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21-22 October 2003

(Cover image courtesy of Alenia Spazio)

ABSTRACT

This document contains the minutes of the 17th European Thermal and ECLS Software Workshop held at ESTEC, Noordwijk, The Netherlands on the 21st and 22nd October 2003. 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	2003-11-13	Document creation
1.1	2003-11-18	Draft for internal comment
1.2	2003-12-16	Initial release to participants

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17th European Thermal and ECLS Software Workshop
ESTEC, Noordwijk, The Netherlands
21st-22nd October 2003

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1. Tuesday 21 October 2003: Morning Session

1.1. Welcome and Introduction

C. Stroom (ESA/ESTEC) greeted the participants to the workshop, gave the objectives of the workshop and introduced various members of the workshop organization team. (See Appendix A)

1.2. ESATAN, FHTS and ThermXL current status

H. Brouquet (ALSTOM) described the new features available in the most recent releases of the tools. (See Appendix B)

H. Peabody (TMS) asked whether there was a possibility of transposing the comma-separated value output produced by the new ESATAN output routines to avoid the “256-column limit”. H. Brouquet said that it was Excel which was limited, not ESATAN, but even so, it wasn’t possible to transpose the columns. H. Peabody said that he had often needed to work the other way, with values across the columns and nodes down the rows. The ability to transpose the data was useful when dealing with a large number of nodes.

1.3. THERMICA - news of the year

M. Jacquiau (EADS-ASTRIUM) presented some of the latest features being added to THERMICA and described the current priorities for future work, based on a survey of users within Astrium. He also commented on data exchange issues, the Astrium position on the harmonisation activities, and THERMICA funding and licensing. (See Appendix C)

R. Schlitt (OHB System) noted that the CAD interface to THERMICA which had been described contained both STEP AP203 and CATIA solutions. He asked why both were required when it should be possible to import a CATIA model using STEP. M. Jacquiau said that he had first wanted to support only a STEP interface, but had found in practice that the amount of information contained in the STEP files made them very large when compared to similar files in the native CAD formats. Therefore it was more efficient to use native CATIA files directly. He noted that the OpenCascade libraries provided access to both STEP and CATIA files. HP. de Koning (ESA/ESTEC) said that his understanding was that the CATIA import facilities of OpenCascade were not available for free. M. Jacquiau agreed that they were not free to developers but the import facilities were free for end users, although a CATIA licence was needed during the input of the CATIA model.

M. Molina (Carlo Gavazzi Space) asked about the new functionality for calculating thermal radiation forces on spacecraft. He wanted to know the magnitude and relative importance of these forces, and which sort of application required this information. M. Jacquiau said that Boeing had asked for this functionality, but Boeing had not given any information about the application area. He thought that it might relate to GPS systems. HP. de Koning commented that the forces on the solar arrays were significant for GPS satellites because these had tight pointing requirements. M. Jacquiau said that this related to emission from thermal radiators: if the temperatures across the radiators were not uniform, then the difference in thermal radiation forces could result in a slight torque on the spacecraft.

O. Pin (ESA/ESTEC) asked why M. Jacquiau did not consider TASverter as a suitable long term solution to the data exchange problem. M. Jacquiau said that he did not have all of the technical details of TASverter, and therefore didn't know whether TASverter would be well-suited for the long term. He wanted to be pragmatic and take the best solution.

F. Boursier (EADS-SPACE) noted the description of using NTP files to visualize the temperature results on the THERMICA model. He wanted to know how to produce NTP files in ESATAN for use in THERMICA. Where was this documented? M. Jacquiau answered that this was described in one or two pages in the THERMICA documentation. He suggested that anyone needing help with this should contact Astrium for help. There was a subroutine, freely provided by Astrium as part of the THERMICA distribution, which needed to be called from within the ESATAN code. He said that this subroutine was not available as source code, but the same routine for SINDA was.

J. Kanis (Dutch Space) said that one limitation of THERMICA was the lack of boolean operations on surfaces. He wanted to know whether these were planned. M. Jacquiau said that he had not given any information about THERMICA version 4, but one of the first requirements was for boolean operations and the management of more complex shapes. He said that the ray-tracing code was ready to handle boolean operations, but the modeller and the rest of the framework was not yet complete. The pure calculation part was already available [in version 4] and confirmed that THERMICA would handle boolean operations in future.

