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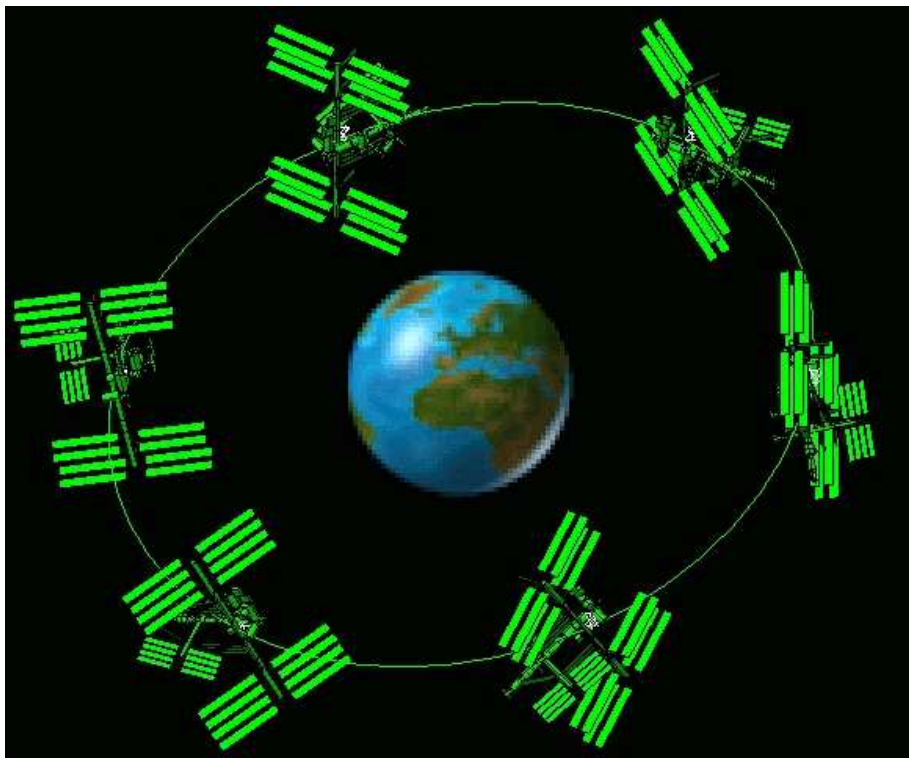
21st European Workshop

on

Thermal and ECLS Software

ESA/ESTEC, Noordwijk, The Netherlands

30-31 October 2007



European Space Agency
Agence spatiale européenne

Abstract

This document contains the minutes of the 21st European Thermal and ECLS Software Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on the 30th and 31st October 2007. It is intended to reflect all of the additional comments and questions of the participants. In this way, progress (past and future) can be monitored and the views of the user community represented. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.

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Final Programme

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

Tuesday 30th October 2007

09:00	Registration	
10:00	Welcome and Introduction	Harrie Rooijackers, ESA/ESTEC, Netherlands
10:15	Parallel thermal analysis with Linux clusters	Duncan Gibson, ESA/ESTEC, Netherlands
10:45	GAETAN V5 : a Global Analysis Environment for Thermal Analysis Network	Hélène Pasquier, CNES, France
11:15	Coffee break	
11:45	ESARAD radiative analyser : Development status	Julian Thomas, ALSTOM, UK
12:15	Alstom Thermal Analysis Suite	Julian Thomas, ALSTOM, UK
13:00	Lunch	
14:00	Guidelines for High Accuracy Thermal Modelling : Experiences and Results from the ESA study: Improvement of Thermal Analysis Accuracy	Ulrich Rauscher, EADS Astrium, Germany
14:30	ESATAN Thermal Suite : Development status	Chris Kirtley, ALSTOM, UK
15:00	LISA Pathfinder thermal stability analysis	Denis Fertin, ESA/ESTEC, Netherlands
15:30	Coffee break	
16:00	Thermal model correlation using Genetic Algorithms	Frédéric Jouffroy, EADS Astrium, France
16:30	SYSTEMA V4 : New framework of THERMICA	Christophe Theroude, EADS Astrium, France
17:00	THERMICA Suite : Complete thermal analysis package	Timothée Soriano, EADS Astrium, France
17:30	Social Gathering	ESTEC Wintergarden North
20:00	Dinner	Paul's Recept, Noordwijk

