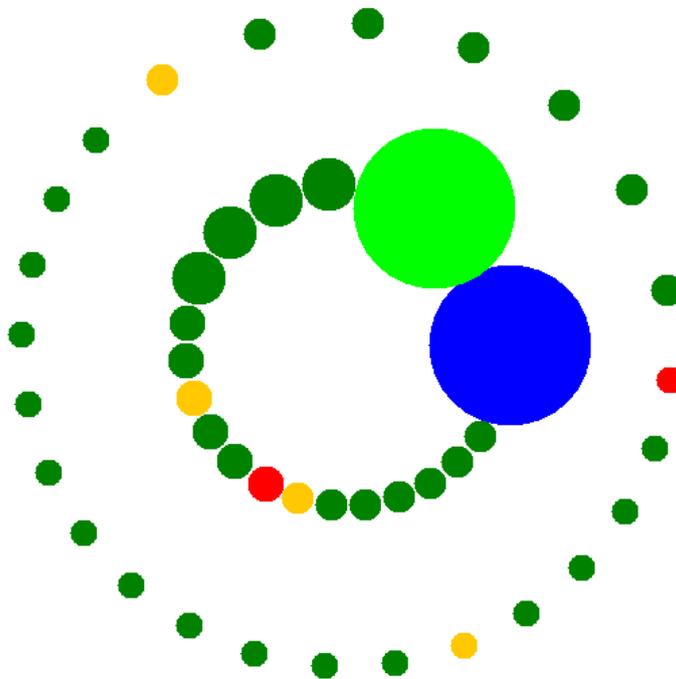Proceedings of the

25th European Workshop

on

Thermal and ECLS Software

ESA/ESTEC, Noordwijk, The Netherlands

8–9 November 2011

credits: National Aerospace Laboratory (NLR) - The Netherlands

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Abstract

This document contains the minutes of the 25th European Workshop on Thermal and ECLS Software held at ESA/ESTEC, Noordwijk, The Netherlands on 8–9 November 2011. 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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Opening address

Good morning Ladies and Gentlemen.

On behalf of the European Space Agency I have the honour and pleasure to address the audience of the 25th European Workshop on Thermal and ECLS Software, here at ESTEC.

I would like to express a warm welcome to all participants coming from various ESA Member States and beyond.

It is fair to mention that the European Workshop on Thermal and ECLS Software is one of the longest running workshops at ESA. It was started as "The ESATAN Workshop" by, the now retired, Mr Charles Stroom in 1985 to introduce the ESATAN space thermal analysis tool to the European thermal community as a replacement for SINDA, and to exchange information between users and developers. This first workshop was attended by 38 participants.

The second workshop was held in 1987 and called "ESATAN Users Meeting". Since then the workshop has been taking place every year and already from the early days it was intended that this event will serve the exchange of information between users. The scope of the workshop has significantly evolved over the years, as ESA's approach to the thermal tools also evolved.

In these 25 events we have had more than 470 presentations and almost 1500 registered participants, some of them attending almost all workshops. Over 70 participants have registered for the present workshop, and confirm the continuous value and use of this workshop to the space thermal community.

The objectives of this workshop are:

- to promote the exchange of views and experiences amongst the users of European and worldwide space thermal analysis tools and related methods

- to provide a forum for contact between end users and software developers

- to present new features of thermal tools and solicit feedback for development

- to present innovative advancements

- to address standardisation activities.

This year's workshop program consists of 22 presentations covering recent developments of thermal analysis tools and methods used by the thermal space community. The presentations cover a wide range of topics, and we are particularly happy to see in this Workshop many colleagues from industry, research institutes, universities, national agencies and thermal analysis tool developers.

Engineering tools are evolving rapidly where the keywords include integration of the workflow, reducing time and effort to build a model from CAD and process the results, multiphysics approaches, concurrent design engineering, model verification and model exchange. These important aspects are addressed in the various presentations.

This 2011 edition might be appropriately called "the user's perspective" since many of the presentations come from users of the various tools. It continues to be a particularly important aspect of this workshop to acquire feedback from the users.
This workshop takes place in a difficult economic period. The financial constraints are affecting not only some of our programs, but also led to various limitations affecting travel budgets in most companies, universities and research institutes. Therefore I especially thank you all for your attendance here today and your participation in this workshop. It demonstrates the importance and continuous interest by the space community in the development and application of space thermal analysis methods and related software.

A very special "thank you" to all colleagues who have contributed in organising this workshop and in particular I would like to thank Mr Rooijackers who has been the main organiser of many of these workshops.

This evening you are all invited by ESA to the welcome drink, which will take place in the Foyer.

For me it is a real pleasure and honour to address such distinguished participants and to declare open the 25th European Workshop on Thermal and ECLS Software here at ESTEC. I would like you to feel at home, and I hope you will find this event both enjoyable and rewarding. I now want to hand over to my colleague Mr Harrie Rooijackers, the main organiser of the workshop, who will provide you with some details on the logistics.

Dr C. Stavrinidis
Head of the Mechanical Engineering Department, TEC- M.

Day 1

Tuesday 8th November 2011

1.1 Welcome and introduction

H. Rooijackers (ESA/ESTEC) welcomed everybody and quickly ran through the main goals of the workshop and various logistical points, such as the Workshop dinner that evening. (See appendix A)

1.2 Thermal Analysis for Re-entry Vehicles — Ablative tool integration in ESATAN

S. de Palo (Thales Alenia Space) presented the work done by his colleagues to create a new tool, integrated with ESATAN, for representing ablative thermal protection systems using a 1D finite volume model. The design of the new tool had used the lessons learnt from a previous tool, `AblaTherm`, so that the results could be much more easily integrated into the `ESATAN` model. (See appendix B)

J. Persson (ESA/ESTEC) asked about the reference cases which had been used: one had used NORCOAT for EXOMARS, but NORCOAT was also used by various launchers. He wondered whether they had considered using a launcher as a reference case. S. de Palo replied that they had not been looking at the material itself but had been focusing on the analysis process. The reference cases had used NORCOAT and AVCOAT but it was important to be able to use the analysis process for any ablative material, and to have a simple way of providing input. S. de Palo said that they had found the `ABLAT` software to be very complex to use due to the input data required. The new tool had been designed to simplify the effort needed to build the model.

G. Chirulli (ESA/ESTEC) asked how many components could be modelled using the Arrhenius Law, because the NASA CMA software had some limits. S. de Palo said that there were three components, so it was similar to the NASA CMA. G. Chirulli asked how the blocking factor was handled: did the user need to give a number? S. de Palo said that the blocking factor was computed by the software. The formulas to describe the physics of blocking were quite complicated. There were pages of equations required to calculate the values. The software took into account the blocking in the pyrolysis cases. The assumption was that any gas produced was instantaneously transferred outside the porous material. This assumption was OK if the material was highly porous: if not porous, then the flow needed to be computed in order not to over-estimate any blocking effects due to trapping of the gas within the system.