1.4. ESARAD current status

B. Castelli (ALSTOM) described the new features in the recent release of ESARAD such as the improved spacecraft pointing options, the simplified language for invoking the calculation, the NASTRAN model import facility, and the first stage of the automatic conductor generation. (See Appendix D)

H. Peabody (TMS) asked whether there were any plans to support BAR elements in the NASTRAN import facility as well as the TRIA and QUAD elements. B. Castelli did not know. H. Peabody explained that the BAR element was a linear conductor and would easily convert to ESATAN. He said that it was useful for electronic boxes attached to plates. B. Castelli said that this functionality had only recently been released, and he welcomed any user feedback about it. C. Kirtley (ALSTOM) stressed the need for user feedback in order to provide the users with what they really wanted.

S. Appel (ESA/ESTEC) asked whether the NASTRAN interface just provided a list of shells from the database which the ESARAD user then needed to combine manually. B. Castelli confirmed that the user needed to combine the flat list of shells manually, and then set the appropriate thermo-optical and material properties. This was where the new functionality for recursive attribute editing came in useful. In fact, this was one of the main drivers for the development of recursive attribute editing. S. Appel said that it might be an idea to join the shells automatically based on their material properties.

M. Gorlani (Blue Group) asked whether the link between ESARAD and NASTRAN worked in both directions. B. Castelli said that the interface worked from NASTRAN to ESARAD, but not in the other direction.

1.5. Capabilities of the ThermPlot Pro Thermal Post-Processing Program

H. Peabody (TMS) presented ThermPlot Pro, a program for producing plots and derived results from the output of the standard thermal modelling tools. He described the simplification of the interface to ThermPlot which was currently under development, and the new features being introduced. (See Appendix E)

V. Perotto (Alenia Spazio) wanted to know whether the implementation of the sink temperature for any particular node considered the contributions from all nodes, or whether it was possible to limit it to specific nodes of interest, or groups of such nodes. H. Peabody explained that the calculations were based on the external RadK's, and that there was the capability to consider ranges of nodes. For calculating back-loads, the engineer did not usually want instrument to instrument exchanges. The free flier model handled this. It was also possible to consider the self view range as well as the back-load range. V. Perotto asked whether it was possible to exclude the space node from the sink temperature calculations. H. Peabody answered that this was possible by including the space node in the "self include" range, and therefore exclude it from the calculation.

V. Perotto asked whether the groups feature could be used to perform model reduction. H. Peabody said that it could, but he did not know that he would do so. The engineer needed to know how to subdivide the nodes into groups in order to give the total conductances between groups. This subdivision was very model dependent. He had not used the group functionality for model reduction. HP. de Koning (ESA/ESTEC) asked whether there were any checks or constraints on the grouping, and was told that each node could only be assigned to one group.

1.6. Overview of GAETAN's latest developments around ESATAN-FHTS

M. Imhof (Silogic) described how GAETAN could be used for all phases of spacecraft design, and the integration of ESATAN-FHTS into the environment. (See Appendix F)

O. Pin (ESA/ESTEC) noted that ESATAN had been released on Linux, and asked whether there were any plans to provide GAETAN on Linux too. M. Imhof said that they were still thinking about it, but had not done anything about porting to Linux so far. C. Marechal (CNES) said that if GAETAN users asked for a Linux version, the priority for a Linux version would become higher.

M. Gorlani (Blue Group) asked whether the CONDOR module within GAETAN made use of its own solver or whether it used ESARAD. M. Imhof said that the user had ESARAD for handling complex geometries. M. Gorlani wanted to know whether CONDOR could calculate fluxes directly. M. Imhof explained that CONDOR had its own solvers, but that these were limited to simple geometries. However, it was possible to use CONDOR to generate the initial mission parameters, and then chain these to ESARAD. M. Gorlani confirmed his understanding that for simple geometries it was possible to just use CONDOR.

R. Schlitt (OHB System) asked whether GAETAN was restricted to French users. He was told that it was not.

1.7. Web Support and Future Developments on ESATAN, FHTS, ESARAD and ThermXL

C. Kirtley (ALSTOM) described new functionality that had already been, or was being implemented in the development versions of the tools, and gave some ideas about features which were still being considered. He stressed that ALSTOM were really interested to hear from users about the features which they actually needed. He said that the ALSTOM web site now allowed users to submit feature requests as well as support problems, and encouraged the user community to make use of it. (See Appendix G)

H. Brouquet (ALSTOM) gave a demonstration of ALSTOM's web site, and showed how users could generate Software Support Requests, and how the visible status changed as the support desk dealt with each request. He also described the on-line user survey, and highlighted the fact that ALSTOM would be giving away a electronic organizer in a prize draw of all eligible respondents.