Thursday 5th October 2006

09:00	Thermo-elastic analysis of the LISA Pathfinder spacecraft James Etchells, ESA/ESTEC, Netherlands
09:30	Thermal design and analysis of the FMOS IR Camera Allan Dowell, Rutherford Appleton Laboratory, UK
10:00	Thermal Analysis for Re-Entry Vehicles : Software needs and expectations Savino De Palo, Thales Alenia Space, Italy
10:30	Use of ThermXL for rapid evolution of ExoMars rover vehicle design Andy Quinn, EADS Astrium, UK
11:00	Coffee break
11:30	Thermal Concept Design Tool Software Matteo Gorlani, Blue Engineering, Italy
12:00	ESATAP : Handling large thermal results data with HDF5 François Brunetti, Dorea, France
12:30	ThermNV : Post-processing multiple results sets Henri Brouquet, ALSTOM, UK
13:00	Closure Harrie Rooijackers, ESA/ESTEC, Netherlands

Day 1

Tuesday 30th October 2007

1.1 Welcome and introduction

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

1.2 Parallel thermal analysis with Linux clusters

D. Gibson (ESA/ESTEC) explained that the improvements in speed of both hardware and software were matched by the growth in complexity of thermal analysis models, and that new ways were needed to improve analysis throughput. He described the key points in the evolution of the hardware and software environment provided by the Analysis and Verification section for the thermal engineers in ESTEC that had led to the creation of a Linux cluster. He emphasised that although some level of parallel thermal analysis was available to everyone, the developers needed to provide more support to make it easier to use for an individual analysis case, and managers needed to start planning deployment and usage policy for competing analysis campaigns. (See [appendix B](#)¹)

U. Rauscher (Astrium GmbH) asked how the ESARAD parallel facility was used, and how all of the parallel results were merged at the end. D. Gibson explained that the user first created or loaded a radiative case into the ESARAD GUI. Under the Radiative Case menu there was an option to Save Analysis Files. On the dialog box that popped up, there was a Multiple Files option. If the user selected this option, ESARAD would save the calculations for the different overall orientations at the different orbit positions into separate batch files. It was then the user's responsibility how to run these batch files on the different remote machines. D. Gibson had written a shell script that first ran all of the VREF calculations on a list of remote machines, and then the HF calculations. For each job to access the ESARAD geometry and database, all of the jobs ran in a single directory that was shared across the network, and were synchronised using lock files created in the directory. As a result, there was no need to merge anything afterwards because each job had simply updated the central database.

O. Pin (ESA/ESTEC) stressed that it was ESA's role to support the European Thermal Community and to help maintain its competitiveness. He foresaw that parallel computing would become

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

important for industry because of the need to handle the continuing increase in model and mission complexity, and that Linux clusters could provide a favourable performance to cost ratio. The transfer of knowledge given in this presentation was important for both developers and users. To develop for, or to create, a cluster would require planning, investment, and people.

K. Caire (Thales Alenia Space) asked whether special scripts had been needed to merge the data from the multiple analysis case runs to enable post-processing. D. Gibson said that scripts had only been written to provide the framework to run each series of parametric cases. It had been left to the user to merge and extract the data that he required.

M. Huchler (EADS Astrium) asked how to handle the problem of multiple users running jobs. D. Gibson said that the queue management system allowed the configuration of the total number of active jobs, number of active jobs per user, and priority of particular jobs or users. Ultimately it was down to management to provide planning and define policy about which analysis campaigns had priority, just as it was at the moment.

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

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

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

H. Pasquier (CNES) presented the overall design case data hierarchy of GAETAN, and then demonstrated the new user interface for defining these cases. She then described the new CONDOR and GENETIK modules. (See [appendix D](#))

E. Overbosch (Dutch Space) said that sometimes when looking for the worst case, the worst case also depended on the time constant of the object being considered. A large satellite would have a large time constant, whereas solar arrays would have a fast response time. He asked whether GAETAN handled this. H. Pasquier said that this was not implemented. GAETAN only looked for the ‘worst’ steady state value and did not consider the inertia of the satellite.

U. Rauscher (Astrium GmbH) asked whether the GENETIK module used the couplings or the geometrical model. H. Pasquier answered that it worked with both the radiative and conductive models and could do all calculations throughout the orbit.

