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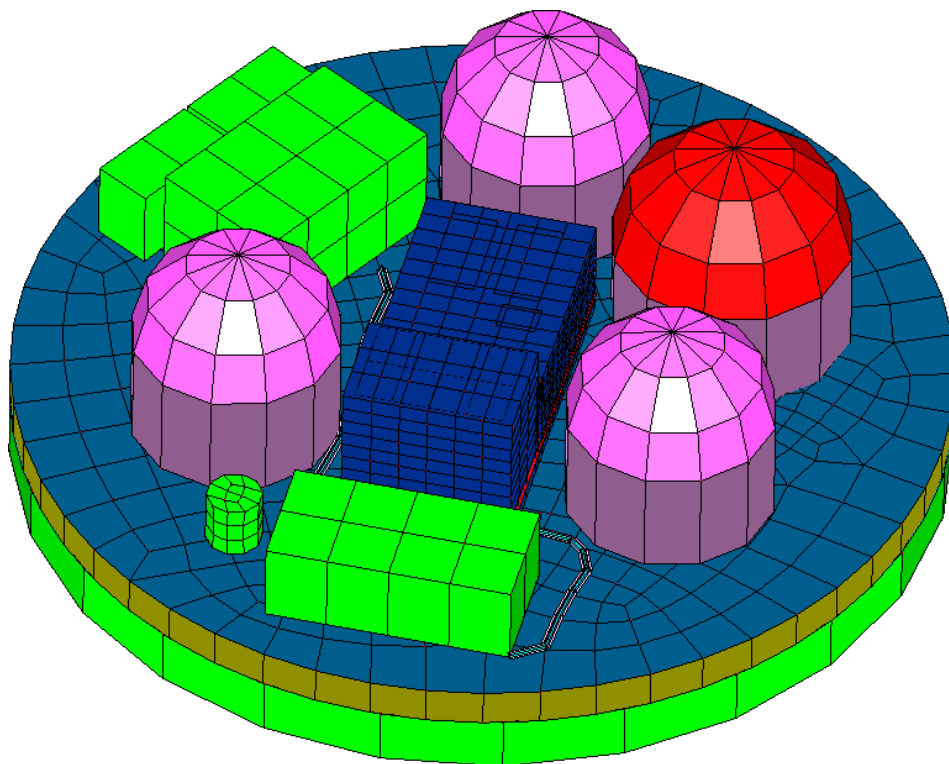
24th European Workshop

on

Thermal and ECLS Software

ESA/ESTEC, Noordwijk, The Netherlands

16–17 November 2010



*European Space Agency
Agence spatiale européenne*

Abstract

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

Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under ‘Workshops’.

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Contents

Title page	1
Abstract	2
Contents	3
Programme	5
1 Tuesday 16th November 2010	7
1.1 Welcome and introduction	7
1.2 Presentation, demonstration of new TAS thermal software e-Therm and associated strategy	7
1.3 Exchange of Thermal Model Algorithms via STEP-TAS	8
1.4 Exchange of TMG thermal models via STEP-TAS	9
1.5 Genetic algorithm shape optimisation of radiant heaters	10
1.6 Development of numerical tools for design and verification of ablative thermal protection systems	11
1.7 ESATAN2SS tool — from ESATAN to Space State	11
1.8 ESATAN Thermal Modelling Suite — Product Developments & Demonstrations	12
1.9 SYSTEMA 4.3.4	13
1.10 THERMICA-THERMISOL 4.3.4	14
1.11 TMRT	14
2 Wednesday 17th November 2010	17
2.1 LHP module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses	17
2.2 Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES	17
2.3 Thermal Concept Design Tool — 4th Year	18
2.4 Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks	18
2.5 Validation of the Martian Thermal Environment Modelling Method using Flight Data	19
2.6 Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests	19
2.7 Workshop Close	20

Appendices

A	Welcome and introduction	21
B	Presentation, demonstration of new TAS thermal software e-Therm and associated strategy	29
C	Exchange of Thermal Model Algorithms via STEP-TAS	37
D	Exchange of TMG thermal models via STEP-TAS	55
E	Genetic algorithm shape optimisation of radiant heaters	73
F	Development of numerical tools for design and verification of ablative thermal protection systems	85
G	ESATAN2SS tool — from ESATAN to Space State	101
H	ESATAN Thermal Modelling Suite — Product Developments & Demonstrations	111
I	SYSTEMA 4.3.4	135
J	THERMICA-THERMISOL 4.3.4	151
K	TMRT	169
L	LHP module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses	181
M	Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES	199
N	Thermal Concept Design Tool — 4th Year	215
O	Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks	225
P	Validation of the Martian Thermal Environment Modelling Method using Flight Data	237
Q	Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests	253
R	List of Participants	269