G. Chirulli commented that the analysis therefore assumed a certain atmosphere around the

vehicle, in this case the calculations were for Mars, which had a different atmosphere to Earth. He said that the data for the Earth's atmosphere should also be available, and he expected the reaction to be different. S. de Palo said that the data had been collected from the EXOMARS colleagues, and he didn't know the real details about the atmospheric data that had been collected. He could answer any further questions on the boundary modelling by email.

G. Chirulli asked whether it was foreseen to extend the modelling to include swelling of the material layers. S. de Palo didn't think so.

1.3 The Use of ESATAN-TMS r3 software for Ray Tracing Visualisation

R. Speight (Astrium UK) described using the `ESATAN-TMS` r3 feature for displaying the rays striking a particular face during the solar flux ray tracing calculations as part of a design study for the solar array yoke on Sentinel 3. (See appendix C)

H. Isik (Turkish Aerospace Industries) asked about the different specular and diffuse reflectivity values that had been used. R. Speight said that it was possible to create different optical properties in the geometric model. H. Isik continued by saying that each surface had specific reflectivity, absorptivity and emissivity values, and wondered whether the results had been derived from existing materials, or whether the results were from using totally specular and totally diffuse values. R. Speight said that the first analysis shown in the presentation had used fully specular materials on the solar array yoke, and the second had been fully diffuse.

P. Ferreira (Max Planck Institute) asked whether the analysis had been made for a single inclination of the solar array, or for many. R. Speight said that only one orientation had been chosen because this was part of the early analysis phase. The inclination corresponded to the worst case at the closest approach to the Sun.

J. Persson (ESA/ESTEC) wondered whether a method like this would also be useful to see the heat transfer in a molecular regime in a rarefied gas. He could see different applications of this technique. R. Speight said that she did not know about that, and suggested that he talk to ITP directly.

1.4 First year using ESATAN-TMS — A newcomer's reflections

E. Jones (STFC/RAL) presented his experiences of using the `ESATAN-TMS Workbench` after having previously worked with commercial CAD software tools. (See appendix D)

S. de Palo (Thales Alenia Space) commented that he had described his experiences of `FHTS` at a workshop more than 10 years previously, and that he always hoped to see new developments on `FHTS`. He would be interested to see a similar presentation on `FHTS` now.

S. de Palo was curious to know whether E. Jones had taken advantage of the experience of colleagues, and training from ITP, or whether he had started to learn `ESATAN-TMS` from scratch on his own. E. Jones said that his manager had taken him through the use of `ESATAN-TMS`, but had shown him how to use `ESARAD` and `ESATAN` as separate tools. His use of the `Workbench` had come from the `ESATAN-TMS` training course that he had attended in February, and by studying the manual and tutorials. A lot of the details of the GUI he had had to work out on his own. He found it strange that different people in the same department worked in different ways to use the same programs.

H. Rooijackers (ESA/ESTEC) asked whether he had been using the GUI only, or whether he also made use of the batch mode tools. E. Jones said that he had mainly used the GUI, but the MIRI film modelling had already been created by pure coding in the ".erg" and ".d" files, and so for MIRI he had used the batch processes. Initially he had found it difficult to take an established split `ESARAD` and `ESATAN` work flow and implement it in one integrated `Workbench` session.

G. Sieber (Jena-Optronik) asked about the post-processing of results and whether he had used `ThermNV` or the internal `Workbench` visualisation. E. Jones said that in general he had written his results to a CSV file so that he could use Excel. The post-processing for mapping temperature results onto the geometry had been done in the `Workbench`. Some of the ray-tracing and heat load analysis had been done in the `Workbench`, but plotting temperatures had been done in Excel.

1.5 Application of ESATAP for automatic thermal model validation

SA. Kuhlmann (OHB) described the implementation of `ESATAP` components for calculating some overall model properties in order to provide a first check before detailed model verification. (See appendix E)

A. Fagot (DOREA) thanked SA. Kuhlmann for working with the beta version of `ESATAP` and for looking at some of the new functionality. He said that the evaluation shown in the presentation had been completed only shortly before the workshop, and that the initial versions of these new `ESATAP` components had only printed the results to the window. The latest versions of these components now gave better formatted output in HTML, or as CSV files for inclusion in Excel. He said that there would be more improvements to the components before the final version was released.

> B. Laine (ESA/ESTEC) took this opportunity to say something about a current activity on thermal model verification. This is described in the next section.

P. Ferreira (Max Planck Institute) asked whether it had taken SA. Kuhlmann a long time to become acquainted with `ESATAP`. SA. Kuhlmann said that `ESATAP` provided a tool box of components, and the basic drag and drop way to build a tool layout was quite easy. However he had initially found it tricky to set the specifications within the components correctly, when in fact usually only one or two of the fields needed to be filled. `ESATAP` was divided into parts. He had used the super-user GUI where the user could combine tasks, and create new ones, but this only really needed to be done once. After that, all that was needed was to just use the list of tasks, click to select and connect them, and then click on the "run" button to start the model validation task. This activity had shown that if a company wanted to set up a standard set of checks on all of its models it could do so, and then it was possible to click a button to see if the models were OK.

T. Soriano (EADS Astrium) commented that many ordinary users would have difficulties to define the tasks themselves, and wondered whether it would be possible to set up an open source system to share simple tasks of interest to everybody, and to allow people to comment and offer corrections.

A. Fagot said that all components that had been created for `ESATAP` were already shared as they were included in each release. The ESA development had provided tasks that would be useful to everyone, and could be used by everyone. If a company wanted a specific task creating, they could pay to have their own task developed.

A. Fagot said that the expert or super user mode in `ESATAP` for developing tasks was complicated, but once a task had been created and finalised, it was easy for an ordinary user to launch the task. `ESATAP` would ask simple questions about the inputs required. Each task that had been validated

had a wizard, a sort of GUI, to call it in simple mode. Most end users would work with components in simple mode.

B. Laine wanted to go back to the question about sharing tasks and the model verification work. He asked what checks should be done as part of the model verification. He said all ideas would be welcome. If specific model checks already existed in industry, ESA could capitalise on them and get them implemented as part of the contract with DOREA.

1.6   ESA Internal Activity on Thermal Model Verification

B. Laine (ESA/ESTEC) took the opportunity to say something about a current ESA activity on thermal model verification, and which would be discussed further in the NESTA meeting. He pointed out the white papers on the walls which were "mind maps" of the various topics under consideration. He also said that there was a draft paper on Thermal Model Validation and Verification available for comment on the table, (see appendix X) and he invited people to browse through them and add comments. He suggested people add their initials so that they could be consulted afterwards if clarifications were needed. He said that it would be useful if input from company guidelines could be shared too. All input would be welcome. The goal was to have thermal model verification documents that were useful to the whole community.