HP. de Koning (ESA/ESTEC) said that the comparison shown had involved eight variables. He asked about the run time for a complete scan with CONDOR and GENETIK. H. Pasquier said that the run time depended on the initial thermal model, but GENETIK took longer because CONDOR only involved a single parameter. HP. de Koning asked what would happen when running the same mission in both tools. H. Pasquier said that the computation would take longer with GENETIK, but she did not remember the exact differences in time.

F. Jouffroy (EADS Astrium) asked how many radiative cases were calculated typically, because this determined the sizing. H. Pasquier agreed, but didn’t have the number in her head. She would look on the system and tell him afterwards.²

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

1.5 ESARAD radiative analyser - Development status

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

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

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

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

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

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

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

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

U. Rauscher (Astrium GmbH) summarized the critical design issues on the GAIA and LISA Pathfinder spacecraft and why high accuracy was required, and then described the findings of an ESA-funded study into different parts of the analysis chain. These included model pre-processing in ESATAN, the steady state and transient solvers, with a comparison against THERMISOL. He

described the number of rays fired in `ESARAD`, and using the random number seed to demonstrate confidence in the results. (See [appendix F](#))

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

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

1.7 `ESATAN` Thermal Suite - Development status

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

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

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

U. Rauscher asked whether there were any guidelines on when to use the solver. J. Strutt (ALSTOM) said that the solver used a linearised method so there were some limits on the accuracy, but to give precise limits would be impossible. The accuracy would depend on the model. If it was a linear model, or a radiative model with no temperature variation then the guidelines for linearisation would be that temperature variation should be much less than $\frac{2}{3}T_e$ (where T_e was the equilibrium temperature field used for the linearisation). If the model had a higher value, then it would be outside the linearisation. C. Kirtley asked whether there were any guidelines. J. Strutt

repeated that it was not really possible to give fixed guidelines because they were so strongly related to the model, relaxation criteria, etc.

1.8 LISA Pathfinder thermal stability analysis

D. Fertin (ESA/ESTEC) presented the mission requirements and the need to be able to demonstrate that the ‘noise’ produced during analysis would be within acceptable levels and would not swamp the stringent thermal variation requirements during flight. He described the concept of a power density spectrum using a simple thermal filter model, and how this could be derived from `ESATAN` results. He then showed how the same technique could be applied to the LISA model. (See [appendix H](#))

J. Etchells (ESA/ESTEC) commented that U. Rauscher (Astrium GmbH) had already raised the transfer function approach during his presentation. J. Etchells said that if you assumed a linearised system, then it would be possible to use superposition, but then there would be a loss of phase information. D. Fertin said that was why he had asked for a dump of all of the `ESATAN` matrices so that he could then calculate the state space matrices that handled phase. The result showed that although the FECP CPU is the major source of the thermal disturbance, it was also related to the variations in other five power sources.

1.9 Thermal model correlation using Genetic Algorithms

F. Jouffroy (EADS Astrium) described why thermal model correlation against test data was difficult and presented details of a study to determine whether genetic algorithms could be used to optimise the process. He described how genetic algorithms worked and how they had investigated the effect of population size, and varying the effect of crossover and mutation to alter the model parameters during subsequent analyses. He described the effects using two test models. (See [appendix I](#))

E. Overbosch (Dutch Space) asked how to handle the fact that in practice there might be a measurement error of 0.5°C for a thermocouple, but the correlation required only a 0.1°C variation, as given in the example. F. Jouffroy answered that it would always be possible to stop the genetic algorithm at an earlier point because the same level of accuracy was not needed. But the approach still needed further investigation.

E. Overbosch asked what happened if the stop criterion was a 2°C variation, but there were three families of solutions within the 2°C range, but with different parameters being changed (e.g. one with different optical properties, one with different heater power or thermostat settings). If there were three right answers, how was the “correct” parameter chosen? A given family of parent solutions could have clusters of potential parameter solutions that satisfied the correlation limits. F. Jouffroy said that it was necessary to limit the parameter solutions to those that had physical meaning within the system.

M. Gorlani (Blue Engineering) noted that the genetic algorithm approach had been compared with a random method, and wanted to know which one. F. Jouffroy said that they had simply run 4000 cases with random values for some of the parameters.

