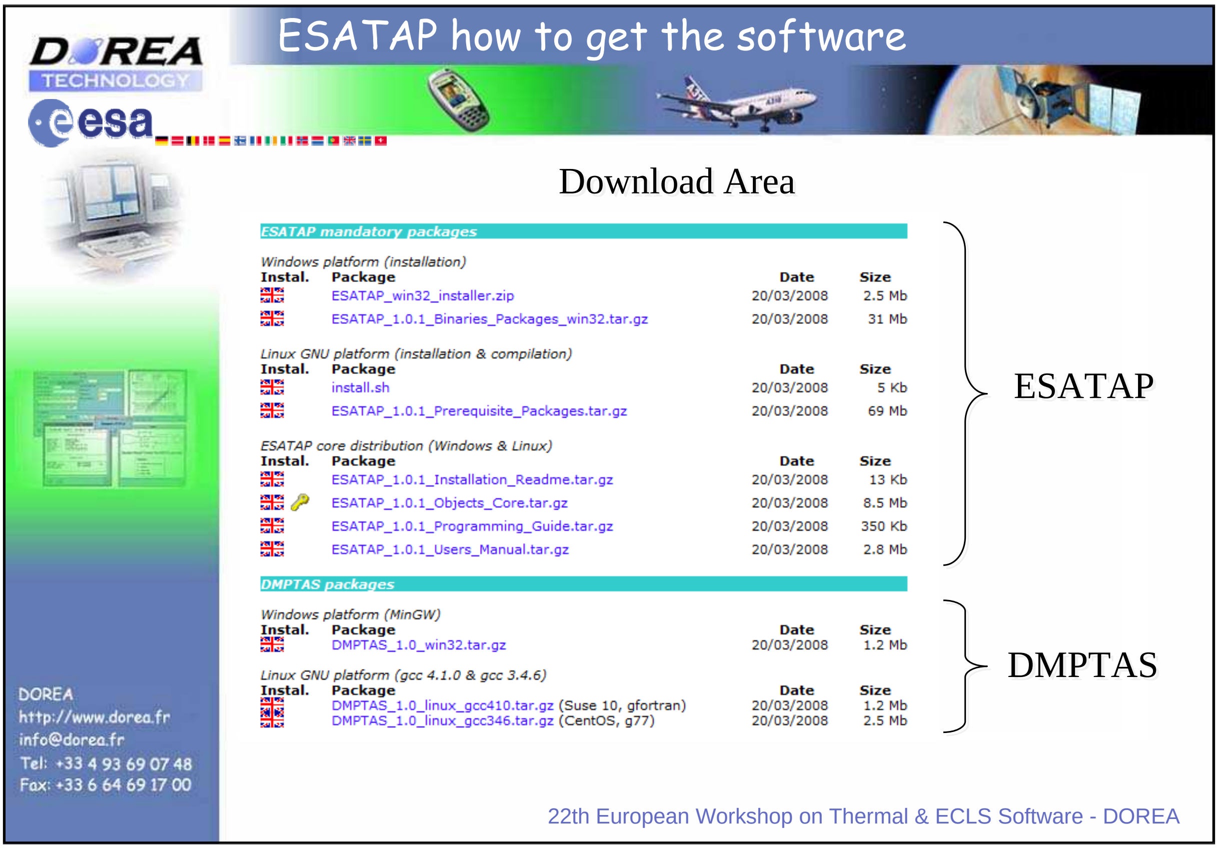
ESATAP how to get the software
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Download Area
ESATAP mandatory packages
Windows platform (installation)
Instal. Package Date Size
ESATAP_win32_installer.zip 20/03/2008 2.5 Mb
ESATAP_1.0.1_Binaries_Packages_win32.tar.gz 20/03/2008 31 Mb
Linux GNU platform (installation & compilation)
Instal. Package Date Size
install.sh 20/03/2008 5 Kb
ESATAP_1.0.1_Prerequisite_Packages.tar.gz 20/03/2008 69 Mb
ESATAP core distribution (Windows & Linux)
Instal. Package Date Size
ESATAP_1.0.1_Installation_Readme.tar.gz 20/03/2008 13 Kb
ESATAP_1.0.1_Objects_Core.tar.gz 20/03/2008 8.5 Mb
ESATAP_1.0.1_Programming_Guide.tar.gz 20/03/2008 350 Kb
ESATAP_1.0.1_Users_Manual.tar.gz 20/03/2008 2.8 Mb
ESATAP
DMPTAS packages
Windows platform (MinGW)
Instal. Package Date Size
DMPTAS_1.0_win32.tar.gz 20/03/2008 1.2 Mb
Linux GNU platform (gcc 4.1.0 & gcc 3.4.6)
Instal. Package Date Size
DMPTAS_1.0_linux_gcc410.tar.gz (Suse 10, gfortran) 20/03/2008 1.2 Mb
DMPTAS_1.0_linux_gcc346.tar.gz (CentOS, g77) 20/03/2008 2.5 Mb
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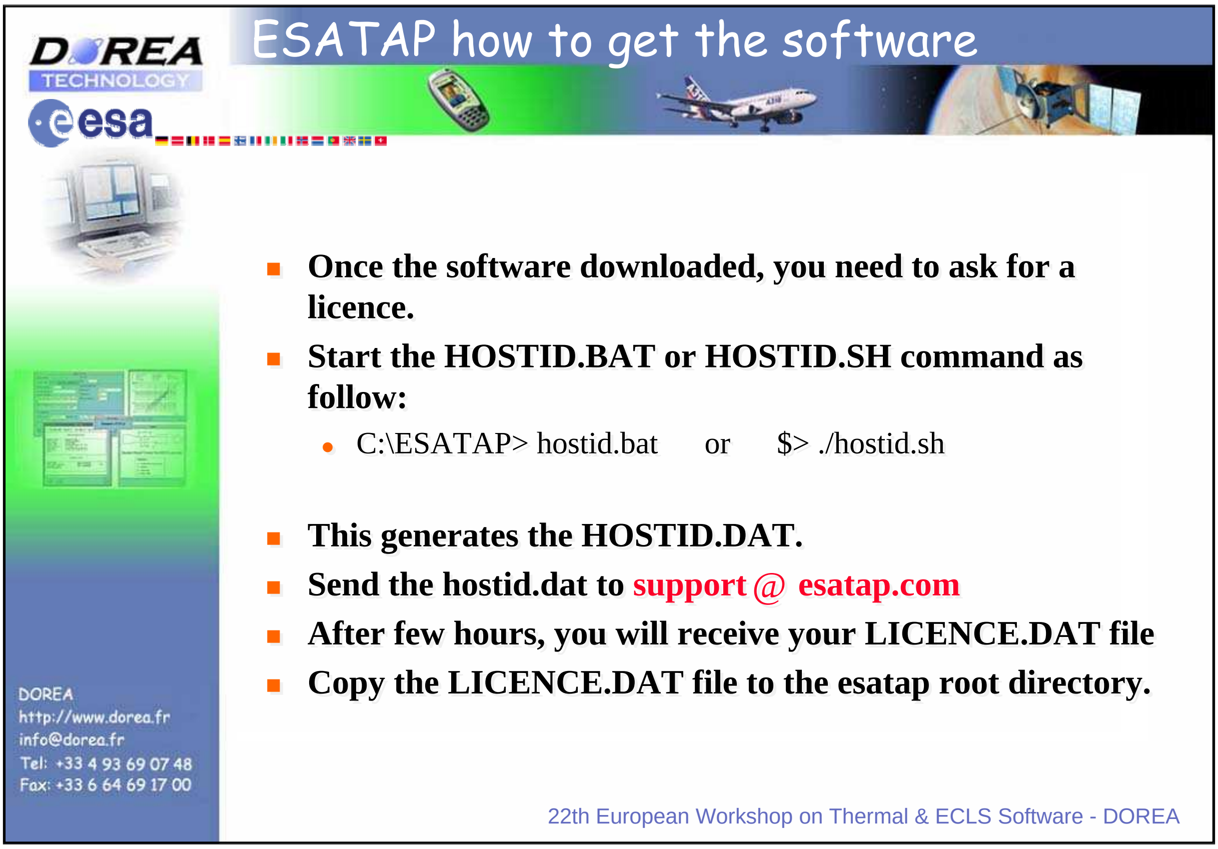
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Once the software downloaded, you need to ask for a licence.
Start the HOSTID.BAT or HOSTID.SH command as follow:
C:\ESATAP> hostid.bat or $> ./hostid.sh
This generates the HOSTID.DAT.
Send the hostid.dat to support @ esatap.com
After few hours, you will receive your LICENCE.DAT file
Copy the LICENCE.DAT file to the esatap root directory.
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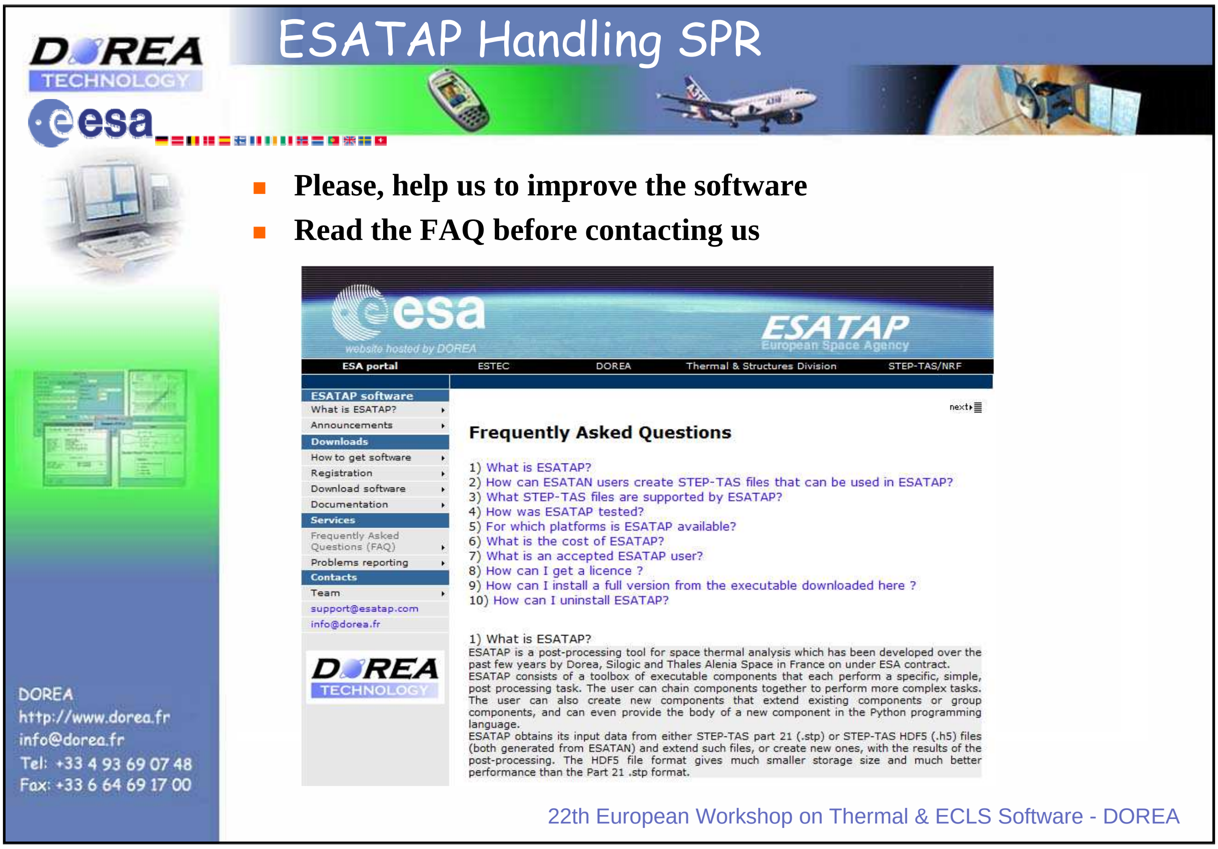
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Frequently Asked Questions
1) What is ESATAP?
2) How can ESATAN users create STEP-TAS files that can be used in ESATAP?
3) What STEP-TAS files are supported by ESATAP?
4) How was ESATAP tested?
5) For which platforms is ESATAP available?
6) What is the cost of ESATAP?
7) What is an accepted ESATAP user?
8) How can I get a licence ?
9) How can I install a full version from the executable downloaded here ?
10) How can I uninstall ESATAP?
1) What is ESATAP?
ESATAP is a post-processing tool for space thermal analysis which has been developed over the past few years by Dorea, Silogic and Thales Alenia Space in France on under ESA contract.
ESATAP consists of a toolbox of executable components that each perform a specific, simple, post processing task. The user can chain components together to perform more complex tasks. The user can also create new components that extend existing components or group components, and can even provide the body of a new component in the Python programming language.
ESATAP obtains its input data from either STEP-TAS part 21 (.stp) or STEP-TAS HDF5 (.h5) files (both generated from ESATAN) and extend such files, or create new ones, with the results of the post-processing. The HDF5 file format gives much smaller storage size and much better performance than the Part 21 .stp format.
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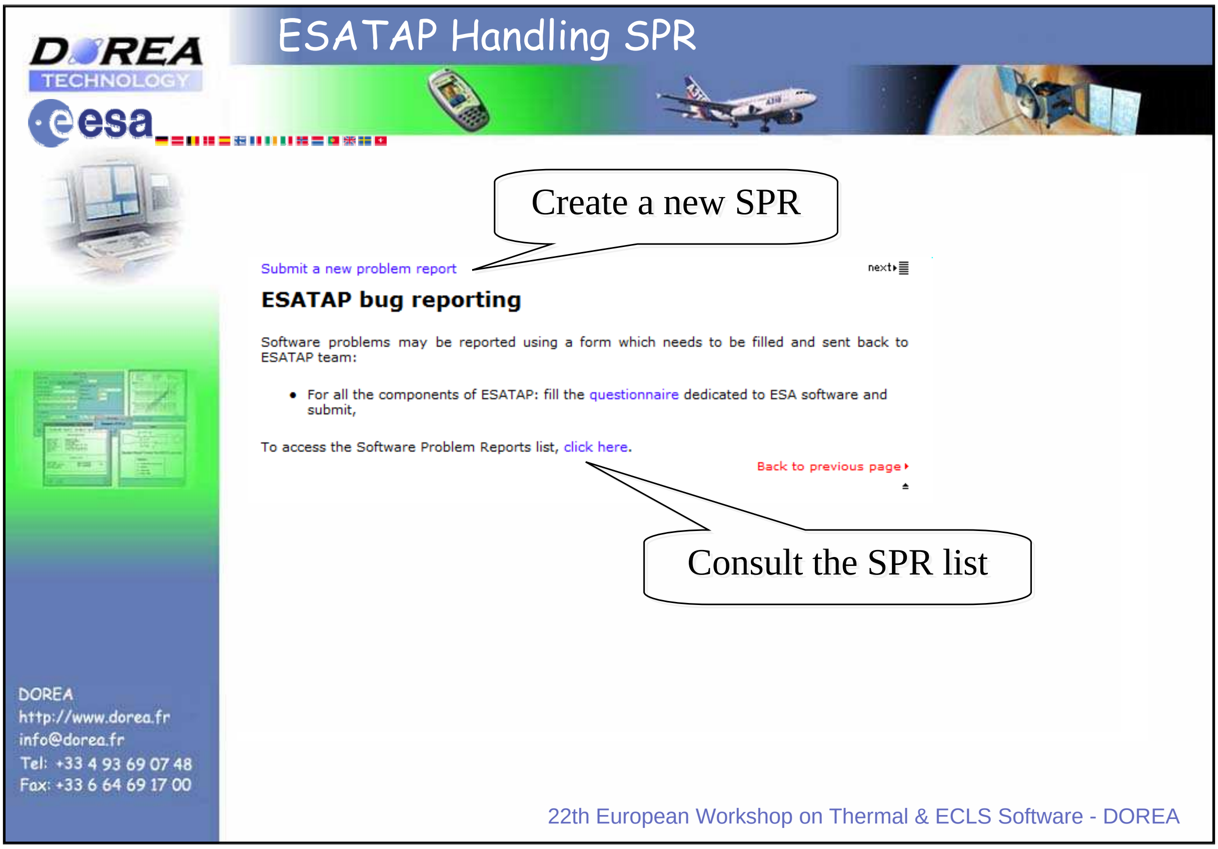
ESATAP Handling SPR
Create a new SPR
Submit a new problem report
ESATAP bug reporting
Software problems may be reported using a form which needs to be filled and sent back to ESATAP team:
For all the components of ESATAP: fill the questionnaire dedicated to ESA software and submit,
To access the Software Problem Reports list, click here.
Back to previous page
Consult the SPR list
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Create a new SPR
ESATAP
How to fill this form ?
ESATAP Version :
SOFTWARE PROBLEM REPORT
SPR N° :
Date :
Originator :
1. SOFTWARE ITEM TITLE:
ESATAP (GUI)
ESATAP (CORE COMPONENT)
ESATAP (TOOLBOX)
ESATAP (DOCUMENTATION)
DMPTAS
3. PRIORITY:
Critical
Urgent
Routine
4. PROBLEM DESCRIPTION:
5. DESCRIPTION OF ENVIRONMENT:
Windows XP
Windows Vista
Windows 2000
Linux
6. RECOMMENDED SOLUTION:
7. SOFTWARE REVIEW BOARD DECISION:
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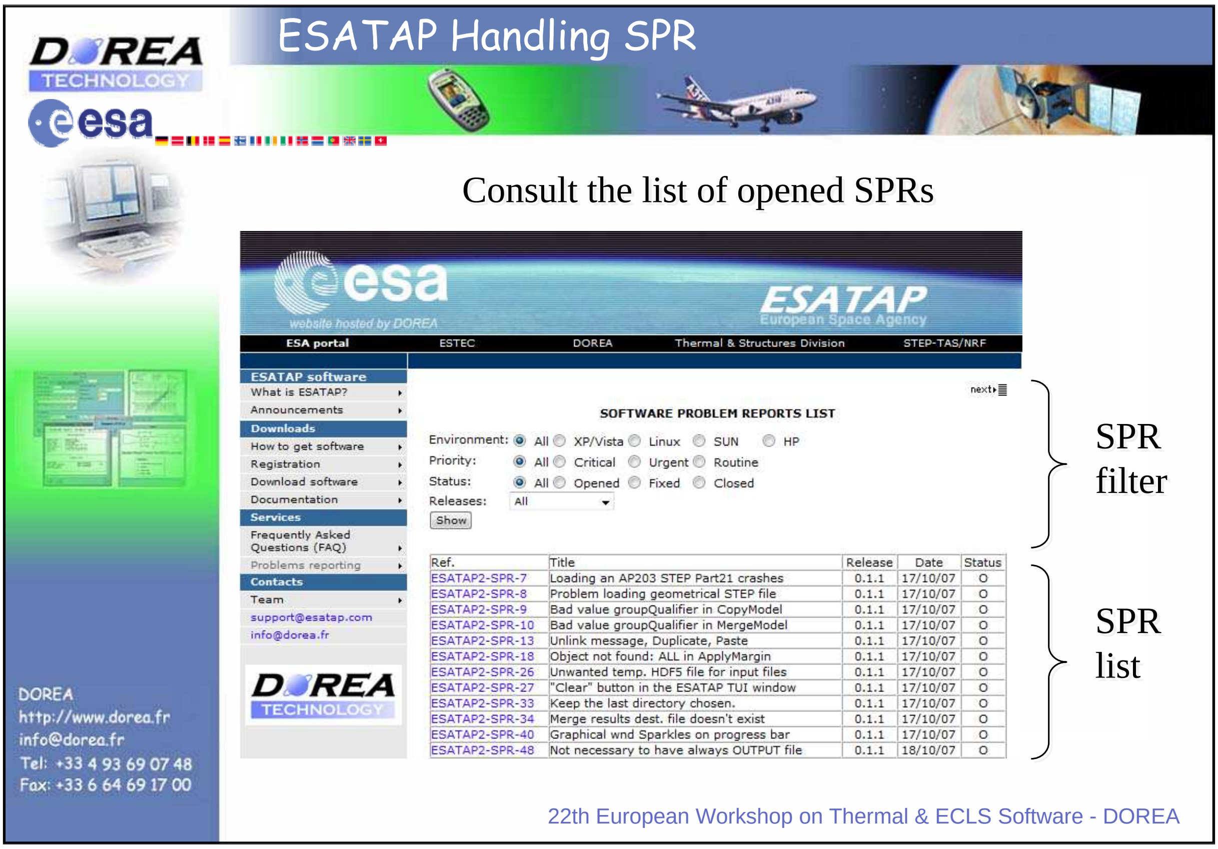
ESATAP Handling SPR
Consult the list of opened SPRs
SOFTWARE PROBLEM REPORTS LIST
Environment: All XP/Vista Linux SUN HP
Priority: All Critical Urgent Routine
Status: All Opened Fixed Closed
Releases: All
Show
Ref. Title Release Date Status
ESATAP2-SPR-7 Loading an AP203 STEP Part21 crashes 0.1.1 17/10/07 O
ESATAP2-SPR-8 Problem loading geometrical STEP file 0.1.1 17/10/07 O
ESATAP2-SPR-9 Bad value groupQualifier in CopyModel 0.1.1 17/10/07 O
ESATAP2-SPR-10 Bad value groupQualifier in MergeModel 0.1.1 17/10/07 O
ESATAP2-SPR-13 Unlink message, Duplicate, Paste 0.1.1 17/10/07 O
ESATAP2-SPR-18 Object not found: ALL in ApplyMargin 0.1.1 17/10/07 O
ESATAP2-SPR-26 Unwanted temp. HDF5 file for input files 0.1.1 17/10/07 O
ESATAP2-SPR-27 "Clear" button in the ESATAP TUI window 0.1.1 17/10/07 O
ESATAP2-SPR-33 Keep the last directory chosen. 0.1.1 17/10/07 O
ESATAP2-SPR-34 Merge results dest. file doesn't exist 0.1.1 17/10/07 O
ESATAP2-SPR-40 Graphical wnd Sparkles on progress bar 0.1.1 17/10/07 O
ESATAP2-SPR-48 Not necessary to have always OUTPUT file 0.1.1 18/10/07 O
SPR filter
SPR list
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
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ESATAP Handling SPR
ESATAP Version : 1.0.2 build 20080531
SPR N° : 85
Date (dd/mm/yy): 06/10/08
SOFTWARE PROBLEM REPORT
1. SOFTWARE ITEM TITLE:
ESATAP (TOOLBOX)
3. PRIORITY:
Urgent
4. PROBLEM DESCRIPTION:
CompareDataset component problem
When using the CompareDataset component to compare 2 data sets and assigning each dataset to an input channel, clicking OK shows just one input channel. Again editing the component properties shows that just one input channel exists. The behaviour is repeatable. As a result this component cannot be used.
5. DESCRIPTION OF ENVIRONMENT:
Linux
6. RECOMMENDED SOLUTION:
7. SOFTWARE REVIEW BOARD DECISION:
To be fixed
8. COMMENT:
9. STATUS:
Opened
Consult SPR
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
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ESATAP Coming Soon
DOREA TECHNOLOGY
esa
Trainings
We elaborated training sessions.
Training sessions are performed in site.
First training is schedule the 30th of October
2 more trainings are coming in the next 2 months
To arrange a session, contact us.
Demo & Videos
The training excercises will be available soon in November on the web site http://www.esatap.com.
New release 1.0.2
Before the end of 2008
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
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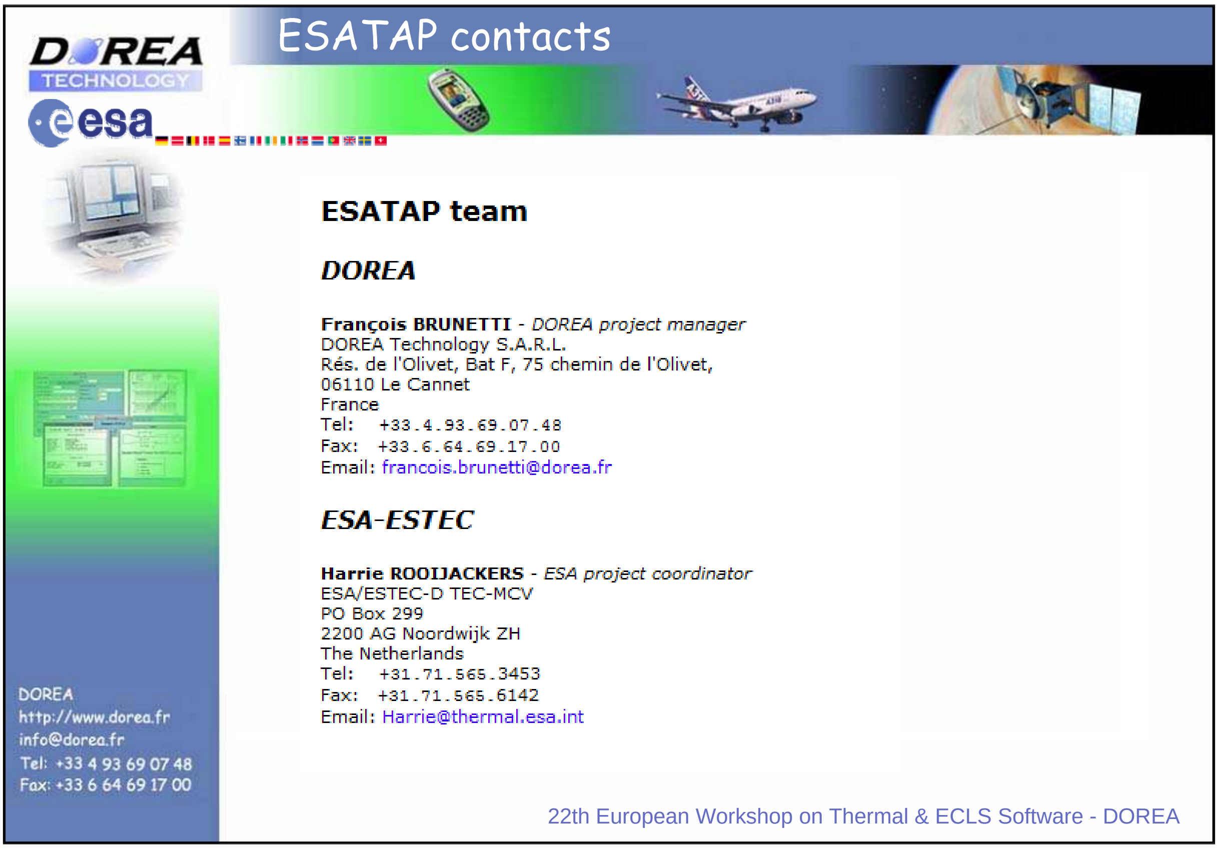
ESATAP contacts
DOREA TECHNOLOGY
esa
ESATAP team
DOREA
François BRUNETTI - DOREA project manager
DOREA Technology S.A.R.L.
Rés. de l'Olivet, Bat F, 75 chemin de l'Olivet,
06110 Le Cannet
France
Tel: +33.4.93.69.07.48
Fax: +33.6.64.69.17.00
Email: francois.brunetti@dorea.fr
ESA-ESTEC
Harrie ROOIJACKERS - ESA project coordinator
ESA/ESTEC-D TEC-MCV
PO Box 299
2200 AG Noordwijk ZH
The Netherlands
Tel: +31.71.565.3453
Fax: +31.71.565.6142
Email: Harrie@thermal.esa.int
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
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Appendix O

Implementation of the Equation of Time in Sun Synchronous Orbit Modelling and ESARAD Planet Temperature Mapping Error at the Poles

Arne Sauer
(EADS Astrium, Germany)

Abstract

The Equation of Time describes the change of the solar reference vector causing a virtual sun movement (i.e. noon point) due to orbital effects. This has effects on the difference between True and Mean Local Solar Time causing inaccuracies of up to 16 minutes Local Solar Time or $\backsim 4°$ of Ω (RAAN).
In the course of the MIPAS instrument thermal analysis (ENVISAT Mission Extension) it showed how important it is to know the exact angle of the Solar Vector because it had to be assessed if optical components inside of baffles and radiators have solar incidence, due to the degraded ENVISAT orbit. For this reason the Equation of Time had to be considered. It showed that the thermal software did not consider this virtual sun movement. For this reason a workaround had to be established considering the date dependant Equation of Time and the resulting difference between Mean and True Local Solar Time.
In the course of the presentation the Equation of Time will be explained, as well as the mission related problems caused by the non-consideration of the EoT. The workaround will be presented, related to the different thermal software tools THERMICA and ESARAD.
Additionally to this issue a problem will be presented related to mapping of planet temperature and its effect on sun synchronous dawn/dusk orbits. Due to the variation of distance between longitudes from pole to pole and the circular pole elements, the planet temperatures are mapped to varying element surfaces, causing erroneous flux variations along a dawn/dusk orbit with a local minimum at the poles. This problem will be presented accompanied with the workaround to minimize the flux error.