B. Laine then brought everyone's attention to the other posters which promoted the different facilities available within the Mechanical Systems Laboratory at ESTEC, and asked people to come and see him if there were any tests which the MSL could do for them.

1.7   ESATAP 2.1.0 evolutions and implementation of new User's requirements

M. Bernard (Astrium) described a series of feature requests that ASTRIUM had proposed for `ESATAP`, and A. Fagot (DOREA) described how these has been realised in the latest beta version currently under test at ASTRIUM. (See appendix F)

Someone asked whether there was a user manual and whether `ESATAP` was user friendly. A. Fagot said that there was a user manual with a lot of exercises. The exercises had initially been created for expert mode and were therefore complex, but the new user manual had been rewritten for ordinary thermal users calling tasks via the wizards. He said that anyone wanting to develop tasks could always talk to DOREA. All of the simple tasks and predefined components were already available to everyone and were covered in the user manual.

A. Fagot said that to make it easier for end-users, the new version had involved some re-engineering of `ESATAP` to re-manage tasks to avoid changes to too many links. It was now possible to run `ESATAN` or `THERMISOL` and generate CSV output, and read it into `ESATAP`, and then re-run and re-import the data without changing the task.

1.8   Thermal Model Reduction using the Super-Face Concept

L. Masson (University of Liége) described work on reducing computation time by creating super-faces from finite element models using the METIS algorithm and then using either numerical integration or ray tracing to calculate the view factors. (See appendix G)

S. Leroy (DOREA) asked whether this technique applied only to the radiative part of the thermal model, or whether it included the conductive part as well. L. Masson said that the technique was

only applied to the radiative part, although Open Engineering had proposed a method to ESA to have a sort of thermal super-element to provide model reduction in the conductive part. The work shown only handled the radiative part, but in future he could imagine linking together the two reduction models.

T. Soriano (EADS Astrium) noted that the reduction had focused on view-factors, and was interested to know whether the method would also handle multi-reflection and specularity. L. Masson said that it was not possible at the moment because they had only looked at the numerical integration part so far. It would be possible in the future with the ray-tracing part.

M. Bernard (Astrium) was concerned about the irregular shapes produced and wondered whether it was possible to configure the super-face mesher to give more regular shapes, or to limit the aspect ratio. He said that after the geometrical model reduction the user might want to provide the reduced model containing just the usual simple shapes. L. Masson said that the software currently used the METIS algorithm without any changes, and that this gave irregular shapes. If the software could know that the faces in a plane were regular shapes, then maybe it would be possible to customise the algorithm to give regular super-faces too. He explained that what had been presented was just the start of the research in this area.

1.9   Wavelength-selective filters in ESATAN-TMS

P. Ferreira (Max Planck Institute) described the problems encountered when trying to model instruments on Solar Orbiter that had wavelength dependent optical coatings. (See appendix H)
T. Thiebert (University of Liége) asked whether it would have been possible to couple the thermal analysis with an optical ray-tracing software tool and use an iterative approach, with absorption and reflection handled in one tool, and then applying the heat fluxes in the other model. This would also allow other optical properties to be modelled, such as the refractive index of the glass. P. Ferreira said that he had not thought of using such an iterative approach, and didn't know anyone running any optical software tools. He was familiar with `ESATAN-TMS`, and anyway he had needed to model the instruments in orbit and allow for the finite size of the Sun. Using optical software would remove the solar calculation from the `ESATAN-TMS` analysis.

1.10   ESATAN Thermal Modelling Suite — Product Developments

C. Kirtley (ITP Engines UK) described the time-line of the recent developments leading to the release of `ESATAN-TMS` r4 and how these related to the customer requirements. (See appendix I)
S. Leroy (DOREA) asked about the geometry import from CAD models and wanted to know whether the format of the .erg and .d files had changed. C. Kirtley said that the .d file format had not changed.
J. Etchells (ESA/ESTEC) wondered about the new axi-symmetric geometry features and asked whether radiation exchange was handled. C. Kirtley said that it was not.

1.11   ESATAN Thermal Modelling Suite — A New User Interface for CAD Geometry

H. Brouquet (ITP Engines UK) gave a live demonstration of `CADbench`, the new GUI for actively visualising, selecting and manipulating parts of a finite element CAD model prior to conversion and import into the `ESATAN-TMS Workbench`. (See appendix J)

S. Price (Astrium UK) asked whether `CADbench` would be available on all of the platforms on which `ESATAN-TMS` was supported. H. Brouquet said that `CADbench` would only be available on PC because it made use of Microsoft technology. S. Price asked whether it would be possible to connect it to a Linux installation of `ESATAN-TMS`. H. Brouquet said that `CADbench` used the same path variables, and could therefore read from or write into a file system shared between both the PC and Linux systems. H. Rooijackers (ESA/ESTEC) asked whether ITP had tried to run `CADbench` under the Wine emulator for Windows on Linux. H. Brouquet said that they had not tried.

H. Rathjen (Astrium GmbH) asked what `CADbench` did with non-regular shapes that did not fit into one of the standard geometric primitives. H. Brouquet said that it would try to recognise the shapes as best it could, otherwise it would mesh them using triangles. H. Rathjen asked whether it was possible to recognise an ellipsoid and convert it to an approximation using cones or spheres. H. Brouquet said that the user could bring the triangle mesh for the complex shape into the `Workbench` and pick ranges of points from the triangles to re-create the cones or whatever the user wanted. H. Brouquet said that what was important in R4 were the new methods for creating shells using points. It was not always possible to convert complex shapes, but the user could make the most of the points available on the triangles and rectangles to re-create the shells that they wanted.

G. Sieber (Jena-Optronik) said that `CADbench` looked to be a nice tool for importing the STEP files from the designers and converting from 3D to 2D shapes. He had immediately asked himself whether the process could be used the other way round. He asked whether it could also be used to reverse the mapping, in order to put temperature results on the 3D CAD model to give back to the structural tools. H. Brouquet said that `CADbench` currently allowed one way conversion from CAD or STEP [AP-203 and AP-204] into `ESATAN-TMS`. `CADbench` was a new product, and ITP would try to improve it in the future. H. Brouquet said that if the geometry was imported into `ESATAN-TMS` as a finite element geometry, then the temperatures could be exported and passed back to the structural engineers via a temperature mapping file. He said that `CADbench` filled the gap for importing from CAD into `ESATAN-TMS`. If users wanted specific features, then they should ask.