There were no questions.

2. Tuesday 21 October 2003: Afternoon Session

2.1. Harmonization of thermal and space environment analysis software

R. Schlitt (OHB System) described the current status of the harmonization activity which had been set up since the previous year's workshop, and the composition of the steering board of which he was chairman. He had deliberately included several provocative statements in order to stimulate discussion. He emphasized that although HP. de Koning (ESA/ESTEC) had been shown as the co-author of the presentation, he might not agree with all of the statements made. (See Appendix H)

HP. de Koning noted that an ALSTOM representative had since joined the steering board as an observer. He also said that the steering board had commissioned a first study, to be lead by eta_max, and involving Astrium (UK, D, F).

Questions were deferred until the round table discussion at the end of the afternoon.

2.2. Open Source Software for Engineering Purposes

M. Haupt (TU Braunschweig) described the results of a search for third party and open source software packages which could be used in the production of engineering software. (See Appendix I)

Questions were deferred until the round table discussion at the end of the afternoon

2.3. Applicability of OSS to Space Thermal Engineering

R. Schlitt (OHB System) gave details of the study which he had mentioned in his previous presentation and to which M. Haupt's presentation also related. (See Appendix J)

R. Schlitt noted that part of this study had involved the production of a web site which could be used to support a thermal community software development.[1]

Questions were deferred until the round table discussion at the end of the afternoon.

2.4. Innovations in using Finite Element Modelers for Spacecraft Thermal Design

R. Behee (Network Analysis) described the differences in approach between typical thermal analysis software using a small set of geometrical shapes with simple meshing compared to finite element analysis software which uses simple planar shapes to represent more complex geometries. He explained that some of the advantages of both approaches could be incorporated into new thermal tools. (See Appendix K)

There were no questions.

2.5. Application of the Open Source Approach to Space Environment Analysis Tools

H. Sdunnus (eta_max) described the development of PC-ESABASE using several open source software packages to form the Open Frontier supporting framework into which the ESABASE/ Debris module could be plugged. (See Appendix L)

B. Castelli (ALSTOM) asked whether any enhancements had been made to the ESABASE/ Debris module. H. Sdunnus said that some enhancements had already been made before the project had started, and that these enhancements had not been implemented in the last industrial release of ESABASE.

M. Jacquiau (EADS-ASTRIUM) asked which open source software solution had been chosen for the ray-tracing. H. Sdunnus said that this had not yet been addressed, and that they were still

1. See http://www.therm-oss.org

using a self-developed ray-tracer. The software would be distributed with the new ray-tracing routines. The IPR would rest with ESA. C. Kirtley (ALSTOM) asked whether this ray-tracing code would be available as open source software. H. Sdunnus said that the hoped so. Everything in the Debris plug-in belonged to ESA, and it would be up to ESA to decide whether to release it as open source software or not. C. Kirtley asked whether this include the source for the Debris module as well. H. Sdunnus said that ESA still needed to decide.

C. Stroom (ESA/ESTEC) said that the general mechanics of releasing software as open source was still under debate. The different groups within ESA knew what they wanted on a technical level, but the legal and contractual levels were taking a lot more time to define. He said that discussions were on-going.

2.6. Round Table Discussion

HP. de Koning (ESA/ESTEC) introduced some viewgraphs showing possible points for discussion. (See Appendix M)

C. Stroom (ESA/ESTEC) asked for the users' opinions on open source software. He said that this was an informal workshop and that users could speak on their own behalf, rather than needing to represent their respective companies. He made the appeal for users to speak freely because ESA needed the users' honest input.

HP. de Koning stressed that the current OSS projects were an experiment, and could not be considered as fixed developments with all aspects cast in stone. He said that there were many opportunities for the users to get involved. He noted that R. Schlitt (OHB System) had made many provocative statements in his presentation in order to elicit discussion and to provoke users to give their opinions. He said that no decisions would be made during the session: it was intended for discussion only. The steering board covered all areas of the user community, with all major space companies being represented. He added that people could still apply to be members of the steering board. He hoped that the harmonization had a good chance of succeeding.