HP. de Koning (ESA/ESTEC) asked whether the genetic algorithm approach had been compared against methods used in existing stochastic tools, such as the hypercube, which had a mathematical basis for the optimisation. F. Jouffroy said that N. Durand (DSNA), his partner in the study, had discussed using the latin hypercube with J. Etchells (ESA/ESTEC), but further investigation was required.

1.10 SYSTEMA V4 - New framework for THERMICA

C. Theroude (Astrium Satellites) gave a brief overview of the history of the SYSTEMA framework, and described the philosophy behind the infrastructure where it was possible to construct a complex mission without a complete satellite geometry. He went on to demonstrate importing a CAD model and then constructing a simpler version of it by picking points from it, and then showed the mission visualisation and animation. (See [appendix J](#))

There were no questions.

1.11 THERMICA Suite - Complete thermal analysis package

T. Soriano (Astrium Satellites) presented developments in THERMICA, THERMISOL and POSTHER, and their integration into SYSTEMA V4. He described the limitations of the current linear conductor generation algorithm in THERMICA, and announced that it would be replaced with a “Volume Element” approach. He also announced changes to the \$VARIABLES blocks in THERMISOL in order to produce speed improvements in the solution routines: \$VARIABLES1 would only contain temperature dependent code, and \$VARIABLES2 would contain time dependent code. He then described the POSTHER post-processing tool. (See [appendix K](#))

HP. de Koning (ESA/ESTEC) raised objections to the change in meaning of the \$VARIABLES blocks. He said that \$VARIABLES1 and \$VARIABLES2 had established meanings in ESATAN and SINDA, and that they were known terms that everyone understood. He felt that it was dangerous to reuse such names for new functionality because it would become quite confusing in practice. T. Soriano agreed that it could be confusing, and had thought about it. However, unless the \$VARIABLES2 block contained output routines, then the old way was compatible with the new way. The new way had the advantage of better accuracy and was faster. Provided there was no output in \$VARIABLES2 then there would be no risk.

O. Pin (ESA/ESTEC) asked what would happen to time dependent data in an ESATAN model if it were run in THERMISOL. T. Soriano said that it would be the same as having the data in \$VARIABLES2 but the interpolation would be called many times and would waste time, but if the time dependencies were isolated in \$VARIABLES2 and the temperature dependencies in \$VARIABLES1 then there would be speed improvements. O. Pin said that this had been available in ESATAN for years. H. Brouquet (ALSTOM) confirmed that this was what was recommended in ESATAN. T. Soriano disagreed because he believed that the Crank-Nicolson implementation was wrong. He said that using the median time for the interpolation was not optimum and was not true Crank-Nicolson. Proper Crank-Nicolson allowed automatic time-stepping and better time switching for thermostats and switching logic. The current implementation was adequate for small time-steps, but a better scheme was really needed for large time-steps. Currently the \$VARIABLES1 and \$VARIABLES2 blocks were not called at one specific moment in the solution. O. Pin argued that this was new functionality, and should therefore be identified as such by using a new label, otherwise it would be confusing for users migrating models between ESATAN and THERMISOL. HP. de Koning agreed that developers had to be careful about overloading existing functionality. He gave the examples of SINDA and Cullimore and Ring’s implementation of SINDA that introduced a \$VARIABLES0 block for initial conditions. The changes made sense, but there was always the need to be careful with naming. T. Soriano said it was important to make the concepts consistent, but he could change the names before the release.

C. Kirtley (ALSTOM) said that the Crank-Nicolson implementation in ESATAN did not use the mean time: it called \$VARIABLES1 at the start of the time-step and called it again at the end.

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

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

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

Clarifications

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

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

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

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

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

Day 2

Wednesday 31st October 2007

2.1 Thermo-elastic analysis of the LISA Pathfinder spacecraft

J. Etchells (ESA/ESTEC) presented the challenges involved in a shadow engineering activity to verify that the thermal variation requirements for LISA Pathfinder could be met. The first problem involved bringing the different structural and thermal models written using different tools up to the same reference baseline. Then there was the issue of the lack of convergence in the model because of the isolation of the test masses from the rest of the thermal network, and which was solved by introducing linear conductors during an initial steady state calculation and by subsequently disabling these couplings. Problems with temperature drift during the transient solution were investigated using `ECOSIMPRO`. The final stage was mapping the resulting temperatures from the thermal to the structural models by calculating overlay data using `TASVERTER` and `SINAS`. He gave a quick demonstration of how this could be achieved for a small model of an instrument mounted on a panel. (See [appendix L](#))

M. Gorlani (Blue Engineering) asked about `SINAS` and whether a direct link to `PATRAN` was available. J. Etchells said that a `PATRAN` PCL-library add-on for `SINAS` was available for Windows via the Exchange web site¹, although the version shown during the demonstration had been from ESTEC's Linux development version.