J. Etchells (ESA/ESTEC) went back to the process of de-featuring, which would be useful to remove feed-through holes on tanks, etc. and asked whether this relied on the feature tree in the CAD model, or was simply based on shape recognition. He wanted to know whether the CAD user had to structure the CAD model in a particular way to allow the feature recognition in `CADbench`. H. Brouquet said that `CADbench` worked on what was displayed. The de-featuring only worked on the shapes that were displayed. The export worked in the same way, so the user could control what was exported by only displaying those parts which needed to be exported. The user could therefore create a specific component by selecting and displaying just the parts of interest from the CAD hierarchy.

J. Etchells asked which CAD formats were handled by `CADbench`. H. Brouquet showed the formats available on the Save-As menu, which included AutoCAD, STEP, IGES, Rhino, Sketchup and SpaceClaim. He said that if the model were saved in SpaceClaim format, this was the native tool format, and so it could be written without conversion to another tool format, which made it much quicker.

G. Jahn (Astrium GmbH) asked whether it was possible to save a history file in `CADbench`. H. Brouquet admitted that he did not know, as he was not fully trained in the tool. He thought that there might be a log file, and therefore it might be possible to re-use this somehow.

1.12 Prototype demonstration of Thermal Design Module for automated design and temperature calculation of space harness

R. van Benthem (NLR) described how techniques used for designing cable harnesses for the aircraft industry had been applied to the space environment, and how analysis had shown that the standard requirements to limit overheating may be too strict. (See appendix K)

P. Poinas (ESA/ESTEC) had a question about the graph showing relaxation of the ECSS requirements. R. van Benthem clarified that he was not asking for a relaxation, but suggested that it could be a possibility.

P. Poinas asked whether this was the result of an iteration of the model. If you removed convection, this left only radiation. Did this lead to a better temperature? R. van Benthem said they applied a rating factor. The basis was the current in vacuum to give a certain temperature, and then they applied a rating factor when using the same cable in a bundle. If the same cable were used in air then the rating factor would be different. P. Poinas then understood that the rating factor applied to a single cable compared to a cable in a bundle, so they had been looking at the radiation of a single cable compared to the radiation of a bundle. R. van Benthem said that radiation related mainly to the surface area, but if convection was involved there were more factors that came into play.

P. Poinas asked whether the difference was related to the way of measuring the temperature in the cable. He could see that there was a need to validate the Thermal Design Module, and that it had not been possible to see the details, but how had they modelled the conduction and convection in and around the cables? How had they performed the measurements? Based on temperature, or based on dissipation? R. van Benthem said that they had performed an extensive test campaign, in a test facility, using different bundles. The model had then been tuned using the test results. The model had started as an aircraft model with the convection and air conduction taken out in order to model space. However, they had only tested at low pressure and not vacuum.

P. Poinas still wanted to know how they had done the measurements. R. van Benthem said that they measured a lot of things such as the current and the power loss in the cables, and they had used a lot of thermo-couples. The sample bundle was 0.8m long and was the same through the complete section. They had also used pressure sensors. P. Poinas asked about the diameter of the thermo-couples and the dimensions of the wires. R. van Benthem said that they had used the smallest thermo-couples that they could find. These were 40 gauge thermo-couples, and were very thin, and did not affect the test.

JB. Meurisse (Sodern) observed that the test had assumed that the power dissipation in the cable was the same and that the whole system was homogeneous. He wondered about the connectors, as these might dissipate more power. R. van Benthem said that they had only considered the cables. The test took into account the change in resistance due to the change in temperature as part of the power dissipation.

1.13 SYSTEMA-4.5.0

M. Jolliet (Astrium) presented some improvements in SYSTEMA to provide a scripting interface so that models and meshes could be programmed in Python; changes to the 3D modelling and rendering; and the introduction of a mission time-line tool. (See appendix L)

M. Bernard (Astrium) asked whether the Python scripts could be executed on their own, outside of SYSTEMA. M. Jolliet said that the scripts could be run from within SYSTEMA, or from the batch

mode of SYSTEMA. M. Bernard wondered whether the script feature could be used by another software tool to provide a translator from that tool into a THERMICA model directly without having to launch the SYSTEMA user interface. M. Jolliet said that it would be possible to use another tool, and from it generate a Python script to create the model in SYSTEMA, and then use the SYSTEMA command line mode to execute the script just generated and to create and import the model into SYSTEMA.

H. Rooijackers (ESA/ESTEC) asked whether the Python module was fully integrated in the SYSTEMA release or whether it was limited in some way. M. Jolliet said that the complete Python would be delivered with SYSTEMA. It was fully integrated, so it was possible to use all of the standard Python modules from within SYSTEMA.

1.14 THERMICA-THERMISOL 4.5.0

T. Soriano (EADS Astrium) presented developments within THERMICA and THERMISOL, to include non-grey body modelling for multi-spectral analysis; a means of identifying and handling edges; and improvements to the generation of conductors for shape-to-shape couplings. (See appendix M)

JB. Meurisse (Sodern) asked about the grey body and wavelength dependent modelling. The slides had shown emissivity, and specularity, but he wanted to know whether wavelength dependent transmissivity was also taken into account. T. Soriano said that the wavelength dependent properties were not limited to emissivity. All of the infra-red properties could be wavelength dependent.

1.15 Spatial Infra-red Objective thermal analysis

JB. Meurisse (Sodern) described the problems inherent in modelling the thermal gradient in the lenses of an infra-red objective where the wavelength dependent properties of the the lenses needed to be taken into account, and the techniques used to do this in NX 7.5. (See appendix N)

R. Nadalini (Active Space Technologies) asked how they expected to be able to validate the model and all of the assumptions made. JB. Meurisse said that they planned to do a small experimental validation, using a simple case with the equipment in front of a cold plate. They would then measure the structural gradient, as this would be representative of the actual heat flux emitted from the equipment to the cold plate. If the gradient in the structure was calculated correctly then they could assume that the method was validated. They could not measure the temperature of a lens directly because it made no sense to put thermo-couples on it.

R. Nadalini asked whether they had thought of using thermal imaging. JB. Meurisse said they had not used thermal imaging. They had thought that because the spectral wavelength limits of the lenses meant that the lenses would absorb and filter some of the infra-rad radiation, affecting any thermal image of the structure, it would not be possible to use infra-red imaging. [1]

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[1]There were new techniques which used software to analyse the actual radiation received in the un-filtered part of the spectrum and then used Wien's displacement law to reconstruct the probable radiation in the missing part of the spectrum to create a representative thermal image.

Day 2

Wednesday 9th November 2011

2.1 STAR-CCM+ for Complex CAE Design Problems

A. Davoodi (CD-adapco) gave a brief history of the company, and then I. Greig (CD-adapco) described the capabilities of `STAR-CCM+` and its application in continuous multi-physics simulations, and showed how it had been used to model heat flow in battery cells and in the passenger cabin of an aircraft. (See appendix O)

M. Molina (POLIMI) asked whether the software could model phase change materials. I. Greig said that they did have some melting and other phase change examples but that these were proprietary models, and that he could not distribute them. They did have tools for circuit board level analysis.