Programme Day 1

- 9:00 Registration
- 9:45 **Welcome and introduction**
Harrie Rooijackers (ESA/ESTEC, The Netherlands)
- 10:00 **Presentation, demonstration of new TAS thermal software e-Therm and associated strategy**
Thierry Basset & Jean-Paul Dudon & Patrick Hugonnot (Thales Alenia Space, France)
François Brunetti (DOREA, France)
- 10:30 **Exchange of Thermal Model Algorithms via STEP-TAS**
Alain Fagot (DOREA, France)
Hans Peter de Koning & Harrie Rooijackers (ESA/ESTEC, The Netherlands)
- 11:00 Coffee break in the Foyer
- 11:30 **Exchange of TMG thermal models via STEP-TAS**
Mouloud Bourbel (Maya, Canada)
- 12:00 **Genetic algorithm shape optimisation of radiant heaters**
Bryan Shaughnessy (RAL, United Kingdom)
- 12:30 **Development of numerical tools for design and verification of ablative thermal protection systems**
Marco Giardino & Elena Campagnoli (Politecnico of Turin, Italy)
Gianni Pippia (Sofiter System Engineering, Italy)
Massimo Antonacci (Thales Alenia Space, Italy)
- 13:00 Lunch in the ESTEC Restaurant
- 14:00 **ESATAN2SS tool — from ESATAN to Space State**
Savino De Palo (Thales Alenia Space, Italy)
Donata Pietrafesa (Sofiter System Engineering, Italy)
- 14:30 **ESATAN Thermal Modelling Suite — Product Developments & Demonstrations**
Chris Kirtley & Henri Brouquet (ITP Engines UK, United Kingdom)
- 15:30 Coffee break in the Foyer
- 16:00 **SYSTEMA 4.3.4**
Marc Baucher (EADS Astrium, France)
- 16:30 **THERMICA-THERMISOL 4.3.4**
Timothée Soriano (EADS Astrium, France)
- 17:00 **TMRT**
Mathieu Bernard (EADS Astrium, France)
Thierry Basset (Thales Alenia Space, France)
James Etchells (ESA/ESTEC, The Netherlands)
- 17:30 Social Gathering in the Foyer
- 19:30 Dinner in *La Galleria*

Programme Day 2

9:15 **LHP module for ESATAN & THERMICA thermal solvers, dedicated to system level thermal analyses**

Frédéric Jouffroy (EADS Astrium, France)
Anne-Sophie Merino (Thales Alenia Space, France)
Amaury Larue de Tournemine (CNES, France)

9:45 **Use of ThermXL & THERMICA in THERMAL CONTROL ENGINEERING for CNES BALLOONS VEHICLES**

Gaël Parot (CNES, France)

10:15 **Thermal Concept Design Tool — 4th Year**

Andrea Tosetto & Matteo Gorlani (Blue Engineering, Italy)
Harrie Rooijackers (ESA/ESTEC, The Netherlands)

10:45 Coffee break in the Foyer

11:15 **Advances in Frequency Domain Thermal Analysis Based On Linearized Thermal Networks**

Martin Altenburg & Johannes Burkhardt (EADS Astrium Friedrichshafen, Germany)

11:45 **Validation of the Martian Thermal Environment Modelling Method using Flight Data**

Stéphane Lapensée (ESA/ESTEC, The Netherlands)

12:15 **Adaptation of LSS Thermal Radiative Models for Bepi-Colombo 10 Solar Constants Tests**

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

12:45 Closure

13:00 Lunch in the ESTEC Restaurant

14:00 ESATAP Training

Day 1

Tuesday 16th November 2010

1.1 Welcome and introduction

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

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

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

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

P. Hugonnot (Thales Alenia Space) presented a brief overview of the development of e-Therm as a replacement for CORATHERM, and described the long term strategy to extend the tool to cover the complete analysis process and possibly link to other disciplines. (See [appendix B](#))

L. Tentoni (Thales Alenia Space) commented that the demonstrations had shown how to import models from ESARAD and CAD, and asked whether it was possible to build such models from zero. F. Brunetti (DOREA) said that the user could build models using e-Therm because it was a complete modeller, but said that it was also important to have an import facility from CAD. The demonstration had shown the import from CATIA-v5.

L. Tentoni asked whether there had been any cutting operations in the model shown in the demonstration. F. Brunetti said that the model had included cutting operations because this was a capability of the CAD tool. It was possible to click to select points in the CAD model, and that e-Therm would try to recognize geometric primitives and transfer them into the thermal model. L. Tentoni asked whether it was possible to use cutting operations when building the model yourself using e-Therm. F. Brunetti said that CAD models could be imported into e-Therm,

but `e-Therm` also provided primitives. The user could also create surfaces from 2D polylines and then mesh them using the `GMSH` mesher.

P. Ferreira (Max Planck Institute) commented that the video had shown many warnings during the import of the `ESARAD` model, and wondered what these errors were. F. Brunetti said that the warnings related to matching materials. The materials used by the existing internal model were already known, but those being imported from the external model were not yet known, and needed to be created in the reference database. This was the reason for the error messages.

B. Benthem (Dutch Space) observed that the video had shown a picture of 3D calculation on solid elements, and asked how to do this in `ESARAD`. F. Brunetti explained that the two videos were not linked: the first showed how to import a model from `ESARAD`; and the second showed how to import a model from `PATRAN`. The 3D calculation on solid elements related to the `PATRAN` model. F. Brunetti added that it was also possible to perform 3D meshing using the `GMSH` mesher, but then the user would need to use the `e-Therm` solver rather than `ESATAN`.