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

Arne Sauer (arne.sauer@astrium.eads.net)

All the space you need

EADS astrium

Satellites

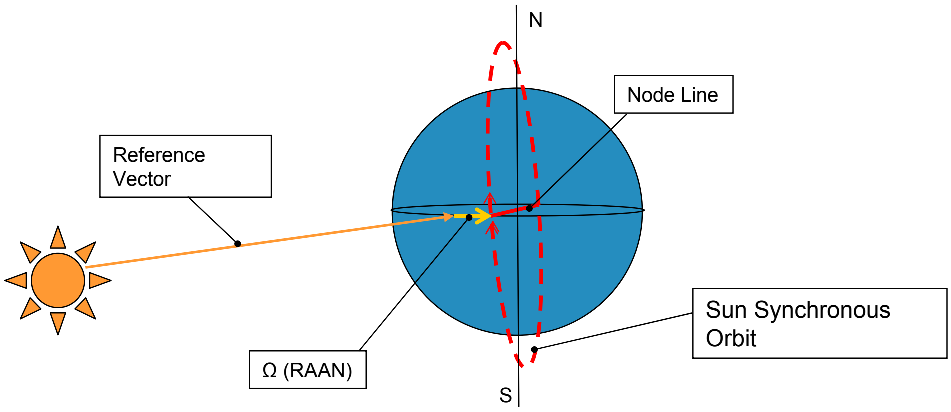
Overview

- Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling
    - The Equation of Time and Analemma
    - The MIPAS Mission Analysis Specifics (Importance of an accurate Local Solar Time)
    - Workaround to implement the Equation of Time in current Thermal Software

Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

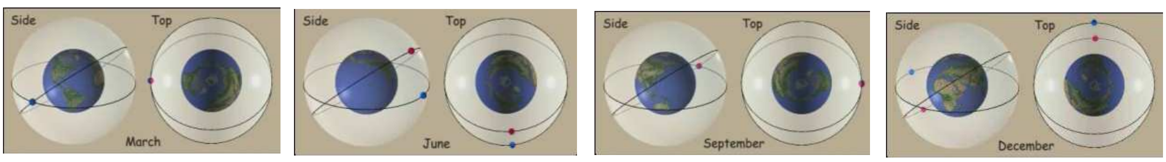
- The Equation of Time
  - Describes the virtual sun movement concerning the Solar Reference Vector
  - Reference Vector is not constant due to physical effects
  - Shifting of the Reference Vector around a Mean Reference Vector
  - Causes difference between True Local Solar Time and Mean Local Solar Time

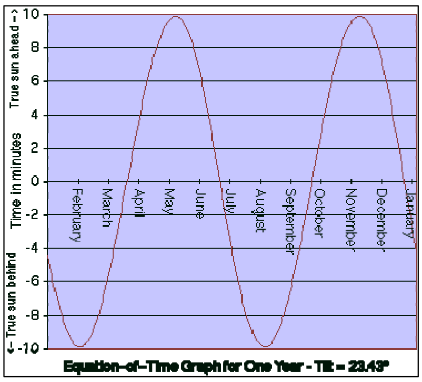


Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Equation of Time
  - Effects causing the Equation of Time:
    - Varying Solar Declination over the Year

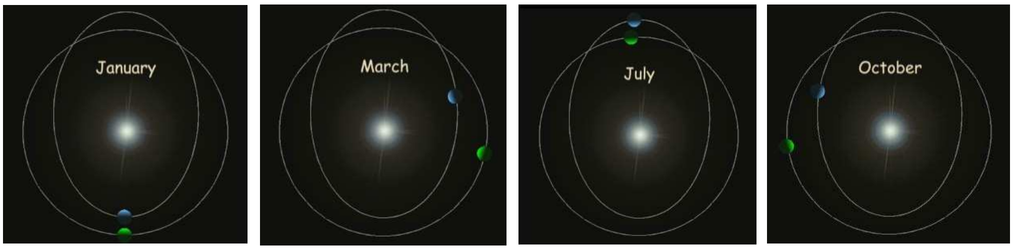




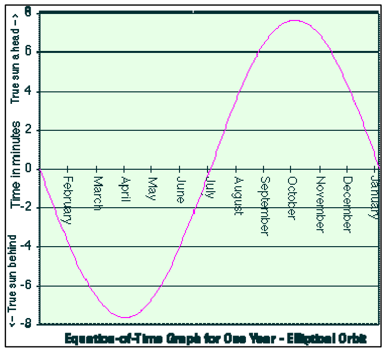
Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- The Equation of Time
  - Effects causing the Equation of Time:
    - Eccentricity of Earths Orbit around the Sun



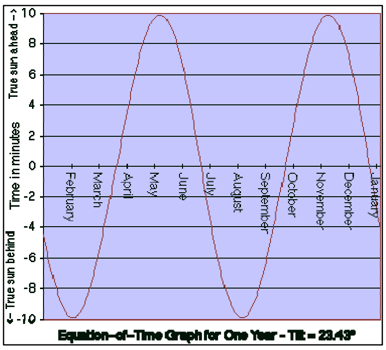
- Mean Sun (Circular Earth-Orbit around the Sun)
- True Sun (Elliptic Earth-Orbit around the Sun)

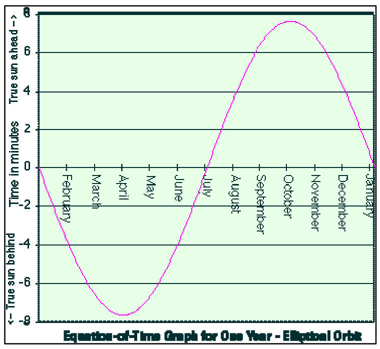


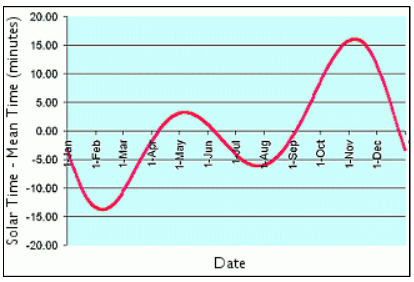
Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Impact on Local Solar Time
  - Causes Differences between Mean and True Local Solar Time (Up to 16 minutes of Local Solar Time – Corresponds to about 4° in Beta-Angle)







$$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$$

with:

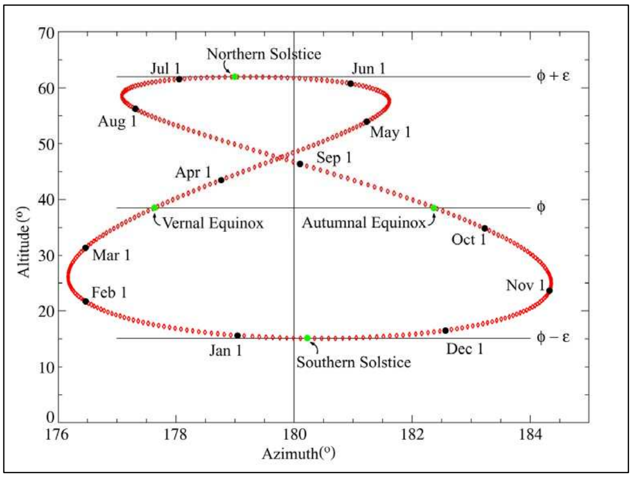
$$B = 2\pi(N - 81)/364$$

N = Days (1.Jan. = 1)

Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

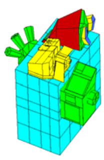
- The Analemma
  - Caused by the Equation of Time
  - Describes the movement of a virtual position of the sun at one certain time of day
  - Solar Reference Vector (i.e. Noon Point) changes thus over the Year:



12:00 Analemma (Source: Greenwich Observatory)

Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling



- The MIPAS Mission Analysis Specifics
  - ENVISAT Mission Extension (Analysis of the Impact of the Degraded Orbit)
    - ENVISAT Mission Extension Scenario comprises modification of orbit altitude
    - Loss of Altitude causes turning of Nodeline of the Sun-Synchronous ENVISAT Orbit
    - Turning of Nodeline causes Change of Local Solar Time
      - Originally MLST 22:00 hrs Ascending Node
      - Worst Case + 10 minutes (22:10 LST)
  - Analysis to determine Impact of worst case Local Solar Time on Baffles and Radiators
    - Incident Solar Flux on Optical Components ?
    - Major Temperature Raise on Radiators?
  - For this Analysis the use of the exact Angle of the Sun to the Satellite is essential!
  - Analysis was decided to do with an existing and running Thermal Model to save effort
  - Results based on used Thermal Software Version do not consider Equation of Time
  - Consideration of a constant Local Solar Time over the year (Corresponding to MLST – Not Realistic)
  - Error was confirmed by means of Beta-Angle check at the Equinoxes
  - Error caused by constant coupling between Solar Reference Vector and Nodeline

Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Workaround to implement the Equation of Time in current Thermal Software:
  - THERMICA:
    - Mission Modelling of THERMICA considers Solar System Physicality (Date Dependant Sun / Earth Positions and attitudes)
    - Definition of Date changes automatically Orbital Parameters (Solar Declination, Solar Constant, etc…)
    - Implementation of Season Dependant True Local Solar Time into the Software is thus possible by means of decoupling the Solar Reference Vector of the Nodeline
    - Only MLST would have to be supplied, Equation of Time is calculated by Software depending on Date
    - Until Implementation of Equation of Time in Software: Workaround as in ESARAD
  - ESARAD:
    - No automatic Change of Orbit Parameters with Season Change is considered (“Snapshot” Mission Modelling), all Parameters have to be supplied for specific Date
    - Direct manual implementation of True Local Solar Time (Ω)
    - Utilisation of a table showing Date dependant True Local Solar Time based on Mean Local Solar Time and Equation of Time

Satellites

Implementation of the Equation of Time in Sun-Synchronous Orbit Modelling

- Workaround Table
  - Date Dependant True Local Solar Time (MLST + EoT)

Mean Local Solar Time: 22:10

$$E = 9.87\sin(2B) - 7.53\cos(B) - 1.5\sin(B)$$
$$B = 2\pi(N-81)/364$$

Date	Day (N)	B	EoT (min)	Real True Local Solar Time (min)	EoT (h)	Real True Local Solar Time (h)
1.1.08	1	-1.381	-3.607	22:06	-0.060	22.1066
2.1.08	2	-1.364	-4.054	22:05	-0.068	22.0991
3.1.08	3	-1.346	-4.496	22:05	-0.075	22.0917
4.1.08	4	-1.329	-4.932	22:05	-0.082	22.0845
5.1.08	5	-1.312	-5.364	22:04	-0.089	22.0773
6.1.08	6	-1.295	-5.789	22:04	-0.096	22.0702
7.1.08	7	-1.277	-6.208	22:03	-0.103	22.0632
8.1.08	8	-1.260	-6.620	22:03	-0.110	22.0563
9.1.08	9	-1.243	-7.025	22:02	-0.117	22.0496
10.1.08	10	-1.226	-7.423	22:02	-0.124	22.0430
11.1.08	11	-1.208	-7.813	22:02	-0.130	22.0365
12.1.08	12	-1.191	-8.194	22:01	-0.137	22.0301
13.1.08	13	-1.174	-8.567	22:01	-0.143	22.0239
14.1.08	14	-1.157	-8.932	22:01	-0.149	22.0178
15.1.08	15	-1.139	-9.287	22:00	-0.155	22.0119
16.1.08	16	-1.122	-9.632	22:00	-0.161	22.0061
17.1.08	17	-1.105	-9.968	22:00	-0.166	22.0005
18.1.08	18	-1.087	-10.294	21:59	-0.172	21.9951
19.1.08	19	-1.070	-10.610	21:59	-0.177	21.9898
20.1.08	20	-1.053	-10.914	21:59	-0.182	21.9848
21.1.08	21	-1.036	-11.208	21:58	-0.187	21.9799
22.1.08	22	-1.018	-11.491	21:58	-0.192	21.9751
23.1.08	23	-1.001	-11.763	21:58	-0.196	21.9706
24.1.08	24	-0.984	-12.023	21:57	-0.200	21.9663
25.1.08	25	-0.967	-12.272	21:57	-0.205	21.9621

Satellites

Conclusion

- For certain Mission Profiles the exact Angle to the Sun is essential to be modelled
- Equation of Time is not considered in used Thermal Software versions, due to constant coupling between Solar Reference Vector and Nodeline over the Year
- EoT – Error was confirmed by checking the THERMICA generated Beta-Angle at the Equinoxes and comparing it to the hand-calculated Beta-Angle considering all Date dependant orbit data including the EoT
- In THERMICA an implementation of the EoT should be feasible due to the consideration of Solar System Physicality by decoupling the Solar Reference Vector from the Nodeline
- For ESARAD due to “Snapshot” Modelling of the Mission, the True Local Solar Time has to be provided for the specific Date to be taken for the Load Case (using EXCEL-Table)
- Workaround accuracy was checked by Beta-Angle comparison between the THERMICA generated Beta-Angle and the hand-calculated Beta-Angle for each Load Case based on orbit data (EXCEL-Table with Date dependant Solar Declination and Equation of Time resulting in the Date dependant Beta-Angle)
- MIPAS Analysis Experience showed Importance of Maintenance of a Thermal Model throughout the Mission

Satellites

Sources

- Greenwich Observatory Homepage (Status: 07/2008)
  - http://www.nmm.ac.uk/server/show/conWebDoc.351
- www.analemma.com (Status: 07/2008)
- MIPAS Mission Document

ESARAD Planet Temperature Mapping Error at the Poles

Arne Sauer (arne.sauer@astrium.eads.net)
Marc Maschmann (marc.maschmann@astrium.eads.net)

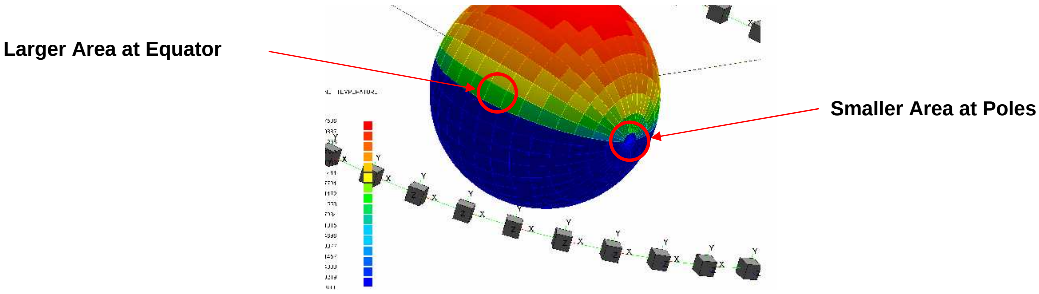
All the space you need

EADS astrium

Satellites

Planet Temperature Mapping Error at the Poles

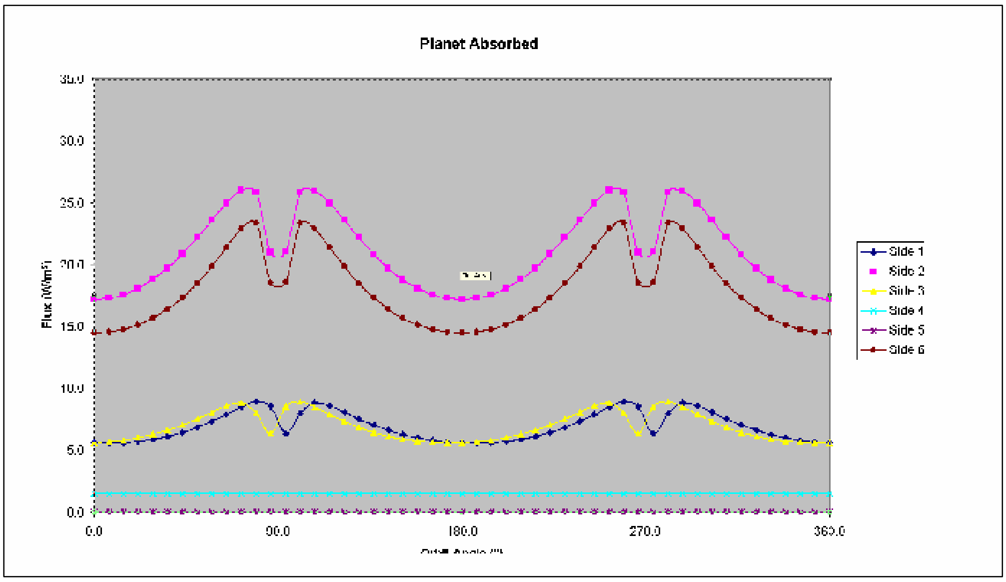
- Planet Temperature Mapping Error at the Poles
  - planet_temperature_method = "CALCULATED„
    - Cold Side of the Planet is User Defined
    - ESARAD calculates the Temperature on Hot Side automatically based on User Information
    - Temperatures are assessed on Latitude and Longitude Intersections and interpolated on Intersection Areas
  - Problem
    - Varying Distances between Longitudes along Latitudes



Satellites

Planet Temperature Mapping Error at the Poles

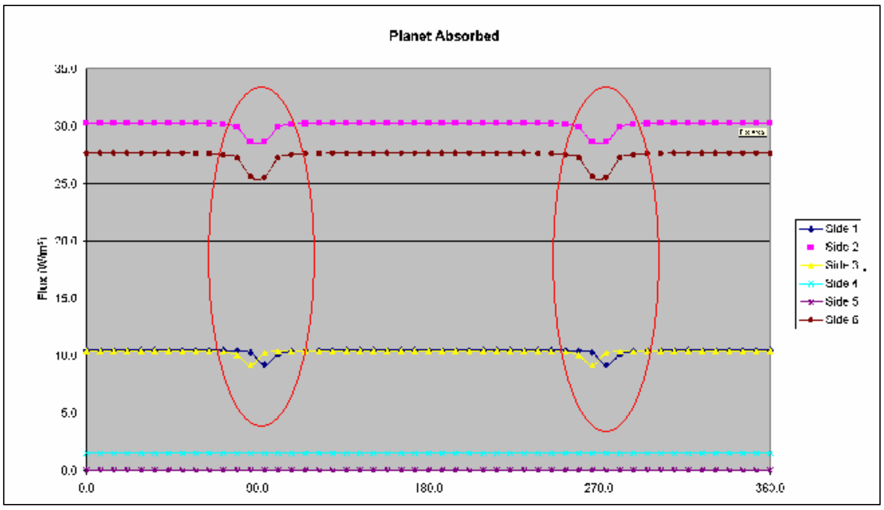
- Results in incorrect Representation of Planet Fluxes, particularly at the Poles
- For a 6:00/18:00 Orbit (Dawn/Dusk) the Fluxes should be constant



Satellites

Planet Temperature Mapping Error at the Poles

- Results are more accurate when increasing the Latitude/Longitude Resolution
  - Recommended Resolution : 181 Latitudes and 360 Longitudes
    - Odd number of Latitudes in order to have a Sub-Solar Point at Cell Intersection to consider maximum Temperature



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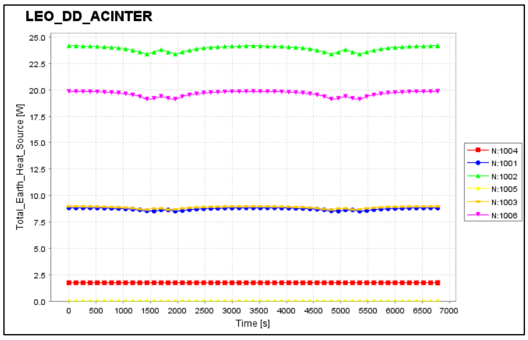
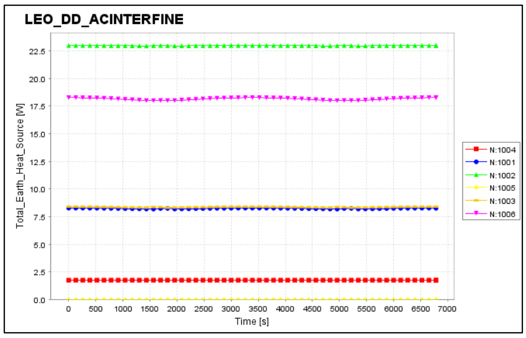
Planet Temperature Mapping Error at the Poles

- Interpolation Routine has been improved for next ESARAD Version

50000m, 90 deg Inclination, RA 90 deg, interpolate temperatures = TRUE - **[LATEST RESULTS]**





Coarse mesh: 19 lat x 36 long mesh

Fine mesh 73 lat x 720 long mesh

Appendix P

TCDT
New features

Matteo Gorlani
(Blue Engineering, Italy)

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

The new features that are currently under development for the TCDT will be presented.

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 Users
- 1° TCDT User Survey
- TCDT Maintenance Activity
- TCDT Improvements

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Sheet 2

Thermal Concept Design Tool

Background

1° YEAR OF DISTRIBUTION & MAINTENANCE STARTED NOVEMBER 2007

- TCDT is distributed FREE of CHARGE to the European Thermal Community
- TCDT web pages available for download, PR, FR
- TCDT is regularly maintained by BLUE
- Small developments are regularly implemented to improve operability
- TCDT version 1.2.3 will be available at the end of 2008

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Thermal Concept Design Tool

TCDT Users (1/2)

SOME NUMBERS

• Number of web site account	35
• Number of requests of account	35
• Number of rejected requests	0
• Number of released licenses	23

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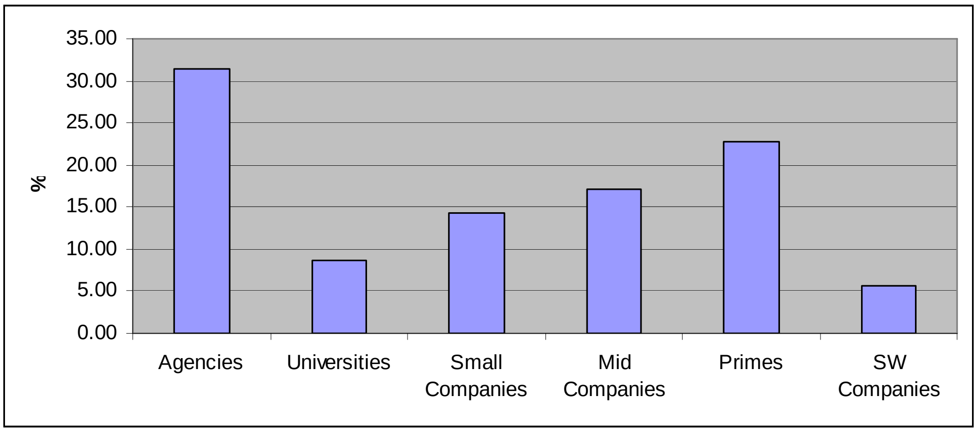
TCDT Users (2/2)

TYPE OF COMPANIES



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Sheet 5

1° TCDT User Survey (1/2)

USER REQUEST FOR ENHANCEMENTS

GEOMETRY DEFINITION & ANALYSIS

- Allow the use of formulas in Gnodes sheet
- Simplify geometric transformations
- Account for lateral and perpendicular conductance for high primitive

CONDUCTORS SHEET

- Suppress conductive couplings automatically when you suppress a node or a primitive.

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Thermal Concept Design Tool

1° TCDT User Survey (2/2)

USER REQUEST FOR ENHANCEMENTS

ORBIT VIEWER

- Show S/C axis and/or geometry on the orbit

3D VIEWER

- Have the overall characteristics of one face by clicking on it

SOLVERS

- Provide the TCDT of internal solvers

DBs

- Introduce internal DBs (e.g. materials)

RADIATOR SIZING

- Allow several virtual equipments on 1 panel
- Be able to treat several radiator primitives in the same time

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Thermal Concept Design Tool

TCDT Maintenance Activity (1/2)

BUGS CORRECTION

CRASH AFTER A SEQUENCE OF COMMANDS

- Error FATAL: necessary to stop Excel application
- Temporary workaround: open the 3DViewer by pushing the "Display 3D" button, before pushing the "Modify" button.
- Solution: It will be corrected in the next TCDT version

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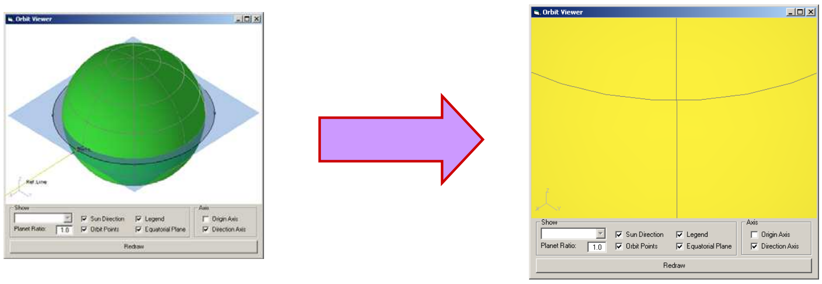
TCDT Maintenance Activity (2/2)

BUGS CORRECTION

ORBIT VIEWER

- Malfunction in changing from Planet-centred to Sun-centred
- Error MINOR



- Solution: It will be corrected in the next TCDT version

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TCDT Improvements (1/5)

ENHANCEMENT IN GMM DEFINITION

- Possibility To Use Formulas In Gnodes
- Improved Esarad Files Readability

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Sheet 10

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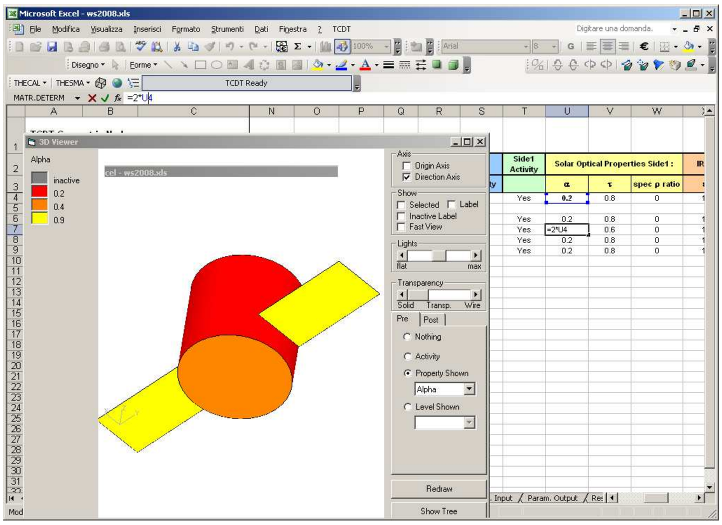
TCDT Improvements (2/5)

POSSIBILITY TO USE FORMULAS IN GNODES



Parametrisation of Optical Properties

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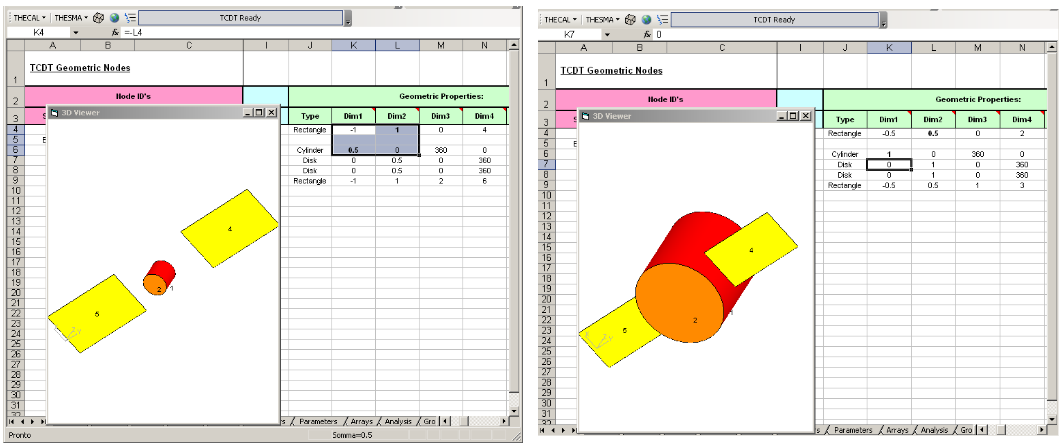
Sheet 11

TCDT Improvements (3/5)

POSSIBILITY TO USE FORMULAS IN GNODES



Parametrisation of Geometry

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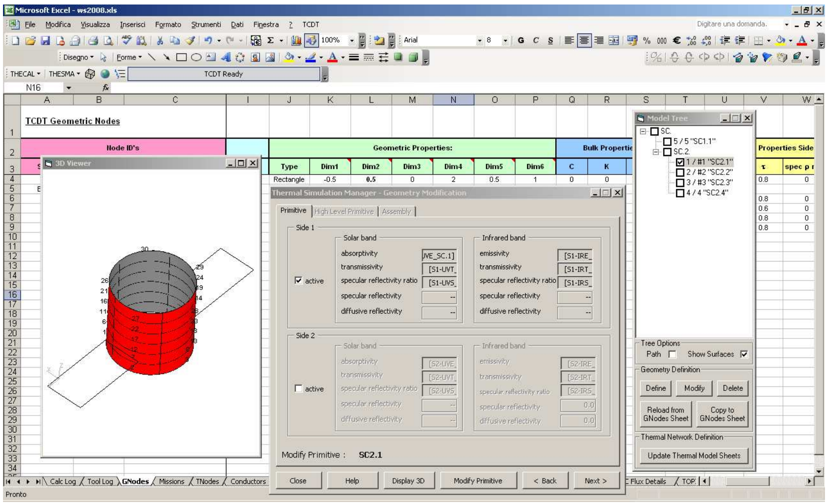
Sheet 12

TCDT Improvements (4/5)

POSSIBILITY TO USE FORMULAS IN GNODES



Full compatibility with TCDT meshing functionality

22nd European Thermal and ECLS Software Workshop
28-29 October 2008, ESA/ESTEC
Sheet 13

TCDT Improvements (5/5)

IMPROVED ESARAD FILES READABILITY

ws2008_g.t - Blocco note

```
BEGIN_MODEL ws2008
/*
==========================================================================

    ESARAD geometric model generated by the TCDT


==========================================================================
*/

/* ------------ SC_2_ (tree level=1) ------------ */

OPTICAL OPT1_SC_2_1;
    OPT1_SC_2_1 = [1.0000, 0.0000, 0.0000, 0.2000, 0.0000, 0.8000, 0.0000, 0.0000];

SHELL SC_2_1;
    SC_2_1 = SHELL_SCS_CYLINDER(radius    = 1.000000,
                    hmax     = 2.000000,
                    hmin     = 0.000000,
                    angmin   = 0.000000,
                    angmax   = 360.000000,
                    label    = "SC2.1",
                    opt1     = OPT1_SC_2_1,
                    nodes1   = 1,
                    nbase1   = 1,
                    ndelta1  = 1,
                    side1    = "ACTIVE",
                    side2    = "INACTIVE");

SC_2_1 = TRANSLATE (object_name = SC_2_1,
            x_dist = 0.00000,
            y_dist = 0.00000,
            z_dist = 0.00000);


OPTICAL OPT1_SC_2_2;
    OPT1_SC_2_2 = [1.0000, 0.0000, 0.0000, 0.4000, 0.0000, 0.6000, 0.0000, 0.0000];
```

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TCDT Team

DISTRIBUTION & MAINTENANCE

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

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

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Appendix Q

Applicability of EcosimPro to simulate a Life Support System

Victor Guirado Viedma
(NTE, Spain)

Abstract

The project MELiSSA Adaptation for Space Phase II (ESTEC/contract 20104/06/NL/CP) carried out by NTE (Barcelona, Spain) consists of finding a preliminary design of a Life Support System (ECLSS) for a future Moon base providing 100% air closure, 90% water closure and a 5% food production first and a 40% food production in a second steps. The study is mainly based on MELiSSA know-how but using as well other European sub-systems as the Air REvistalisation System (ARES), the Gray Water Treatment Unit (GWTU) and the Urine Treatment Unit (UTU). In our modeling approach, each of these sub-systems is composed of several components that can actually be combined and joined to finally obtain a robust and efficient ECLSS.

These different sub-sytems have been modeled at component level and interconnected using EcosimPro to generate a mass balance static model. Using this software tool, several designs have been created and simulated in order to evaluate which configuration is the most appropriated regarding efficiency, size, mass and energy consumption (i.e ALISSE criteria).

The implementation of a mathematic model for each component has been one of the more important and difficult steps. The difficulty came not only due to the complexity of the processes that take place but also due to the fact that many technologies are under study and several assumptions had to be done. This issue specifically raised the management of the degree of confidence and the need to add specific function for uncertainties calculations.

Another difficulty turned up when the whole system was closed due to the algebraic loops and because the EcosimPro mathematic solver needs the indication of which are the variables to iterate to find a solution to the equation system.

In the European Workshop on Thermal and ECLS Software, it is intended to expose in general terms how the EcosimPro works, how it has been used, as well as the difficulties found and the solutions performed. The library created in EcosimPro contains the models of several subsystems for different ECLS technologies, and endeavors to be a tool base to develop more sophisticated models, which will allow system engineers to evaluate ECLSS architecture and anticipate the ALISSE criteria.