M. Molina asked whether they could handle capillary phenomena, with multi-phase materials, such as a loop heat pipe. I. Greig said they could, but that the problem was one of fidelity. It would probably take a powerful desktop machine a whole day or two to do a steady state analysis depending on how many loops were required, the number of heat exchanges, the number of times through the phase change calculations, etc. The user would probably need to restrict the model: a rough guide would be 1Gb for every million cells.

S. de Palo (Thales Alenia Space) asked whether it was possible to mix 3D modelling with 2D and 1D modelling. `STAR-CCM+` did not have its own coupling API at the moment so there was no nice way to couple tools at the socket level that was accessible to the users. I. Greig said that the next version would provide an API so that `STAR-CCM+` would be open at the socket to allow the exchange of data back and forth between tools. At the moment what `STAR-CCM+` did was to use Java macros to save data to files on hard disk, exchanging data that way and sharing it between codes. It was easy to couple one `STAR-CCM+` model with another, as had been shown in the cabin airflow example.

J. Etchells (ESA/ESTEC) asked whether `STAR-CCM+` supported MPCCI or similar technology for exchange of data between tools. I. Greig said that the examples shown had used Java macros to achieve the exchange. `STAR-CCM+` did have a socket-based coupling with `ABAQUS` which did not use MPCCI. Obviously MPCCI was a generic code, and could theoretically be used to access `STAR-CCM+` in the same way as accessing other tools. There was no restriction; `STAR-CCM+` had not said "no" to the use of MPCCI.

H. Rooijackers (ESA/ESTEC) asked whether the software was only available on Windows. Was it available on both 32- and 64-bit systems? I. Greig said that it was available on both 32- and 64-bit Windows system, and also on Linux systems such as Red Hat Enterprise, OpenSUSE and CentOS, but it was less well tested on Linux.

2.2 Multi-Physics Simulation Technology in NX

C. Ruel (MAYA) presented features of NX that allowed multi-discipline analysis, particularly in the thermal and structural areas where thermal deformation of the structure might change the contact heat paths through the structure. (See appendix P)

J. Persson (ESA/ESTEC) wondered whether the coupling between the CFD and thermal analysis also handled two phase systems. C. Ruel said that two phase systems were not supported.

G. Sieber (Jena-Optronik) asked whether thermal radiation analysis was supported. C. Ruel said that it was and that NX could also calculate solar, albedo and infra-red planet fluxes if required.

2.3 Thermal Correlation of BepiColombo MOSIF 10 Solar Constants Simulation Test

S. de Palo (Thales Alenia Space) described two approaches to correlating the results of the MOSIF thermal balance test held at ESTEC in November 2010 and the results from the thermal mathematical model: the first applied rules from a TAS-I internal procedure, and the second applied stochastic techniques and the iSight software. (See appendix Q)

M. Loche (ESA/ESTEC) asked whether they had considered using STORM. S. de Palo said that STORM did not work any more. They had used it for stochastic optimisation in the past so they were able to compare the performance of the algorithm. The first part involved a reduction of the range for optimisation followed by a refinement using the Simplex method. STORM was no longer sold, and there had always been difficulties in setting up the problems to be optimised. The iSight software offered multi-physics interactions and it was much easier to interface to Excel, Matlab and other tools used in-house.

M. Loche asked whether they had found any benefit for the final results: had the second phase gained any benefit from the first phase work? S. de Palo said that the correlation of the next tests for BepiColombo would use the optimisations to speed up the standard approach. M. Loche asked whether the next test would use both methods. S. de Palo said that the activity had given them an idea of what to optimise.

M. Molina (POLIMI) asked whether the software provided a confidence level in the results that had been identified. S. de Palo replied that it was possible to get any output from iSight that the user wanted. With most output it had to be exported to file, but with the appropriate licence it was possible to view the results via a web interface.

M. Molina commented that he had noticed effective emittance values with four significant figures. He wondered who or what was choosing how many digits to consider, and how this related to the accuracy of the actual temperatures being measured in the LSS during the test. S. de Palo said that this was a good question, but that he would need to ask his colleagues in Turin for the answer.

B. Laine (ESA/ESTEC) commented that in the model of the spacecraft in the LSS, there was more than just the geometry of the beam to consider, like, for instance, the homogeneity of the beam. He said that several models of the beam had been produced in ESTEC. S. de Palo agreed that the model of the LSS could be refined further.

B. Laine asked whether there had been any change in the emissivity between the phases. S. de Palo said that, as far as he knew, only one emissivity was used for the phases. B. Laine was concerned that there could be a change in optical properties under such high illumination. S. de Palo said that there had been discussions in-house about such changes, but he was not aware of the current status.

2.4   Lessons Learned on Modelling of Cryogenic Systems

M. Branco (ESA/ESTEC) described some of the issues that had been encountered when modelling a compact cryostat where the temperatures of the complete chain varied from 300 K to 2 K. (See appendix R)

C. Kirtley (ITP Engines UK) asked whether it would be possible to provide the models to the ITP support group. He was interested in the convergence problems and wanted to see if they could solve the issues raised. M. Branco said that he would provide the model.

C. Kirtley asked about the problem when setting TABS equal to zero: did this cause the solver to crash? M. Branco said that the solver crashed. H. Brouquet (ITP Engines UK) asked whether he had tried to use the new `SOLVCG` instead of `SOLVFM`. M. Branco said that he had not tried `SOLVCG`.

2.5   Model reduction of Sentinel 1

D. Kintea (ESA/ESTEC) described some experiences of trying to apply the Thermal Model Reduction Tool to create a reduced model of the payload module panels of Sentinel-1. (See appendix S)

During the presentation he asked whether anyone could guess why the results from the reduced model were not as close to those of the detailed model as expected. M. Loche (ESA/ESTEC) commented that the meshing of the inner panel of the reduced model did not match that of the detailed model. D. Kintea said that that was not a problem because the `TMRT` would generate non-physical conductors that were still mathematically correct.

M. Bernard (Astrium) said that he had been involved in the development of `TMRT` and his advice was to take the positions of the components into account based on the temperature hot and cold spots. D. Kintea said that this would mean that the reduction would be less effective so he had been obliged to keep more nodes. M. Bernard also suggested that the internal radiative fluxes were negligible, so the model could have been reduced to have only one node on the inside. D. Kintea said that he needed more nodes on the inside to take equipment dissipation into account. M. Bernard argued that this could be handled via the `TMRT` and anyway was not dependent on the meshing on the inside layer of the panel. The radiator powers were the conditioning conductors on the panels. There was no need to group everything into 1K banded groups. D. Kintea said that he had tried this as well. His strategy was based on the proximity of nodes. However, this was not the reason for the temperature difference.