B. Benthem asked whether `e-Therm` also calculated radiative couplings. F. Brunetti said that it did, but only on the 2D thin shells that made up the skin of the model, and not on 3D solids.

B. Benthem asked how the software took the radiative couplings into account. P. Hugonnot said that `e-Therm` made use of the `EQUIVALE` method that had been applied to 2D panels on telecom satellites for many years, and which had now been developed further for 3D.

B. Laine (ESA/ESTEC) had understood that the tool had already been released last year, and wondered whether there had been any feedback, and whether there were still plans to distribute the tool for free. F. Brunetti said that last year's release had been of the previous version, and what had been distributed had basically offered `CIGAL2` pre- and post-processing. Thales now had `e-Therm-1.0`, and the next versions would contain full solvers because the `CIGAL2` solvers could not perform all of the analysis chain. It would offer users simple import/export model capabilities and various calculations, but it didn't include the other analysis tools themselves. If users had already `ESARAD` or `THERMICA` then `e-Therm` could use them, but if users were missing these applications they would only be able to exchange models via `STEP-TAS`. He said that users needed the full integration of the analysis chain with `STEP-TAS`, and that this was now possible with `e-Therm`.

P. Hugonnot said that Thales would perform "corrective maintenance", so if users found and reported bugs then they would try to solve them. They were willing to look at adding new features as part of "evolutionary maintenance" if needed, but they would need feedback from users. At the moment the tool addressed general user needs, and would be available on the market for a small distribution cost, and they hoped that they would receive community support.

B. Laine asked about the possibility of hot-line support: was there a telephone number that users could call? P. Hugonnot said that they would try to offer support as long as it didn't become too heavy. F. Brunetti added T. Basset (Thales Alenia Space) was happy for people to contact him with questions.

1.3 Exchange of Thermal Model Algorithms via `STEP-TAS`

A. Fagot (DOREA) presented some of the design considerations needed in `TMMverter` to handle the different features of `ESATAN` and `SINDA/Fluint` thermal mathematical models, and how these could be mapped via the `STEP-TAS` protocol. (See [appendix C](#))

M. Bernard (Astrium) asked about the import of `ESATAN` models. He wondered whether they had considered creating a node export function that could be called from within `ESATAN`, rather than designing a new `ESATAN` model parser. A. Fagot said that one of the aims of `TASverter` was

to be independent of the software tools, and it was important to be able to import the tool formats without needing to have the tools themselves, although this raised problems because the tools were evolving. The `ESATAN` node export facility did not output any of the user logic, and `TMMverter` was a test to see if it would be possible to capture and exchange the user logic too. `TMMverter` was looking at importing ASCII models in order to simplify testing, because it was easier to read user logic in `FORTTRAN` than trying to decode tool specific data files.

`TMMverter` was also trying to deal with the high-level concepts such as being able to convert a node definition loop into `STEP-TAS` rather than the specific `ESATAN` node definition loop. M. Bernard said that the `FORTTRAN` syntax was more strict than `ESATAN`. A. Fagot agreed that the node definition was not easy to achieve in pure `FORTTRAN`, but said that to handle user models, it was a question of parsing user code, and then applying the "visitor" design pattern to convert them.

1.4 Exchange of TMG thermal models via STEP-TAS

M. Bourbel (MAYA) described the implementation of `STEP-TAS` import/export facilities in `IDEAS/TMG` and `NX Space Systems Thermal` using the software development toolkit provided by the IITAS project sponsored by ESA. (See [appendix D](#))

S. Leroy (DOREA) asked how they had tested the thermal node numbering on the node faces imported from `STEP-TAS`. M. Bourbel said that they had tested converting from `IDEAS/TMG` to other tools and back again to `NX-SST`, and compared the result. It was possible to compare the two models side by side.

S. Leroy wondered whether it was now possible to show the node numbering and shell meshing in `BagheraView`. M. Bourbel said that they had done the comparison in `NX-SST`: each primitive in `STEP-TAS` had a number, and during import they applied the same number in `NX-SST` and could then visualise it, but he admitted that it wasn't a convenient way to check the numbering.

S. Leroy said that their version of `BagheraView` did not show node numbering, so they had found it very difficult to check. M. Bourbel noted that the list of primitives shown in `BagheraView` also contained the element number that came from `NX-SST`.

S. Leroy noted that there could be cases where it was possible to modelize entities but still have errors in the conversion. M. Bourbel admitted that `NX-SST` did not support non-planar quadrilaterals, and that these had to be split into two triangles, and would result in a change in the model during conversion, but `NX-SST` did give a warning to the user that the nodal breakdown could change.

H. Brouquet (ITP Engines UK) asked whether there was any plan to make the `STEP-TAS` files available to allow testing of the European thermal tools. M. Bourbel said that all of the models were available from the IITAS repository. O. Svensson (ECAPS) asked whether users had access to these models. O. Pin (ESA/ESTEC) explained that there was a central repository available to the IITAS developers, and that although the models themselves were publicly available, the repository itself was only available to IITAS developers, and not to general users. The repository had been created for the IITAS partners in order to support the validation of the tools. H. Brouquet remarked that ITP had not been notified that the `IDEAS/TMG` models were now available in the repository.

