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15th European Workshop on

Thermal and ECLS Software

ESTEC, Noordwijk, The Netherlands

9-10 October 2001

ABSTRACT

This document contains the minutes of the Fifteenth European Thermal and ECLS Software Workshop held at ESTEC, Noordwijk, The Netherlands on the 9th and 10th October 2001. 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 related documents.

Table 1: Printing History

Release	Date of issue	Reason
1.0	2001-10-29	Document creation
1.1	2001-11-23	Incorporated internal comments

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ESTEC, Noordwijk, The Netherlands
9th-10th October 2001

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1. Tuesday 9th October: Morning Session

1.1. Welcome and Introduction

O. Pin (ESTEC) welcomed everyone to the workshop, and said that he appreciated the effort that people had made in coming, in spite of recent international events[1]. He described the aims and structure of the workshop. (See Appendix A)

He explained that the workshop was intended to have three main purposes:

- allow an exchange of views on the use of thermal analysis software
- provide a forum for contact between the developers and the users
- present new versions of the software and get feedback from the users

He introduced the teams from ESTEC and Alstom.

He explained the change in the format of the workshop away from presentations only to having mornings dedicated to such presentations, with more informal software demonstrations in the afternoons. The round table discussion would move to the end of the first day rather than the end of the workshop when many people had to rush for flights. Topics for discussion had derived from questionnaire answers received prior to the workshop.

He informed everyone that 5 PCs had been set up at the back of the room, each with a different software tool, and people were encouraged to play with the tools and ask for demonstrations and help as appropriate.

He reminded everyone about the ICES conference in 2002, and that the deadline for the receipt of abstracts had almost arrived.

1.2. Managing the Interface between ThermXL and ESARAD

A. Robson (Astrium-UK) presented details of working with both ESARAD and ThermXL and the requirements and problems of transferring information between the two. (See Appendix B)

F. du Laurens (Alstom) noted that the presentation had involved the use of ThermXL version 1.0. He said that ThermXL version 2.0 would be demonstrated later in the day, and this version did have an ESATAN file export facility. O. Pin (ESTEC) said the ESATAN export facility provided a static view of the nodes. It was not possible to export the time and temperature formula for each conductor, so it was difficult to model variable conductors. However, the software would highlight any areas where there might be problems with the conversion. F. du Laurens said that ThermXL version 2.0 was now undergoing final testing, and would be available shortly.

O. Pin said that one of the current ESARAD developments was an export facility so that data

1. The attack on the World Trade Center in New York on the 11th September 2001.

could be imported into tools such as ThermXL. A work package to import such files into ThermXL was currently being defined.

P. Poinas (ESTEC) asked whether there was an ESATAN import facility. He felt that ThermXL was a tool for local analysis, and he didn't see any point in exporting a 10-node model to ESATAN, but he could see the need for extracting a set of nodes from an ESATAN file. A. Robson said that the main reason to improve the interface between the tools was the move from the quick design sizing analysis, where the model tended to develop quickly, but then it was difficult to convert from ThermXL to ESATAN. O. Pin said that he took P. Poinas' point and that ESTEC would look into the matter.

O. Pin asked whether anyone else had used ThermXL. M. Molina (Carlo Gavazzi Space) said that he had tried, but had been unable to run it. O. Pin asked whether the PC was configured with an Italian environment, with comma as the decimal separator, but M. Molina said that the PC was configured with the UK environment. E. Cosson (EADS) said he had used it, but had experienced slight problems. O. Pin reminded everyone that there was a known problem of using a comma as the decimal separator for those machines with non-UK settings. S. Kasper (Jena-Optronik) said that he had been using ThermXL without any problems.

1.3. An Introduction to G-DELTAN V3 - An Interactive Thermal Analysis Tool

C. Williamson (Eutelsat) described the development of a simple thermal analysis tool which interpreted the input data and which didn't require a compilation stage. He also gave a demonstration of the tool. (See Appendix C)

P. van Leijenhorst (Fokker Space) asked whether it was possible to use G-DELTAN to perform a complete thermal analysis without plotting any data, and then plot the areas of interest afterwards. C. Williamson said that it was. P. van Leijenhorst asked whether the whole of the analysis could be saved for use at a later time. C. Williamson said it was, and that all data could be saved to disk, including the text.

O. Pin (ESTEC) asked why there was a 500 node limit. C. Williamson answered that it as a relatively arbitrary limit, although he had found that the software became less and less efficient as the arrays became larger. The solver ignored unused node numbers in the input.

J. Persson (ESTEC) asked whether it was possible to generate conductors in the nodal breakdown when using the autogen function. C. Williamson said that it was possible for simple shapes. J. Persson asked which shapes were supported. C. Williamson said that for nodes and conductors the supported shapes were rectangles, cylinders, disks, fins and loops.

O. Pin asked whether it was transparent what algorithms were used. C. Williamson said that the user entered the properties for the nodes, and then the software used a simple iteration technique rather than a specific algorithm.

O. Pin asked whether it was possible to have a variable conductor depending on the temperature when using autogen. C. Williamson said that it was not possible when using autogen, but it was possible elsewhere.

M. Molina (Carlo Gavazzi Space) asked what was the suggested size of model which could be handled by the software. He realized that there was a limit of 500 nodes, but wanted to what number was best. C. Williamson admitted that he didn’t have any empirical data on this, but would guess that 300 nodes probably the optimum number.

M. Molina asked why the software had been developed when MINITAN had already been available. C. Williamson said that he now had a role as a customer rather than a sub-contractor, and often needed to do simple analysis. O. Pin felt that G-DELTAN was not really like MINITAN. It was more like ThermXL because it provided real-time plotting capabilities. C. Williamson admitted that it was possible to do a lot of things using Excel, but felt that the overhead of using Excel made any analysis slow.

M. Molina asked what plans there were for distribution of the software once the beta testing had been completed. C. Williamson answered that there were no definite plans at the moment. M. Molina asked whether it would be possible to distribute the software outside the company. C. Williamson said that it would be possible because it was his software.

P. Poinas (ESTEC) asked whether there had been any comparison of the speed of G-DELTAN compared to ESATAN. C. Williamson said that you had to be careful in making any such comparison. ESATAN was optimised for larger models. G-DELTAN wasn’t intended to replace ESATAN. G-DELTAN was intended to be a tool for quick analysis. There was a hole between using hand calculations and using ESATAN. G-DELTAN was a head-start into filling this hole.

P. Poinas asked whether it wouldn’t be possible to reduce ESATAN run times by reducing the sizes of the arrays used. C. Williamson felt that he could not really comment on ESATAN. G-DELTAN could use small arrays because it was intended for small models. O. Pin said that ESATAN runs involved a lot of overhead. A lot of checking had to be done because, for example, the user could switch on nodes in each iteration. All of this checking took time. He admitted that the ESATAN solvers where old, and agreed that there might be a need to look at whether more modern solvers and software techniques might be better and faster.

P. Poinas asked whether there had been any research into the time problems in ESATAN. O. Pin said that a lot of the time could be accounted for in the VARIABLES1 block handling. This had been discovered during the work with CNES into the FHTS solvers. Initially it was thought that the new solver routines were the source of the problem, but the time was actually taken in the service routines which are used to check the various properties. What was true for the FHTS solver probably applied to a certain extent to the ESATAN solvers.

C. Williamson said that ESATAN loses when using small models because of the additional overhead involved in pre-processing the model and generating and compiling the Fortran.

1.4. Improving Ray-Tracing Algorithms for Monte-Carlo Simulations.

B. Shaughnessy (RAL) presented some ideas on using discrete probability functions to determine the path of rays after multi-reflections. (See Appendix D)

HP. de Koning (ESTEC) asked whether B. Shaughnessy was aware of the extended view factors in ESARAD. These had certain similarities to the presentation in that they combined incident and specular behaviour. B. Shaughnessy had looked into using the Markov chain of transition probabilities and matrix algebra.

P. Renard (Astrium-SAS) asked whether the accuracy of the results was dependant on the meshing. B. Shaughnessy said that it was, but noted that so far he had only studied simple geometries. He didn’t yet know whether the algorithm would scale to handle more complex geometries. If it didn’t work with more complex geometries, then he would be forced to drop this approach.

1.5. New Ray-Tracing Technique for THERMICA

M. Jacquiau (Astrium-SAS) described improvements to the ray-tracing used in THERMICA to make use of oct-trees and other techniques. (See Appendix E)

HP. de Koning (ESTEC) asked whether the oct-tree algorithm started with a cube or with a rectangular block. M. Jacquiau answered that they used a rectangular block, and used voxels of the same ratio.

F. du Laurens (Alstom) wondered about how well the model was encapsulated in the voxel space. He asked about the voxel breakdown for an unmeshed sphere. M. Jacquiau said that at the surface of the sphere there would be a lot of small voxels. During initialization the sphere would be meshed, but voxels were only required for the surface. It was possible to tune the initial meshing.

O. Pin (ESTEC) asked about the number of levels of voxels in the oct-tree. M. Jacquiau said that the oct-tree typically went down to between 6 and 8 levels, but for pathological cases the oct-tree could have more levels, even 20. However, it wasn’t usually possible to have too many levels for the whole model, so more levels were only usually used for specific small areas such as electronic equipment. O. Pin asked about the criteria which were used. When there were empty voxels? How was it possible to stop the increase in levels? M. Jacquiau said that the recursion usually stopped when the voxel was empty, but it was also possible to limit the levels by stopping when there were just 2 or 3 surfaces in the voxel.

1.6. Report on TFAWS and Introduction to ThermPlot

HP. de Koning (ESTEC) described the TFAWS workshop and highlighted the interesting developments. He went on to describe ThermPlot, a utility written by Hume Peabody of Swales, and presented at TFAWS. (See Appendix F)

B. Shaughnessy (RAL) asked about the maximum size of ESATAN file which could be handled by ThermPlot. O. Pin (ESTEC) said that he had been able to process a 16Mb ESATAN output file for METOP corresponding to a transient case. HP. de Koning said that the model contained about 1200 nodes.

O. Pin admitted that processing the ESATAN output files did take time. It was usually better to work with binary data files rather than parsing ASCII files. He said that it took 3 hours to process the ESATAN output file for METOP in order to obtain the heat balances. This was on a system with a 400 MHz Pentium 3 processor with 128 Mb of memory. M. Molina (Carlo Gavazzi Space) asked how big the ESATAN output and Excel files had been. O. Pin said that the ESATAN output file for this particular METOP model was 16Mb. This file contained heat balance data rather than temperature data.The Excel file produced from this by ThermPlot was 10Mb. However the size of the files would vary on a case by case basis. If the user created a large number of plots, or a plot involving a large number of nodes, then the resulting Excel file could become much larger.

O. Pin asked whether anyone would be interested in using ThermPlot. It was a free tool, and could be downloaded from the Swales Web site. This was a first but still limited answer to the recurrent need for a post-processing tool. He said that Hume Peabody was very enthusiastic, and was very responsive to problem reports. He stressed that the ESATAN side of ThermPlot was still in being tested. E. Cosson (EADS) and two others said that they were interested. O. Pin said that in any event, various people at ESTEC would experiment in using ThermPlot.

K.Caire (Alcatel) asked whether ThermPlot also had an interface for TMG. HP. de Koning said Hume Peabody was working on providing a TMG interface, but he was working single-handed. HP. de Koning said that ThermPlot was a nice initiative, but it depended on a single person. The software was free, but there were also no guarantees about its future.

2. Tuesday 9th October: Afternoon Session

2.1. Artifis/Topic/ThermXL

F. du Laurens (Alstom) described the use of three light weight tools for early design studies, and demonstrated Artifis and Topic. He said he would demonstrate ThermXL after the session to anyone interested. (See Appendix G)

O. Pin (ESTEC) asked whether anyone had used the version of Artifis that had been included on the ESARAD 4.2 CD. A. Robson (Astrium-UK) said that he had tested it, but had not actually used it. He agreed that it was very quick.

J. Persson (ESTEC) asked whether it would be possible to extend the Topic demonstration to use the STK file as input. F. du Laurens said that he didn’t have STK installed on the PC, but it would be possible to use the STK compatible file which had been generated during the previous run of Topic. All that was needed was to remove the initial comment line from the file.

O. Pin asked whether the data could be easily imported into Excel. F. du Laurens said that it was possible, and users could also create and Excel macro to extract data.

O. Pin said that Artifis and Topic had been distributed on the ESARAD 4.2 CDROM, and asked how people could access the tools now. F. du Laurens said that it would be possible to include them with the next version of ESARAD, if there was sufficient demand, and if it was OK with ESA. It might then be possible to incorporate D.Gibson's speed improvements.

P. van Leijenhorst (Fokker Space) noted that the user could see the percentage of eclipse per orbit, but asked whether it was possible to see the complete duration of eclipse during the whole mission. F. du Laurens said that the user would currently need to set the mission time step to be the same as the orbital period, and then sum the relevant columns of data in a tool such as Excel.

K.Caire (Alcatel) was interested in the Low Earth Orbit capabilities, and specifically wanted to compute the orbital drift. F. du Laurens said that Topic could handle J2 perturbations to the standard Keplerian orbits, so the orbit precession could be taken into account.

T.Basset (Alcatel) asked whether Artifis and Topic handled yaw steering in the attitude control. F. du Laurens said that Artifis and Topic used the so-called “Euler angles” just as in ESARAD 3.2. The user had to fix the attitude at the start of the run using these Euler angles. HP. de Koning (ESTEC) said that it wasn't currently possible to do yaw steering. The user could not change the attitude of the geometry within an orbit. This could be one possible extension of the tools.

The discussion went on to the presentation of ThermXL by H. Brouquet (Alstom).

O. Pin said that in the new version of ThermXL the user could call the solvers from Visual Basic, so it was now possible to do parameter runs by using Visual Basic to generate the parameters and then call the solvers. O. Pin stressed that any model which had been built in ThermXL 1.0 would still be valid in ThermXL 2.0.

V. Perotto (Alenia) remarked that ThermXL could calculate the heat flux for each node, and asked whether it was also possible to calculate the sink temperature. O. Pin said that this was a good idea in principle, but asked what V. Perotto meant by sink temperature. The question of sink temperatures had been raised at previous workshops, but there had never been complete agreement on the definition.

O. Pin said that there had been a demo version of ThermXL 1.0 which allowed a maximum of 21 nodes. ThermXL 2.0 would probably be released in a commercial version only, with no demo version, but it would only cost 1000 euros (i.e. 2 days of engineer time).

2.2. Stochastic Approach to Spacecraft Thermal Control Subsystem

F. Lamela (CASA) described a stochastic method of performing thermal analysis, to identify the critical parameters in a spacecraft thermal design, for example. (See Appendix H)

C. Williamson (Eutelsat) asked about the calculation of the variation of parameters for MLI. F. Lamela said that in order to decide the interval for the normal distribution used for the parameters, it was necessary to negotiate with the designers of the other parts if possible, but there was not really any distribution law which could be applied to satellite components. For the

MLI they had used a normal distribution. For dependant variables, the software would accept any formula, so the user could specify a logarithmic law for example, but user was free to use a normal distribution, or whatever made sense. The software offered a “calculator” panel to allow the user to input the formula used to calculate the variable dependency. He stressed that user often had to push to get information about the other subsystems to use as input.

C. Williamson asked how the stochastic approach affected systematic errors. F. Lamela said that the user did not need to assume that there would be systematic errors. The software used Monte Carlo methods and the sampling used a combination of data. C. Williamson asked about pure calculation errors. F. Lamela said that they had run 100 Thermica and ESATAN model cases.

S. Kasper (Jena-Optronik) asked how the ESARAD results had been exported into ESATAN. In running parametric cases there was a need to perform a lot of runs without manual intervention, so some sort of batch file was required. F. Lamela said that it had been difficult in ESARAD, but Thermica allowed the user to add a copy command to get the data into the ESATAN file. S. Kasper commented that it was often necessary to have additional small programs to manage parameter data.

HP. de Koning (ESTEC) asked how much CPU time and power had been needed for the battery analysis. F. Lamela said that the CPU time for the overall analysis was the CPU time for one run multiplied by the number of runs, therefore the user needed to find ways of reducing the time per run. One way was to add a subroutine to the ESATAN model to read the parameters each time, rather then pre-processing the whole model with a new set of parameters. Using some READ statements could save a lot of time. HP. de Koning asked how long the analysis had taken. F. Lamela said that the basic analysis had taken one hour for the MiniSat case, but the stochastic approach had needed only 24 hours for 80 cases.

HP. de Koning asked whether the software ran on a Linux cluster. F. Lamela said that the software only ran on one CPU, but some clever scripting was needed to send the ESATAN runs to other machines.

C. Puillet (CNES) asked how it was possible to know the confidence interval for the results without knowing the distribution law for the parameters. F. Lamela said that by using a probability density function on the results, it was possible to order the temperatures and accumulate cases. When 95% of them matched, the user knew that the results have been achieved.

O. Pin (ESTEC) announced that ESA intended to open an ITT on the subject.

2.3. ESARAD

F. du Laurens (Alstom) presented details of various assumptions used in ESARAD, and tips and useful pieces of information which could be used to improve the users’ modelling capabilities. (See Appendix I)

H.Rathjen (Astrium-D) asked why the user couldn’t put the capacitance values in the

VARIABLES1 block so that they could be used to define temperature dependencies. O. Pin (ESTEC) answered that this was possible, and the user could do it using cut and paste editing.

S. Kasper (Jena-Optronik) commented that when the cutting facilities are used, sometimes ESARAD is unable to calculate the capacitances. F. du Laurens said that the capacitance calculation should work, even for cut surfaces. If S. Kasper had a model with this specific problem he should forward it to user support for investigation.

S. Appel (ESTEC) asked whether the thickness parameter affected the outer surface of a shell. F. du Laurens said that ESARAD worked with thin shell geometries, so the thickness is only a notional value which gives a means of calculating the mass of the shell and doesn't affect the geometry as such.

S. Appel asked whether there was any limitation in the value of NBDIV which the user could specify, because there was no mention of this in the manual. F. du Laurens said that he was not sure, and would need to check. P. Renard (Astrium-SAS) said that NBDIV was used by the planet flux calculations, in a different parser. NBDIV was not the same thing as the box meshing. In Thermica, NBDIV was not a user parameter.

P. Renard had a question about the projection of the Sun onto the bounding box in the case of non-parallel solar flux. The circle representing the projection of the Sun on the enclosing box was very small. This implied that NBDIV would have to be large. F. du Laurens said that normally the user left the NBDIV parameter set to zero. In this case, ESARAD would calculate the optimal value for NBDIV.

B. Shaughnessy (RAL) asked whether the intersection test between the ray from the spacecraft to the planet, or the sun, was with the edge of the bounding box or with the voxels. F. du Laurens said that the test was made with the projection on the bounding box.

HP. de Koning (ESTEC) said that there was a publicly available ESARAD algorithms document which explained all of the calculations. This document had been supplied with ESARAD 3.2, but was still valid, and could be made available to users.

S. Kasper asked about the exp3to2 utility. Where could he find it? F. du Laurens replied that it was only relevant to the PC version of ESARAD, and could be found in the ESARAD_DIR\bin directory of a PC installation.

I. Renouf (Astrium-UK) mentioned that he had experienced problems with importing GFF files into ESARAD. S. Kasper said that he had used this, but wondered whether it was possible to have more than 8 colours for displaying the results. F. du Laurens said he was aware of this. The user had to click on the colour selection dialog box. The default number of colours was 8, but the user could select up to 16 if needed.

HP. de Koning warned everyone that under Windows NT, there was an inherent limit of 2GB maximum memory which could be used by any particular process (as opposed to most Unix platforms which provide up to 4Gb memory per process). Therefore, if the model was very large, or there were many orbit positions, it was possible to get past this memory limitation by using the batch processes. This released the memory which would otherwise be used by the

GUI.

S. Appel said that when running batch versions of a model, it was often convenient to be able to run several versions of the same model, each with slightly different parameters. This could be achieved by resetting the $HOME variable to point to the current directory so that different versions of the model could be run in parallel in different directories.

A. Robson (Astrium-UK) commented that ESARAD generated a single ESATAN file and that this often needed to be split up further in order to include the different blocks in a master skeleton ESATAN file. He wondered whether there was any way of automating this. F. du Laurens said that one problem with this was that ESARAD didn't know about ESATAN sub-models. HP. de Koning acknowledged the problem and added that the next release of ESARAD would allow the user to define an ESATAN template file containing place-holders for the blocks of interest. The ESATAN file formatting would then insert the blocks at the appropriate places. This feature should be in the next major release.

F. du Laurens said that he would be talking about the up-coming releases in a presentation on the following day.

2.4. Round Table Discussion

HP. de Koning (ESTEC) introduced the last part of the day, which was a Round Table Discussion (even if the table wasn't really round). He told everyone that O. Pin (ESTEC) had sent out a questionnaire with a space to indicate subjects for discussion. ESTEC had scanned these replies for common topics. He showed "bullet-lists" of the main points. (See Appendix J)

2.5.1. Model reduction

The first common topic was "model reduction".

HP. de Koning asked why people felt that model reduction was important. Was it for reasons of computing time? Or to simplify post-processing of results? Or for the integration of models from sub-contractors.

J. Persson (ESTEC) answered that for the International Space Station analysis there was an obvious need to have reduced interface models otherwise the analysis would be completely unmanageable.This was an example of a reduced model being made available from the system level for the sub-system or payload level analysis.

S. Price (Astrium-UK) said that the integration of sub-contractors' models into an overall satellite model was the main reason in Astrium-UK. O. Pin thought that integrating large numbers of detailed and reduced models would also be difficult to manage. S. Price admitted that these resulted in very large models.

O. Pin asked whether they would have the same approach if the thermal software tools could handle models of 10000 nodes.

S. Price said that the CPU time was also an important factor. For a satellite such as Rosetta with 20 instrument sub-models, if each sub-model was allowed to have 1000 nodes then the overall model would be too large. There was the question of CPU time, as well as the physical capabilities of ESATAN and ESARAD.

J. Persson felt that the use of reduced models was a system integration issue: each module developer was not interested in the details of the other modules.

HP. de Koning agreed that there were actually two kinds of reduced model usage: the top-down interface specification approach needed in phases A and B and the bottom-up approach needed in the phase C/D verification of interfaces, etc.

F. Lamela (CASA) asked what was the real meaning behind model reduction. If there is an interface for a prime contractor, what were the main parameters for the model. The supplier of the platform was only interested in the overall heat flux. Why was it necessary to supply a model to specify single heat fluxes? The reduced model could be as simple as a table of fluxes, or temperatures of key points, and need only contain 20 values. S. Price said that it really depended on how many instruments existed in the model. There was also the issue of whether the integrator was also the supplier of the non-thermal side as well. It wasn't sufficient to simply define the interface in terms of temperatures or fluxes because often the complete geometry model was needed too, for thermal-radiation interaction. HP. de Koning agreed that if the interface was limited to a conductive mounting plate only, then just supplying temperatures or fluxes was fine, but if there were radiative links then something more was required.

F. Lamela said that models often contained 100 to 200 nodes to model internal nodes which were not needed for the external interface. There was a difference in the quality of the models required internally and that needed by the prime contractor. S. Price argued that the prime contractor also needed the internal interaction in order to get the heat flows from the instrument into the spacecraft. F. Lamela admitted that the final decision was the responsibility of the prime contractor and that they might need the whole model. S. Price said that the detailed design was done by the instrument sub-contractors, but they still needed realistic flight conditions at the spacecraft level. The prime contractor needed geometrical models, and not just the interface temperatures. He stressed that what was required was a representative model, and that this didn't necessarily have to be a detailed model.

F. Lamela said that a condensed model gave information on the temperatures of 15 or so elements. When there was a small problem, the temperatures could be extrapolated from these elements. This was how it had been done 20 years ago by the structures people. A model was needed for the interfaces. A condensed mathematical model could be used for extrapolation in the whole model. S. Price felt that a condensed model only reflected a limited number of parameters, and that they were only valid for certain conditions. F. Lamela said that the models should contain independent parameters only. HP. de Koning said that the main parameters were usually represented. S. Price said this gave a reduced model which the prime could use but it was still better to take the detailed model in order to remove an errors introduced by the model reduction, provided the software could handle the complete detailed model HP. de Koning said the prime contractor could keep on running the complete model, but there were problems with configuration control and integration.

O. Pin felt that there was a problem of feasibility in using the detailed models. There were two options which needed to be considered for future developments. In the first case where users needed to work with the complete models, the tools had to be scalable to handle the large models. In the second case where users needed to work with reduced models, the tools would need to support model reduction or help to automate it.

HP. de Koning said that the thermal tools needed to be adapted to handle large models in order to make the complete model approach feasible. The question of model reduction always generated lots of discussion. There was also the problem that serious verification of the reduced model against the detailed model was often very difficult, and sometimes impossible. Everyone needed to have confidence in the results.

S. Price said that Astrium-UK had specifications of how to define models and the relationships between detailed and reduced models, even though using reduced models could introduce errors.

HP. de Koning felt that model reduction was enough of a problem that verification of any model reduction tools was necessary. These were often a black box with some matrix linking input to output.

S. Price felt that most large projects had specifications for model reduction, and most had some software to help do it. He was concerned about trying to analyse conditions for which no correlation data was available, because often there was no way to ask a sub-contractor for the data years after the original work had been completed. To investigate such cases an analysis run for Envisat would take 24 to 36 hours even with the reduced instrument models.

O. Pin said it looked as though model reduction was something that everyone would have to live with, but he asked whether there was a standard way of doing it. Should ESA address this? Should there be studies into automatic model reduction functions? The question would then be how to compare the different model reduction schemes. He felt that in the end it would all come down to engineering judgement.

S. Price said that Astrium-UK had been involved in Rosetta, Envisat and Metop. A common approach had been developed within Astrium on how to provide models to other groups within Astrium. This approach would also need to look at reduced models.

C. Williamson (Eutelsat) felt that there was not one correct answer when it came to model reduction. The model reduction required for one instrument might not be the same as required by another instrument. The prime contractors needed to have a pragmatic approach.

HP. de Koning summarized the discussion so far:

- for the foreseeable future everyone would have to live with reduced models. For example, the ISS environment specifications had to be top-down, but allow a bottom-up approach for integration.
- in addition to the ECSS standard for thermal control, there was a need to have checklist for model reduction in order to standardise the procedures used.
- project specifications could then refer to this checklist and guide the discussions towards a

common approach.

HP. de Koning informed everyone that W. Supper (ESTEC) would give a short talk about the ECSS Thermal Standard. He felt that the level 2 documents could focus on such thermal analysis issues. O. Pin asked whether anyone would be interested in taking part in the ECSS Working Group.

C. Puillet (CNES) said that model reduction had been discussed in previous round table sessions and that a lot could be achieved by specifying a sink temperature. O. Pin said that the Thermal Control Standard did provide one definition, but not everyone was agreed on this definition. He went on to say that the Thermal Control Standard could also provide modelling and model reduction guidelines. He felt that this was an issue because people often needed to work with someone else’s models. He said that he had been called in to help with problems in ESATAN models where the model reduction had been a real mess.

P. van Leijenhorst (Fokker Space) remarked that if you didn’t trust the model, or were doing shadow engineering, then this needed a different approach to working with an interface model. When dealing with an interface model, it could be treated as a black box and you didn’t need to care about the internals. If you needed the model for shadow engineering then you needed to be able to understand the model.

A. Aguilar (SpaceContact) asked whether it was possible to have a combined interface between models in order to allow several sub-modellers working in parallel. O. Pin replied that if we took ESATAN as an example, which allowed the user access to the Fortran, it would be necessary to have message-passing between the different sub-model parts. HP. de Koning admitted that, technically speaking, such model coupling was possible: it would require the addition of very clean inter-process communication to ESATAN. However, he felt that it would not solve the problem of managing a multitude of models, and there would still be problems in integrating models.

K.Caire (Alcatel) said that every thermal mathematical model which she worked on always resulted in a reduced model. Everyone knew that the reduced model is not a true physical model, but it could be used for random parameter variations. You don’t always have enough information about the heat flow in the reduced model and it was difficult to correlate. GAETAN could do it, but it was not complete. She said that the main criterion was the heat balance. HP. de Koning agreed that to verify that a reduced model represents the detailed model the heat balances should be similar.

O. Pin once more asked whether there were any volunteers to work on the ECSS standards.

F. Koorevaar (Fokker Space) asked about NASA standards. O. Pin said that there was a NASA handbook from Marshall Space Flight Center, but this was not available to everyone.

S. Price said that Astrium had a working group which was trying to tackle these issues.

V. Perotto (Alenia) said that he was a little puzzled about the usefulness of model reduction. He had been involved in cases where model reduction had been tried, but they had ended up in using the detailed models anyway because it was less work to use the detailed models than to prove that the detailed and reduced models were equivalent. When you need to use a reduced model from elsewhere, it was always necessary to identify the requirements as to why the reduced model had been produced. If these were not well defined then you can have a reduced model that is difficult to correlate to the complex model. Often you end up reducing the complex model again, and this couldn't be done automatically. There was some need for support in the post-processing of models. However it was important not to lose any visibility in the model, especially if there was a need to use the model again at some point in the future.

HP. de Koning asked whether automatic model reduction was only realistic for interface models. He felt that humans needed meaningful numbers in the model.

2.6.2. Cryogenic Systems

The second issue which had been identified from the questionnaires concerned cryogenic systems, and HP. de Koning asked about the specific issues which needed to be discussed.

B. Shaughnessy (RAL) said that RAL had a number of projects involving cryogenic systems. There were problems of getting models to converge in various cold stages, or in the cool-down stages.

S. Price answered that on the Astrium projects involving cryo-coolers they used their own logic and software rather than using ESATAN solvers directly.

HP. de Koning said that for Herschel-Planck there was one sensor which needed to be kept at 0.1K. There was a heat balance which was very sensitive to small changes in the heat flux, and this sensor was not far from a unit with an 800W dissipation. The model was very ill conditioned.

HP. de Koning asked whether anyone had any more specific issues relating to cryogenic modelling.

I. Renouf remarked that as the systems became cooler. the conductivities of the materials also went down. This often means that the meshing needed to be changed for the lower temperatures because if the nodes were too big then the results were too optimistic.

F. Lamela said that achieving convergence in some cases was sometimes difficult, and to overcome this they used transient runs over 5000 seconds instead of a simple steady state calculation. O. Pin agreed that this was one way of doing it, and in fact the same strategy of obtaining a steady state by time marching was used in fluid systems and with heat pipes.

F. Lamela said that even when using the same software the solution was highly dependent on the actual conductors. It was possible to reach a solution with virtually no heat imbalance, but if a single high conductance was suppressed the results could be different. It was possible to reach a solution where the heat balance was perfect but adding or removing a single node could make a difference of 20 degrees in the results. This made it difficult to perform correlation or sensitivity analysis.

S. Price said that the Astrium cryogenic solver took this into account. O. Pin asked whether it used a time-marching or a SOLVIT type approach. S. Price answered that it used steady state iterations and that the number of nodes made a big difference as the conductivity changed. This was important for example on a strap which had a different conductivity at each end because of the temperature difference. He asked what assumptions were made in the ESATAN equations for the steady state solvers which were not valid for cryogenic analysis. HP. de Koning added that for transient analysis using SLFWBK the $VARIABLES1 block was only called once, at the start of each time step, and this meant that the values were often out of date as far as cryogenic processes were concerned.

P. Renard (Astrium-SAS) commented that when using ESARAD or THERMICA for very cold parts of the model, the use of the extinction parameter in the ray tracing could make a big difference. In THERMICA this was normally set to 1%. This was usually acceptable for normal temperature ranges, but not for cryogenic conditions. The user needed to set the extinction threshold to a low value and specify more rays to improve the accuracy.

2.7.3. CAD and FEA Software

The next issue thrown up by the questionnaires related to the use of CAD and FEA software. HP. de Koning asked whether people needed to use it on a routine or an occasional basis.

P. van Leijenhorst said that he had only needed to use it once in 11 years. V. Perotto said that Alenia didn't use it.

K.Caire said that Alcatel had missions which involved the use of CATIA. They tried to use CATIA surfaces, but were always obliged to construct another model for conversion to THERMICA for use in the thermal analysis. HP. de Koning said that they could use the idealisation of the CAD model within the CAD tool to give a simplified geometrical model. E. Cosson (EADS) said that they had the same approach using IDEAS, and converted the geometrical mathematical model to THERMICA. HP. de Koning asked why they didn't use IDEAS/TMG and was told that they hadn't used it for the thermal side for a long time.

JP. Dudon (Alcatel) said that Alcatel had a problem with a tool which handled the connections between CORATHERM and a CAD tool. They were currently sub-contracting some extensions to OPEN/CASCADE in order to be compatible with new requirements. HP. de Koning asked whether the idealisation was being done manually or automatically within the tools. JP. Dudon replied that they were still at the first step of the development and were working on creating all of the geometries in the tool. The second phase would be to import the geometries from the CAD tool and them simplify them. O. Pin wanted clarification that the idea was to use the CAD tool. He wondered what had happened to CIGAL. JP. Dudon said that they had used CIGAL in the past, but were looking at a period when both CIGAL and the CIGAL-compatible new tool could be used, but after certain point only the new tool would be used.

A. Aguilar commented that there had been a presentation about introducing NURBS into ESARAD at the previous workshop. He felt that this would solve the problem to some extent.

HP. de Koning explained that there had been a study into converting STEP AP203 geometry into ESARAD and using NURBS for ray-tracing. The study had almost been finalized and had resulted in a functionally working product. However, it was computationally very expensive, so it wasn't obvious whether it would be usable in its current form. It wasn't clear whether the best approach would involve using the NURBS directly or whether the NURBS would be handled using facets. He noted that there were other areas which could be investigated, such as the oct-tree implementation used in TSS and also presented by Astrium-F, but there wasn't an easy solution to handling large models. Good meshing algorithms were available in Finite Element tools, so no new development was really necessary there, but new algorithms would be needed in the thermal tools. However it would be the interface which would be delivered. For example, it would be possible to input CATIA models into ESARAD. If NURBS were used for the primitive shapes, then it would be possible to recognise these and simplify them to the primitive shapes rather than continuing to treat them as NURBS. HP. de Koning asked whether anyone had any experience in exporting models or results back into the CAD/FEA tools.

C. Williamson said that he had never had to do this for the design phase, but had needed suppliers' temperature maps in the CAD model. This would be the real application of an export capability.

2.8.4. Post-processing

The final issue which had been selected from the questionnaires related to generic post-processing.

HP. de Koning said that there were a lot of issues concerning post-processing, and trying to find budget and resources to duplicate what was already available in commercial off-the-shelf (COTS) packages would be very difficult.

F. Lamela said that as far as CASA was concerned this was an issue which could be ignored. ESATAN needed to calculate temperatures, and it needed to do it well. Other tools could be used to perform other functions. It was always possible to generate post-processing software to use the ESATAN results and ESARAD geometry information. However this would present problems later because each company had different needs. This was also true within companies. An antenna analysis had one set of requirements, a complete satellite analysis had different requirements, etc.

HP. de Koning stressed that there was a need to get away from monolithic applications which did everything. If there was a set of standard data files, then it would be possible to develop suites of tools which made use of the standard format. He felt that it would be better to have Unix-type filter tools to do the post-processing of these standard files.

F. Lamela said that as far as the post-processing for the structural people was concerned, they didn't always know what they wanted, or the models were not fully compatible, or there was a need to interpolate results in bracket assemblies, etc. Allowing a general formula was a little dangerous. One important area was the visualisation of results.

A. Aguilar commented that it would be interesting to allow the user to have some template functions so that the user could select the format and content of output, to have tab separated output, or spaces, or whatever, in order to allow the integration with in-house or COTS software. He felt the user should be allowed to define the output format.

HP. de Koning said that the HDF5 binary data format had complete C and F77 application programmer interfaces to enable users to read the data. This was one approach. Another widely recognised format was the use of comma separated variable lists. He felt that there should a small number of simple, straight-forward formats, or space-efficient formats, and that should be all that the tools should support. He would hesitate about developing specific formats, because there would always be someone with a new requirement.

V. Perotto said that the post-processing information was interesting, but felt that the users would be able to do a lot more for themselves if a clear explanation of ESATAN's COMMON blocks were made available. Everyone had been obliged to experiment with the COMMON blocks if they wanted to extend the output for post-processing. He asked why this information had never been made available. HP. de Koning admitted that many people had reverse-engineered this information so that they could use it for their own tools. Maybe it would be possible to create a feature request for the supply of the COMMON block specification. The original reason for not disclosing the format had been to allow Alstom the flexibility to change the implementation of the software and COMMON blocks without affecting the users.

A. Aguilar said that Alstom should produce some APIs to allow retrieval of data from the COMMON blocks. HP. de Koning repeated that HDF5 had such APIs. He stressed that direct access to the COMMON blocks endangered the portability of the software and models between partners, or with SINDA, and could make shadow engineering difficult. What was needed was a simple call in the $OUTPUT block to dump data into a standard format.

P. Renard said that he had some experience of converting an ESATAN model to SINDA for a customer. He warned that using knowledge of the ESATAN COMMON blocks within MORTRAN subroutines made it harder to convert the model to SINDA. HP. de Koning agreed that the more MORTRAN there was in a model, the more likely it was that there would be problems in model portability with SINDA, etc. If models needed to be ported, then maximum portability could only be achieved if only the standard features of the software were used.

3. Wednesday 10th October: Morning Session

3.1. Temperature Control Loop Analyzer (TeCLA) Software

V. Perotto (Alenia) described work done by his colleague F.Burzagli on the TeCLA software. (See Appendix K)

M. Molina (Carlo Gavazzi Space) noted that the software worked for single phase loops, and asked how much effort would be needed to handle two phase loops. V. Perotto said that Alenia did not have any two phase loops in their part of the ISS work, so there had been no need to provide a two phase capability.

O. Pin (ESTEC) asked whether it would be difficult to provide a two phase capability. V. Perotto said that it would be necessary to find the correct transfer functions. The control interface with the loop was not usually done on the branches which had two phase flow. These were normally only single phase. Adding the control interface which truly reflected the physics of the loop could greatly increase the complexity of the model. M. Molina summarised by saying that the physics of the loop was changing in one place, but the control was actually handled elsewhere. V. Perotto said this was the case, and changes to the model would need to reflect the physics.

O. Pin remarked that, at ICES, V. Perotto had mentioned the use of EcosimPro to handle the control laws, and wondered whether they had thought about using it. V. Perotto confirmed that they had tried EcosimPro, but had only used in the same way as they used ESATAN/FHTS or FLUINT, so this was not really different. They needed to run lots of cases with changed parameters, and spend a lot of effort for multiple parametric runs. O. Pin said that it was possible to create components to handle this, but it was still necessary to identify all of the control coefficients. He added that functionality was available in EcosimPro to identify the control parameters. V. Perotto agreed. It was necessary to identify the control coefficients in advance to be able to perform parametric studies.

3.2. Analysis of Spacecraft Thermal Stability

B. Shaughnessy (RAL) presented some ideas on the start of a project to determine the stability of spacecraft thermal design and analysis. (See Appendix L)

HP. de Koning said that if ESARAD was used for the prediction [it was], then ESARAD used double precision throughout, but the transfer to ESATAN via an ASCII file caused truncation. There was some work in progress to look at a full binary transfer process in order to preserve the accuracy of results.

HP. de Koning asked whether the trade-off between lumped parameters and finite difference and finite element methods had been considered. He felt that finite element methods might provide a better representation. B. Shaughnessy said that the lumped parameter approach was better for representing spacecraft. The different projects at RAL used ESATAN, so this investigation into the analysis methods was to validate the original work. If the investigation disproves the accuracy of the results, there would be a need to look again at the methods being used. HP. de Koning said that it would be possible to use hybrid systems, with finite element analysis for the optical instruments and ESATAN for the rest of the spacecraft. B. Shaughnessy said that the results had to be mapped to the structural finite element models eventually anyway, and that would be another area where errors could be introduced. With more methods the requirements became less well defined.

V. Perotto (Alenia) asked whether it was possible to use the standard tools for analysis such as ESATAN, ESARAD and finite element methods. He wondered whether an analytical simulation might be better, or a combination of using the standard tools down to a certain level and then use values from that level as boundary conditions or input to the next layer of analytical tools. Perturbations could be calculated using Fourier transformations. B. Shaughnessy felt that it was a good suggestion to couple finite difference methods with something else.

C. Williamson (Eutelsat) remarked that there would always be uncertainty in the data. In the example given during the presentation, there were uncertainties in the temperature gradients within the sphere. He felt that conductivity and capacity values were also needed.

G. Barbagallo (ESTEC) commented that the thermal requirements had been expressed in terms of the spectral power density at a certain frequency. He asked about the thermal fluctuation which needed to be predicted. B. Shaughnessy said that the temperature variation was a peak to peak difference of 2.0×10^{-6} kelvin at room temperature. G. Barbagallo agreed and said that this would give 10^{-11} kelvin per root hertz at certain frequencies. There was the need to divide by the bandwidth. He wondered how the 10^{-4} figure had been obtained. B. Shaughnessy said that this number had been specified in the structural analysis report. G. Barbagallo remarked that ESATAN had not be designed for such a small variation. HP. de Koning said it was a question of whether the user could live with the convergence criteria. It might be necessary to look at the heat balance rather than the temperature differences. O. Pin (ESTEC) said that this area of ESATAN was currently being investigated, but he was sceptical of whether this would really help for such requirements. HP. de Koning said that normal double precision was accurate down to 10^{-13}, and offered 13 significant digits, so the analysis needed accuracy which was already quite close to the limits of what was achievable.

V. Perotto said that if a solver could be upgraded to support convergence on the heat balance, it would also be interesting to work with the energy, which was the integration with respect to time.

C. Williamson commented that this accuracy was required during Phase A. Thinking ahead though, if the hardware was actually built during Phase B or C, how could it ever be validated? B. Shaughnessy said that verification would be someone else's task. F. Lamela (CASA) said that it would be possible to measure it optically using the laser in the instrument. HP. de Koning agreed that the instrument itself could be used in the verification. It was clear though, that to ensure the spacecraft worked, it needed to be simulated with a high degree of accuracy.

3.3. An Overview of Bepi-Colombo Thermal Analysis

I. Renouf (Astrium-UK) gave an overview of the Bepi-Colombo mission and the challenges for the thermal design to handle the wide range of thermal environments for the different phases of flight, as well as the orbit and landing on Mercury. (See Appendix M)

F. du Laurens (Alstom) asked whether I. Renouf would be interested in wider planetary modelling in ESARAD at some time in the future, or a hyperbolic orbit capability for modelling the Venus fly-by. I. Renouf said he would be interested, and said that they could discuss it after the presentation. It would certainly be relevant for the thermal analysis. The design for the fly-by behind Venus was important because of the need to keep the spacecraft warm. F. du Laurens asked whether I. Renouf had used his own routines for planetary modelling. I. Renouf replied that he used in-house routines for varying the temperature. F. du Laurens asked whether this temperature was based on the sub-satellite point, or used the field of view of the planet. I. Renouf said that it used the average value.

C. Williamson (Eutelsat) commented that he had also tried doing something, but it was not elegant. He had used Thermica with different planet temperatures held in arrays, with some logic to select different temperatures from the array at various points around the orbit. These arrays had to be generated in advance, and added to the ESATAN model as well.

I. Renouf said that the main problems in the design and analysis had to do with the scale an variation in the flux values for the different phases of the flight and within the final orbit. At the closest point to Mercury, the altitude was 400km with flux values above 10000W/m^2. The variation of the flux around the orbit was also very rapid. He was concerned about the scaling effects.

3.4. ECSS Initiative

W. Supper (ESTEC) gave an impromptu explanation of the ECSS standards work, and described some of the results so far. He said that everyone should remember the home page for the ECSS standards in order to download the existing standards. These standards could be downloaded for free. There as a lot of information on management aspects, product assurance, quality assurance and various technical areas. For Thermal Control, the level 2 documents already existed, and there were on-going activities to define level 3. He had a limited number of old news letters which people could take away with them, but anyone could download electronic versions of the latest news letters from the web site. He stressed that the process needed input from, and co-operation of different teams from the space industry with Europe rather than just from ESA.

The web address was http://www.estec.esa.int/ecss

O. Pin (ESTEC) emphasized that volunteers were required to help with this work. HP. de Koning (ESTEC) said that EuroSpace were helping to co-ordinate the work of all of the different space contractors. EuroSpace would pay for the travel and subsistence of those contractors who participated in ECSS meetings, so not all of the costs had to be borne by industry directly.

W. Supper said that the high level Thermal Control standard, level 2, had already been issued, although there were some errors which needed to be corrected. Three level 3 documents where foreseen:

- thermal handbook (one version had been developed for CDROM, but this would need reworking to be a paper-based document)
- reference data (solar constants, etc. so that everyone worked with a common set of data)
- guidelines for analysis (a cookbook containing working practices)

The more people who were involved in providing input, the better the acceptance level across European space industry. This was better than a small group developing a standard to be imposed on everyone else.

3.5. Application of CORATHERM for Spacecraft Thermo-Elastic Analysis

JP. Dudon (Alcatel) described the current state of CORATHERM, and the recent developments of the tool to improve its use in the thermo-elastic analysis of spacecraft. (See Appendix N)

S. Appel (ESTEC) was interested in hearing more about the method used to transfer temperatures from the thermal nodes to the finite element nodes. JP. Dudon said that the software made use of the partial nodes used in the EQUIVAL method. These gave local temperature information on structural panels, or the power on unit nodes. Then it was possible to use the recalculation process to transfer the temperatures from the automatically created partial nodes onto the classical thermal model. Points could be created on the finite element mesh which matched these nodes.

S. Appel asked whether this was a consistent method. JP. Dudon said that it was difficult to discuss the method without needing to go into more detail than could be given in such a short presentation. The engineers at Cannes had found that combining the radiative and conductive aspects of panels gave a better way for the conductor processing, and allowed the possibility of having local information about the geometry and the interpolation of values between points. O. Pin (ESTEC) said that in EQUIVAL the panels were meshed finely, and then star delta transformations were applied to the mesh to reduce it, taking environmental conditions into account.

JP. Dudon gave an example of a panel which was cut into element nodes. The conductive and radiative links of the nodes were calculated. Some nodes could be eliminated and some combined to give classical thermal nodes. The thermal nodes have the averaged temperatures of the partial nodes which have been eliminated. Unit nodes were considered as classical nodes.

HP. de Koning (ESTEC) asked whether the method was limited to rectangular shapes. JP. Dudon said that there was a constraint on using rectangular shapes at the moment.

3.6. Transient CPL modelling with ESATAN/FHTS and SINDA/FLUINT

C. Puillet (CNES) described work to model capillary pumped loops using FHTS and FLUINT, and the new capillary pumped elements in FHTS. (See Appendix O)

O. Pin (ESTEC) asked whether anyone else in the audience had used the capillary pumped loop (CPL) elements provided with ESATAN/FHTS 8.6. V. Perotto (Alenia) said that they had tried at Alenia, but they had used a simpler loop than C. Puillet had shown. The loop had consisted of only one evaporator and one condenser. They had found similar problems to the ones presented, such as the time step, and the sensitivity to the number of nodes. He was concerned about how well physical phenomena could be modelled. He wanted to know when a method would be available which got rid of the current test cycle of building the loop and running the tests just to verify the model.

O. Pin asked whether C. Puillet could be more precise about the physics which the loop had represented. What still needed to be investigated? C. Puillet answered that low mass flow rates leading to stratified flow had not been modelled, therefore the results were not accurate. It was necessary to have a high mass flow rate in the experiment in order to give homogeneous flow.

O. Pin said that there was a paradox. It would be possible to add more physics to FHTS, but the real requirement for thermal engineers would be to get rid of FHTS. Everyone would be happy to overcome the use of fluid nodes.

O. Pin asked whether Alenia could provide more feedback on the problems they had experienced. V. Perotto explained that they had tried to get rid of the pre-built capillary pump elements. They had modelled specific capillary elements using subroutines, but they were still not happy with the result. They had a student who had been looking into this, but he was currently away on military service. He felt that rather than develop the tool further, there was a need to develop experience of modelling such loops. C. Puillet agreed that experience was needed which matched the models, for example, models having no stratified flow.

O. Pin said that one of the major problems had been how to test the CPL elements themselves (evaporator, condenser and isolator). The results had to be verified against unit testing of the elements themselves, and not in experimental loops. C. Puillet admitted that it was not easy to get a model to match the experiment.

3.7. Status of Model Data Exchange

HP. de Koning (ESTEC) described the growing interest amongst the tool vendors in STEP, and the current state of development of the STEP-TAS and STEP-NRF interfaces. (See Appendix P)

H.Rathjen (Astrium-D) asked how cut surfaces from ESARAD were handled by STEP-TAS and imported into other software tools. He had tried using STEP-TAS for converting ordinary surfaces from ESARAD to Thermica but had found that coordinate information was missing.

HP. de Koning said that all surfaces where converted to a point definition within STEP-TAS, so a rectangle which had been defined by width and height in ESARAD would be converted to use a P1, P2, P3 definition in STEP-TAS. The final coordinates also depended on how translations and rotations were handled in the database, so some intermediate coordinate transformation information might also be lost in the conversion. H.Rathjen said that losing coordinate information made model transfer difficult. HP. de Koning agreed. Another problem area was that labels were lost, but this would be corrected. In the current converters, this information was not properly mapped, but this would be fixed. Cut surfaces were not taken into account in STEP-TAS exchange. The existence of the surface was transferred, but not the surface itself. The primitive surfaces used as operands to create the cut surface were transferred, but not the resulting cut surface. Therefore the receiving tool needed manual intervention to handle the cut surface.

F. du Laurens (Alstom) remarked that user support had received many calls about transferring Thermica models to ESARAD via the STEP-TAS interface where there were a lot of statements such as SHELL A = SHELL B + SHELL B. He wondered whether this was a similar problem.

HP. de Koning admitted that there were several bugs in the converter which needed ironing out. The three different levels of interface used in the conversion all had bugs. This was one reason to simplify the architecture, remove the old SET-ATS layer, and identify where the bugs occurred. The implementation of the converter for different tools had unearthed various bugs, issues to be resolved, and feature requests. These would all be corrected or consolidated in future releases. Even though it was a slow process, he felt that there was convergence.

M. Molina (Carlo Gavazzi Space) commented that Carlo Gavazzi Space and OHB had been using the Trasys to ESARAD converter successfully.

HP. de Koning said that anyone who was interested in using the converter should send him a request via electronic mail. There were a lot of test cases for the converter so it was relatively completely validated.

A. Robson (Astrium-UK) asked whether the opportunity existed to use the STEP protocols to transfer thermal results into finite element models. HP. de Koning said that Lockheed Martin had asked him to expand AP209[2] to include thermal data, but this was still under consideration. This would be a logical way of doing it. However, it would still take time. The other tools were slowly going the same way. Patran was the only tool which handled AP209 so far, so handling results was still limited.

4. Wednesday 10th October: Afternoon Session

4.1. Thermica v4.

P. Renard (Astrium-SAS) described the reasons behind the development of a new interface for Thermica, and gave a demonstration of the new GUI and interactive model builder prototypes. (See Appendix Q)

O. Pin (ESTEC) asked whether the multi-shape node shown in the interactive model builder used the centre of gravity for the conductive link. P. Renard replied that it was the geometric centre rather than the centre of gravity. The density of the material was not taken into account.

H. Rathjen (Astrium-D) asked whether the new user interface would allow the user to specify cutting tools. P. Renard answered that new shapes had been required in the geometry to handle cutting tools, but this had now been done. Work was still required on the ray-tracing to support cut surfaces, but the goal was to support cut shapes in Thermica.

V. Perotto (Alenia) asked for more details of the albedo and infra-red modelling. P. Renard said that currently the models used constant albedo or temperature values for the planets, but many people wanted to have different albedo or temperature values for different areas of the planet model. This could be achieved in the future by allowing the user to edit a table of values. V. Perotto asked whether such an infra-red model would compute the infra-red fluxes based on these temperatures. P. Renard replied that there would be no computation within the model. The temperatures could be used to model the effect of an atmosphere.

2. AP209 is the STEP protocol for the exchange of FEM data.

F. Koorevaar (Fokker Space) said that in previous versions of Thermica it had been difficult to see the difference between active and inactive surfaces. P. Renard said that this had been improved.

F. du Laurens (Alstom) asked to what extent did Thermica support the calculation of conductive links. P. Renard said that the contact conductance between classical shapes was handled, such as disk with cylinder, etc.

J. Persson (ESTEC) asked whether cut surfaces would be handled. P. Renard answered that conductive links for surfaces with boolean operations still needed to be investigated. The current idea was to re-mesh the cut shape and then check the conductive links.

A. Robson (Astrium-UK) asked whether it would be possible to run the conductive link calculation in batch mode. P. Renard admitted that batch mode was also important, but there was a need to prioritise which features went into the next version.