D. Kintea stated that the temperature difference between the detailed and reduced models was due to the snapshot of the detailed thermal mathematical model used as input to the `TMRT`. There had been no power dissipation in the DTMM in the snapshot used, but there was dissipation on this node in the reduced model analysis.

At the end of the presentation S. Husnain (RST Aerospace) asked about the analysis case shown on slide 14. Did it involve a repeating orbit? He wondered about the repeatability of the start and end temperatures, because they appeared to be different. D. Kintea admitted that maybe the criteria for convergence had not been low enough, leading to different temperatures.

S. Husnain was interested in the integration of such a reduced model in the launcher analysis, and asked about the format produced by the reduction. D. Kintea reassured him that the model stayed in the same format, but simply had fewer nodes, and maybe more conductors, so integration was not a problem.

M. Gorlani (Blue Engineering) asked whether the reduced model was only applicable for the one particular case shown in the presentation, or whether it could be used for different thermal cases. D. Kintea said that he had only tried the reduction for one case, but it should be applicable for other cases as well.

M. Gorlani had understood that, for this thermal case, at the end of the loop the reduced model was not within the initial requirements. He asked whether the model needed to be changed if the requirements were not met at the end of the loop, or whether more loops should be run. What he understood was that the loop always had to start again from the beginning: the user could not work on the model at the end of the loop because there was no physical meaning in the conductors, so the user had to create a new snapshot and start again. D. Kintea confirmed that the reduced model was only a mathematical construct, so it was hard to see the physical links in it. As a result, if the initial requirements were not met, the user needed to change the reduction and start over again.

M. Molina (POLIMI) asked about the heaters. The slides had shown a 5% discrepancy between the complete and reduced models. How was the heater power defined in the reduced model? Was it the average, or the peak power? He would expect to choose a sampling rate such that all of the duty cycle effects were averaged out. If the sampling was on a subscale of the duty cycle it was possible to get temperatures that were too hot or too cold and not representative of the average. D. Kintea said that the thermostats were kept in the reduced model, but the dissipations were evaluated at a certain point in time, and if the dissipations are really time dependent this would, of course, lead to deviations. It would be possible to take the average values, but he had not done so. M. Molina summarised that the reduced model had used the peak nominal power dissipations for the heaters, rather than the average. He expected that the deviation would have been closer using the average.

M. Bernard asked whether, after the corrections for the first iteration, there had been any analysis to find the reason for the deviation? D. Kintea repeated that the temperature deviation had been due to the DTMM snapshot that had been used as input.

M. Bernard had some comments on the extended work flow diagram. From the TMRT reduced model output file, it appeared that D. Kintea had only considered using the reduced node definition and the reduced conductor list. Had he considered using the power distribution command lines in ESATAN in order to implement the varying thermal dissipations and heating powers directly in the reduced model? D. Kintea said that he had only looked at the redistribution for the heating power. M. Bernard said that this would have avoided having different disspiations for the DTMM run and the RTMM run.

M. Bernard had a comment on the generation of the snapshot. Yes, it was necessary to remove the time and temperature dependencies on the conductors. It would have been possible to use the power distribution feature in the TMRT and then validate the comparison of the DTMM and RTMM results for each snapshot. Examining the external flux or heat flow through the conductors would have allowed validation of the stabilised case.

M. Bernard understood the need for going further with orbital analysis to include the orbital GRs and external fluxes in the RTMM and that this had to be done outside of the TMRT. But he said it would have been possible to validate the reduction process itself by comparing results from thermally stabilized cases with constant external GRs and external heat fluxes. This would then have given an idea of the performance of the reduced model on a stabilised case, and then allowed further work on the orbital analysis.

2.6 Validation of a Method to transfer Heat Transfer Coefficents from a Computational Fluid Dynamics Simulation to a Lumped Parameter Thermal Mathematical Model

L. Hagemann (Astrium Space Transportation) described the problem of convective heat flow in a cavity within the upper stage of the Ariane V launcher with a forced flow of inert gas; an experimental test set up to investigate the flow and heat transfer; and the coupling of the CFD simulation in `FLUENT` with `ESATAN`. (See appendix T)

P. Poinas (ESA/ESTEC) observed that the presentation had shown a comparison of temperatures, but not the results in terms of the heat transfer coefficients, which he felt were more important. He wanted to know what was the lesson learnt from this activity. He could see that the CFD could simplify a given calculation, but everything had to be redone each time, and the shape function was not the same. What had been learnt? Was the simple vertical plate model that had been used in the past still valid? L. Hagemann said that the investigation had been deliberately directed at a typical cavity with one hot and one cold wall. Most cavities were similar. The heat transfer coefficients were very robust. The example shown had contained a wide range of temperatures. The heat transfer coefficient had been extracted for the 310 K case.

P. Poinas said that he understood what had been done, but felt that what was missing from the presentation was what was new that had been learnt from this analysis. He had been involved in a review for Ariane V five years previously, where this problem already existed, and the recommendation had been to perform a CFD analysis and then to derive the heat transfer coefficient from the CFD calculation. He wanted to know what was the conclusion from the current analysis. Did it provide a good simulation and agreement with what existed before, which was horizontal, with Grashof-Prandtl, natural convection and so on, or were the results very different. Were these models different from those presented five years ago? L. Hagemann said that the CFD calculations were now very good, and he had shown that there were no errors in the method. He said that the results depended on the flow in the CFD tool. P. Poinas said that what had been presented was the correlation of the heat transfer coefficients, which were then entered into `ESATAN`. He wanted to know the values of those heat transfer coefficients. L. Hagemann said that they were between 5 and 6 $W\ m^{-2}\ K^{-1}$.

L. Fusade (Astrium Space Transportation) commented that these heat transfer coefficients had been compared with results derived from classical and analytical sources. L. Hagemann said that the results had been compared with those from other programmes, such as Ariane V/ESC-A.

P. Poinas asked whether they had used CFD because there had been a problem with the previous correlation or the empirical formula. L. Hagemann replied that this work had been an exercise to show that the empirical formula was good. There had been no major discrepancy between the measured temperature and the temperature calculated by the simulation using `ESATAN` and the old formula.

L. Fusade said that the objective was always to improve the analysis models being used. He admitted that this work had looked at a cavity with a relatively simple shape, where it was easy to apply a formula, but the objective was to deal with far more complex cavities, particularly in cryogenic areas, local effects, etc. and to be able to predict and assess the temperature gradients in the structure. He admitted that the question from P. Poinas was justified, but this work had been needed to validate the method in order to deal with more complex cases.