A. Fagot (DOREA) asked about project continuity once the IITAS funding and development finished, and whether MAYA had also tested exchange with the other IITAS software such as `THERMICA` and `ESARAD`. M. Bourbel said that they had used the publicly available models, but had not had direct feedback from the other IITAS developers. As far as future work on

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

1.5 Genetic algorithm shape optimisation of radiant heaters

B. Shaughnessy (RAL) presented high-level details of an old study into using genetic algorithms to calculate the shape of heating elements in electric cookers. He felt it important to highlight such alternative techniques. (See [appendix E](#))

JP. Dudon (Thales Alenia Space) asked about the relative time taken in the preparation of the model, and how to choose the "best" solutions for input to the next generation of calculations, compared to the actual computation time. B. Shaughnessy said that when he had done the study, the preparation time had been mainly constrained by his own C++ capabilities, although the coding of the program had been straightforward. JP. Dudon explained that he had really meant the question from the user point of view. B. Shaughnessy admitted that the model had been very specific to the particular application. It had been relatively easy and quick to tune the parameters, but it had taken a few days of playing around in order to decide which parameters were needed, and their constraints. Once that had been decided, the run-time was then a few hours. He said that the main difficulty was choosing the parameters and the range of variation.

J. Persson (ESA/ESTEC) remarked that he didn't know whether the technique would be suitable for furnaces, but he saw that it could be interesting for thermal testing, especially for infra-red lamp analysis. B. Shaughnessy admitted that he had not tried this, but he had heard anecdotal evidence about thermal test problems due to heat gradients where he thought that this method might be useful.

B. Benthem (Dutch Space) noted that the example shown probably only had 8-10 degrees of freedom, and wondered whether it had really been necessary to try to optimise it using genetic algorithms. B. Shaughnessy answered that he could have used other techniques for the problem, but that this work had been part of a case study into using genetic algorithms. B. Benthem asked whether 8-10 parameters were typical for such a problem. B. Shaughnessy said that most systems using genetic algorithms needed to be developed with the particular problem and set of parameters in mind, as this would determine whether to use some sort of binary encoding for two-value parameters, or a floating point representation for parameters with a range of possible values. The combination and mutation of parameters to be passed to the next generation also needed to be tailored to the problem.

M. Gorlani (Blue Engineering) wanted to make the remark that this was interesting work, but also to remind everyone that Blue Engineering had done a study into stochastic algorithms for ESA in 2003, and that the results were available on the ESA site¹. He said that for the last ten years he had been trying to take these methods further. B. Shaughnessy admitted that he was aware of the Stochastic study.

J. EtcHELLS (ESA/ESTEC) asked whether the end result was sensitive to the choice of the mutation or crossover algorithm being used, and whether this could explain the differences between the triangle- and step-heating cases shown. B. Shaughnessy said that he remembered making some trials, and that it was difficult to optimise the mutation parameters. After making some initial trials, he had simply stuck with the same values. He had not looked into how to optimise it further. B. Laine (ESA/ESTEC) said that he was aware that genetic algorithms were also being

¹ <https://exchange.esa.int/stochastic/>

investigated by Astrium Toulouse. F. Jouffroy (EADS Astrium) confirmed that they were looking at using genetic algorithms to correlate thermal models. At the moment they were only using the TMM scalar parameters, but the method showed that to improve the correlation there was a need for consistency between the test results and the prediction model. The prediction model had to be reasonably good otherwise the genetic algorithms would take too long to reach a solution. On the Astrium Toulouse side, all of the parameterization aspects of genetic algorithms had been performed in a previous study, and that they now no longer needed to consider the propagation and crossover aspects.

B. Shaughnessy said that he saw genetic algorithms as part of a separate tool for simple algorithms, such as how to determine the best heater position on a plate, but to then use the results from this separate tool in the main TMM. F. Jouffroy said it was clear that genetic algorithms had been shown to be a heavy method for optimisation. The Astrium Toulouse experience had been that the genetic algorithm approach always found the optimum solution in the end, and although their aim was always to find the best solution, in reality they were limited to using just 6 or 7 parameters in the correlation studies because of the computation time required.

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

M. Giardino (Politecnico di Torino) gave a brief overview of the physical processes involved in ablation, and described the development of two tools to analyse models of 1D and 3D ablative decomposition. (See [appendix F](#))

M. Komarek (L.K. Engineering) asked whether the models also included the external gas flow. M. Giardino said that they did not. The 1D code was based on a simple model from a 1969 NASA report for the Apollo missions, where the mass reduction was directly proportional to the gas ejection. The 3D code did not contain any reduction modelling, and only considered atmospheric pressure over time as an influence on the gas flux within the material.

1.7 ESATAN2SS tool — from ESATAN to Space State

D. Pietrafesa (Sofiter System Engineering) presented details of the ESATAN2SS tool for converting non-linear ESATAN thermal networks into linear State Space models. (See [appendix G](#))

B. Benthem (Dutch Space) asked whether the method also handled radiative couplings, as these were non-linear with respect to temperature. Conductive couplings between nodes, GLs, were linear, but radiative couplings, GRs, were non-linear. D. Pietrafesa replied that the tool would also handle GRs, and that the software had been validated on both linear and non-linear models. It had been used on the Galileo models, which were non-linear.