4.2. Developments in ESARAD, ESATAN and User Support

F. du Laurens (Alstom) and H. Brouquet (Alstom) described the latest developments in ESARAD and ESATAN, and explained the self-help ideas behind the Alstom web site. (See Appendix R)

A. Robson (Astrium-UK) remarked that the new cyclic solver routine in ESATAN would not converge if the model contained logic to control heaters. The model might converge by itself, but the heater would interfere.

HP. de Koning (ESTEC) asked whether the user could specify a range of nodes for which the convergence criteria applied. H. Brouquet said that this was possible, or the user could specify a sub-model.

O. Pin (ESTEC) said that the fact that the calling interface allowed the user to specify “ALL” or “NONE” was because future work was foreseen to implement events. This feature of the calling interface was the first step towards this implementation. HP. de Koning explained that events would be named, so the user would be able to specify a particular event.

F. Lamela (CASA) asked at what time the min./max. calculation took place. The user might be interested in partial values, of those at the beginning or end of particular time steps. What if the user only wanted the min./max. temperature after 52.55 seconds? O. Pin answered that when using the new cyclic solver routine the user might only want the min./max. values during the final solution stage. The user could specify when the STORMM routine was called. One way to do it could be to use the cyclic solver first, then run one additional orbit which contained calls to STORMM. H. Brouquet explained that the user needed to add some logic to the ESATAN model so that if the time was greater than a certain value, for example, STORMM would be called. F. Lamela was relieved that the model would not need to be restarted with different starting conditions in order to extract the correct min./max. values for a particular range of times.

In answer to a question from C. Williamson (Eutelsat), H. Brouquet said that the min./max. routine compared the variable which had been defined, and stored the result in other variables. HP. de Koning said that the user could access these variables if required. There was a minT variable for each node in the model. H. Brouquet said the user had access to all of the standard nodal attributes as well as those defined in USRNOD.DAT.

P. Renard (Astrium-SAS) asked whether the introduction of FlexLM would give rise to an additional cost to the user. F. du Laurens said that there would be no additional cost to the user. The use of FlexLM would allow the user to have 4 floating licences.

D. Labuhn (OHB) asked about the status of POLYTAN. F. du Laurens answered that POLYTAN was now a project rather than a specific product. New features of ESARAD would fall under the POLYTAN project. HP. de Koning explained that originally POLYTAN was to have been a new product. Work started in 1995/6 and there had been a number of prototypes for various aspects of the tools. However, it was decided that the POLYTAN product was just too ambitious, and there were likely to be problems with a smooth migration from the existing tools, and problems with backwards compatibility. Current space projects ran for many years, so there would still be a need to use the original tools for a long time, so the switch to a completely new tool would have been difficult to manage. POLYTAN functionality could only have been added a little bit at a time. Therefore the decision was made to provide a series of incremental upgrades to ESARAD and ESATAN, and to build the POLYTAN functionality into successive industrial releases of the existing tools. F. du Laurens announced that the version of ESARAD which could be considered as forming part of POLYTAN release 0 was scheduled for release in February 2002. HP. de Koning said that this version would feature better integration with ESATAN to allow splitting the model into the different ESATAN blocks, mission capabilities, and improvements to the visualisation.

E. Cosson (EADS) said that there was often a need to handle ESATAN internal variables for determining the heat balance, or to monitor the phase change of materials, or just to test the variables themselves. The QRATES routine gave the imbalance, but it was not possible to use this as part of a test. O. Pin asked whether he needed access to these variables in order to modify the user logic. The answer was yes: access to these variables was required. HP. de Koning said that it should be possible to declare a nodal entity and to check this entity in the user logic. He agreed that there was a need for someone to write some example code to show users how to do it.

V. Perotto (Alenia) had some comments on the latest version of ESARAD. He said that they had tried ESARAD 4.3.2, but it was not really being used. They were running across a network, and the processing times for the geometry were worse than the old version. Running the geometry took longer. HP. de Koning asked whether this was using the esrdg batch process. V. Perotto answered that this was just loading and processing the geometry in interactive mode. F. du Laurens suggested to process the geometry using batch mode and then load this into the GUI. V. Perotto said that he was not sure of the details, but he thought that the batch process was used, and then the geometry was loaded into the GUI. F. du Laurens said that it should only take about 10 to 15 seconds to load a 3000 node model.

V. Perotto said that they had also had problems with transfer orbits. To model Mercury orbiting the Sun, they had found some strange fluxes. It appeared there was a problem with solar constants not being calculated. F. du Laurens said that the solar constant was currently calculated as the mean value over the transfer orbit, but this would be changed in the future.

V. Perotto said that to calculate the orbital fluxes for the Bepi Colombo mission to Mercury it had been necessary to have two runs in order to take Mercury’s slow rotation into account. Mercury only had 3 planetary rotations every 2 Mercury years. However, modelling two successive orbits was not simple in ESARAD. HP. de Koning said that if the model contained 24 orbit positions but they were unable to run 48 orbit positions in sequence then this was problem. This needed to be investigated and resolved. V. Perotto said that they had run two models and then combined the fluxes.

S. Appel (ESTEC) asked whether the Web site could also be used for reporting problems. F. du Laurens said that this was not possible at the moment, but was an idea for the future. The user should be able to recall and track reported problems on line. He said that user support would continue to handle electronic mail, but the Web site should take over as the first point of contact. S. Appel asked if he sent electronic mail to user support, would his problem be added to the Web. Would he have access to the problem reports submitted by other users? F. du Laurens answered that there was no direct interface between the user support mail system and the Web site. Users would only have access to their own problem reports because of confidentiality issues.

4.3. Workshop Close

O. Pin (ESTEC) said that all of the presentations would be made available on the ESTEC web site, and people who were new to the Workshop would be added to the mailing list.

He said that producing the Minutes of the Workshop had to be on a best effort basis: it took a lot of work to produce the Minutes and there were always other tasks to be done.

He thanked Alstom and the other presenters for the effort they had made for the Workshop.

He hoped to see everyone again the following year at the next Workshop.

Appendix A: Welcome and Introduction

Welcome and Introduction

O. Pin
ESTEC/TOS-MCV

esa

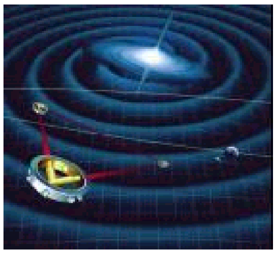
ESTEC
Thermal and Structures Division

Workshop objectives

- To promote the exchange of views and experiences amongst the users of the Agency's (and others) software packages in the fields of thermal control and ECLS
- To provide a forum for contact between end users and software developers
- To present new versions of the software tools and to solicit feedback for development

esa

ESTEC
Thermal and Structures Division



ESA team

Charles Stroom	Head of the Analysis & Verification Section
Duncan Gibson	Software Support & Workshop Secretary
Hans Peter de Koning	Topic, Artifis, ESARAD & Model Data Exchange
Olivier Pin	ESATAN, FHTS, ThermXL & EcosimPro

ALSTOM team

Frédéric du Laurens	Support Manager
Henri Brouquet	ESATAN/FHTS and User Support

esa

ESTEC
Thermal and Structures Division

Programme

- Mornings - Presentations on the use of thermal analysis tools and methodologies (with 5-10 mins discussion at the end of each presentation).
- Afternoons - Interactive demonstrations of 45 / 90 minutes.
- 17:15 today - ESA Round-Table discussion (Hans Peter de Koning). Topics have been chosen according to your questionnaire answers.
- Discussion on major feature requests for ESARAD and ESATAN/FHTS will be covered tomorrow afternoon by ALSTOM.
- PCs are available at the back of the room to try the software ESARAD, ESATAN, ThermXL, ThermPlot and EcosimPro

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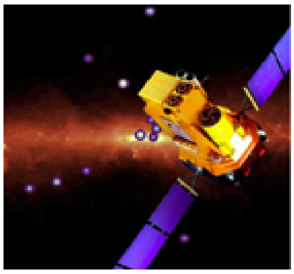

Practical Information

- Presenters: Please leave your presentation (floppy or CD-ROM with Powerpoint file) with D. Gibson or O. Pin before end of Workshop. Please leave a paper copy if possible to avoid problems with embedded fonts/logo's or Mac.
- Workshop Minutes (for morning sessions and round-table discussion) will be supplied to participants on the Web.

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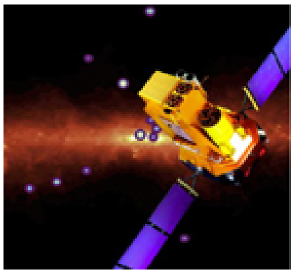
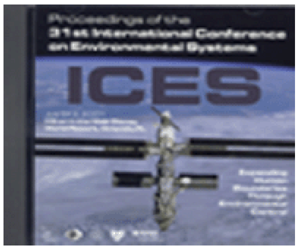
Thermal and Structures Division



Practical Information

- Lunch: 13:00 - 14:00. The “foyer” tables are reserved for us
- Cocktail today at 18:00 outside the Workshop room
- Restaurant booked today for 20:00 (maps available). Please let us know by 14.00 if you need a lift to the restaurant
- Fax (+31-71-565-5949) and telephone available outside the Workshop room
- Check your details on the list of participants and inform the Conference Bureau of any modifications.

ICES 2002



- The 32st International Conference on Environmental Systems will be held 15-18 July 2002 in San Antonio, Texas
- Deadline for submitting abstracts: 19 October 2001
- Thermal software related abstracts to be sent to: Charles Stroom - Charles.Stroom@esa.int

Appendix B: Managing the Interface between ThermXL and Esarad

Managing the Interface
between
ThermXL and Esarad

A. Robson
Astrium-UK

Managing the Interface Between ThermXL and Esarad

Presented by

Andy Robson, Astrium UK

15th European Workshop on Thermal/ECLS Software
ESTEC 9-10th October 2001

Summary

astrium

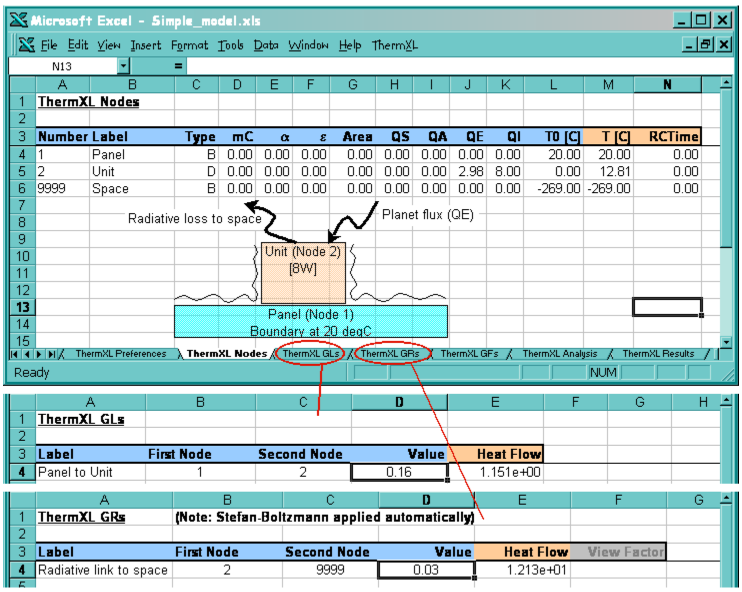
- Thermal Modelling Tools
- ThermXL Overview
- The Thermal Modelling Process
- Esarad Interface
- Other Interface Issues
- Conclusion

Thermal Modelling Tools

ANALYSIS TOOLS			GEOMETRY TOOLS		
	PROs	CONs		PROs	CONs
ESATAN or SINDA	Powerful and flexible.	Too cumbersome for early study phases	ESARAD	Integrates well with Esatan	Does not interface with any other analysis tools
THERMXL	Simple, Powerful and flexible	Not appropriate for detailed analysis. No interface with other tools	SYSTEMA	Integrates well with Esatan and SINDA	Does not interface with ThermXL
HAND CALCULATION	Quick answers to simple problems	No use for analysis of more than 2 or 3 nodes	HAND CALCULATION	No interface issues	Simple geometry only

What is ThermXL?

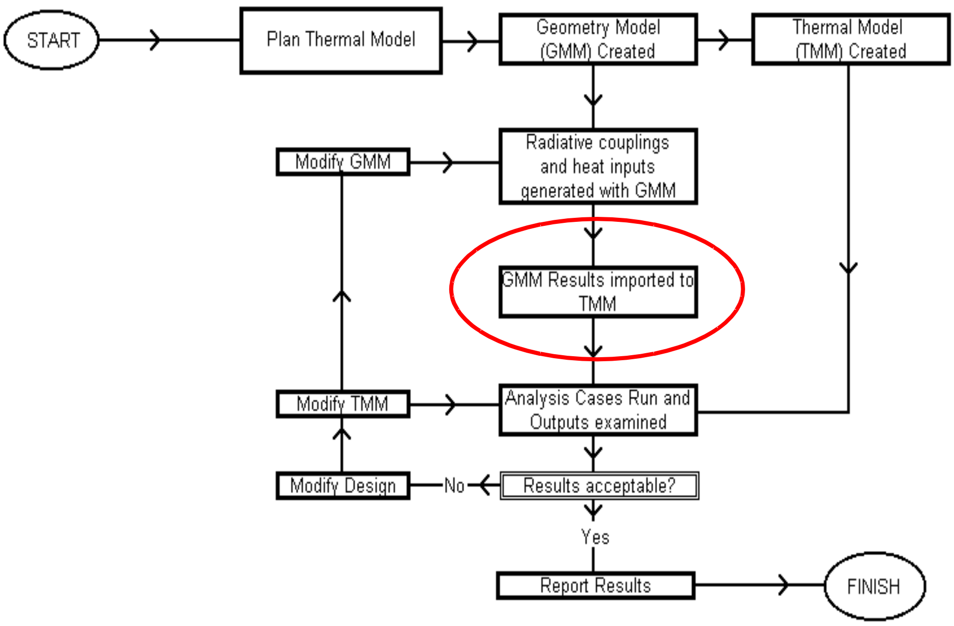
- **An add-in for MS Excel that provides Thermal modelling and analysis capabilities in a spreadsheet environment.**



Why ThermXL?

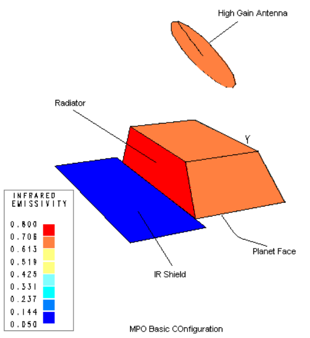
- **ThermXL provides a flexible and simple environment for performing early study thermal design and analysis.**
- **Fast turn-around of analyses**
- **Spreadsheet functionality**
  - Ability to define time and/or temperature dependent values using Excel formulae or macros
  - Direct plotting facility using Excel charts as required
- **Flexibility**
  - Ability to change parameters easily and see instant results

The Thermal Modelling Process



The ThermXL Model

- ThermXL used by Astrium UK for preliminary Bepi Colombo model development
- ESARAD used for geometry modelling
- Steady state fluxes for interplanetary cruise phases and for the Mercury Surface Element (MSE) in situ
  - no problem inserting ESARAD results into ThermXL
- Transient fluxes for orbiting elements, such as the Mercury Planetary Orbiter (MPO), and the descent phase of the MSE with its Chemical Propulsion Module (CPM)
  - Interfacing tools required to import Esarad results into ThermXL



Microsoft Excel - BepiColombo_orbiter_model_2.xls

ThermXL Nodes			Total Q	5992									
			Time Now	8312									
Number	**Label**	**Type**	**mC**	**α**	**ε**	**Area**	**QS**	**QA**	**QE**	**QI**	**T0 [C]**	**T [C]**	**RCTime**
1	Top (-Z) MLI (OSR)	D	10.00	0.20	0.80	2.25	0.00	0.00	18.40	0.00	108.13	-76.82	5.83
2	Bottom (+Z) MLI	D	10.00	0.20	0.80	3.80	0.00	0.00	5350.09	0.00	127.94	143.29	0.67
3	-X MLI (70% OSR, 30% SOAR)	D	10.00	0.36	0.81	1.05	0.00	0.00	133.27	0.00	166.24	-29.89	9.88
4	+X MLI (70% OSR, 30% SOAR)	D	10.00	0.36	0.81	1.05	0.00	0.00	119.54	0.00	166.74	-34.66	10.36
5	-Y Radiator (Bulk Body)	D	300000.00	0.20	0.80	1.59	0.00	0.00	5.20	200.00	75.39	75.60	34967.33
6	+Y MLI (70% OSR, 30% SOAR)	D	10.00	0.36	0.81	1.74	0.00	0.00	234.52	0.00	100.77	-27.48	5.79
7	IR shield (OSR)	D	5000.00	0.20	0.80	3.37	0.00	0.00	11.84	0.00	134.00	-22.14	832.84
8	HG Antenna	D	6000.00	0.27	0.70	2.71	0.00	0.00	486.18	0.00	113.59	6.45	2168.47
17	IR Shield MLI	D	10.00	0.20	0.80	3.37	0.00	0.00	4821.62	0.00	131.39	142.76	0.79
99	SPACE	B	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	-270.00	-270.00	0.03

FLUX data / FLUX / Case / ThermXL Nodes / ThermXL Results / St St Hot Case R

Importing ESARAD generated GRs

- Fixed GRs are manually imported from ESARAD, with Excel formulae to modify optical properties during design iterations

Microsoft Excel - BepiColombo_orbiter_model_2.xls

ThermXL GRs	(GRs are directly defined as values)								
							Esarad	New	Old
Label	**First Node**	**Second Node**	**Value**	**Heat Flow**	**View Factor**		Value	Emissivity	Emissivity
Top - Antenna	1	8	1.387e-01	-36.38			1.387e-01	0.56	0.56
Top - Space	1	99	1.657e+00	139.56			1.657e+00	0.8	0.8
Bottom - Space	2	99	3.041e+00	5185.56			2.661e+00	0.8	0.7
-X to Space	3	99	8.398e-01	166.77			8.398e-01	0.806	0.806
+X to Space	4	99	8.385e-01	153.82			8.385e-01	0.806	0.806
Radiator - Shield	5	7	3.490e-01	214.18			3.490e-01	0.64	0.64
Radiator - Space	5	99	9.213e-01	772.82			9.213e-01	0.8	0.8
+Y - Space	6	99	1.402e+00	289.49			1.402e+00	0.806	0.806
Shield - Antenna	7	8	4.909e-02	-5.96			4.909e-02	0.56	0.56
Shield - Space	7	99	2.313e+00	520.53			2.313e+00	0.8	0.8
Antenna - Space	8	99	1.692e+00	586.50			1.692e+00	0.7	0.7
Shield MLI - Space	17	99	2.696e+00	4573.71			1.685e-01	0.8	0.05
MLI	1	5	0.11229975	-84.74					
MLI	2	5	0.19003680	164.69					
MLI	3	5	0.05239420	-33.54					
MLI	4	5	0.05239420	-34.34					
MLI	6	5	0.08700335	-55.01					
Shield MLI	7	17	1.685e-01	-2.479e+02					
MLI Efficiency	0.05								

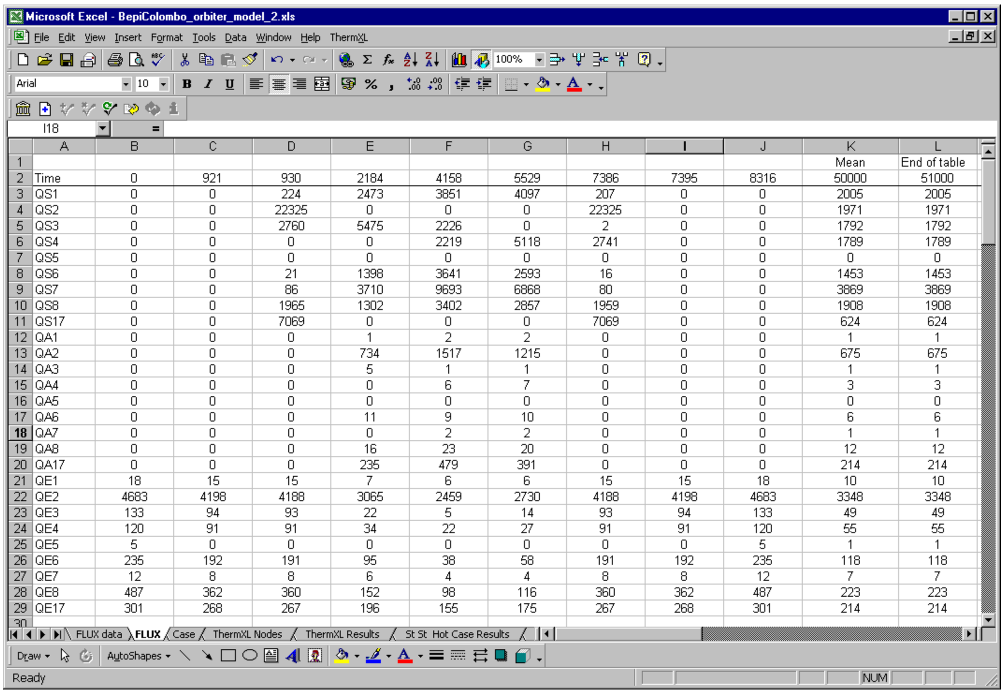
ThermXL GRs / ThermXL Preferences / ThermXL GLs / ThermXL GFs

Importing ESARAD Generated Fluxes

Importing the data is an issue for two reasons:

- **Esatan output format not compatible with ThermXL, so importing tool required.**
  - Tool written with Visual Basic macros to deal with the format
- **Excel does not support interpolation**
  - Interpolation performed using a sequence of Excel formulae with the spreadsheet

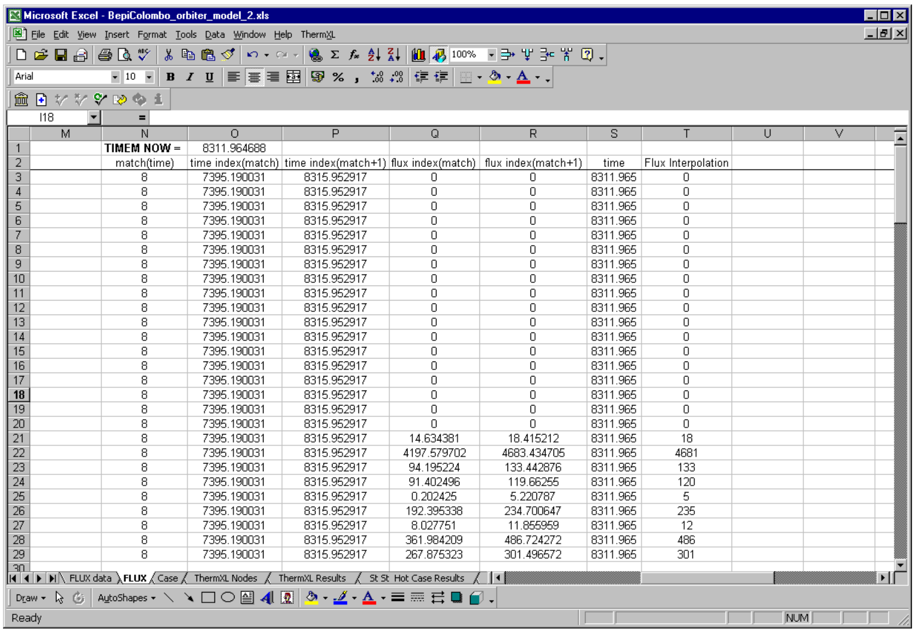
Flux data after importing to ThermXL


Microsoft Excel - BepiColombo_orbiter_model_2.xls

	A	B	C	D	E	F	G	H	I	J	K	L
1											Mean	End of table
2	Time	0	921	930	2184	4158	5529	7386	7395	8316	50000	51000
3	QS1	0	0	224	2473	3851	4097	207	0	0	2005	2005
4	QS2	0	0	22325	0	0	0	22325	0	0	1971	1971
5	QS3	0	0	2760	5475	2226	0	2	0	0	1792	1792
6	QS4	0	0	0	0	2219	5118	2741	0	0	1789	1789
7	QS5	0	0	0	0	0	0	0	0	0	0	0
8	QS6	0	0	21	1398	3641	2593	16	0	0	1453	1453
9	QS7	0	0	86	3710	9693	6868	80	0	0	3869	3869
10	QS8	0	0	1965	1302	3402	2857	1959	0	0	1908	1908
11	QS17	0	0	7069	0	0	0	7069	0	0	624	624
12	QA1	0	0	0	1	2	2	0	0	0	1	1
13	QA2	0	0	0	734	1517	1215	0	0	0	675	675
14	QA3	0	0	0	5	1	1	0	0	0	1	1
15	QA4	0	0	0	0	6	7	0	0	0	3	3
16	QA5	0	0	0	0	0	0	0	0	0	0	0
17	QA6	0	0	0	11	9	10	0	0	0	6	6
18	QA7	0	0	0	0	2	2	0	0	0	1	1
19	QA8	0	0	0	16	23	20	0	0	0	12	12
20	QA17	0	0	0	235	479	391	0	0	0	214	214
21	QE1	18	15	15	7	6	6	15	15	18	10	10
22	QE2	4683	4198	4188	3065	2459	2730	4188	4198	4683	3348	3348
23	QE3	133	94	93	22	5	14	93	94	133	49	49
24	QE4	120	91	91	34	22	27	91	91	120	55	55
25	QE5	5	0	0	0	0	0	0	0	5	1	1
26	QE6	235	192	191	95	38	58	191	192	235	118	118
27	QE7	12	8	8	6	4	4	8	8	12	7	7
28	QE8	487	362	360	152	98	116	360	362	487	223	223
29	QE17	301	268	267	196	155	175	267	268	301	214	214

Interpolating the Data

- A series of Excel formulae are used to interpolate the data during the solution, to give a QS value for any specified time during the analysis.

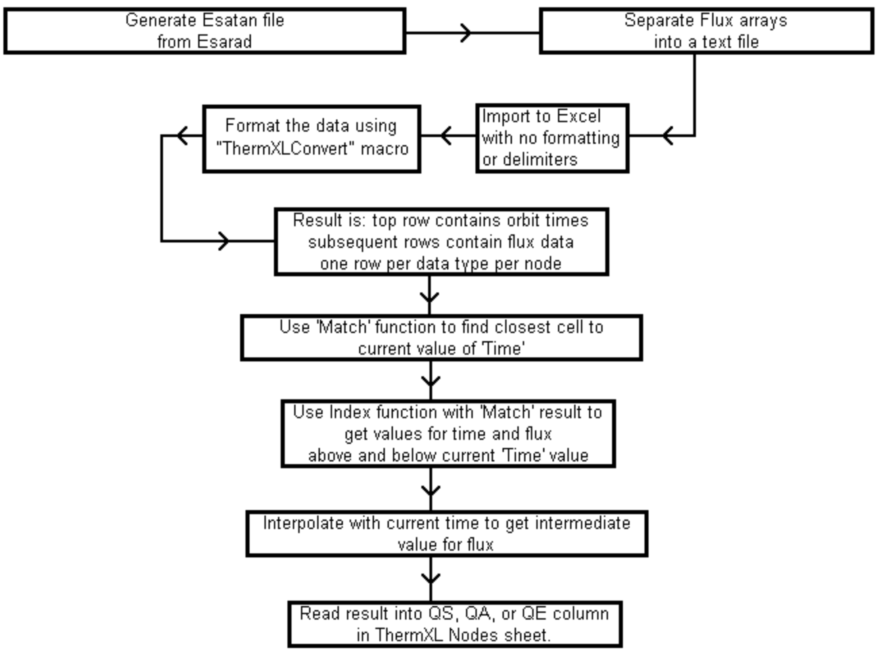


Microsoft Excel - BepiColombo_orbiter_model_2.xls

	M	N	O	P	Q	R	S	T
1		TIMEM NOW =	8311.964688					
2		match(time)	time index(match)	time index(match+1)	flux index(match)	flux index(match+1)	time	Flux Interpolation
3		8	7395.190031	8315.952917	0	0	8311.965	0
4		8	7395.190031	8315.952917	0	0	8311.965	0
5		8	7395.190031	8315.952917	0	0	8311.965	0
6		8	7395.190031	8315.952917	0	0	8311.965	0
7		8	7395.190031	8315.952917	0	0	8311.965	0
8		8	7395.190031	8315.952917	0	0	8311.965	0
9		8	7395.190031	8315.952917	0	0	8311.965	0
10		8	7395.190031	8315.952917	0	0	8311.965	0
11		8	7395.190031	8315.952917	0	0	8311.965	0
12		8	7395.190031	8315.952917	0	0	8311.965	0
13		8	7395.190031	8315.952917	0	0	8311.965	0
14		8	7395.190031	8315.952917	0	0	8311.965	0
15		8	7395.190031	8315.952917	0	0	8311.965	0
16		8	7395.190031	8315.952917	0	0	8311.965	0
17		8	7395.190031	8315.952917	0	0	8311.965	0
18		8	7395.190031	8315.952917	0	0	8311.965	0
19		8	7395.190031	8315.952917	0	0	8311.965	0
20		8	7395.190031	8315.952917	0	0	8311.965	0
21		8	7395.190031	8315.952917	14.634381	18.415212	8311.965	18
22		8	7395.190031	8315.952917	4197.579702	4683.434705	8311.965	4681
23		8	7395.190031	8315.952917	94.195224	133.442876	8311.965	133
24		8	7395.190031	8315.952917	91.402496	119.66255	8311.965	120
25		8	7395.190031	8315.952917	0.202425	5.220787	8311.965	5
26		8	7395.190031	8315.952917	192.395338	234.700647	8311.965	235
27		8	7395.190031	8315.952917	8.027751	11.855959	8311.965	12
28		8	7395.190031	8315.952917	361.984209	486.724272	8311.965	486
29		8	7395.190031	8315.952917	267.875323	301.496572	8311.965	301

FLUX data / FLUX / Case / ThermXL Nodes / ThermXL Results / St St Hot Case Results

Flow chart to import Esarad data to ThermXL



Other Interface Issues

- **Inactive Nodes.**
  - ThermXL does not support 'inactive' nodes. ThermXL users must therefore delete the ESARAD generated node and all the couplings to it as part of the process of importing to ThermXL.
- **Couplings Between a Node and Itself.**
  - ThermXL does not support 'Self Couplings', where a node is connected to itself. While such links have no impact on the heat balance, they are retained by ESARAD for information, so they must be manually removed.
- **Export to Esatan format**
  - There is no function to export ThermXL models into ESATAN format. This step will always be necessary when the scale of the model exceeds the practical limits of ThermXL.
  - It would be a simple matter to generate an Excel macro to format the nodes, couplings, fixed heat sources, and analysis control into ESATAN form. However, this would not deal with any functions and macros used during the analysis for time or temperature varying properties, functions to vary fluxes and couplings according to thermo-optical properties, and so on.

Conclusion

- **The BepiColombo proposal analysis was successfully completed and ThermXL was found to be a very suitable tool for early phase thermal design and analysis.**
  - Short model development time
  - Simple and Intuitive to build and develop the model
  - Very quick to analyze parameter changes
  - Simple to plot results on Excel charts

- **The most significant issue with using ThermXL is the amount of work needed to import the results from ESARAD. Astrium UK has developed a solution to this interface which results in much faster turn-around of analysis.**

Appendix C: Introduction to G-DELTAN V3

Introduction to
G-DELTAN V3

An Interactive
Thermal Analysis Tool

C. Williamson
Eutelsat S.A.

G-Deltan V3

An *Interactive* Thermal Analysis Tool

By Craig Williamson, Eutelsat SA

G-Deltan Contents

- Broad Specification
- Capabilities
- Variables
- Solution Routines
- Features
- Model Interpreter
- User Interface
- Benchmarks
- Autogen
- Postpro
- Development
- Annex - Syntax

G-Deltan Broad Specification

- Compatible with PC using Windows 95+
- Stand alone program
- Ease of use
- Rapid user interaction
- Complex problems
- Simple data transfer

G-Deltan Capabilities

- 500 Nodes
- Linear, radiation and fluid conductors
- User defined constants
- Steady state, transient and combined analysis
- Algebraic definitions of parameters
- Variable properties

G-Deltan Solution Routines

- ***Steady state:*** successive single point iteration with user set over-relaxation (damping) factor
- ***Transient:*** explicit forward difference with automatic reset of time step if required
- Results validated against industry standards

G-Deltan Variables

- ***Power:*** thermostat, cyclic interpolation, update with time
- ***Conductance:*** vs temperature, update with time, natural convection
- ***Capacitance:*** vs temperature, update with time
- ***Limits:*** stop analysis at defined node max/min temperature

G-Deltan Features

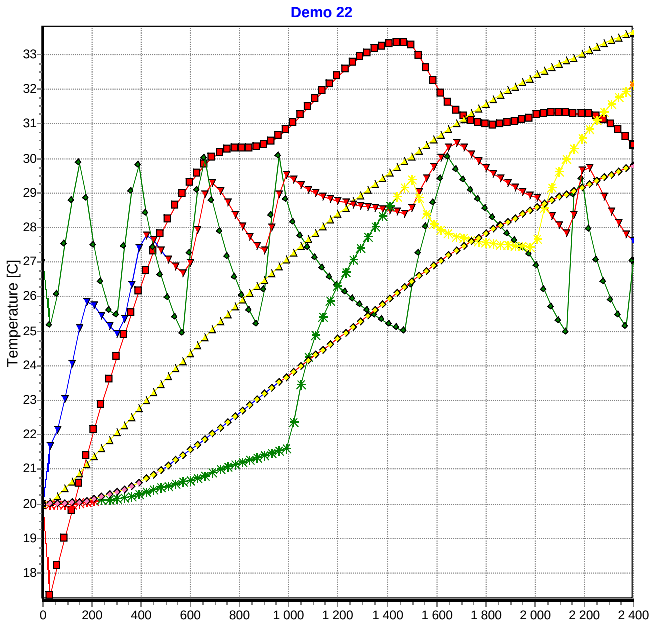
- Word processor style interface
- Familiar syntax
- Model interpreter requires no compilation
- Numerous output formats (T, Q, C, etc.)
- Real time on-screen plotting of transients
- De-bugging and error trapping
- Help files in HTML format

G-Deltan Model Interpreter

- Parses model and loads program arrays
- Free format input
- No limit for expression length
- Predefined variables: Pi
- Operators: + , - , * , / , ^ , div, mod
- Functions: cos, sin, sinh, cosh, tan, arctan, exp, ln, log10, log2, logN, sqrt, sqr, abs, int
- Bracketing to a level of 20

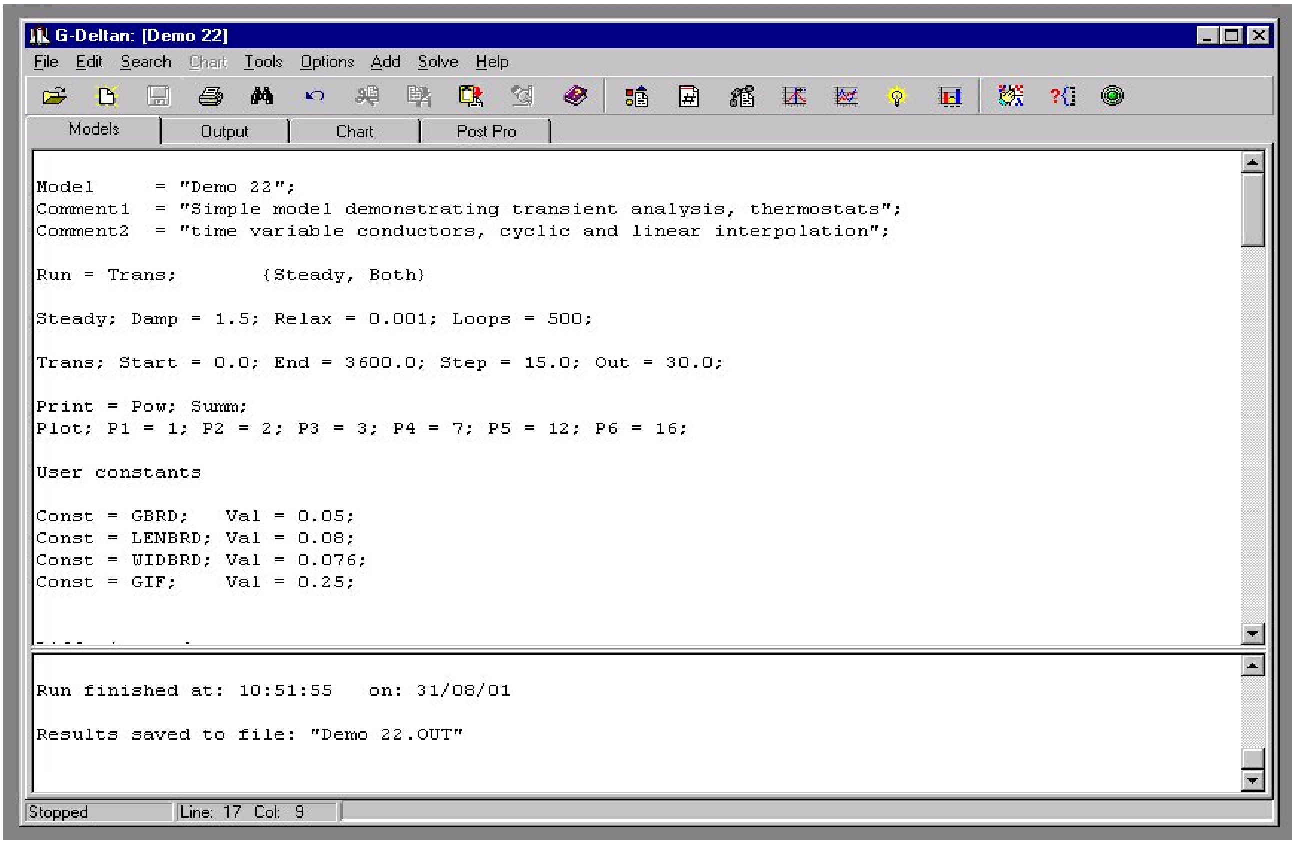
G-Deltan Screen Plot

- Nodes and title loaded from model
- Automatic real time scaling
- Fully editable chart parameters such as line styles and colours
- Zoom feature
- Copy, print and save options (EMF)



G-Deltan User Interface

- Menus for all file, print and edit operations together with run start and help
- Buttons for most common functions
- Blank nodes, conductors, etc. added by a simple click
- Tabbed window for access to model, outputs and chart
- Log window
- Line/column counter for model window
- Progress indicator



G-Deltan Benchmarks

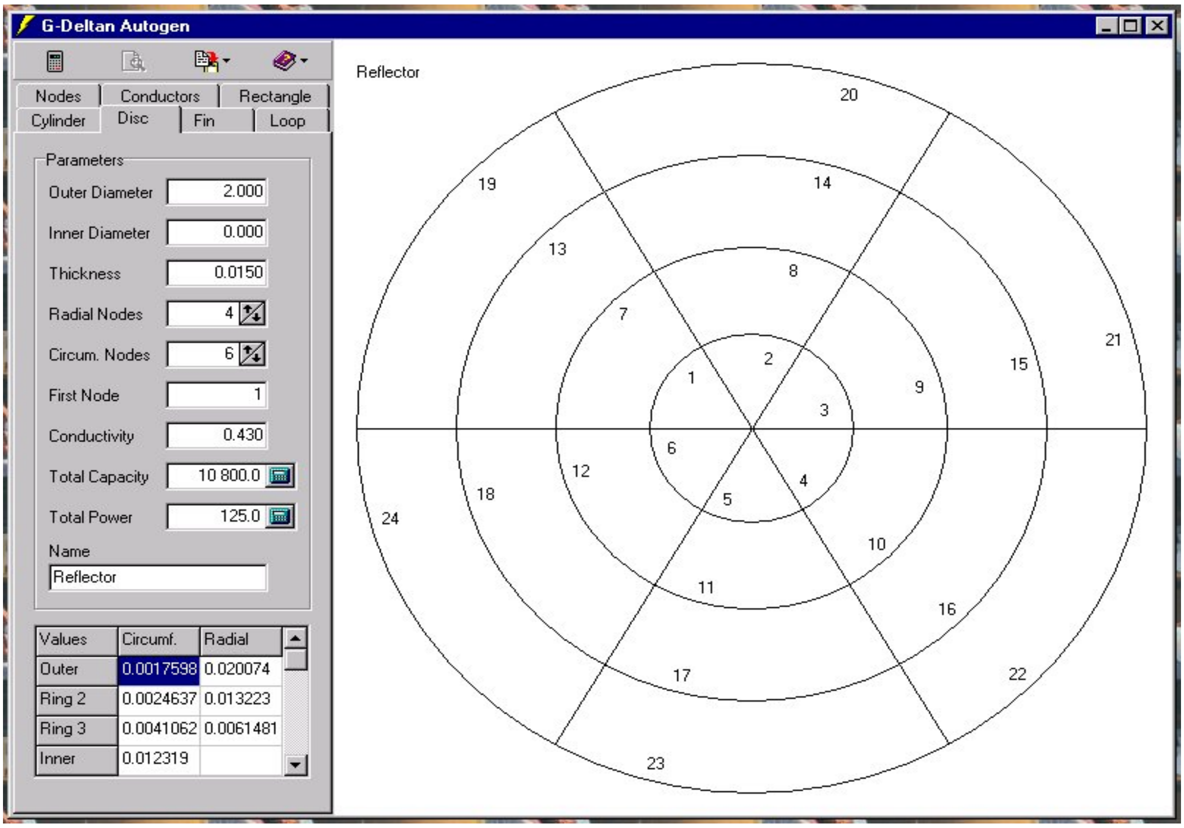
- Favourable performance compared with ESATAN for small to medium sized models

NB: G-Deltan run on a 600 MHz PIII laptop PC. ESATAN was compiled and run on a Sun Ultra 1 workstation. Transient simulation of 24 hours, outputs each 60 s.

Model	Step	G-Deltan	ESATAN
105 node SS	Prepro/parse Solve Total	<1 1 1	8 14 22
22 node TR	Prepro/parse Solve Total	<1 11 12	2 19 21
22 node TR + real time plot	Prepro/parse Solve Total	<1 70 71	N/A

G-Deltan Autogen

- Automatic generation of nodes and conductors and meshing for common shapes (rectangle, cylinder, fin, disc, loop)
- User input of dimensions and material properties
- Visual feedback of meshing
- Copy/Paste data to **G-Deltan**



G-Deltan Postpro

- Generation and printing of multiple charts from transient output file
- Full editing capabilities for line styles and colours
- Automatic scaling
- Zoom feature
- Charts can be copied and pasted into Word documents, etc. for reports
- Charts can be saved as EMF files

G-Deltan Development

- V3 currently in Beta phase
- GUI being refined
- Additional solution algorithms desirable for speed and flexibility
- Further variable routines required
- Users sought for testing and de-bugging

G-Deltan Syntax: Control

- Control of run and outputs
- Examples:

```
Model = "Demo 105"; {Model Filename}
Comment1 = "105 Node model..."; {String <= 70 chars}
Comment2 = "and …..."; {As Comment1}
Run = Steady; {Steady, Trans, Both, Diag for error checking}
Damp = 1.65; Relax = 0.001; Loops = 100; {SS}
Start = 10; End = 3600; Step = 15.0; Out = 60.0; {TR}
Print = Diag; Temp; Tab; CondL; CondR; Pow; Flow; Min; Max;
Tau; Cap; Summ; {Output routines, selectable}
Plot; P1 = 1; P2 = 2; P3 = 3; P4 = 4; P5 = 5; P6 = 6;
{Screenplot, 6 nodes}
```

G-Deltan Syntax: Constants

- **`Const = String; Val = Number; Comment`** `{Comment optional not used by program}`
- Examples:

```
Const = PRGPL; Val = 0.9; Percentage coverage
Const = AMBIENT; Val = 12.5;
Const = MASSFL; Val = 10 * 0.15 / 25.4;
```

- Note: Constants must be defined before they are called

G-Deltan Syntax: Nodes

- **`Node(I)`**`{<=500}`**`; Type = D`**`{B=Boundary or D=Diffusion}`**`;C:=No`**`{Capacitance}`**`; T = No`**`{Starting temp}`**`; Q=No`**`{Power}`**`;Name = String`**`{<= 30 chars}`**`;`**
- Examples:

```
Node(104); Type = B; T = 20.0; Name = Boundary[104];
Node(105); Type = B; T = 10.0; Name = Boundary[105];
Node(1); Type=D; C=15000; Q=4*8.3; T=20; Name=PCB[1];
Node(2); Type = D; T = AMBIENT + 5; Name = PCB[2];
```

G-Deltan Syntax: Conductors

- **`GL(Node i, Node j) = Val;`** `{GL for Linear conductor, GR for radiation, GF for fluid}`
- Examples:

```
GL(1, 2) = 0.1234;
GL(5, 57) = PRGPL * 2.3 / 0.76;
GR(34, 345) = 0.63;
GF(45, 46) = MASSFL * CP;
```

- For GF the upstream node is placed first

G-Deltan Syntax: Variables

- **Examples:**

```
ThStat(2); Ton=25; Toff=30.0; Stat=Off; Q=50.0;

CycliQ(1);Pts=5;Per=800;0;0;240;15;400;20;600;15;800;0;

VariaG(1,21);Type=GL;Pts=4;0;150;50;175;100;200;150;225;

UpdatG(1,21);Type=GL; Time > 1500.0;  New = Old * Pi/2;

Limits(3); Min = 0; Max = 50;

UpdatQ(12); Time > 1000; New = 5;
```

Appendix D: Improving Ray-Tracing for Monte Carlo Simulations

Improving Ray-Tracing
Algorithm
for
Monte Carlo Simulations

B. Shaughnessy
RAL

Improved Ray-Tracing Algorithm for Monte Carlo Simulations

Bryan Shaughnessy

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Rutherford Appleton Laboratory
Oxfordshire, OX11 0QX, UK.

Tel: +44 (0)1235 445061
Fax: +44 (0)1235 445848

e-mail: b.m.shaughnessy@rl.ac.uk

Monte Carlo (MC) Approach

• Exchange-factors are calculated through ray-tracing the paths of many discrete 'energy-bundles'.
- complex geometries can be modelled.
- but, lengthy computation time to achieve adequate convergence.

• Emitted and reflected directions are selected randomly from probability functions.

• About 75 - 95% of the ray-tracing process is due to 'intersection calculations' [1].

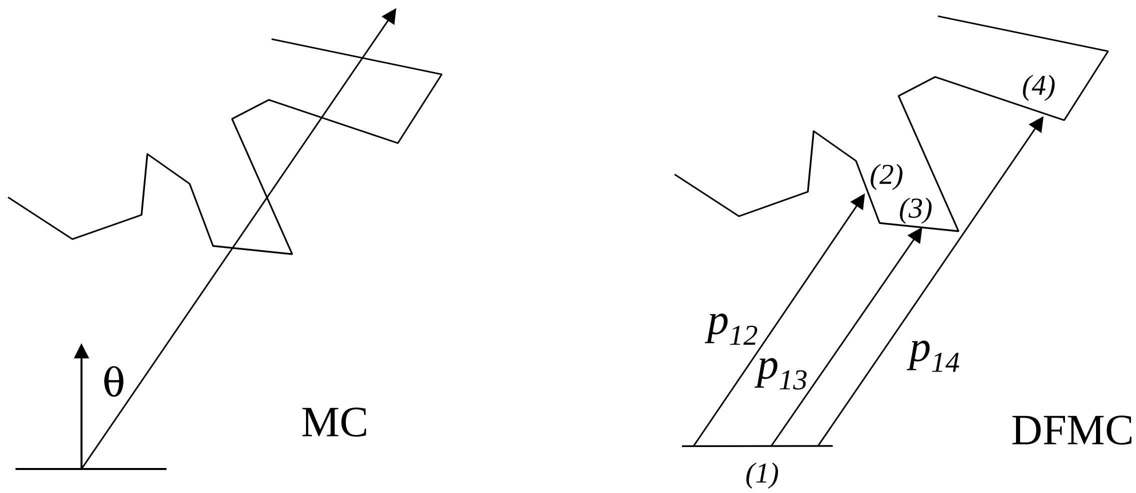
• Conventional speed-ups:
- bounding volumes, graphics hardware, vector/parallel computing.

Discrete Function Monte Carlo (DFMC) Approach

- Change in data structure used for ray-tracing. Remove or reduce the number of intersection calculations.
- Discrete functions describe the probability of radiation exchange between each surface.
- Instead of sampling directions, the destination of the ray is sampled.
- Pre-processing is required to evaluate the 'transition probabilities'.
  - Less ray-intersection calculations are required compared with traditional Monte Carlo.
  - Specular/bi-directional reflection:
    - 'n-bounce' approximation.
    - mesh refinement.
- Very fast algorithms can be used to determine the paths of each ray of radiation (ray-intersection calculations are NOT required).

Rutherford Appleton Laboratory
Space Science and Technology Department

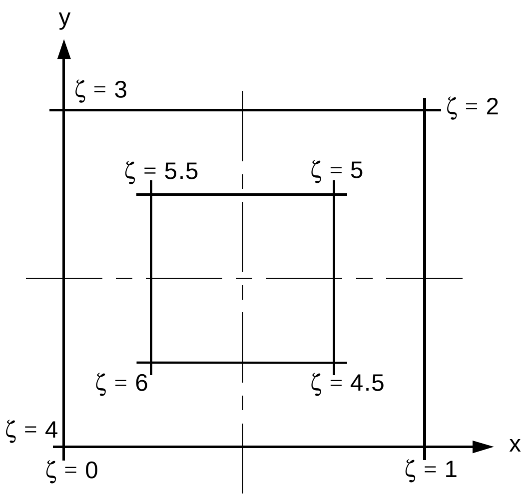
Direction Selection in MC and DFMC



Advantages of the DFMC Approach

- A new way of looking at radiative heat transfer calculations.
- Computational speed improvements.
- Discrete probability functions are independent of (overall) radiative properties.
  - Pre-processing not required if properties are changed.
- Data structure permits rapid updates of the discrete probability functions:
  - Moving geometry.
  - Transient simulations.

Analysis Case



- 'North' enclosure wall (2 ≤ ξ ≤ 3) at 320 K.
- Rest of geometry at 300 K.
- Emissivity:
  - $\varepsilon_{enclosure} = 0.1$
  - $\varepsilon_{obstruction} = 0.9$
- Reflections ('one-bounce' approximation):
  - Specular.
  - Bidirectional:

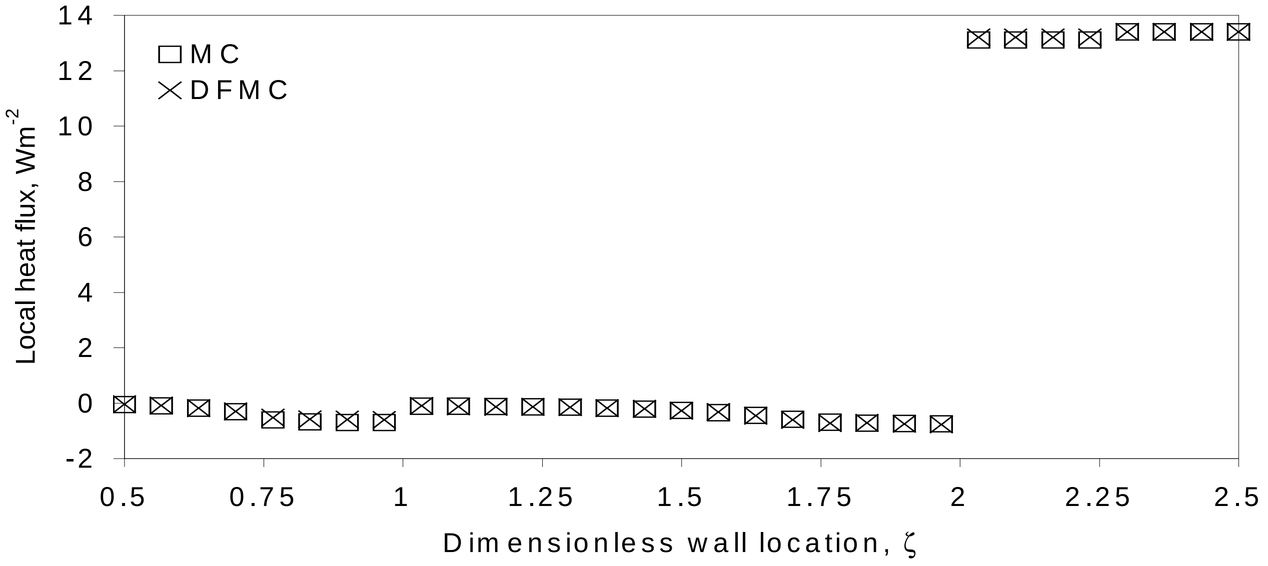
$$f(\theta_I, \theta_R) = \frac{(s^2+1)\cos(\theta_R) e^{-s|\theta_I+\theta_R|}}{2s\cos(\theta_I) + e^{-s(\pi/2+\theta_I)} + e^{-s(\pi/2-\theta_I)}}$$

$$-\pi/2 \geq \theta \geq \pi/2$$

Computational Speed Improvements

Convergence criteria	Simulation time relative to Monte Carlo, %		Reference
	Specular case	Bi-directional case	
±5% (99% conf.)	13	17	[2]
±10% (95% conf.)	33	50	[3]

Comparison of Local Heat Fluxes for Specular Case



Conclusion

- A very fast ray-tracing algorithm for Monte Carlo simulations has been presented.
- Initial simulations have indicated that speed-ups to a factor of 8 are possible.
- Suited to high-reflectivity geometries.
- The data structure:
  - permits changes to the radiative model to be assessed quickly.
  - offers many possibilities with respect to numerical methods.
- Starting point for developing a new improved radiation simulation technique.