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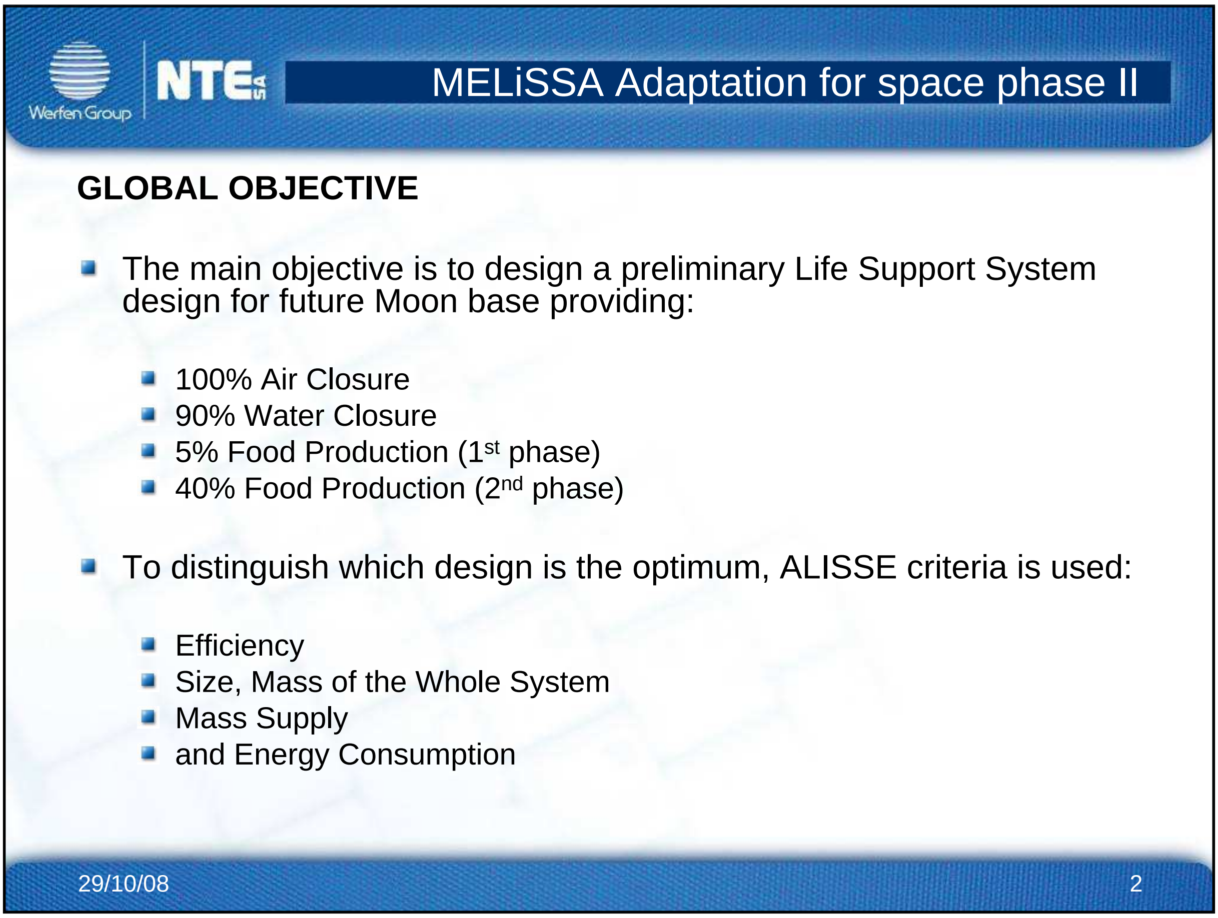
NTE SA
Applicability of EcosimPro to simulate a Life Support System.
Victor Guirado Viedma
Can Malé , s/n · 08186 Lliçà d'Amunt · Barcelona (España) · Tel. +34 938 60 90 01 · Fax. +34 938 60 90 19 · www.nte.es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NTE SA
MELiSSA Adaptation for space phase II
GLOBAL OBJECTIVE
The main objective is to design a preliminary Life Support System design for future Moon base providing:
100% Air Closure
90% Water Closure
5% Food Production (1st phase)
40% Food Production (2nd phase)
To distinguish which design is the optimum, ALISSE criteria is used:
Efficiency
Size, Mass of the Whole System
Mass Supply
and Energy Consumption
29/10/08
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What is Ecosim Pro?

- It is a software created by Empresarios Agrupados, EA, (Madrid)
- Consist of basically making a “component” where take place the mathematical model
  - A component may be simple, for example an electrical resistor or capacitor (with a couple of equations); or it may be very complex, for example the pressurized cabin of a space vehicle (with dozens of physics equations and many events)
- Ecosim Pro uses an own language called EcosimPro Language (EL)
- It is thought to dynamic systems but can be useful for static systems too
- In Ecosim are several libraries with different components already created and available to be used
- The version used has been 4.4.0

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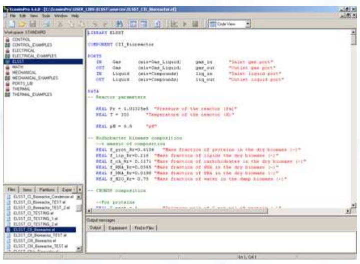
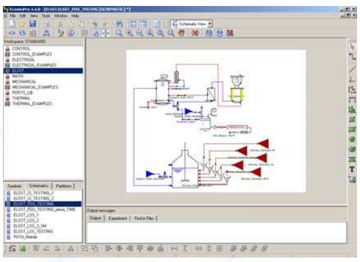
What is Ecosim Pro?

Ecosim Pro can be divided in three parts:

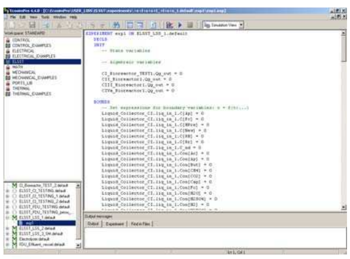
Code View



Schematic View



Simulation View



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What is Ecosim Pro?

- Code View
  - Creation of:
    - **Components** → It is the most important element in Ecosim Language. It represents a subsystem model by means of variables and equations
    - **Enumerative Types** → They are valid for representing a set of names valid of this type. For example: the chemical compounds that can participate in the System (NH3, CO2, O2, etc)
    - **Functions** → It is a piece of code that carries out operations and optionally returns values. It has been used to do common operations in the different components
    - **Ports** → It connect components and must have a mode, either IN (implies inward flow) or OUT (implies outward flow)

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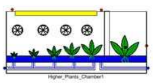
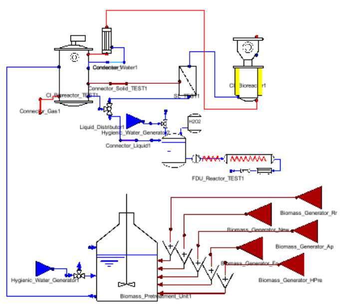
What is Ecosim Pro?

- Schematic View
  - Creation of:

Symbols → It is the drawing representation of a component



Schematics → It is the creation of a block diagram where the symbols are connected by means of their ports



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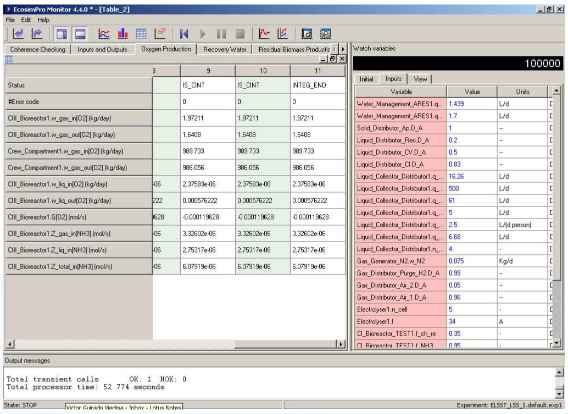
What is Ecosim Pro?

- Simulation View
  - Creation of:
    - **Experiments** → Here you can choose several characteristics to run the simulation and to view the results in different ways (for example using **Ecomonitor** where you can see tables and graphs)



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Applicability of EcosimPro

ACTIVITIES

1. Review of Technologies to be modeled
   - MELiSSA (MicroEcological Life Support System Alternative)
   - ARES (Air REvitalization System)
   - GWTU (Grey Water Treatment Unit)
2. Use and/or elaboration of a mathematic model for each subsystem of each technology
3. Implementation of the model in EcosimPro (components creation)
4. Simulation and validation of each subsystem separately (coherence of mass balances and fitting with the experimental data)
5. Design and simulation of an optimum configuration for the two phases of the study

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Werfen Group NTE SA — Applicability of EcosimPro

Review of each Technology

- MELiSSA (MicroEcological Life Support System Alternative)
  - Compartment I (Liquifying)
  - Compartment II (Removal of dissolved organic carbon)
  - Compartment III (Transform the ammonia into nitrate)
  - Compartment IVa (Produce oxygen and edible biomass)
  - Higher Plants Chamber (Produce oxygen, edible biomass and water)
- ARES (Air REvitalization System)
  - CCA (Carbon dioxide Collection Assemble)
  - CRA (Carbon dioxide Reduction Assemble)
  - OGA (Oxygen Generation Assemble)
- GWTU (Grey Water Treatment Unit)

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Werfen Group NTE SA — Applicability of EcosimPro

Elaboration of a Model for each Subsystem and its Implementation in EcosimPro

STEPS:

1. Simplification and adaptation of existing knowledge based models (MELiSSA)
2. Elaboration of mathematical models for other technologies (ARES, GWTU, etc)
3. Generation of Components in EcosimPro using the mathematical models
   - capable to represent the real subsystem
   - capable to connect one another in order to check what connection is most suitable under different operational conditions
4. Creation of new components that represents interface subsystems (Gas Collector, Valves, etc) and other that represent a subsystem that does not exist but is necessary.

→ There are about 35 subsystems modeled and get together in a library within EcosimPro

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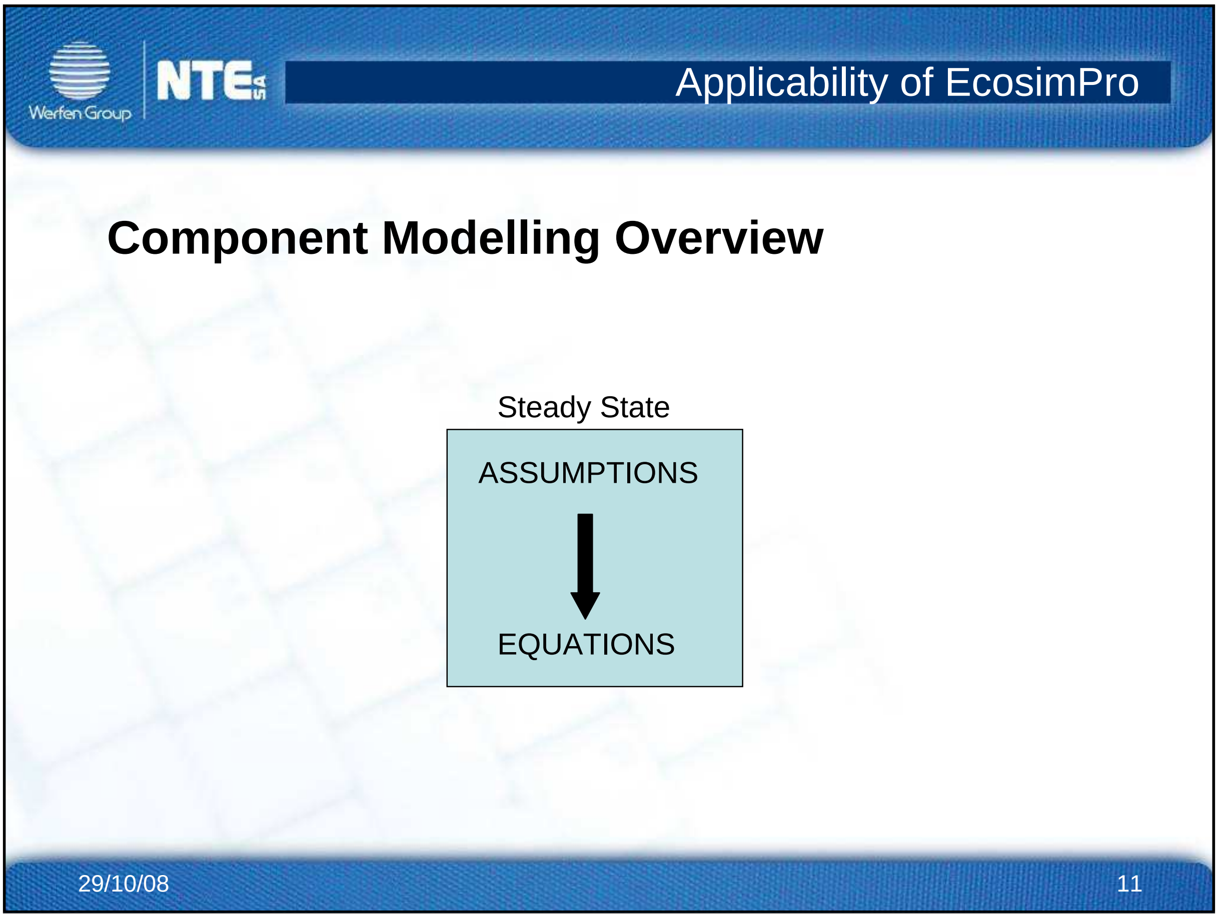
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Applicability of EcosimPro
Component Modelling Overview
Steady State
ASSUMPTIONS
EQUATIONS
29/10/08
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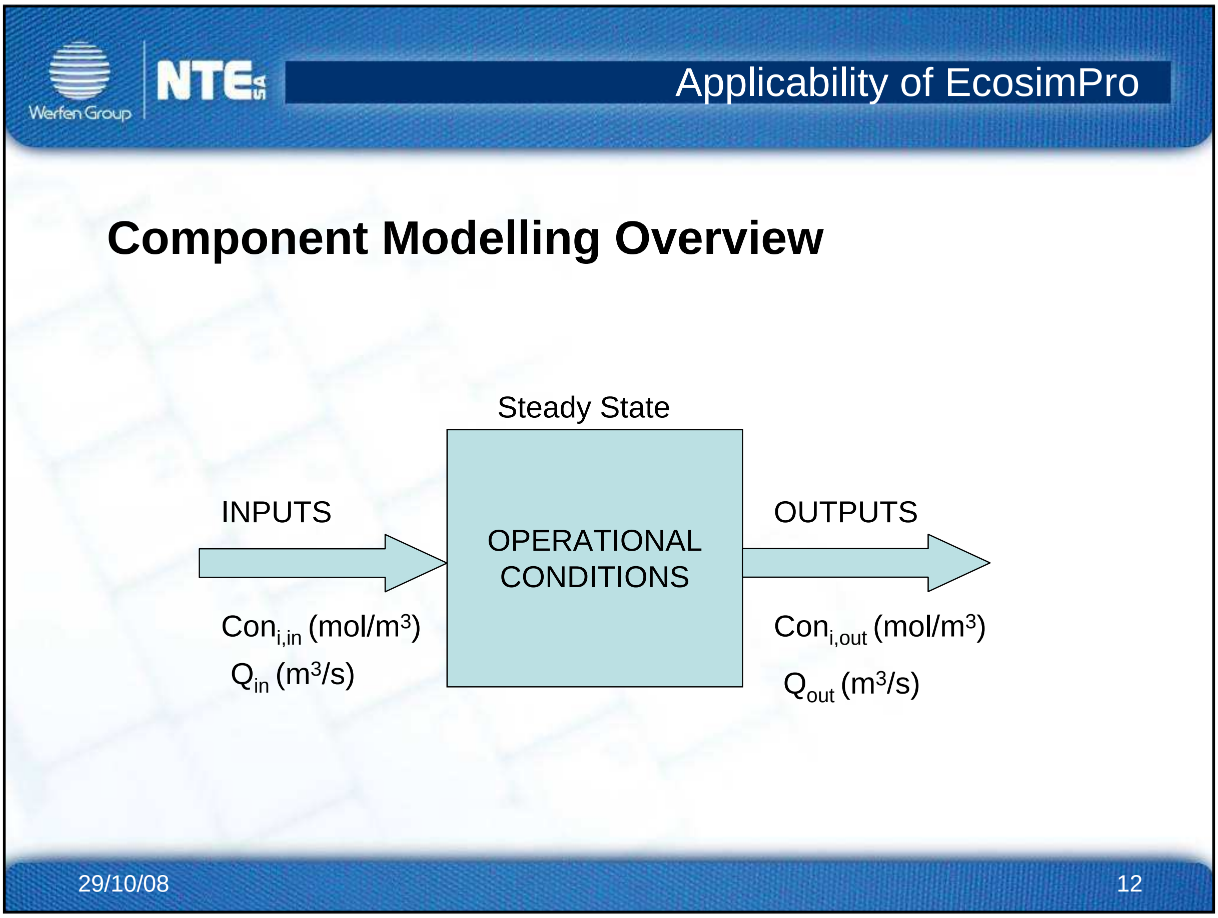
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Component Modelling Overview
Steady State
INPUTS
OPERATIONAL CONDITIONS
OUTPUTS
Con_i,in (mol/m3)
Q_in (m3/s)
Con_i,out (mol/m3)
Q_out (m3/s)
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Applicability of EcosimPro

Simulation and Validation of each Subsystem Separately

- Coherence of mass balances → Checked for all Components
- Fitting with the literature experimental results → Checked for some Components

Design and Simulation of an Optimum Configuration for the Two Phases of the Study

- 1 Preliminary design for the 1s phase (5% of food production)
- 1 Preliminary design for the 2nd (40% of food production)

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Applicability of EcosimPro

Steps to Simulate a Configuration with an Optimum Preliminary Design

1. Creation of a block diagram
2. Creation of a Partition (Election of: boundary variables, algebraic variables, etc)
3. Generate an Experiment (Election of the time stop, initial time, etc)
4. Run the simulation
5. Check the coherence of the whole system (mass balances and requirements achieved)
6. Optimization of the System (to change some operational data and maybe some connections to improve the results)
7. Interpretation of the Results

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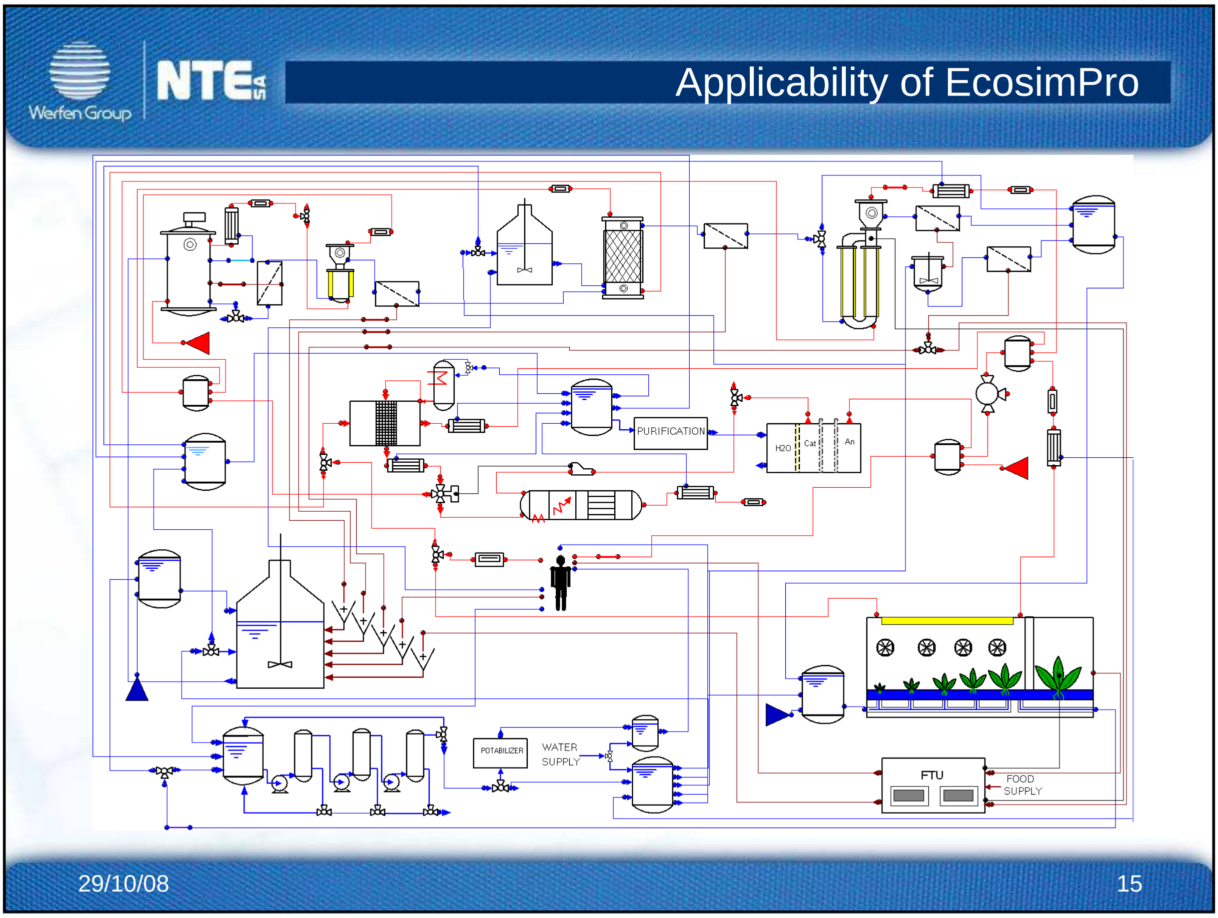
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Applicability of EcosimPro
PURIFICATION
H2O
Cat
An
POTABILIZER
WATER SUPPLY
FTU
FOOD SUPPLY
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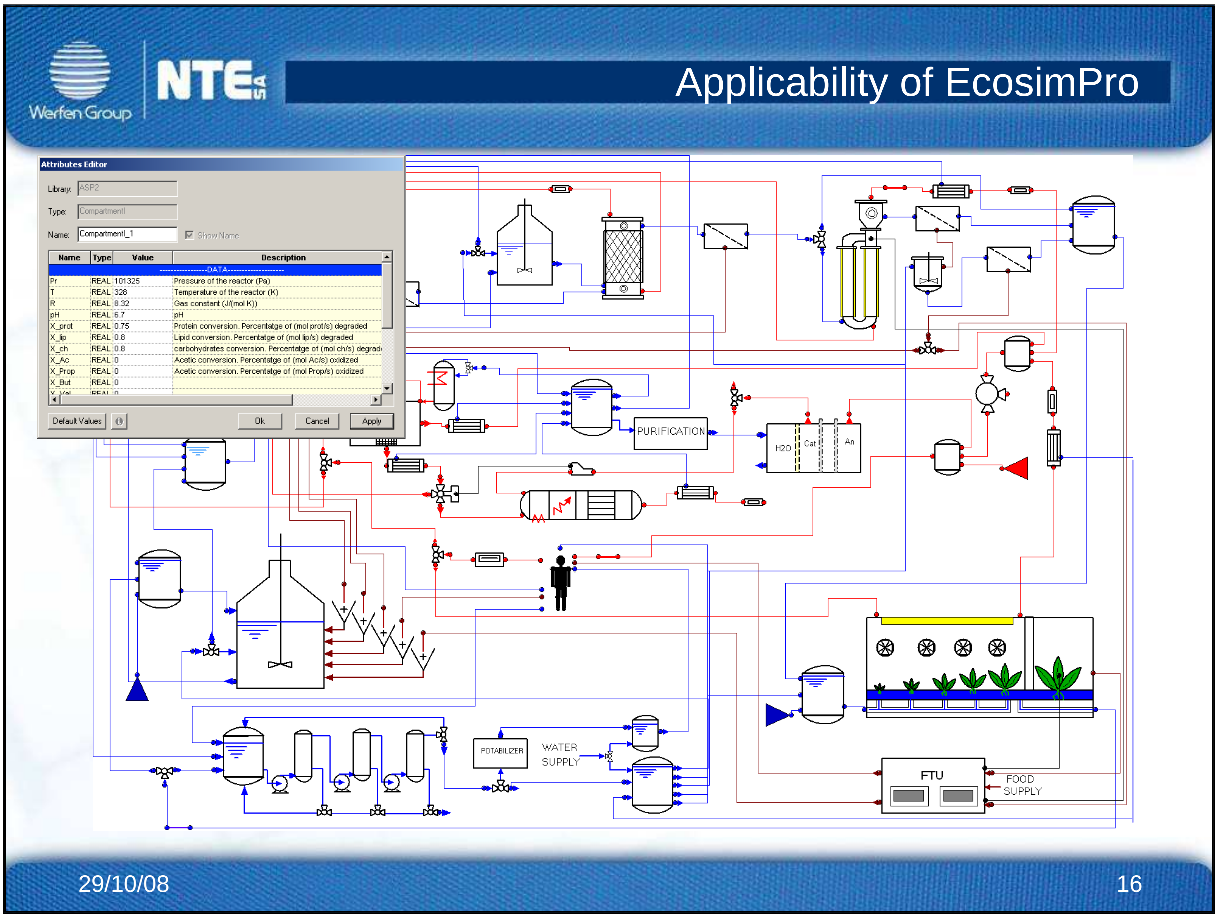
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Attributes Editor
Library: ASP2
Type: CompartmentI
Name: CompartmentI_1
Show Name
Name Type Value Description
DATA
Pr REAL 101325 Pressure of the reactor (Pa)
T REAL 328 Temperature of the reactor (K)
R REAL 8.32 Gas constant (J/(mol K))
pH REAL 6.7 pH
X_prot REAL 0.75 Protein conversion. Percentatge of (mol prot/s) degraded
X_lip REAL 0.8 Lipid conversion. Percentatge of (mol lip/s) degraded
X_ch REAL 0.8 carbohydrates conversion. Percentatge of (mol ch/s) degrad
X_Ac REAL 0 Acetic conversion. Percentatge of (mol Ac/s) oxidized
X_Prop REAL 0 Acetic conversion. Percentatge of (mol Prop/s) oxidized
X_But REAL 0
Default Values
Ok
Cancel
Apply
PURIFICATION
H2O
Cat
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POTABILIZER
WATER SUPPLY
FTU
FOOD SUPPLY
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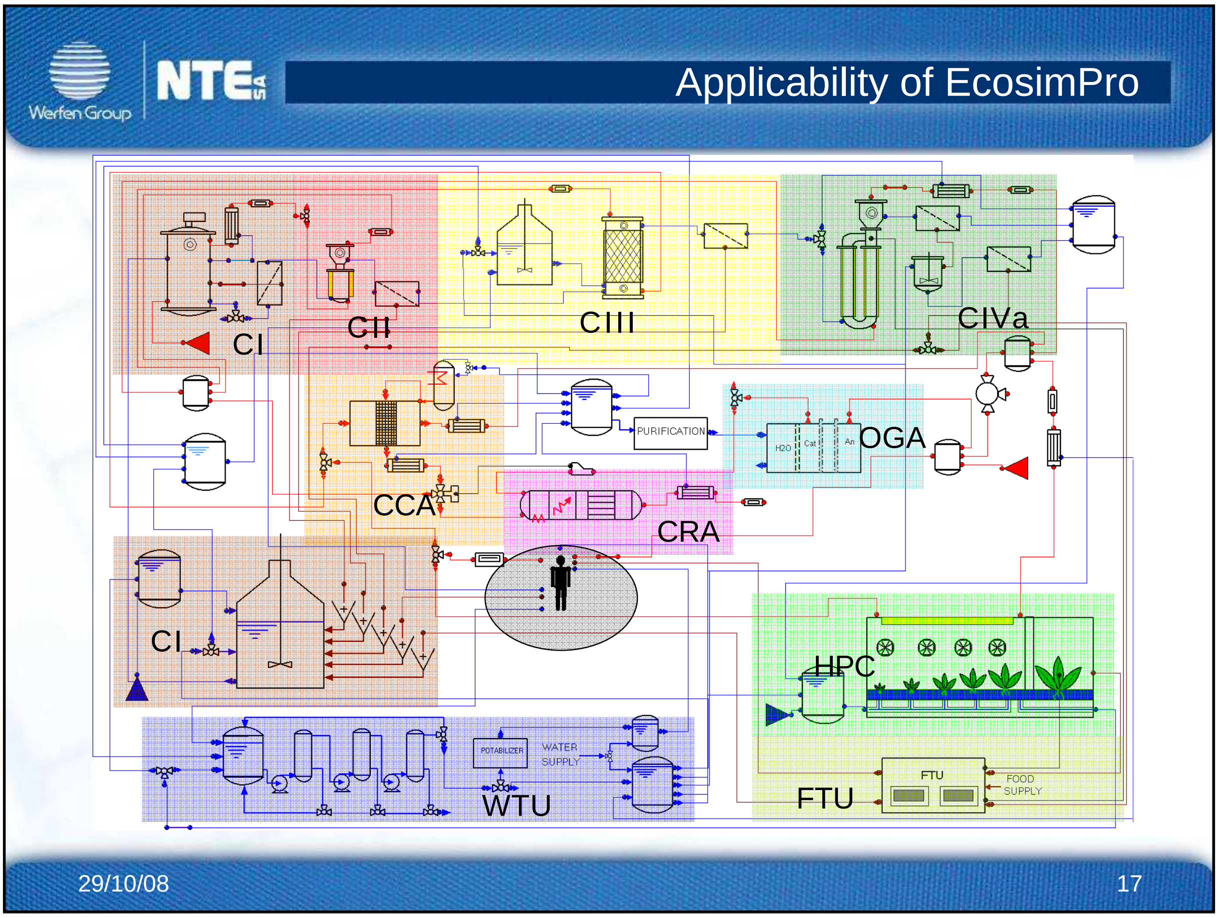
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NTE SA
Applicability of EcosimPro
CI
CII
CIII
CIVa
CCA
PURIFICATION
H2O
Cat
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OGA
CRA
CI
HPC
POTABILIZER
WATER SUPPLY
WTU
FTU
FOOD SUPPLY
FTU
29/10/08
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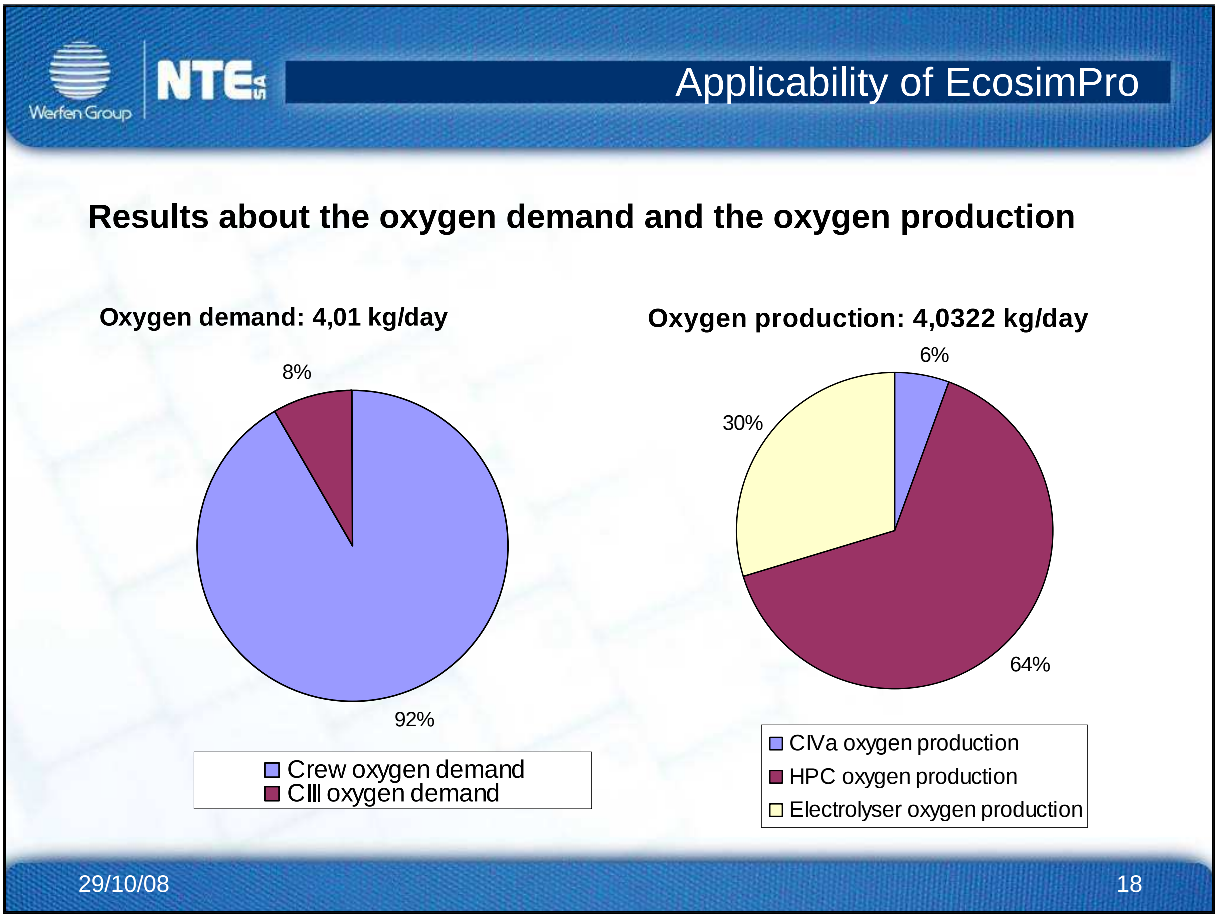
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Applicability of EcosimPro
Results about the oxygen demand and the oxygen production
Oxygen demand: 4,01 kg/day
8%
92%
Crew oxygen demand
CIII oxygen demand
Oxygen production: 4,0322 kg/day
6%
30%
64%
CIVa oxygen production
HPC oxygen production
Electrolyser oxygen production
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Applicability of EcosimPro

Difficulties found & Solutions Performed

Difficulty	Solution	Consequence
Error message when the denominator is zero:	Creation of a function to return zero, when the denominator is zero.	▪ The program works properly
Algebraic Loop generated in some Components: ▪ Several variables to be iterated ▪ Too high computation time ▪ The system does not converge	Reorganize the equations to force the system to iterate only one variable. ▪ A good knowledge about the mathematical model and about the process that takes place is necessary to choose the variable to be iterated	▪ The equation system does not always converge: The results obtained are limited to certain inputs

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Applicability of EcosimPro

Difficulties found & Solutions Performed

Difficulty	Solution	Consequence
Algebraic Loop generated in the whole system when it is closed: ▪ A component needs inputs that are actually the outputs of the previous component	Creation of a dynamic Component: ▪ It's a dynamic component that delays the inputs: ▪ For long times the outputs are equal to the inputs	▪ The results are good for long times

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Applicability of EcosimPro

Conclusions

- EcosimPro is a good tool to run simulation about any system:
  - You can have a previous idea about the design of a system and about its feasibility
  - You can compare between different design and distinguish which is better depending on your criteria
  - You can take advantage from the models already elaborated to simplify it or to get it more complex

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Applicability of EcosimPro

Thank you for your attention

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Appendix R

ALSTOM Product Demonstration

Ian Guest
(ALSTOM, United Kingdom)

Abstract

Demonstration of the latest versions of the products.