C. Stroom asked whether everyone agreed with R. Schlitt, but nobody responded.

C. Kirtley (ALSTOM) asked what had been decided about the licence agreement for the open source software developments. HP. de Koning (ESA/ESTEC) said that no licence agreement had been selected so far. There were various issues concerning how to proceed with development, intellectual property rights, etc. that were still undecided, and hence still completely open. He said that it was one of the tasks of the steering board to find a suitable licensing model.

O. Pin (ESA/ESTEC) said that it was worth mentioning about the "go/nogo" decision for the open source development. HP. de Koning explained that the first study phase, taking 4 or 5 months, was intended to establish a working model for cooperation, IPR, licensing and look at maintenance and funding issues. The outcome of the study would be a "go" or "nogo" recommendation to the ESA Council. Even though this would be open source development, funding would still be required in the end. The project was entering the study phase with all options open, and would probably continue with the current open basis, but the change to a more commercial way was still possible.

JP. Dudon (ALCATEL) asked who was partner to the “go/nogo” decision. HP. de Koning said that there were 14 voting members on the steering board, and it would be decided by a majority vote. This would involve votes from ESA, CNES, the Canadian Space Agency, Alcatel, Alenia, Astrium, Carlo Gavazzi Space, EADS, eta_max, OHB, Onera, Qinetiq and RAL. Additional members representing ESA, CNES, Astrium and Maya would not be able to vote.[2] C. Stroom said that the harmonization effort was concerned with both thermal and space environment software combined.

C. Marechal (CNES) asked how the first study had been awarded to Astrium and eta_max. He wanted to know why no-one else had been involved. HP. de Koning said that the decision for the first part of the study had been made with a major practical consideration for speed. This had been the topic of the first meeting of the steering board, and Astrium and eta_max had been chosen by the steering board as a whole. The outcome of the vote had to be accepted by the other members of the steering board.

J. Kanis (Dutch Space) asked who had selected the members of the steering board. HP. de Koning said that ESA had invited the space companies to participate, but only those who had replied positively had been considered for the steering board. C. Marechal asked whether other members of the audience would like to apply to the steering board who had not received the original invitation. J. Kanis said that Dutch Space had not received the invitation. F. Crampé (Silogic) said that Silogic were working on GAETAN, and that they hadn’t been involved in any mailing list. HP. de Koning said that L. Ney (Silogic) should have received the information. C. Stroom admitted that knowing who to include on a mailing list was always a problem, but in principle the list which had been used should have been the same as that used to inform people about the workshop.

A. Sgambati (Laben) said that this was the first time that Laben had heard about the use of open source software in ESA and the involvement of the whole space community. She said that Laben were not aware of the open source activities. O. Pin said that the ITT for the open source activity had been available to all companies. A. Sgambati said she didn’t know why Laben had not received the information. C. Stroom said that all of the on-going open source activities, such as PC-ESABASE and THERMOSS, had all been issued as open calls for tender on ESA’s EMITS system. These activities were part of the ESA’s General Studies Program under a heading such as “applicability of open source software to space projects”. He said that they only were listed on EMITS, and not sent out to each company explicitly. A. Sgambati said that they had only received the mail for the workshop and didn’t know the purpose of the workshop was to discuss open source development.

F. Lamela (EADS-CASA) felt that he was working under some misunderstanding, and asked whether everyone was seriously talking about the development of radiation analysis code based on open source software. He said that many years of effort had already been spent on both THERMICA and ESARAD, and he wondered why this time should be lost. He said that for a

2. This was the membership of the steering board at the time of the Workshop. It was possible for other companies to apply to become members in the future.

small company like CASA it was important to have competition to improve the tools, and argued that ESARAD had reached its current level because of competition from THERMICA. He said that there was always something announced for ESARAD which became available in a future development of THERMICA, and vice versa.

HP. de Koning argued that the application of open source software did not have to be black and white, and that there needed to be a balance between the different areas. There might be some areas where open source development would be useful, and others where competition would be important. He felt that it was important to have the steering board in the driving seat in order to determine the way forward.