References

[1] Plunkett, D. J., and Bailey, M. J., 1985, “The Vectorization of a Ray-Tracing Algorithm for Improved Execution Speed,” *IEEE Computer Graphics and Applications*, Vol. 5, No. 8, pp. 53-60.

[2] Shaughnessy, B. M., and Newborough, M., 1998, “A New Method for Tracking Radiative Paths in Monte Carlo Simulations,” *ASME Journal of Heat Transfer*, Vol. 120, No. 3, pp. 792-795.

[3] Shaughnessy, B. M., and Newborough, M., 1999, “Calculating the Reflected Paths of Radiation in High Reflectivity Enclosures,” 5th *ASME/JSME Joint Thermal Engineering Conference, March 15-19, San Diego, California*.

Appendix E: New Ray-Tracing Technique for THERMICA

New Ray-Tracing Technique
for
THERMICA

M. Jacquiau
Astrium-SAS

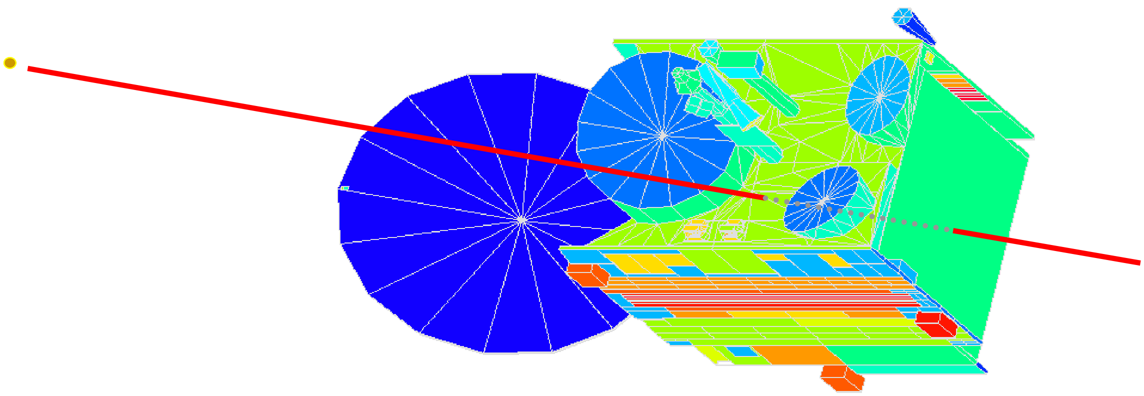
Ray Tracing Evolution

Marc Jacquiau
Astrium

- *Main purpose*
- *Octree technique description*
- *First results*
- *Development status*

Why use the Ray Tracing

- Model physical phenomena
  based on *rectilinear* propagation of particles



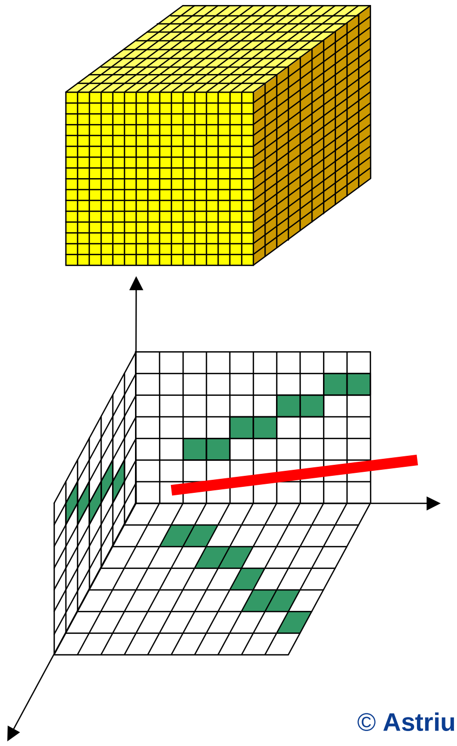
Applications :
- thermal radiation
- radiation dose
- perturbing forces/torques
- contamination
- électromagnetism
- micrometeoroids ...

Present technique (Thermica/Esarad)

- Space discretization
  in *homogeneous* voxels

- Ray propagation in voxels :
  simple & fast algorithm
  (few integer additions)

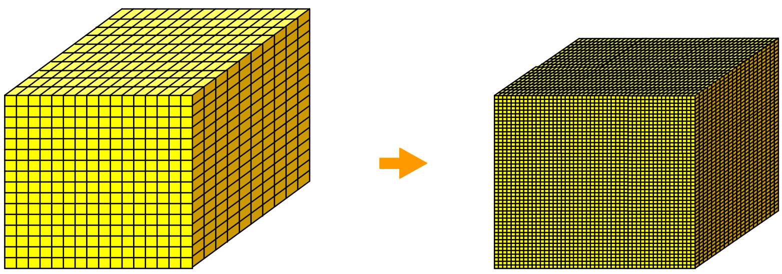
- Intersection tests with each surface of
  voxels along the ray path :
  directly impacts *Performances*



Engineering evolution constraints

- Today 's modelling requires (all together) :
  - bigger models
  - more accuracy (i.e. more rays)
  - parametric studies

⇒ Reduction of voxel size



⇒ **Exponential increase of the memory size**
⇒ **Reduction of the ray propagation speed**

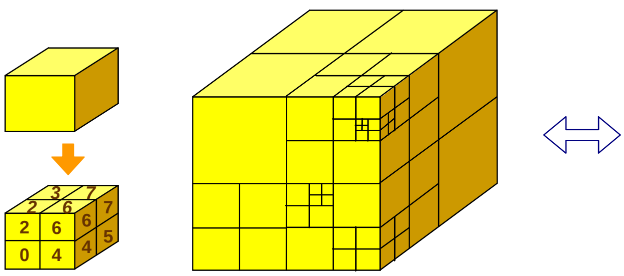
Industrial approach

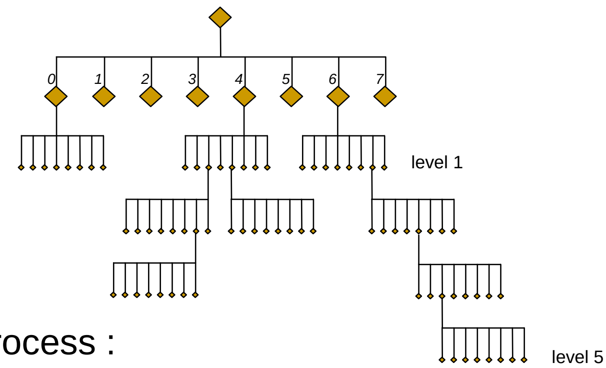
- CPU and memory evolutions are likely not to be sufficient

- Development of a new technique :
  - solving the engineering modelling problems for the next 10 years
    ⇒ **think of additional features**
  - with optimal investment (other priorities exist)
    ⇒ **avoid too sophisticated methods**
  - available quickly
    ⇒ **use what is already proven**

Octree method

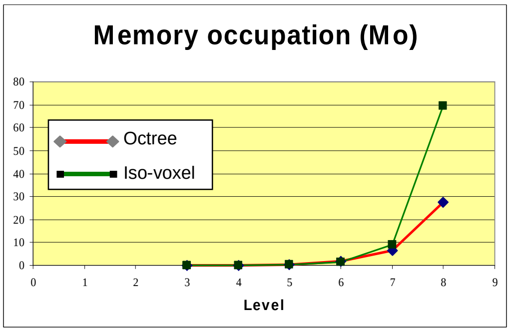
- The space decomposition is represented by a tree with nodes being terminals or fathers of 8 other nodes

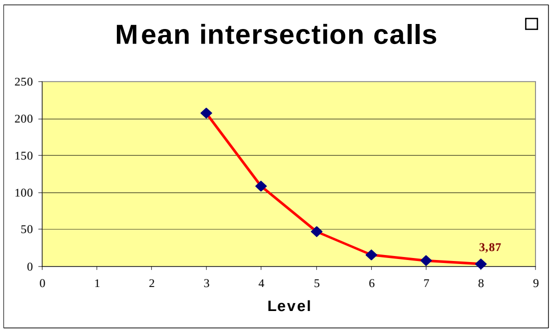


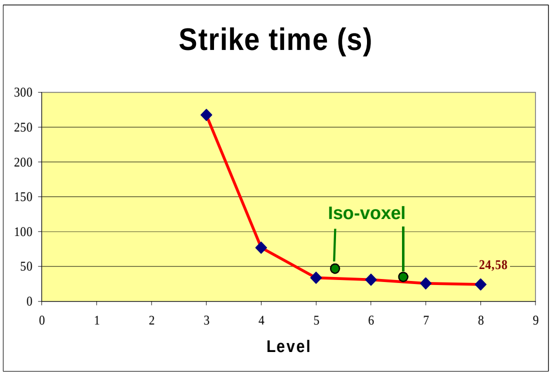


- Initialisation is the most delicate process :
  - not enough nodes/levels
    ⇒ CPU consumption during RT
  - too many nodes/levels
    ⇒ CPU consumption during initialisation
    ⇒ memory size

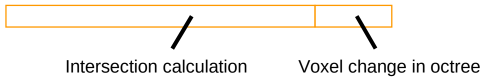
First results (HB7 model)







RT CPU time :



The higher the number of levels, the higher the voxel changes

Development status

- Performed on **classical Thermica shapes**, including prisms and revolution shapes
  Additional tests still necessary on various big models to confirm the initialization method
- Current development on **cut surfaces**
  with significant improvements compared to MMS algorithms developed in Esarad phase 1 (1990).
- Ray-Tracing on **Nurbs and Meshed surfaces** to be done
- Ray-Tracing **implementation** in Thermica V4 foreseen in **June 2002**

Appendix F: Report on TFAWS and Introduction to ThermPlot

Report on TFAWS

and

Introduction to ThermPlot

HP. de Koning
ESTEC/TOS-MCV

Report on TFAWS 2001

12th Thermal and Fluids Analysis Workshop
NASA Marshall Space Flight Center / Univ. of Alabama
Huntsville, AL, USA, September 10-14, 2001
http://tfaws01.msfc.nasa.gov
Hans-Peter.de.Koning@esa.int

Mechanical Engineering Department
Thermal and Structures Division

Format

- 5 days - 196 registered attendees
- 13 half-day Paper Sessions (mostly 2 tracks in parallel)
  - Spacecraft and Vehicle Fluid Systems Design, Analysis and Test
  - Spacecraft and Vehicle Thermal Systems Design, Analysis and Test
  - Interdisciplinary Analysis and Integration
  - Propulsion and Launch Vehicle Thermal Systems Design, Analysis and Test
- 4 Keynote addresses
- Product Overview Lectures / Short Courses
- Hands-On Computer Classes
  - 4 classrooms equiped with 40 PCs or SGI workstations each

POLs, Short & Hands-On Courses

- CFD Tools
  - CFDRC: CFD-Fastran, CFD-ACE+, CFD-GEOM, CFD-VIEW, MDICE
  - NASA: Corsair, Gridgen
  - ???: FIELDVIEW
- Spacecraft / instrument thermal control and thermo-hydraulics
  - Cullimore & Ring: Thermal Desktop/RadCAD, FloCAD, SINDA/FLUINT
  - Harvard Thermal: Thermal Analysis System (TAS)
  - Maya / SDRC: I-DEAS/TMG and FEMAP/TMG
  - NASA-MSFC: Generalized Fluid System Simulation Program (GFSSP)
  - Network Analysis: SINDA/G, SINDA/ATM (FEMAP), THERMICA
  - Space Design: TSS, SINDA/FLUINT 3.0

Mechanical Engineering Department
Thermal and Structures Division

Papers

- “Usual” mix of overviews, case studies, specialist subjects
- Highlights (personal selection)
  - Inovative application of optical fiber to measure (radiation) temperature
  - ThermPlot Excel-based postprocessor for SINDA and ESATAN
    Freeware by Swales (Hume Peabody)
- Good response to ESA Thermal Model Data Exchange using Open Standards “evangelist” paper
  - Maya will start STEP-TAS interface implementation in TMG
  - MSC/Patran now has a beta-version STEP-TAS interface

General Trends - Tools

- Increase in interest for thermal control and CFD
  – Large programs: NASA's 2nd Gen Reusable Launch Vehicle (RLV)
- Back to basics: improvements of basic algorithms
  – new sparse matrix solvers
  – enhancements for ray-tracing
- Connect to CAD and structural FEA
  – increase scaleability of tools for very large models
- Engineering analysis process integration / speed-up
  – multi-disciplinary and multi-physics analysis
  – concurrent engineering
  – computer aided workflow & configuration control

Specific tool developments

- Use of Conjugate Gradient sparse matrix solvers
  – SINDA/G and TMG claim significant solve speed increase
- Advanced oct-cell algorithm in TSS to speed up ray-tracing
  – For large models (several thousand surfaces) need to go to 12 levels deep
- Thermal Desktop focus on "CAD-like" GUI modelling
  – Some users like this: model building speed, quick results
  – Other users dislike it: difficult to know/verify/control/rerun model
- MS-Office (Excel, Visio) toolkit for SINDA/G
- FEMAP/TMG sister product to I-DEAS/TMG

Conclusions

- Well organised, very practical workshop
- Very interesting detailed hands-on courses
  - At beginner, routine, advanced user levels
- Open atmosphere - even between competing tool developers
- Renewed interest in thermal control and CFD
- Trend: integration of thermal analysis into engineering process
  - Ingest CAD / FEA models
  - Analysis with large set of surfaces
- Renewed activity in thermal tools development

Intro to ThermPlot

- Tool developed by Hume Peabody of Swales Aerospace, USA
- Used successfully on METOP Phase C/D analysis
  - Swales is responsible for the US instruments on METOP
- Freeware - download from www.swales.com after registration
- Can read files from standard output routines of SINDA/G, SINDA/FLUINT, ESATAN
- ESATAN interface can be considered a beta release
  - No formal validation performed (yet)
- Need to use quite high spec PC: 128+MB RAM, 500+MHz

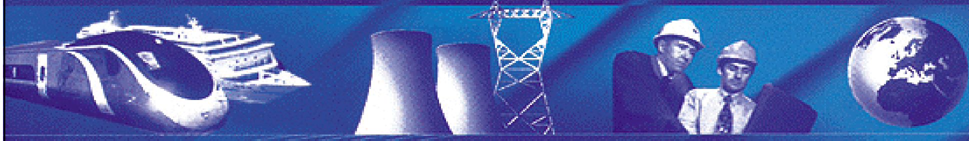
Appendix G: Artifis / Topic / ThermXL

Artifis

Topic

ThermXL

F. du Laurens d'Oiselay
Alstom



15th European Workshop on
Thermal and ECLS Software
ESTEC, The Netherlands
October 9-10, 2001

ARTIFIS / TOPIC / ThermXL

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Frédéric du Laurens d'Oiselay
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esa.support@power.alstom.com

ALSTOM

ARTIFIS – Thermal Analyser

ALSTOM

A.R.T.I.F.I.S.: *'Accurate Reference Tool for Incident Fluxes Impinging on Spacecraft'*

- Presented at ESTEC in 1996 (ECLS Workshop)
- Benchmarked with handbook *'Spacecraft thermal control design data'*
- Acted as reference to validate incident fluxes calculated by ESARAD v-3

ARTIFIS – Features

ALSTOM

- Pre-phase A in-house *thermal analyser*
  - Fast and easy to use
  - Same 'concept' as ESARAD
  - Simple orbiting surfaces
  - Batch process, MS-DOS / Unix
- Incident fluxes calculated by means of analytical expressions
  - Accurate and reliable results
  - One single orbit

ARTIFIS – Current Developments

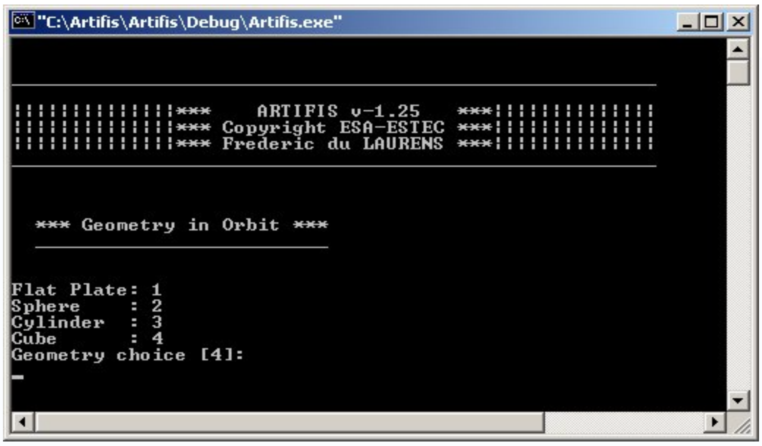
ALSTOM

- Already in use at ESTEC since 1998
- First version distributed with ESARAD v-4.2 earlier this year
- Improvements carried out over the last year by Duncan Gibson (ESTEC)
  - New code standards
  - CPU improvements
  - No new major functionality

ARTIFIS – Geometry

ALSTOM

- Flat plate
- Cylinder
- Sphere
- Cube



- Spin available for flat plate and cylinder
- Coating is assumed to be black paint

ARTIFIS – ‘Kernel’

ALSTOM

- Same standards as ESARAD v-3
  - One single orbit
  - LOCS – planet or ‘Sun’ oriented
  - Euler angles – φ, ψ and ω
- Incident fluxes calculated by means of analytical expressions
  - Simpson’s integration method
  - Accurate and reliable results

ARTIFIS – Ouput

ALSTOM

- Output Files
  - FluxResults.rpt
  - FluxResults.GFF

FluxResults.rpt - WordPad

File Edit View Insert Format Help

```
ARTIFIS v-1.0 REPORT
--------------------

Flat Plate.

Flat plate area=1.00 m2
LOCS: Planet oriented.

Euler angles:  phi=0.0 deg  psi=180.0 deg  omega=0.0 deg

E=1360.0 W/m2      delta=23.00 deg
Rp=6371.0 km       gc=9.80655 m/s2
Temp=288.0 K       Albedo=0.300

Za=800.00 km       Zp=800.00 km
a=7171.00 km       e=0.000000  i=98.0 deg
alpha=0.0 deg      Omega=135.0 deg

Beta=36.17 deg     Eclipse: Yes
```

ANGLE	TIME	IS	IP	IA	IS+IA+IP
0.00	0.00	0.000	307.928	0.000	307.928
18.83	316.39	0.000	307.928	0.000	307.928
19.33	324.79	620.285	307.928	0.000	928.212
45.00	755.95	166.733	307.928	2.371	477.032
90.00	1511.90	0.000	307.928	152.023	459.951
135.00	2267.85	0.000	307.928	254.024	561.952
180.00	3023.80	0.000	307.928	207.221	515.149
225.00	3779.76	0.000	307.928	41.401	349.329
268.14	4504.39	620.285	307.928	0.000	928.212
268.64	4512.79	0.000	307.928	0.000	307.928
270.00	4535.71	0.000	307.928	0.000	307.928
315.00	5291.66	0.000	307.928	0.000	307.928
360.00	6047.61	0.000	307.928	0.000	307.928
AVERAGE		76.499	307.928	81.959	466.386

For Help, press F1

ARTIFIS – Quick Demo

ALSTOM

"C:\Artifis\Artifis\Debug\Artifis.exe"

```
Number of orbital positions, N [8]:
60
Number of orbital positions = 60

Shadow offset, offset [0.50 deg]:

Shadow offset = 0.50

  *** LOCS Orientation ***
  ________________________


PLANET ORIENTED: 1
SUN ORIENTED    : 2
LOCS orientation choice [1]:
1
PLANET_ORIENTED. Please wait...

Solar flux:
0   10   20   30   40   50   60   70   80   90   100%
|----+----+----+----+----+----+----+----+----+----|
*************************************************** Completed!

Planet flux:
0   10   20   30   40   50   60   70   80   90   100%
|----+----+----+----+----+----+----+----+----+----|
*************************************************** Completed!

Albedo flux:
0   10   20   30   40   50   60   70   80   90   100%
|----+----+----+----+----+----+----+----+----+----|
*********************
```

TOPIC – Thermal Designer

ALSTOM

T.O.P.I.C.: *'Thermal and Orbital Propagated Information Calculator'*

- Presented at ESTEC in 1998 (ECLS Workshop)
- Built on top of ARTIFIS
- Benchmarked with handbook *'Spacecraft thermal control design data'*

TOPIC – Features

ALSTOM

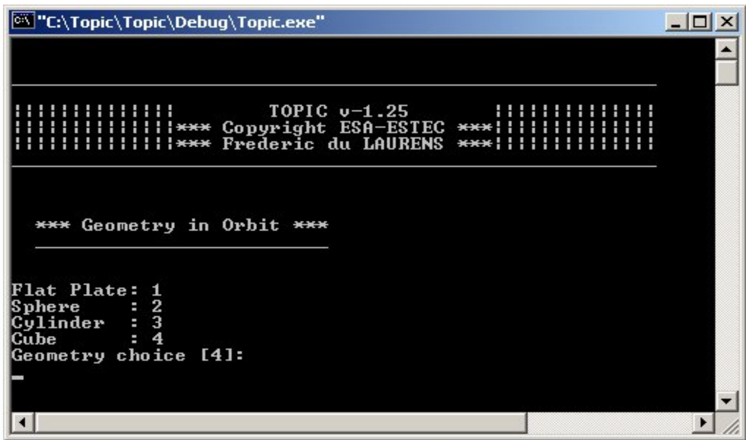
- Pre-phase A in-house *thermal designer*
  - Fast and easy to use
  - Simple Earth-orbiting surfaces
  - Analysis performed throughout a mission timeline
  - J_2 perturbation, Sun-synchronous orbit
  - Batch process, MS-DOS / Unix
- Incident fluxes calculated by means of analytical expressions
  - Accurate and reliable results

TOPIC – Current Developments

- Already in use at ESTEC since 1999
- First version distributed with ESARAD v-4.2 earlier this year
- Improvements carried out over the last year by Duncan Gibson (ESTEC)
  - New code standards
  - CPU improvements
  - No new major functionality

TOPIC – Geometry

- Flat plate
- Cylinder
- Sphere
- Cube



- Spin available for flat plate and cylinder
- Coating is assumed to be black paint

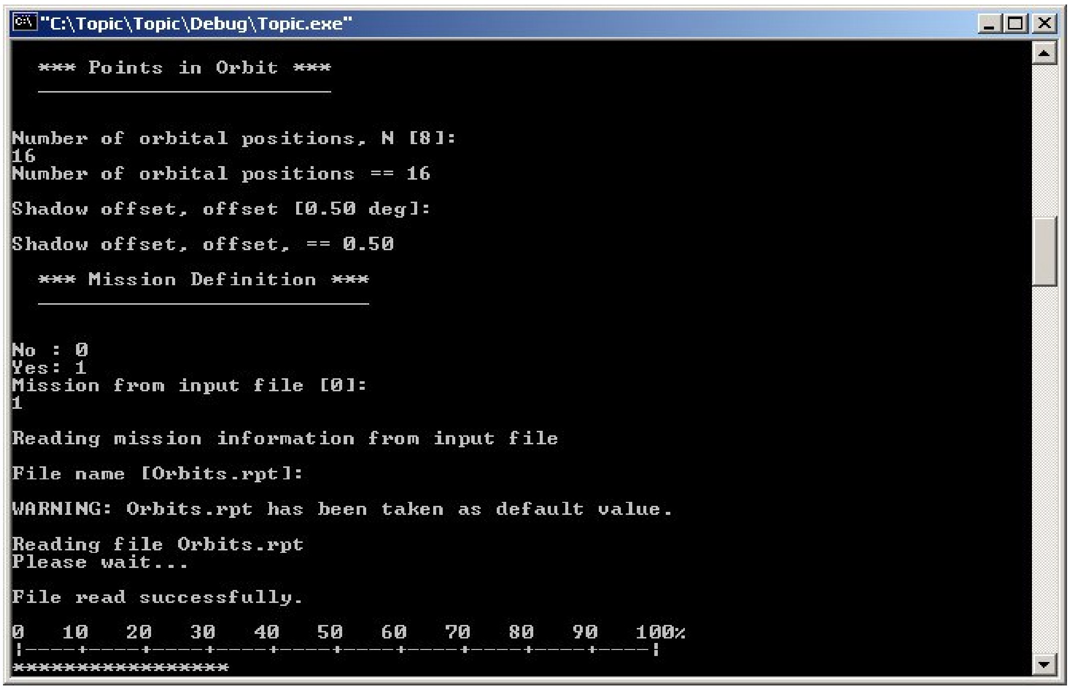
TOPIC – Thermal Design

- Same standards as ESARAD v-3
  - One single orbit
  - LOCS – planet or 'Sun' oriented
  - Euler angles – φ, ψ and ω
- Incident fluxes calculated by means of analytical expressions
  - Simpson's integration method

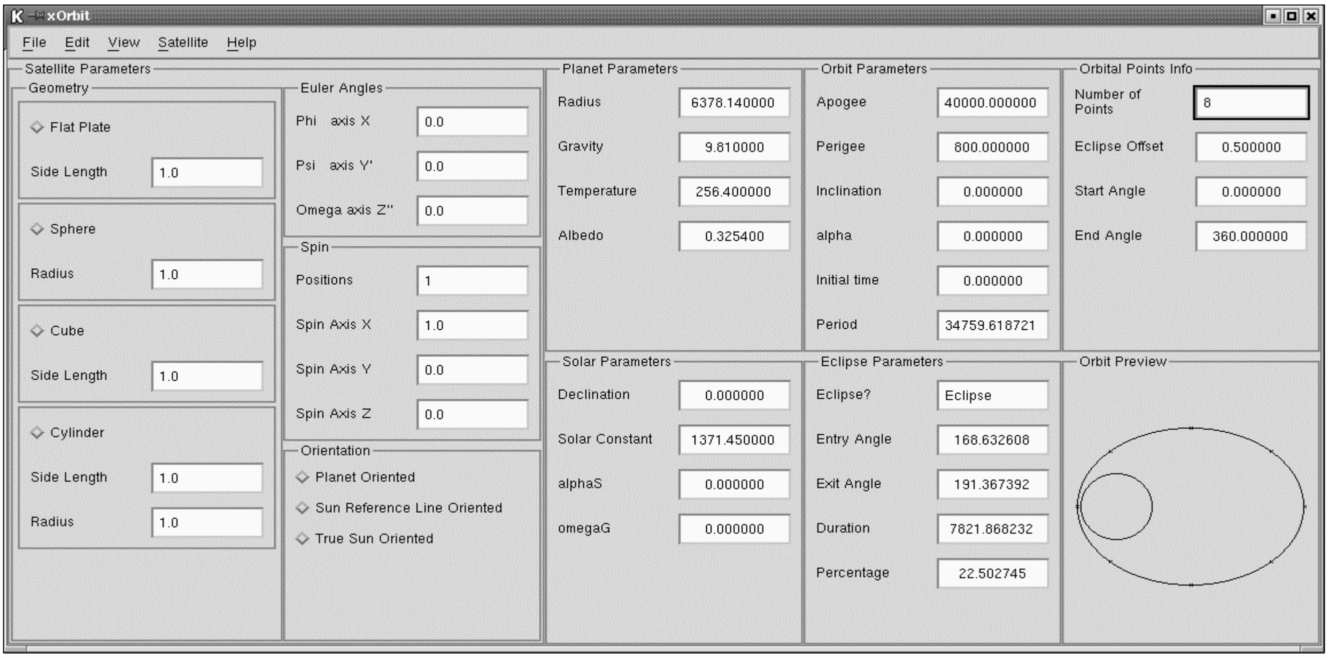
TOPIC – Ouput Files

- FluxDetails.rpt
  - Flux values in detail, each orbital position
- Thermal.rpt
  - Fluxes, eclipse, β angle, solar constant...
- Solar.rpt
  - Equation of time, Julian date, solar declination...
- MinMaxESH.rpt
  - Min and max values, ESH...
- Orbits.rpt

TOPIC – Quick Demo



TOPIC – Future Developments

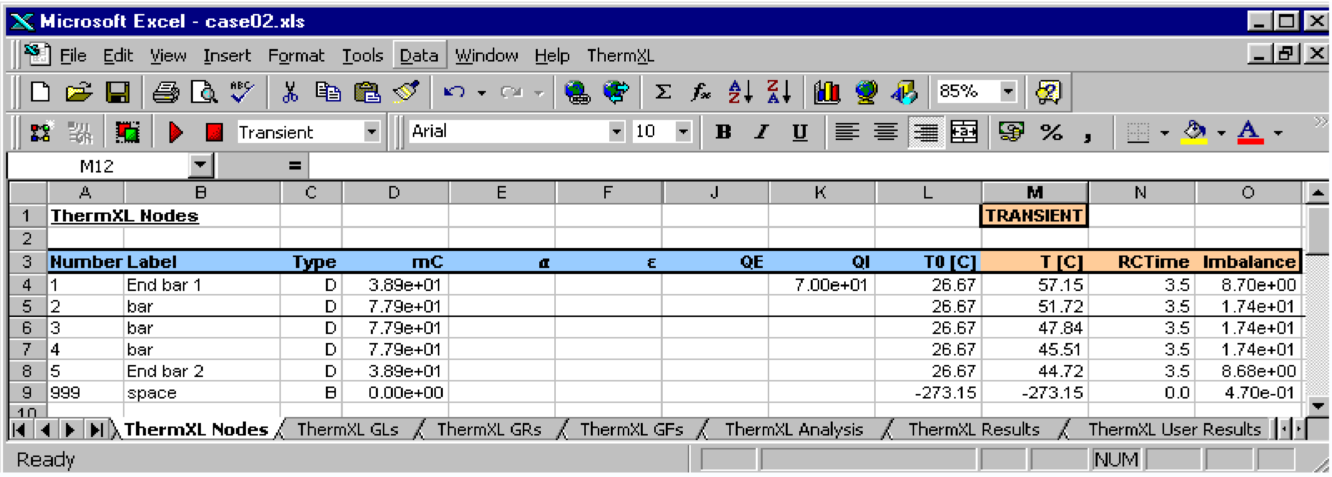


ThermXL v-2.0 – Status

- Final testing currently on-going
  - Actual release expected late October 2001

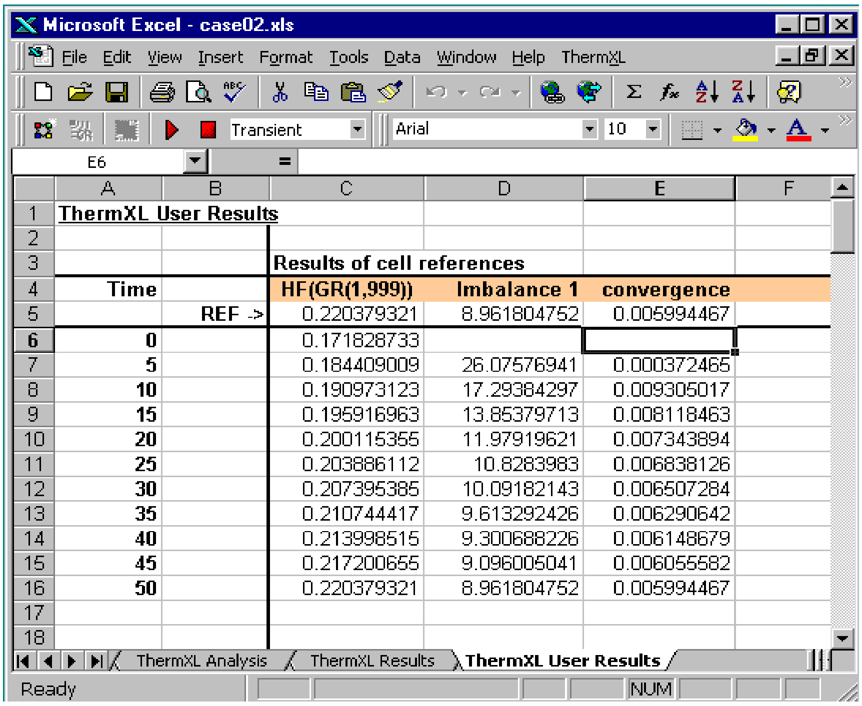
- Four major enhancements
  - Heat balance calculation for each node
  - Worksheet ‘User Results’ automatically generated
  - ESATAN file export
  - Possibility of using Visual Basic (macros...)

ThermXL v-2.0 – Imbalance



Number	Label	Type	mC	α	ε	QE	QI	T0 [C]	T [C]	RCTime	Imbalance
1	End bar 1	D	3.89e+01				7.00e+01	26.67	57.15	3.5	8.70e+00
2	bar	D	7.79e+01					26.67	51.72	3.5	1.74e+01
3	bar	D	7.79e+01					26.67	47.84	3.5	1.74e+01
4	bar	D	7.79e+01					26.67	45.51	3.5	1.74e+01
5	End bar 2	D	3.89e+01					26.67	44.72	3.5	8.68e+00
999	space	B	0.00e+00					-273.15	-273.15	0.0	4.70e-01

ThermXL v-2.0 – User Results

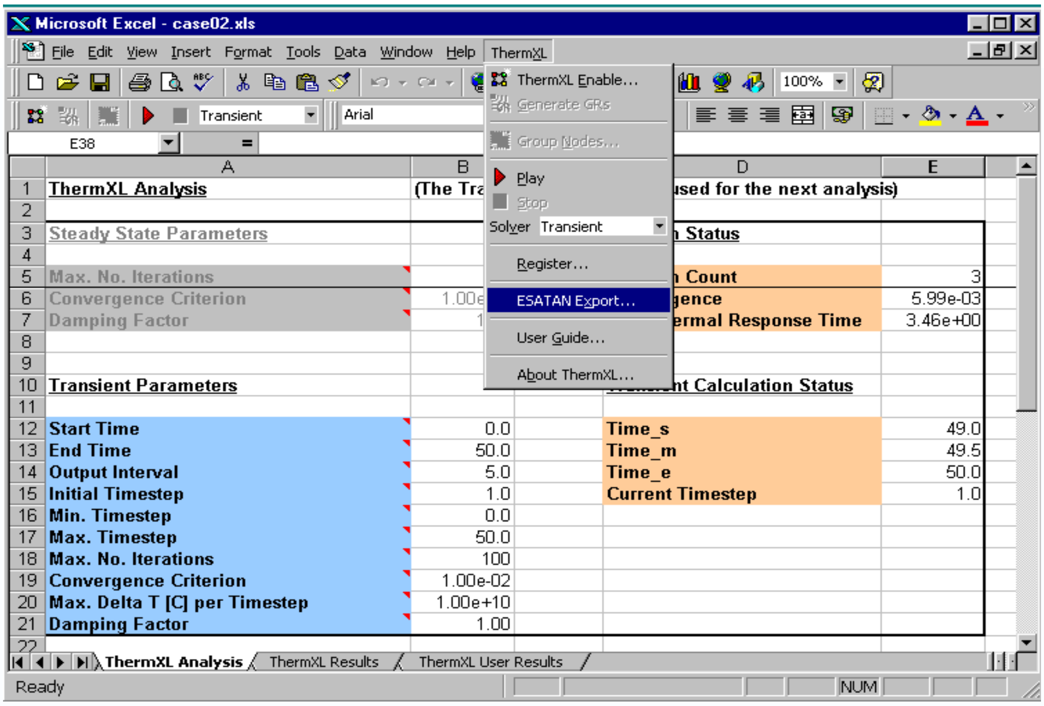


Microsoft Excel - case02.xls

	A	B	C	D	E
1	ThermXL User Results				
2					
3			Results of cell references		
4	Time		HF(GR(1,999))	Imbalance 1	convergence
5		REF ->	0.220379321	8.961804752	0.005994467
6	0		0.171828733		
7	5		0.184409009	26.07576941	0.000372465
8	10		0.190973123	17.29384297	0.009305017
9	15		0.195916963	13.85379713	0.008118463
10	20		0.200115355	11.97919621	0.007343894
11	25		0.203886112	10.8283983	0.006838126
12	30		0.207395385	10.09182143	0.006507284
13	35		0.210744417	9.613292426	0.006290642
14	40		0.213998515	9.300688226	0.006148679
15	45		0.217200655	9.096005041	0.006055582
16	50		0.220379321	8.961804752	0.005994467
17					
18					

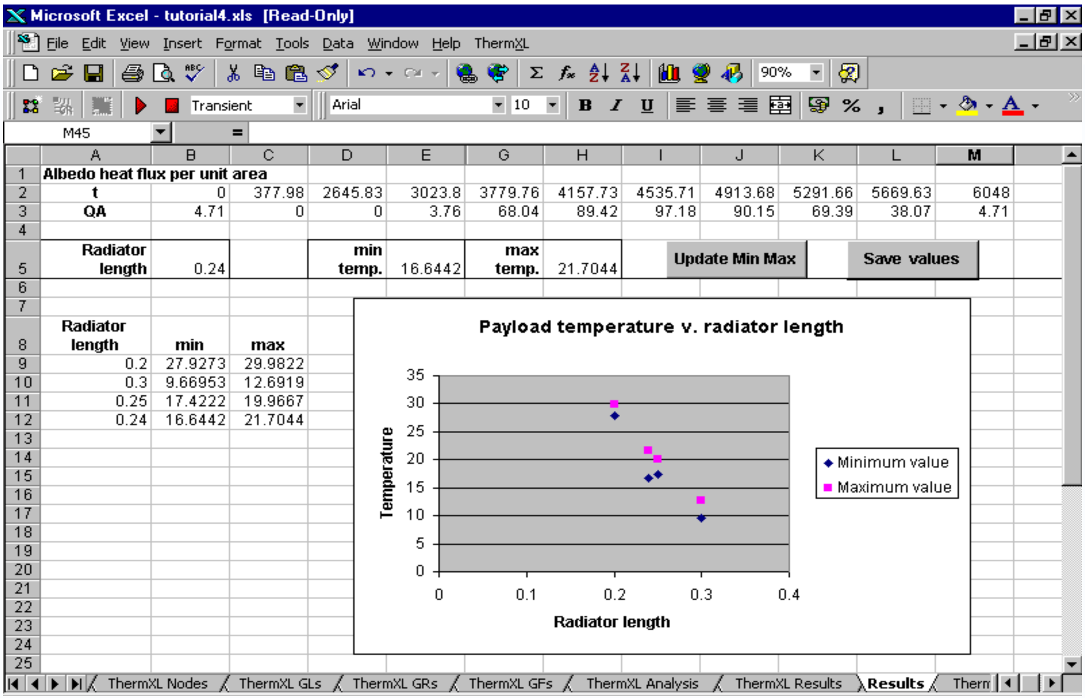
ThermXL Analysis / ThermXL Results / ThermXL User Results

ThermXL v-2.0 – ESATAN Export



ThermXL v-2.0 – VB Macros

ALSTOM



Appendix H: Stochastic Approach to Spacecraft Thermal Control

Stochastic Approach to Spacecraft Thermal Control Subsystem

F. Lamela Herrera
CASA

STOCHASTIC APPROACH TO SPACECRAFT THERMAL CONTROL SUBSYSTEM

Why?

- Scatter on physical parameters
  - Thermo-optical properties
  - Contact conductances
  - Handling process
  - Density
- Scatter on environment parameters
  - External fluxes
  - AOCS
- Scatter on interface definition
  - Units power dissipation
  - Harness

STOCHASTIC APPROACH TO SPACECRAFT TCS

How?

- Creating a Mother mathematical model
- Selecting input parameters and giving them a variation law
- Selection of a combination of input values with the Monte Carlo methodology
- Cloning the Mother model for each set of input variables combination
- Running deterministic cases with a cloned model per combination

STOCHASTIC APPROACH TO SPACECRAFT TCS

What?

- Thermal Problems on Spacecraft
  - Radiation and conduction
- Fluid Systems
  - CPL and Loop Heat Pipes (bubbles, non-homogenous wicks, ...)
- Launchers Aerothermal Fluxes
  - Angle of attack, density,…
- Reentry Vehicles
  - Angle of attack, density,...

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STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal problems on spacecraft solved by STORM

Stochastic Problems

- Uncertainty analysis
- Correlation of test results
- Design improvements

Non Stochastic Problems

- Critical design cases selection
- Definition of designs
  - Radiation areas
  - Robust heating systems

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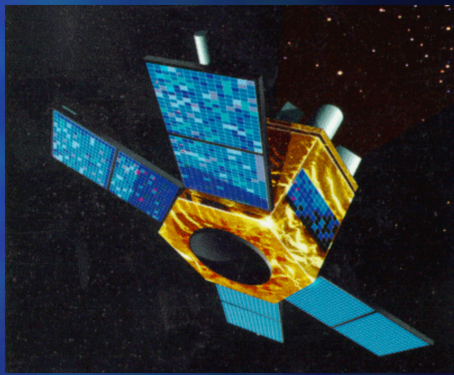
STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite

- Typical Uncertainty Analysis
  - Steady State
  - Transient
- Output is the temperature of an item (i.e. equipment) by combining all input parameters simultaneously
- Identification of highly sensible parameters in order to propose, if necessary, a specific development test or interface control follow-up
- Definition of maximum uncertainty
- Definition of uncertainty with levels of confidence (98%, 95% or 90%) in one run

Uncertainty analysis of a satellite (cont.)

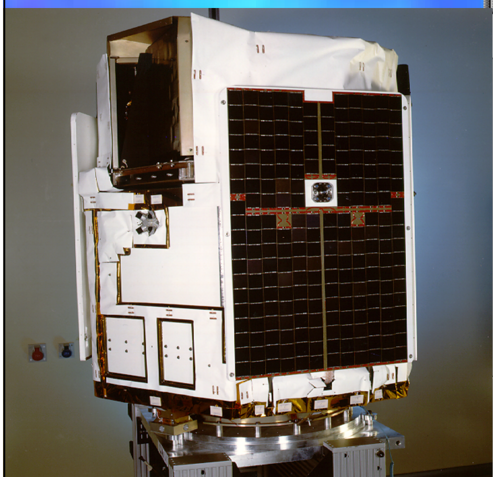
- Example: Spanish MINISAT equipment response varying:
  - Absorptivity of the rear frame
  - Emittance of rear frame
  - MLI shape factor (2 to 7)
  - Power dissipation of units (±20%)

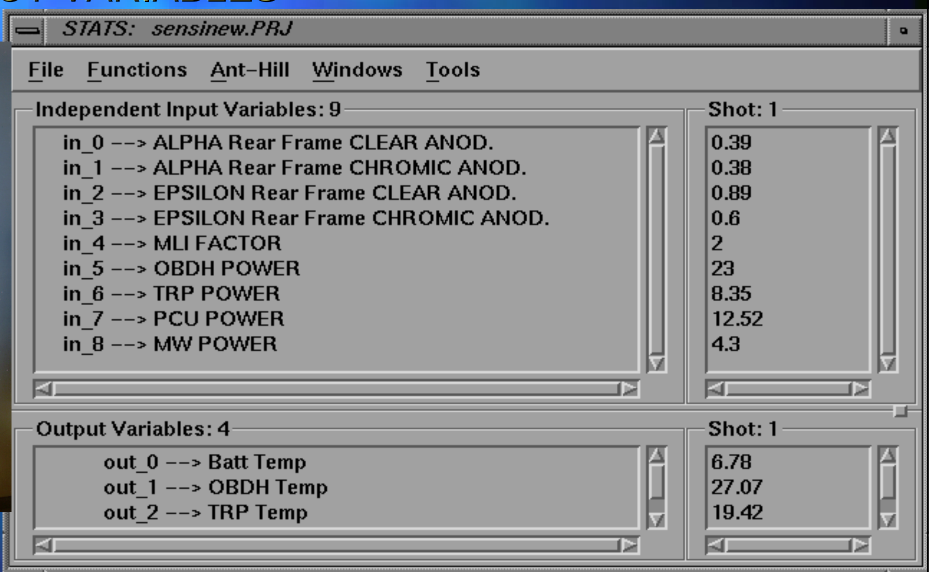


Note: All input variables have uniform distribution.
Initial phase for uncertainty analysis.
In the final project phase the distributions will be changed to Normal or Uniform distribution, as defined

Uncertainty analysis of a satellite (cont.)

- SIGNIFICANT INPUT VARIABLES

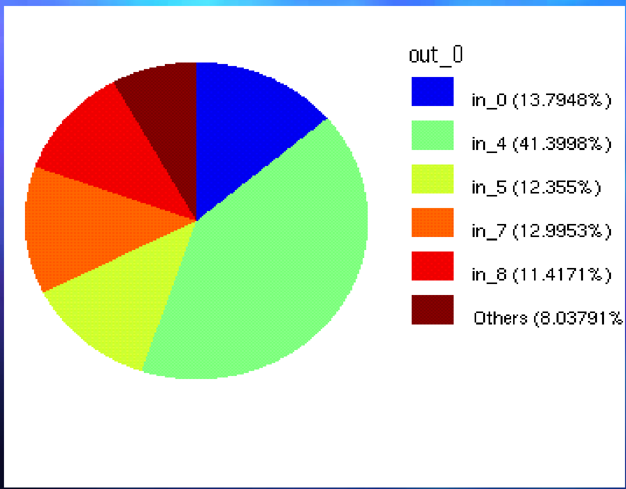




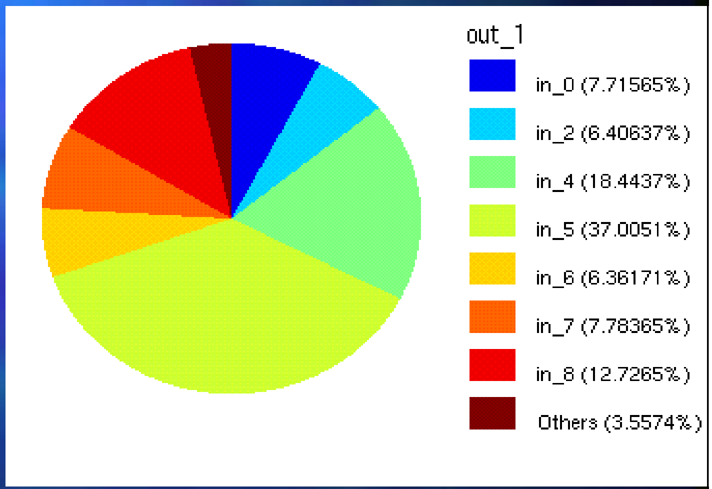
STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite (cont.)

- SIGNIFICANT INPUT VARIABLES



MLI Factor the most significant for the Battery

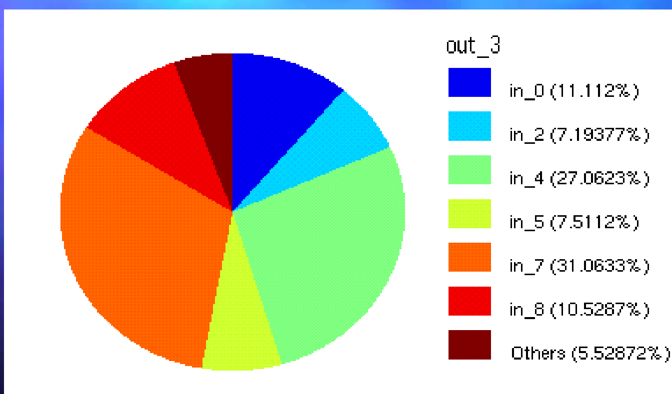


The Power and MLI factor the most significant for the OBDH

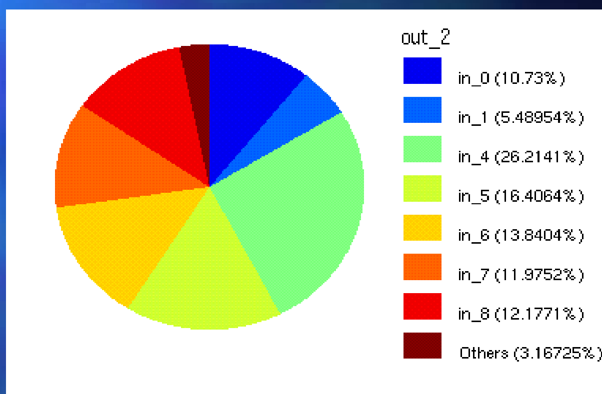
STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite (cont.)

- SIGNIFICANT INPUT VARIABLES



MLI Factor and its Power the most significant for the PCU

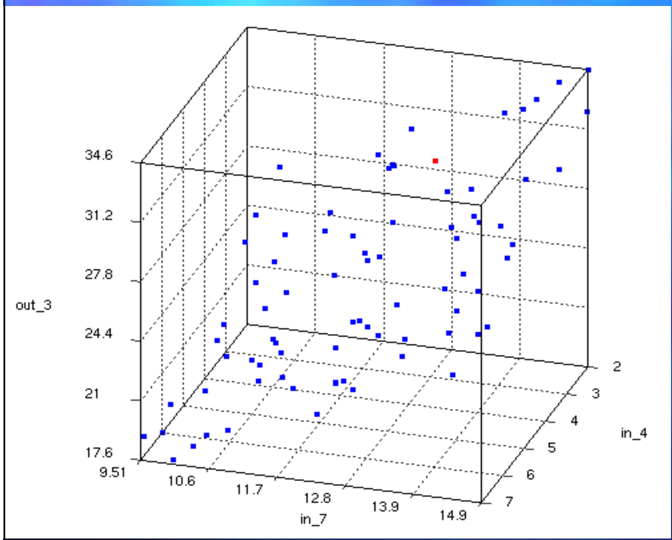


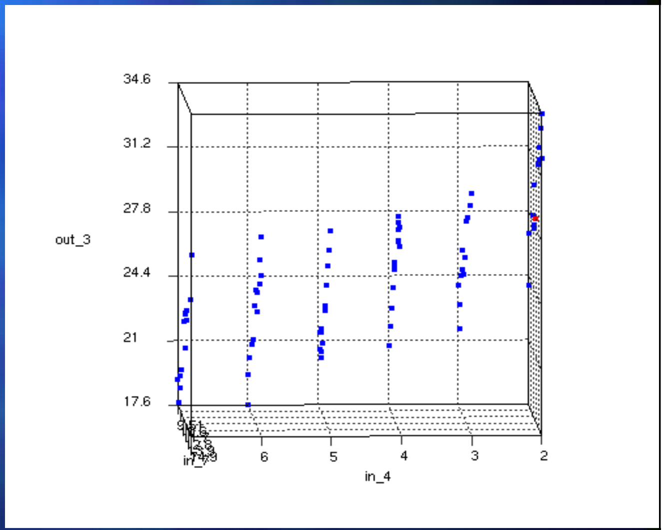
The Power of OBDH, its Powerand MLI factor the most significant for the TRP

STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite (cont.)

- SIGNIFICANT INPUT VARIABLES

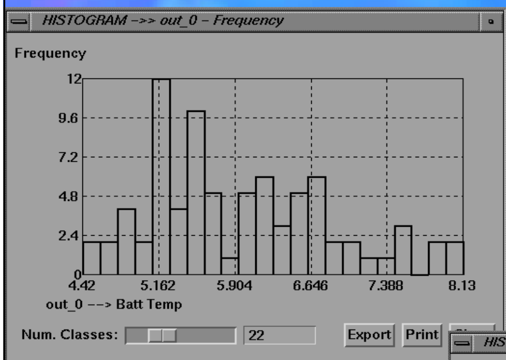




STOCHASTIC APPROACH TO SPACECRAFT TCS

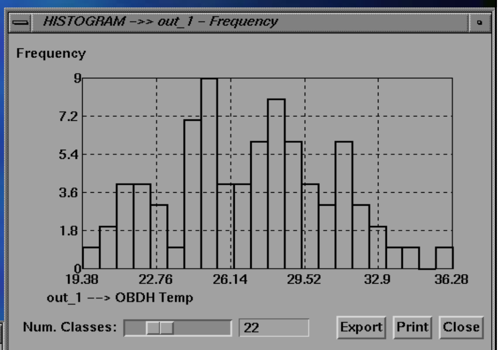
Uncertainty analysis of a satellite (cont.)

- PROBABILISTIC DATA OF UNCERTAINTY ANALYSIS

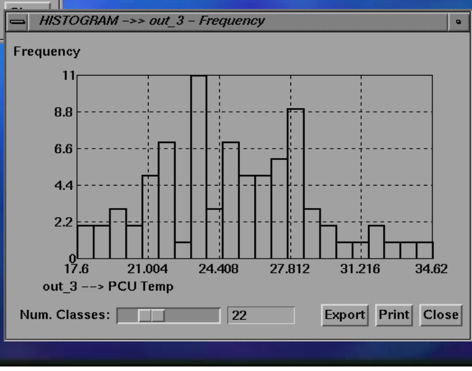


Batt profile

PCU profile



OBDH profile



Uncertainty analysis of a satellite (cont.)