2.2 Thermal design and analysis of the FMOS IR Camera

A. Dowell (RAL) presented the design and modelling of a ground-based infra-red camera that would form part of a spectrograph coupled to an 8m telescope in Hawaii. He described the main aspects of the construction, and how these had been modelled in `ESARAD`, including the problems encountered when modelling the parabolic lens assemblies and how this had been handled in `ESATAN`. (See [appendix M](#))

HP. de Koning (ESA/ESTEC) asked whether it would have made the thermal design easier if it had been possible to model refraction in the `ESARAD` ray tracing code. A. Dowell agreed that it would have made it simpler, but in reality the heat load through the lenses did not contribute much compared to the parasitic loads through the cryocooler. He said that the camera was ground-based, and admitted that if it had been space-based then modelling the ray tracing through the lenses would be important because even small heat loads could be significant.

¹<http://exchange.esa.int/restricted/sinas>

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

S. de Palo (Thales Alenia Space) presented two study cases for re-entry vehicles that required using more than the standard `ESARAD` and `ESATAN` type analysis. The first involved a semi-real time thermal control monitoring system that interfaced to `MATLAB/Simulink`. The second involved integrating multi-physics models, with the specific example of using `FHTS` to model water cooling pipes in the leading edge of a wing section during re-entry. (See [appendix N](#))

M. Huchler (EADS Astrium) asked whether the thermal mathematical model was maintained in `Simulink` in the first example. S. de Palo said that `Simulink` was used as the equation solver. He had not needed a linear system. The problem had been how to translate the capacity matrix into `Simulink`, and also the radiative and linear conductor matrices. It would have been better if there had been a direct method of extracting the information from `ESARAD` and `ESATAN` into `Simulink`. M. Huchler asked whether radiative heat exchange had been included. S. de Palo said that if they considered passive cooling then they only needed to handle radiation for the heat rejection. However, if they wanted to have an accurate model then they would need to consider radiative exchange, but he did not think it was fast enough to be able to make a linearisation for several time-steps in real time. He had not needed to consider radiative heat exchange so he was able to use linearisation in this case.

J. Etechells (ESA/ESTEC) said that it would be possible to use `EcosimPro` and create a thermal model similar to that used in `ESARAD` and `ESATAN` and then create C++ classes and objects which could be wrapped in `Simulink`. S. de Palo said that it would have been possible, but he had not wanted to be tied to any particular topology because it was difficult to update. He admitted that `EcosimPro` could be useful.

J. Persson (ESA/ESTEC) asked why `EcosimPro` had not been considered. S. de Palo said that partly because the study had been an exercise, and also because he did not want to be forced to create schematic layouts of all nodes and conductors. He felt that it would be better to use a smart method that involved matrices that could be generated automatically. He did not want to add an extra step into the modelling process.

J. Etechells asked about the second example study, of the wing section, and how the cooling ducts had been modelled in `ANSYS`. S. de Palo said that the ducts had been modelled as boundary nodes, and he had then created a less detailed model in `FHTS` to provide the boundary data. `ANSYS` could perform both CAD with a lumped-parameter-like approach for the fluidic problems inside. He said that there was someone trying to do something similar with `Thermal Desktop` for the fluidic part within a `PATRAN` model.

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

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

C. Kirtley (ALSTOM) asked whether the use of ESARAD had been considered. ESARAD analysis cases could have been used for the separate mission cases. A. Quinn said that he had not considered it. It might have been possible, but he thought that some parts of the network could not be modelled in ESARAD, so ThermXL would still have been needed.

R. Nadalini (Active Space Technologies) had noted the difficulties trying to handle multiple cases within a single analysis file, and the problems with nested IF states, and asked whether any macros had been used. A. Quinn said that they had used Visual Basic, which had simplified some parts, but it really depended on what you were trying to do, and they had still had some problems. R. Nadalini suggested that it would be possible to have a single model sheet with a switch or button that called the appropriate logic. A. Quinn agreed, but said that there was always the question of knowing when it was appropriate to move on and convert the model to a more complex tool. They had expected to be doing a “simple” analysis and had chosen ThermXL for that reason.