M. Gorlani (Blue Engineering) assumed that the model was linearized at the beginning so that the tool could then handle it, and D. Pietrafesa confirmed this.

J. Etchells (ESA/ESTEC) commented that arithmetic nodes could not be added to the state vector, and wondered how the tool was able to handle their effect. D. Pietrafesa said that she did not know, and would need to ask colleagues.

B. Laine (ESA/ESTEC) asked about the linearization process, and whether there was a warning about being too far from the local state, and whether the temperatures would still be calculated correctly. D. Pietrafesa admitted that she did not know as she had not developed the tool.

1.8 ESATAN Thermal Modelling Suite — Product Developments & Demonstrations

C. Kirtley (ITP Engines UK) summarized the recent releases of ESATAN-TMS and described how the features that had been introduced were part of a roadmap defining the tool strategy, based on both feedback from users, and ITP's vision for an integrated modelling tool. He described some of the new features of ESATAN-TMS-r3, which was currently planned for release at the end of the month. H. Brouquet (ITP Engines UK) gave demonstrations of both the new features in the ESATAN-TMS Workbench, showing the import of finite element models, and the latest improvements to ThermNV. (See [appendix H](#))

L. Tentoni (Thales Alenia Space) commented that there had been mention of the finite element mesh, and wondered whether this meant a particular mesh for use with the lumped parameter model. He was also concerned about lumped parameter nodes connected to finite element nodes and wondered whether they continued to be finite element nodes once values were assigned in the Workbench. H. Brouquet assured him that if they had been imported as finite element nodes then they would continue to be finite element nodes. C. Kirtley said that they continued to be finite element nodes but the usual Workbench calculations were available on them so the user could post-process them.

H. Kneistler (Astrium Space Transportation) asked about the availability on 64-bit Windows platforms. H. Brouquet said that this was a major item on their "to do" list, but the problem was the availability of the GNU FORTRAN compiler on 64-bit Windows. ITP had been looking at another compiler, but they still favoured using the open source GNU compiler in order to keep the cost down for the users. He assured people that the 32-bit version would still work on 64-bit Windows machines. C. Kirtley said that ITP were doing their development on 64-bit machines. H. Brouquet said that they were not aware of any problems as long as the correct versions of Java, etc. were installed on the machine.

G. Sieber (Jena-Optronik) asked whether ITP had any test or experience of changing a lumped parameter model into a finite element model. H. Brouquet admitted that it would be possible to change the shell attributes from finite element to lumped parameter versions. He did not see any inherent problems as far as the software was concerned, but noted that the results would depend on whether the boundary conditions were applied to the corners of the mesh rather than the centre. He said that leaving the model as a finite element model would be much faster because there would be no need to run the automatic conductor generation as all of the node mesh would be congruent. H. Rathjen (Astrium GmbH) asked whether the new combined finite element model capability was related to ESATAN/TMG or the ESATAN export facility provided by IDEAS/TMG. H. Brouquet replied that there was no connection at all, and that using the new finite element capability did not require having IDEAS/TMG.

A. Jarrier (DOREA) asked how the user could import the CAD STEP file and then display the baseline geometry without the mesh. H. Brouquet said that in the demonstration he had shown how to import the model using the CADconverter. He stressed that the CADconverter was not a CAD viewer. The shapes were imported into ESATAN-TMS, and if the converter recognised a collection of shapes as equivalent to a primitive geometry shape, then those shapes could be converted.

S. Leroy (DOREA) asked whether to display the CAD model they had added polyline or b-spline element handling. C. Kirtley said that when the CADconverter recognised such a surface it would bring it in and re-mesh it as triangles. S. Leroy asked whether the CADconverter would handle high-level shapes such as a thick cylinder. H. Brouquet said that a thick cylinder would be imported as a cylinder and two disks, but that these would be thin shells.

P. Ferreira (Max Planck Institute) asked how the node numbering was handled during model import. What happened if the node numbers were already used? H. Brouquet said that the numbers would not conflict because the nodes were only given numbers when the model was assigned, or when the user redefined a shell and set or changed the node number explicitly. C. Kirtley said that the import process involved importing the CAD geometry and applying a mesh, not importing the node. P. Ferreira asked what happened if he needed a different node number per triangle: would he need to go through them one-by-one? H. Brouquet admitted that if the user wanted to impose a specific node number then they would have to do this manually.

H. Rathjen asked whether there was a limit to the size of CAD model that could be imported. H. Brouquet said that some CAD models were very large, and that was the reason for trying to display the model hierarchy, so that the user could import the CAD model bit-by-bit, and then simplify or impose the mesh for each submodel. He admitted that if the CAD model was made up of 500,000 triangles in a flat hierarchy then maybe it would be too big to import.