PROBABILISTIC DATA OF UNCERTAINTY ANALYSIS

N.Var	Num. shot	X_Min	X_Max	Conf_Mean	Mean	Conf_Mean+	Conf_Std	Std	Conf_Std+	Var
in_0	80	0.37	0.42	0.391	0.395	0.399	0.015	0.0174	0.0206	0.0003
in_1	80	0.35	0.44	0.389	0.395	0.401	0.0238	0.0275	0.0325	0.00075
in_2	80	0.87	0.91	0.887	0.89	0.893	0.0123	0.0142	0.0169	0.0002
in_3	80	0.4	0.7	0.538	0.553	0.567	0.0584	0.0675	0.0799	0.00455
in_4	80	2	7	4.11	4.49	4.86	1.48	1.71	2.03	2.94
in_5	80	20	30	24.4	25	25.6	2.5	2.89	3.42	8.33
in_6	80	8.01	10.9	9.28	9.48	9.67	0.754	0.872	1.03	0.76
in_7	80	9.51	14.9	11.9	12.2	12.6	1.41	1.63	1.93	2.66
in_8	80	4	6.9	5.25	5.45	5.64	0.765	0.884	1.05	0.782
out_0	80	4.42	8.13	5.76	5.96	6.15	0.774	0.895	1.06	0.8
out_1	80	19.4	36.3	26.2	27	27.9	3.2	3.7	4.38	13.7
out_2	80	12.9	25.9	18.1	18.7	19.3	2.32	2.68	3.18	7.19
out_3	80	17.6	34.6	24.3	25.1	25.9	3.26	3.76	4.46	14.2

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STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite (cont.)

PROBABILISTIC DATA OF UNCERTAINTY ANALYSIS

N.Var	Modal class	Modal class+	CV(%)	Avdev	Skewness	Kurtosis	Description
in_0	0.407	0.414	4.4	0.0152	-0.0219	-1.31	ALPHA Rear Frame CLEAR A.
in_1	0.35	0.361	7	0.024	-7.47E-06	-1.24	ALPHA Rear Frame CHROMIC A.
in_2	0.87	0.875	1.6	0.012	-7.55E-06	-1.3	EPS Rear Frame CLEAR ANOD.
in_3	0.475	0.512	12.2	0.06	0.158	-0.246	EPS Rear Frame CHROMIC AN.
in_4	2	2.62	38.2	1.49	-0.00899	-1.24	MLI FACTOR
in_5	25	26.2	11.5	2.45	-0.00318	-1.12	OBDH POWER
in_6	9.82	10.2	9.2	0.768	-0.0243	-1.3	TRP POWER
in_7	11.5	12.2	13.3	1.39	0.00353	-1.22	PCU POWER
in_8	4.36	4.72	16.2	0.765	0.00477	-1.27	MW POWER
out_0	4.88	5.35	15	0.742	0.558	-0.399	Batt Temp
out_1	27.8	29.9	13.7	3.05	0.0917	-0.621	OBDH Temp
out_2	17.8	19.4	14.3	2.07	0.408	0.226	TRP Temp
out_3	21.9	24	15	3.05	0.238	-0.348	PCU Temp

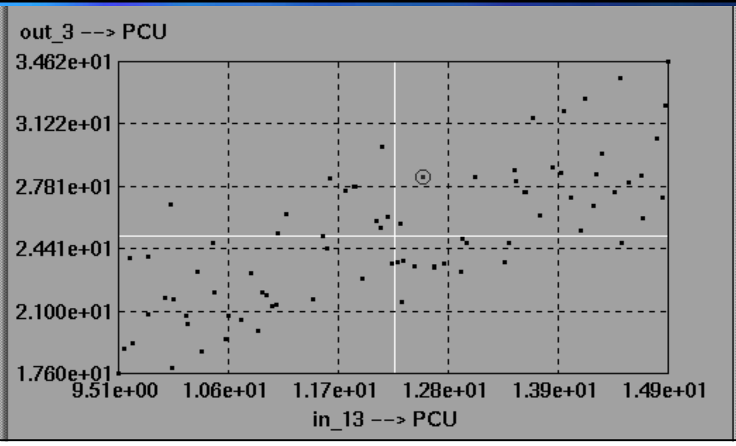
STOCHASTIC APPROACH TO SPACECRAFT TCS

Uncertainty analysis of a satellite (cont.)

- PROBABILISTIC DATA OF UNCERTAINTY ANALYSIS

			90% Confidence level		95% Confidence level		99% Confidence level	
	Mean	Std	Uncer	Tmax	Uncer	Tmax	Uncer	Tmax
Batt Temp	**5.96**	0.895	1.48	**7.44**	1.75	**7.71**	2.51	**8.47**
OBDH Tem	**27**	3.7	6.12	**33.12**	7.25	**34.25**	10.40	**37.40**
TRP Temp	**18.7**	2.68	4.43	**23.13**	5.25	**23.95**	7.53	**26.23**
PCU Temp	**25.1**	3.76	6.22	**31.32**	7.37	**32.47**	10.57	**35.67**

- PCU RESULTS



STOCHASTIC APPROACH TO SPACECRAFT TCS

Critical cases selection

- Critical Cases Selection based on temperatures for a fixed design and not based on environments
  - Steady State
  - Transient
- All thermal parameters (Radiation data, heat inputs and thermal model) can be changed
  - Orbit altitude, inclination, ascending node…
  - Satellite attitude
  - External Radiation values (solar, albedo, terrestrial)
  - Season
  - Conductances

Critical cases selection (cont.)

- Thermal Capacities
- Heating Power and/or thresholds
- Unit power dissipation (sunlight/eclipse)

Note:

- *THERE IS A CRITICAL CASE FOR EACH UNIT OR SATELLITE ELEMENT*
- *CRITICAL CASES SELECTION DEPENDS ON THE RESPONSE OF THE DESIGN, NOT ON THE INPUTS*

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STOCHASTIC APPROACH TO SPACECRAFT TCS

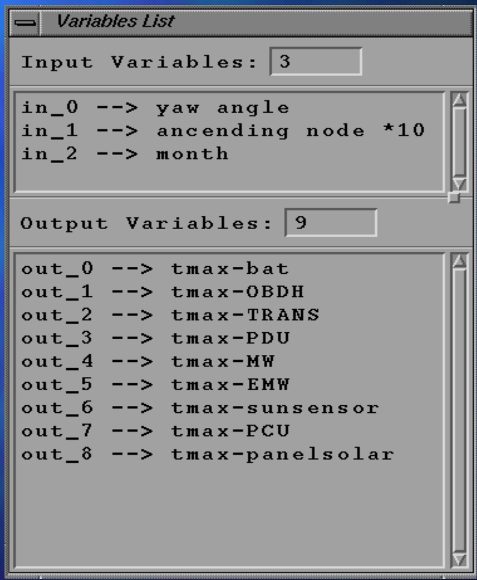
Critical cases selection (cont.)

- Example: Spanish MINISAT. 3 years of flight .
  - Radiators on lateral faces
  - Sun pointed (Nutation up to 7 degrees)
  - Attitude around sun axis 0÷360°. YAW angle
  - Orbit inclination 150° (any ascending node)

  - Note: Any combination of orbit ascending node, season and satellite attitude is feasible depending on launch day.

Critical cases selection (cont.)

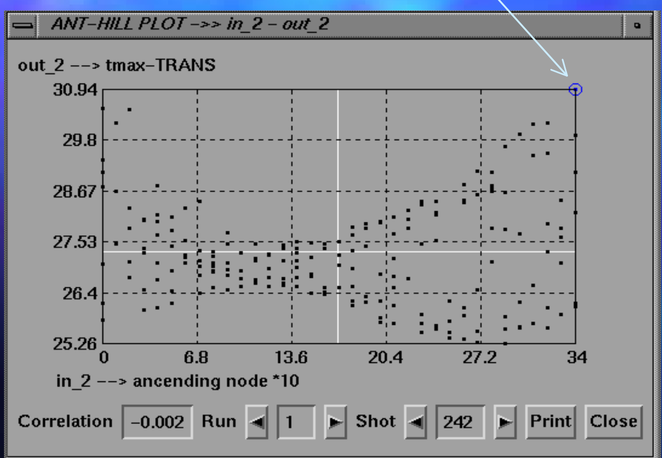
- Example: Spanish MINISAT. 3 years of flight .

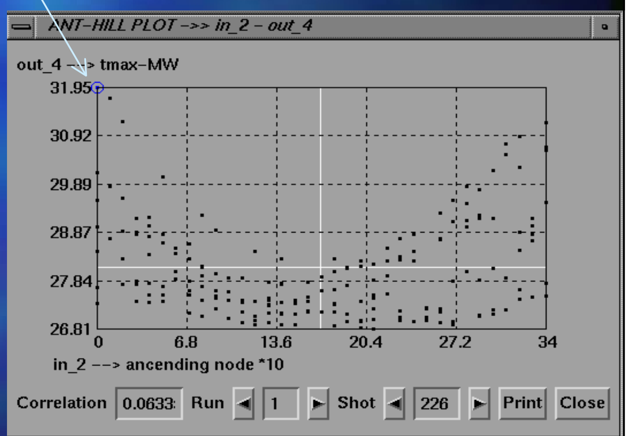


Critical cases selection (cont.)

– Transponder Y OBDH
Tmax 30.94°C
Yaw 178 °
Ascen node 340
Season December

– MW, Battery, PCU, PDU and EMW
Tmax 31.95°C
Yaw 107 °
Ascen node 0
Season December





Critical cases selection. "LESSONS LEARNED":

- 0° and 180° rotation w.r.t. Sun pointing vector based on max/min external heat inputs identified during system study (**Classical** Environmental critical cases selection) .
- A stochastic analysis for critical cases selection based on temperatures shows unexpected more extreme temperature profiles for YAW angles of 178 and 107. Flight data confirms this new critical case.
- For other satellite units additional critical cases were found. Stochastic analysis supplies more information for accurate determination of critical design cases.

Thermal test correlation

Present Approach

- Check temperature deviations
- Select a parameter. Modify model
- Verify the response for all thermocouples
- Select other parameter. Modify model
- New runs and verification of results
- Repeat process to meet correlation criteria
- Total analysis loop working time in weeks to months

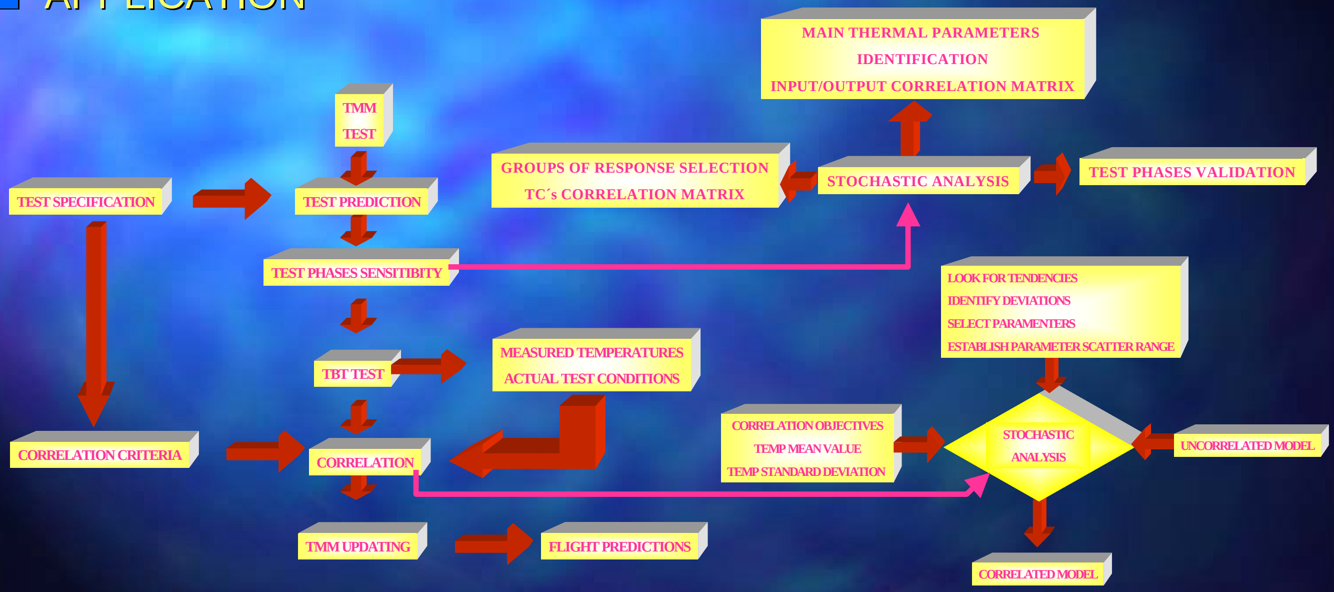
Stochastic Approach

- Definition of main parameters related to heat transfer in the model. **CORRELATION MATRIX**
- Selection of parameters variation range and interval to move their range.
- Run all test cases imposing objectives
- Verification of feasible correlation results.
- Local problems solution
- Total analysis working time in days

STOCHASTIC APPROACH TO SPACECRAFT TCS

TEST RESULTS CORRELATION & FLIGHT PREDICTIONS. PHASE C/D

- APPLICATION



STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal test correlation (cont.)

- Example of XMM-MSP thermal balance test

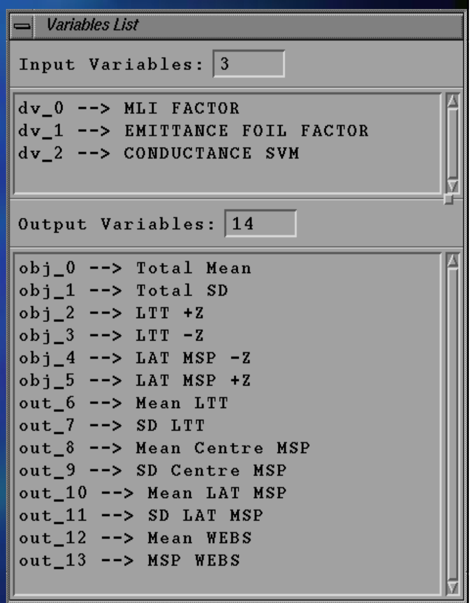
  Temperature depends on three main parameters (Conductance to SVM, MLI conductance, Closing foil internal emittance)

Thermal test correlation (cont.)

- Test correlation requirements
  - Mean deviations lower than 2 degrees.
  - Standard deviation lower than 3 degrees.
  - Critical elements deviation lower than 5 degrees.

Thermal test correlation (cont.)

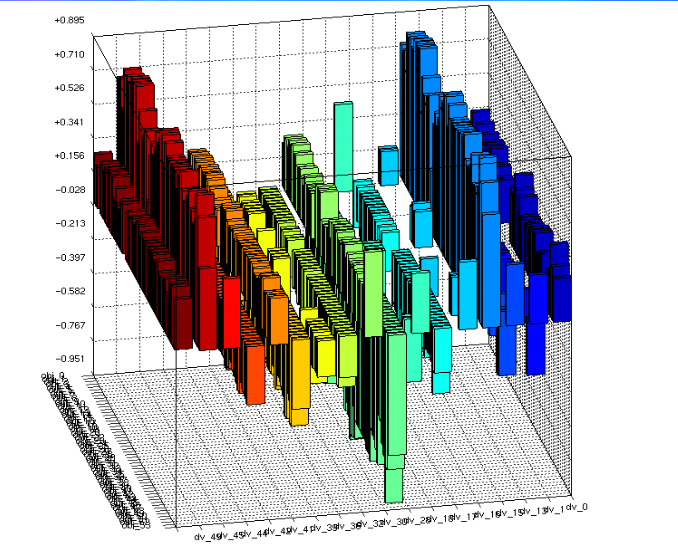
- Test correlation requirements
  - Mean deviations lower than 2 degrees.
  - Standard deviation lower than 3 degrees.
  - Critical elements deviation lower than 5 degrees.

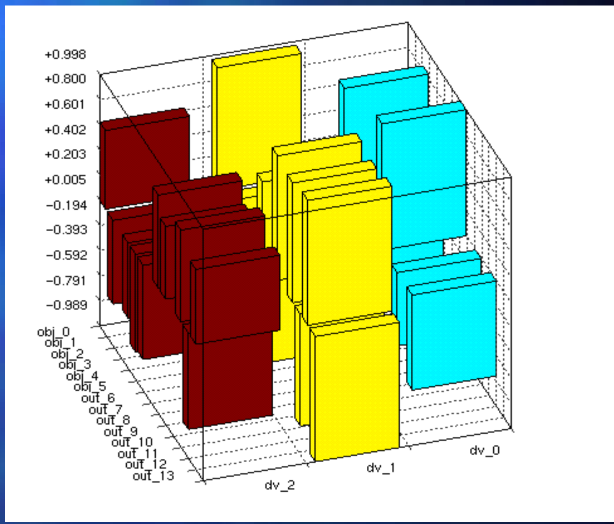


STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal test correlation (cont.)

- EVALUATION OF SIGNIFICANT INPUT PARAMETERS





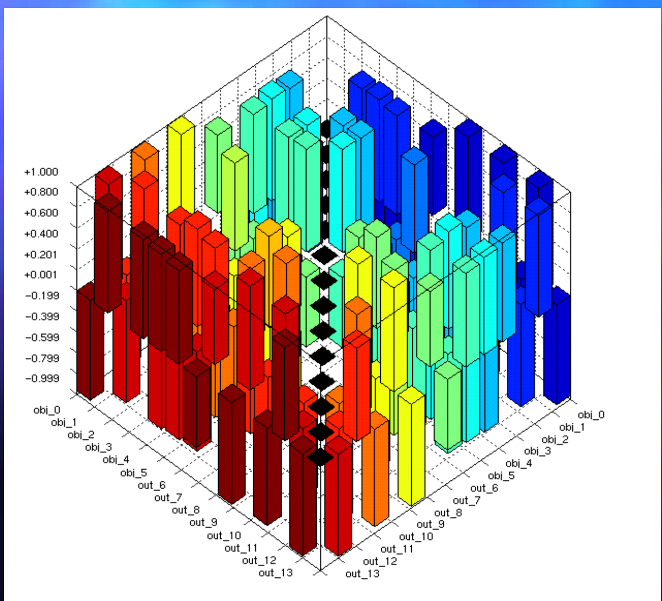
- Global correlation matrix

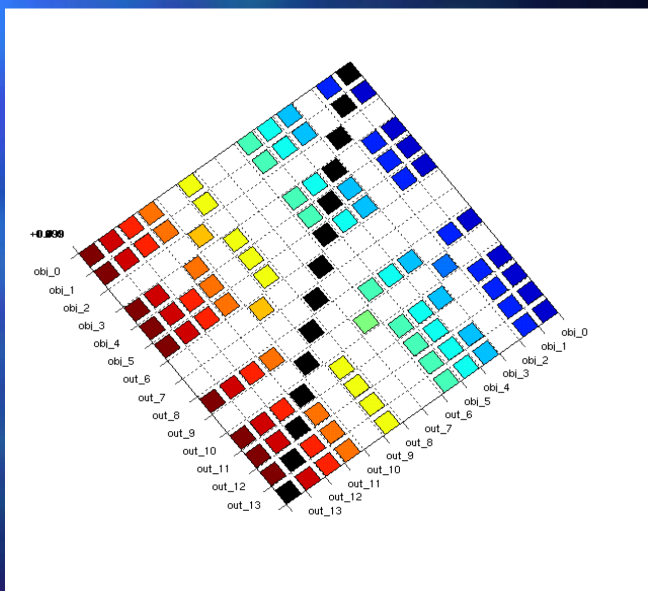
Main significant parameters

STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal test correlation (cont.)

- MAIN OUTPUT CORRELATION MATRIX. GROUPS OF RESPONSE

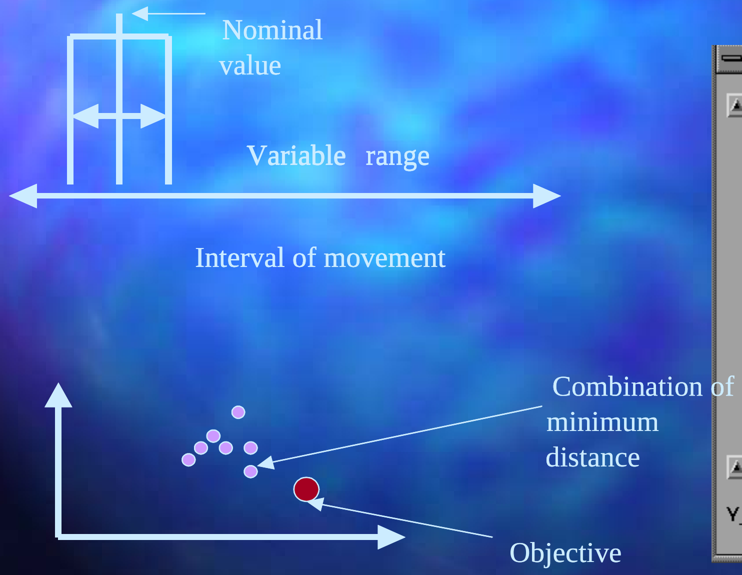


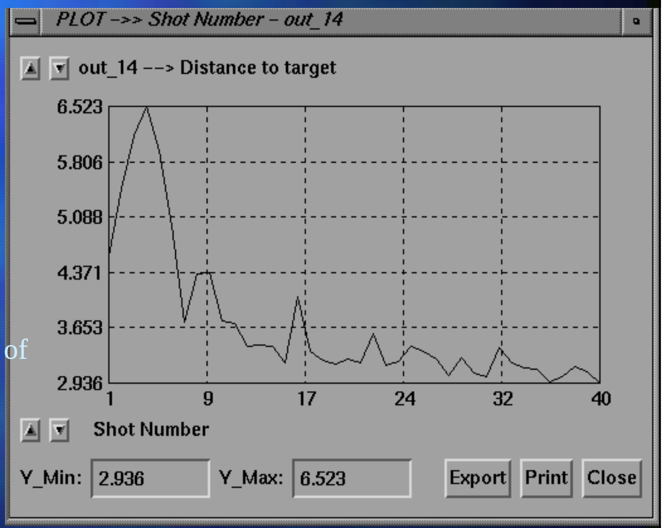


STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal test correlation (cont.)

- CORRELATION EXERCISE IMPOSING OBJECTIVES

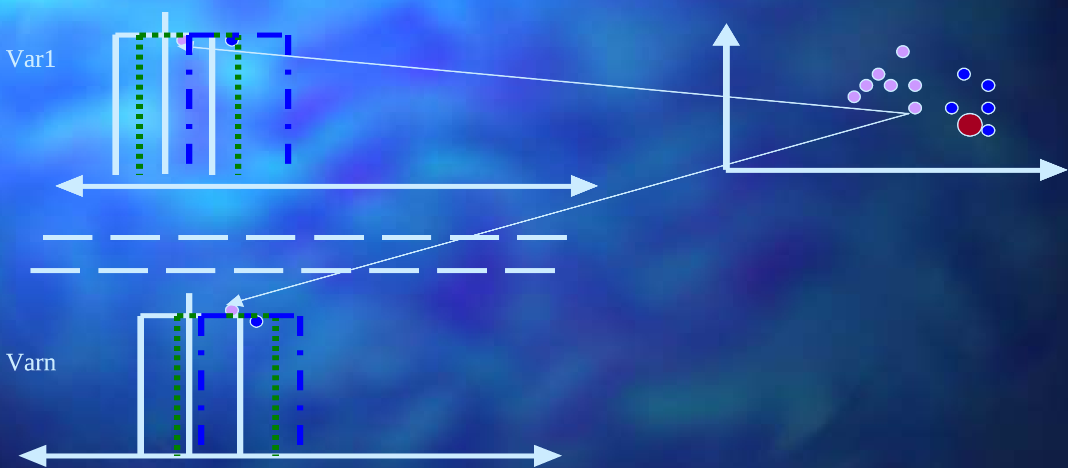




STOCHASTIC APPROACH TO SPACECRAFT TCS

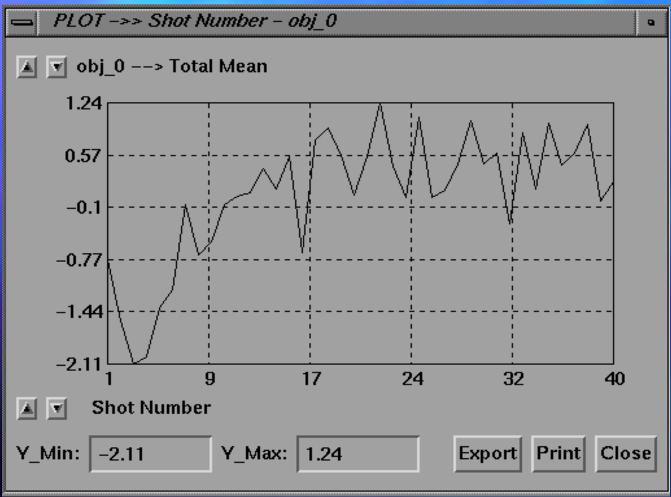
Thermal test correlation (cont.)

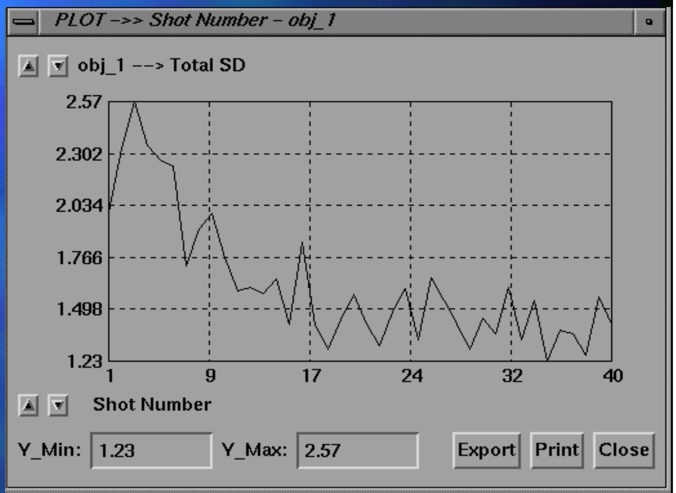
- CORRELATION EXERCISE IMPOSING OBJECTIVES



Thermal test correlation (cont.)

- CORRELATION EXERCISE IMPOSING OBJECTIVES





EADS CASA ESPACIO

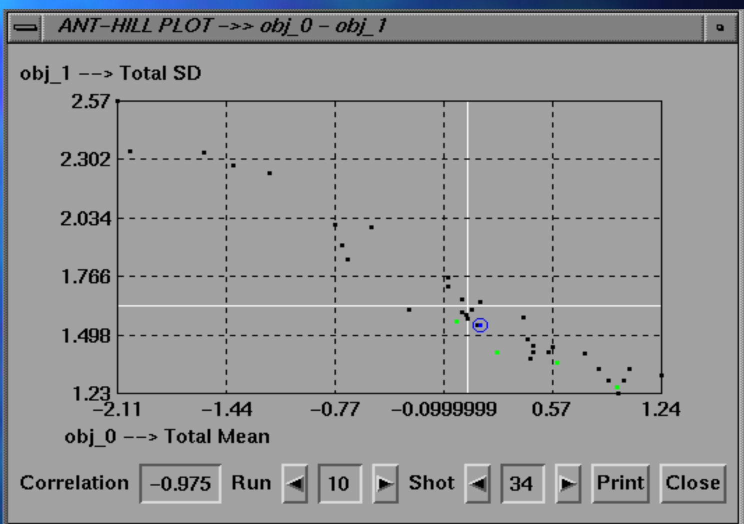
STOCHASTIC APPROACH TO SPACECRAFT TCS

Thermal test correlation (cont.)

- IS IT POSSIBLE TO REACH ALL OBJECTIVES?

It is not possible to reach a mean deviation cero and standard deviation cero

That is the effect of non used input variables

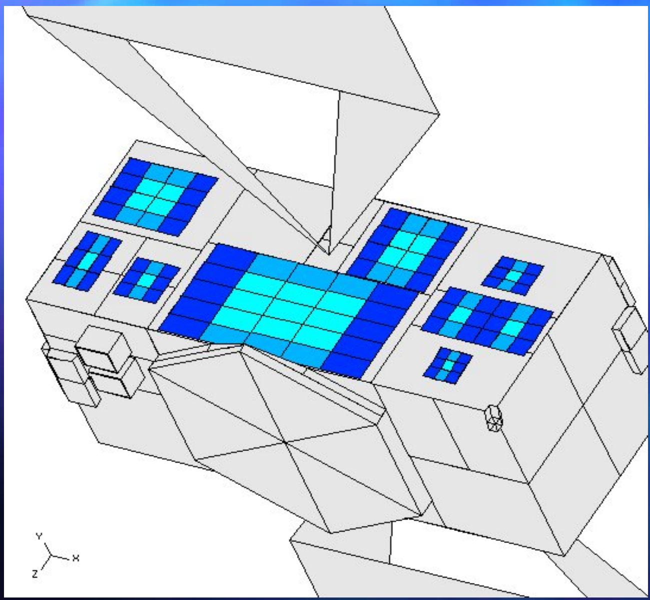


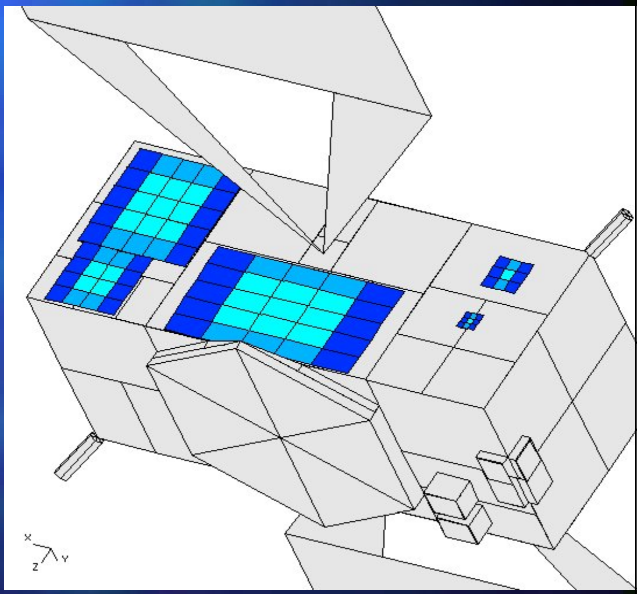
FLIGHT RESULTS CORRELATION. PHASE E

- OBJECTIVES
  - To verify in-orbit performances
  - To justify anomalies and deviations
- PROBLEMS IN THIS PHASE
  - Correlation between model and telemetry data with uncertain enviromental conditions
  - Limited data from S/C to assess anomalies and deviations
- PROPOSAL
  - Stochastic analysis combining all parameters and statistical treatment.
    - Great amount of scenarios to be evaluated
    - Pathologic behaviors
    - Levels of confidence to support conclusions
    - Corrective actions

DESIGN IMPOSING OBJECTIVES

- RADIATORS SIZE AND LOCATION DEFINITION



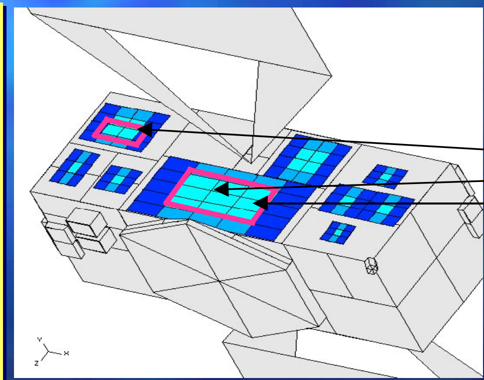


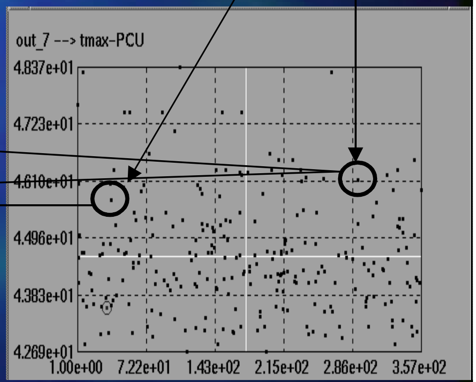
NOMINAL DESIGN AND DESIGN LIMITS. PHASE A

- APPLICATION
  - The design is a input variable.
  - The range of data is larger than the nominal ones.

PCU	32,2W	37,4 W
RWLS	11,3W	11,7W
GYRO E	30,3W	37,8W
OBDH	47,0W	44,5W
Exper 1	58,9W	60,2W
Camera	21.2W	19,5W

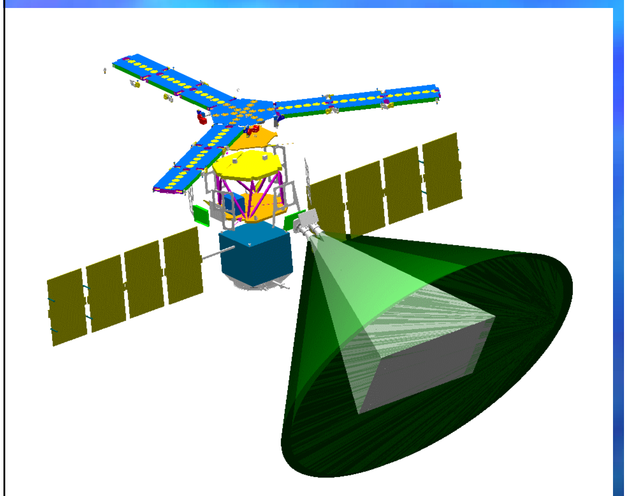
PCU	35W±20%
RWLS	13W±30%
GYRO E	35W±20%
OBDH	45W±15%
Exper 1	60W±20%
Camera	18W±40%

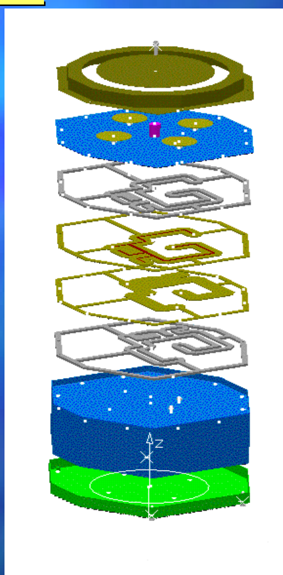


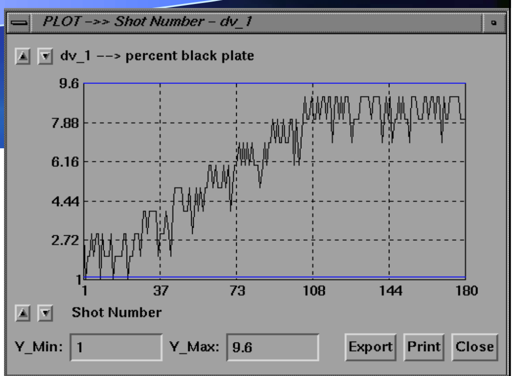


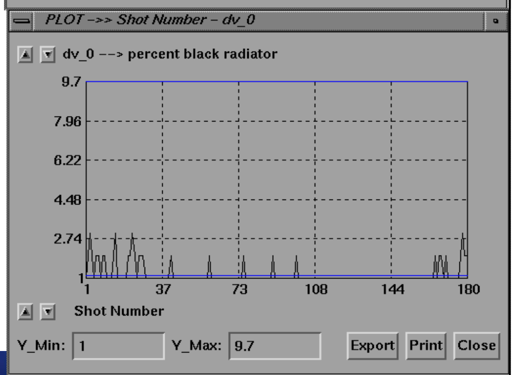
DESIGN IMPOSING OBJECTIVES

- COATINGS SELECTION









- PATTERN between black coating and aluminium. Tmax<50ºC

STOCHASTIC APPROACH TO SPACECRAFT TCS

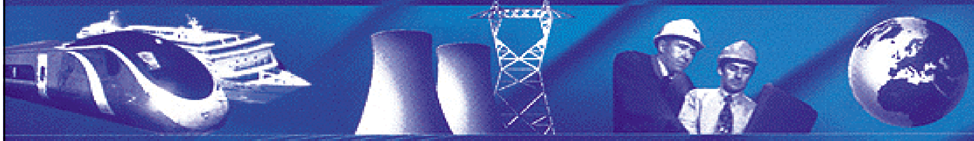
CONCLUSIONS

- Utilization of probabilistic analysis methods directly considering the scatter of parameters and their distributions (e.g. loads, geometry, and material properties) provides additional information of the designs.
- Introduction of concepts such as Robustness, Flexible, Optimum or Cost Effective allows choosing the “BEST DESIGN”
- Drawbacks: The use of massive analysis requests a very well conditioned heat transfer phenomena of the S/C. This method does not substitute expertise by number of uncontrolled runs.
- Implementation at EADS CASA Espacio:
  - Soil Moisture and Ocean Salinity (SMOS) instrument, (phase A).
  - XMM Mirror Support Platform and Meteosat Second Generation thermal test correlation.
  - Spanish Minisat flight performance verification.
  - NEXT: GalileoSat, A5 Vehicle Equipment Bay

Appendix I: ESARAD

ESARAD

F. du Laurens d'Oiselay
Alstom



15th European Workshop on
Thermal and ECLS Software
ESTEC, The Netherlands
October 9-10, 2001

ESARAD v-4.3
Advanced Support

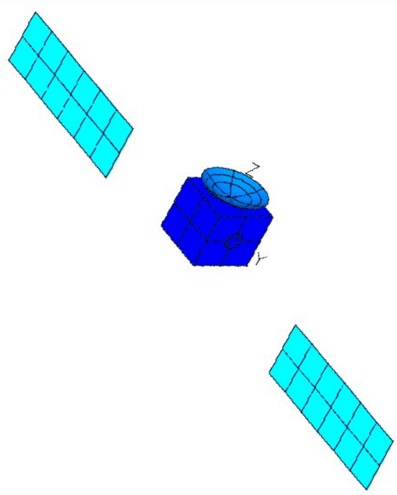
Frédéric du Laurens d'Oiselay – Support Manager
ALSTOM Power Technology Centre
+44 116 284 5748
esa.support@power.alstom.com

ALSTOM

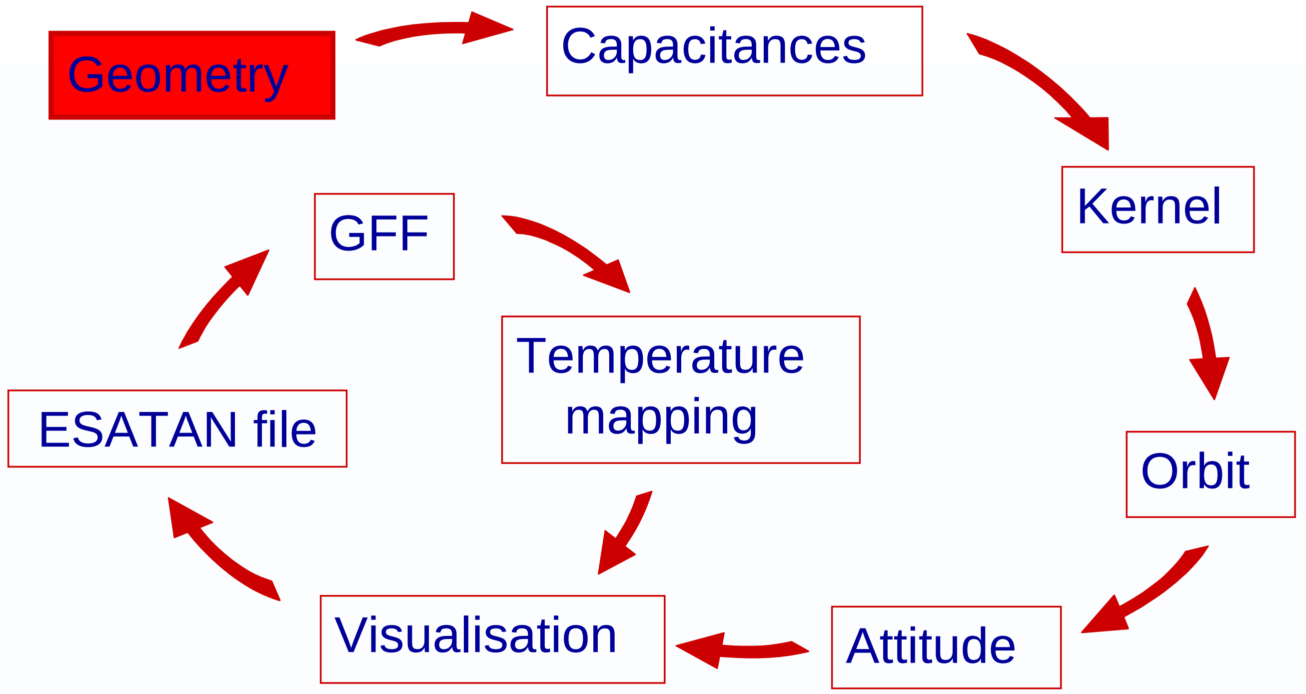
Objectives

ALSTOM

- Run a model through a complete loop
  - Geometry modeling to temperature mapping
- Make use of advanced features
  - Capacitance calculations
  - Visualisation of complex attitude
  - Defining complex orbit
  - Importing a model into ESATAN
  - Retrieving temperatures in ESARAD
- Batch mode techniques

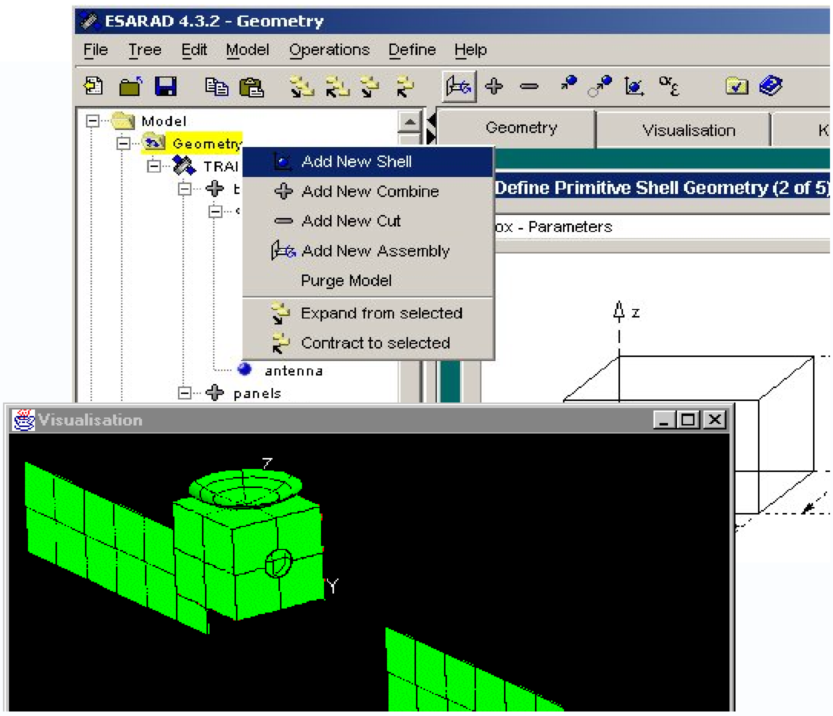


Analysis Loop – Geometry

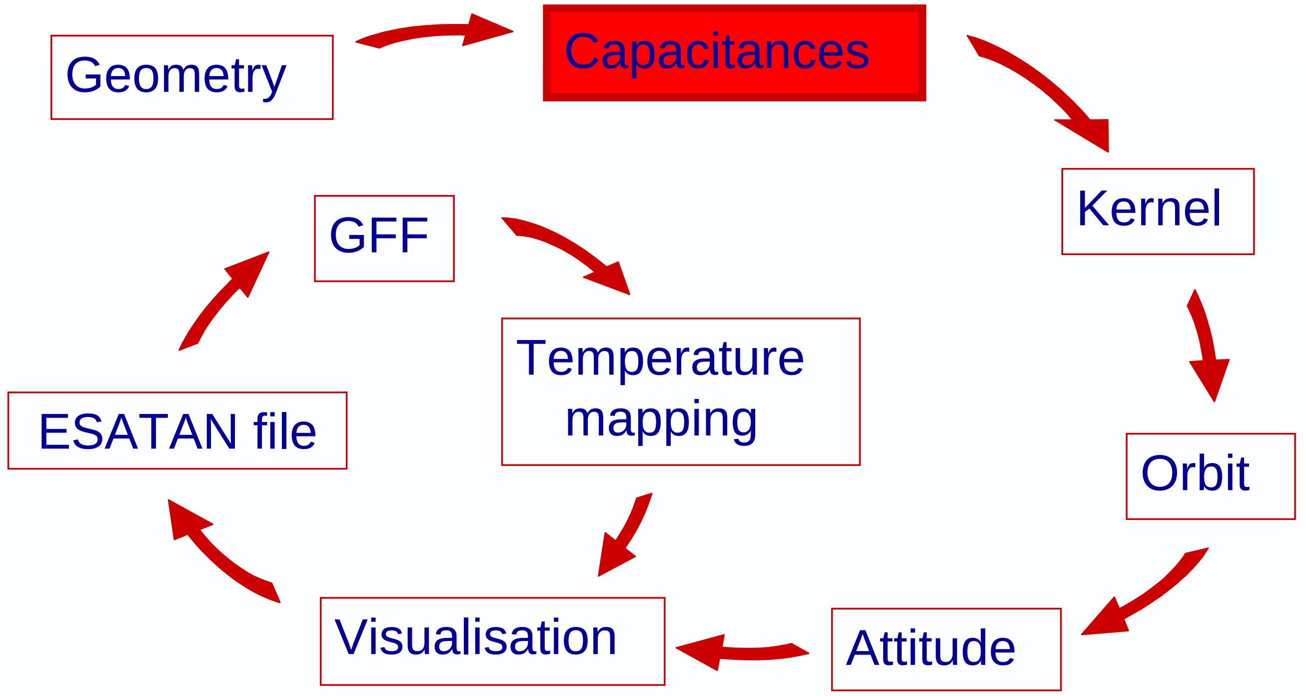


Geometry – Interactive Modeling

- Geometry building
  - Model tree
  - Visualisation
  - On-line help
- Visualisation
  - Customisable
  - Additive
  - Interactive

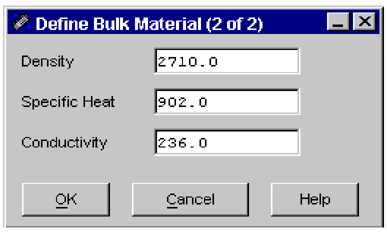


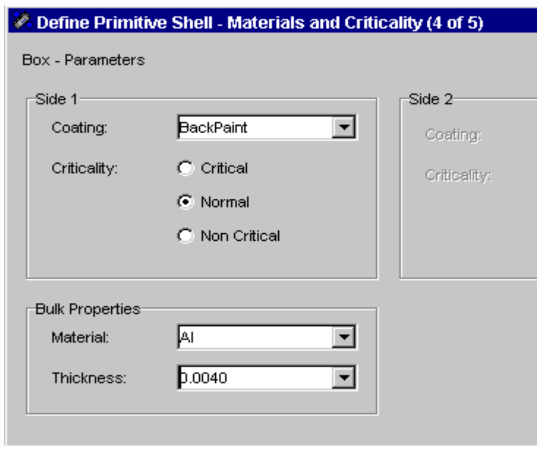
Analysis Loop – Capacitances



Geometry – Capacitances

- Creating a bulk
  - Density
  - Specific heat
  - Conductivity
- Defining shell
  - Geometry
  - Bulk
  - Thickness





Capacitances in ESATAN

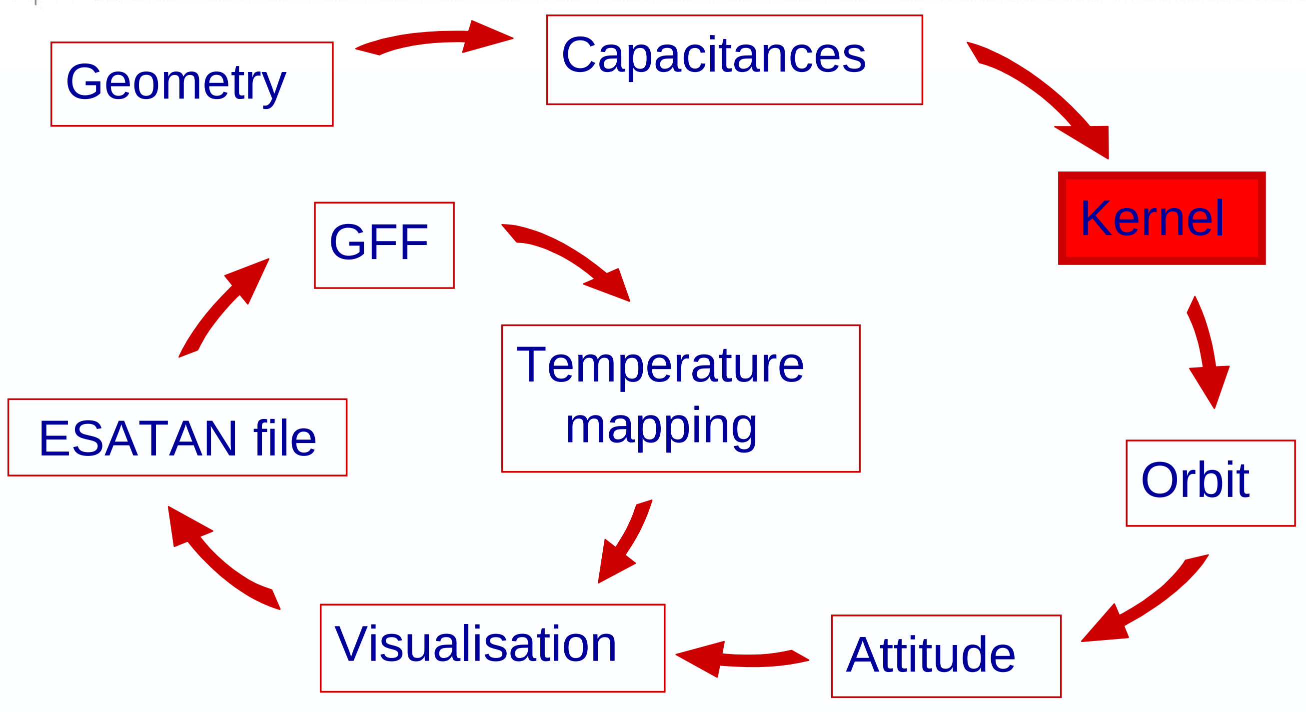
ALSTOM

- Capacitance definition
  - Ability of a material to store energy
  - C = density ·volume ·specific heat = mass ·Cp
- Stored in ESATAN in **$INITIAL**

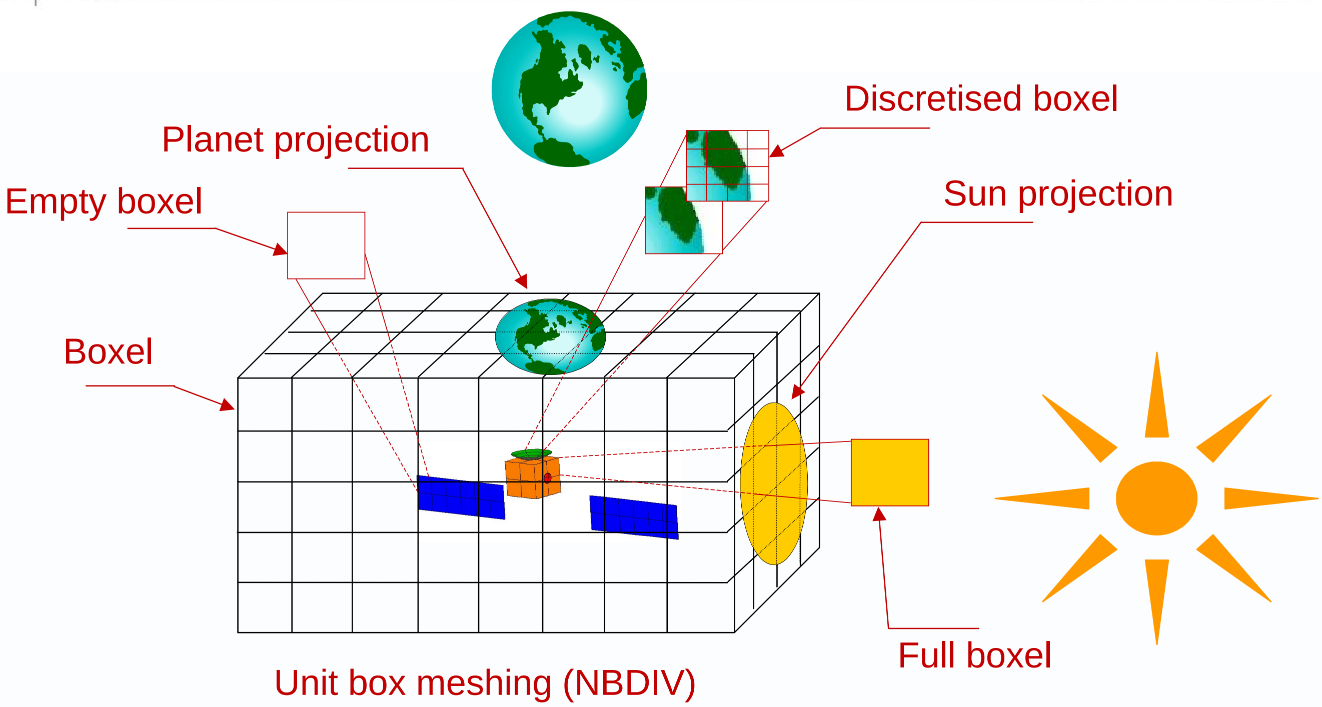
```
$CONSTANTS
    $REAL
        # Material data for 'Al'
        Cp_Al = 902.000000;
        Dens_Al = 2710.000000;
$INITIAL
      C100 = 0.001000 * Cp_Al * Dens_Al    # box
      C101 = 0.001000 * Cp_Al * Dens_Al    # box
```