B. Shaughnessy (RAL) asked about the ranges of latitude and the seasons for the landing sites. A. Quinn said that they had considered a range between 45°N and 15°S and the mission included contingency cases between LS0 and LS180, i.e. from equinox to equinox.

J. Etchells (ESA/ESTEC) asked about the effect of the Martian atmosphere and how they had handled the attenuation of the solar fluxes. A. Quinn said that they had used information from the European Martian Database to get the correct optical depth, but they had found some limitations. They were now looking at different interpolation strategies.

H. Rooijackers (ESA/ESTEC) suggested that for configuration control they might be interested to know that there was now a Subversion plug-in for Microsoft Office.

2.5 Thermal Concept Design Tool

M. Gorlani (Blue Engineering) presented a brief summary of the development phase of the TCDT and an overview of the functionality. He went on to describe the TCDT web site that had been established for registration for use and download of the software, problem reporting, etc. He explained what was available in the TCDT download package and for which platforms it was intended. (See [appendix P](#))

U. Rauscher (Astrium GmbH) asked whether it would be possible to have a summary of the features. He felt that the presentation had been a bit short. Was there a limit to the size of model for instance? M. Gorlani replied that there had been a full demonstration of the TCDT at the previous year’s workshop, so he had not wanted to go into too much detail. The TCDT allowed the user to build a full geometrical mathematical model by defining surfaces in the graphical user interface and providing dimensions, number of nodes, meshing details and thermal node numbers and then assigning thermo-optical properties. When the surface is added to the database it is also added to the Excel worksheet. All parts of the GMM could be visualised using the 3D viewer available in the Excel environment. The GMM could be exported as an ESARAD model. The user could then define an orbit. The logic of the orbit construction in the GUI was similar to geometry construction. The orbit parameters were similar to what was available in ESARAD. When the orbit was saved to the database it was also downloaded to an orbit worksheet and could be checked with a 3D orbit viewer. It was possible to define multiple orbits for different cases. The user could create a thermal mathematical model from the GMM via a worksheet, and all data would be available in the ESATAN \$NODES block.

U. Rauscher wanted to know whether the TCDT could run ESARAD on the file that it had created. M. Gorlani said that the Thermal Simulation Manager within TCDT could be used to start the calculation on either the local or a remote machine. He said that the user could perform high level

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

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

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

H. Pasquier (CNES) noted that there was a clear link from the TCDT to ESARAD and ESATAN. She wanted to know about the possibility of export to THERMICA and THERMISOL. M. Gorlani said that there had been no work in that area. O. Pin (ESA/ESTEC) explained that the history of the TCDT was to provide a tool specifically for the Concurrent Design Facility at ESA. The CDF infrastructure involved sharing data via Excel spreadsheets, and this was the reason why the TCDT was based on Excel. It had not been based on Excel to work with ThermXL as such, so the link to ThermXL was a bonus. The CDF used ESARAD and ESATAN, and this was why the TCDT exported to these formats. The tool had been developed explicitly with the CDF requirements in mind, so the decision to distribute the tool to the rest of the European thermal community was simply an added bonus. ESA had foreseen that there were unlikely to be many paying customers for this sort of tool, and had decided to make it available anyway. The maintenance budget that had been allocated would be insufficient to provide compatibility with other tools. This was simply not a priority for ESA and the CDF. If someone wanted to use the TCDT, then the tool was available to them, as is. Of course, if someone decided to provide direct funding for new functionality or interfaces, then O. Pin was not against capitalizing on the framework provided by the TCDT. HP. de Koning (ESA/ESTEC) reminded everyone that they could use TASverter to convert the ESARAD model produced by the TCDT into another format, so the building blocks were available. O. Pin said that THERMISOL was supposed to be compatible with ESATAN (with the possible exception of the \$VARIABLES1 and \$VARIABLES2 blocks) so in principle there should be no problem with importing an ESATAN model produced by the TCDT into THERMISOL. He repeated what HP. de Koning had said: to get a THERMICA model, simply export an ESARAD model from the TCDT and then use TASverter to convert it. This was the approach that was already being used within Blue Engineering.