L. Fusade said that there were many other cavities on the Ariane V upper stage. There were six or seven between the stages, the frames and the rear bulkhead, and so on. The idea was to improve the modelling of these cavities. Up to now it had been sufficient to give a simple empirical formula

to describe the cavity based on models with bulk nodes. The objective had been to optimise the structure and to have more confidence in the assessment of temperatures. The analysis had been related to the design of the structure and whether it would be possible to remove some of the thermal protection. For more complex cavities, or for long duration missions, or for the ballistic flight phase of the Ariane V it would be necessary to master all of the basic cases. Calculating the temperatures within the launchers was therefore very important.

H. Rathjen (Astrium GmbH) commented that the analysis had related to a very particular configuration, with felt insulation and a liner between the cavity and the tank. There was gas in the felt, so it was possible to have convective flow in the cavity, and heat transfer to the cold tank. Therefore there was additional uncertainty and this made it difficult to correlate. He said that they really needed an extra test without this felt layer in order to correlate the model.

2.7 Evaluation of stochastic & statistic methods for spacecraft thermal analysis

JP. Dudon (Thales Alenia Space) described an activity looking at the different options of stochastic, heuristic and meta-modelling techniques, and the use of the OPTIMUS tool, to help with optimisation and sensitivity analysis. (See appendix U)

T. Soriano (EADS Astrium) asked whether the approach could handle complex models. How many nodes or surfaces could be handled? JP. Dudon said that the RSM was correlated with respect to the response of the model. It used the usual model, with inputs for the algorithm, and the expected responses, and then created a best fit of the responses using an analytical formula, which could be stochastic or deterministic. The size of the model only impacted the time to design the inputs.

T. Soriano asked how many parameters, conductors, emissivities, etc. had been handled so far. JP. Dudon said that the process was as shown: the more parameters there were, the more simulations were required in order to create a high quality RSM. The number of simulations depended also on the type of the RSM. Typically when using a least squares RSM, a polynomial RSM, there were no parameters to fit in the code, but it was necessary to perform a certain number of experiments. The number of experiments required, or simulations in this case, effectively depended on the number of inputs. There were different types of design of experiments, which were more or less costly. Therefore the cost of generating a high quality RSM depended on the number of inputs, and the design of the experiments.

M. Molina (POLIMI) asked about the source of the parameter distributions in the 10-parameter study shown. JP. Dudon said that the source was from an ESA study performed by Blue Engineering. M. Molina said that the study was back in 2004, and was surprised that there had been no further work on the distribution of the parameters. JP. Dudon said that was not the purpose of this study, and he had been confident in the results of the previous study that had been presented at the 2004 Workshop by M. Gorlani (Blue Engineering).

M. Molina asked about the validation of the meta-model: did it rely on the DOE tool or some independent method? JP. Dudon said that they referred to the DOE, derived the RSM, and then replayed the optimal point found. If the result differed by more than $0.5°C$ then it was necessary to add a point and start again. This was an iterative method and therefore a bit heavy. The EGO used in the RSM was powerful, and was self-adaptive during the optimisation process. Therefore the user could have confidence in the result.

M. Gorlani said the presentation had been interesting. It was the first work he had seen that had looked at tackling the drawbacks highlighted by the ESA/Blue study in 2004. He wondered

whether there were plans to address these further. JP. Dudon said that the work on these two test cases had shown that it was possible to gain time. There was a plan to roll out the tool in Cannes and at CNES, and to test the method in their analysis processes.

S. Dolce (ESA/ESTEC) said that the ECSS standards called for requirements on test predictions using sensitivity analysis. The stochastic analysis technique looked interesting, but introduced a potential change in the standard. He wondered, therefore, whether it would be necessary for the standards to change to allow either a classical analysis with margins, or stochastic analysis with probability. He asked the audience what they felt was the long term perspective. JP. Dudon answered that this was not the first work that had been done in the European thermal community on the stochastic approach, and that the community had started to have a view on the use of stochastics for simulation, for meta-modelling, and genetic algorithms, and he felt that it would be a good idea if these ideas were also visible in the standards. S. Dolce said that the current ECSS standards stated that whenever there was an analysis, there was also an uncertainty in the analysis, and the level of uncertainty had to be determined by sensitivity analysis. The standard could be changed to instead say to do the sensitivity analysis and/or a stochastic analysis to define the probability of being within the design range. B. Laine (ESA/ESTEC) felt that one did not necessarily replace the other. It was one way of doing the sensitivity analysis. It was just another tool to help with the sensitivity analysis rather than doing it all by hand. It was not necessarily a choice of using just one method or the other. He felt that the approaches were complementary.

JP. Dudon said that the engineer could use the sensitivity analysis to get a first feeling for the model, and then use iSight or OPTIMUS to check which parameters were important and to give a complementary deeper knowledge of behaviour of the model. B. Laine said that stochastic methods were just another tool to help choose the parameters in a more systematic way. JP. Dudon said it was another tool to help facilitate the design exploration.

L. Fusade (Astrium Space Transportation) said that ECSS did not require specific methods to calculate uncertainty margins. S. Dolce said that sensitivity analysis was there so that the engineer could say that he or she had looked at certain parameters, and had verified them during the thermal balance test results and that therefore the engineer had reduced the uncertainty. In the stochastic analysis case, the results could be used to check the probability. The classical approach involves evolution: check the model against the thermal balance test, and then reduce the uncertainty values. Both methods could be used to help improve the uncertainty levels in specific areas. He felt that the stochastic method provided a good alternative but did not replace the classical approach. JP. Dudon thought it would be a good idea to start to introduce the stochastic approach into the ECSS: not to replace the existing one, but to complement it.

M. Gorlani argued that the new stochastic methods did not provide any requirements on the uncertainties. He felt that what M. Molina had said was important: there was a need to know the uncertainty distributions of certain parameters in order to define the design margins. JP. Dudon admitted that knowing what to add to the results to handle any modelling error was not taken into account in the stochastic approach.

2.8   The ESATAN-TMS Finite Element Analysis Method — User Experiences

G. Sieber (Jena-Optronik) described using the relatively new features in `ESATAN-TMS` for importing Finite Element geometry and how working with such a finite element model differed from the traditional lumped parameter approach. (See appendix V)

S. Husnain (RST Aerospace) said that in the geometry model shown the electronic components had not really been visible. Did that mean that the dissipations of the electronic components had been distributed to the geometric model of the plates? G. Sieber explained that he had modelled the dissipations using non-geometric nodes and then creating links between those nodes and the plate. This was a little different to the lumped parameter modelling where one node was explicitly connected to another node using its node number. He said that the finite element geometry introduced a lot of nodes, and the easiest way to work with them was to identify an area on the panel for the footprint of the component and then create a group of faces corresponding to that area by picking, add the dissipation between the non-geometric node and the group, and not to worry about the explicit node numbering of the finite element geometry parts.

S. Husnain asked about the definition of the conductance between the electronic components and the plate, where there might be fillers between the unit and the panel. G. Sieber had handled electronic units in a similar way. He was no longer sure exactly what he had done, but thought that all he had done was to use the dissipation of the electronic box and apply it to the appropriate area of the panel. He did not think that they had defined explicit conductance.