Analysis Loop – Kernel

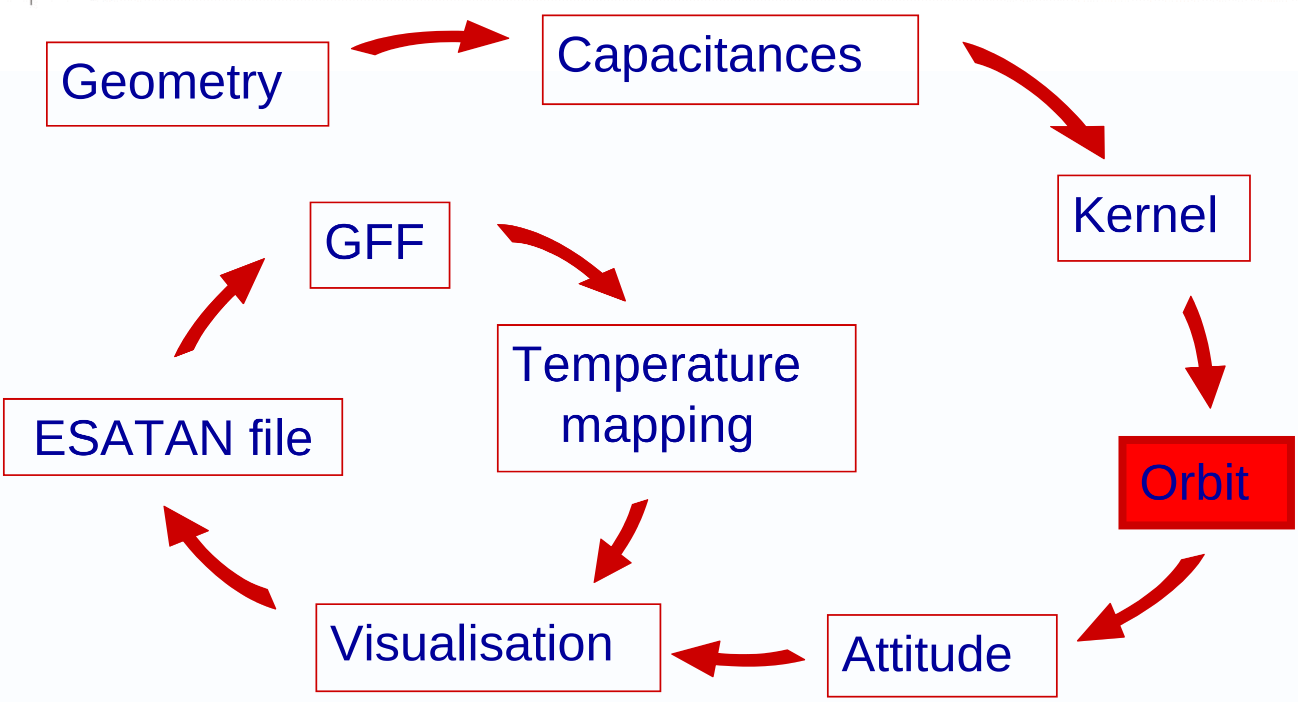
ALSTOM



MCRT Method in ESARAD



Analysis Loop – Orbit



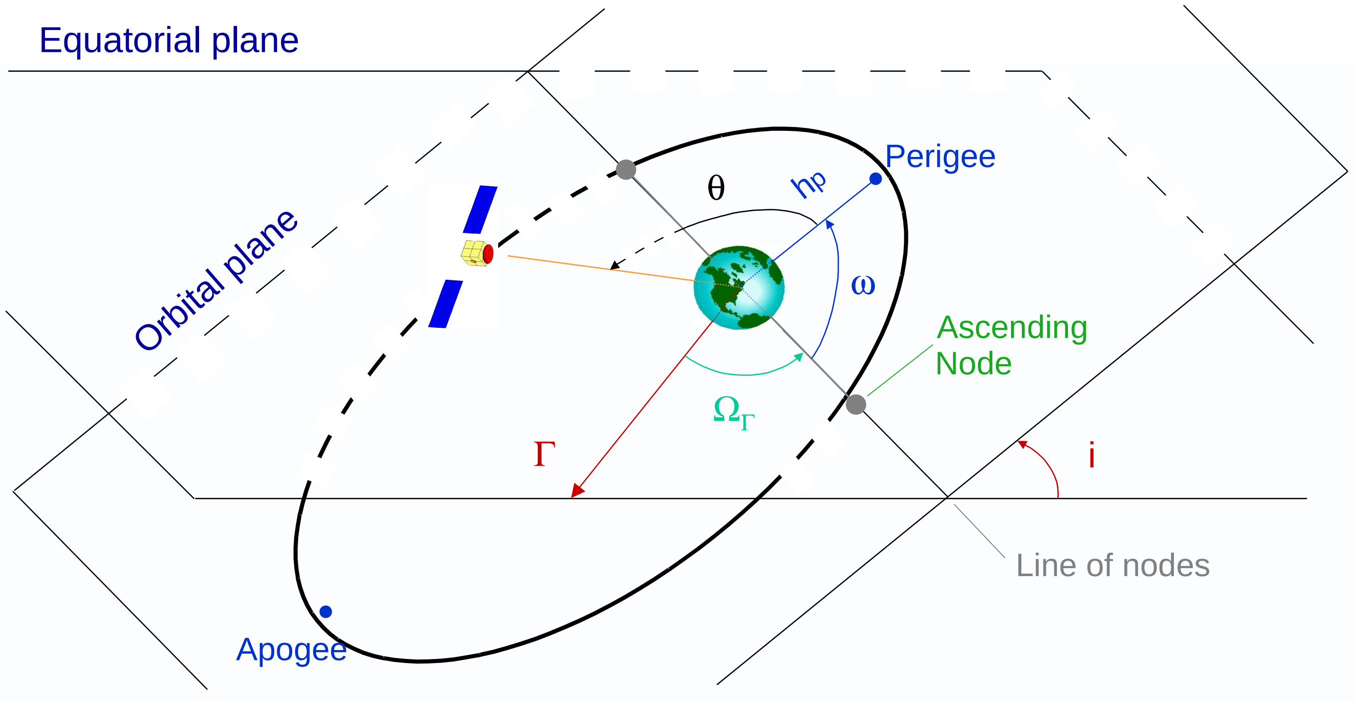
Orbital Parameters

ALSTOM

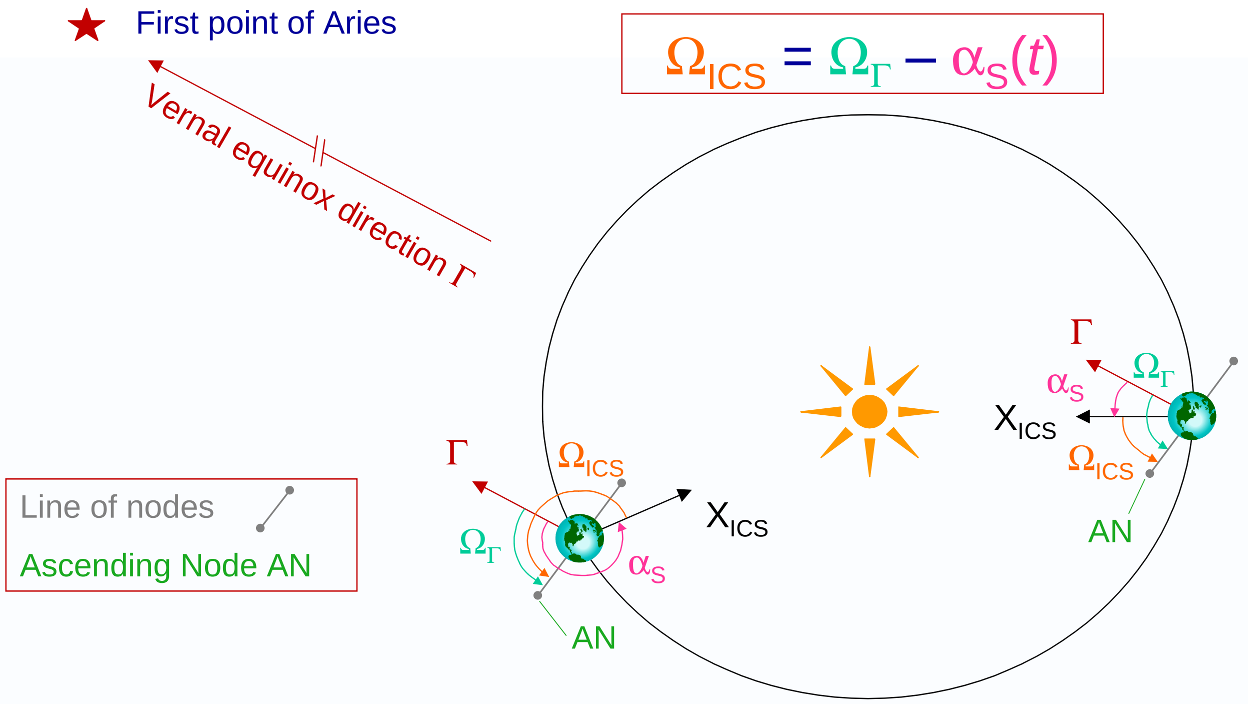
- Classical orbital parameters
  - *a* – semi-major axis
  - *e* – eccentricity
  - *i* – inclination
  - Ω_Γ – right ascension of the ascending node (RAAN)
  - ω – argument of periapsis
  - θ – true anomaly
- ESARAD orbital parameters
  - $h_a = a \cdot (1 + e) - R_{planet}$
  - $h_p = a \cdot (1 - e) - R_{planet}$
  - $i = i$
  - $\Omega_{ICS} = \Omega_\Gamma - \alpha_S(t)$
    $\alpha_S(t)$ – right ascension of the Sun at time *t*
  - $\alpha = \omega$
  - $\theta = \theta$

In-Orbit Satellite Positioning

ALSTOM



ICS and J2000



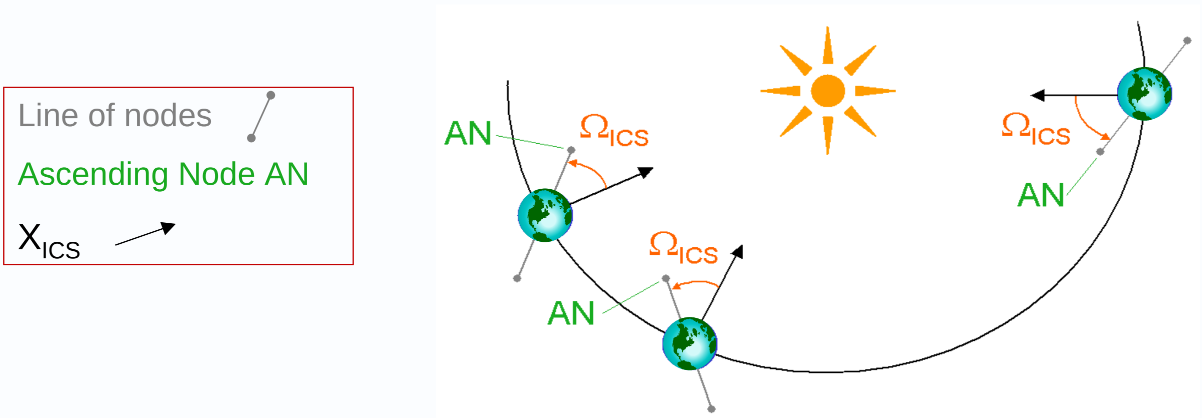
Sun-Synchronism

- Sun-synchronous orbits (SSO):
  - Low altitude (~ 800 km), circular orbit
  - Inclination i > 90° (~ 98°), related to altitude
  - Fixed local solar time of ascending node LST
- Achieved in practice by drifting the ascending node of the orbit
  - $d\Omega_\Gamma/dt$ ~ 0.985 °/day i.e. 360° over 365.24 days
  - Angle between Earth-Sun vector and line of nodes is constant throughout the mission
  - Drift physically induced by natural shape of Earth

Sun-Synchronism in ESARAD

ALSTOM

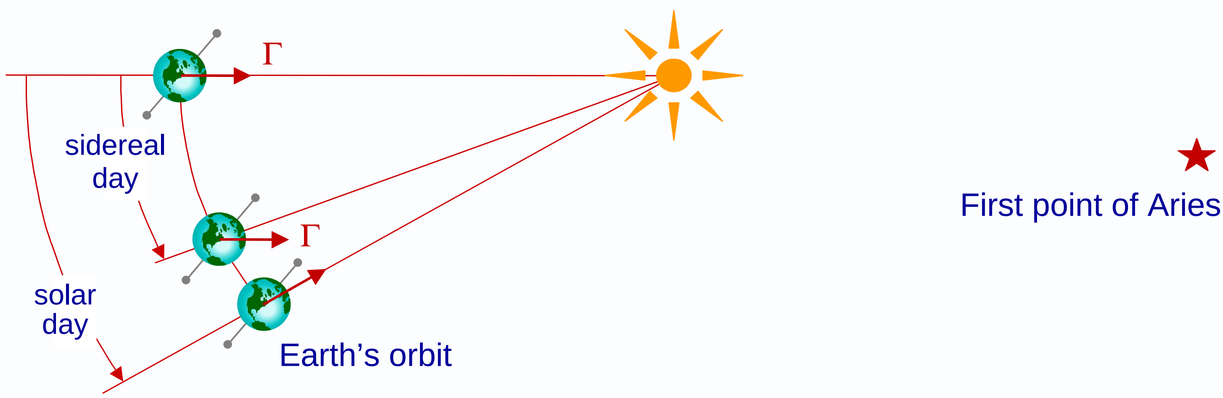
- SSO are easy to model in ESARAD since the reference line X_{ICS} points always at the Sun
- $\Omega_{ICS} = (LST^h - 12^h) \cdot 360° / 24^h$



Geostationary Orbits

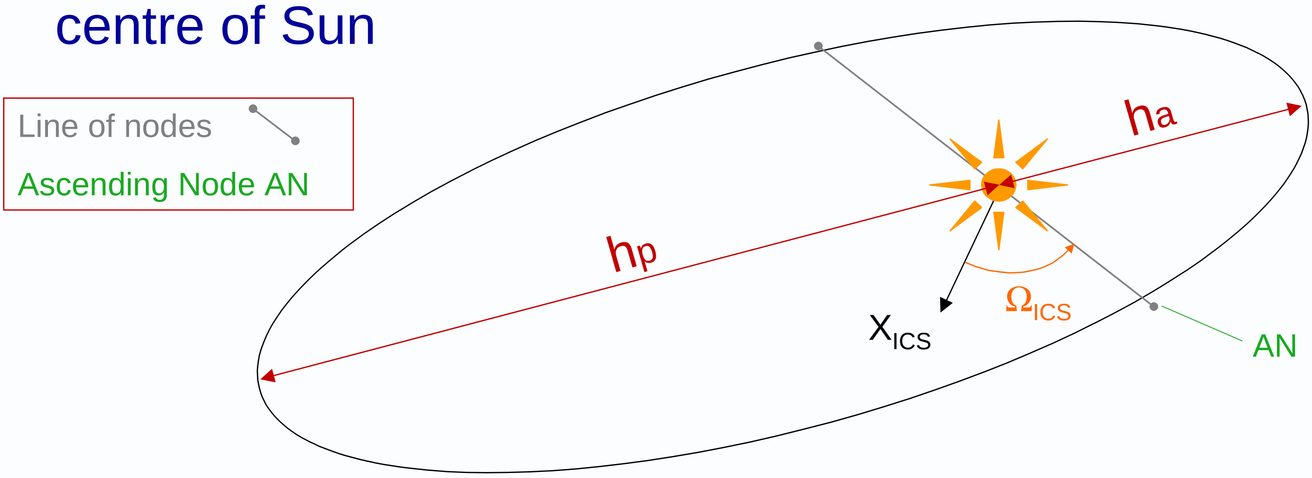
ALSTOM

- Virtually constant equatorial sub-satellite point
- Period = 23h 56min 4.09 sec = 86164.09 sec
- Solar day = 24h 0min 0.0 sec = 86400.00 sec
- (86400 – 86164.09) × 365.2414 = 86164.09 !

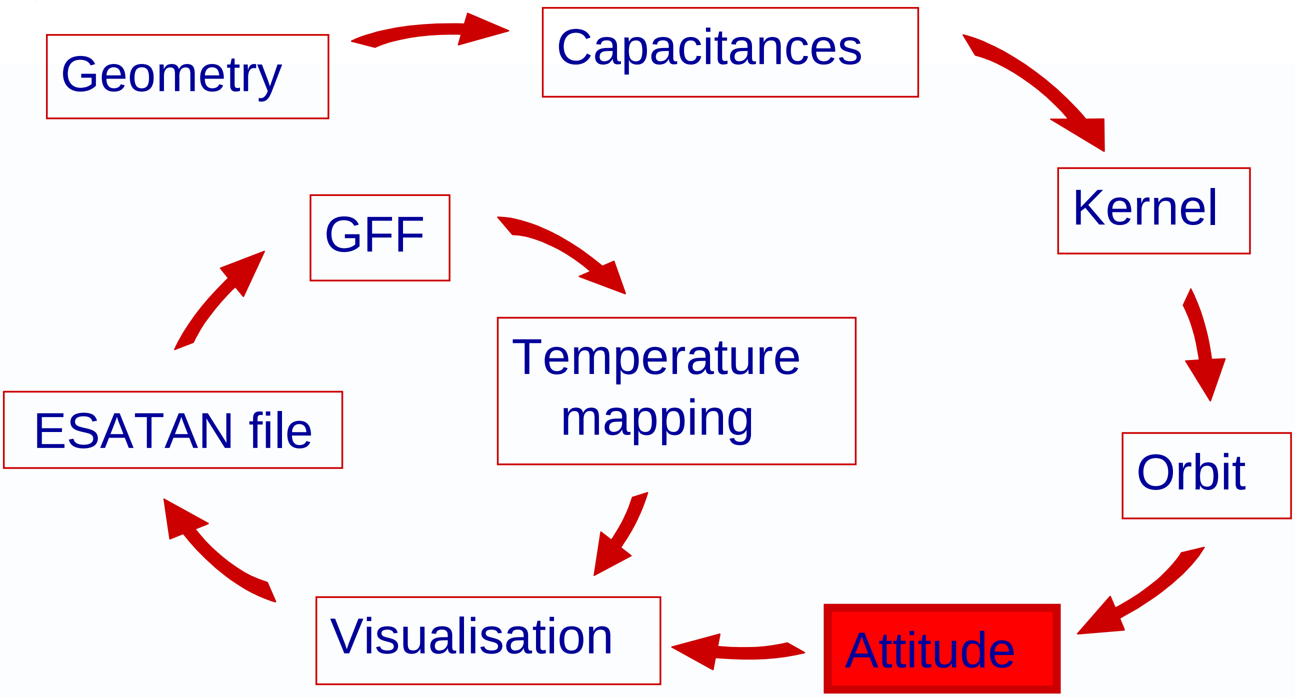


Sun Centred Orbits

- So-called **TRANSFER_ORIENTED**
- X_{ICS} points to an arbitrary direction (e.g. Γ)
- Altitudes ha and hp are actually distances from centre of Sun



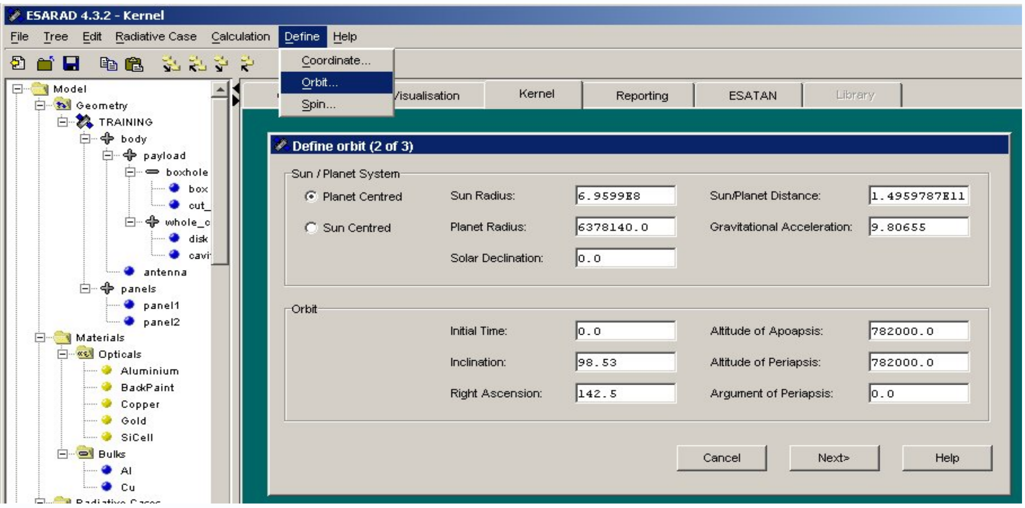
Analysis Loop – Attitude



Variable Euler Angles – Orbit

ALSTOM

- Euler angles are attributes of orbit
- Orbit is attribute of radiative case
  - Need to define an orbit up-front



Variable Euler Angles – Arrays

ALSTOM

- Define a radiative case
- Define 3 arrays of reals
  - Need to know the number of orbital positions

```
ORBIT sso_orbit;
...
RADIATIVE_CASE rad_782km;
...
REAL OMEGA_ANG[21] = {180.0, 40.0,…, 300.0, 310.0};
REAL PHI_ANG[21] = {0.0, 40.0,…, 300.0, 310.0};
REAL PSI_ANG[21] = {0.0, 80.0,…, 40.0, 80.0};
```

Variable Euler Angles – Rad Case

ALSTOM

- Affect first angle values to **INIT**ial values

```
sso_orbit.INIT_PSI = PSI_ANG[1];
sso_orbit.INIT_PHI = PHI_ANG[1];
sso_orbit.INIT_OMEGA = OMEGA_ANG[1];
```

- Affect the pre-defined orbit to radiative case

```
rad_782km.ORBIT = sso_orbit;
```


Variable Euler Angles – Loop

ALSTOM

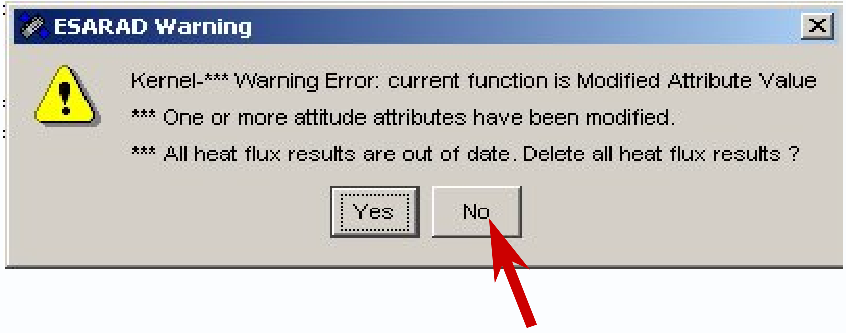
- Affect the Euler angles at each iteration
- Affect the pre-defined orbit to radiative case

```
INTEGER orbit_index;

FOR (orbit_index = 1; orbit_index <=
rad_782km.NUM_ORBIT_POSITIONS; orbit_index = orbit_index + 1)

    sso_orbit.INIT_PSI = PSI_ANG[orbit_index];
    sso_orbit.INIT_PHI = PHI_ANG[orbit_index];
    sso_orbit.INIT_OMEGA = OMEGA_ANG[orbit_index];

    rad_782km.ORBIT = sso_orbit;
```

Variable Euler Angles – Analysis

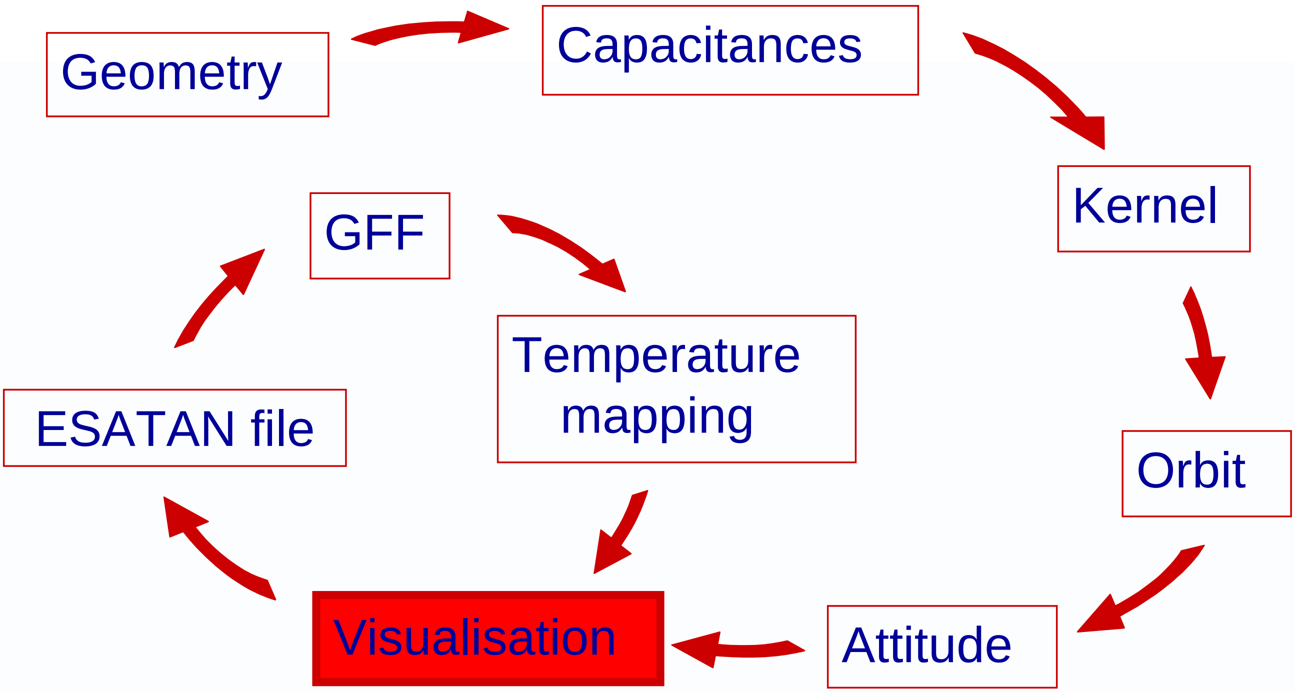
ALSTOM

- Launch analysis from GUI via Copy/Paste



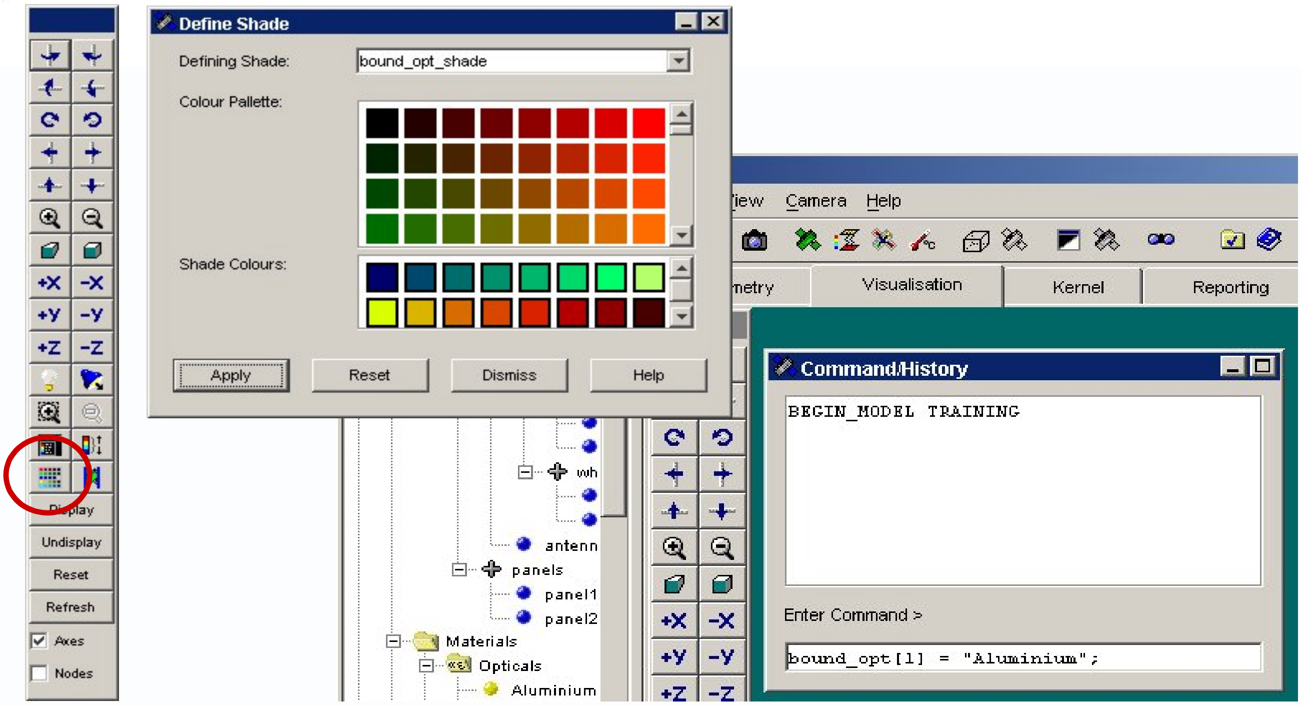
Analysis Loop – Visualisation

ALSTOM



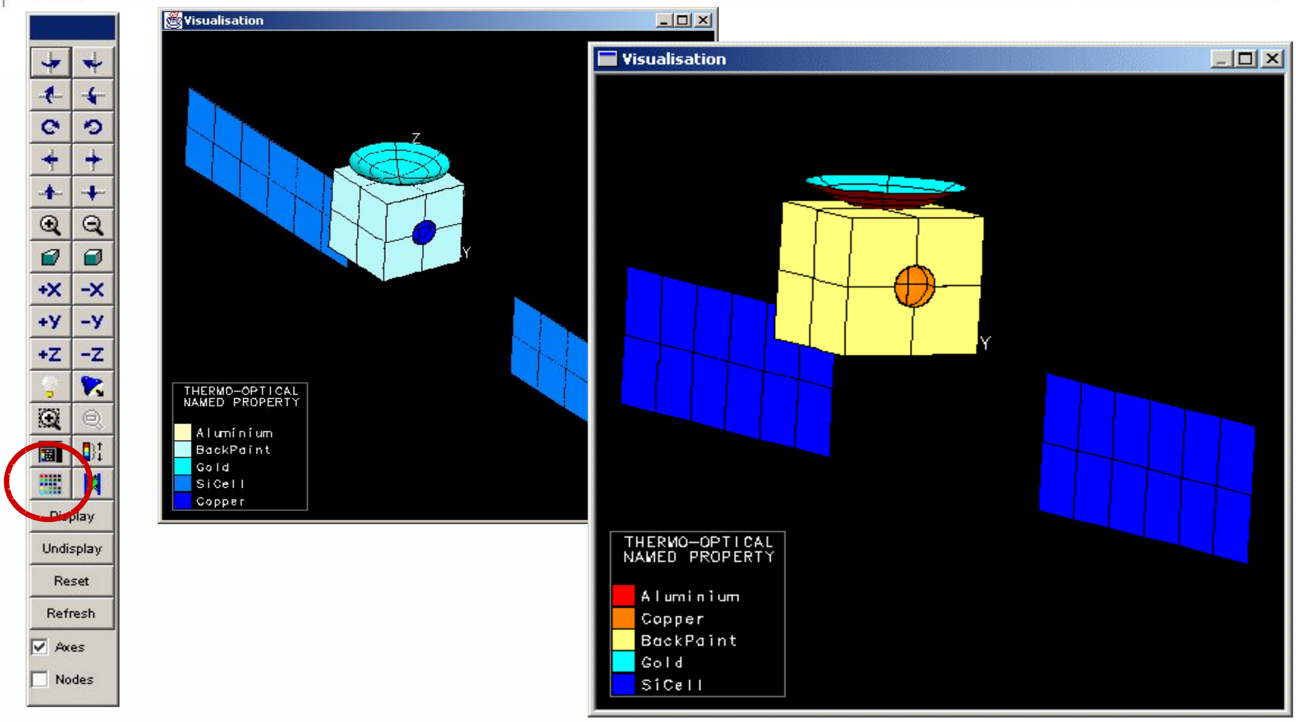
Visualisation – Shade Settings

ALSTOM

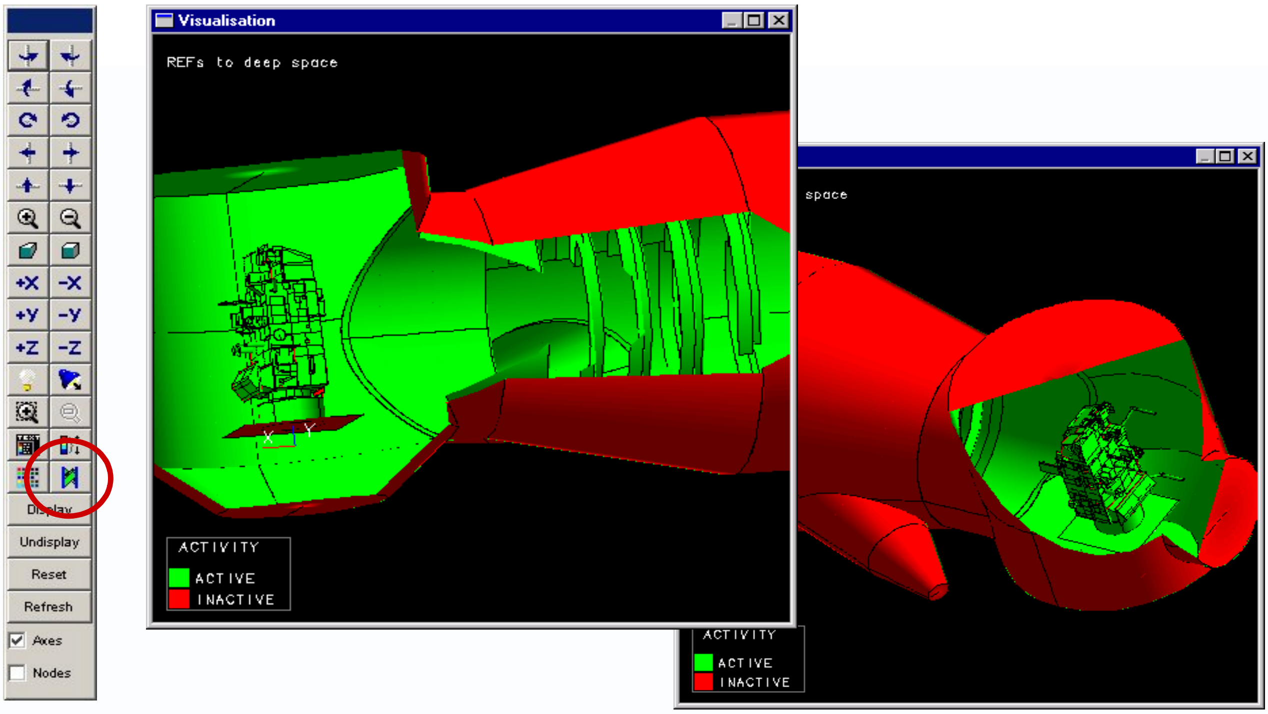


Visualisation – Colour Settings

ALSTOM



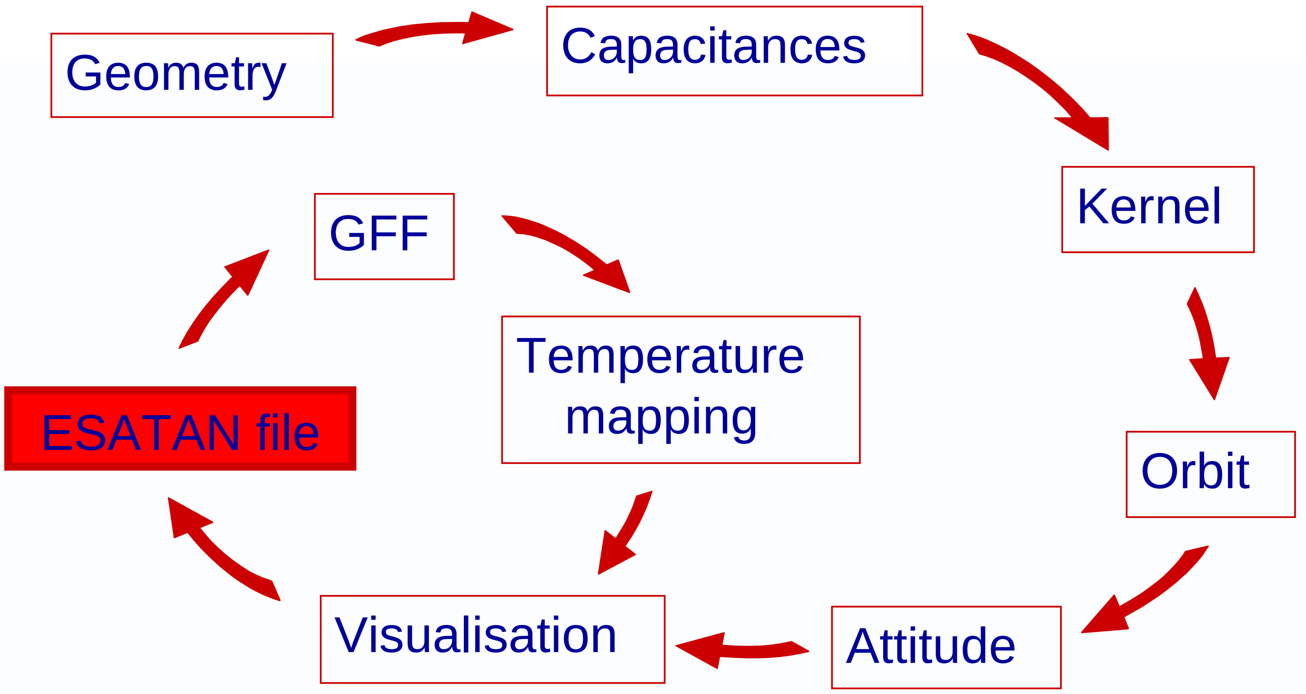
Visualisation – Clipping Planes



Visualisation – Matching Kernel

- Visualisation process independent from kernel
- Apply the orientation of the first orbital position throughout the orbit
- Any parametrisation within the kernel should be plugged into the visualisation Command/History window

Analysis Loop – ESATAN File

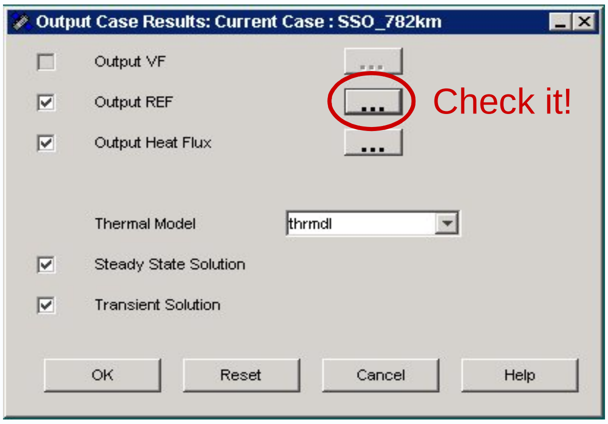


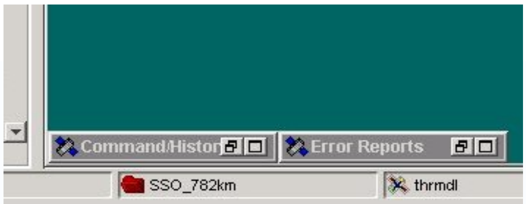
ESATAN File Formatting

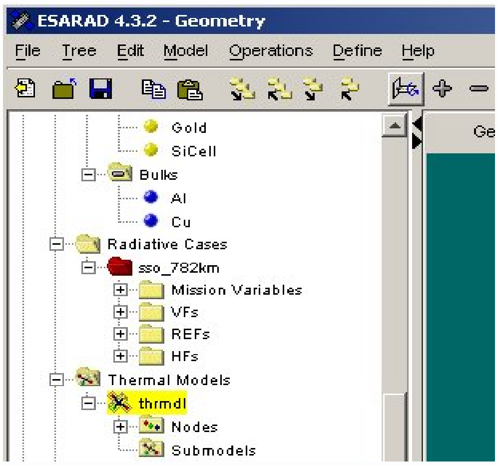
- Takes geometric model and calculated results
- Outputs an ESATAN input file representing the thermal model
- User specifies which quantities to output e.g. REFs and HFs
- User can specify a minimum cutting threshold and an average deviation threshold
- A number of different thermal models can be output from a single geometry

ESATAN File Output

- Thermal Model →Open…
- Output →Case Results…

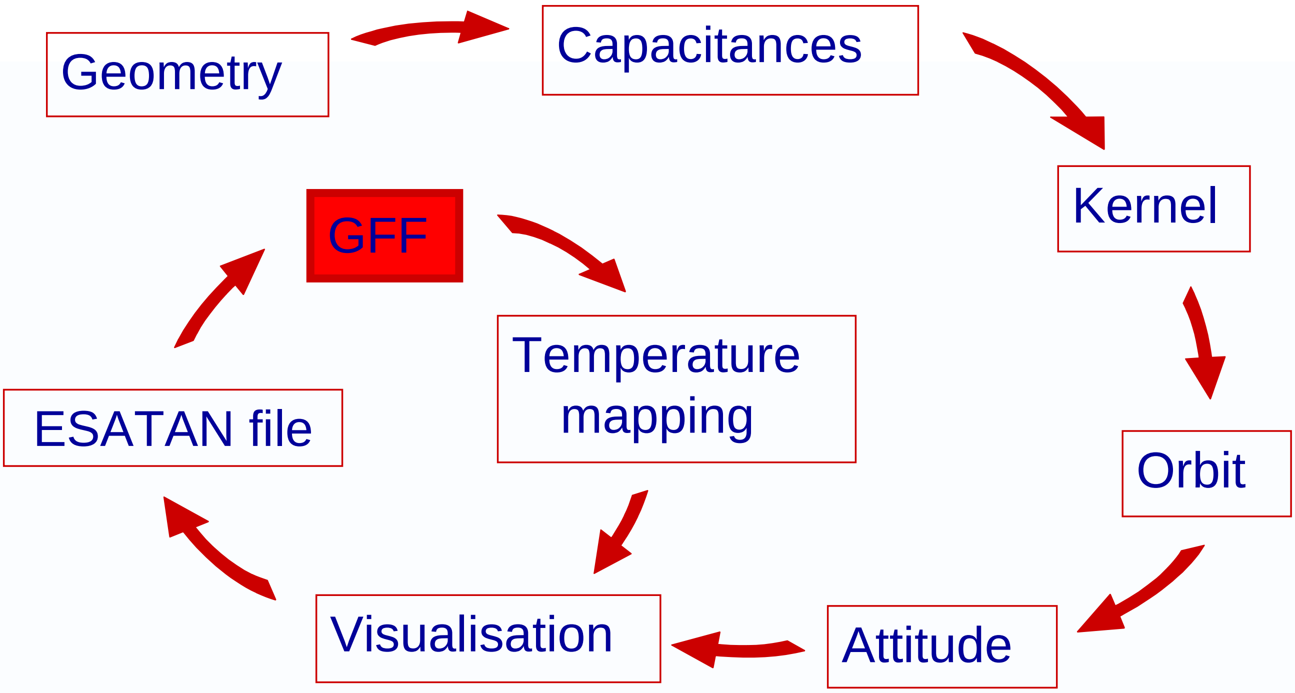






- File →ESATAN Output...

Analysis Loop – Creating GFF



Running ESATAN

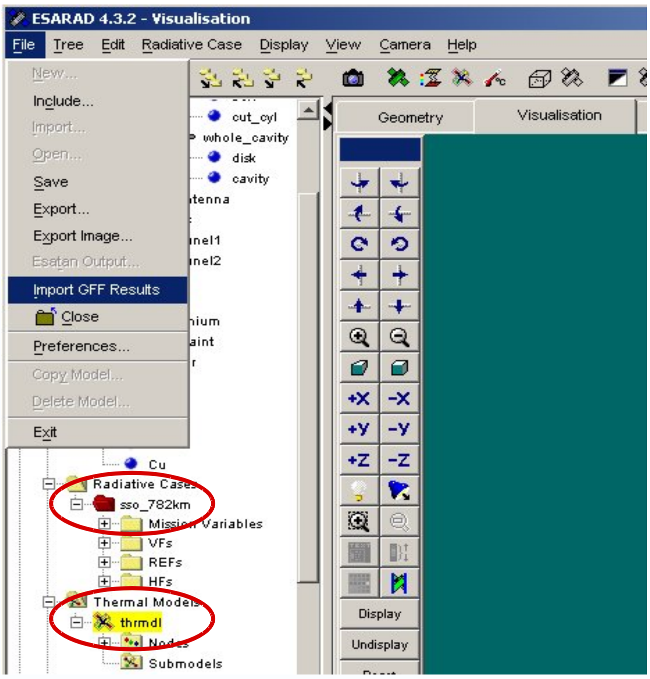
ALSTOM

- Filter exponents in file **`*.d`** – PC only
  - exp3to2 < outputfile.tan > outputfile.d
- Set capacitances in **`$INITIAL`** and GLs
- Call routine **`DMPGFF`** in **`$OUTPUTS`**
- Run steady state and transient case
- ESATAN will create two GFF output files:
  - **`*.GFF1`** – corresponds to steady state
  - **`*.GFF2`** – corresponds to transient case

Importing GFF into ESARAD

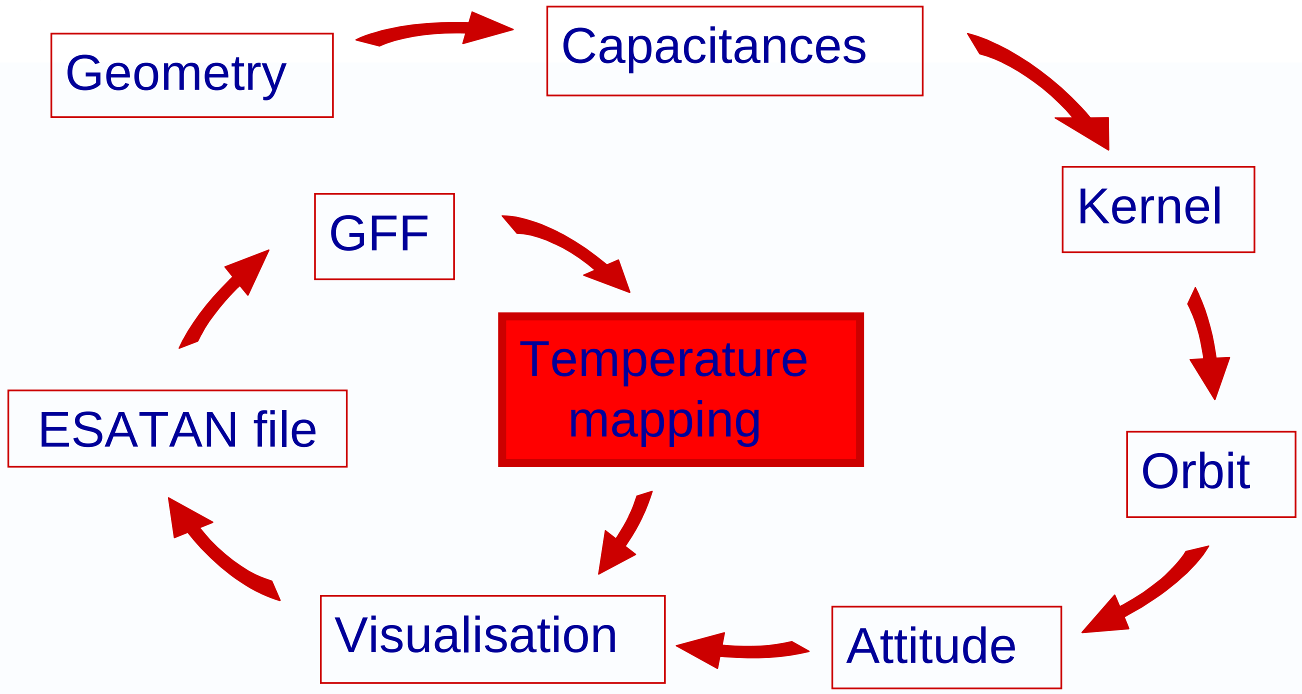
ALSTOM

- Open appropriate...
  - Model
  - Radiative case
  - Thermal model
- ...and import GFF file
  - Steady state: **`GFF1`**
  - Transient: **`GFF2`**



Analysis Loop – T°(C) Mapping

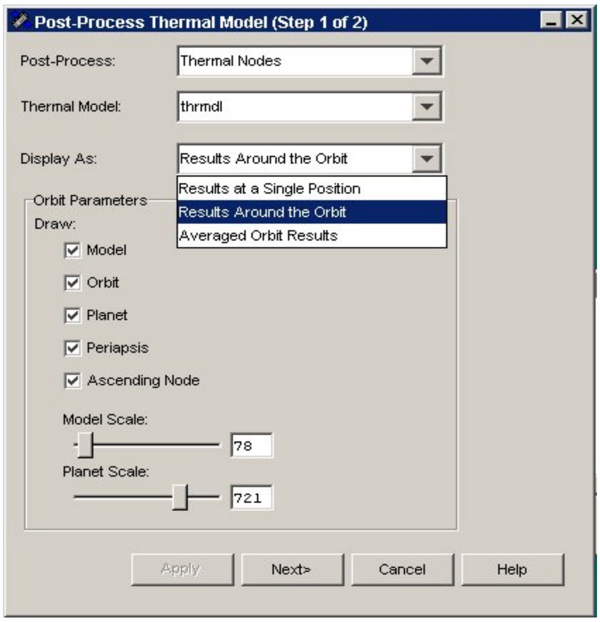
ALSTOM

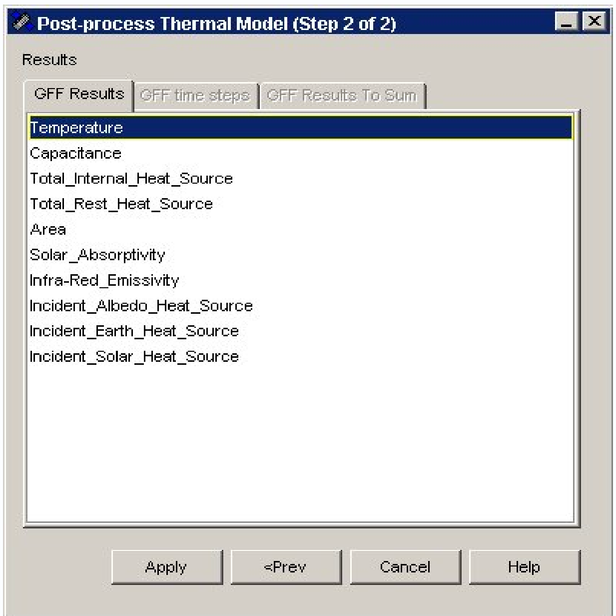


Temperature Mapping Setup

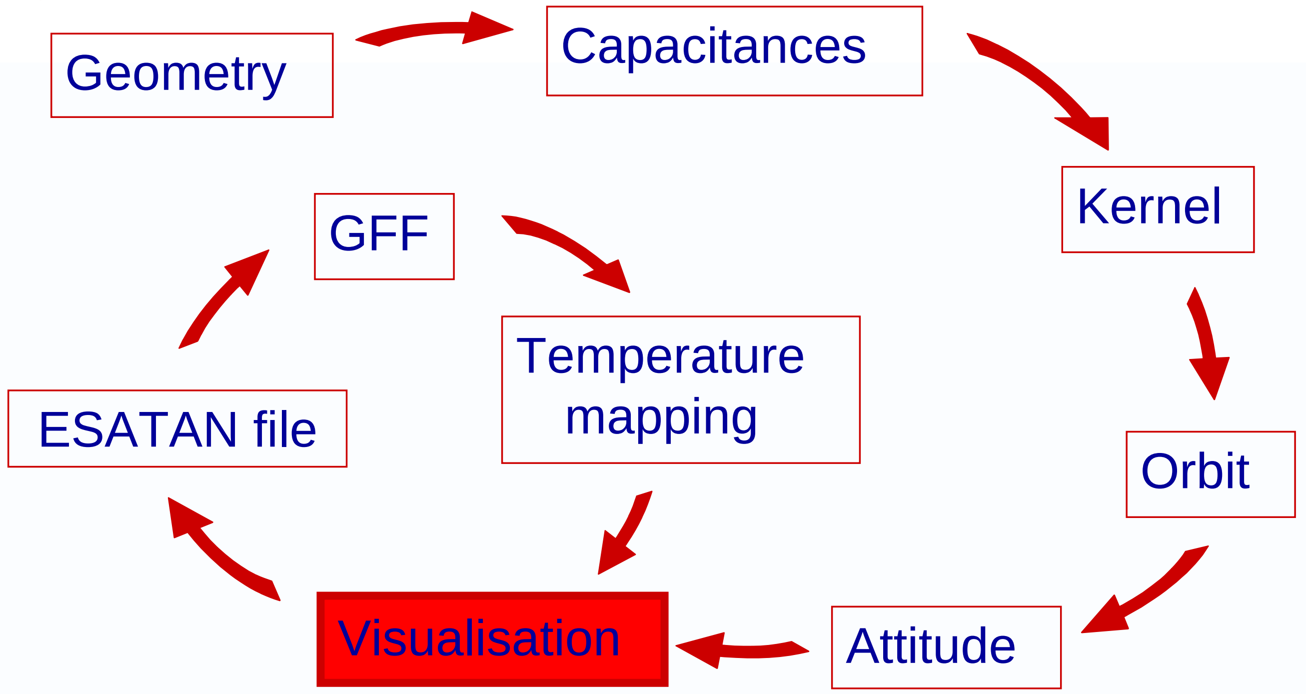
ALSTOM

- Display Post-Proc Thermal...