B. Laine (ESA/ESTEC) wondered about being able to go back to the original finite element model and apply the results calculated by `ESATAN-TMS`. What happened if the user simplified the mesh? Would there still be some traceability? H. Brouquet said that the `NASTRAN` converter would keep a mapping file so that when the results were sent to the mechanical engineer, they would still see the same node number. H. Brouquet said that if the model had been imported using the `CADconverter`, the user would need to turn off the shape recognition option in order to avoid simplification and to retain the original mapping. If the model had been imported from `NASTRAN` then the node numbers were retained. The software would keep a record of the state of the model when it had been imported, and the state of the model now, and so would output the original node numbers where possible.

M. Komarek (L.K. Engineering) asked how the radiative couplings were handled for the finite element mesh. H. Brouquet said that the radiative calculations were done on the shell, regardless of whether that shell had a finite element or a lumped parameter mesh. However, with a finite element mesh, the GR would be associated with the corners of the mesh, and with a lumped parameter mesh the GR would be associated with the centre. The radiative calculations were done on the geometry, not the mesh if the shape recognition was enabled. C. Kirtley said that the user could create user-defined conductive interfaces if conductors were not created automatically as a result of non-congruent meshes between shells.

1.9 SYSTEMA 4.3.4

M. Baucher (EADS Astrium) presented recent developments of the `SYSTEMA` framework, which now allowed thermal calculations to be run on CAD as well as thermal models, import and export of `STEP-TAS`, and extended simulation facilities for all planets in the Solar System. (See [appendix I](#))

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

1.10 THERMICA-THERMISOL 4.3.4

T. Soriano (EADS Astrium) described the new features in the latest release of THERMICA and THERMISOL, including multi-threading support for the ray-tracing, visualisation of the ray-tracing, a new approach to conductor generation, and changes to the multiple time-step algorithms. (See [appendix J](#))

M. Bernard (Astrium) wanted to know more about the management of the multiple time-steps, and asked when the \$VARIABLES2 block was run and therefore when the user had control of the execution again. T. Soriano said that the sub-timesteps were managed in exactly the same way as the main timesteps. Some nodes would not need recalculating for the sub-timesteps, and although they were really diffusive nodes, could be considered boundary nodes in the sub-timesteps. The same logic applied as usual, \$VARIABLES1 would be called at the start of the timestep, and \$VARIABLES2 at the end.

M. Bernard wanted more clarification. If he had a main timestep of 10s and sub-timesteps of 0.5s when would output be produced? T. Soriano said that \$VARIABLES2 could be written to produce output at the times chosen by the user. M. Bernard asked when the output was done: was it at the end of the main timestep or the sub-timestep? T. Soriano said that if the user specified to have output every 500s or 1000s then the output would be called at those times. There would always be synchronisation so that the main timestep coincided with the desired output times. M. Bernard wondered what would happen if he had some post-processing in \$VARIABLES2: would this be run every 10s or every 0.5s. T. Soriano answered that \$VARIABLES2 would be run every 0.5s, but it was possible to add a control variable so that parts of \$VARIABLES2 would only be handled as part of the main timestep.

J. Etchells (ESA/ESTEC) wondered about the ray-tracing on the CAD geometry, and asked whether this worked on NURBS or B-REP surfaces. T. Soriano said that the CAD geometry was imported "as-is" into SYSTEMA. He wasn't aware of any software system that displayed true curves and instead broke down such curves into small triangles for display. So THERMICA already had all of these small facets for the display of these shapes, and because of the improvements in the ray-tracing speed, could just use these small discretizations directly. J. Etchells commented that care would be required for specular surfaces. T. Soriano said that to handle specular surfaces the user should really change the CAD shape into one of the analytical shapes. This would give a better result, but there would still be a small error due to the stochastic nature of the ray-tracing.

B. Laine (ESA/ESTEC) asked whether THERMICA offered the new conductive coupling calculations by default, or whether the user could choose. T. Soriano said that the new conductive coupling calculation technique was the only method provided in SYSTEMA-v4. He said that it was very efficient, and was the only method he was aware of that had a mathematical proof and was consistent with the radiative calculations. He said that it also handled calculations on a non-compliant mesh without problems. The conductive couplings with a non-conformant mesh were well behaved, and mathematically proven. However, the new method was not yet fully implemented for all of the cutting surfaces at the moment.

1.11 TMRT

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

P. Zevenbergen (Dutch Space) asked whether the tool also included a means of renumbering nodes within a model. M. Bernard said that the user could specify a node-to-node reduction, and so the TMRT could be used for node renumbering, but it would be very inefficient. It would be far easier to simply edit the model, or use shell scripts. He said that the TMRT was used in e-Therm to provide a route from CORATHERM to ESATAN, so it was used in a non-reduction mode there.

M. Gorlani (Blue Engineering) asked whether it would be possible to have a trial version of the TMRT to understand how it worked and whether it could be used as part of existing tool chains. He was interested in looking at the compliance between temperatures and powers within detailed and reduced models. M. Bernard said that it might be possible, but would need to be discussed. T. Soriano (EADS Astrium) explained that there would only be a small fee (probably about € 500) to cover the costs of distribution, compiling, and basic support, but he thought that it would be possible to have it for a short term for free.