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

2.6 ESATAP - Handling large thermal results data with HDF5

F. Brunetti (DOREA) gave only a brief overview of ESATAP because it had been demonstrated at the previous year's workshop, and went on to describe the challenges that ESATAP had faced in working with the STEP-TAS Part-21 files written in ASCII. The process of reading the ASCII file was slow, and it also used a lot of memory because the complete file needed to be read. This had led to the development of an implementation of the STEP-TAS Part-21 file using HDF5, which allowed storing the data in a hierarchical binary format that would be portable across platforms. Dorea were also working to provide an ESATAN output routine for dumping results data into STEP-TAS format using HDF5. A. Fagot (DOREA) described the results of running test cases using both the ASCII and HDF5 versions of the STEP-TAS data and demonstrated importing the HDF5 data files in real time. (See [appendix Q](#))

R. Patricio (Active Space Technologies) asked whether the HDF5 format would spread to the other tools, such as ThermNV. J. Thomas (ALSTOM) answered that when the development toolkit became available ALSTOM would be looking at how to use HDF5 format data within ThermNV. He said that the toolkit had not yet been delivered, so they could not make immediate plans and could only consider it as a long term option.

2.7 ThermNV - Post-processing multiple results sets

As H. Brouquet (ALSTOM) was unable to speak because of a cold, J. Thomas (ALSTOM) took over the talking while H. Brouquet gave a live demonstration of the improvements to ThermNV that had been released since the previous workshop. Most of the features were a direct result of user feedback on the previous versions. The first major improvement related to large models, where a dialog containing the list of available nodes was automatically presented to the user so that a selection could be made of the nodes of interest. H. Brouquet demonstrated how this could be used, along with the automatic grouping and layout tools to create a meaningful schematic of the network. The next improvement was the comparison of results data against two levels of maximum and minimum limits which could be used to highlight whether the results exceeded qualification and design requirements. The final feature shown was the ability to define and save the layout of all of the schematics, tables and charts and then apply these to multiple data sets, and to display the min/max values over all data sets. This functionality could be driven via a batch method as well as from the graphical user interface. (See [appendix R](#))

There were no questions.

2.8 Closure

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

Appendix A

Welcome and Introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Appendix B

Parallel thermal analysis with Linux clusters

Duncan Gibson
(ESA/ESTEC, The Netherlands)

Appendix C

New technology for modelling and solving radiative heat transfer
using TMG

Kevin Duffy
(MAYA, Canada)

Appendix D

GAETAN V5: a Global Analysis Environment for Thermal Analysis Network

Hélène Pasquier
(CNES, France)

Appendix E

ESARAD radiative analyser - development status

Julian Thomas
(ALSTOM, United Kingdom)

Appendix F

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

Ulrich Rauscher
(EADS Astrium, Germany)

Appendix G

ESATAN Thermal Suite - development status

Chris Kirtley
(ALSTOM, United Kingdom)

Appendix H

LISA Pathfinder thermal stability analysis

Denis Fertin
(ESA/ESTEC, The Netherlands)

Appendix I

Thermal model correlation using Genetic Algorithms

Frédéric Jouffroy
(EADS Astrium, France)

Appendix J

SYSTEMA V4 - New framework for THERMICA

Christophe Theroude
(EADS Astrium, France)

Appendix K

THERMICA Suite - Complete thermal analysis package

Timothée Soriano
(EADS Astrium, France)

Appendix L

Thermo-elastic analysis of the LISA Pathfinder spacecraft

James Etchells
(ESA/ESTEC, The Netherlands)

Appendix M

Thermal design and analysis of the FMOS IR Camera

Allan Dowell
(Rutherford Appleton Laboratory, UK)

Appendix N

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

Savino De Palo
(Thales Alenia Space, Italy)

Appendix O

Use of ThermXL for rapid evolution of ExoMars rover vehicle design

Andy Quinn
(EADS Astrium, UK)

Appendix P

Thermal Concept Design Tool

Matteo Gorlani
(Blue Engineering, Italy)

Appendix Q

ESATAP - Handling large thermal results data with HDF5

François Brunetti
(Dorea, France)

Appendix R

ThermNV - Post-processing multiple results sets

Henri Brouquet
(ALSTOM, United Kingdom)

Appendix S

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