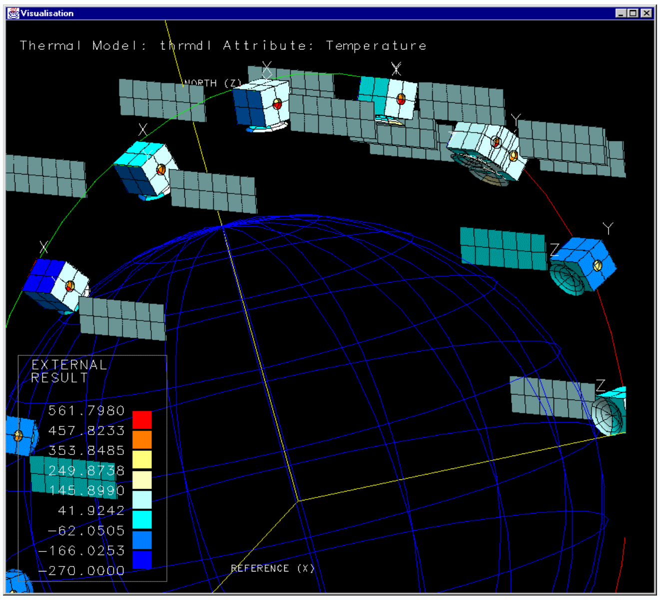


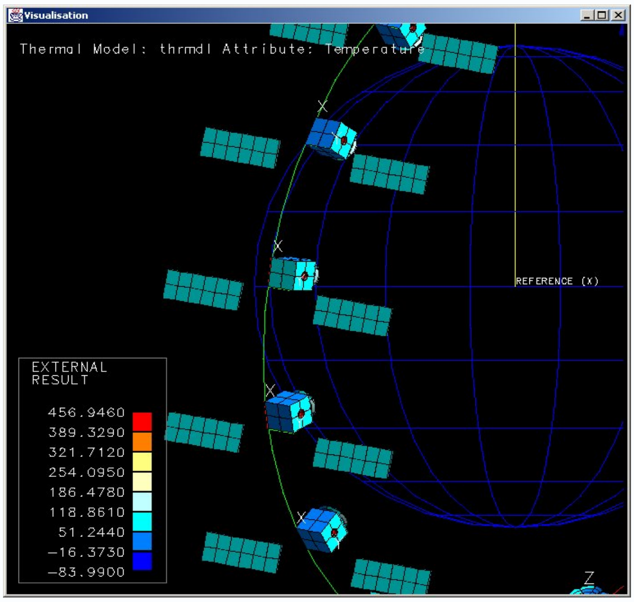
Analysis Loop – T°(C) Display



In-Orbit Temperature Display

- In-orbit results

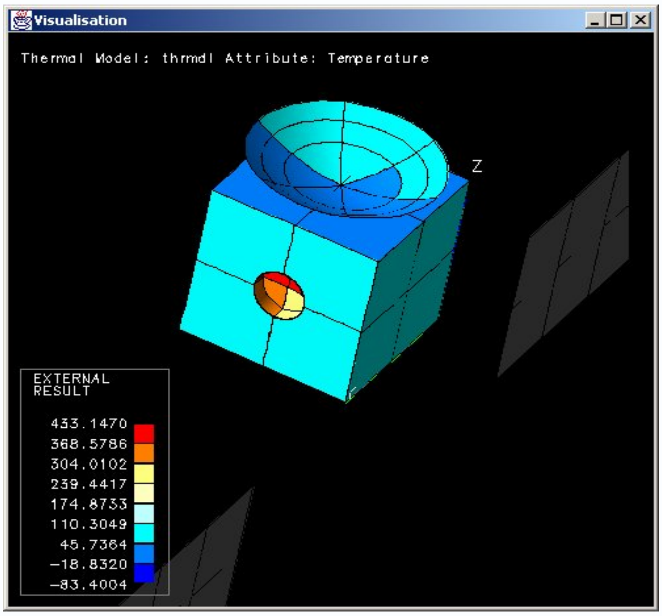


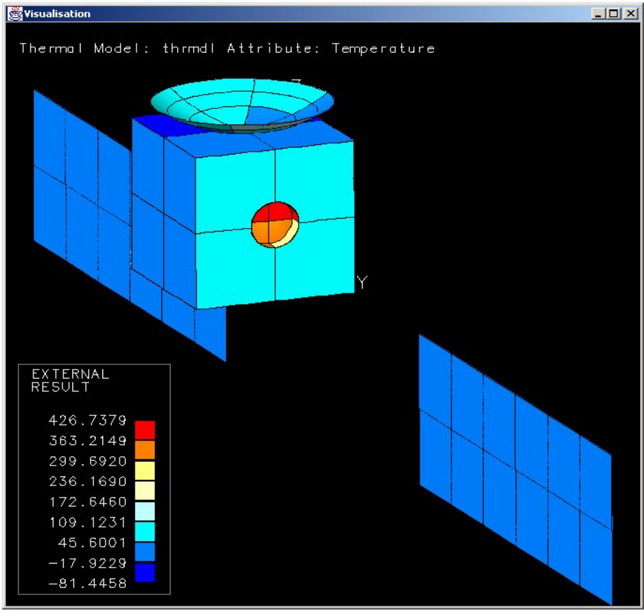


Single Temperature Display

ALSTOM

- Single position
- Average results

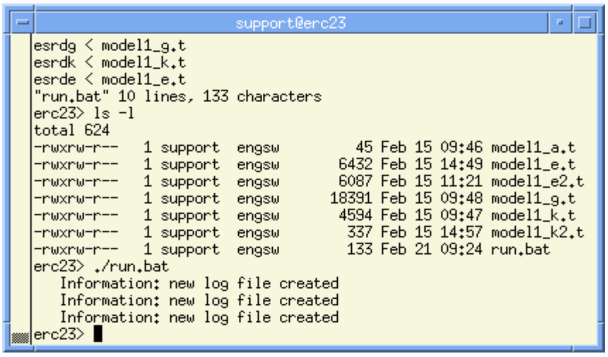




Running ESARAD in Batch

ALSTOM

- Easier
  - DOS/Xterm environment
  - Handling text files
- Faster
  - Geometry loading
  - Kernel run
- Configuration control
  - Choose version of model
- Chaining analysis



Batch Analysis Techniques

ALSTOM

- File names
  - training.erg
  - training.erk
  - training.ere

training.era - Notepad

File Edit Format Help

```
DELETE_MODEL "TRAINING";
```

- Extra files
  - training.era
  - run.bat

run.bat - Notepad

File Edit Format Help

```
call del *.log
call del *.GFF*
call del TRAINING#*
call esrda < training.era
call esrdg < training.erg
call esrdk < training.erk
call esrde < training.ere
call exp3to2 < training.d > training.tan
```

Appendix J: Round Table Discussion

Round Table
Discussion

H.P. de Koning
ESTEC/TOS-MCV

Round Table Discussion

Hans-Peter.de.Koning@esa.int

Mechanical Engineering Department
Thermal and Structures Division

Topics

- Model Reduction
- Analysis of cryogenic systems
- Connection to CAD/FEA models
- Generic post-processing

Model Reduction

- What is the purpose of model reduction?
  - Acceptable computation time?
  - Manageable post-processing / interpretation?
  - Manageable integration subco models in system model?
- Model reduction versus reduced/consolidated view of model and results, and keep running the complete model
- How is reduced model verification handled?

Analysis of cryogenic systems

- User experience?
- Particular requirements for modelling
- Numerical accuracy
- Handling non-linearities
- Adequate representation of materials/properties
- ESARAD/THERMICA, ESATAN OK? Special pre-cautions?

Connection to CAD/FEA models

- Are users importing CAD/FEA models routinely?
  - What standards? Or proprietary interfaces?
- How is idealisation done?
  - By hand / automatic? In CAD tool? In thermal modelling tool?
- Typical model size?
  - Hundreds of surfaces? ~1000? ~5000? ~10000? ~50000? ~100000?
- Closing the loop: export back to CAD/FEA necessary?

Mechanical Engineering Department
Thermal and Structures Division

Generic post-processing

- Asked many times…
- Is it possible to agree on common functionality?
- Can current proprietary packages be merged into one public one
- Build around common open standard results data format
  - STEP-NRF / HDF5 results format is planned to become available in 2002
  - Then output routines for ESATAN, ESARAD, ...

Appendix K: Temperature Control Loop Analyzer (TeCLA) Software

Temperature Control Loop Analyzer (TeCLA) Software

F. Burzagli
Alenia Spazio

Temperature Control Loop Analyzer (TeCLA) Software

F. Burzagli - S. De Palo - G. Santangelo
(Alenia Spazio)

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15th European Workshop on Thermal and ECLS Software

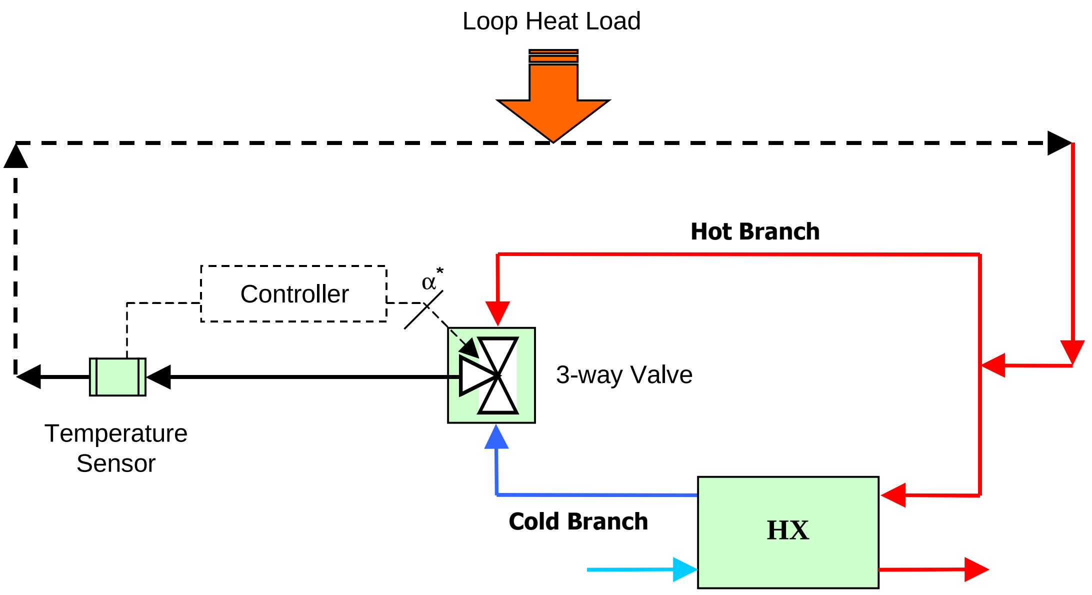
Foreword

A typical feature of an active loop thermal system is to guarantee a tight temperature range to external and/or internal users through a stable and fast control dynamics.

This goal is obtained through a compromise between
- stability (“bullet-proof”, relatively slow system)
- performance (reactive, potentially nervous system)

This compromise is not always possible.

Standard Temperature Control Configuration



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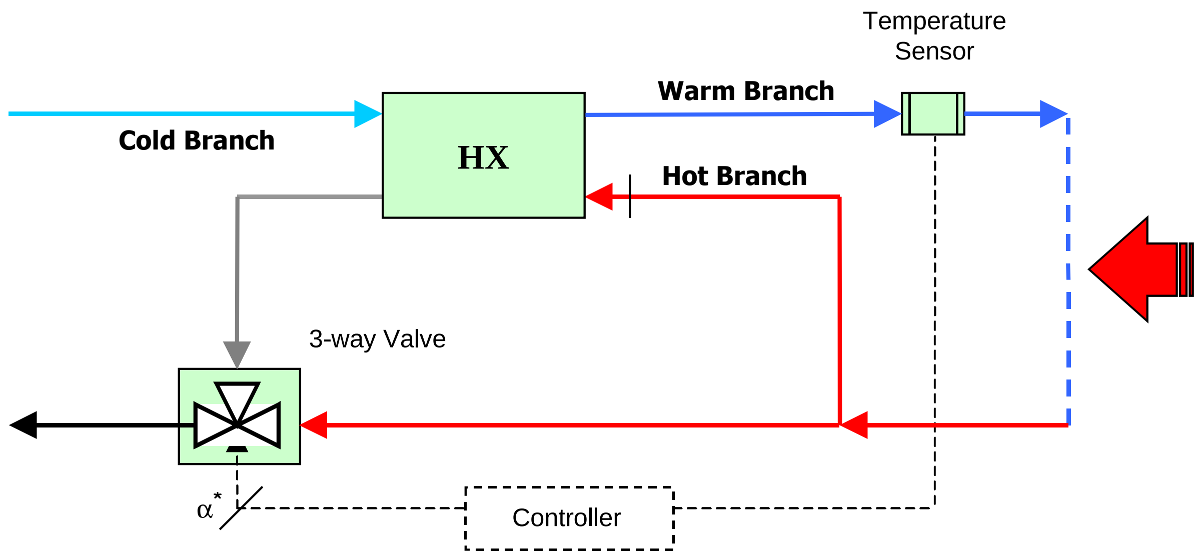
Regenerative Temperature Control Configuration



Approaches to Stability Analysis

Method	Pros	Cons
Experimental Testing	❑ Stability directly assessed for the tested configurations	❑ Usually expensive ❑ Huge number of scenarios to be investigated ❑ Stability not guaranteed in other configurations than the tested ones
Numerical Simulation	❑ No test set-up costs ❑ Utilization of standard simulators	❑ Huge number of scenarios to be investigated ❑ Stability not guaranteed in other configurations than the tested ones ❑ Modeling uncertainties
Theoretical Analysis	❑ Extensive investigation of all the possible loop configurations ❑ Worst case identification (parametric) ❑ Possible use of robustness indicators	❑ Simplified representation of the loop

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Approaches to Stability Analysis (cont'd)

A detailed analysis of the loop stability and performance has to consider the following points:

- investigation of stability based on automatic control theory (linear and/or non-linear) ➔ **[theoretical analysis]**
- choice of "optimal" and "robust" control law coefficients ➔ **[numerical simulation and theoretical analysis]**
- identification of operational worst case scenarios ➔ **[theoretical analysis]**
- simulation of transients leading to worst case scenarios (verification of stability regions) ➔ **[numerical simulation]**
- optional testing campaign focused on worst case operational scenarios (verification of stability regions and system performance) ➔ **[experimental testing]**

Node 2/Columbus Testing Experience

Examples of the experimental activity are the testing campaign on Node 2 Breadboard and on Columbus Water Loop Step IV (both carried out in the period July-August 1998) .

Some limits of the trial and error methods were highlighted:

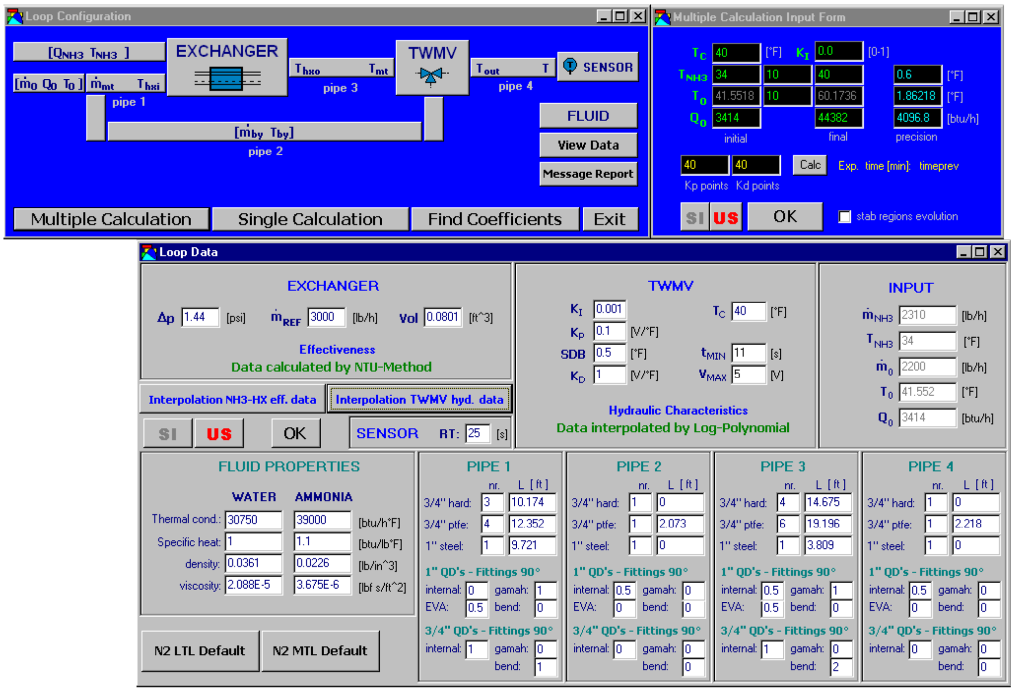
- the stability/instability assessment of the system was limited only to the tested cases;
- various sets of control coefficients were tested to investigate the influence on the system stability;
- evidence about the reliable identification of the worst case scenario was not obtained;

TeCLA Code

Temperature **C**ontrol **L**oop **A**nalyser (**TeCLA**) was developed by Alenia to perform stability analysis on Node 2 layout and software. The main features of the code are:

- The loop layout can be interactively inserted by the user
- 3-way and heat exchanger hydraulic and thermal data are interpolated by means of neural network
- the worst case scenario is found inside a range of operational parameters given by the user (and derived from requirements)
- stability regions in terms of controller gains are evaluated
- stability regions evaluated on the basis of Nyquist (linear) and circle (non-linear) criteria
- robustness indicators (vector, phase or gain margin) are given for each pair inside the stable zone

TeCLA Code - graphic user interface



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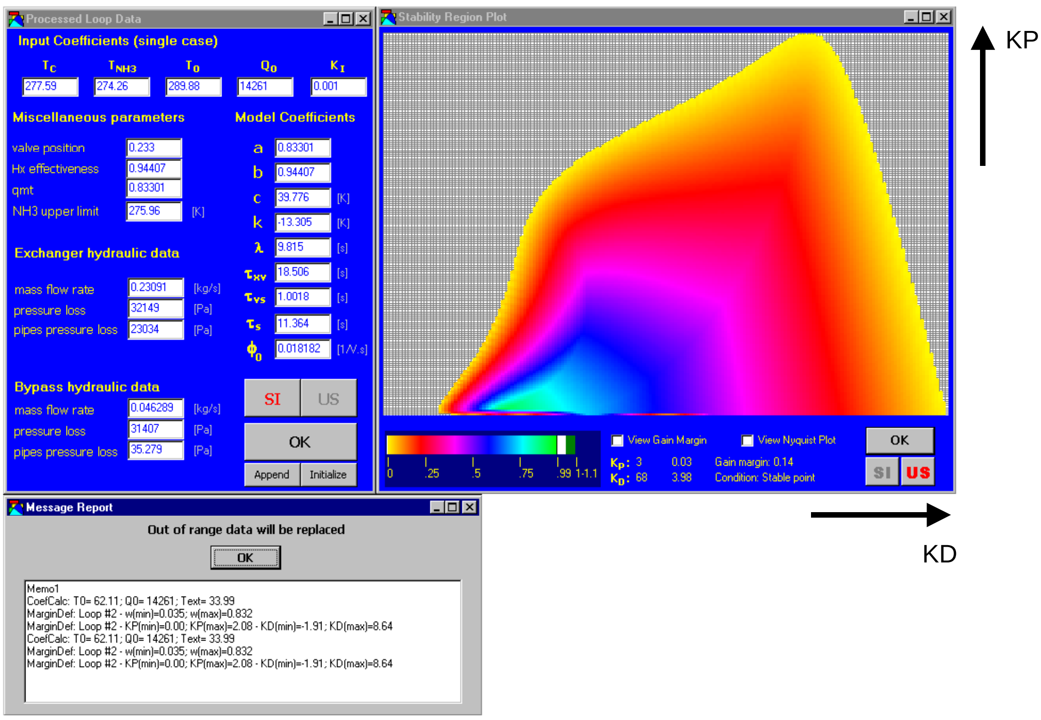
TeCLA Code - stability region screen shot



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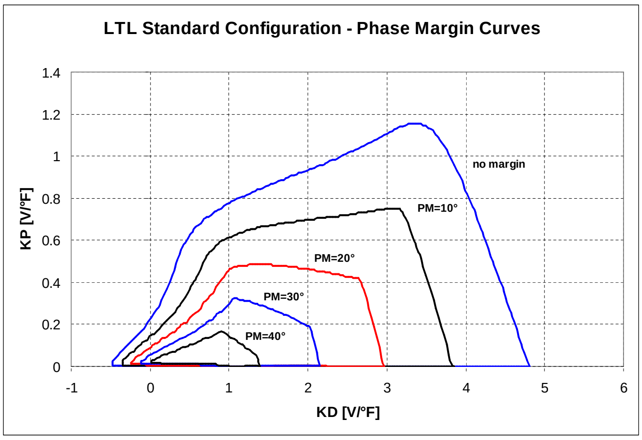
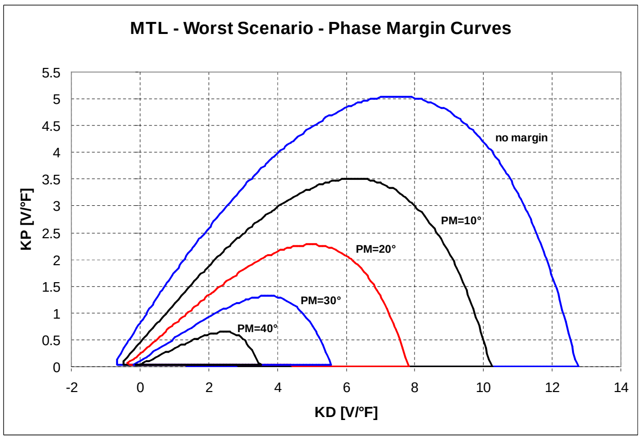
Application to Node 2 LT and MT loops
(iso-phase margin curves - standard configuration)





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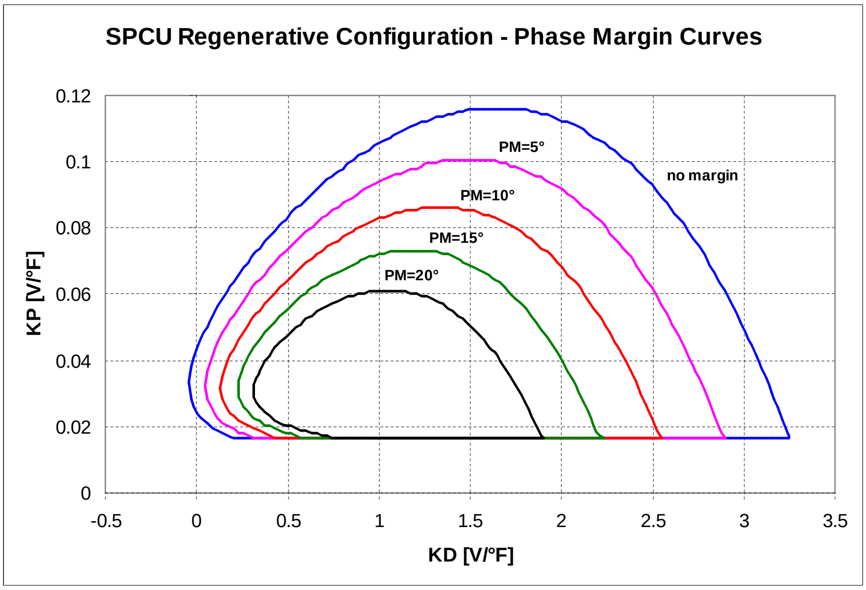
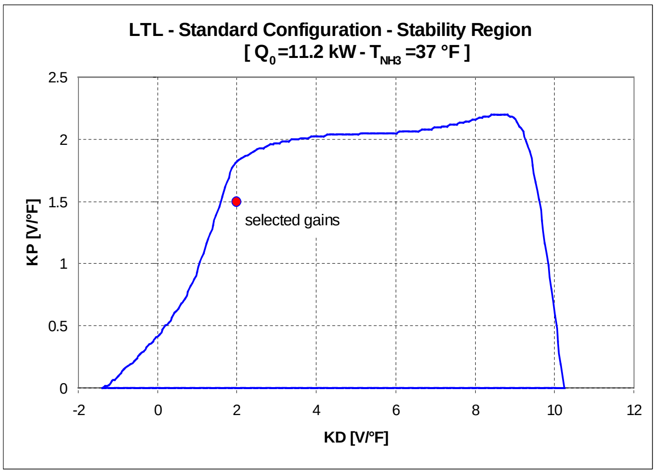
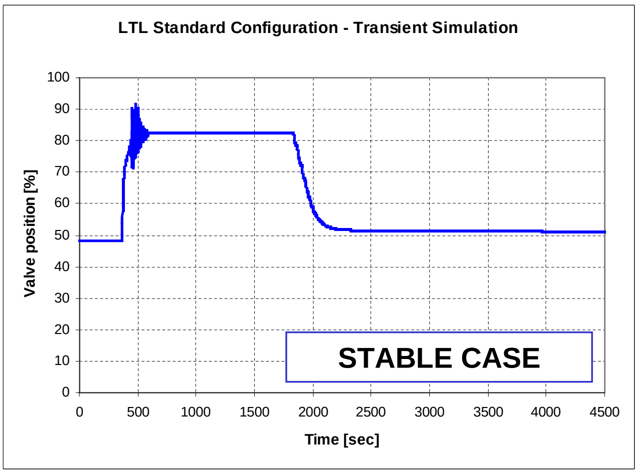
Application to Node 2 LT loop
(iso-phase margin curves - regenerative configuration)



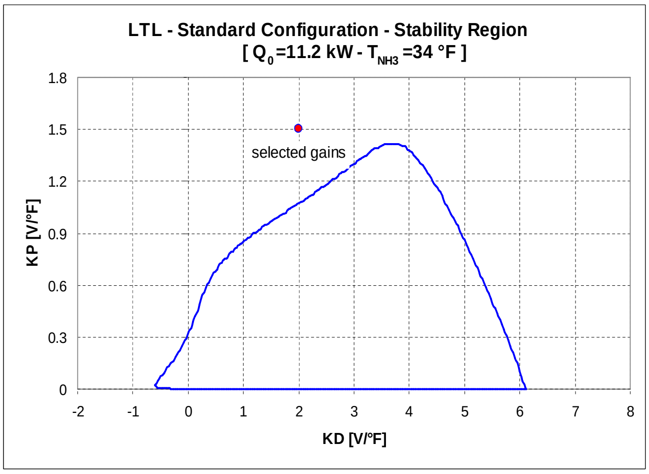
SINDA-Fluint Simulations vs. TeCLA predictions

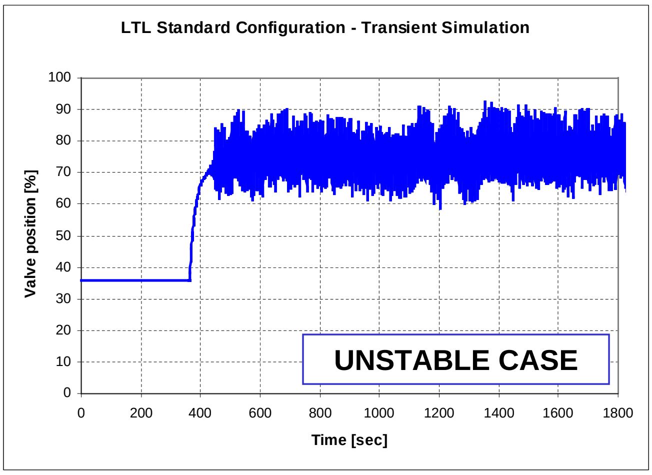




Heat variation: ± 10 kW (max injected power: 11.2 kW)
Ammonia T: 37 °F - KP = 1.5 - KD = 2 - KI = 0.001

SINDA-Fluint Simulations vs. TeCLA predictions (cont’d)





Heat variation: + 10 kW (max injected power: 11.2 kW)
Ammonia T: 34 °F - KP = 1.5 - KD = 2 - KI = 0.001

TeCLA ongoing development

The software is being updated in order to:

- cover a wider range of layout configurations (100% completed, debugging ongoing)
- cover a wider range of control laws (50% completed)
- utilize a wider spectra of stability and robustness indicators (20% completed)

TeCLA will be structured in two separate units:

- the solver (ANSI C) runs on Unix platform
- Intranet/Internet access to graphic pre- and post-processing (Java)

Development schedule:

- mid 2002

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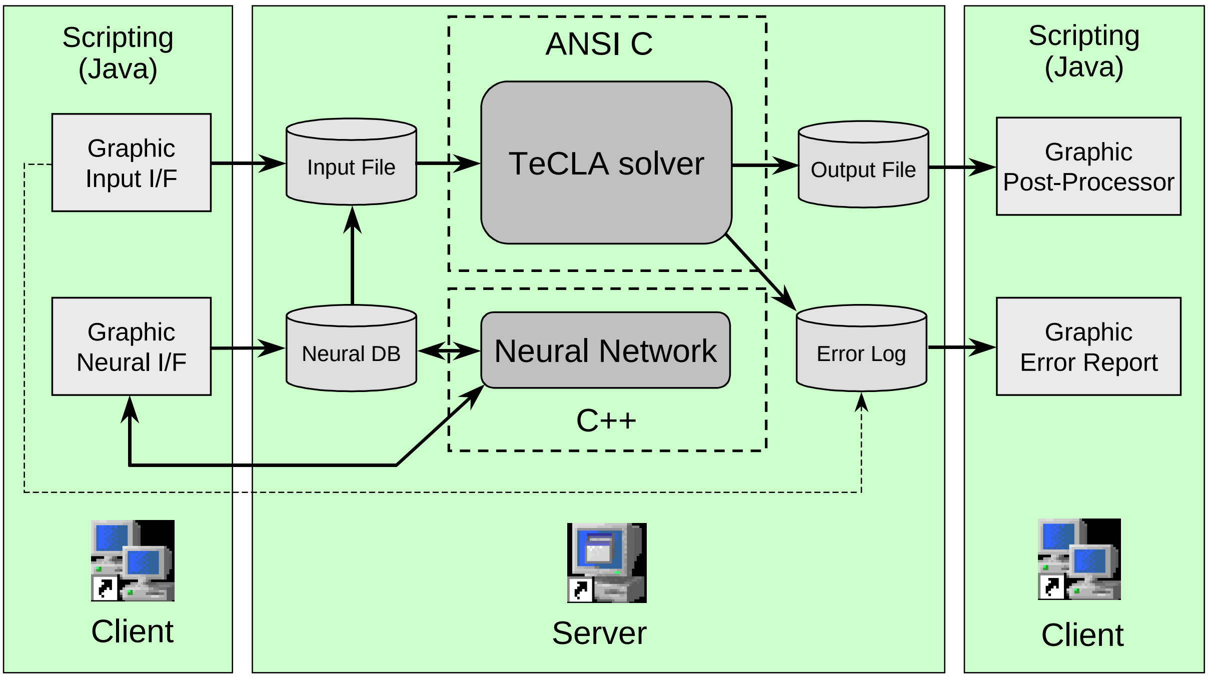
TeCLA Architecture (ongoing development)



Future Work

- Coefficient optimization:
  Insert an inverse Laplace transform routine to provide information on the system performance inside the stable region
- Mission control utilization:
  Link of the software to real-time flight telemetry to analyze off-nominal scenarios and verify the stability of the implemented control law parameters
- Extension to pressure and mass flow rate controls
- Software validation:
  In the framework of Node 2 Testing activity at integration level (if possible)

NOTE: once the Java I/F has been assessed for TeCLA, its use can be extended to develop connection tools between mission control telemetry and simulation software (SINDA-FLUINT, ESATAN-FHTS) to analyze flight transient with considerable time saving.

Appendix L: Analysis of Spacecraft Thermal Stability

Analysis
of
Spacecraft Thermal Stability

B. Shaughnessy
RAL

Analysis of Spacecraft Thermal Stability

Bryan Shaughnessy

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e-mail: b.m.shaughnessy@rl.ac.uk

Objectives of Presentation

- A short study is just underway to assess the Phase A thermal stability analysis that has been made for the Laser Interferometer Space Antenna (LISA).

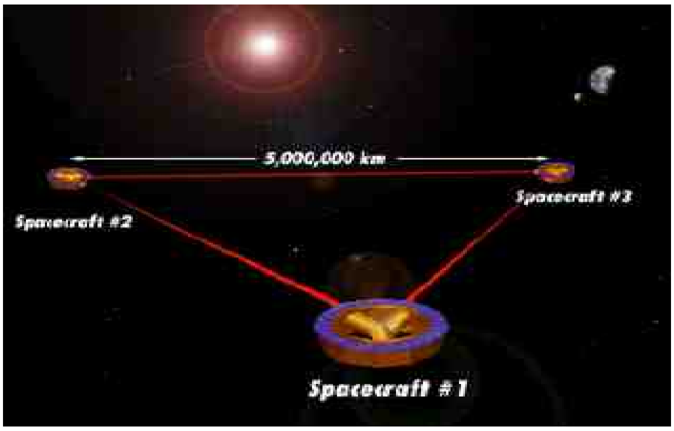
- The study aims to:
  - assess the validity of the standard thermal modelling approaches when investigating small temperature fluctuations.
  - recommend methods for improving analysis of spacecraft thermal stability.

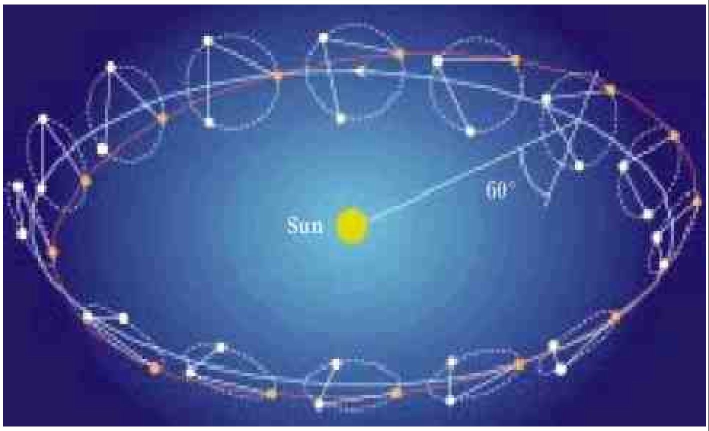
- The purpose of this presentation is therefore to describe the work in progress:
  - summarise the initial review of uncertainty and error sources.
  - place the review in the context of spacecraft thermal stability analysis.
  - invite ideas and suggestions.

LISA Mission Summary

- Gravitational wave detector based on a Space interferometer:
  - Measures changes in separation between free falling test masses to 10pm accuracy.
  - Six test masses on three spacecraft in an equilateral triangle formation.
- Major thermal disturbances are due to:
  - Variation in solar constant due to Sun's normal modes of oscillation.
  - Fluctuations in electrical power dissipation.
- Thermal stability requirements:
  - Optical Bench temperature stability better than 1×10^{-6} K/Hz$^{1/2}$ at 1 $\times10^{-3}$ Hz.
  - Electronics temperature stability better than 1.2×10^{-3} K/Hz$^{1/2}$.
  - Telescope optical path length changes resulting from thermo-elastic effects < 40pm/Hz$^{1/2}$

LISA Mission Summary





Thermal Modelling

- The thermal response of the unit is assessed by applying fluctuations, at specific frequencies, due to:
  - Solar Constant.
  - Electrical power dissipations.
- The semi-amplitude of temperature fluctuations is obtained from the absolute temperature predictions (i.e., ½(T_{max} - T_{min})).
  - numerical stability must be achieved
- Therefore, the thermal model must be able to identify temperature differences smaller than 2×10^{-6} K (the difference between the absolute temperature predictions).

Rutherford Appleton Laboratory
Space Science and Technology Department

Thermal Stability Analysis Issues

- Understand the sources of instability
  - numerical instability.
  - ‘real’ instability.
- How to select appropriate model parameters
  - time steps.
  - meshing density.
- What are the limits on the accuracy for stability analysis predictions?

The Three Main Sources of Numerical Error

Data Uncertainty

Differences between the thermal model and the final ‘as-built’ spacecraft. For example,

- Heat capacities.
- Radiative exchange-factors.
- Conductances.

Rounding

Computer approximation to the real number.

Truncation

Replacing the exact partial differential equations with finite difference approximations.

Data Uncertainty

• LISA thermal analysis is for Phase A - details of the final spacecraft configuration are not known.

• The data uncertainty can be reduced to some extent as the design is developed (e.g., through Phases B and C).

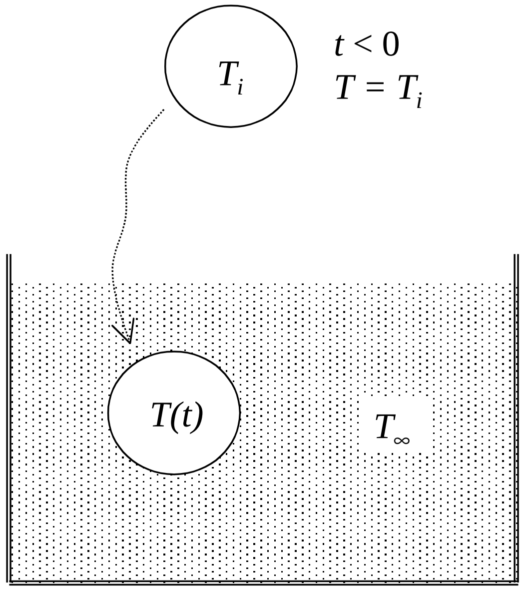
• Sensitivity analysis can be used to quantify these uncertainties.

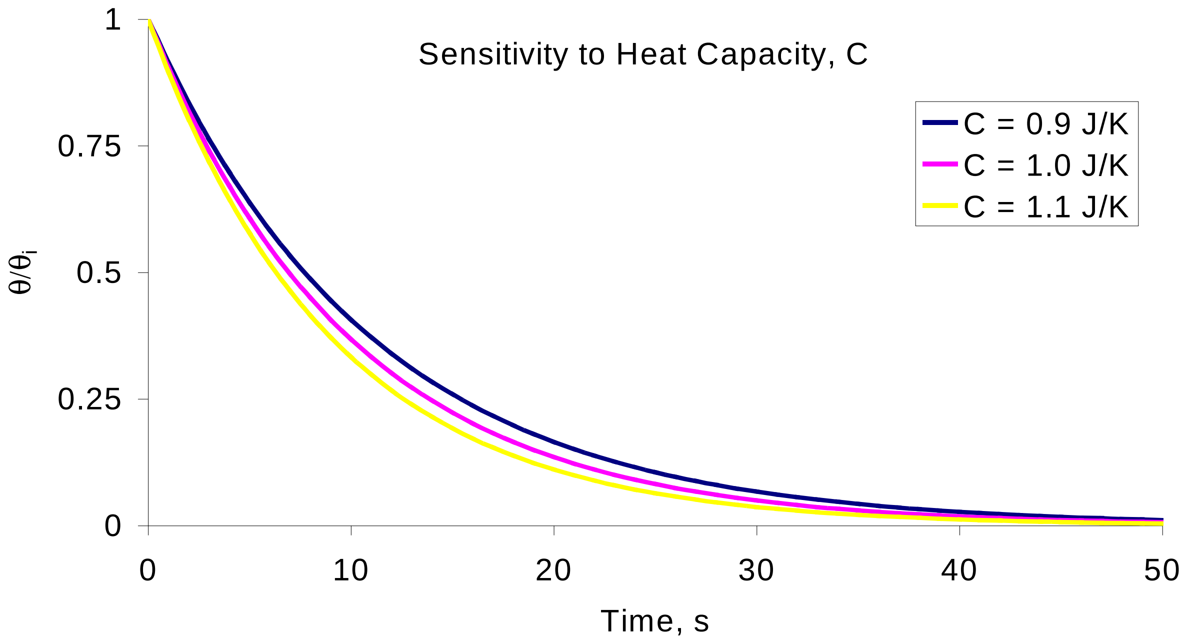
Data Uncertainty Example

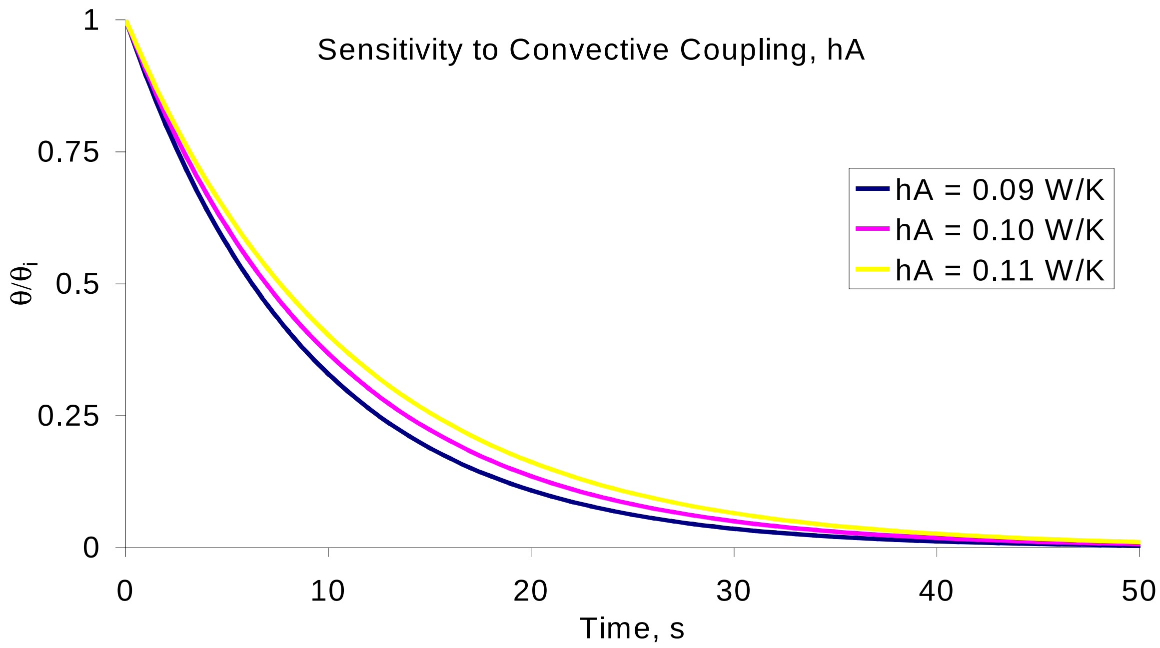
- Object at uniform initial temperature T_i
- Immersed in fluid at temperature T_∞ at t=0
- Convective coupling = hA = 0.1 W/K
- Heat capacity = $C = mc_p$ = 1.0 J/K

$$\frac{\theta}{\theta_i} = \frac{T - T_\infty}{T_i - T_\infty} = \exp\left[-\left(\frac{hA}{C}\right)t\right]$$

$$\tau = \frac{C}{hA}$$







Rounding

- A characteristic of computer hardware.

- Floating point number system: $y = \pm m \times \beta^{e-t}$,
where m = mantissa; β = base; *e* = exponent range; *t* = bias.

- The sign, mantissa, and exponent range only are stored to represent floating point numbers.

- The two main floating point formats are:

Type	Size (bits)	Mantissa (bits)	Exponent (bits)	Unit roundoff	Range
Single	32	23+1	8	$\sim 6\times10^{-8}$	$10^{\pm38}$
Double	64	52+1	11	$\sim 1\times10^{-16}$	$10^{\pm308}$

- ESATAN solution routines use Double Precision

Accumulation of Rounding Errors

- Theoretically, in finite difference routines the rounding errors accumulate linearly with time.
  - the occurrence of rounding errors is not random.

- Minimising the time step will increase the rounding errors.
  - ‘larger’ time step is desirable.

- Cancellation
  - is when two nearly equal numbers are subtracted.
  - can exacerbate problems.
  - occasionally beneficial because errors are also cancelled.
  - avoid subtracting values that are in error.

Truncation

- Truncation error would exist even if a computer had perfect representation of numbers and no round-off error.

- Truncation errors are associated with the discrete approximation of a continuous quantity.
  - time-steps.
  - spatial discretisation.

- Minimising time step and refining mesh is desirable.

- Spatial discretisation is generally coarse in Phase A models and becomes finer, as appropriate, during Phases B and C.

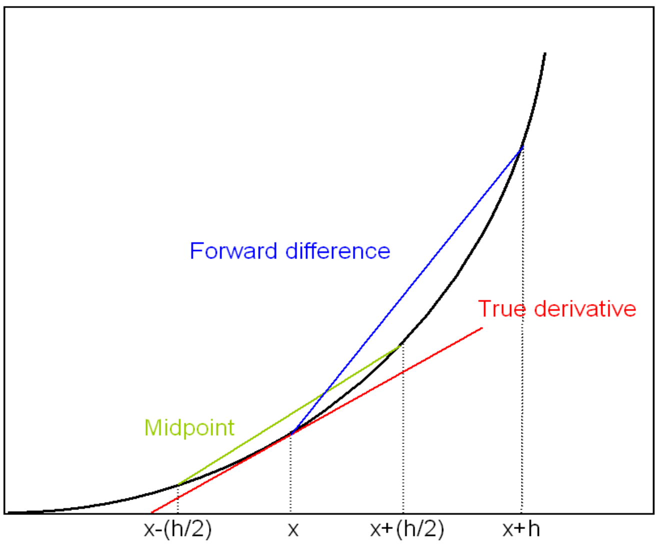
- A fine mesh is desirable for predicting temperature gradients over low conductivity structures.

Truncation

- The ESATAN 'SLFWBK' solver was used for the LISA Phase A thermal analysis:
    - Crank-Nicholson forward-backward difference method.
    - centred on the midpoint of the time-step.
    - 'implicit scheme': simultaneous solution of temperatures at each time-step.
    - numerically stable for any size of time-step.
    - the time discretisation is 'second order' correct (i.e., proportional to the square of the time step):
        - halving the time-step reduces the truncation error by a factor of 4.

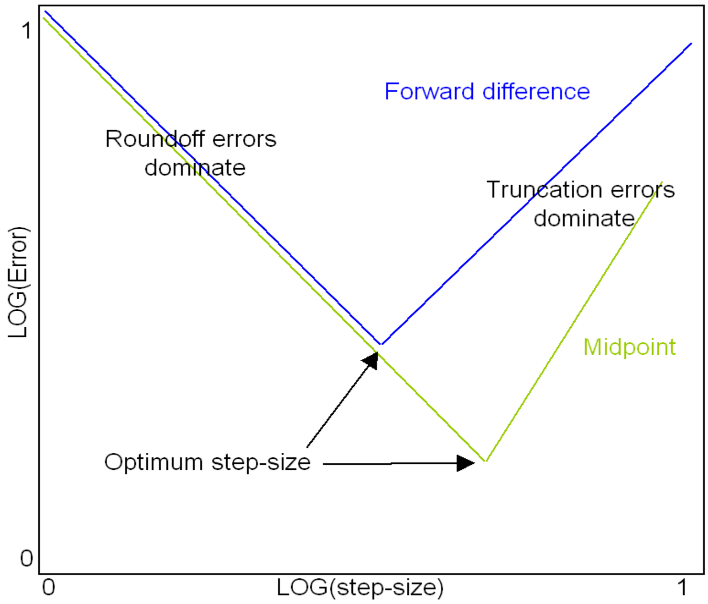
Midpoint Scheme

- The slope of the tangent to a function at the midpoint is a better approximation to the derivative than the 'forward difference' scheme



Influence of Step-Size on Truncation and Rounding

- Simply reducing the step-size as much as possible does not achieve the best accuracy.
  - truncation : minimise step-size.
  - rounding : 'larger' step-size.
- The optimal step-size therefore needs to be determined.
- Can the transient response be analysed to identify optimal step-size:
  - statistical.
  - noise.



Conclusions

- Three main sources of error that can influence thermal stability analysis:
  - data uncertainty.
  - truncation.
  - rounding.
- Planned work:
  - Complete review of error sources.
  - Assess hardware/software characteristics.
  - Develop methodology for setting up and undertaking thermal stability analysis.
  - Is present analysis capable of assessing the LISA thermal requirements?

Appendix M: Overview of Bepi-Colombo Thermal Analysis

Overview
of
Bepi-Colombo
Thermal Analysis

I. Renouf
Astrium-UK

An Overview of BepiColombo Thermal Analysis

Presented by

Ian Renouf, Astrium UK

15th European Workshop on Thermal/ECLS Software
ESTEC 9-10th October 2001

Summary

- About BepiColombo
- Thermal Design Issues
- Required Thermal Analysis
- Thermal Modelling Issues
- Proposed Software Developments
- Conclusions

About BepiColombo

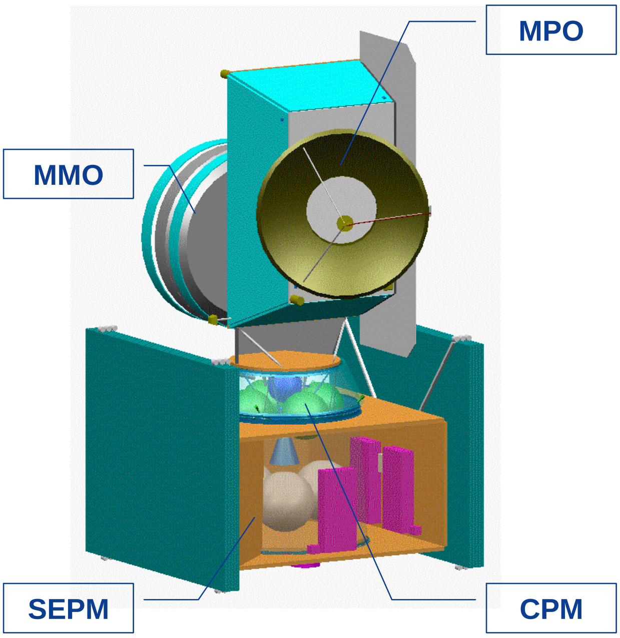
1

What is BepiColombo?