Thermal & ECLS Software Workshop

ESATAN-TMS Development Status

2008

Author: Ian Guest
Date: 29th Oct 2008

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Aerospace

ALSTOM

Recap of new features presented so far…..

Recent developments

- New layout for the ESATAN-TMS workbench
- Additional Geometry Building Capabilities
- Modelling Time & Temperature Dependency
- Non-Orbital (Ground based) Analysis support
- Extended Analysis Case Tree Menu Options

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Discussion of Further Developments

Presentation of further developments

- New Utilities Menu for complete thermal tool integration
  - Direct launch of ThermNV, Parametrics Manager…
- Support for new HDF result data file
  - Compatible with all of ESATAN-TMS
  - More scalable and smaller file
- Maintenance and Enhancement
  - Pre-processor error message improvement
- Improvements for transient solver SLCRNC
- ThermNV latest developments
  - Unit labels, etc

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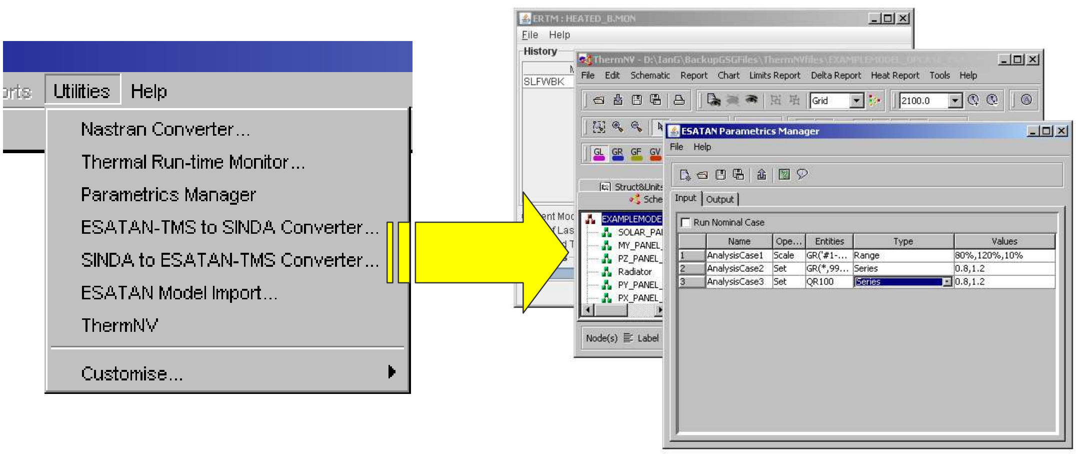
Expanded Utilities Menu

- presents a convenient way for user to quickly extend the Workbench to launch other applications
- creates an integrated environment



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Support for Binary HDF files

- Models larger and more complex → Bigger Results Files
- Implementation of new Thermal Model Data (TMD) file type
- use Hierarchical Data Format (HDF5) industry standard file format.
  - Platform independent binary format
  - Far more compact (2 orders of magnitude reduction in file size seen for large models)
  - Reduced loading times
  - Same interactive performance

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Support for Binary HDF files

- New DMPTMD output call
  - Same argument set retained

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

- Used for transfer of results data across all processes
- Automatically generated from Workbench

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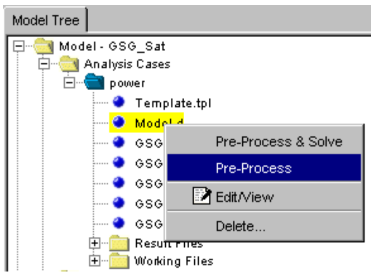
Improvement of Pre-processor Error Detection

- In order to improve creating models directly from model scripts, pre-processor error detection has been improved to detect:
  - Unbalanced parentheses
  - Duplicate node definitions
  - Missing semi colons e.g. $NODES, $CONDUCTORS



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Improved performance for transient solver SLCRNC

- Improved performance with larger time steps
- Implementation of an enhanced 'first-stab' calculation
- Quicker convergence for some models
- SLCRNC the recommended 1st choice of transient solver because:
  - Allows much larger time steps which reduces the solution time compared to SLFWBK
  - Features automatic time step control (user sets accuracy limit)
  - Dynamic definition of arithmetic nodes.

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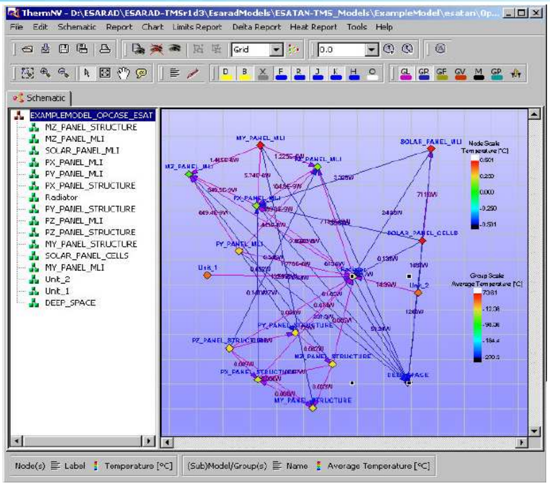
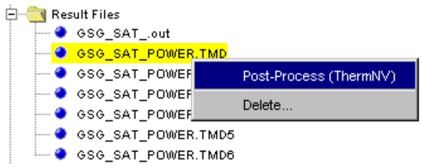
ThermNV Enhancements

- Introduced in ThermNV 3.2
  - Display of Unit Labels
  - Attribute Layout
  - Batch Runner Utility
  - New Getting Started Guide



- Introduced in ThermNV 4.0
  - Support for Binary HDF Files



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Live Demo of ESATAN-TMS

- Based around Getting Started Guide Model
- Processing an Analysis Case via the GUI
  - Running case from model tree/ relevant updates
  - Importing results into GUI
  - TMD vs GFF results files
  - Importing TMD results file into ThermNV
  - Running a Parametric Analysis via the Utilities Menu
  - Processing Parametric Results files (TMD) via the ThermNV batch runner

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www.esatan-tms.com
ALSTOM

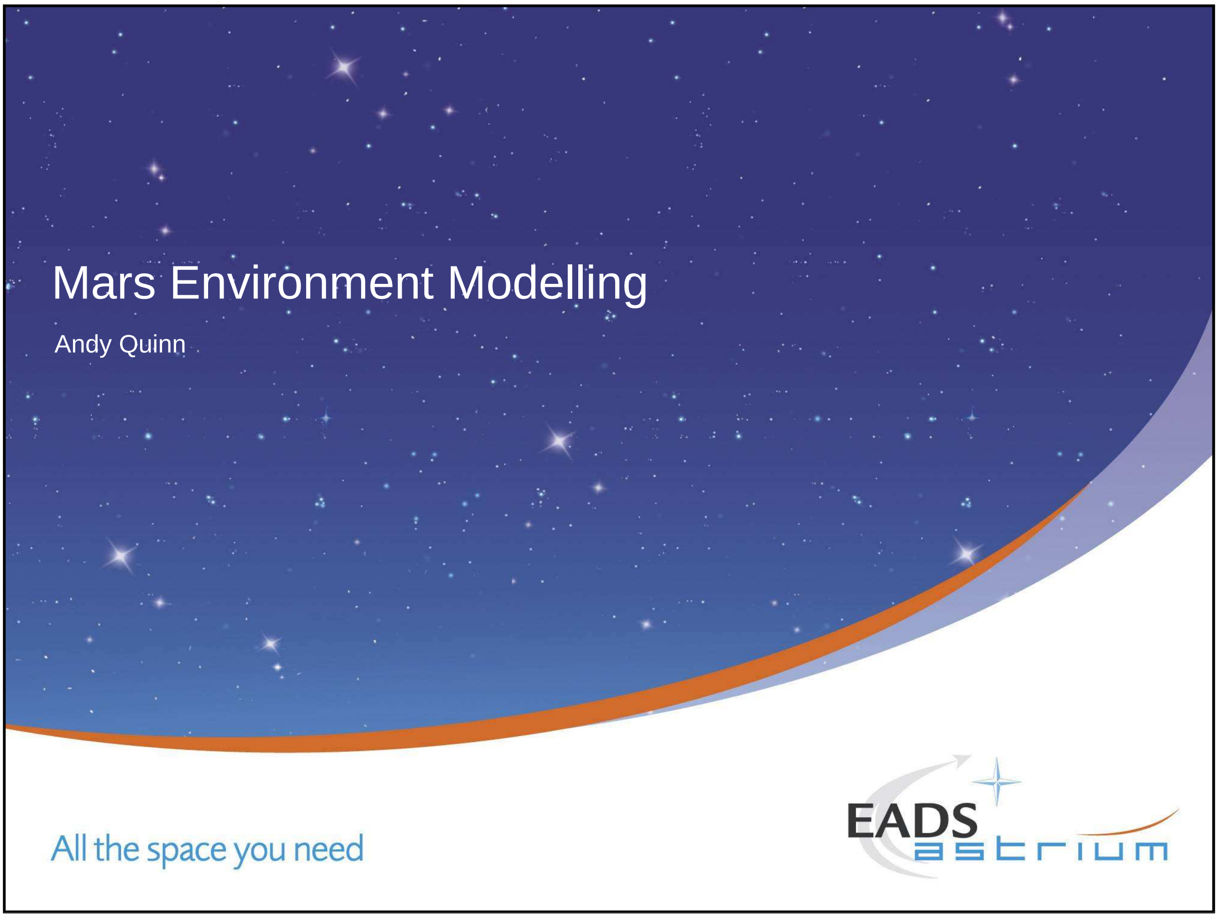
Appendix S

Implementation of a Mars thermal environment model using standard spacecraft analysis tools

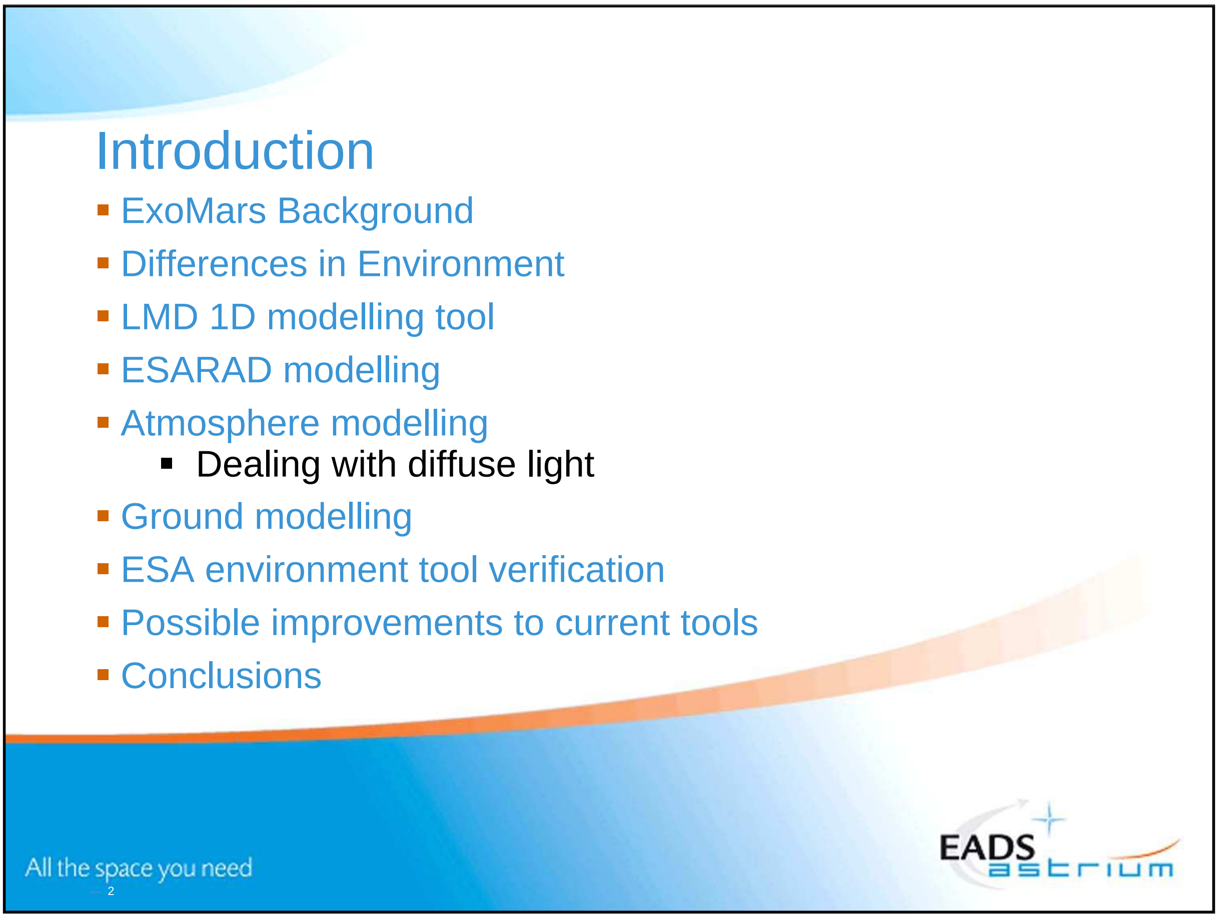
Andy Quinn
(EADS Astrium, United Kingdom)

Abstract

A number of models of the surface of Mars exist which can be used as inputs to thermal analysis. On ExoMars ESATAN and ESARAD have been used along with a simplified one dimensional Mars climate model supplied by the Laboratoire de Météororologie Dynamique in Paris. These tools can be used to generate flux profiles including diffuse load due to atmospheric dust, dynamic ground temperatures which take into account shadowing and soil thermal response, and representative diurnal cycles. The methods for achieving these are presented here.



Mars Environment Modelling
Andy Quinn
All the space you need
EADS astrium



Introduction
ExoMars Background
Differences in Environment
LMD 1D modelling tool
ESARAD modelling
Atmosphere modelling
Dealing with diffuse light
Ground modelling
ESA environment tool verification
Possible improvements to current tools
Conclusions
All the space you need
2
EADS astrium

ExoMars Background

- Prime Contractor Thales Alenia Space in Turin
- Astrium UK Rover Vehicle lead
- Nominal launch in 2013 with backup in 2015
- Landing in 2015/16
- Recently completed phase B2
- PDR held in September

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Environment Differences

- Atmosphere
  - Primarily CO_2
  - Pressure range 570-700 Pa
  - Temperature range -125 to 5 °C
- Variation in suspended dust
  - Affects how flux reaches rover
  - Varies over year and over short periods
- Diffuse light
- Planet surface, not an orbit

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LMD Modeling tool

- Tool created at the Laboratoire de Météororologie Dynamique in Paris under ESA contract
- Based on European Mars Climate Database
- Builds on previous power analysis tool
- Includes surface temperature, solar flux, diffuse flux and effective sky temperature as outputs.
- Outputs such as sky temperature and diffuse flux used directly in model
- Other parameters used to verify model outputs

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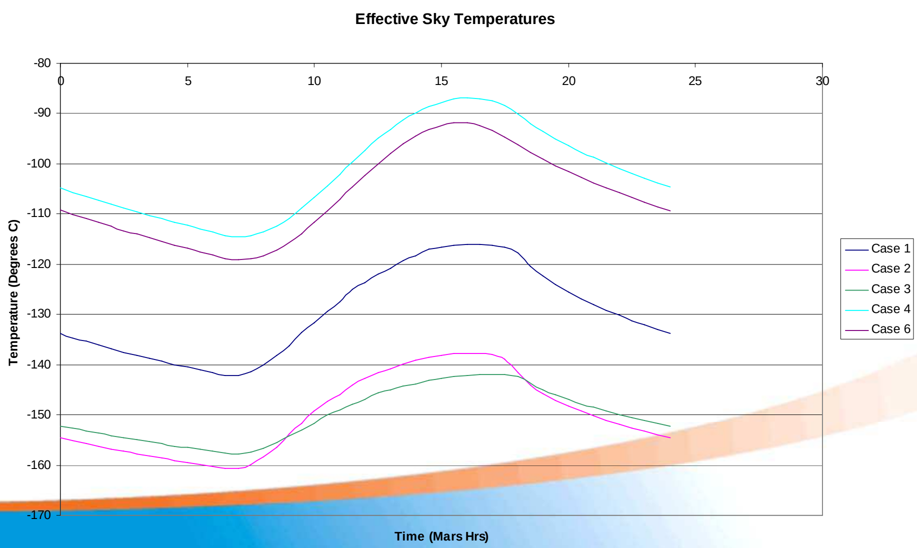
5

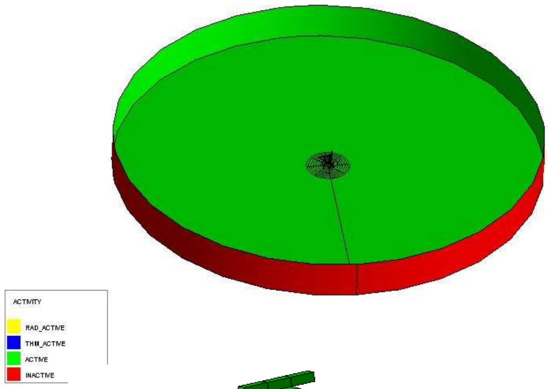
Sky temperatures from LMD tool

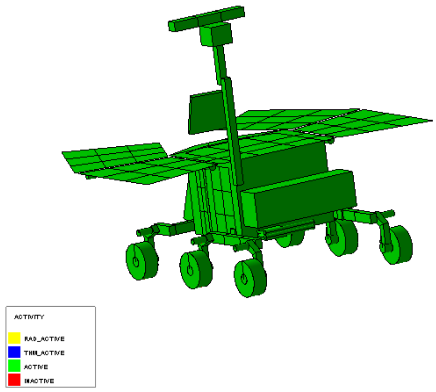


All the space you need

ESARAD Modelling

- Modelled as surface in orbit about sun with mars orbit parameters
- Large sunshade including cylinder for horizon at 10°
- 1 day orbit arc considered
- Geometry model rotated to angle of latitude
- Geometry reference axes rotated in line with axial tilt
- Planet rotation introduced around tilted axis





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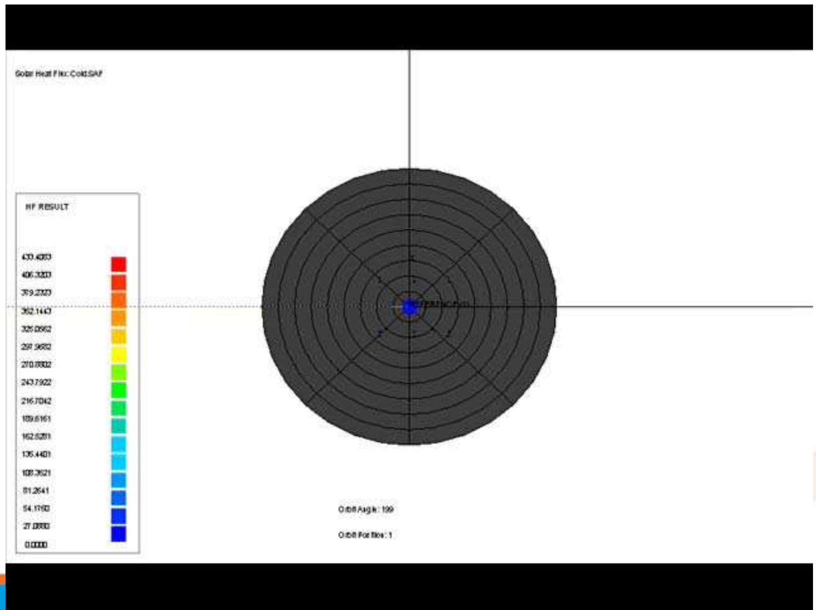
7

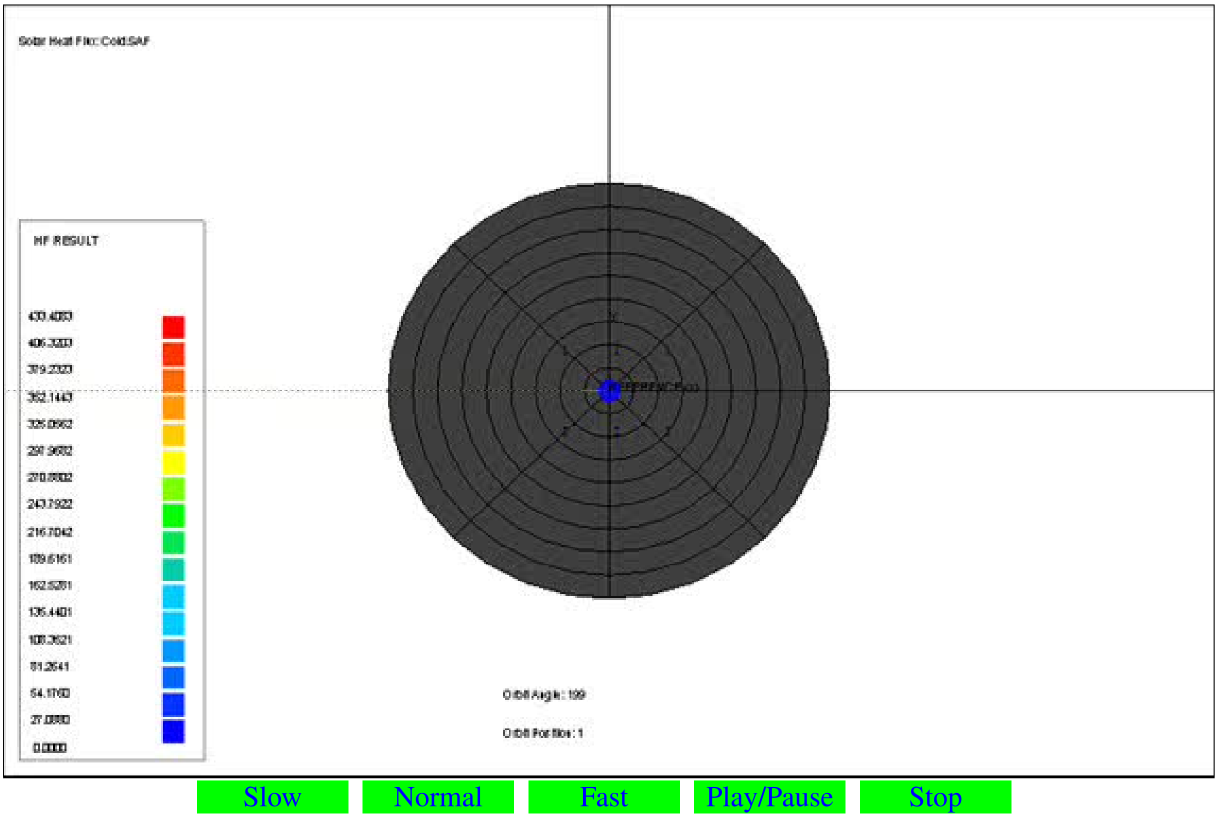
EADS astrium

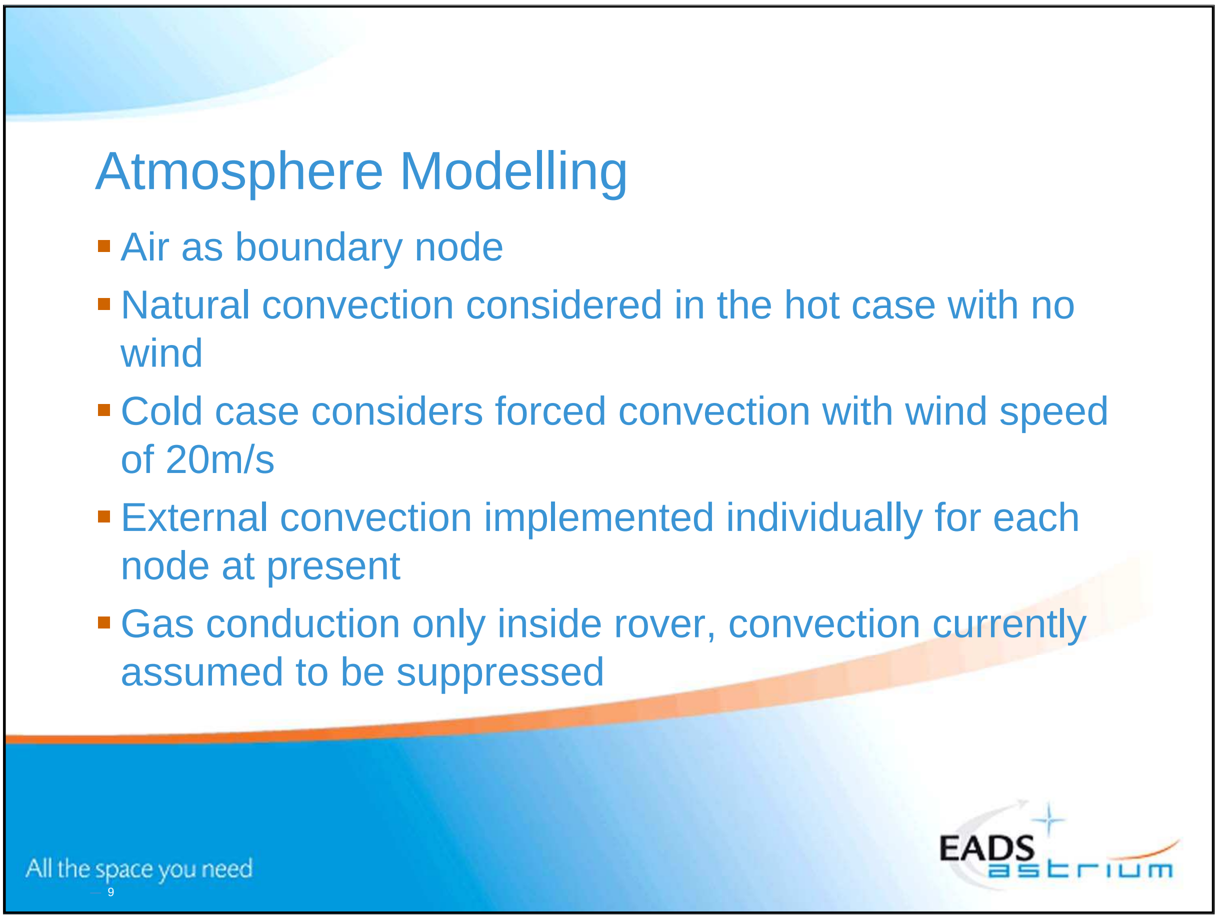


All the space you need

8

EADS astrium


Solar Heat Flux: Cold.SAF
HF RESULT
433.4083
406.3203
379.2323
352.1443
325.0562
297.9682
270.8802
243.7922
216.7042
189.6161
162.5281
135.4401
108.3521
81.2641
54.1760
27.0880
0.0000
Orbit Angle: 199
Orbit Position: 1
Slow
Normal
Fast
Play/Pause
Stop


Atmosphere Modelling
Air as boundary node
Natural convection considered in the hot case with no wind
Cold case considers forced convection with wind speed of 20m/s
External convection implemented individually for each node at present
Gas conduction only inside rover, convection currently assumed to be suppressed
All the space you need
9
EADS astrium

Handling Solar Flux

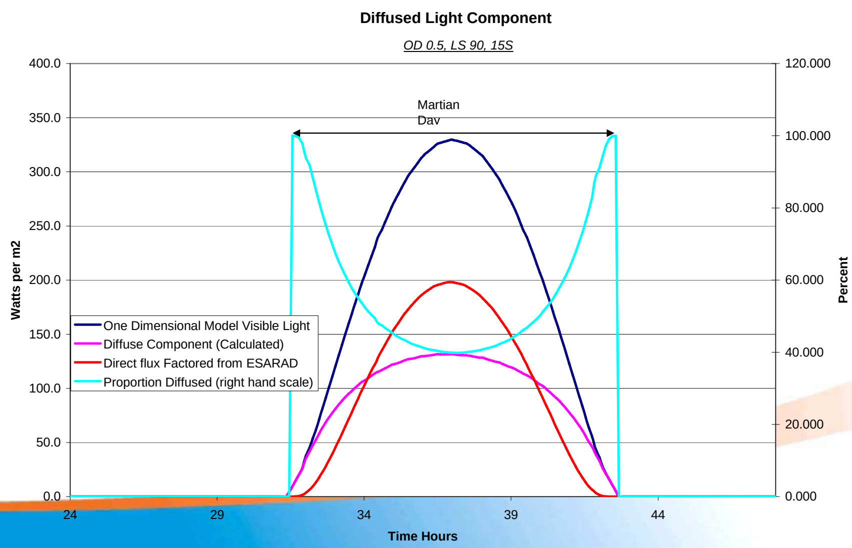
- Can't be handled entirely in ESARAD
- Dust optical depth major parameter
  - Affects effective Sky temperature
  - Proportion of direct/diffuse light
- Sky temperature determined from external tool
- Tool cannot handle shadowing and reflections
- Optical depth factor applied to ESARAD generated direct flux
- Diffuse flux applied using model GR's to space

$$Qdi = D \,.\, (bi/\varepsilon i).\, ai$$

All the space you need
10

EADS astrium

Diffuse light

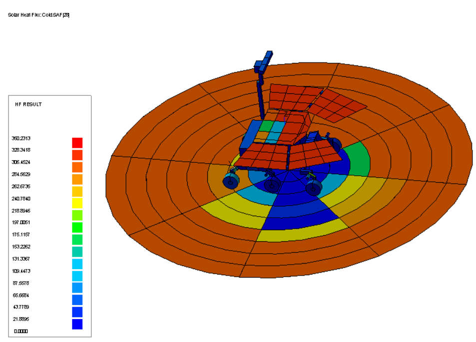


All the space you need
11

EADS astrium

Ground Modelling

- Dynamic ground model local to rover
- Large boundary remote from rover
- 72 nodes at surface in detailed ground
- 5 nodes deep under surface
    - Simplified version of ESA model
- All coupled through to a subsurface boundary node



All the space you need

12

EADS astrium

Ground variation

- Ground parameters vary across surface
- Major parameter is ground thermal inertia

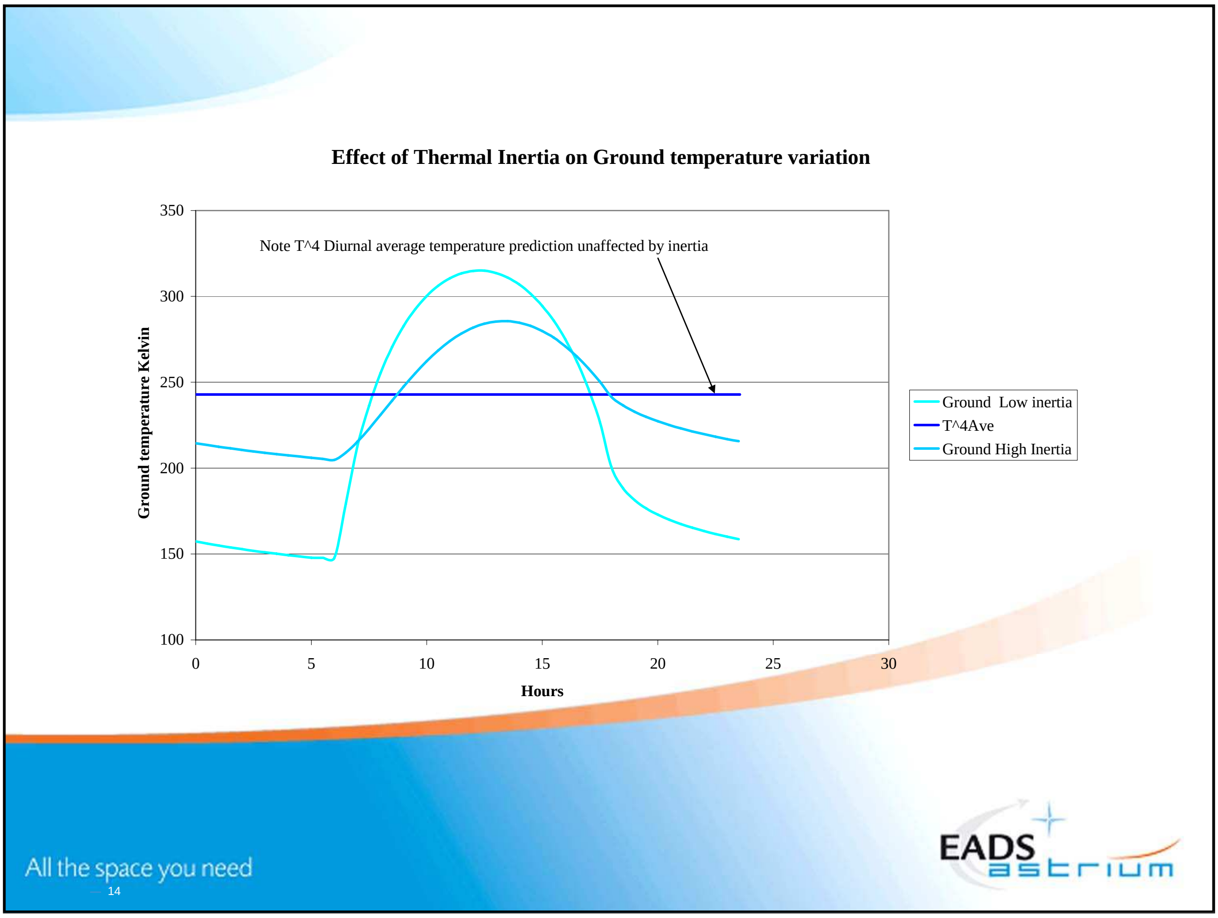
$$I = \sqrt{\lambda C}$$

- Light dusty surface means large daily temperature variation
- Solid hard rock means smaller daily temperature variation
- Diurnal T^4 average temp unaffected by thermal inertia.