M. Gorlani said he did not think that it would be possible to use the TMRT as a black box tool, and that the user would need some understanding of the method before using it. M. Bernard said that not all of the users in Astrium were experts who understood the full mathematical details. He said that sometimes the reduced model produced was not as good as expected, and the user did not always know why, even though they knew that they should be able to do better. So M. Bernard agreed that it was better to know the theory behind the tool. He said a possible second phase of the project would be to produce guidelines on how to use the method, but he thought that it would take at least a year before there would be any progress in such an activity.

B. Benthem (Dutch Space) asked whether the TMRT was able to handle temperature dependent conduction. M. Bernard said that, no, unfortunately it could not. The tool took the set of conductances as a whole, and was only able to extract fixed literal values. So if the TMM needed temperature dependent couplings there would be a problem extracting them from the model. M. Bernard suggested that it might be possible to work round this by limiting the analysis to specific temperature cases, and then generating reduced models for each of the temperature cases. P. Zevenbergen asked about the use of the TMRT to determine the worst analysis cases. M. Bernard said that the TMRT could not know which steady state case it should use as the basis for the reduction. He suggested to use one reduced model for the expected hot case and another for the cold case. P. Zevenbergen wondered whether it would be possible to specify a temperature at the beginning and then let the tool choose accordingly.

B. Benthem asked what was required as input to the TMRT: a *.d file? MB replied that the TMRT required a *.d file, but with restrictions. The model could not make use of \$CONSTANTS parameters within the data blocks. Everything was extracted as literal values or expressions, so temperature or time dependent conductors and capacitances were not handled. The user might need to make a snapshot at given fixed values so that the TMRT could extract them from the model.

P. Ferreira (Max Planck Institute) asked how it was possible to guarantee temperatures and fluxes in the reduced model were within 10% of those of the detailed model. Or could this only be achieved by a process of trial and error? M. Bernard said that there was no easy way of predicting the quality of the reduced model, hence the need for guidelines. If you looked at the theory, there were ways of treating the differences between the detailed and reduced models. It was necessary to consider the hypothesis of proportionality. If you reduced an isothermal plate and one with gradients, then the reduced isothermal plate would radiate more and so you would need to raise the temperature of the average node to compensate. If you had both hot and cold zones in the node, you would need to transport more power into the hot zone. If there were groups where the gradient was limited, then the problem would be limited and the difference between the detailed

and reduced models would be minimized. He said it was important to have a detailed thermal map in order to decide how to group nodes for the reduction process.

O. Pin (ESA/ESTEC) said that the TMRT was an interesting tool. He recalled that last year there had been discussion with Astrium UK about providing TMRT training in Stevenage. He wondered whether T. Soriano could talk to S. Price (Astrium UK) whether that would still be possible, or even whether it would be possible to have such a training in ESTEC.

M. Bernard said that the TMRT was available on Solaris, on 32-bit Linux and Windows platforms, and also on 64-bit Linux. He advised people that it was better to have the 64-bit version when trying to reduce complex models.

O. Pin wondered whether M. Bernard could say anything about the testing of the TMRT, and give an idea about the time taken for model reduction. M. Bernard said that the TMRT validation had just ended, and had raised an issue requiring a late bug correction in the last few weeks. There had been a lot of validation on simple test cases, and some more complex industrial test cases had been used to measure CPU time. In Astrium, where they had models of telecom payload panels with more than 40000 nodes, the old in-house tools had needed more than 4 hours to produce the reduced model. With TMRT, Dorea and Thales had improved efficiency and memory usage, a 43000 node model could be reduced in 2.5 hours, although this was on a machine with a lot of memory and a large disk. The time to perform the model reduction on simpler models of 3000 nodes was about 20s.

Day 2

Wednesday 17th November 2010

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

F. Jouffroy (EADS Astrium) described the results of a partnership between the agencies, Astrium and Thales to produce a validated module for modelling loop heat pipes that could be included in both ESATAN and THERMICA. (See [appendix L](#))

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

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

G. Parot (CNES) presented an overview of the various sorts of balloon systems that CNES had developed for use in atmospheric monitoring, and the differences in the thermal environment compared to space. She described the analysis of the thermal control systems within the payload gondola, and the results of a recent balloon flight campaign in Antarctica. (See [appendix M](#))

T. Tirolien (ESA/ESTEC) wondered about the coupling with the power and accumulator model and asked whether the goal had been to model the behaviour depending on temperature, or to predict the temperature. G. Parot said that there was a power model and the thermal network and that they were coupled together. The main interest had been to know the charge on the batteries and accumulators for the predicted flight trajectory and duration. T. Tirolien asked whether the model had been provided by an external company, and was told that G. Parot had built it herself.

P. Ferreira (Max Planck Institute) said that the radiative environment was not the same as that of spacecraft in orbit and calculated by the space thermal tools. He asked how these additional non-orbital factors were handled. G. Parot said that it was necessary to calculate the factors based in the predicted trajectory. She used an Excel sheet for calculating various trajectory and related parameters such as the direct and diffuse solar flux, and other fluxes due to the different layers within the atmosphere. She felt that a proper tool needed to be developed for the calculation of the parameters relating to a given trajectory.