T. Soriano (EADS Astrium) felt that this approach neglected the radiative aspects of the equipment. G. Sieber admitted that he had only modelled direct dissipation for the electronic components and had not handled the radiative effects. The baffle involved radiative effects for the orbit case, but the electronic components only involved conduction.

JB. Meurisse (Sodern) asked why `ESATAN-TMS` had been used for this sort of analysis. G. Sieber said that it was the standard tool used in Jena, and that it was required by ESA. There was never any time to investigate or learn new tools that could have been more appropriate. He had tried to keep using the new features of the tool in the best way possible for the analysis.

2.9   Thermal Concept Design Tool — 5th Year

M. Gorlani (Blue Engineering) described how the development of the main features of the `TCDT` had been completed, and how the latest capabilities, demonstrated by A. Tosetto (Blue Engineering), had been added at the request of users. (See appendix W)

M. Molina (POLIMI) asked about the long term plan for the maintenance: how long would ESA support the `TCDT`, or would there be a charge for using the tool? M. Gorlani said that the current maintenance contract would end next March, due to the timing of the frame contract. After that, there would need to be some discussions to see what would happen in the future.

B. Laine (ESA/ESTEC) said that plans for the `TCDT` would depend on how much use people will make of it, and this would be discussed at the NESTA meeting after the workshop. Blue Engineering currently promoted the `TCDT`, and were responsible for training, but if the community did not want to use the tool, then ESA would need to think again. He stressed that user feedback was therefore very valuable to ESA.

P. Poinas (ESA/ESTEC) said that he had been encouraging people to use the `TCDT`. He had already been using it for a long time, but he would be going to the hands-on `TCDT` training session being held that afternoon after the Workshop anyway to learn about using the new features, especially the model import. He said that the `TCDT` was very good for quick sensitivity analysis.

P. Poinas then asked how the `TCDT` handled any Boolean surfaces when importing geometry models from `ESARAD`. A. Tosetto said that Boolean surfaces were imported, and had a suffix added to the label to show the sense of the cutting surface, but they were only displayed as normal surfaces. However, when the geometry was exported, any such cutting surfaces were interpreted and output correctly. P. Poinas wondered what happened when the imported geometry contained

a cutting operation such as $c = a - b$; and how would the `TCDT` show it? A. Tosetto explained that the `TCDT` would show the shells with labels with a suffix denoting the cutting sense, such as *a* and *b_minus* . Both shells would be displayed in their original, uncut, form by the viewer.

A. Uygur (Turkish Aerospace Industries) asked whether the `TCDT` could be used to create new geometry, or whether the geometry had to be imported. M. Gorlani said that the `TCDT` had always been able to create new geometry, but now had added features for importing and exporting geometry.

P. Ferreira (Max Planck Institute) asked how to convince someone to use the `TCDT`. It looked very good, but even using `ESATAN` for small analysis could be very quick. The question was how to sell the `TCDT` to someone who didn't know it very well. M. Gorlani answered that he was not at the workshop to sell the `TCDT`, but to provide information on its features. It was in Blue Engineering's interest for the `TCDT` to continue. He was involved in thermal analysis and design, and Blue Engineering used the `TCDT` internally.

M. Gorlani said that there would be a `TCDT` training course later in the day, so people would be able to see what it could do. It would be possible for new features to be added to the tool, but that would require a budget from somewhere. He said that the `TCDT` had not been designed to be used everywhere that `ESARAD` and `ESATAN` could be used, but was intended to be used for fast analysis and fast creation of small models. There were lots of features of the thermal calculator which had not been shown, but which allowed the user to make analytical calculation inferences in order to help prepare the model. He recommended that people followed the training course later in order to get a better feel for the tool.

C. Theroude (Astrium Satellites) had difficulties to understand how the `TCDT` was positioned relative to the more detailed analysis tools. On the one hand it was presented as simple, but it seemed that every year new functionality was included and it was developing into an ever more complex tool. There was a difference between simple and detailed analysis, but he felt that where the `TCDT` was going was not clear. M. Gorlani said that the first four years of maintenance Blue Engineering had added functionality that had been identified at the end of the first year by a survey of users, where they were also asked to give priorities to new functionalities. During the last year they, along with ESA, had decided to add the import/export features in order to close the functionality. He felt it would be interesting to have a new survey to understand what the users would still like to have.

F. Bodendieck (OHB) commented that the `TCDT` was not really a stand-alone tool as it required the user to have `ESATAN-TMS`. He wondered how it would work with the latest release of `ESATAN-TMS` r4. M. Gorlani said that the `TCDT` had no solver of its own, so it relied on the user also having `ESATAN-TMS` installed. He said that all of the `TCDT` testing had been done using the last version of `ESATAN-TMS`. F. Bodendieck wondered whether the `TCDT` was really a free tool because there was the cost of the `ESATAN-TMS` licence.

F. Bodendieck asked what was the advantage of using the `TCDT` over a simple Excel model? P. Poinas wanted to answer that point. He said that from the ESA side he had seen lots of input for design studies from industry provided via Excel sheets, which therefore confirmed that a lot of initial design was done with Excel and simple tools. The `TCDT` allowed everyone to use something that was more advanced, more standard, and not hand-made, on-purpose and specific to each design. The engineer could do the initial design using the `TCDT` and then export it and refine the model in `ESARAD` and `ESATAN`. The big advantage of the `TCDT` is the level of integration and validation of the features, and also the fact that the user could work very quickly with the Excel sheet. The `TCDT` was useful for pre-design and start of a design. The image of the ISS model in the `TCDT` was certainly impressive, but once all of the couplings were taken into account, the

`TCDT` would be too slow for real analysis work. His experience was that once the model went beyond 40 nodes the `TCDT` was no longer easy to use. P. Poinas also felt that Blue Engineering should not have to answer questions about the position of the `TCDT` compared to the other thermal tools. He felt that the users should determine for themselves when it was appropriate to use the `TCDT` in their analysis chain.

B. Laine emphasised that the `TCDT` had been developed as a tool for use in the Concurrent Design Facility at ESTEC, and there was a need to promote the `TCDT` with those users. It was an early design tool for use in the ESTEC CDF, but as he knew of several companies with their own CDF, he could see that the `TCDT` could also be useful in a company CDF.

2.10   Workshop Close

H. Rooijackers (ESA/ESTEC) said that there had been a lot of interesting presentations about different applications of both old and new tools. He wanted to thank all of the authors and presenters, especially the new and young presenters, whose contributions were very valuable, and to all the participants for their questions and discussions, as these were what made the Workshop come alive. It had been a pleasure to organise this Workshop. He hoped to see everyone at the Workshop next year.