O. Pin said that it was important to have a common framework. He said that there was commonality between ESARAD and THERMICA, but these two examples had made different choices. He felt that there was a need to look at why these choices had been made. He said that it might be necessary to have competition for the individual modules that plugged into the common framework. C. Stroom agreed that there could still be competition if that was what was required. What had been said about open source software was quite valid, but it usually related to large user communities with a large number of contributors to the software. He said that the open source software model had not really been tried in a small user group such as the space thermal community. He emphasized that THERMOSS was a prototype, a vehicle to test whether open source software would work for the space thermal community. He said, yes, it was possible to build a tool using open source software, but would the process work in this particular community. He said that ESABASE/Debris was a running tool, THERMOSS was an experiment.

M. Jacquiau (EADS-ASTRIUM) wanted to know whether open source software was the unique solution to the problems of harmonization. C. Stroom answered that open source software might not be the answer to all of the space thermal community questions, but that it was a serious contender that should not be excluded out of hand. It was something which needed to be considered seriously. Yes, you could take open source software and use it for free, but if it was to survive in the space thermal community, it was necessary to give something back. M. Jacquiau admitted that open source software looked interesting, but said that the harmonization should look at frameworks too. He suggested that any future open source software solution should be compatible with the proprietary software so that the user could choose to use one or the other as required. He gave the example that building a spacecraft geometry could be done using open source tools, the mission aspects could be provided using THERMICA, and the radiative calculations could use ESARAD. C. Stroom agreed that this should be possible.

HP. de Koning agreed that this interaction between the different aspects of design and analysis was the reason why the first set of open source software tools had to be data exchange modules. Data input and output would form an important part of any tool, and it would be a big advantage to be able to release data exchange modules as open source to provide the basis of such a framework.

M. Jacquiau was concerned that the current tools already existed: ESARAD and THERMICA had already reached a certain level of maturity. He asked how long it would be for similar open source software tools to reach the same level of maturity. C. Stroom wondered whether it might not be sooner than many people would think, and said that one of the reasons for proceeding with THERMOSS had been to discover the answers to this sort of question. He said that M. Jacquiau had already shown that THERMICA was benefiting from using open source software such as vtk and fltk. HP. de Koning said that it always took time to assess the quality of any given software. It took time to learn how to use it. It wasn't possible to decide based on the documentation and a few screen-shots alone. He felt it important that there had to be a robust verification of what the tool was supposed to do.

M. Jacquiau noted that for any tool to provide efficient calculation modules it was necessary to have competent people in both the software and thermal areas. He felt that any developer had to be close to the users, and to have a good relationship with them, just like the THERMICA development team had with Astrium's internal users. He wondered whether it would be possible to find the same user community mix for the open source software tools. He agreed that examples of open source software such as Linux and FreeBSD were successful, but their user and developer communities were quite big. However, the space thermal community was very small. C. Stroom said that this was one of the objectives of the THERMOSS study: to set up a web site, provide a download area, and a forum for discussion and comment. One of the questions was whether it would work, whether people would even look at it. He said that everyone's remarks on the thermal tools were valuable, and that was one reason for the workshop: to provide a place where users could discuss their requirements in front of the developers. However, it was necessary to try out other ways of communicating, such as the Internet, with a user forum and discussion groups.

H. Sdunnus (eta_max) said that people should be careful to avoid a common misunderstanding. The open source software activity didn't aim to replace the existing thermal tools, and in fact it might be that the proprietary tools proved to be better in the long run. What was needed was a common framework for plug-ins to overcome the shortcomings of existing tools. One example already given had been the user framework for SINDA. He said that the open source activity should aim to provide a framework which could permit access for both proprietary and open source software solutions.

O. Pin noted a theme from the space environment discussion, and that was that the tools were "sophisticated" and that the components used to build them were complex. He said that the thermal users were not software people. He wondered whether it was realistic to assume that in 5 years the thermal guys would still be participating in any open source development. He was not sure that the open source maintenance model would work for the space thermal community. To make it a success would require 20 developers like Hume Peabody dedicated to the tools.

HP. de Koning said that maintenance could be a paid activity, or involve some sort of contribution in kind. He said it was unlikely that the small user community would be able to maintain such a framework in the usual open source way without some additional funding and some development effort to keep the forum and web site running. He said it was not the same as other open source packages such as POVray where users could make contributions in kind.