All the space you need

13

EADS astrium

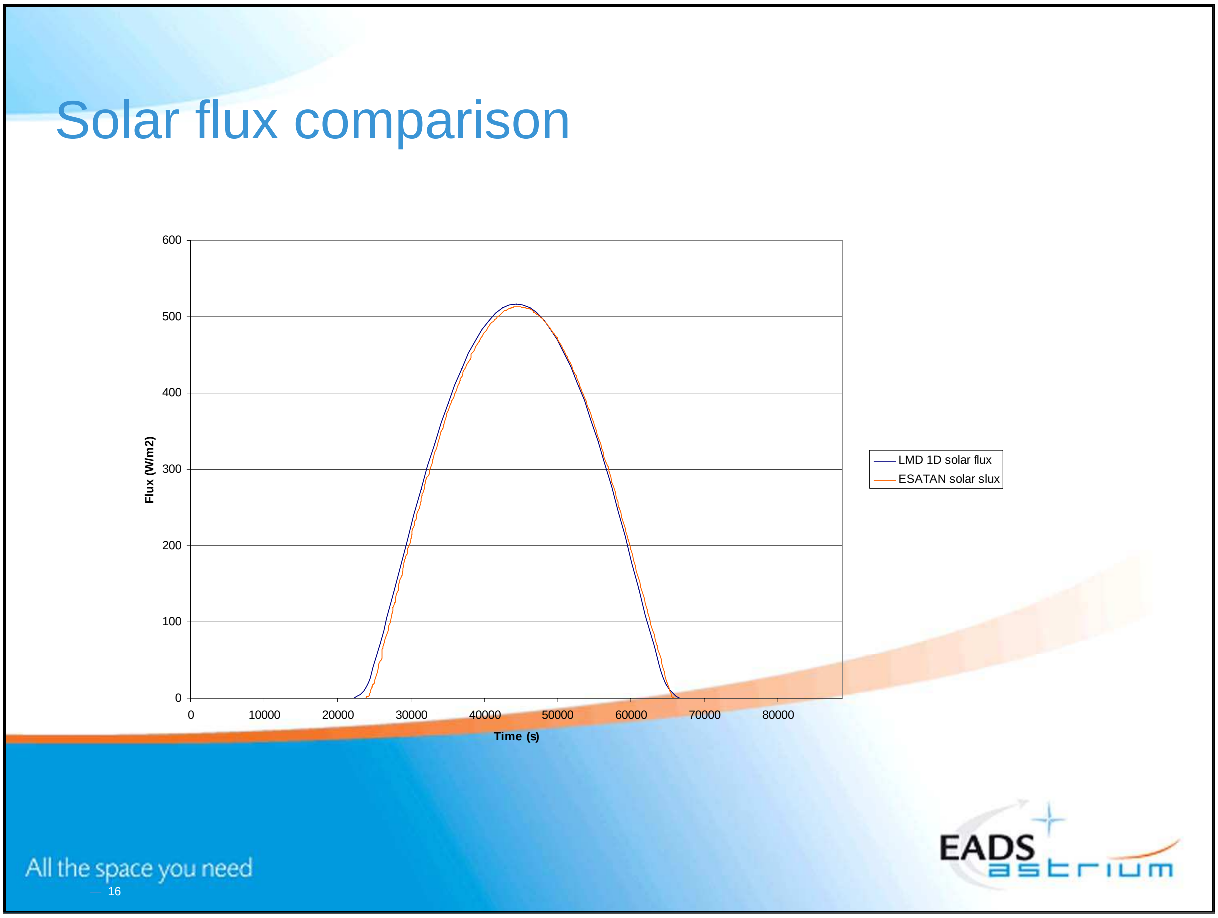


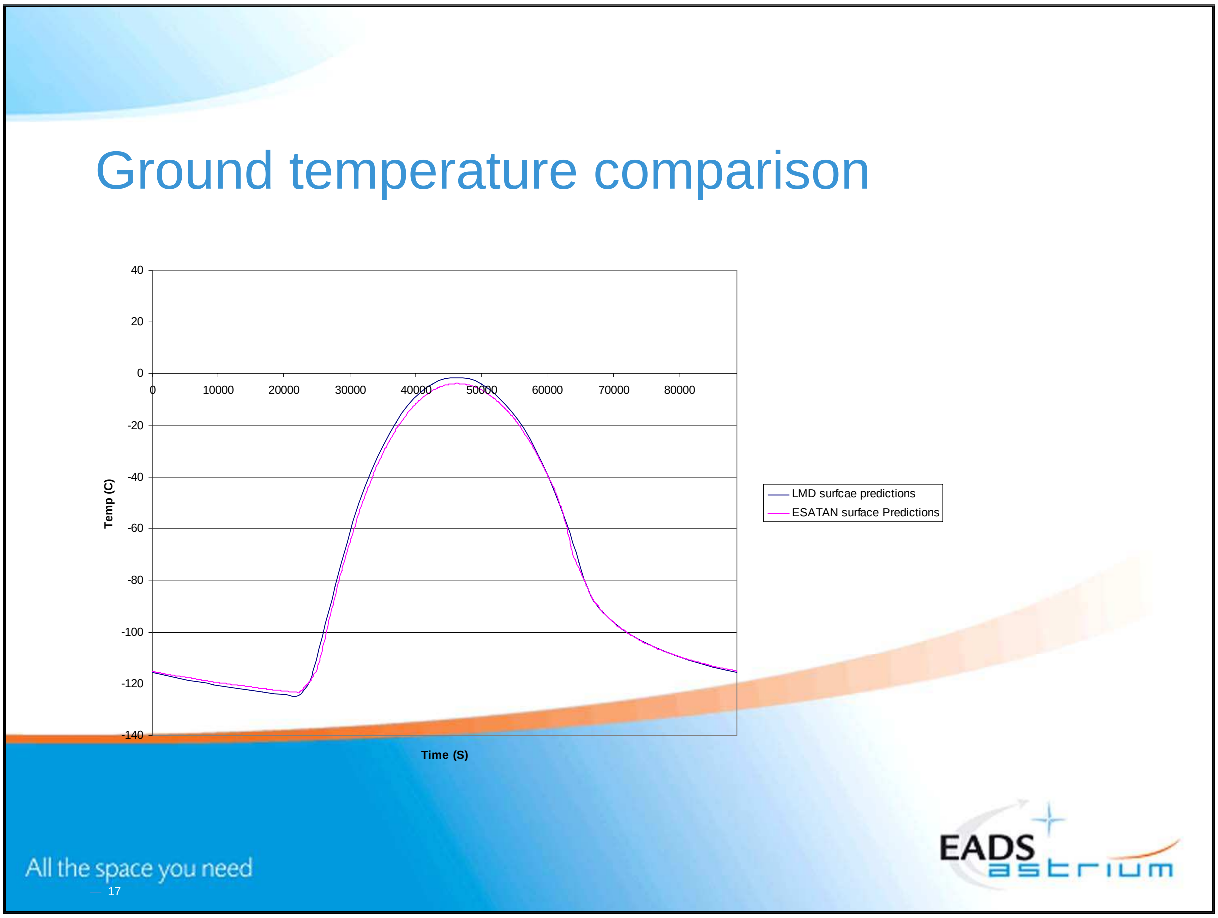
ESA Thermal Tool Verification

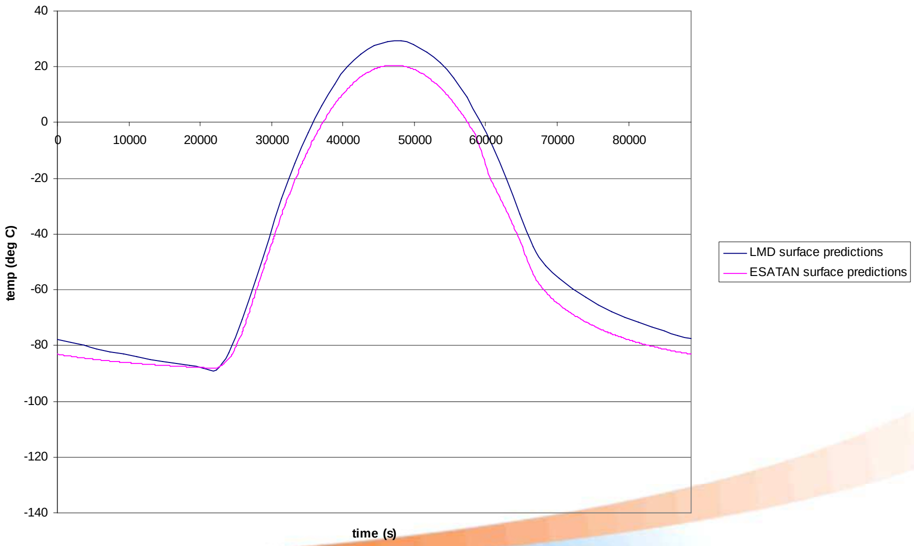
- LMD tool useful to verify that equivalent parameters are being calculated correctly
- Direct solar flux as implemented in ESATAN
- Effects of optical depth
- Ground temperatures have good correlation in most cases
    - Some problems in hotter cases

All the space you need

15


Solar flux comparison
600
500
400
300
200
100
0
Flux (W/m2)
0
10000
20000
30000
40000
50000
60000
70000
80000
Time (s)
LMD 1D solar flux
ESATAN solar slux
All the space you need
16
EADS
astrium


Ground temperature comparison
40
20
0
-20
-40
-60
-80
-100
-120
-140
Temp (C)
0
10000
20000
30000
40000
50000
60000
70000
80000
Time (S)
LMD surfcae predictions
ESATAN surface Predictions
All the space you need
17
EADS
astrium

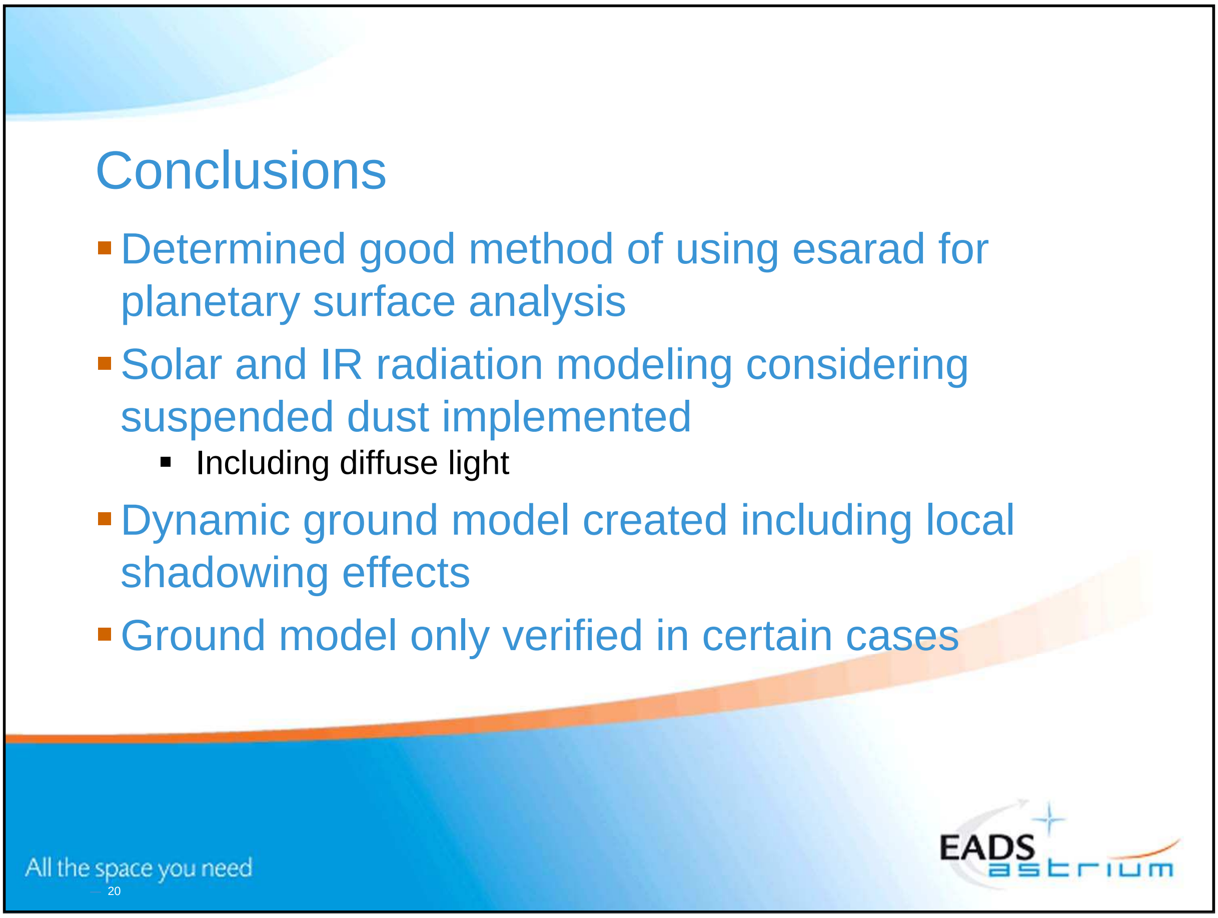


All the space you need

Tool Improvement Suggestions

- Not possible to place model on planet surface in ESARAD
- Night time calculated like eclipse periods
- Optical depth inclusion for solar flux calculations
  - Straightforward for direct flux
  - More complex for diffuse flux
- Better method for calculating external convection
  - Have considered using TMG as a pre-processor

All the space you need


Conclusions
Determined good method of using esarad for planetary surface analysis
Solar and IR radiation modeling considering suspended dust implemented
Including diffuse light
Dynamic ground model created including local shadowing effects
Ground model only verified in certain cases
All the space you need
20
EADS astrium

Appendix T

Thermal Design and Analysis of the BroadBand Radiometer

Oliver Poyntz-Wright
(Rutherford Appleton Laboratory, United Kingdom)

Abstract

The Broadband Radiometer is being designed and built by a UK consortium to fly on ESAs EarthCARE mission. The Rutherford Appleton Laboratory is responsible for the thermal, mechanical and optical design as well as procurement of critical components. The thermal design has undergone much iteration over the course of 2008. The thermal, mechanical and optical models have now converged on a solution that is being put forward for System Requirements Review in November 2008. Key challenges faced by the thermal design include overcoming the high Earth and albedo loads of a low orbit to passively cool internal black bodies to -10°C and achieving tight stability requirements on the three telescope assemblies. ESARAD and ESATAN models were created to model the low earth orbit radiative environment and the instrument thermal design.

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Thermal Design and Analysis of the BroadBand Radiometer

Olly Poyntz-Wright
Thermal Engineering Group

Space Science and Technology Department
Rutherford Appleton Laboratory (RAL), UK

Thermal Engineering Group
www.sstd.rl.ac.uk/thermal

Overview

1. Introduction
2. Instrument Overview
3. BBR Thermal Problem
4. Thermal Design Philosophy
5. ESARAD Geometric Modelling
6. ESATAN Thermal Modelling
7. Model Predictions
8. Modelling Issues
9. Further work

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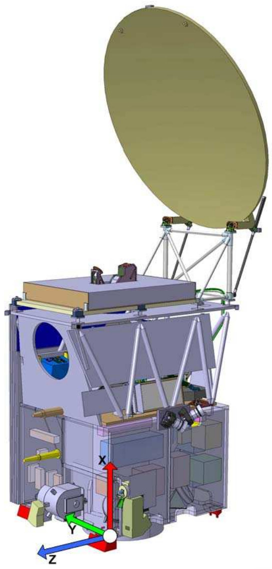
Introduction

- EarthCARE
- Earth Clouds Aerosols and Radiation Explorer
- Launch 2012
- Four instruments on board
  - Cloud Profiling Radar (ESA/JAXA)
  - Multi-Spectral Imager (SSTL)
  - Atmospheric Lidar (Astrium SAS)
  - BroadBand Radiometer (UK consortium)

- Science goals:
  - quantifying aerosol-cloud-radiation interactions to improve climate and numerical weather forecasting



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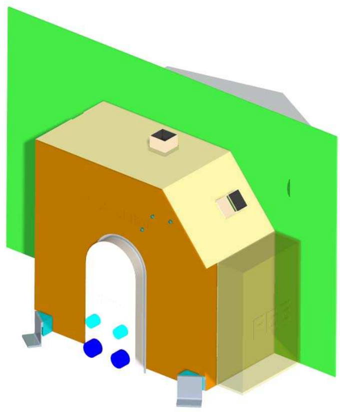
Instrument Overview

- Measures top of atmosphere radiances
- BBR is a mission critical EarthCARE instrument
  - Top of atmosphere radiances taken by BBR serve as a consistency check for the cloud radiance properties taken by the other active instruments

- BBR UK Consortium led by SEA Ltd
- SEA
  - Project management, systems engineering, software
- RAL
  - Thermal, mechanical and electronic design, AIT, procurement of critical components e.g. black bodies, detectors
- Sula Systems
  - Motors and Mechanisms



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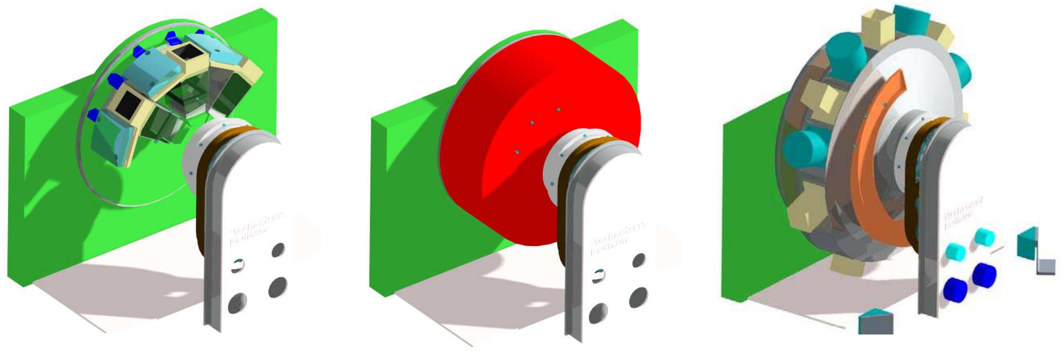
Instrument Overview

- 3 telescopes measure top of atmosphere radiance with forward, aft and nadir views
- Chopper drum slices the telescopes view
- References sources are provided by the on-board black bodies and a solar view
- Calibration drum slews round to provide views to the calibration sources



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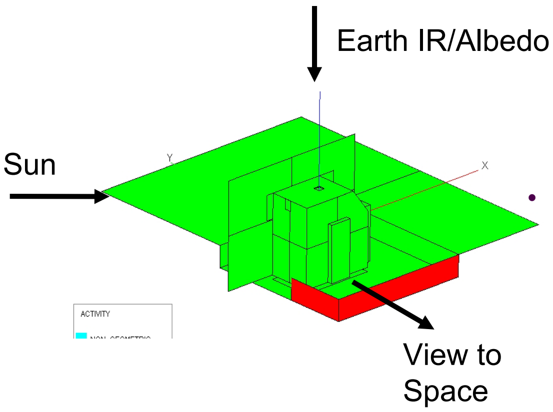
BBR – Thermal Problem

- Requirements Summary:

Component	Absolute temperature	Stability
	(deg C)	(mK/min)
Cold Black Body	-10	n/a
Hot Black Body	28	n/a
Chopper drum	n/a	77
Mirrors	n/a	390
Baffles	n/a	5
Detectors	-10	5



- Key challenges of thermal design
  - Low Earth Orbit (385km) so high Earth IR and Albedo Loads
  - Non-Optimal placement of instrument on spacecraft
  - Internal power dissipations of between 10-17W
  - Radiator size/location restricted by instrument volume envelope

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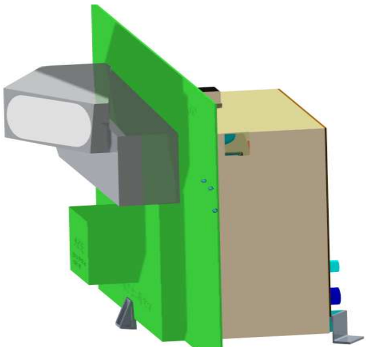
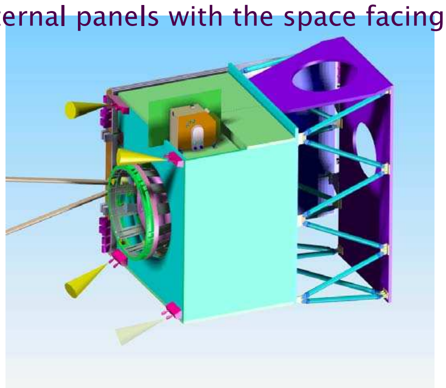
Thermal Philosophy

- Cold-biased design
- Passively cool instrument to -20˚C (includes 10˚C uncertainty margin)
- Use of heaters on telescopes and black bodies to achieve absolute temperatures and thermal stability
- Thermally isolate motors and electronics boxes as far as possible
- Minimise conductance to spacecraft interface
- Maximise radiator area on all external panels with the space facing panel oversized as required





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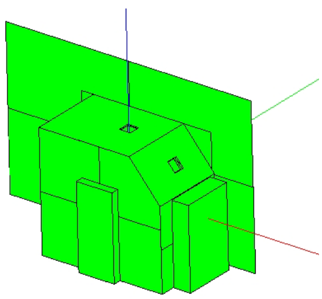
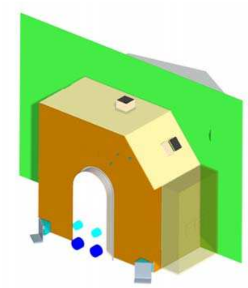
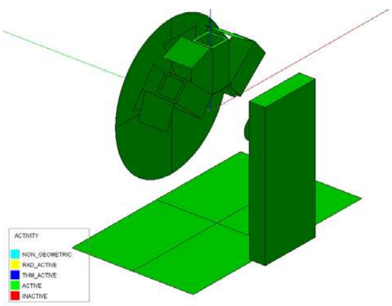
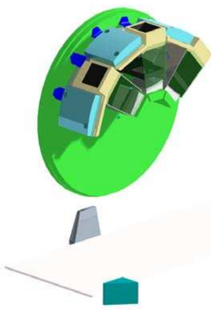
GMM

- ESARAD v6.2
- Created manually from examination of CAD model
- GMM updated as the Solid CA model evolved
- Orbit
  - Low/hot case 385km
  - High cold case 402km
  - 97˚ inclination









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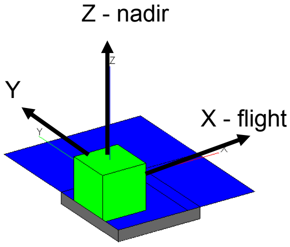
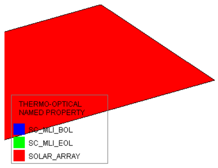
GMM

- Used simplified ESARAD GMM to understand external radiative environment
- BBR panels represented as a box

Panel	Solar Total	Albedo Total	Earth Total	Sum of Incident Loads	Steady State Temperature
	(W)	(W)	(W)	(W)	(deg C)
+Z	0.86	2.50	28.36	**31.7**	**-15.0**
-Y	0.21	1.28	10.19	**11.7**	**-41.0**
+X	3.34	1.55	10.73	**15.6**	**-25.0**
+Y	3.63	1.52	10.53	**15.7**	**-25.0**
-X	3.48	1.00	9.31	**13.8**	**-36.0**





  - Very high Earth IR
  - High Albedo
    → Focus on minimising absorbed Earth loads
    → For radiators low absorptivity more important than high emissivity
  - All panels (except +Z) could be used as useful radiator area

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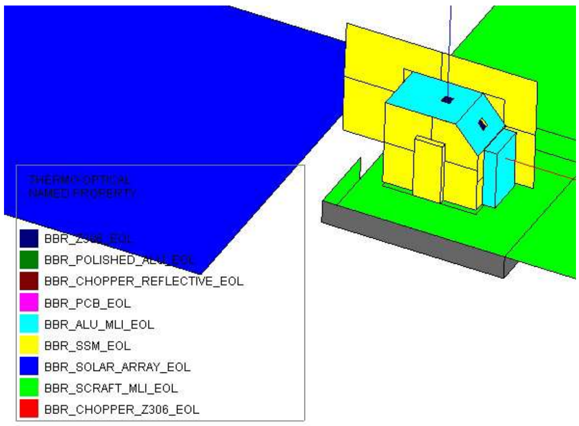
GMM

- Radiator
  - 0.78m x 0.31m
  - Mounted on +Y panel due to volume envelope constraints
- All panels as radiator except +Z
- MLI on +Z panels

- Assumed thermo-optical properties:
- Radiating Surface
  - Secondary surface mirrors
  - ε = 0.81, α = 0.12-0.15

- Internal surfaces
  - black paint
  - ε = 0.84-0.94, α = 0.96

- MLI
  - aluminised kapton
  - ε = 0.05, α = 0.14
  - Effective emissivity 0.02



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TMM

- ESATAN v10.2
- 108 thermal nodes
- 175 linear conductors
  - manually generated rather than ESARAD
- 3212 ESARAD radiative couplings
- Material properties taken from Thermal Group database
- Values for contact conductance based on standard assumptions

- Stability heaters
  - Modelled with ON/OFF control
  - Narrow set-points required to achieve stability (0.01degC)
  - Heaters on each of the 3 telescope assemblies

- Survival heaters
  - Modelled with wider set-points (5deg C)
  - Mechanical thermostats

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Predictions

- Summary of steady state predictions (extreme hot case, no heater control)

Label	Temperature (deg C)	
	Hot Case Nominal	Cold Case Nominal
Mechanism Housing	-6.75	-20.15
Nadir Mirror Assembly Base	-24.62	-38.51
Nadir Mirror	-24.62	-38.51
Nadir Mirror Mount	-24.62	-38.51
FPA - Nadir	-24.30	-38.18
Nadir FPA Mount	-24.44	-38.32
Nadir Internal Baffle Assembly	-24.65	-38.54
Black Body	-21.34	-35.67
Calibration Drum	-21.59	-35.80
Aluminium Base Plate	-26.32	-40.93
+X Panel	-26.22	-40.77
+Y Radiating Panel	-28.53	-42.46
+Z Sloped Panel	-26.75	-41.17
-X Radiating Panel	-27.55	-41.85
-Y Radiating Panel	-26.50	-41.18

- Good margin demonstrated on cooling of black bodies
- ≈15deg C between nominal hot and cold cases
- Thermally isolated mechanisms run ≈ 15-20deg C warmer

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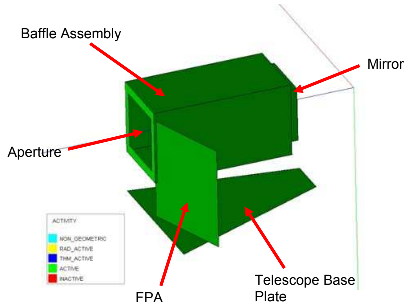
Predictions

- Summary of stability heaters

Heater Location	Power (W)	Duty Cycle (%)	Upper Set-point (deg C)	Lower Set-point (deg C)
Forward Telescope Assembly	4.00	77	-10.00	-9.99
Nadir Telescope Assembly	4.00	77	-10.00	-9.99
Aft Telescope Assembly	4.00	77	-10.00	-9.99
Cold BB1	1.75	5	-10.00	-9.99
Cold BB2	1.75	5	-10.00	-9.99
Hot BB1	1.75	78	27.99	28.00
Hot BB2	1.75	78	27.99	28.00

- Predicted stabilities

Component	Predicted Stability (mK/min)	Requirement (mK/min)
Telescope Assembly Base	33	n/a
Mirror	9	390
FPA	3	5
Baffle	4	5
Chopper Drum	34	77



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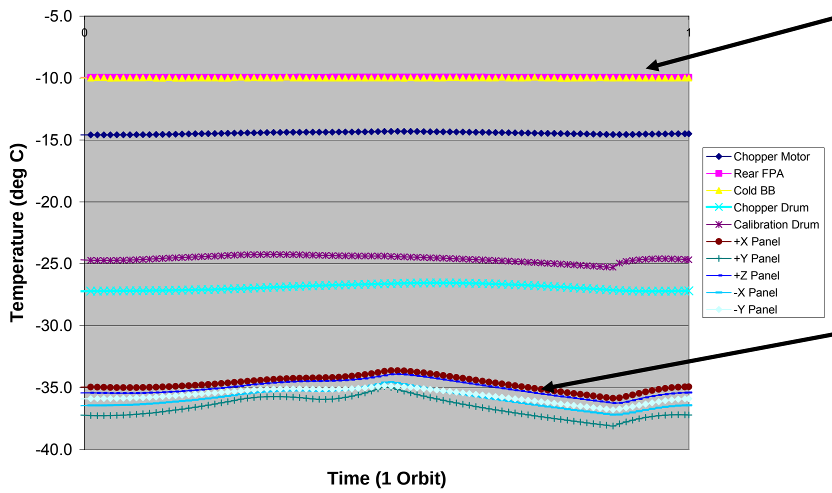
Predictions



Control Heaters stabilise temperatures of BB's and Telescope Assembly

Rest of instrument still subject to orbital variations

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Summary

- Thermal Design
  - Low absorptivity SSM's on external panels to cool instrument and minimise effect of Earth IR
  - Oversized +Y panel to achieve margin
    - Currently occupies full volume
  - Software controlled heaters on each telescope to achieve stability requirements on key components
  - Thermal isolation of mechanisms and electronics to reduce heat load on radiator
  - MLI on +Z panels
- Model Predictions
  - BB's at ≈-21˚C in hot case
    - Margin demonstrated in cooling black bodies
  - High heater powers as a consequence of large radiating area
    - Not a huge issue given instrument size
  - Stability requirements predicted to be met

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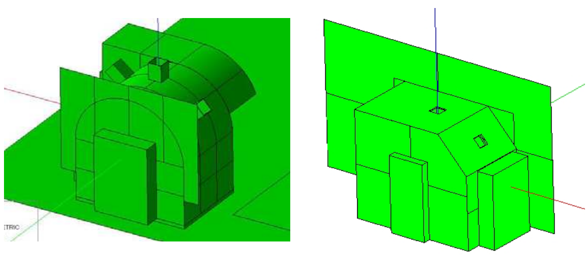
Notes on Modelling

- "Standard" model
- GMM
  - Constantly changing as design progressed
  - Beneficial to have easy and quick manipulation of shells
  - Ability to define shells through parameters useful
    - Could this be expanded to allow definition of reference planes, axes etc..
    - Similar to solid CAD packages



Evolution of BBR GMM

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Further Work

- Current thermal models and results have been submitted for System Requirements Review
- More detailed modelling required:
  - Black bodies (lumped mass assumed thus far)
  - Increase nodal density on primary radiator
  - Sensitivity analysis on key assumptions
    - Conductance from instrument to s/craft
    - Conductance between thermally isolated mechanisms and instrument structure
  - Stability heaters
    - Location
    - Size
    - Control regime
- Specification of
  - Heater circuits and redundancy
  - Temperature sensors and location

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CONTACT DETAILS

Olly Poyntz-Wright
Thermal Engineering Group

Email: olly.poyntz-wright@stfc.ac.uk

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Appendix U

STEP-TAS Activities

Abstract

This is a combined presentation. We will inform you about the progress that has been made in the past year on the following projects:

- IITAS (Industrial Implementation of STEP-TAS) in which Alstom Aerospace, Astrium Satellites (Toulouse) and Thales Alenia Space implement STEP-TAS import/export facilities in their respective tools ESARAD, THERMICA and CIGAL-2 under the lead of CSTB with assistance from DOREA. CSTB has also developed a light C++ software development kit for STEP-TAS and produced new releases of the graphical validation tool BagheraView.
- TASTMM in which DOREA is further developing foundations for the STEP-TAS software libraries and ESATAN / SINDA model exchange.
- TASverter in which ESA TEC-MCV is further validating and completing the STEP-TAS standard, now mainly for the exchange of space kinematic models and space mission aspects.