- **ESA mission to Mercury (Cornerstone 5)**
- **Consists of 3 science spacecraft**
  - MPO: Mercury Polar Orbiter, performs close range study of the planet surface and investigation into gravity field & rotational state
  - MMO: Mercury Magnetosphere Orbiter, performs measurements of Mercury magnetosphere (supplied by ISAS, Japan)
  - MSE: Mercury Surface Element, a lander to record data from the planet surface
- **Includes 2 propulsive modules**
  - SEPM: Solar Electric Propulsion Module, provides ΔV to spacecraft to perform transfer to Mercury (uses Ion engines)
  - CPM: Chemical Propulsion Module, provides ΔV to spacecraft to perform Mercury orbit injection manoeuvres, and descent to surface
- **All modules travel to Mercury as a single composite**

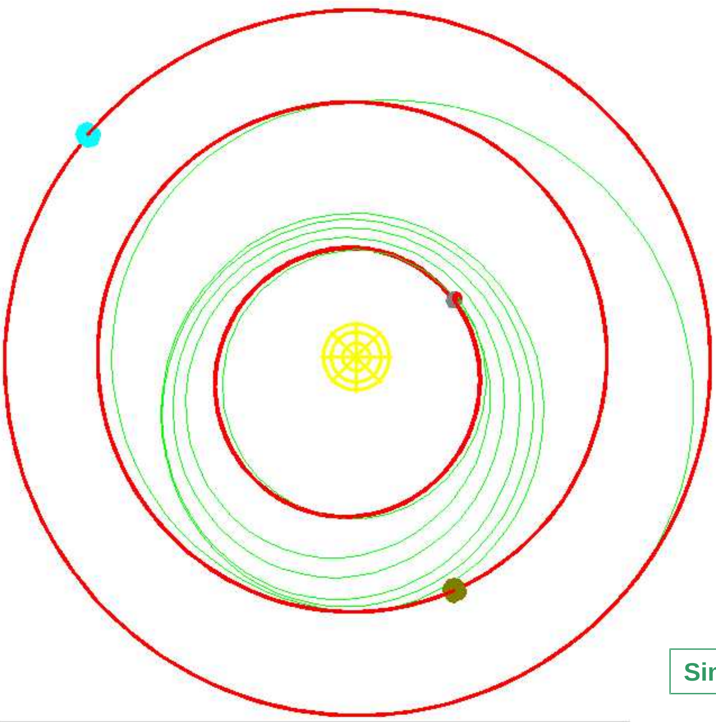
Mission and Spacecraft

- Launch date: 2009/2010
- Launched by Ariane V
- Transfer lasts 2½ years
- Arrive in Mercury Orbit: 2012
- Performs 2 Venus flybys (1 inside, 1 outside)



Picture ESA

Mercury Transfer Path



Simulation of a 2010 launch

Thermal Design Issues

2

Thermal Issues

The thermal subsystem for BepiColombo must maintain the temperature of all components in the system with temperature limits for all phases of the mission.

This includes a wide variation in environmental conditions (Earth to Mercury). In addition the thermal environment at Mercury is very extreme, in a hot case scenario.

The thermal subsystem on the entire BepiColombo spacecraft will push the limits of what can be achieved with current (or near) technology. As such the thermal performance is a critical item with respect to the success of the mission (more so than almost any previous mission).

Thermal Environment

The Solar Flux environments that are seen in the mission include:

- Earth = 1370 W/m² (1 AU)
- Venus = 2940 W/m² (0.7 AU)
- Mercury [Apohelion] = 6290 W/m² (0.45 AU)
- Mercury [Perihelion] = 14490 W/m² (0.3 AU)

The Planet Surface Temperatures that are seen in the mission include:

- Earth = 260K [black body temperature]
- Venus = 232K [black body temperature] (atmospheric = 720K)
- Mercury [Apohelion] = 600K (sub-solar point)
- Mercury [Perihelion] = 700K (sub-solar point)
- Mercury (dark-side) = 100K

Critical Hardware Items

The following have already been identified as critical items that must be thoroughly addressed by the thermal analysis:

- Chemical propellant tanks
- RCS thrusters
- Main chemical engines
- Solar array wings
- Cruise configuration and effects caused by it
- MPO structure
- MPO instrument cooling
- MSE landing site environment
- Thermal parameters of Mercury surface

Required Thermal Analysis

3

Overview of Thermal Analysis

Analysis in the following areas will be required during the project:

- **Transfer analysis**
  - LEOP @ Earth: Transient, Complete Spacecraft Composite
  - Fly-bys @ Venus: Transient, Complete Spacecraft Composite
  - During Transfer: Steady State, Complete Spacecraft Composite
- **In Mercury orbit manoeuvring analysis**
  - Mercury Orbit Acquisition: Transient, Spacecraft Composite minus SEPM
  - MMO to MPO Orbit Transfer: Transient, MPO+MSE+CPM Composite
  - MSE Descent: Transient, MSE + CPM
- **MMO Orbit: Transient, MMO & MPO+MSE+CPM Composite**
- **MPO Orbit: Transient, MPO & MSE+CPM Composite**
- **MSE In-Situ: Steady State/Transient, MSE**
- **Planetary Surface Modelling: Steady State/Transient**

Overview of Thermal Models Required

astrium

The following system level models will be required during the project:

- SEPM: Detailed and Simplified
- CPM: Detailed and Simplified
- MMO: Detailed and Simplified
- MPO: Detailed and Simplified
- MSE: Detailed and Simplified
- Combined models of above
- Planetary and Planetary feature models

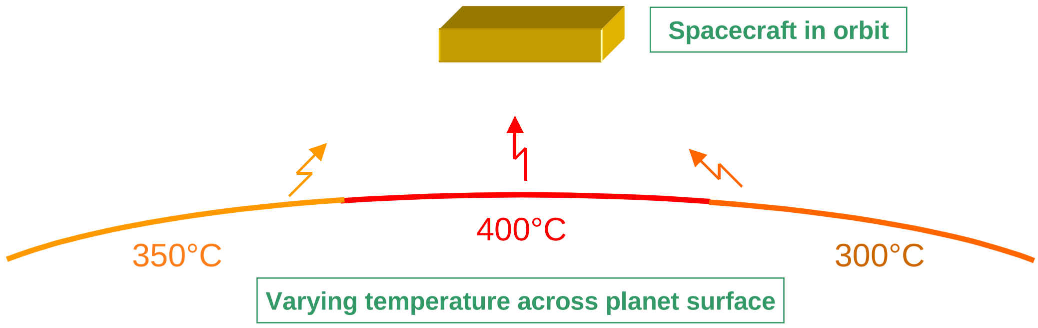
Thermal Modelling Issues

astrium

4

Modelling Issues (1)

- **Simulation of the Mercury body in Planet flux calculations**
  - IR fluxes from the planet are more influential than solar flux at some points in the orbit
  - A common (and easy to use) solution is recommended



Modelling Issues (2)

- **Defining analysis cases (controlling amount of analysis performed)**
  - It is important that the design driving analysis cases have been identified
  - There is potential for very large amount of analysis to be required
- **Updating the design based upon thermal performance**
  - Some of the primary design features are driven by the thermal performance
  - There is little thermal performance margin, therefore design changes could have a significant effect
  - A clear understanding of the thermal performance is mandatory for the project to be successful

Modelling Issues (3)

- **Model Control**
  - The common Astrium modelling philosophy is being used
    - This provides control of model updating
    - Selection of common software is recommended
- **Compatibility of Module models**
  - Models of the various modules in numerous configurations are required to perform the analysis
  - A system is required to ensure that combination of thermal models for different modules is as straight forward as possible (part of the Astrium modelling philosophy)
    - This will reduce the time and effort required (resulting in savings in cost and schedule)
    - Reduce the possibility for errors to be introduced

Modelling Issues (4)

- **Issues relating to thermal testing for this program require considerable consideration. Particularly in relation to:**
  - Performing thermal testing capable of producing realistic data for model correlation at Mercury
  - Obtaining thermal performance data for materials in Mercury environment

Proposed Software Developments

5

Proposed Software Developments

- **Common development of a method of planet modelling (varying planet temperature across the surface)**
  - Recommended that this is added as a new feature of ESARAD and SYSTEMA
  - Alternatively, is it possible to implement this as a function in ESATAN?
  - Development of some method of modelling this is crucial for the project!
- **Common development of model control/processing tools**
  - Such tools have been developed by Astrium within the MetOp project for example to manipulate the data coming out of ESARAD
  - These can be further refined, developed and documented to become integral with performing thermal analysis on this program
  - Such tools can result in significant improvements in the thermal analysis process (and with respect to the amount of analysis required on this program this could be critical)

Conclusions

6

Conclusions

- The major thermal design issues have been identified
- The required thermal analysis has been identified
- The major thermal modelling issues have been identified
- A number of key software developments have been proposed

Appendix N: CORATHERM for Spacecraft Thermo-Elastic Analysis

Application of
CORATHERM
for
Spacecraft Thermo-Elastic
Analysis

J-P. Dudon
Alcatel Cannes

APPLICATION OF *CORATHERM* TO SPACECRAFT THERMO-ELASTICITY ANALYSIS

T. Basset, J.P Dudon

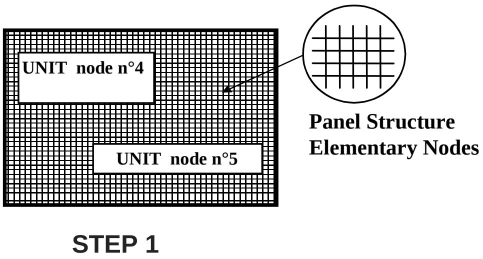
ALCATEL SPACE

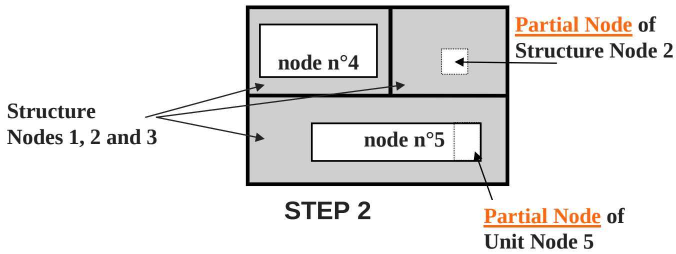
Summary

- 1 – About CORATHERM capabilities
- 2 - Developments dedicated to Thermo-elasticity (T-E) analysis
- 3 - Validation of the developments :
  - ⇒ New method for the computation of thermo-elastic deformations on spacecraft panels.

1- CORATHERM capabilities

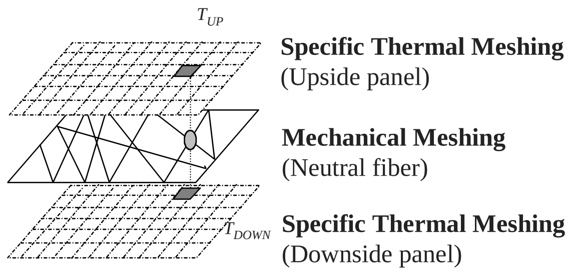
- *Thermal Model nodes for panels* :
  - ⇒Structure nodes : averaged temperature
  - ⇒ Unit nodes : isothermal nodes
- *Out of Model nodes* :
  - ⇒ Elementary conductive nodes : automatically generated and eliminated
  - ⇒**Partial nodes** : Local thermal information within nodes





2 - Development dedicated to T-E application

- *Objective :* Accurate evaluation of the structure deformations under effect of thermal gradients
- *In-house development of specific tools*
  - ⇒ Main development : Automated interface PATRAN/ CORATHERM/ NASTRAN specifically dedicated to mechanical engineers for improving T-E analysis



ALCATEL SPACE

Development dedicated to T-E application

Technical and Industrial Objectives :

- ⇒ Increasing accuracy
- ⇒ Saving time
- ⇒ Increasing reliability

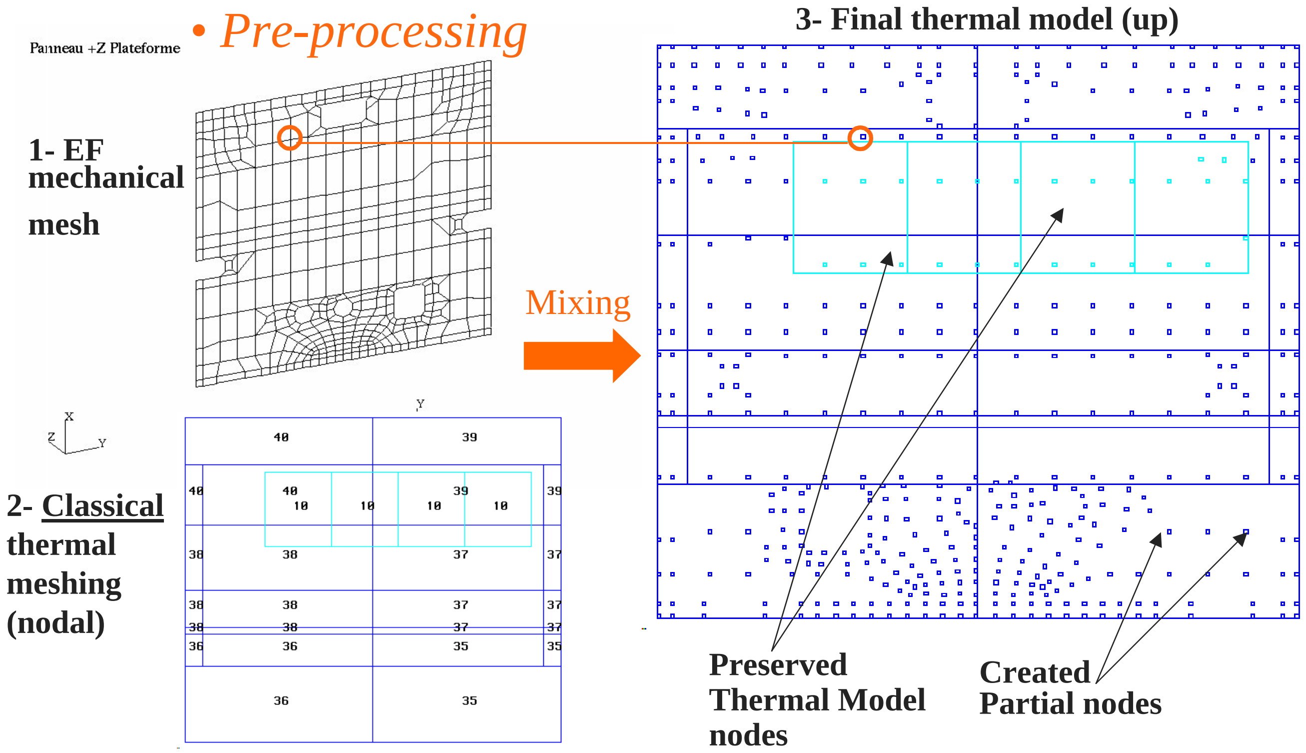
Main requirements :

- ⇒ Keep advantages of both thermal (CORATERM) and mechanical (NASTRAN) framework
- ⇒ Does not increase the Thermal engineer's work
- ⇒ Allows rapid and optimised data exchange between both domains

ALCATEL SPACE

Development dedicated to T-E application

• *Pre-processing*



Development dedicated to T-E application

- **Temperature computation**
  - ⇒ On classical thermal model nodes (Equivalent Temp.)
  - ⇒ On **partial nodes** (Local Temp.) in a recalculation process
  - ⇒ Using a physically consistent method (Equivale)
  - ⇒ For steady and transient cases
- **Interface toward NASTRAN**
  - ⇒ Affectation of local temperatures to the corresponding mechanical nodes (EF terminology)
  - ⇒ Generation of NASTRAN format temperature file

3 - Application to T-E Computation

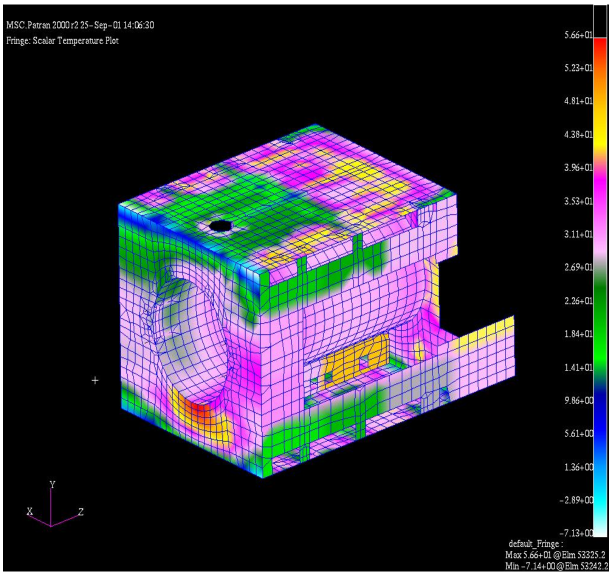
- **Thermo-elasticity is a linear phenomenon**
  - ⇒ Separation between :
    - → Structural behaviour (M_{SENS})
    - → Thermal behaviour (variation of temperature)

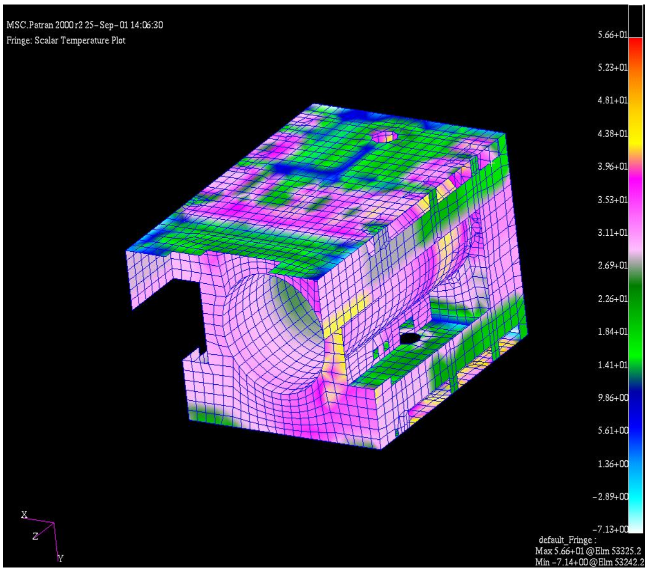
$$\begin{bmatrix} T_j^X \\ T_j^Y \\ T_j^Z \\ R_j^X \\ R_j^Y \\ R_j^Z \end{bmatrix} = M_{SENS} \begin{bmatrix} \Delta T_1 \\ \Delta T_2 \\ \dots \\ \Delta T_N \end{bmatrix}$$

- **Classical computation method**
  - ⇒ CORATHERM provides classical thermal inputs
    - → Rough thermal mapping in PATRAN
  - ⇒ NASTRAN computes Thermo Elastic deformations
    - → Limited to steady state computation
- **Current method (new)**
  - ⇒ CORATHERM *NG* provides <u>accurate</u> and detailed thermal inputs
  - ⇒ Transient effects are still ignored

Application to T-E Computation

Application to a Telecommunication Satellite





PATRAN thermal inputs from CORATHERM NG

Application to T-E Computation

The M_{SENS} concept (in study)

⇒ Use of linear aspects of Thermo-Elasticity

$$\begin{cases} \Delta\theta = M_{SENS} * \Delta T \\ \Delta\theta = \begin{bmatrix} M_{SENS}\big|_{Element1} & M_{SENS}\big|_{Element2} \end{bmatrix} * \begin{bmatrix} \Delta T\big|_{Element1} \\ \Delta T\big|_{Element2} \end{bmatrix} \\ \Delta\theta = \left(M_{SENS}\big|_{Element1} * \Delta T\big|_{Element1}\right) + \left(M_{SENS}\big|_{Element2} * \Delta T\big|_{Element2}\right) \end{cases}$$

$$\begin{bmatrix} T_j^X \\ T_j^Y \\ T_j^Z \\ R_j^X \\ R_j^Y \\ R_j^Z \end{bmatrix} = M_{SENS} \begin{bmatrix} \Delta T_1 \\ \Delta T_2 \\ \dots \\ \Delta T_N \end{bmatrix}$$

NASTRAN (M_{SENS}) — **CORATHERM** (ΔT)

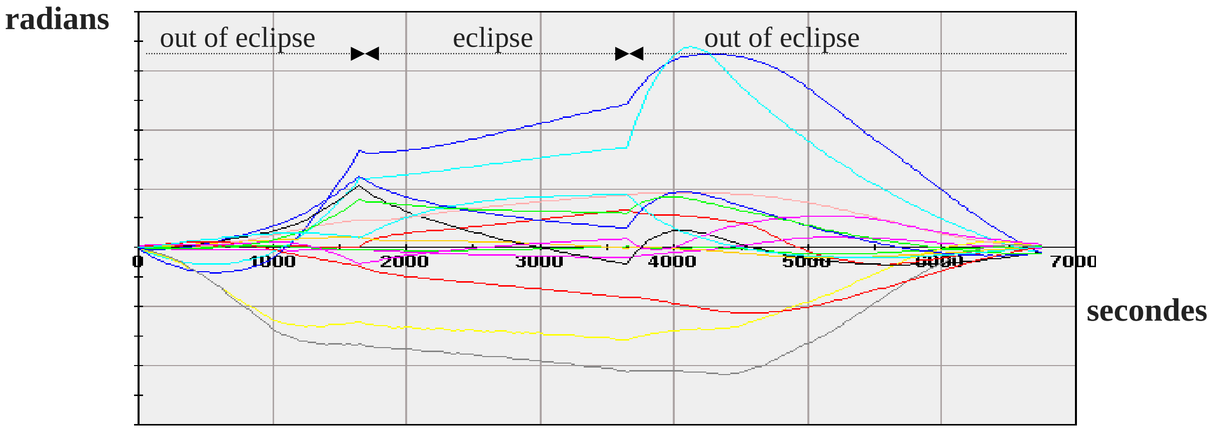
⇒ Accurate thermal mapping is provided by CORATHERM

⇒ M_{SENS} is computed using NASTRAN (pre-treatment) for a given instant

⇒ Applicable to transient calculations

Application to T-E Computation

Application to Jason Model : deformations of 15 DOF



⇒High accuracy of the results

→ avoid over or sub-sizing

⇒ Better understanding of the phenomenon with the transient behaviour

→ determination of realistic sizing cases

4 - Conclusions

- Validation of a new methodology to compute T-E deformations
  - ⇒Optimisation of Thermal (ΔT) and Mechanical (M_{SENS}) analyst`s know-how
- New possibility to Compute accurate thermal mapping on honeycomb panels
  - ⇒ Prevents from abusive approximations
  - ⇒Direct impacts on pointing budget
- Automated procedures are now validated
- Transient results are provided
  - ⇒ Better understanding of the phenomenon

Appendix O: Transient Capillary Pumped Loop Modelling

Transient Capillary Pumped Loop Modelling
with
ESATAN/FHTS
and
SINDA/FLUINT

C. Puillet
CNES

TRANSIENT CAPILLARY PUMPED LOOP MODELLING WITH ESATAN/FHTS AND SINDA/FLUINT

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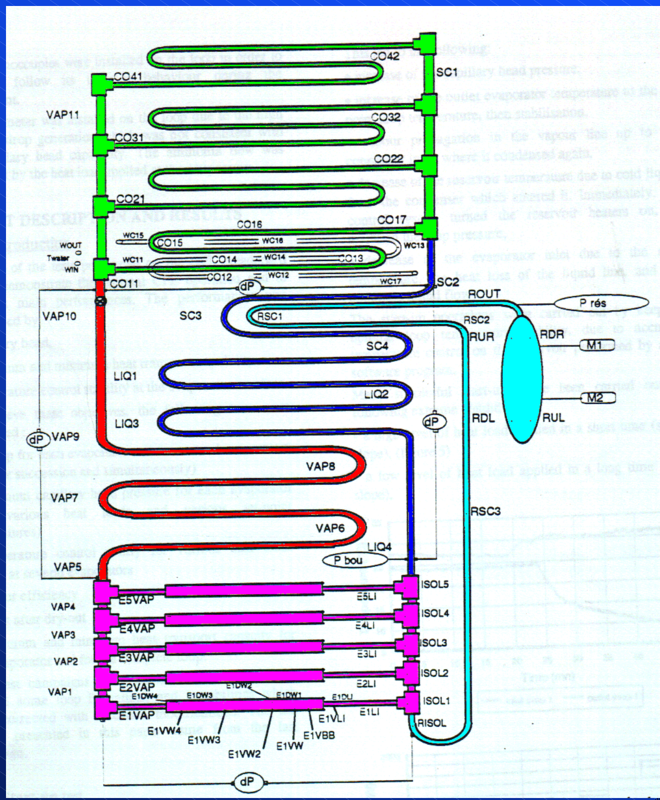
christian.puillet@cnes.fr

CONTENTS

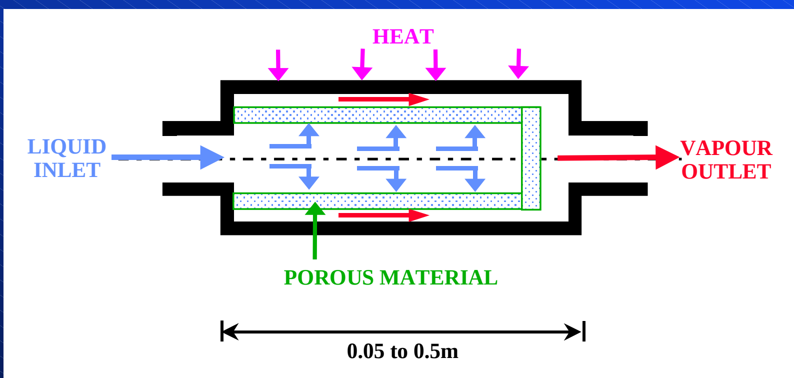
CNES/MMS 5kW AMMONIA CAPILLARY PUMPED LOOP

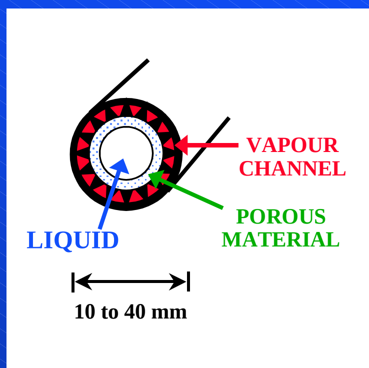
DEVELOPPED UNDER CNES CO-FUNDED R&D CONTRACT (1993-1994)

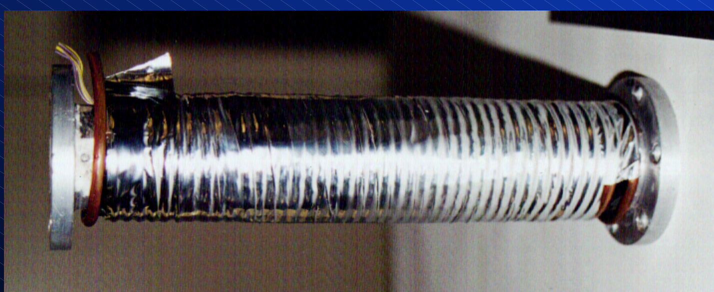


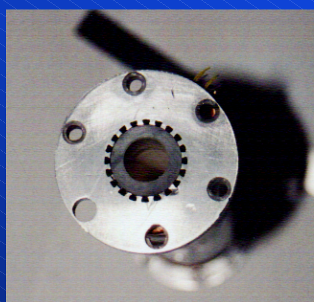
5 CAPILLARY EVAPORATORS
4 CONDENSERS (IN PARALLEL)
1 VAPOUR LINE
1 LIQUID LINE
1 TWO-PHASE RESERVOIR

CAPILLARY EVAPORATOR PRINCIPLE





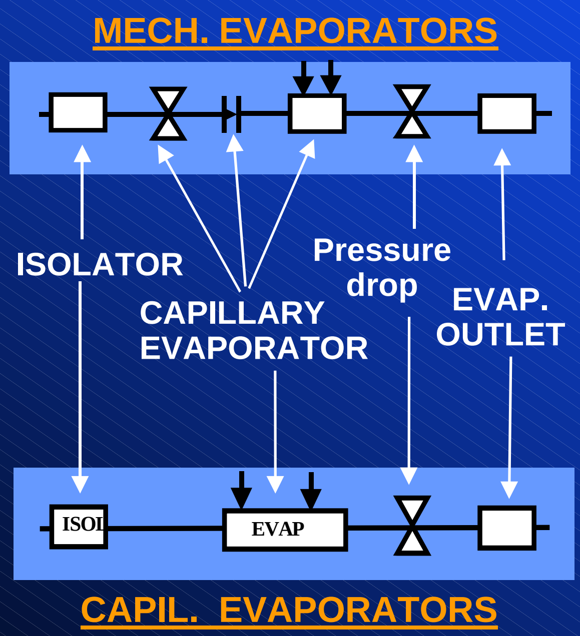




OBJECTIVES

- START-UP MODEL OF 1st EVAPORATOR FROM FULLY FLOADED LOOP. DEVELOPPED IN MID 90's USING MECHANICAL PUMPS AND VALVES.
- MODEL CONVERTED IN ESATAN/FHTS IN 99, PRESENTED AT 13th EWTES.
- REMAINING ISSUES :
  - USE OF FHTS CAPILLARY ELEMENTS
  - COMPARISON WITH SINDA/FLUINT
- OBJECTIVE :
  - TO EVALUATE ESATAN/FHTS CAPILLARY ELEMENTS
  - TO GET A MODEL SIMPLER AND MORE PRACTICAL TO USE
- MAINS POINTS :
  - FLUID TIME CONSTANTS (little solid inertia)
  - EVAPORATORS CLEARING (EVAP. 2 TO 5)
  - VAPOUR FRONT DISPLACEMENT

MODEL



VAPOUR LINE
- Convective coupling with air
- Global pressure drop

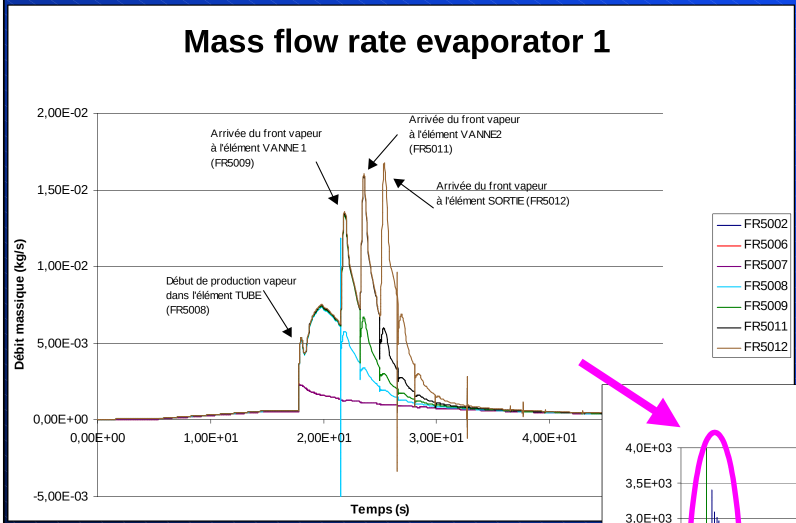
CONDENSER
- Cooling loop @ 0°C

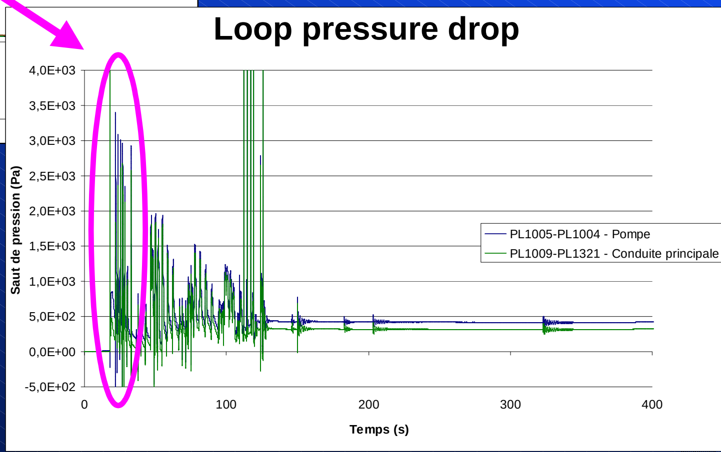
LIQUID LINE
- Convective coupling with air

PRESSURISER
- Heater with prop. regulation

MODEL GEOMETRY CORRECTED
MECHANICAL PUMPS MODELLING AS CLOSE AS POSSIBLE TO CAPILLARY PUMPS

SINDA/FLUINT WITH MECHANICAL PUMPS





PRESSURE OSCILLATIONS CAUSED BY VAPOUR FRONT ENTERING EACH FLUID NODE

=> HIGH MASS FLOW RATE & PRESSURE PEAKS

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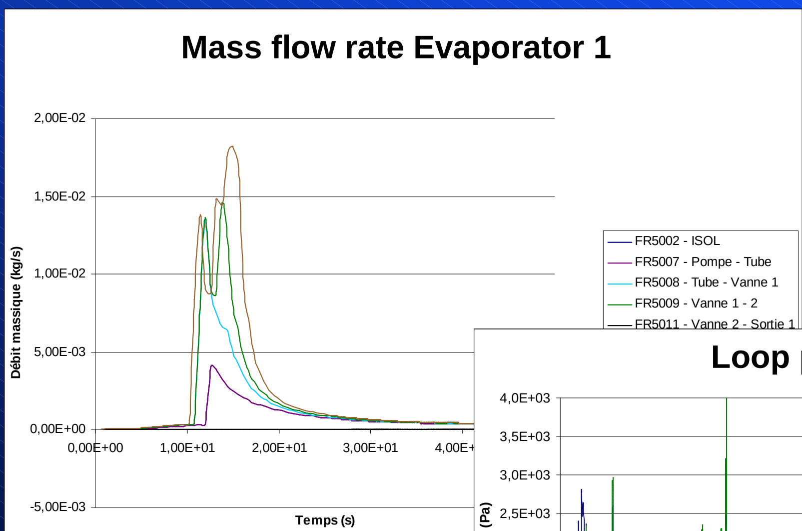
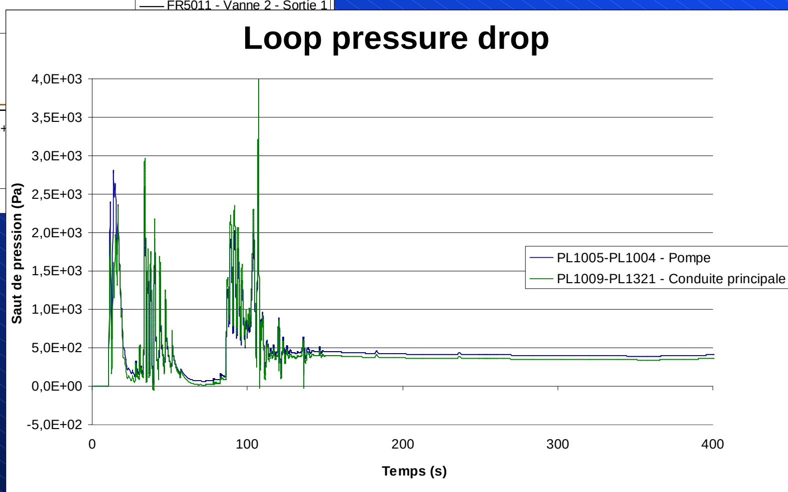
ESATAN/FHTS WITH MECHANICAL PUMPS

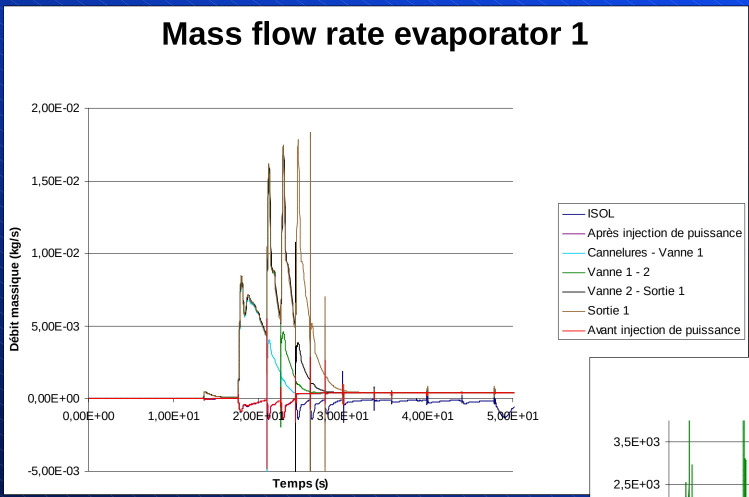




SAME BEHAVIOUR

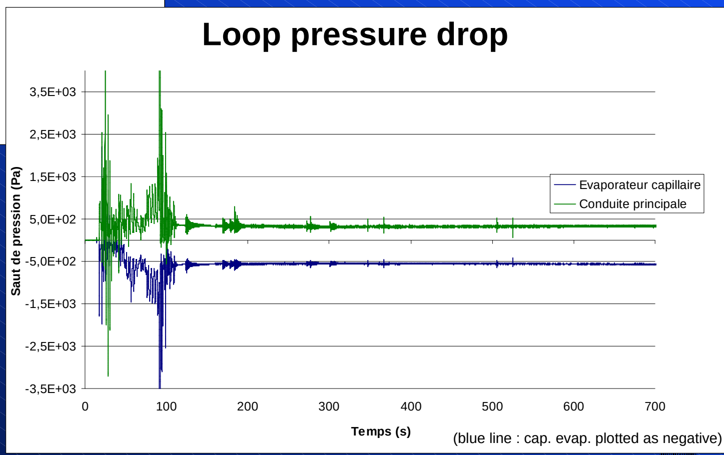
SMOOTHER

SINDA/FLUINT WITH CAPILLARY PUMPS

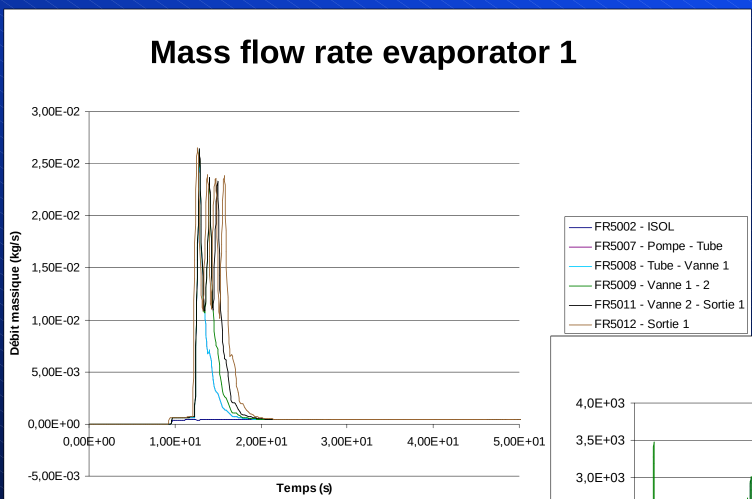


OSCILLATIONS MORE SEVERE THAN WITH MECHANICAL PUMPS

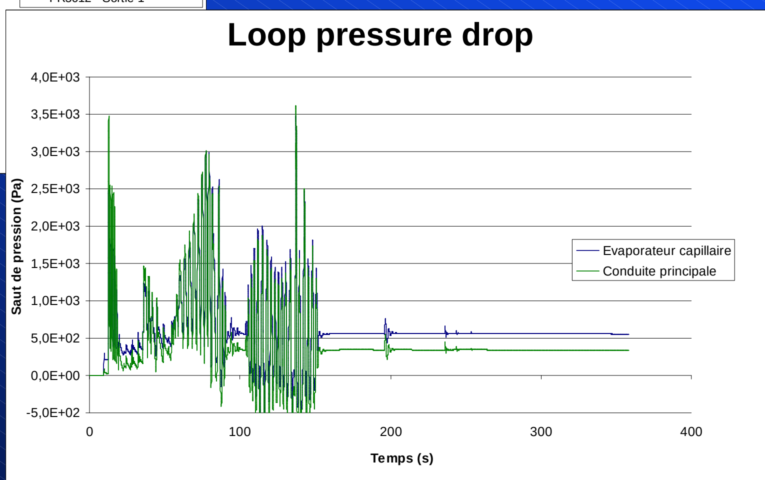
SAME GLOBAL BEHAVIOUR



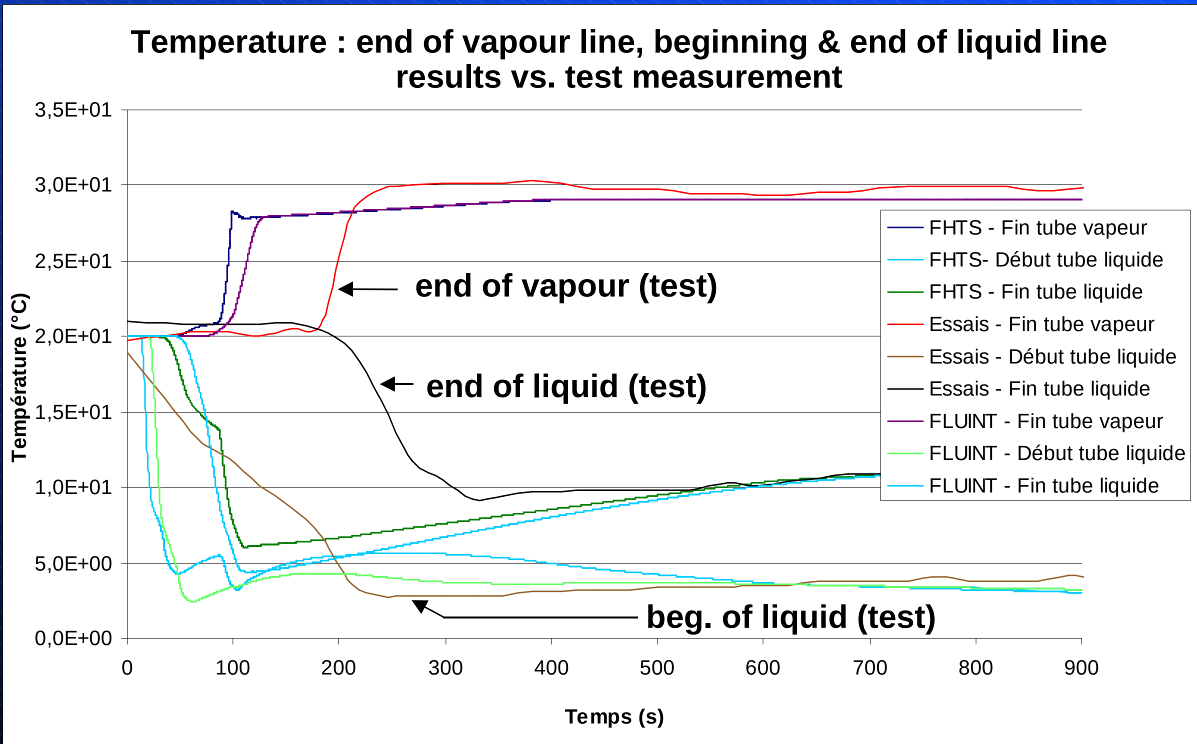
ESATAN/FHTS WITH CAPILLARY PUMPS



SAME CONCLUSION AS WITH SINDA/FLUINT



TEMPERATURE (MECHANICAL PUMPS)



VAPOUR FRONT MOVES TOO FAST

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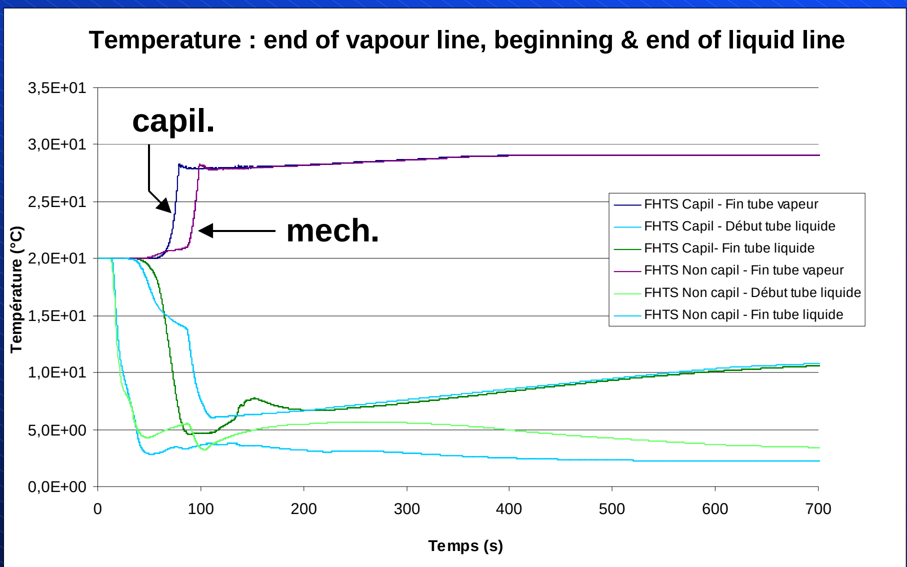
TEMPERATURE ESATAN/FHTS
mechanical vs. capillary

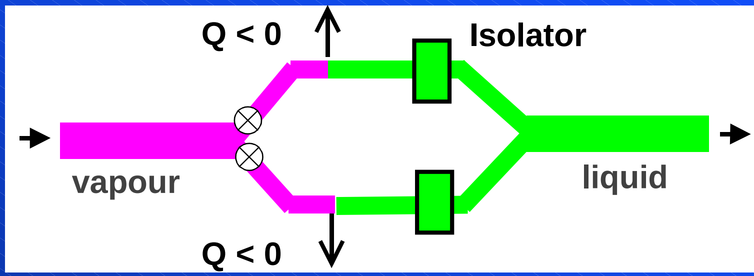


THE VAPOUR FRONT MOVES EVEN FASTER WITH CAPILLARY PUMPS

(NO CONTROL ON MASS FLOW RATE FOR FIRST BUBBLES GENERATION IN THE CAPILLARY PUMP)

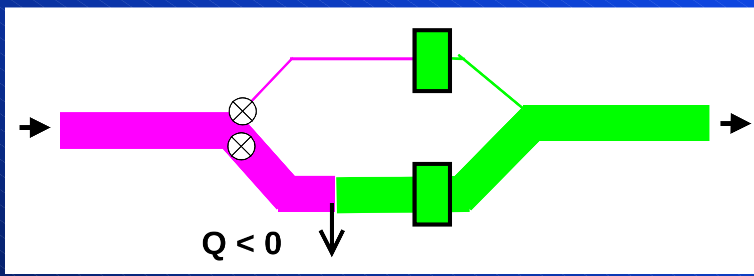
INFLUENCE OF NUMBER OF NODES

INITIAL STEADY-STATE :



THEN THE HEAT EXTRACTION IS REMOVED ON THE UPPER LINE

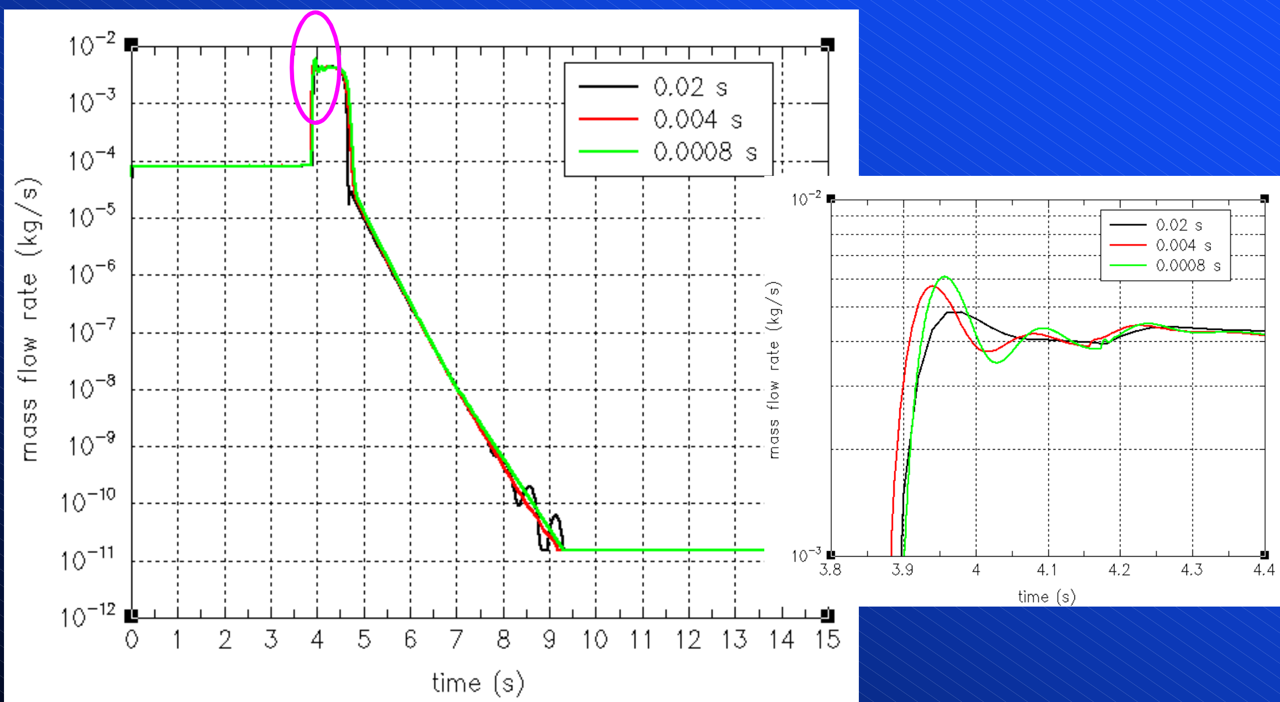
FINAL STEADY-STATE :



INFLUENCE OF NUMBER OF NODES ON MASS FLOW RATE WITHIN ISOLATOR ?

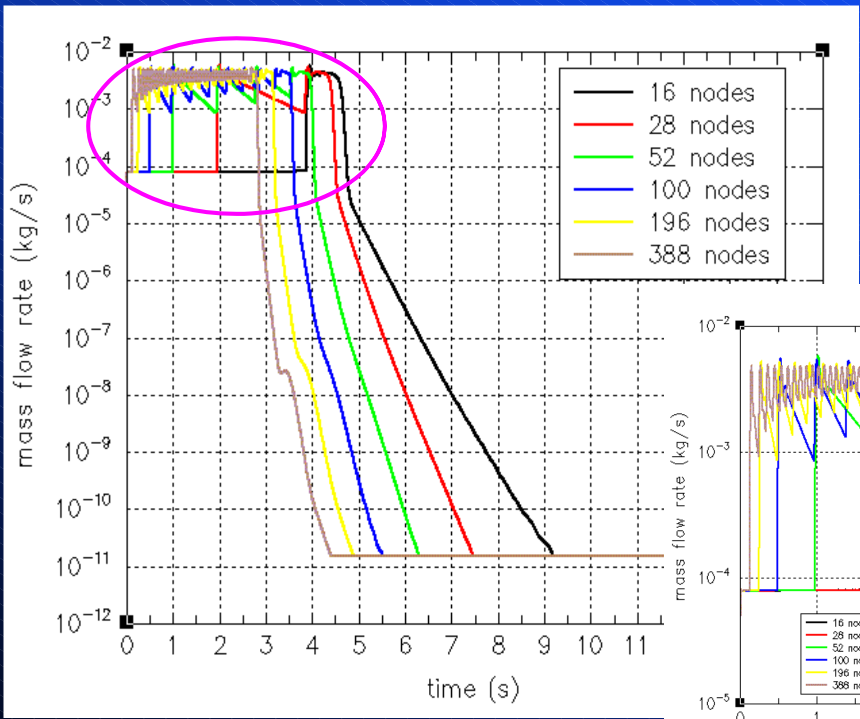
CONVERGENCE IN TIME STEP

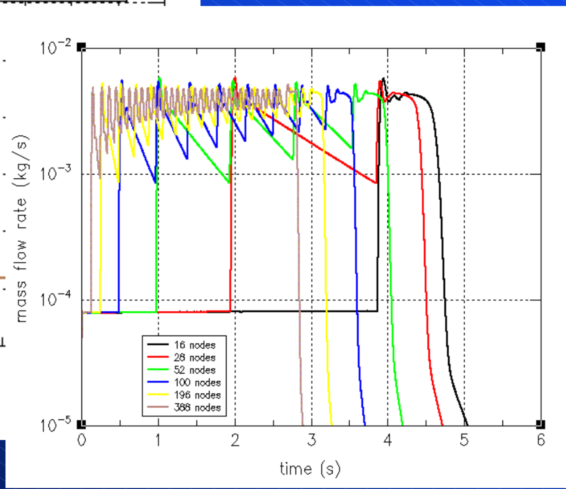
MASS FLOW RATE IN ISOLATOR



CPU: 0.02 s / 42 s, 0.004 s / 81 s, 0.0008 s / 146 s

INFLUENCE OF NUMBER OF NODES





1) CONVERGENCE REQUIRES A VERY HIGH NUMBER OF NODES

2) FRONT MOVES FASTER

CPU: 16 / 1mn21s, 28 / 2mn19s, 52 / 5mn12s, 100 / 10mn6s, 196 / 21mn4s, 388 / 60mn6s

ANALYSIS

- ABILITY TO SOLVE START-UP FROM FULLY FLOADED LOOP WITH PARALLEL LINES

- TYPICAL CPU TIME :

	ESATAN/FHTS	SINDA/FLUINT
MECH. PUMPS	120 mn	10 mn
CAPIL. PUMPS	180 mn	50 mn

- LARGE INFLUENCE OF PRESSURE DROPS ON RESULTS
- NUMERICAL DIFFICULTIES TO SOLVE IF VAPOUR FRONT IS BLOCKED BY EVAPORATORS BEFORE IT REACHES THE CONDENSER
- VERY SMALL TIME STEPS

- HOWEVER, QUESTIONS ABOUT COHERENCE OF PHYSICS MODELLED WITH REALITY
  - LUMPED PARAMETER METHOD
  - HOMOGENEOUS MODEL

- => MORE ANALYTICAL AND EXPERIMENTAL WORK WOULD BE REQUIRED ON A SIMPLER LOOP (1 EVAPORATOR , 1 CONDENSER) TO GET CONFIRMATION

CONCLUSION

THE ESATAN/FHTS CAPILLARY ELEMENTS WORK PROPERLY WITHIN THE LIMITATION OF THE PHYSICAL MODEL

CAPILLARY ELEMENTS SIMPLIFY THE WORK OF THE USER

THE MODELLING OF START-UP IS POSSIBLE

HOWEVER, MAYBE IT SHOULD BE LIMITED TO MODELS IN WHICH FLUID TRANSIENT IS NEGLIGIBLE

- **MORE QUESTIONS THAN ANSWERS AT THE END OF THE WORK**
- **DOUBT ON THE POSSIBILITY TO GET A SIMPLER AND MORE PRACTICAL MODEL FOR FLUID START-UP**

TRANSIENT CAPILLARY PUMPED LOOP MODELLING WITH ESATAN/FHTS AND SINDA/FLUINT

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Appendix P: Status on Model Data Exchange

Status
on
Model Data Exchange

HP. de Koning
ESTEC/TOS-MCV

Mechanical Engineering Department
Thermal and Structures Division

Status on Model Data Exchange

Hans-Peter.de.Koning@esa.int
(ESA D/TOS-MCV)

15th European Workshop on Thermal and ECLS Software
ESTEC, Noordwijk, The Netherlands
9-10 October 2001

Mechanical Engineering Department
Thermal and Structures Division

Topics

- Brief introduction to STEP
- Brief overview of STEP-TAS and STEP-NRF
- State of STEP-TAS implementations
- TRASYS/STEP-TAS and TRASYS/ESARAD converters
- ESARAD STEP-AP203 import and NURBS support
- Road ahead
- Announcement NASA/ESA Aerospace Product Data Exchange based on Open Standards Workshop

Objective of STEP / ISO 10303

- STEP = STandard for the Exchange of Product model data
  = casual name for ISO 10303
- "ISO 10303 is an International Standard for the computer-interpretable representation and exchange of product data. The objective is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent from any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product databases and archiving."