P. Ferreira noted that only one temperature had been used to describe the environment. G. Parot said that one temperature was used for the air temperature, and that the solar flux and view factors were taken into account.

P. Ferreira wondered about the worst case values that could be applied to all flights. Were there generic hot and cold cases, or did the worst cases differ for each trajectory? G. Parot said that it was difficult to define hot and cold cases, but she tried to define temperature margins for each trajectory by considering the solar fluxes, both direct and diffuse.

G. Sieber (Jena-Optronik) asked what inputs would be required for a thermal tool to calculate the boundary conditions. G. Parot said that the inputs would be elevation, latitude, time, and various things relating to clouds, such as the amount of cloud cover, altitude, type of cloud, and emissivity. The main outputs per trajectory would be the solar direct flux, and the diffuse flux, etc.

2.3 Thermal Concept Design Tool — 4th Year

M. Gorlani (Blue Engineering) described recent developments of the TCDT based on four years of use and feedback. The latest features include a material database, improved attitude handling and visualisation, better 3D viewer interactivity, and through-conductor calculations. (See [appendix N](#))

B. Benthem (Dutch Space) asked about the post-processing of results that had been shown. Were these results imported from another tool, or did the TCDT have its own solver? M. Gorlani explained that the TCDT simulation manager provided the means for geometry definition, mission definition, and thermal network definition, and then to run the analysis. The radiative and thermal analysis could be run using ESARAD and ESATAN if they were available. TCDT could generate the models, launch the software, and then import the results for post-processing within TCDT. For example, it was possible to show the temperatures and fluxes in both steady state and transient. The user could follow all of the procedures of the thermal analysis from within TCDT, but the user first needed to provide the configuration needed to run the external tools.

P. Ferreira (Max Planck Institute) asked about the requirements of the Windows and Excel versions, because he had tried to install the TCDT and had encountered some problems. M. Gorlani said that the TCDT had been designed to work with Office 2003.

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

J. Burkhardt (EADS Astrium) gave a brief overview of the requirements and mathematical background for frequency domain thermal analysis and the linearization of thermal networks, and presented screenshots showing the user interface to the TransFAST software. (See [appendix O](#))

B. Benthem (Dutch Space) asked what was the advantage of using TransFAST to extend the analysis into the time domain compared with standard ESATAN. J. Burkhardt said that the only advantage was the linearized system, so the solution should be faster. He noted that using analytical models made it easier to linearize the system and improve the speed. B. Benthem asked whether the main advantage was the CPU time required. J. Burkhardt said that there was a big improvement in CPU time.

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

S. Lapensée (ESA/ESTEC) described some of the challenges involved with modelling the Martian thermal environment, and how flight data from previous missions could be used to validate some of the model assumptions. (See [appendix P](#))

M. Bernard (Astrium) asked whether S. Lapensée had found many correlation parameters on the model that could be improved, or was it more related to the environment. S. Lapensée said that for this mission, they had taken the environment and applied it to the spacecraft. They had needed to add variations to the surface finish due to the different levels of dust during the mission. They had assumed a fixed wind speed of 4m/s and had imposed the wind effect on the model. They had tried not to tweak the model.

M. Bernard said that they appeared to have achieved comparable results to the previous mission data. S. Lapensée said that some of the results were close to what had been achieved in the ground tests. The problem with the ground correlation was the lack of vacuum correlation because the lidar was not qualified to work in a total vacuum. The model predicted a temperature gradient across the structure, but the ground test did not show this due to convection effects. They had been reduced to hand calculations to confirm the results.

J. Etchells (ESA/ESTEC) commented on the lidar test and the effect of natural convection. He recalled the presentation by A. Quinn (Astrium UK)¹ at a previous workshop that had highlighted the Grashof number. S. Lapensée said that he was aware of that work, and said that it had not been possible to re-orient the lidar during the test because of the need for shooting through the chamber window. In the hand calculation for natural convection it is possible to show that it should occur under 1G on Earth, but the 0.3G of Mars was the threshold value of whether there would be natural convection or not.

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

J. Etchells (ESA/ESTEC) described the Large Solar Simulator test chamber at ESTEC and the requirements for the Bepi-Colombo testing. The mirror and lamp system of the LSS had been modified to produce a convergent light beam, giving 10 solar constants at the centre of the chamber. Innovative changes had been introduced to the ESARAD model of the chamber to produce the correct beam characteristics. (See [appendix Q](#))

P. Ferreira (Max Planck Institute) wondered why there was such a noticeable asymmetry in the solar beam calculated in the model when this was not shown in the actual measurements from the LSS. J. Etchells said that the real LSS had a number of discrete lamps shining on a mirror consisting of approximately 50 petals, so the variations in the measured beam intensity were due to individual lamp and petal alignment effects. The ESARAD model of the LSS used real geometric shapes, but the rotation of the chamber relative to the axis of the parabola introduced an asymmetry.

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

2.7 Workshop Close

H. Rooijackers (ESA/ESTEC) thanked everyone for coming, and gave special thanks to all of the people who had given presentations. He hoped to see everyone again at the next workshop.

Before finally closing the workshop, H. Rooijackers asked whether anybody had any comments about what they would like to see in the future.

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