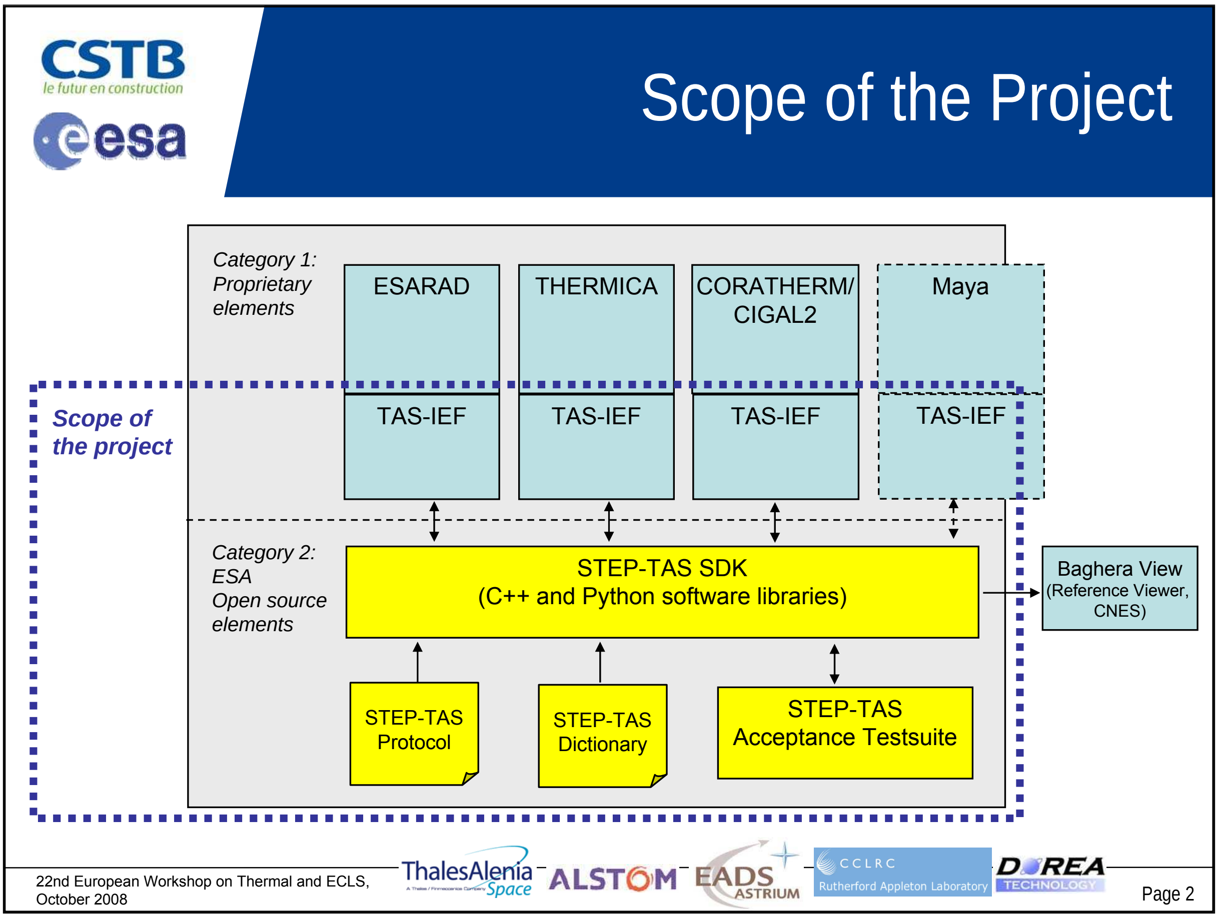
Also a brief outlook will be given on what to expect in the coming year.

U.1

Part 1
IITAS Industrial Implementation of STEP-TAS

Eric Lebègue
(CSTB, France)


CSTB
le futur en construction
esa
IITAS
Industrial Implementation
of STEP-TAS
22nd European Workshop on Thermal and ECLS
28-29 October 2008 at ESA/ESTEC, Noordwijk, The Netherlands
Eric Lebègue
ThalesAlenia Space
ALSTOM
EADS ASTRIUM
CCLRC Rutherford Appleton Laboratory
DOREA TECHNOLOGY
Page 1


CSTB
le futur en construction
esa
Scope of the Project
Category 1: Proprietary elements
ESARAD
THERMICA
CORATHERM/ CIGAL2
Maya
Scope of the project
TAS-IEF
TAS-IEF
TAS-IEF
TAS-IEF
Category 2: ESA Open source elements
STEP-TAS SDK
(C++ and Python software libraries)
Baghera View (Reference Viewer, CNES)
STEP-TAS Protocol
STEP-TAS Dictionary
STEP-TAS Acceptance Testsuite
22nd European Workshop on Thermal and ECLS, October 2008
ThalesAlenia Space
ALSTOM
EADS ASTRIUM
CCLRC Rutherford Appleton Laboratory
DOREA TECHNOLOGY
Page 2

C++ STEP-TAS SDK

- Development of C++ SDK:
  - based on :
    - expressik EXPRESS parser (University of Manchester)
    - + LightCpp C++ source code generator (CSTB) => one C++ class per STEP-TAS EXPRESS entity
  - + convenience classes, translation from PyExpress Python
  - + examples
  - Full validation process on Windows and Linux

22nd European Workshop on Thermal and ECLS, October 2008

Page 3

Status of converters (TAS-IEFs)

- Alpha version available
  - ESARAD and THERMICA with C++ SDK
  - CIGAL2 with Python SDK
- To be started
  - Maya with C++ SDK ?

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Page 4

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Acceptance Testsuite

- > 300 ESA units tests cases
- + 3 industrial models :
  - ESARAD by CCLRC / RAL
  - THERMICA by EADS Astrium (D)
  - CIGAL2 by Thales Alenia Spaca

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ThalesAlenia Space — ALSTOM — EADS ASTRIUM — CCLRC Rutherford Appleton Laboratory — DOREA TECHNOLOGY

Page 5

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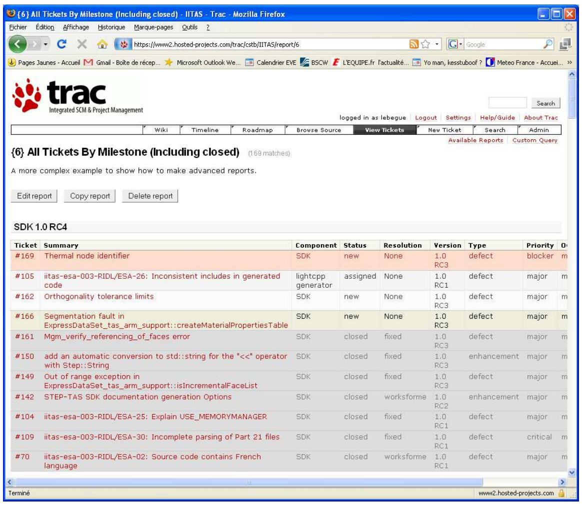
Hosted-projects Trac System



- C++ SDK source code sharing
- Defects and feature requests management
  - For SDK and Baghera View
- Acceptance Testsuite
- Cross sharing of STEP-TAS generated files (from TAS converters)

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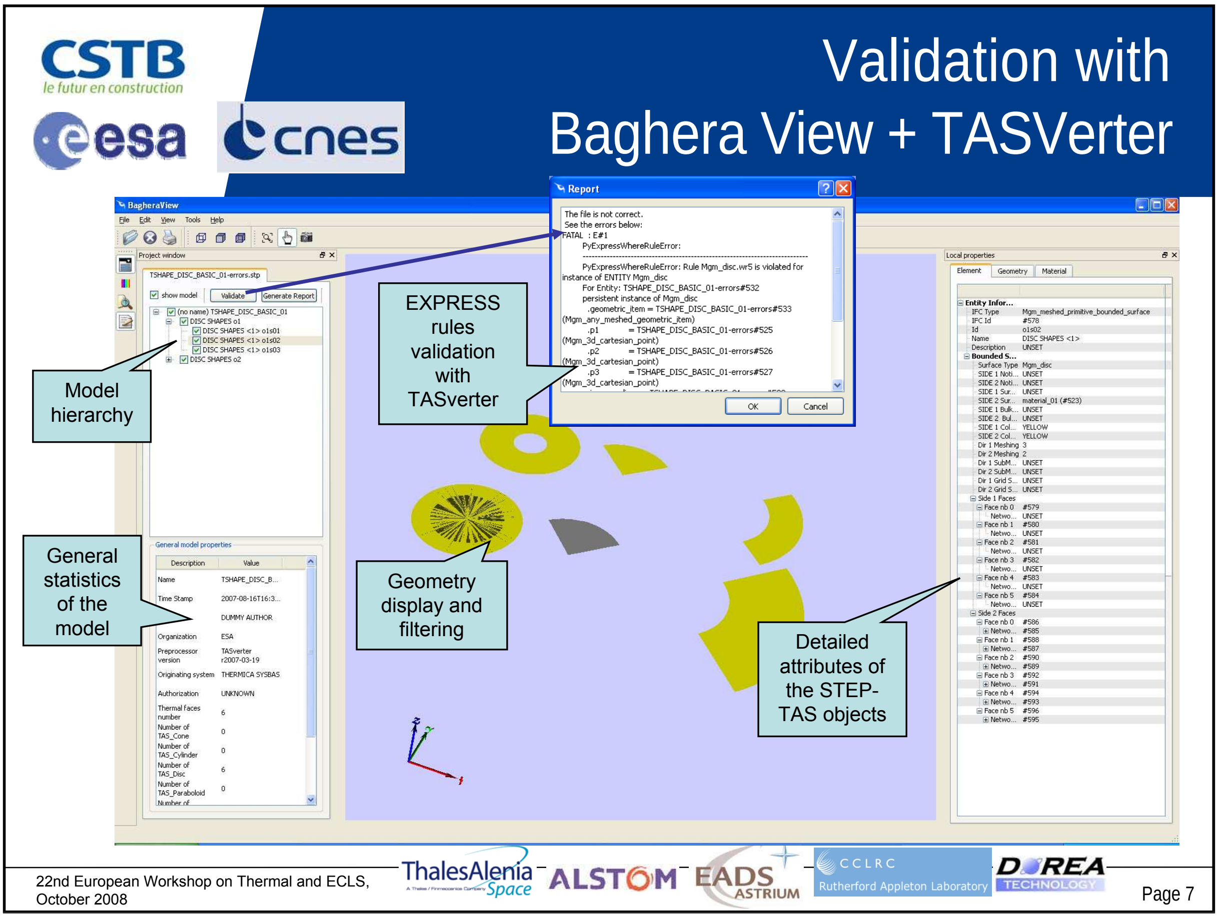
ThalesAlenia Space — ALSTOM — EADS ASTRIUM — CCLRC Rutherford Appleton Laboratory — DOREA TECHNOLOGY

Page 6


Validation with
Baghera View + TASVerter
Model hierarchy
General statistics of the model
EXPRESS rules validation with TASVerter
Geometry display and filtering
Detailed attributes of the STEP-TAS objects
Report
The file is not correct.
See the errors below:
22nd European Workshop on Thermal and ECLS, October 2008
Page 7

U.2

Part 2
TASTMM – Foundations for the STEP-TAS software libraries

Alain Fagot François Brunetti
(DOREA, France)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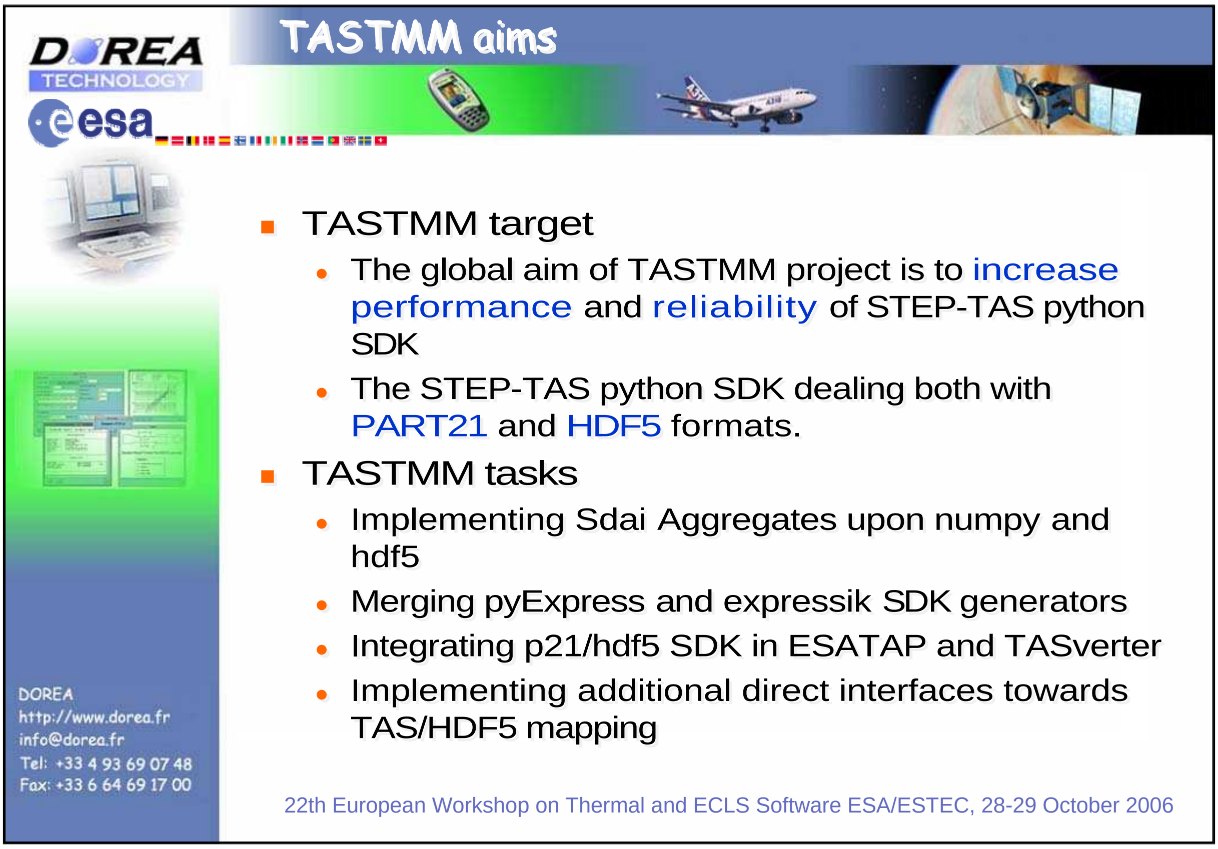
Mechanical Engineering Department
Thermal and Structures Division
ESA
Hans Peter DE KONING
ESA
Harrie ROOIJACKERS
TASTMM
Foundations for the STEP-TAS software libraries
Authors:
alain.fagot@dorea.fr
francois.brunetti@dorea.fr
22th European Workshop on Thermal and ECLS Software ESA/ESTEC, 28-29 October 2006
DOREA
http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00