(From ISO 10303 Part 1)

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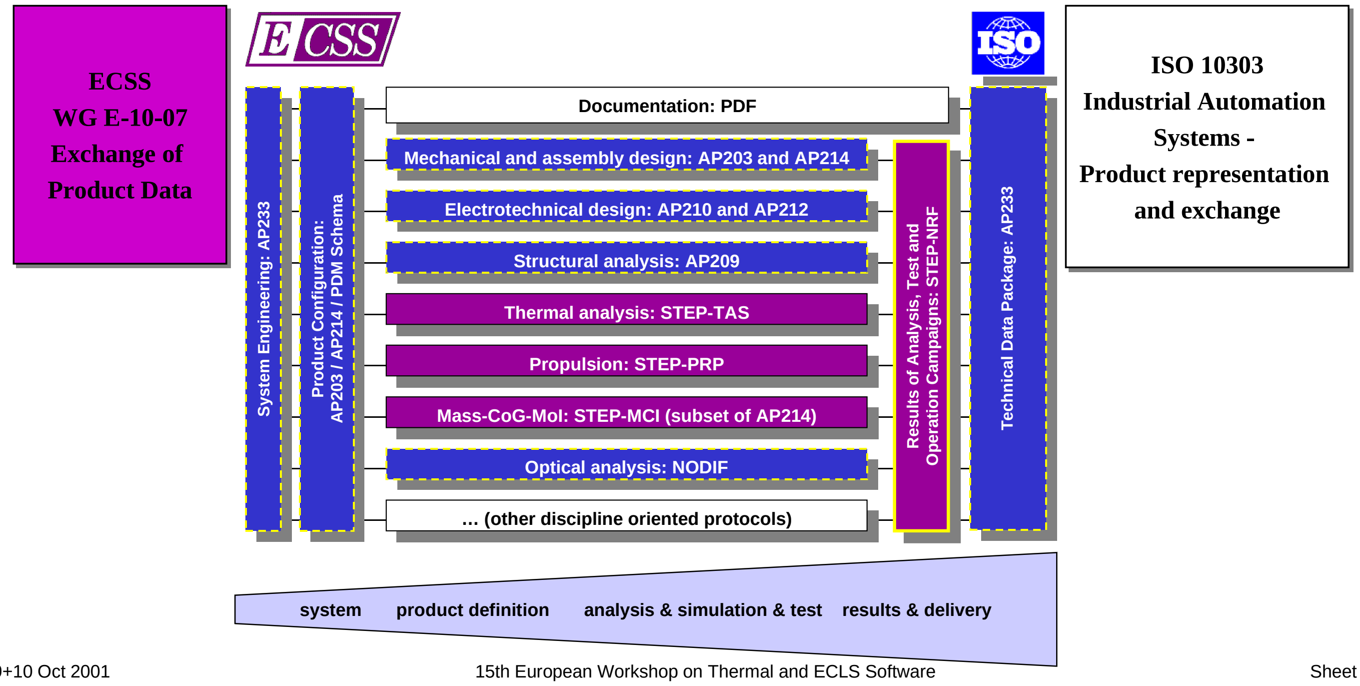
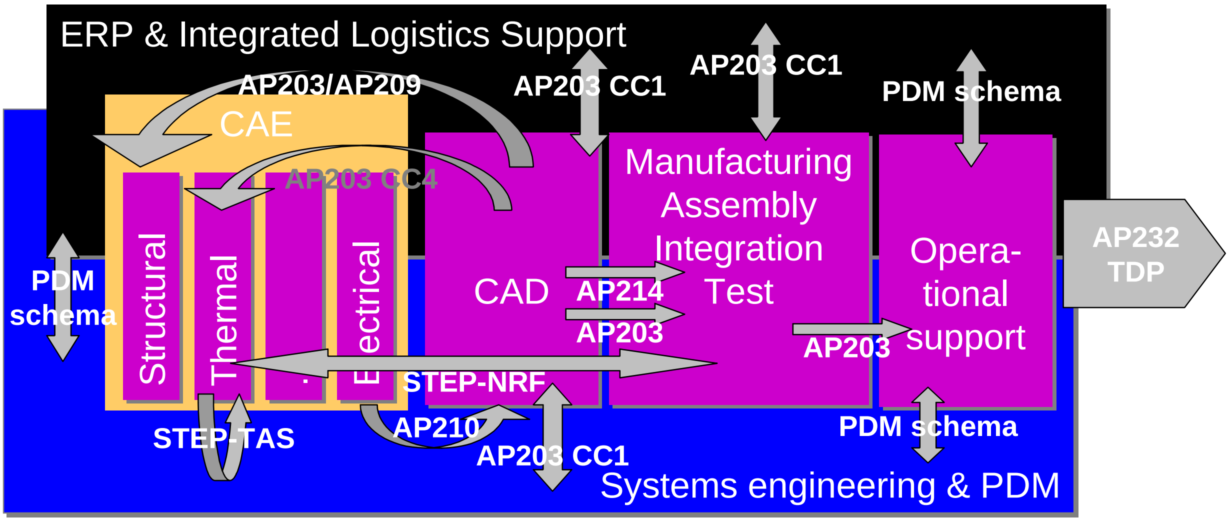
The (Aero)Space STEP Protocols Map



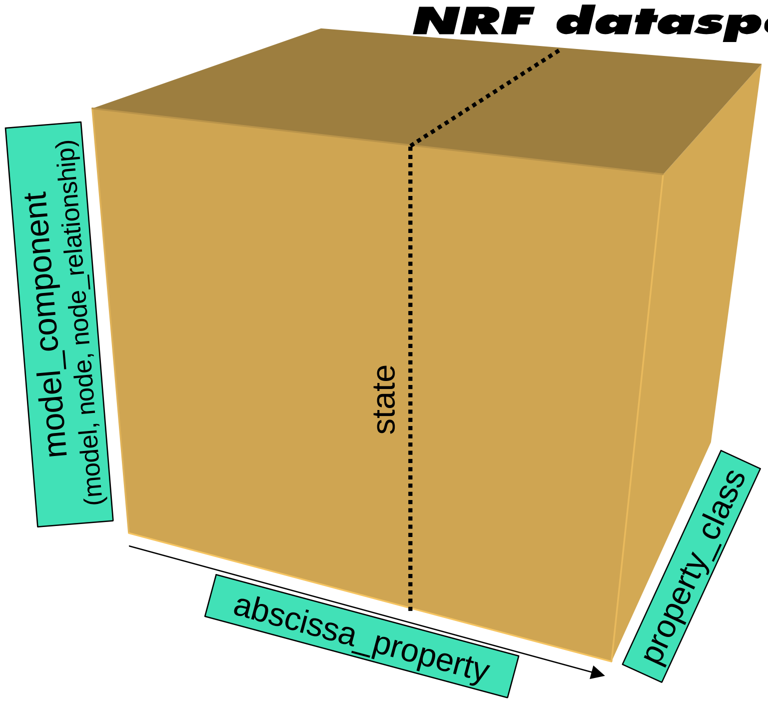
Bigger picture: Open standards based exchange between disciplines in space projects



Main characteristics STEP-NRF (1) Network-model Results Format

- Targets engineering-discipline independent exchange of bulk results data from analysis, test or operation
  - Representation of engineering objects by network models consisting of discrete nodes and node-relationships
  - Hierarchical tree of network models / submodels
  - Definition of properties
    - Quantitative, descriptive and functional properties
    - Scalar, vector and tensor property values
    - Property values only at discrete locations / discrete states
  - Full annotation of analysis / test / operation context
    - Campaign, case, phase, run
    - Facility/tool, environment, date and time, organisation, person, ...

Main characteristics STEP-NRF (2)
NRF dataspace



Each gridpoint in the 3D dataspace is a property value

Each can be scalar, vector, tensor

Data model and implementation designed to handle sparsely populated dataspace efficiently

esa
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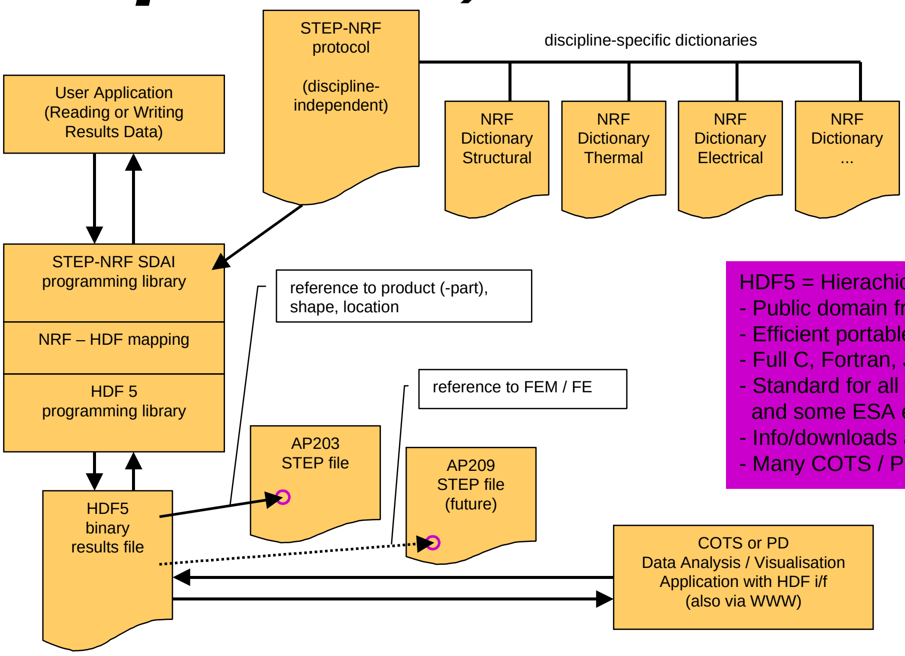
Thermal and Structures Division

Main characteristics STEP-NRF (3)
Proposed NRF/HDF architecture



HDF5 is an efficient alternative for Part21 for large amounts of similar data

HDF5 = Hierachical Data Format v5
- Public domain from NCSA
- Efficient portable binary storage format
- Full C, Fortran, Java libraries on >10 platforms
- Standard for all NASA EOS missions and some ESA earth observation
- Info/downloads at hdf.ncsa.uiuc.edu
- Many COTS / PD tools with HDF interface

Main characteristics of STEP-TAS (1)

- Self contained, complete Application Protocol
  - AAM, ARM, Mapping Table, AIM, Express-G (586 pages)
  - Conforms to TC184/SC4 methods and guidelines
- Geometry defined as AP203 CC4 surfaces
- Thermal-radiative model faces added as associated features
  - Including possibility to support hierarchical submodel tree
  - Associated notional thickness, surface material and bulk material
  - Thermo-optical, thermo-physical properties for named material
  - Concept of material property environment (Part 45)
- Kinematic model conform STEP Part 105
  - for articulated rigid bodies (e.g. rotating solar arrays, gimballed antennas)

Main characteristics of STEP-TAS (2)

- Space mission aspects
  - orbit arc (Keplerian and discrete ephemeris)
  - space co-ordinate system, celestial bodies
  - orientation, general and named pointing, spinning, linear rotation rates
  - space thermal environment, including constant or lat/long dependent albedo / planetshine tables
- Boolean construction surfaces available for advanced tools
- STEP-TAS CC1 Abstract Test Suite
  - conform STEP Part 3xx series
  - test suite has been used in validation of TAS processors

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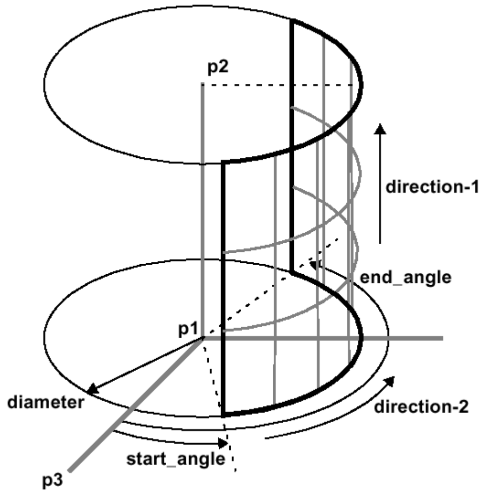
STEP-TAS geometry and thermal-radiative models



- Shapes
  - Primitives: triangle, rectangle, quadrilateral, disc, cylinder, cone, sphere, paraboloid
  - Compound shapes
  - Shapes conform to AP203 CC4 non-manifold surfaces
- Thermal-radiative model
  - associates thermal-radiative faces with surface shapes
  - thermal mesh (uniform and non-uniform)
  - surface and bulk material properties by reference to material

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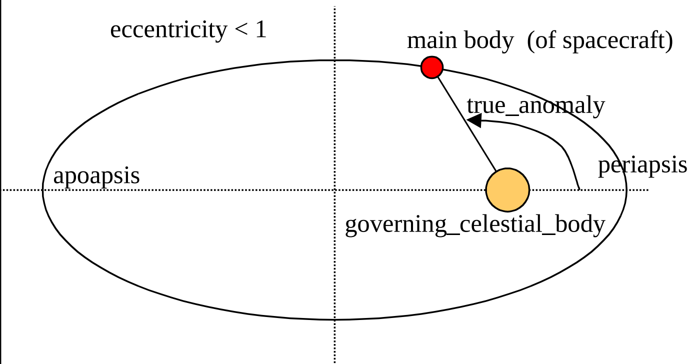
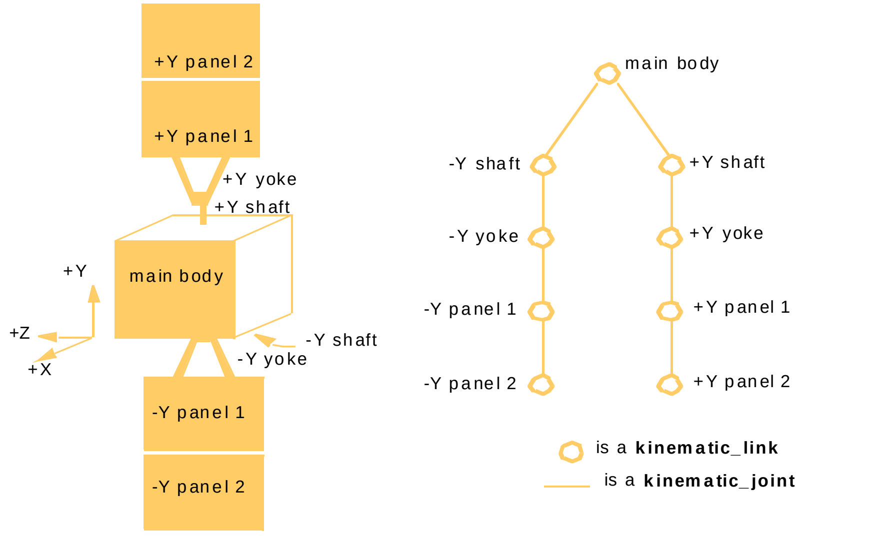
Illustration of basic STEP-TAS Keplerian orbit arc definition




```
ENTITY keplerian_orbit_arc
     SUBTYPE OF (orbit_arc);
     kepler_parameters : kepler_parameter_set;
END_ENTITY;

ENTITY kepler_parameter_set;
  semi_major_axis : length_measure;
  eccentricity : REAL;
  inclination : plane_angle_measure;
  right_ascension_of_ascending_node :
    plane_angle_measure;
  argument_of_periapsis : plane_angle_measure;
  true_anomaly_at_start : plane_angle_measure;
WHERE
  wr1: semi_major_axis >= 0.0;
  wr2: eccentricity >= 0.0;
  wr3: (-180.0 < inclination) AND
       (inclination <= 180.0);
  wr4: (-360.0 < right_ascension_of_ascending_node)
    AND (right_ascension_of_ascending_node <= 360.0);
  wr5: (0.0 <= argument_of_periapsis) AND
     (argument_of_periapsis < 360.0);
  wr6: (-360.0 < true_anomaly_at_start) AND
     (true_anomaly_at_start <= 360.0);
END_ENTITY;
```

STEP-TAS : Product structure and kinematic



(a) Schematic shape model of a typical communications satellite with two fully deployed solar array wings

(b) The corresponding **kinematic_model** presented as a topological graph

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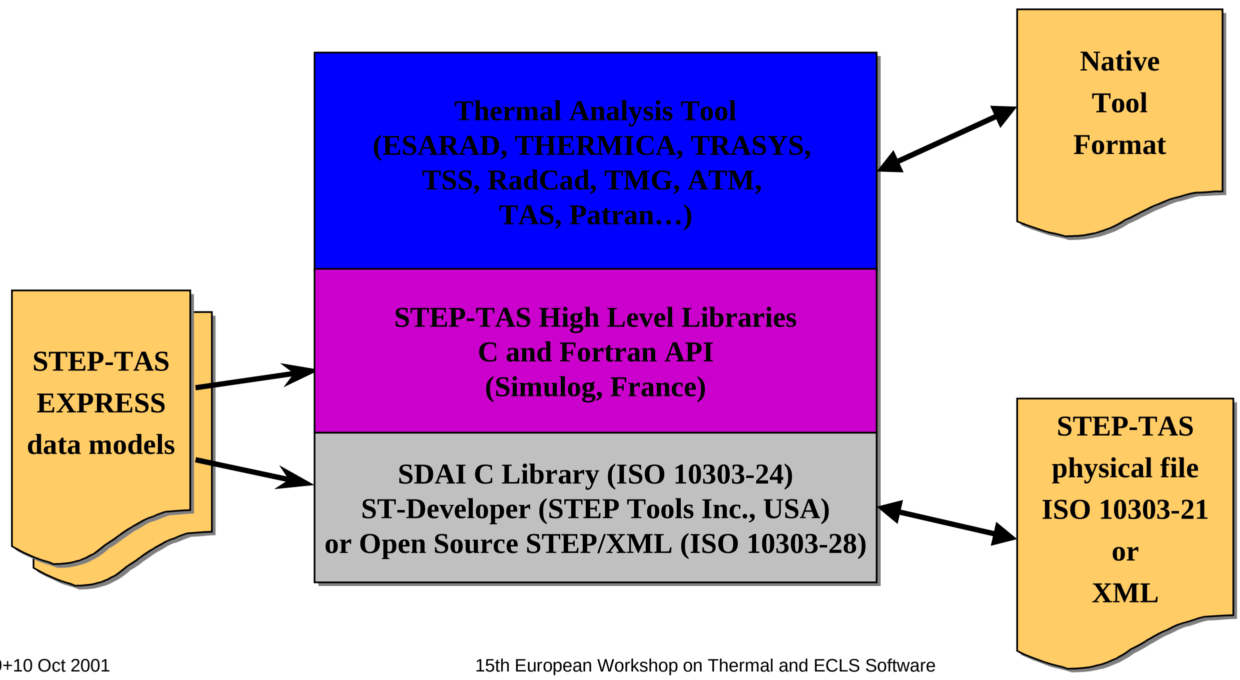
STEP-TAS Conformance Classes

	thermal-radiative model with basic geometry	kinematic model	constructive geometry	space mission aspects
CC-1	✓			
CC-2	✓	✓		
CC-3	✓		✓	
CC-4	✓	✓	✓	
CC-5	✓	✓		✓
CC-6	✓	✓	✓	✓

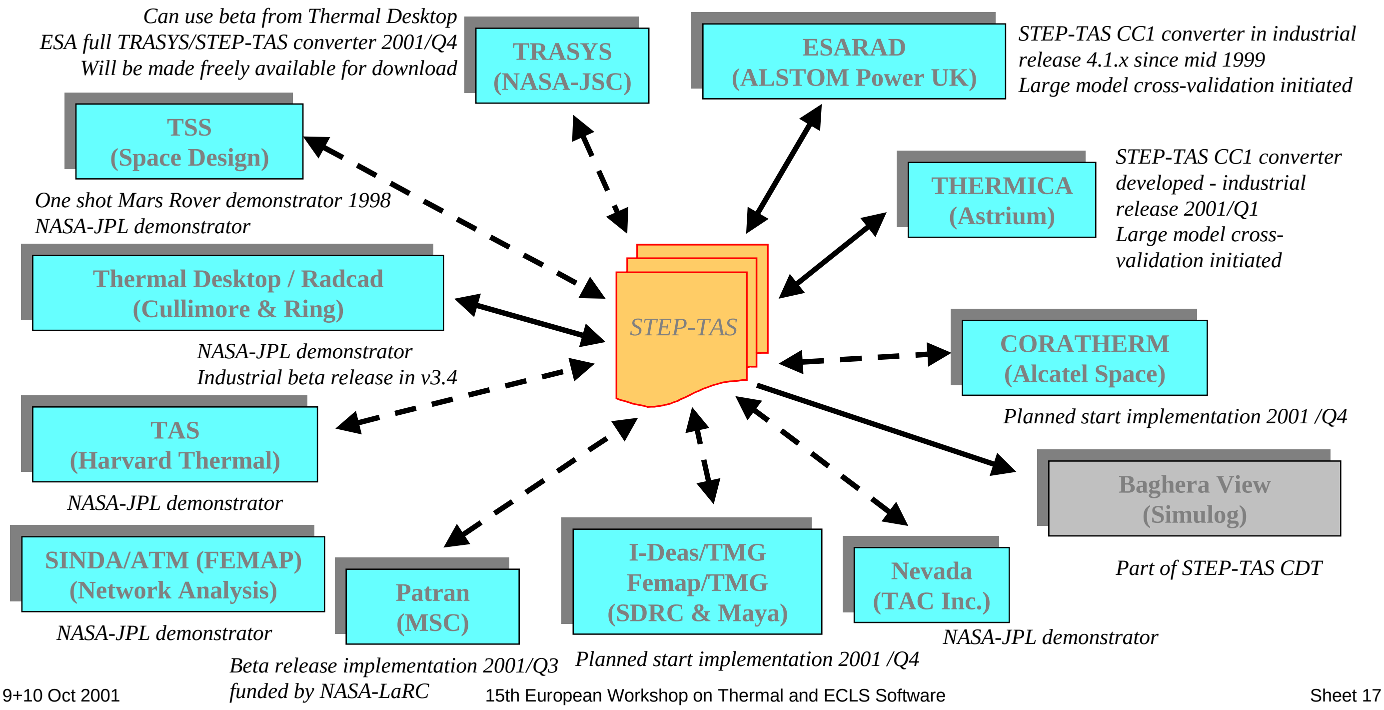
STEP-TAS CDT Converter Development Toolkit (developed by Simulog)

- Programming interface is close to thermal tools
  - hides STEP complexity
  - full set of reading/writing functions in ANSI-C and F77
  - full documentation, examples and test suite
  - Baghera-View to perform independent visual inspection
- Available to tool developers at nominal cost (from Simulog)
  - Platforms: Windows, Sun/Solaris, HP-UX, Compaq/Tru64, SGI/Irix
- Enables efficient converter implementation
  - Reduces validation / verification effort
  - All converters share reading/writing approach - increased reliability
- Extensibility at affordable cost - e.g. for HDF5 and XML

STEP-TAS Converter Architecture



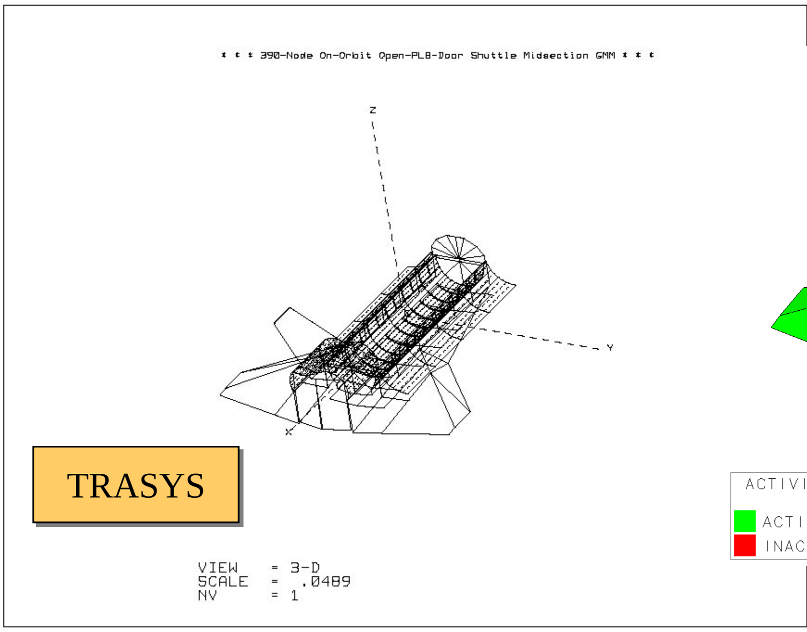
State of STEP-TAS implementations Sep 2001

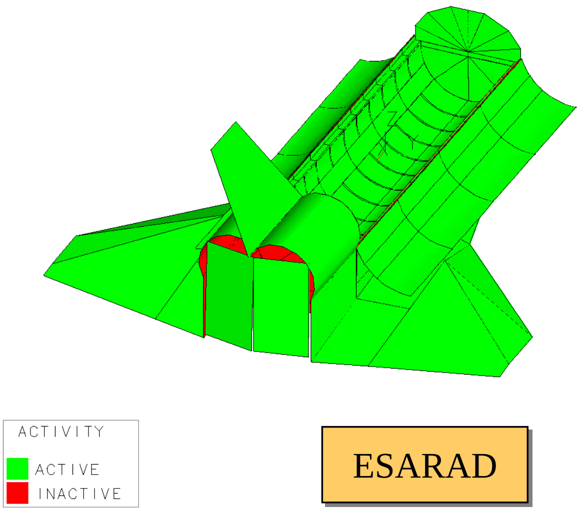


TRASYS/STEP-TAS and TRASYS/ESARAD converters

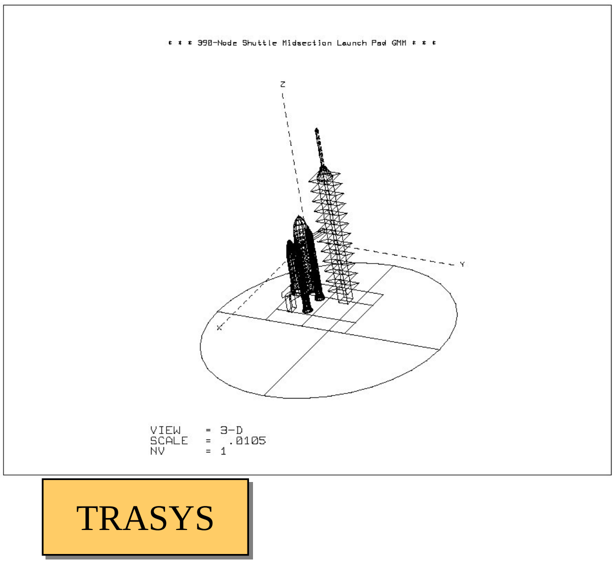
- Full stand-alone TRASYS / STEP-TAS CC1 converter
  - Development by Simulog started Jan-2001
  - Currently in beta testing / closing out phase
  - User option for English/SI unit conversion
- In parallel: TRASYS-to-ESARAD converter
  - Reference implementation by ESA (TOS-MCV) for independent validation of TRASYS/STEP-TAS converter
  - Supports break up of non-uniform meshes
  - Supports conversion of complex shapes (ogive, toroid, spheroid)
  - Full test suite
- Both will be made available at www.estec.esa.int/thermal
  - Free for download - target release November 2001

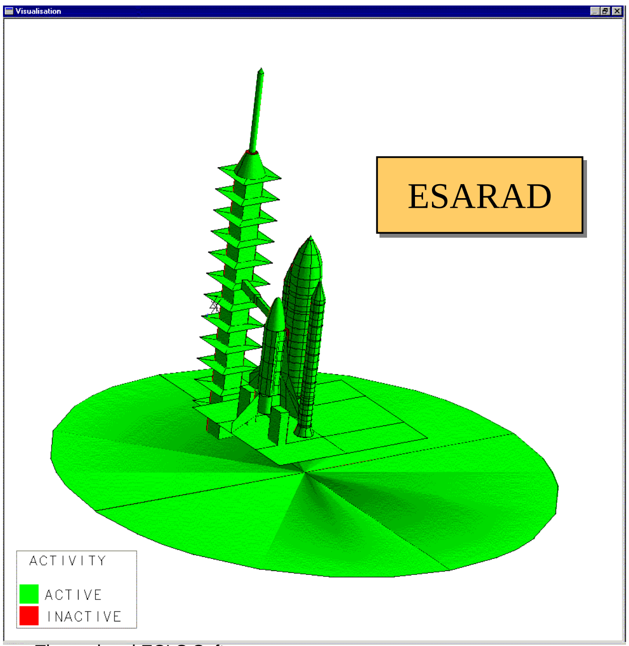
TRASYS/ESARAD converter
STS 390 Node Model - Open Doors





TRASYS/ESARAD converter
STS 390 Node Model - Closed Doors





Prototype SINDA-85 / ESATAN converter

- Developed at ESTEC
- Use: STS / ISS interface model conversion
- Currently Eng/SI unit conversion is being implemented
- Will be made available free of charge 2001/Q4

Road Ahead (1)

- Web-based collaboration on further development:
  STEP-TAS Implementors' Forum (start 2001/Q4)
  - ftp://ftp.estec.esa.nl/step-tas/index.html as a start
  - Will use sourceforge.net open source software development environment
    - distribution of documentation and code
    - bug tracking, configuration control, test suites
  - E-mail tech support
- Take European / US collaboration to a next stage
  - Action ESA and NASA together with Simulog
  - Clarify/establish intellectual property rights and support

Road Ahead (2)

- Trade-off for best 'Return on Investment' next 5 years
  - Appropriate level of formal publishing (ISO, ESA and NASA)
  - Much simplified exchange model (STEP-TAS ARM)
  - Most likely moving to XML physical file (STEP part 28)
  - Upgrade high level API to support all STEP-TAS constructs
    - e.g. submodelling, non-uniform meshing and node numbering
- Upgrade STEP-TAS CDT (planned 2001/Q4-2002/Q1)
  - Resolve all reported issues / bugs
  - Use open source software approach
  - Upgrade converter options (e.g. length unit selection / conversion)
- Complete test suite for large model cross-validation

Road Ahead (3)

- TRASYS/STEP-TAS-CC1 bi-directional converter
  - Stand-alone tool by Simulog on ESA funding
  - Will be made available freely
- Upgrade BagheraView capabilities
  - By Simulog sponsored by CNES
  - Release v1.3 beta ready Sep-2001 (now supports Windows 2000)
- Resume NRF developments
  - HDF5 binding (co-operation with EDF, NCSA and others)
  - ESATAN, SINDA/G, SINDA85 converters via STEP-NRF (with NASA)
  - Links with STEP Engineering Analysis modules - ISO 10303-50 series
  - Pilot web-based remote consultation of structural test results

Announcement

NASA/ESA Workshop
Aerospace Product Data Exchange based on Open Standards

- 9-12 April 2002, ESTEC, Noordwijk
- 3rd edition after 2 successful previous workshops at NASA-JPL
  - See step.jpl.nasa.gov for archive of previous presentations
- Domains: Engineering Analysis, CAD, PDM
- Standards: STEP/ISO 10303, XML/W3C, OMG, ECSS, NASA
- STEP AP 209 (FEM exchange) Seminar
- If interested send e-mail to Hans-Peter.de.Koning@esa.int

Acknowledgements

- STEP-TAS and STEP-NRF were developed under ESA contract in co-operation with CNES by:
  - Simulog (F, prime)
  - Fokker Space (NL)
  - Association GOSET (F)
  - Epsilon Ingénierie (F)
  - Alstom Power (UK)
- Special thanks to
  Georg Siebes (NASA-JPL) and Ruth Amundsen (NASA-LaRC) who are and have been the driving forces for the development and acceptance of STEP-TAS in the US

Appendix Q: Thermica v4

Thermica
v4

P. Renard
Astrium-SAS

Thermica V4

Patrice Renard
Astrium

- *Short description*
- *Demo*

Context and objectives

- Increase in 2001 of the engineering software distribution (Thermica and others) inside Astrium and outside the company
- User interface getting old. Graphics not taking advantage of the potential of PC computers
- Improvements optimizing ROI (avoid cosmetics !)

Team reinforcement

⇒ Interactivity as main driver for the new interface

New functions

Strategy for the new interface

- PC look and feel
- Portable code for Unix and PC (Windows and Linux)

- Interactivity for model building,
  for mission modelling,
  for conduction modelling

- User-friendly menu-driven functions to reduce the learning time and avoid programming
- Up compatibility with previous version to facilitate transition for the current users ;
  also in the way to use the software

Development status

- Developed :
  - Interactive model builder
  - Interactive conduction module
  - Orbit and Kinematics calculation modules with enhanced features
  - Prototype interface
- Under development :
  - New shapes
  - Sub-models
  - Kinematics user interface
  - Albedo and IR models
- Schedule :
  - Beta version in March 2002

Demo

- First part :
  - Interactive model builder
  - Interactive conduction module

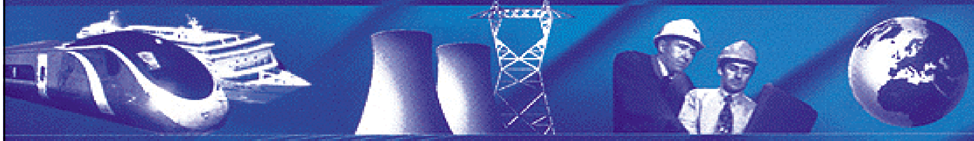
  shows functions in a temporary user interface

- Second part :
  - Prototype interface

Appendix R: Developments in ESARAD, ESATAN and User Support

Developments in ESARAD,
ESATAN
and
User Support

F. du Laurens d'Oiselay
Alstom



15th European Workshop on Thermal and ECLS Software
ESTEC, The Netherlands
October 9-10, 2001

Developments in ESARAD, ESATAN and User Support

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ALSTOM

Summary

ALSTOM

- Status on:
  - ESARAD v-4.3.2
  - ESATAN/FHTS v-8.6 – CPL
  - ESATAN v-8.7
- Developments on user support
  - Web site
  - Future developments
  - Contact details

ESARAD v-4.3.2 – Status

- Released end of May 2001
  - Stabilisation improvements
- Feedback so far:
  - Better stability
  - Few minor bugs or problems identified
  - Performance problem through Unix network

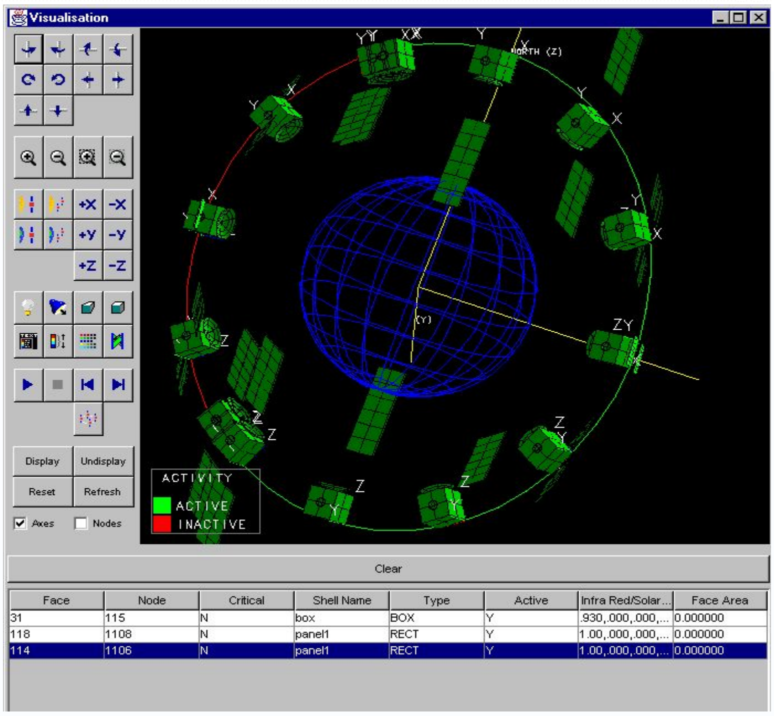
ESARAD – Next Step

- Maintenance release planned
  - No new feature
  - Numerous minor bugs fixed
  - Windows 2000 porting
- Performance issue still outstanding on network
  - Tune eXceed
  - VNC environment could be an alternative

ESARAD – Next Version

- New version planned Q2 2002
- Improved visualisation
- Mission enhancements
  - Pointing
- New license mechanism: FLEXlm®

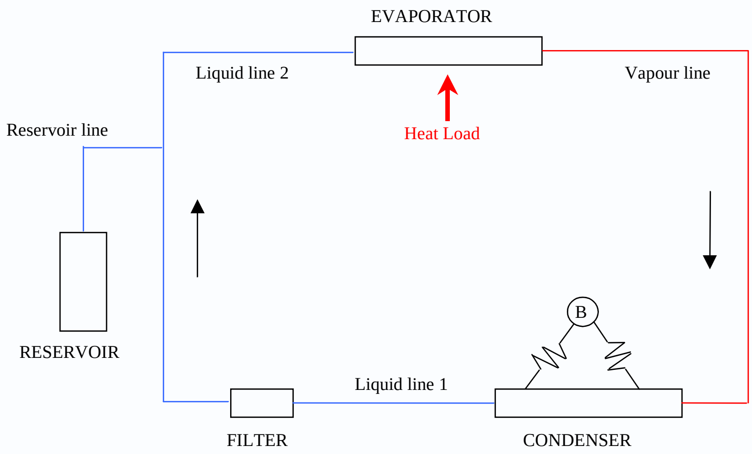
ESARAD New Visualisation



ESATAN/FHTS v-8.6 – CPL

ALSTOM

- ESATAN/FHTS v-8.6 released in June 2001
- Capillary Pumped-Loop facility implemented
- Four new elements to model a CPL (and LHP)
  - Capillary evaporator
  - Tube
  - Capillary filter
  - Two-phase reservoir
- Two new facilities
  - Evaporative link
  - Phase separation



ESATAN v-8.7 – Introduction

ALSTOM

- Release planned mid-October 2001
- Two new major facilities
  - Cyclic transient solver
  - Min/max routine
- Feature requests & bugs fixed
- New license mechanism: FLEXlm®

ESATAN v-8.7 – SOLCYC

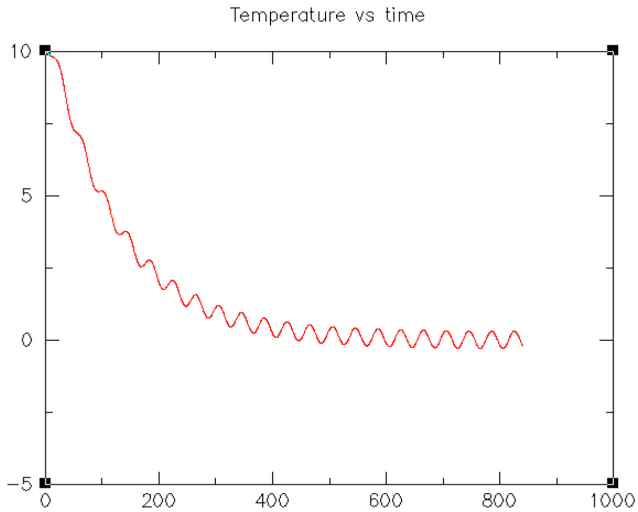
ALSTOM

- SOLCYC is a 'meta-solver' to attain a steady cyclic solution
- Consecutive runs of a standard transient solver until convergence is reached according to the user-defined criteria
- Convergence calculated on temperature and on its derivatives w.r.t. time
- Report at the end of each cycle
  - Number of the cycle
  - Maximum ΔT and node corresponding
  - Maximum $\Delta(dT/dt)$ and node corresponding

ESATAN v-8.7 – SOLCYC – Ex.

ALSTOM

- One thermal boundary node
- One thermal node
- Sinusoidal temperature applied to the boundary node
- GR between the two nodes
- SLFWBK solver




```
$EXECUTION
      CALL SOLCYC('SLFWBK', 0.01D0, 0.05D0, 3600.0D0, 10, ' ','NONE')
```

ESATAN v-8.7 – STORMM

- Used to store the minimum and maximum values attained at each node during a transient solution
- For all nodal entities (T, C, P) and user-defined entities
- User-defined nodal entities have to be defined in USRNOD.DAT

```
$VARIABLES2
      CALL STORMM('T', 'MinT', 'TimeMinT', 'MaxT', 'TimeMaxT')
```


ESATAN v-8.7 – Enhancements

- New minor enhancements
  - TAB character is now allowed in the ESATAN input deck
  - Very large models are now supported without getting an unrecoverable error condition in SICOPY
  - SETNDR, SETNDI, SETNDZ set the value of a nodal entity

```
$INITIAL
      CALL SETNDR(' ', 'MinT', 1.0D+10, CURRENT)
```

ESATAN v-8.7 – Bugs fixed

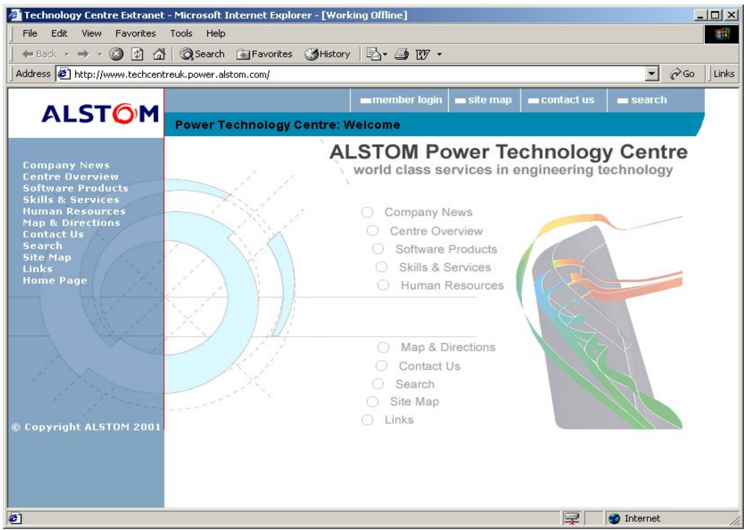
ALSTOM

- The following bugs have been fixed:
  - Maximum length for **`$LOCALS`** and **`$CONSTANTS`** increased to 255 characters
  - 3-digits exponent allowed in an array definition
  - HXKL3 element corrected for the GP calculation
  - On HP-UX, the output format for the temperature depending on the node number is fixed (ex: T1000)
  - The limit value of DYSTOR as it is defined in the user manual is now usable for the user

Web Site – Introduction

ALSTOM

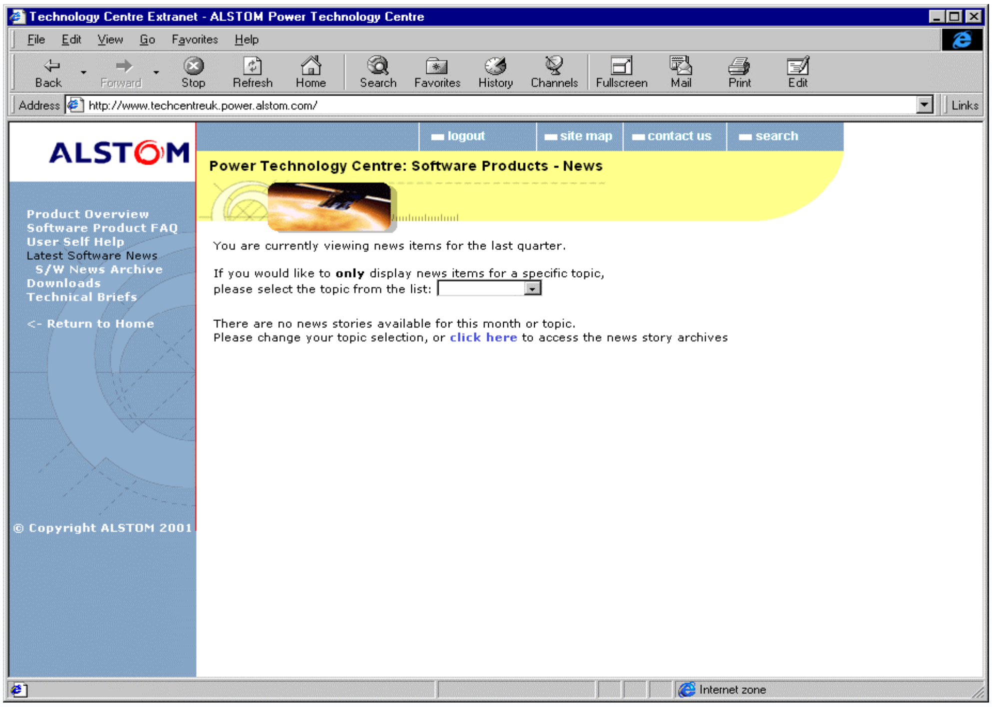
- **`www.techcentreuk.power.alstom.com`**
  - Launched Q1 2001
- Facilities available:
  - News
  - Download
  - Self help
  - Forum
  - ...
- Impact on support
  - Future plans



Web Site – Member Login

ALSTOM

- ESARAD
- ESATAN
- ESABASE
- DLguest

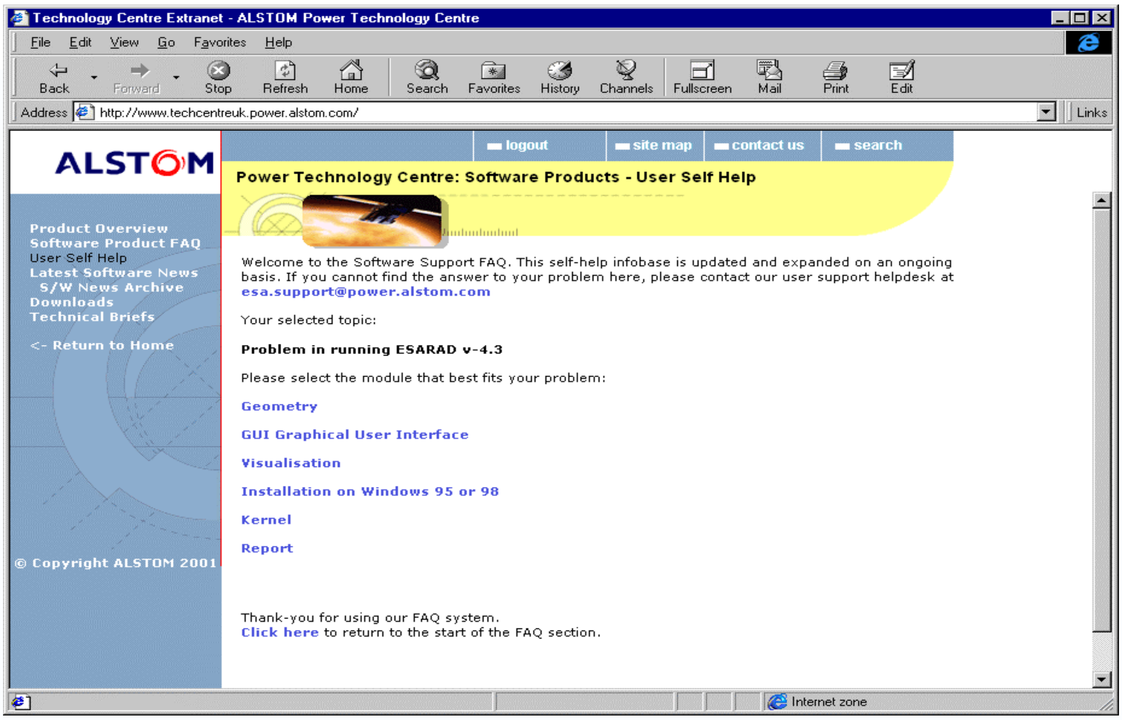


Web Site – Download Section

ALSTOM

Web Site – User Self Help

ALSTOM

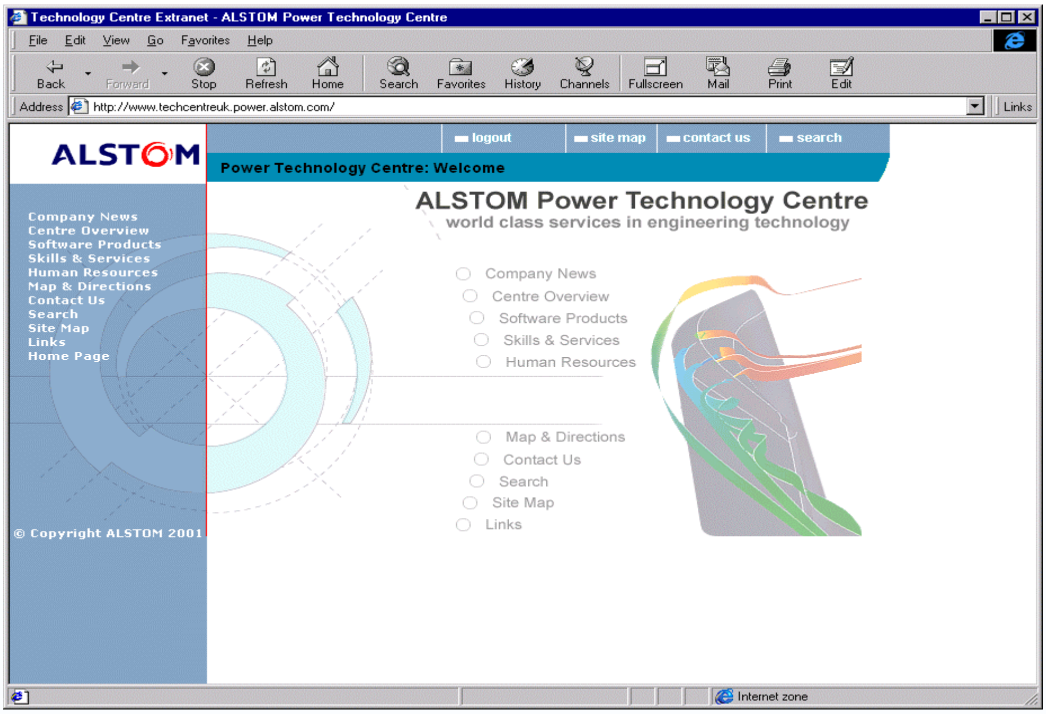


Web Site – Impact on Support

ALSTOM

- User Self Help
  - Record common and frequent issues
  - Include ‘top tips’
  - Users should check this section before submitting a problem
- Next step:
  - On-line recording problems
  - On-line progress and management
  - Forums

Web Site – Quick Demo



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Appendix S: List of Participants

List of Participants

15th European Workshop on
Thermal and ECLS Software

9-10 October 2001
ESTEC, Noordwijk, Netherlands

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