TASTMM aims
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TASTMM target
The global aim of TASTMM project is to increase performance and reliability of STEP-TAS python SDK
The STEP-TAS python SDK dealing both with PART21 and HDF5 formats.
TASTMM tasks
Implementing Sdai Aggregates upon numpy and hdf5
Merging pyExpress and expressik SDK generators
Integrating p21/hdf5 SDK in ESATAP and TASverter
Implementing additional direct interfaces towards TAS/HDF5 mapping
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info@dorea.fr
Tel: +33 4 93 69 07 48
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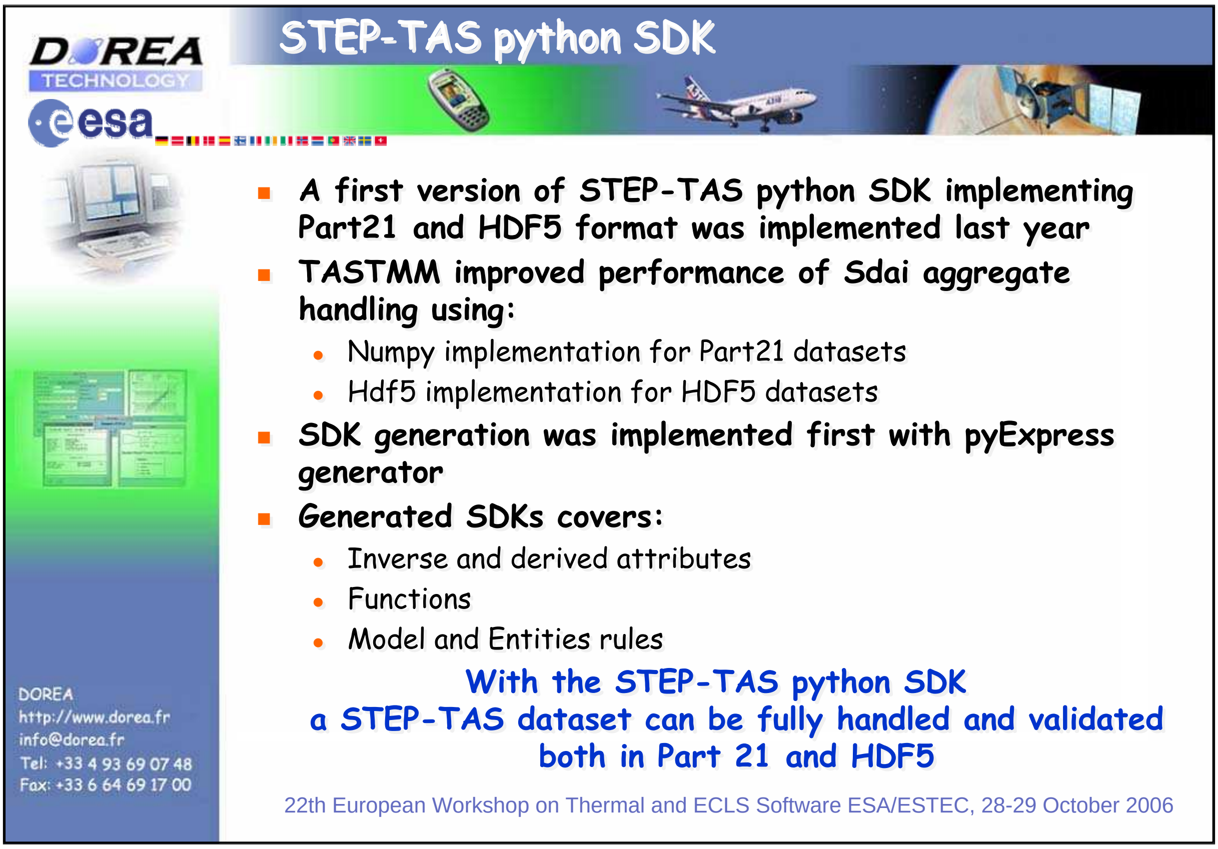
STEP-TAS python SDK
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A first version of STEP-TAS python SDK implementing Part21 and HDF5 format was implemented last year
TASTMM improved performance of Sdai aggregate handling using:
Numpy implementation for Part21 datasets
Hdf5 implementation for HDF5 datasets
SDK generation was implemented first with pyExpress generator
Generated SDKs covers:
Inverse and derived attributes
Functions
Model and Entities rules
With the STEP-TAS python SDK
a STEP-TAS dataset can be fully handled and validated
both in Part 21 and HDF5
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http://www.dorea.fr
info@dorea.fr
Tel: +33 4 93 69 07 48
Fax: +33 6 64 69 17 00
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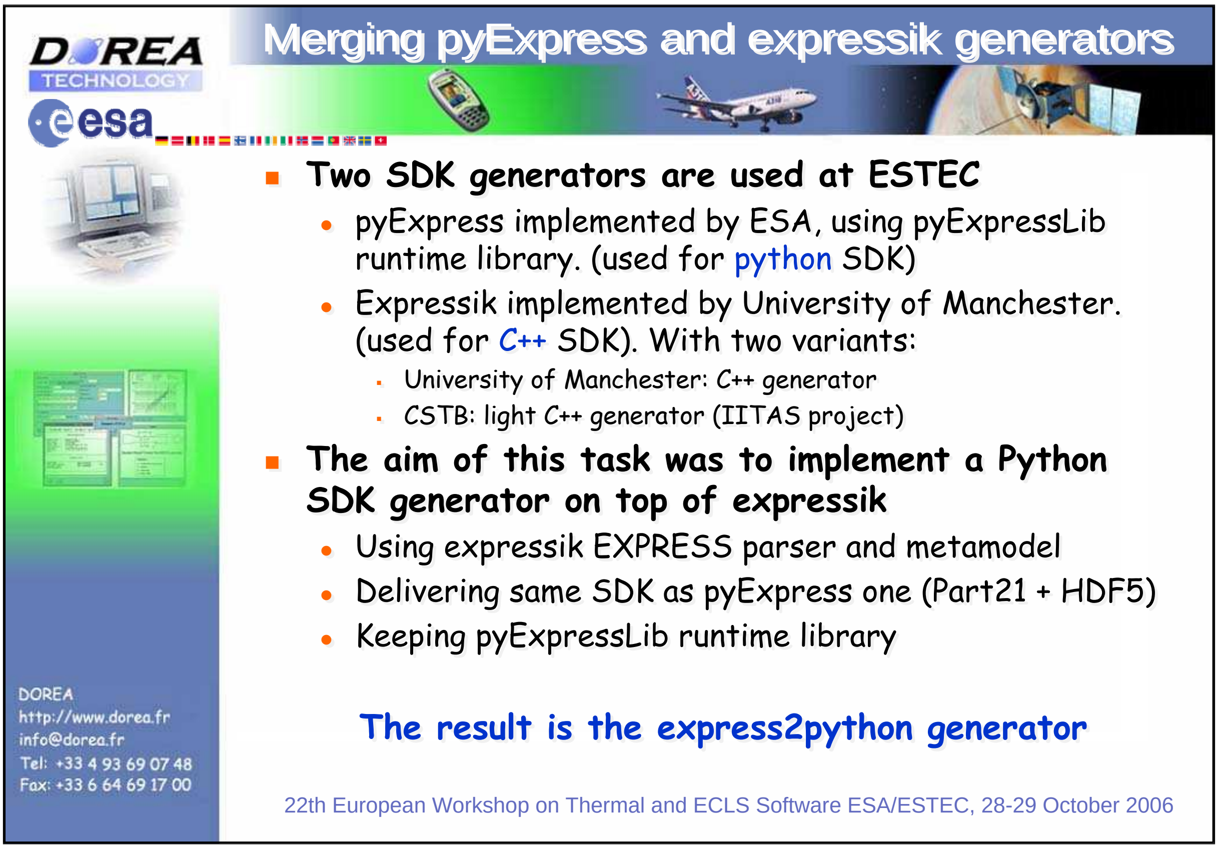
Merging pyExpress and expressik generators
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Two SDK generators are used at ESTEC
pyExpress implemented by ESA, using pyExpressLib runtime library. (used for python SDK)
Expressik implemented by University of Manchester. (used for C++ SDK). With two variants:
University of Manchester: C++ generator
CSTB: light C++ generator (IITAS project)
The aim of this task was to implement a Python SDK generator on top of expressik
Using expressik EXPRESS parser and metamodel
Delivering same SDK as pyExpress one (Part21 + HDF5)
Keeping pyExpressLib runtime library
The result is the express2python generator
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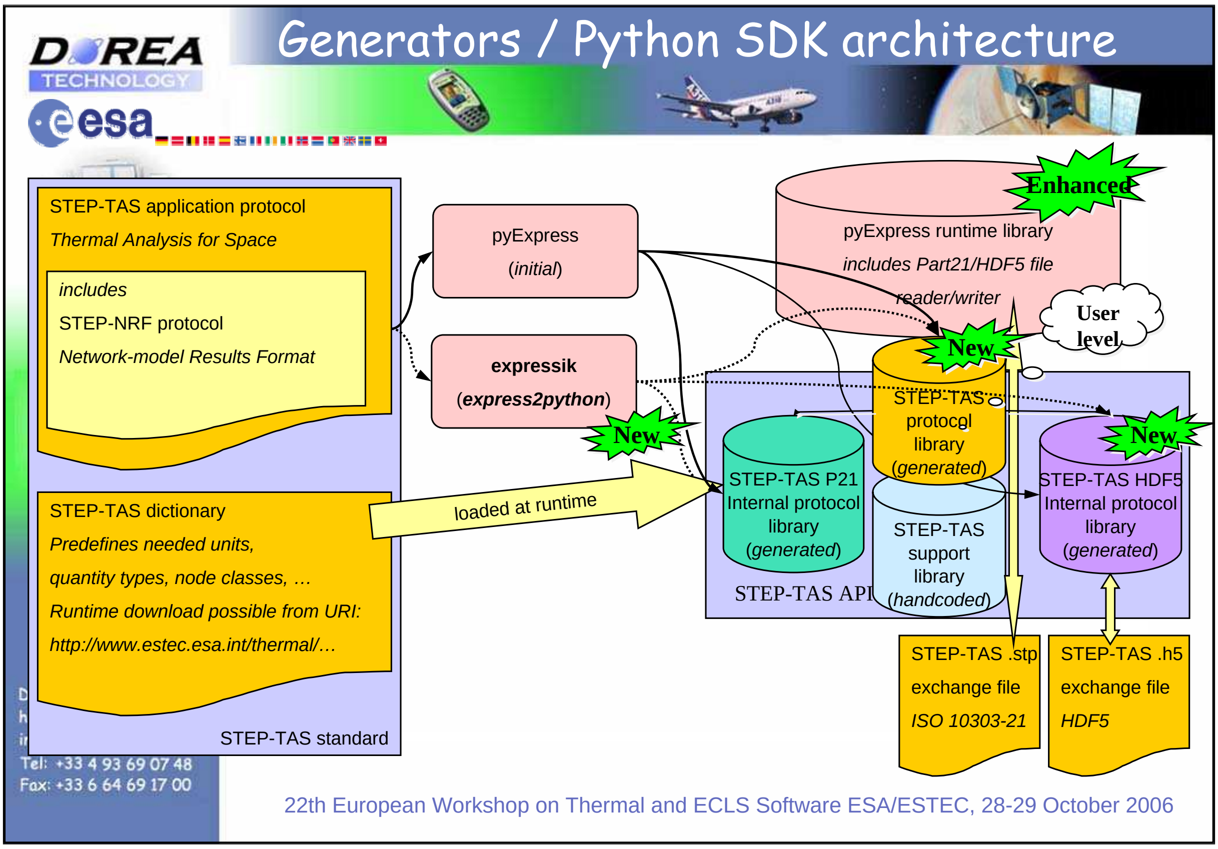
Generators / Python SDK architecture
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STEP-TAS application protocol
Thermal Analysis for Space
includes
STEP-NRF protocol
Network-model Results Format
STEP-TAS dictionary
Predefines needed units,
quantity types, node classes, …
Runtime download possible from URI:
http://www.estec.esa.int/thermal/…
STEP-TAS standard
pyExpress
(initial)
expressik
(express2python)
New
loaded at runtime
Enhanced
pyExpress runtime library
includes Part21/HDF5 file
reader/writer
User
level
New
STEP-TAS
protocol
library
(generated)
STEP-TAS P21
Internal protocol
library
(generated)
STEP-TAS
support
library
(handcoded)
STEP-TAS API
New
STEP-TAS HDF5
Internal protocol
library
(generated)
STEP-TAS .stp
exchange file
ISO 10303-21
STEP-TAS .h5
exchange file
HDF5
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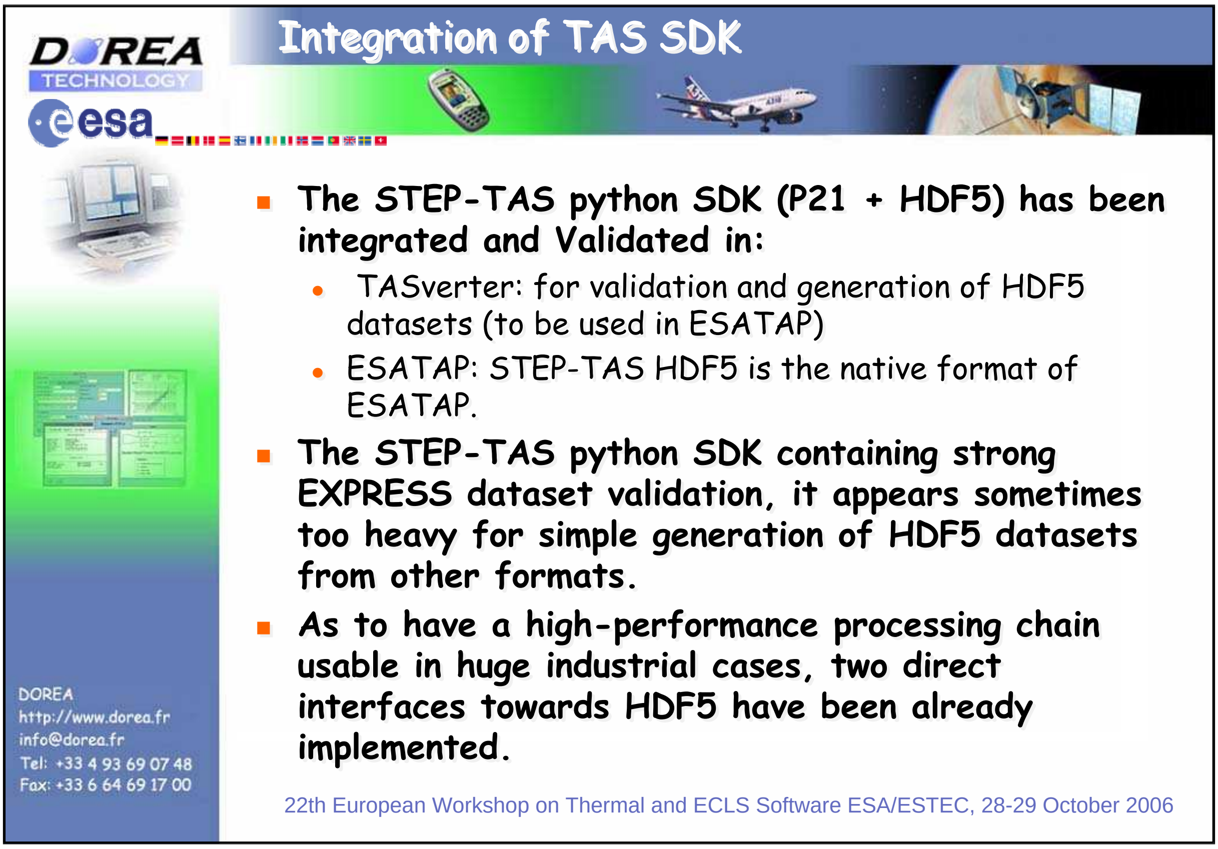
Integration of TAS SDK
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The STEP-TAS python SDK (P21 + HDF5) has been integrated and Validated in:
TASverter: for validation and generation of HDF5 datasets (to be used in ESATAP)
ESATAP: STEP-TAS HDF5 is the native format of ESATAP.
The STEP-TAS python SDK containing strong EXPRESS dataset validation, it appears sometimes too heavy for simple generation of HDF5 datasets from other formats.
As to have a high-performance processing chain usable in huge industrial cases, two direct interfaces towards HDF5 have been already implemented.
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info@dorea.fr
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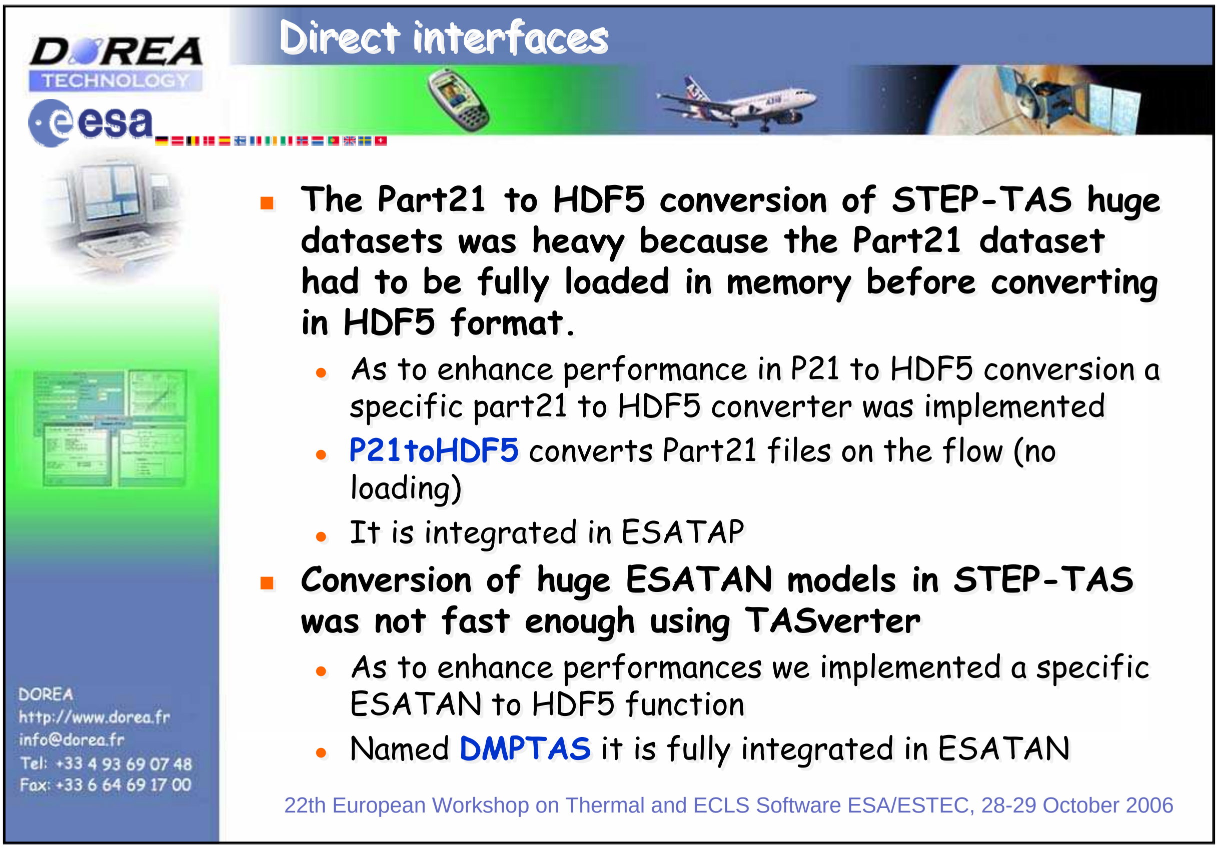
Direct interfaces
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The Part21 to HDF5 conversion of STEP-TAS huge datasets was heavy because the Part21 dataset had to be fully loaded in memory before converting in HDF5 format.
As to enhance performance in P21 to HDF5 conversion a specific part21 to HDF5 converter was implemented
P21toHDF5 converts Part21 files on the flow (no loading)
It is integrated in ESATAP
Conversion of huge ESATAN models in STEP-TAS was not fast enough using TASverter
As to enhance performances we implemented a specific ESATAN to HDF5 function
Named DMPTAS it is fully integrated in ESATAN
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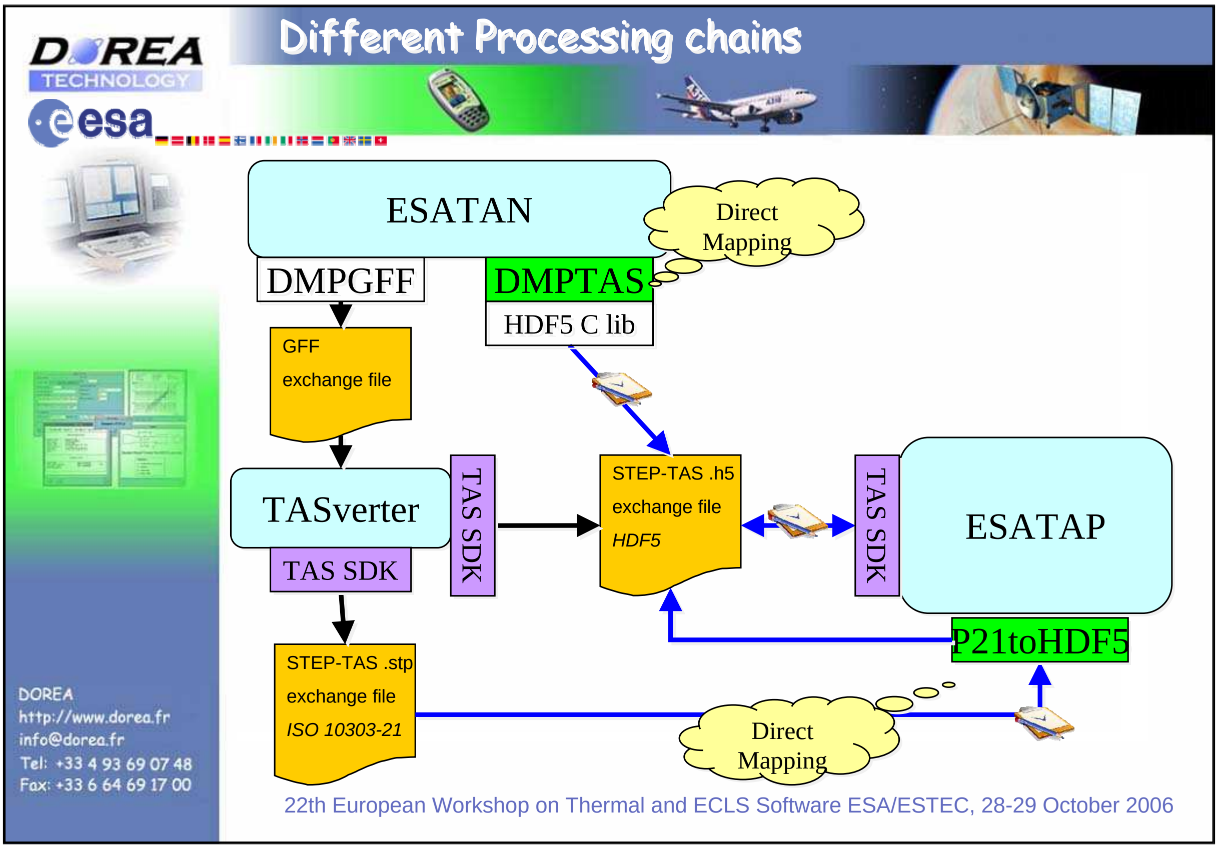
Different Processing chains
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ESATAN
Direct Mapping
DMPGFF
DMPTAS
HDF5 C lib
GFF exchange file
TASverter
TAS SDK
TAS SDK
STEP-TAS .h5 exchange file HDF5
TAS SDK
ESATAP
P21toHDF5
STEP-TAS .stp exchange file ISO 10303-21
Direct Mapping
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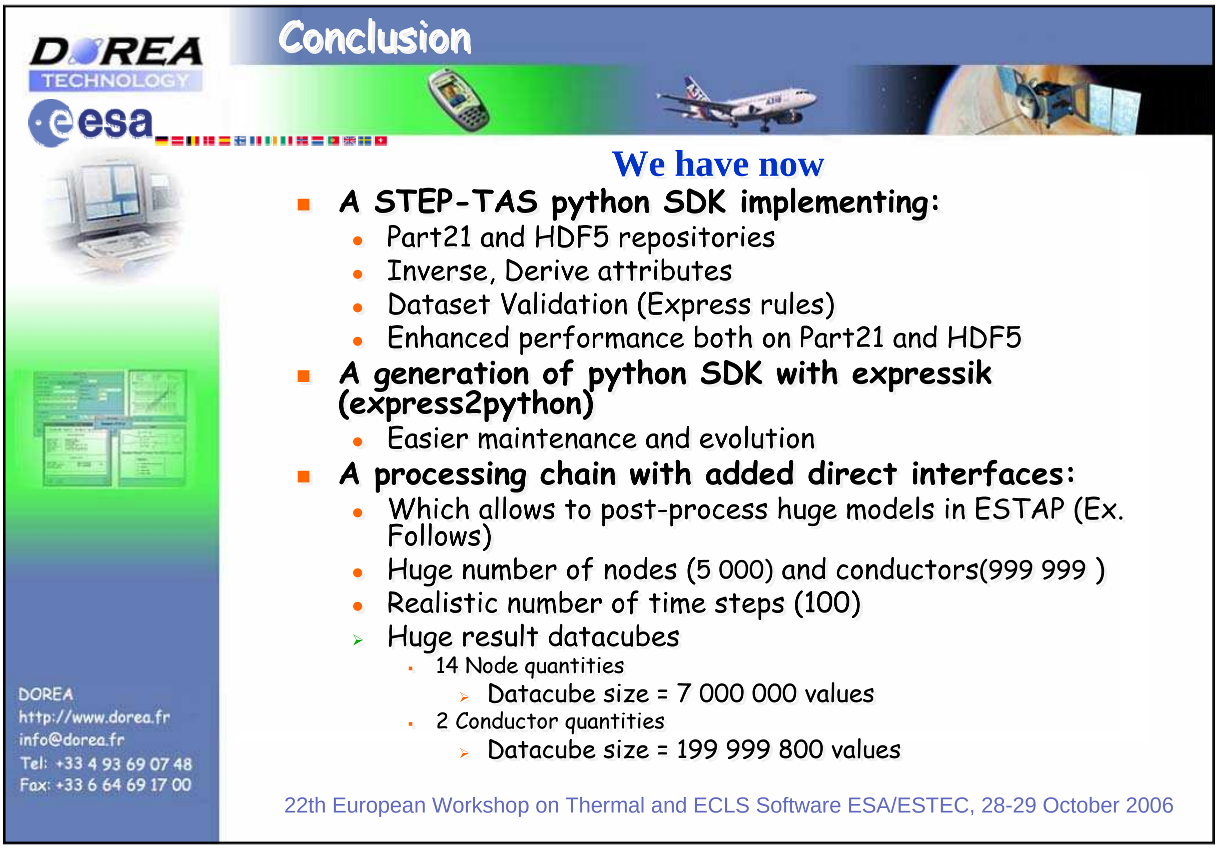
Conclusion
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We have now
A STEP-TAS python SDK implementing:
Part21 and HDF5 repositories
Inverse, Derive attributes
Dataset Validation (Express rules)
Enhanced performance both on Part21 and HDF5
A generation of python SDK with expressik (express2python)
Easier maintenance and evolution
A processing chain with added direct interfaces:
Which allows to post-process huge models in ESTAP (Ex. Follows)
Huge number of nodes (5 000) and conductors(999 999)
Realistic number of time steps (100)
Huge result datacubes
14 Node quantities
Datacube size = 7 000 000 values
2 Conductor quantities
Datacube size = 199 999 800 values
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info@dorea.fr
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Fax: +33 6 64 69 17 00
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U.3

Part 3
Progress with STEP-TAS Activities

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

Progress with STEP-TAS Activities

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

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Mechanical Engineering Department
Thermal and Structures Division

Activities in 2008

- IITAS – Industrial Implementation of STEP-TAS – in progress
  - ESA completes full test suite with automation tools
- IITAS-TMG – Prepared as GSTP activity with Maya (Canada) – KO expected Nov 2008
- TASverter by ESA TEC-MCV
  - Now more than 150 different users (2~5 downloads per week)
  - Routine use in many projects
  - Under maintenance – but very few bugs reported
- Evolution of Expressik to support code generators STEP EXPRESS to C++ and Python
- Evolution mapping STEP data into HDF5 format
- First validation of STEP-TAS Kinematics and Mission Aspects (CC2, CC4, CC5, CC6)
  - Implementation in TASverter for ESARAD
- Proof of concept implementation in DynaWorks® for import of STEP-TAS analysis predictions

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Planned for 2009

- Completion of IITAS and IITAS-TMG
  - Emphasis on testing and obtaining robustness of imports/exports
- Full validation of STEP-TAS Kinematics and Mission Aspects
- First validation STEP-TAS for TMMs (ESATAN, SINDA, …)
  - Model structure basically done under ESATAP
  - Includes approach to exchange user defined logic (MORTRAN, …)
- Formalisation of STEP-NRF/TAS under ISO TC184/SC4
  - Was planned for 2008 but put on-hold due to lack of resources – shifted to 2009
- Support continuation of STEP-TAS for Thermal Desktop with C&R and NASA (hopefully)
- Consolidate support software and test suites as true open source software
  - Depending on ESA open source software policy that is currently being finalised

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STEP-TAS / TASverter team at ESA

- Hans Peter de Koning
- Simon Appel
- James Etchells
- Duncan Gibson
- Harrie Rooijackers

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References

- STEP-NRF and STEP-TAS
  http://www.esa.int/thermalcontrol
  Look for "Standards"
- TASverter
  https://exchange.esa.int
  Look for "TASverter"
  Support requests to tasverter@thermal.esa.int
- ISO TC 184 / SC 4 standardization committee (a.o. STEP standards)
  http://www.tc184-sc4.org
- European Cooperation for Space Standardization
  http://www.ecss.nl

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Appendix V

Thales Alenia Space thermal software suite
Presentation of the tools and current policy

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

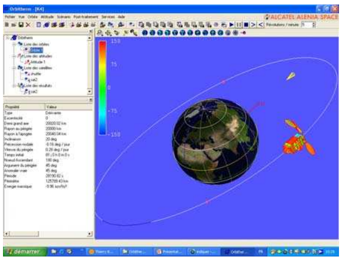
François Brunetti
(DOREA, France)

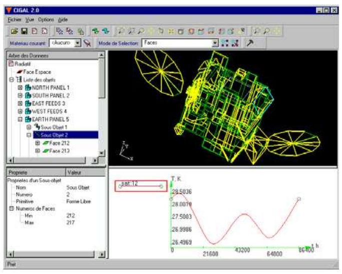
Abstract

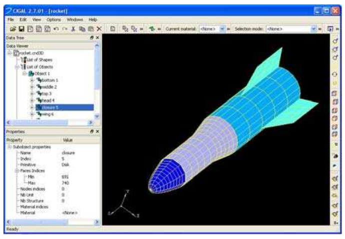
In this paper Thales Alenia Space presents a rapid overview of its thermal software suite developed and used in the site of Cannes. In particular the objective is to announce the free distribution of CIGAL2, the pre and post processing tool dedicated to radiative and conductive modelling. This distribution will be done via CD-ROMs available on site. After a brief presentation of our main in-house tools, we make a demonstration of the last release of CIGAL2. We then focus on the 3D conductive module with a short demo and we conclude by a rapid presentation of Thales Alenia Spaces policy about the development and distribution of the complete conductive chain.

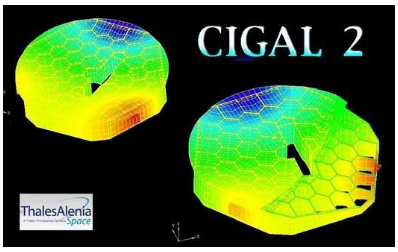
CORATHERM
CIGAL2 & 3D CONDUCTIVE TOOL

Thermal Analysis Tools in Cannes :
Software & Policy



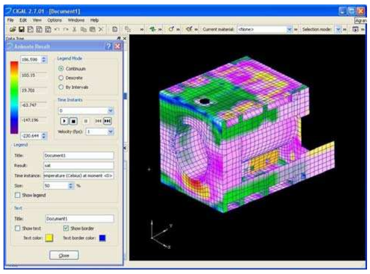






THALES ALENIA SPACE CANNES

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



Presentation Plan

- **Thermal Software in Thales Alenia Space Cannes**
- **Pre and post-processing : CIGAL2**
- **3D Conductive tool**
- **CIGAL2 Distribution project (packaging)**

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HISTORY

- In-House Software History
  - In the sixties Thales Alenia Space became prime on the spacecraft market :
    - ➔ Need of analysis and sizing tool for the Thermal Control (Platforms, payloads, scientific and Telecom programs)
  - First needs : CosB, Symphonie, Meteosat, TVsat
    - ➔ For lack of market tools, development of in-house tools : CORATHERM
  - For 35 Years :
    - ➔ Evolution of CORATHERM : CIGAL2, CORAFILE, ORBITHERM
    - ➔ Still used today : 50 users
      - Interesting and additional functions versus market tools ("Plateau-Equivale": powerful conductive method physically consistent allowing easy reduction of 2D or 3D conductive models, specific pre-post processing tools ...)
  - Reactivity for new program requirement ; flexibility of development and user support
  - No licences

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Pre and Post processing CIGAL2 : Description

- Context
  - Tool developed initially by Open Cascade and since 2007 by DOREA
  - Thales Alenia Space owns Tool : specify and pay entirely the developments
- Functions
  - Pre processing
    - ➔ Building of geometrical radiative model in radiative session
    - ➔ Building of geometrical 2D conductive model in 2D conductive session
    - ➔ Building of geometrical 3D conductive model in 3D conductive session
  - Post processing
    - ➔ Plot 2D curve
    - ➔ Plot 3D cartography in animation

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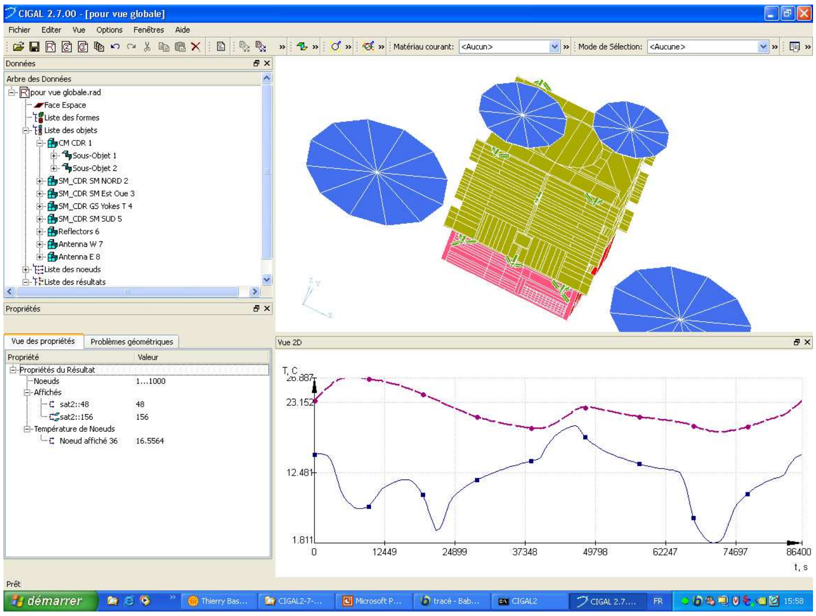
Pre and Post processing CIGAL2 : visualisation

Model Data Tree



3D interactive window (build, check and display)

Properties

Editing

2D plotting (post-process)

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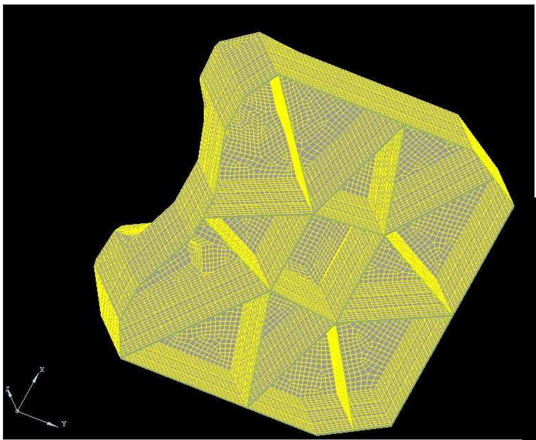
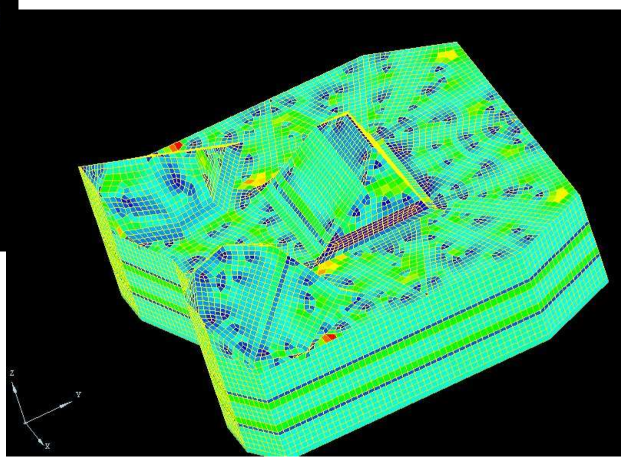
PATRAN Import



Raw PATRAN import

2D meshes Area verification



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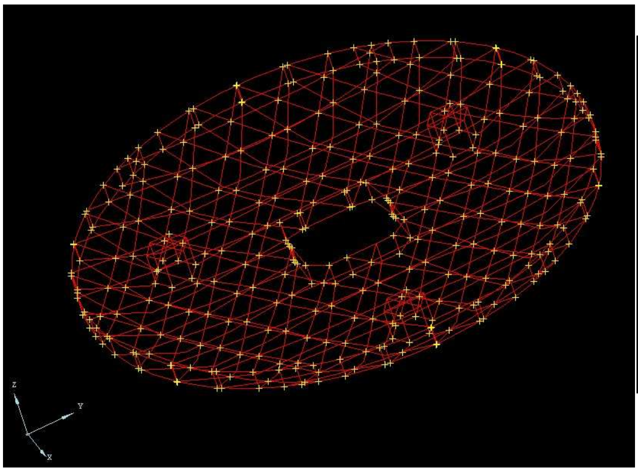
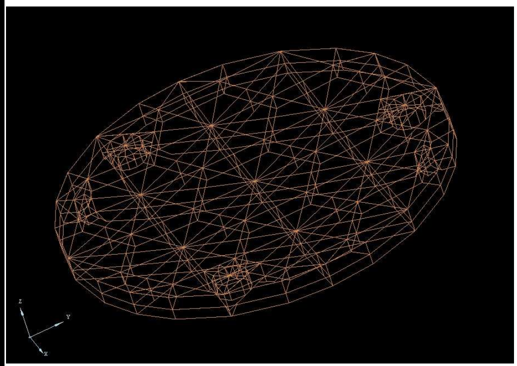
STEP AP203 Import





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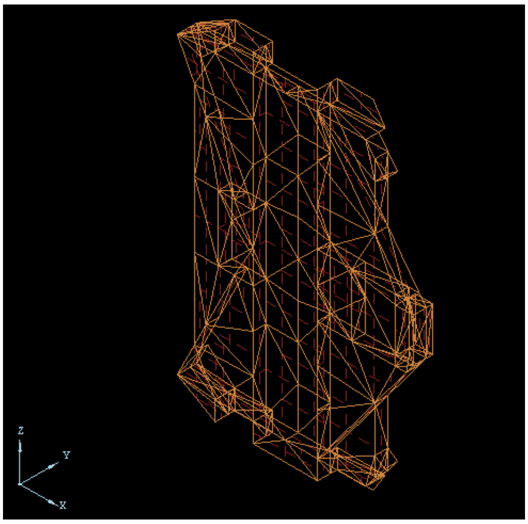
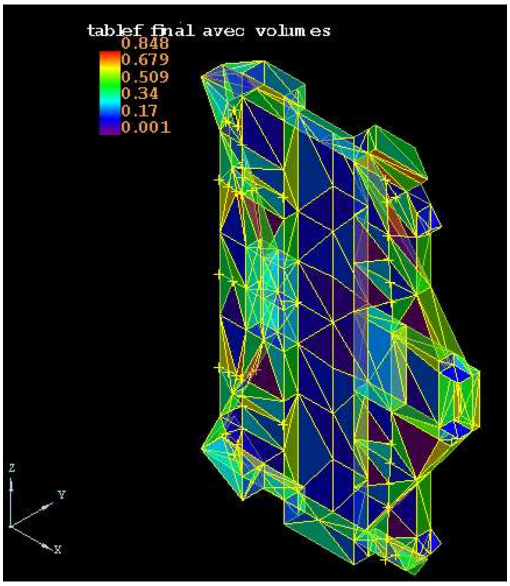
IGES Import



Raw IGES import

Quality of meshes verification



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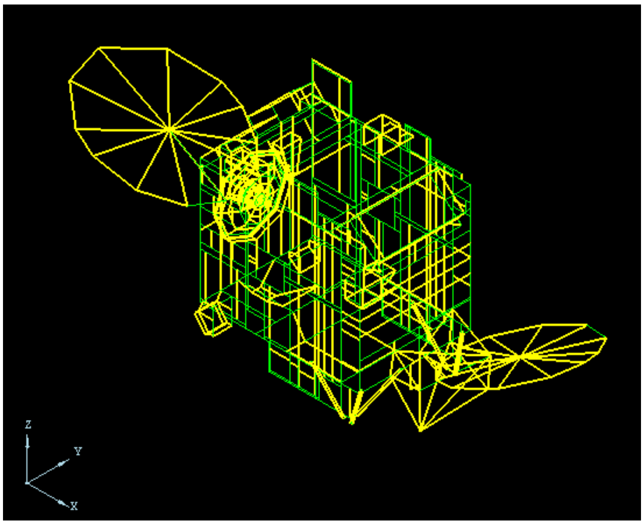
STEP-TAS Import (v6)

Import and Export of STEP-TAS files

(here V6 protocol in the frame of II TAS project)



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CIGAL2 Modeler

DEMO (modeler)

DEMO (model checking)

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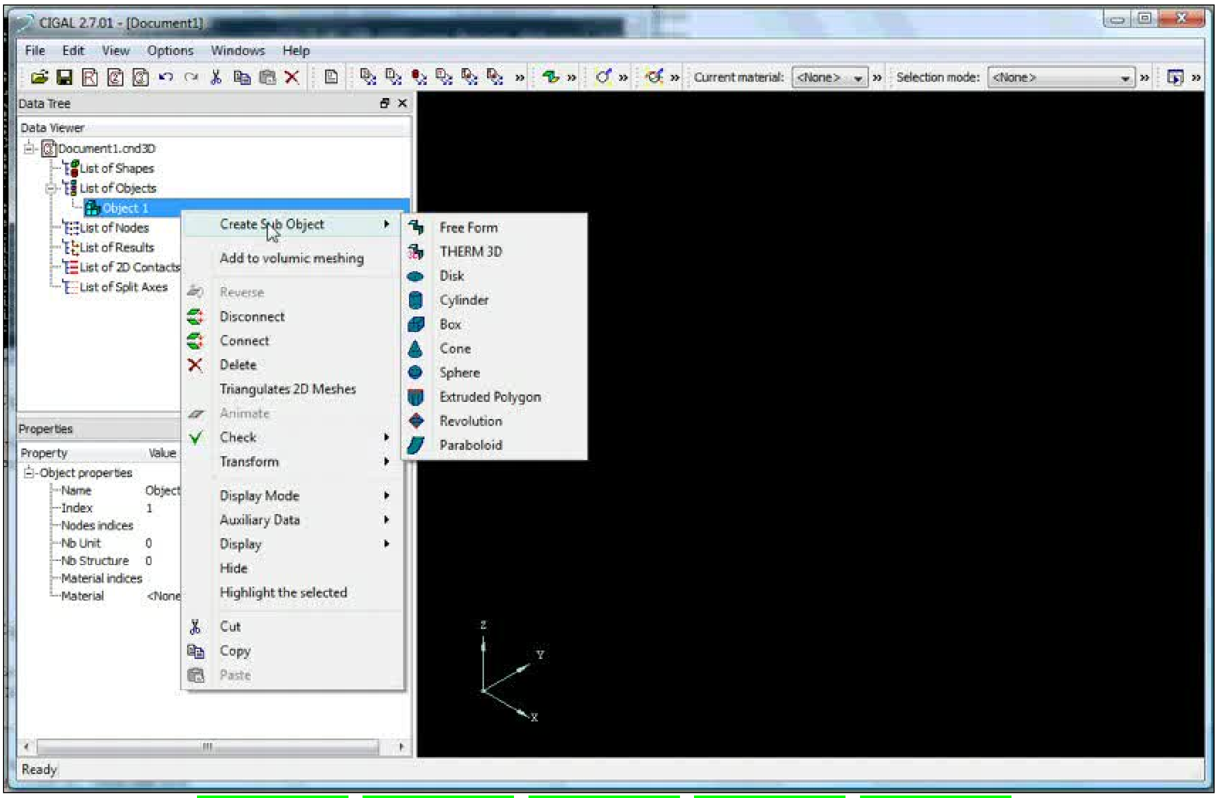
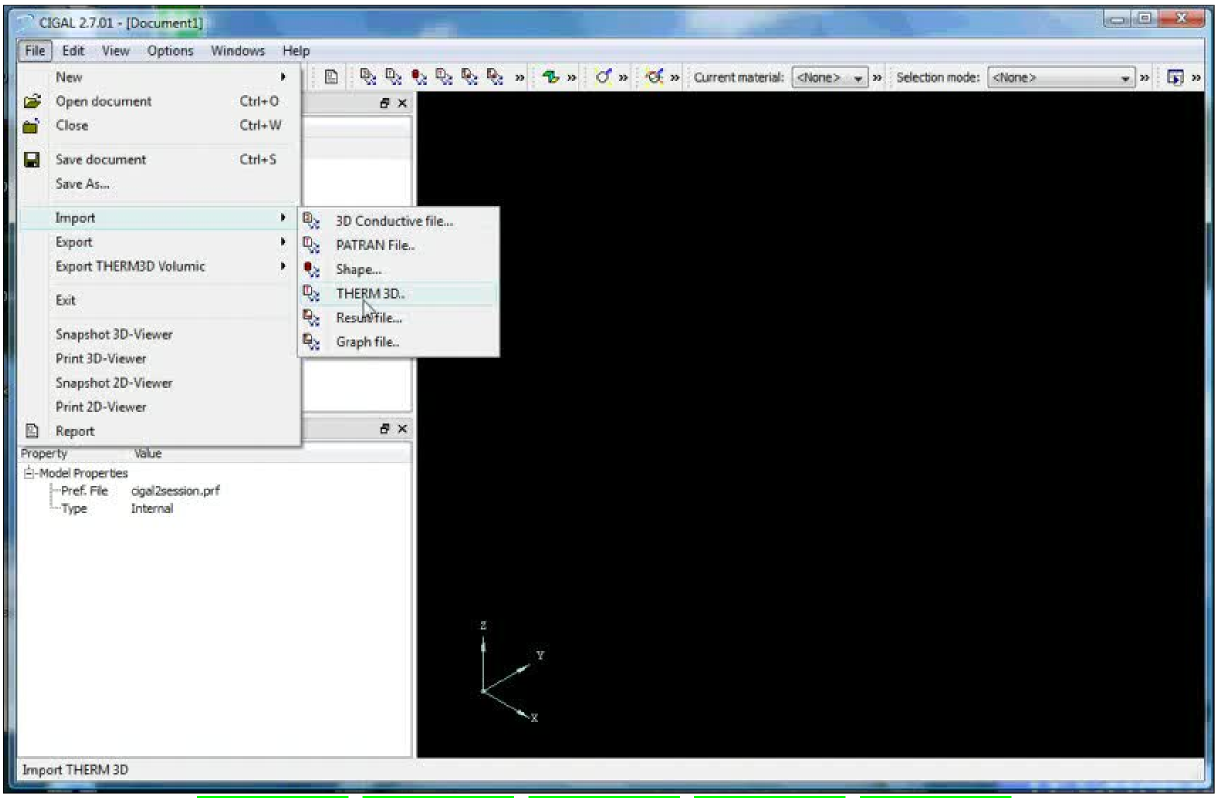


Slow Normal Fast Play/Pause Stop



Slow Normal Fast Play/Pause Stop

3D conductive tool

Context

- User requirement survey
  - Need to improve our reactivity and accuracy in conductive modelling of complex structures
    - Optical structures, mirrors, mechanisms, …

Outcome

- A tool to have the possibility to use a 2D or 3D detailed conductive model at system level modelling assuming :
  - Flexible and automated process to increase reactivity and readability
  - Mathematical method which lead reliable and accurate models
  - Compliance with radiative coaser mesh by use of model reduction
  - Optimized link for thermo-elastic analysis by use FEM for the conductive model
- First release in 2005

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3D conductive tool

Presentation of the tool (1/3)

- Pre and Post processing with CIGAL2
  - Include CAD & PATRAN FEM models import
  - Generation of FEM type GMM (2D & 3D modeler/mesher)
  - Nodal breakdown by gathering skin elements on the 3D object
  - Definition of *unit nodes*
    - Zones of the structure skin in contact with units or other part of the system model
  - Definition of *structure nodes*
    - Free surfaces exchanging conductive and radiative flux
    - Contour corresponding to radiative mesh
    - Also called **averaged nodes**
  - Definition of Material properties
    - Elements associated to conductive material files
    - λ, ρ, C, thickness

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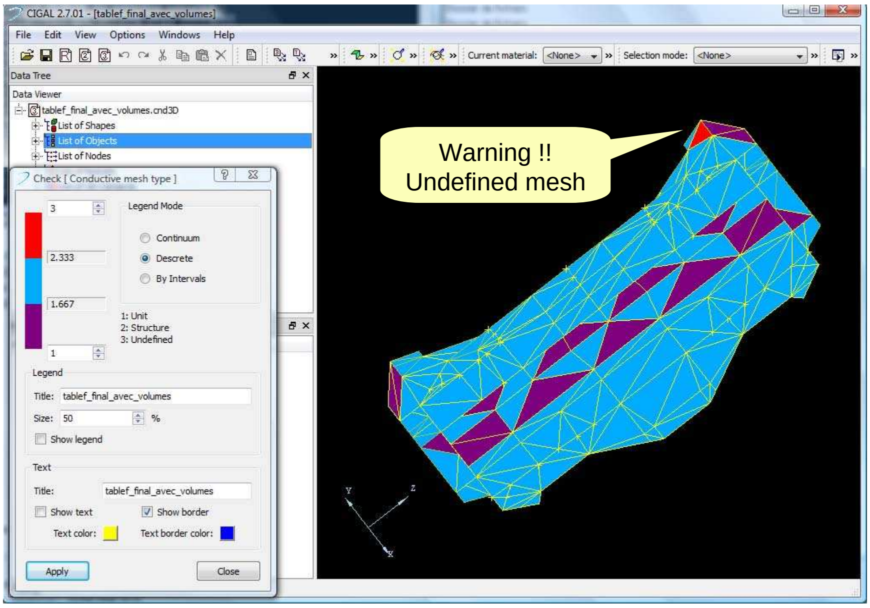
3D conductive tool



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3D conductive tool

Presentation of the tool (2/3)

- Computation of ***Elementary conductive couplings***
  - FEM approach
    - applicable to any 2D or 3D shape, easy interface with CAD
  - FEM type conductors calculated between vertex within the structure and between structure and unit nodes
  - Automated computation of linear contacts for shell models
- Reduction of the **FEM model** and generation of the equivalent ***Thermal model***
  - Condensation of the detailed model (elementary + user defined nodes) to keep only user defined nodes
  - Typical Reduction from thousands FEM nodes into tens TLP nodes
    - THALES's original method also chosen by ESA for TMRT tool
  - Take count of radiative aspects for structure node in the reduction process
    - assuming a uniform radiative flux per node
- Outputs
  - Equivalent couplings between Thermal nodes leading to
    - Averaged temperature for structure nodes
    - Classical nodal temperature for unit nodes
  - **"Equivalent" couplings but compatible with main TLP solvers (ESATAN, THERMISOL)**

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3D conductive tool

Presentation of the tool RC3D

- Other capabilities
  - Easy connection between conductive models in contact via interface nodes (no need of a conformant mesh)
  - Definition of averaged super-nodes by gathering user defined thermal nodes
  - Elimination of thermal nodes non required in the final model
  - Temperature or power zoom on some zone of the model ("partial nodes")
  - Automatic computation of nodal thermal capacitance on shell models
- New • Module for backward calculation of temperature from thermal model to original FEM model
  - **Very useful to transfer detailed temperature cartography to mechanical engineer for thermo-elastic analysis**
  - In the best case the GMM could be the same for both mechanical and thermal analysis
- Soon • Automatic redistribution of nodal capacitance on bulk type models

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3D conductive tool

♦ Conclusions

- ❑ RC3D tool was tested and assessed better than our traditional conductive modelling method in terms of user-friendliness, reliability, accuracy, and model management.
- ❑ It is in industrial use since 2006
- ❑ Typical time to generate conductive model from CAD definition for a mirror structure has been reduced from week(s) to days(s)
- ❑ The tool is now integrated in CORATHERM SW chain but equivalent conductors are usable by any thermal solver

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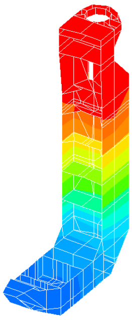
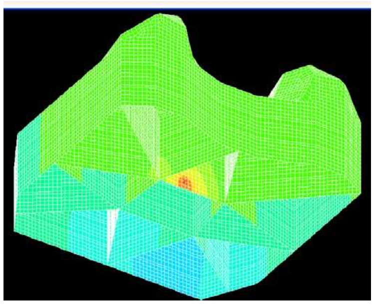
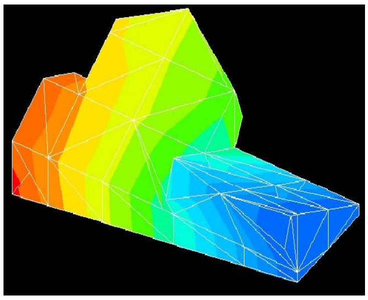
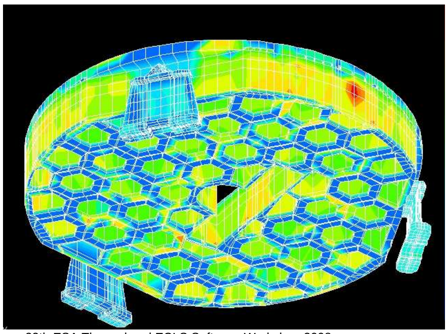
3D conductive tool

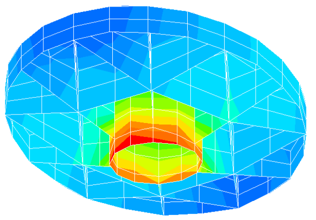


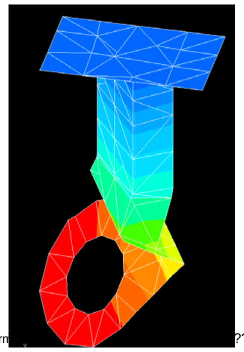






Examples of RC3D applications





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3D conductive tool

DEMO

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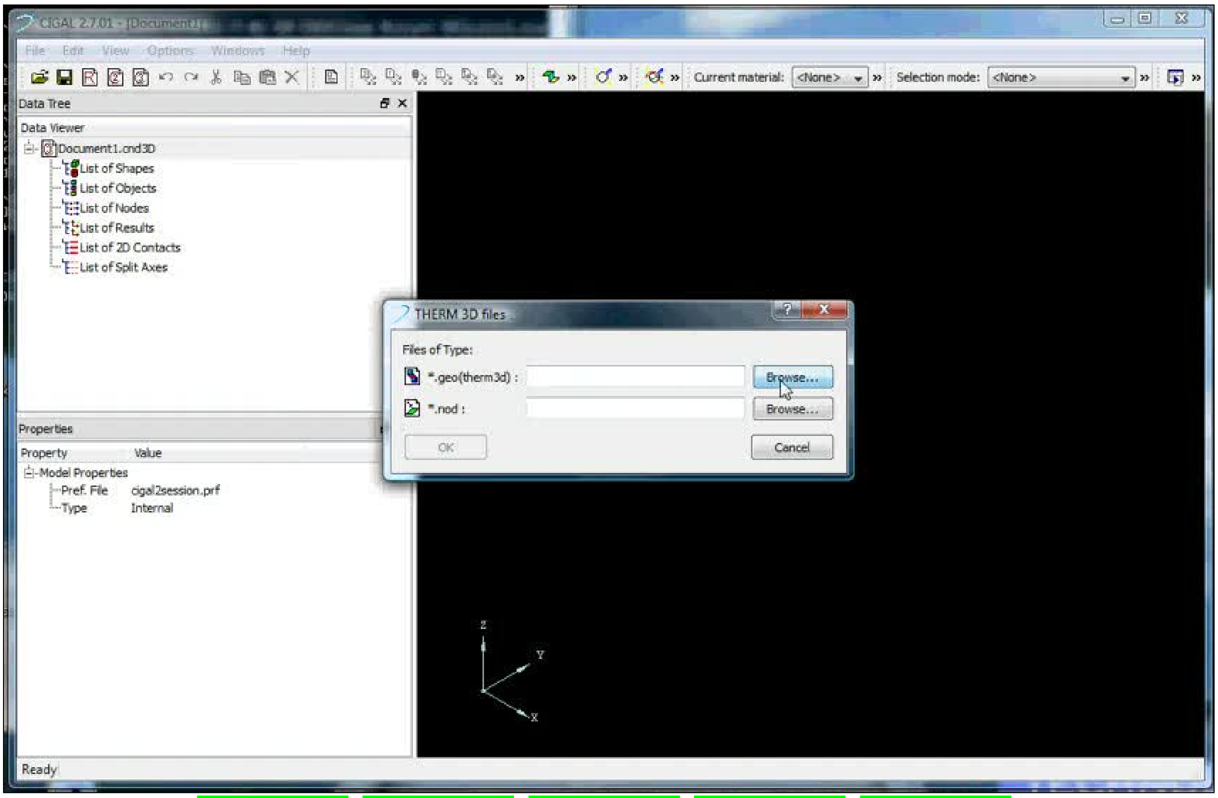
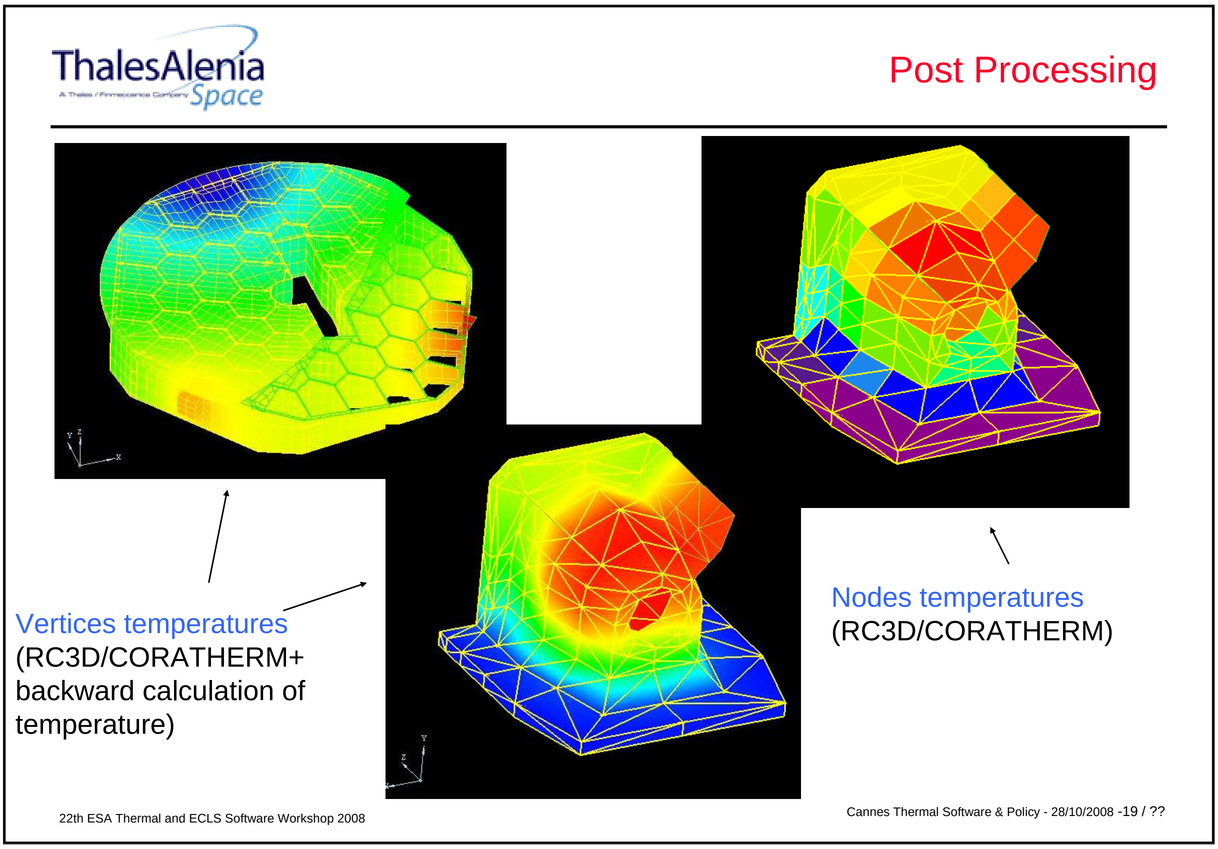


Slow Normal Fast Play/Pause Stop



Current and Future Policy

- Policy is focusing on :
  - Performance, Reliability, Flexibility, Reactivity
  - CORATHERM and data standard exchange (STEP-TAS)
  - Strategy based on opening of CORATHERM
    - ➔ Distribution of the Pre and Post processing tool CIGAL2 by CD-ROM
      - Supply of CIGAL2 according to the software licence agreement and the secured patch
    - ➔ In 2009, for the next workshop, distribution of CIGAL2 including conductive calculation chain
  - This tool, funded 100% by Thales Alenia Space, should not be commercialised but freely distributed with a maintenance funding :
    - ➔ by TAS for corrective maintenance
    - ➔ by customer for specific needs (evolution maintenance)
    - ➔ by agencies for basic needs (evolution maintenance)

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

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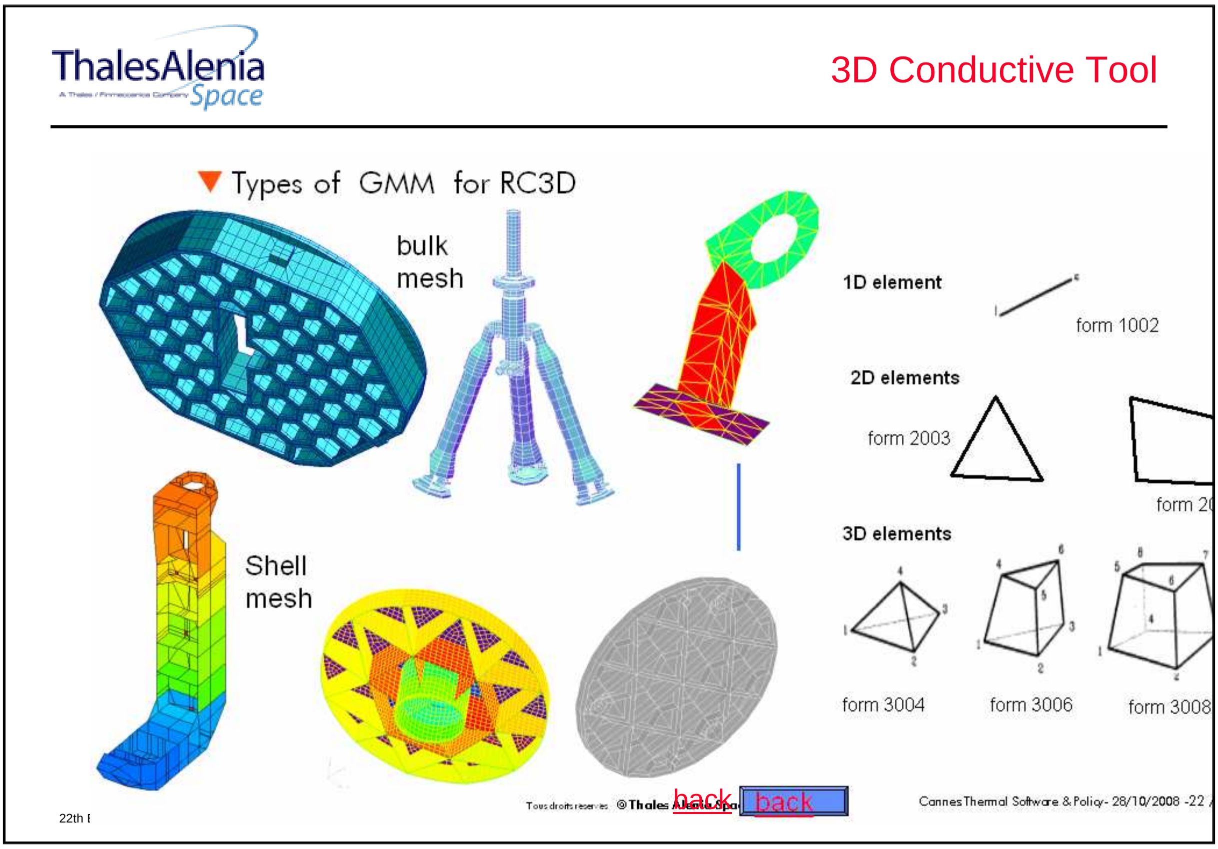

Appendix W

List of Participants

Alary, C.
ESA/ESTEC
SRE-PEE
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ +31 71 565 4039
✉ coralie.alary@esa.int

Altenburg, M.
EADS Astrium GmbH - Satellites
ASG 23 (Thermal Engineering and Test)
Claude-Dornier-Straße 1
88039 Friedrichshafen
GERMANY
☎ +49 7545 8 2494
📠 +49 7545 8 18 2494
✉ martin.altenburg@astrium.eads.net

Appel, Simon
AOES Netherlands B.V.
Huygensstraat 34
2201 DK Noordwijk (ZH)
NETHERLANDS
✉ simon.appel@aoes.com

Basset, Thierry
THALES Alenia Space
THERMIQUE
100 bd du Midi
6156 Cannes La Bocca
FRANCE
☎ +33 4 92 92 67 29
📠 +33 4 92 92 78 72
✉ thierry.basset@thalesaleniaspace.com

Beaumont, H.
Alstom Aerospace
Cambridge Road
LE86LH Leicester
UNITED KINGDOM
☎ +44 116 284 5748
✉ helen.beaumont@power.alstom.com

Bernard, M.
ASTRIUM
ASG24
31 rue des Cosmonautes Z.I. du Palays
31402 Toulouse Cedex 4
FRANCE
☎ +33 5 6219 6144
📠 +33 5 6154 7744
✉ Mathieu.BERNARD@astrium.eads.net

Bodendieck, F.
OHB-System AG
Thermal Design and Verification
Universitaetsallee 27-29
28359 Bremen
GERMANY
☎ +49 421 2020 626
📠 +49 421 2020 900
✉ bodendieck@ohb-system.de

Brouquet, H.
Alstom Aerospace
Cambridge Road
LE86JS leicester
UNITED KINGDOM
☎ +44 116 284 5764
✉ henri.brouquet@power.alstom.com

Brunetti, François
DOREA
Résidence de l'Olivet Bat F; 75 Chemin de l'Olivet
6110 LE CANNET
FRANCE
☎ +33 49 369 0748
✉ francois.brunetti@dorea.fr

Checa, E.
ESA/ESTEC
D/TEC-MCT
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 6606
✉ Elena.Checa@esa.int

Concepcion Gonzalez Alvarado, C.
INTA
Scientific Payloads
Km 4 Torrejón-Ajalvir
28850 Torrejón de Ardoz (Madrid)
SPAIN
☎ +34 91 520 1268
Fax +34 91 520 1949
✉ glezac@inta.es

Cuylle, S.
Verhaert Space
Hogenakkerhoekstraat 9
9150 Kruibeke
BELGIUM
☎ +32 3250 4310
✉ steven.cuylle@verhaertspace.com

de Koning, H.P.
ESA/ESTEC
D/TEC-MCV
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 5878
✉ Hans-Peter.de.Koning@esa.int

De Palo, S.
ThalesAlenia Space
Thermal Control
Strada Antica di Collegno 253
10146 Torino
ITALY
☎ +39 011 7180 875
Fax +39 011 7180 873
✉ savino.depalo@thalesaleniaspace.com

Dudon, Jean Paul
THALES Alenia Space
THERMIQUE
100 bd du Midi
6156 Cannes La Bocca
FRANCE
☎ +33 4 92 92 67 13
Fax +33 4 92 92 78 72
✉ jean-paul.dudon@thalesaleniaspace.com

Etchells, J.
ESA/ESTEC
D/TEC-MCV
Postbus 299
2200 AG Noordwijk
NETHERLANDS
☎ +31 71 565 8503
✉ james.etchells@esa.int

Fagot, Alain
DOREA
Résidence de l'Olivet Bat F; 75 Chemin de l'Olivet
6110 LE CANNET
FRANCE
☎ +33 67 924 1088
✉ alain.fagot@dorea.fr

Fishwick, N. A.
EADS Astrium
Central Engineering, Thermal Team
Astrium Ltd, Gunnels Wood Road
SG12AS Stevenage
UNITED KINGDOM
☎ +44 14 3877 3053
✉ nicholas.fishwick@astrium.eads.net

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

Gorlani, Matteo
Blue Group
Engineering
Via Albenga 98
10098 Cascine Vica, Rivoli (TO)
ITALY
☎ +39 011 950 4211
📠 +39 011 950 4216
✉ m.gorlani@blue-group.it

Guest, I.
Alstom Aerospace
Cambridge Road
LE86LH Leicester
UNITED KINGDOM
☎ +44 116 284 5748
✉ ian.guest@power.alstom.com

Höfner, S.
Max-Planck-Institute for Solar System Research
Max-Planck-Str. 2
37191 Katlenburg-Lindau
GERMANY
☎ +49 176 2410 3720
✉ hoefner@mps.mpg.de

Huermann, B.
Jena-Optronik GmbH
Prüssingstraße 41
7745 Jena
GERMANY
☎ +49 3641 200 291
✉ brian.huermann@jena-optronik.de

Kasper, S.
Jena-Optronik GmbH
Optics & Mechanics
Prüssingstraße 41
7745 Jena
GERMANY
☎ +49 3641 200 176
✉ stefan.kasper@jena-optronik.de

Kirtley, C.
Alstom Aerospace
Cambridge Road, Whetstone
LE8 6LH Leicester
UNITED KINGDOM
☎ +44 116 284 5653
✉ chris.kirtley@power.alstom.com

Klingberg, Tor
ESA/ESTEC D/TEC-MCT
visiting student of Chalmers University
Bosshagsgatan 34
554 46 Jönköping
SWEDEN
✉ tor.klingberg@gmail.com

Lebegue, E.
CSTB
290 route des Lucioles
6904 SOPHIA-ANTIPOLIS
FRANCE
☎ +33 49 395 6423
✉ eric.lebegue@cstb.fr

Leroy, Sandrine
DOREA
Résidence de l'Olivet Bat F; 75 Chemin de
l'Olivet
6110 LE CANNET
FRANCE
☎ +33 63 305 2546
✉ sf.leroy@dorea.fr

Loetzke, H.-G.
DLR German Aerospace Centre
System conditioning
Rutherfordstr. 2
1489 Berlin
GERMANY
☎ +49 30 6705 5617
📠 +49 30 6705 58617
✉ horst-georg.loetzke@dlr.de

Manuel Reina Aranda, M.
INTA
Scientific Payloads
km 4 Torrejón-Ajalvir
28850 Torrejón de Ardoz
SPAIN
☎ +34 91520 1479
📠 +34 91520 1949
✉ reinam@inta.es

Messina, G.
DLR - German Aerospace Center
Institute of planetary research
Rutherford Str. 2
12489 Berlin
GERMANY
☎ +49 306 705 5420
📠 +49 306 705 5303
✉ gabriele.messina@dlr.de

Molina, M.
Carlo Gavazzi Space SpA
via Gallarate 150
20151 MILANO
ITALY
☎ +39 02 38048 259
📠 +39 02 3086 458
✉ mmolina@cgspace.it

Nadalini, R.
Active Space Technologies GmbH
Rudower Chaussee 29
12489 Berlin
GERMANY
☎ +49 179 152 5032
✉ riccardo.nadalini@activespacetech.com

Overbosch, E.G.
Dutch Space
O&E
Mendelweg 30
2333 CS Leiden
NETHERLANDS
☎ +31 71 524 5737
✉ e.overbosch@dutchspace.nl

Patricio, Ricardo
Active Space Technologies
R Pedro Nunes
3030-199 Coimbra
PORTUGAL
☎ +35 123 970 0333
📠 +35 123 970 0301
✉ ricardo.patricio@activespacetech.com

Pennings, N.
ESA/ESTEC
D/TEC-MCT
P.O. Box 299
2200 AG Noordwijk
NETHERLANDS
☎ +31 71 565 6339
✉ nico@thermal.esa.int

Persson, Jan
ESA/ESTEC
D/TEC-MCT
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 3814
✉ jan.persson@esa.int

Pimenta, V.
Spin.Works
Rua Rodrigues Sampaio 97, 4°
1150-279 Lisboa
PORTUGAL
☎ +35 193 426 3497
✉ vasco.pimenta@spinworks.pt

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

Poyntz-Wright, O.
Rutherford Appleton Laboratory
Space Science and Technology Dept
R25 G.08, Rutherford Appleton Laboratory
OX11 0QX Chilton, Didcot
UNITED KINGDOM
☎ +44 123 544 5761
✉ O.Poyntz-Wright@rl.ac.uk

Price, Steven
Astrium
Thermal Engineering
Gunnels Wood Road
SG1 2AS Stevenage
UNITED KINGDOM
☎ +44 1438 773 798
✉ steve.price@astrium.eads.net

Quinn, A.
EADS Astrium
Gunnels Wood Road
SG1 2AS Stevenage
UNITED KINGDOM
☎ +44 143 877 3560
✉ andrew.quinn@astrium.eads.net

Rathjen, H.
EADS Astrium Space Transportation
TE52
P. O. Box 28 61 56
28361 Bremen
GERMANY
☎ +49 421 539 4173
📠 +49 421 539 5582
✉ harold.rathjen@astrium.eads.net

Romera Perez, J.A.
ESA/ESTEC
D/TEC-MCT
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 3979
✉ jose.antonio.romera.perez@esa.int

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

Ruel, C.
MAYA Heat Transfer Technologies Ltd.
4999 Sainte-Catherine st west, suite 410
H3Z 1T3 Montreal
CANADA
☎ +1 514 369 5706
✉ christian.ruel@mayahtt.com

Sauer, A.
EADS-ASTRIUM
ASG 23 (Thermal, Mechanical and Test)
Claude-Dornier-Straße 1
88039 Friedrichshafen
GERMANY
☎ +49 7545 8 2514
✉ arne.sauer@astrium.eads.net

Schubert, A.
EADS Astrium Space Transportation
TE52
P.O. Box 28 61 56
28361 Bremen
GERMANY
☎ +49 421 539 5486
📠 +49 421 539 5582
✉ anna.schubert@astrium.eads.net

Shaughnessy, B.
Rutherford Appleton Laboratory
Chilton
OX11 0QX Didcot
UNITED KINGDOM
☎ +44 1235 445 061
✉ b.m.shaughnessy@rl.ac.uk

Sørensen, J.
ESA/ESTEC
D/TEC-EES
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 3795
✉ john.sorensen@esa.int

Soriano, T.
Astrium
31 rue des cosmonautes
31402 Toulouse
FRANCE
☎ +33 561 19 9176
✉ timothee.soriano@astrium.eads.net

Stroom, C.
Keplerlaan 1
2200 AG Noordwijk
NETHERLANDS
☎ +31 6 5156 0129
✉ charles@stremen.xs4all.nl

Theroude, Christophe
EADS Astrium
rue de Cosmonautes
31402 Toulouse Cedex 4
FRANCE
☎ +33 5 6219 6885
✉ christophe.theroude@astrium.eads.net

Tonellotto, G.
ESA/ESTEC (AOES)
D/TEC-MCT
Keplerlaan 1
2201 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 4817
Fax +31 71 565 6142
✉ giulio.tonellotto@esa.int

van Eekelen, T.
Samtech s.a.
Rue des Chasseurs-Ardennais 8
B-4000 LIEGE
BELGIUM
☎ +32 4361 6969
✉ tom@samcef.com

Varewijck, G.M.
ESA/ESTEC
D/TEC-MCV
Keplerlaan 1
2200 AZ Noordwijk
NETHERLANDS
☎ +31 71 565 5080
✉ george.varewijck@esa.int

Vueghs, P.
University of Liège
of Aerospace and Mechanics
1, Chemin des Chevreuils
B4000 Liège
BELGIUM
☎ +32 4 366 92 13
Fax +32 4 366 95 05
✉ Pierre.Vueghs@ulg.ac.be