O. Pin noted a general issue with the current way of software development. The Bepi-Colombo project had specific new requirements which had been missing in ESARAD [and THERMICA], and that it had taken some time to gather the requirements and to get the development going. He wondered whether open source software development would be any more flexible. He said that there may be individual users who could address their short term needs and develop an internal module as a plug-in to an open source tool framework, but this model was not applicable to the space thermal community as a whole.

C. Stroom said that this could be handled via the maintenance model, where someone could be paid to maintain the tools, which was what currently happened anyway. What would change was that if a user required a particular function, then the user could add this feature for himself if necessary. This was not possible for most of the users at present. Almost all of the companies have this expertise already because they already develop their own tools if the main thermal tools don't offer what they require. With open source software tools a company would be able to see what changes would be needed, and could implement them internally, or ask the developer of the module to implement specific changes for them. The current tool architecture did not support this. C. Stroom said that any open source development would need to have well documented data structures and algorithms in order for different developers to work together. C. Stroom felt that the architectures of the current tools had just grown over time to the point where it was no longer possible to add new data structures and functionality easily.

JP. Dudon (ALCATEL) raised a question about THERMOSS as a prototype thermal software tool. He wanted to know when it had been decided to implement such a tool, and who had been invited to participate. HP. de Koning said that the initial ITT had been available on EMITS, and it had been open to all. C. Stroom said that 8 or 9 offers had been received from different groups. JP. Dudon wanted to know who was involved in the development. C. Stroom said that the group consisted of OHB, IFL, MakaluMedia and Deimos: OHB had defined the user requirements; MakaluMedia had built the web site; and Deimos had been involved in the orbit definition and calculation.

H. Peabody (TMS) said that the critical point on the viewgraph to be considered was “Would you participate as a developer?” and added that if nobody wanted to participate in development then the rest of the questions were irrelevant. If the people you are going to help are also your main competition, what reason do you have to cooperate? HP. de Koning said that this was the whole point of having the harmonization. C. Stroom remarked on the example that R. Schlitt had given where most of the players in the automotive industry had agreed to harmonize certain activities even though they were all competitors. H. Peabody argued that space thermal software was such a niche field. If only 10% of the community agreed to participate, then it would simply not be enough to sustain development. C. Stroom countered by asking how many developers were involved in ThermPlot. H. Peabody answered that there was only one developer, himself, but that it was in his own interest to do it. R. Schlitt said that there were already a lot of developers in Europe, each one developing tools such as CONDOR, ALTAN, etc. H. Peabody argued that in these cases there was funding to address the needs of some project, and such developments were a way of guaranteeing that your own requirements were satisfied once and for all.

C. Stroom said that open source software tools did not just float around and each group modified them in isolation. There needed to be a maintenance model, which usually involved some sort of custodian of the code. A user could make changes to the code and should then submit them to the custodian for inclusion in the main development if the custodian considered the changes appropriate. R. Schlitt said that open source software meant that the source code itself was available to the user. He was sure that THERMICA would have been easier to produce if the source code for ESARAD had been available for inspection. He said that for new requirements in the future, such as the next mission to Mercury, the project would receive some funding for the implementation of the new requirements and it would be possible for them to have access to the source code of any open source software tool and they could make any changes necessary.

C. Kirtley (ALSTOM) said that he would be surprised if companies would be willing to hand over thousands of lines of source code. He could not see any competitive advantage in it. R. Schlitt said that the automotive industry had agreed to standardize on using NASTRAN and CATIA, but even so, there were still some cars that were better than others. He said that simply using THERMICA or ESARAD would not guarantee the success of the satellite.

C. Marechal recalled the statement that the voting members of the harmonization steering board were not supposed to be software developers. He wanted to know how OHB and eta_max were voting members when they were clearly developers. HP. de Koning acknowledged that this was a very grey area. Astrium were major users of the thermal tools, but were also developers of tools. He admitted that the composition of the steering board had involved some compromise. However, he felt that in general the companies which had voting rights tended to be more user than developer. C. Marechal argued that OHB seemed to be the leader in the open source software activity. C. Stroom said that OHB were representing the users of the software, and had produced the user requirements. The developers were actually MakaluMedia, IFL and Deimos. HP. de Koning stressed that the steering board was not a secret society. All companies should have received an invitation to join, but there was a need to be realistic. It would not be practical to have a steering board of 100 members. C. Stroom noted that if of the all companies who had ever developed software had been excluded from the steering board, then only a few companies would have qualified. Almost all companies had developed software at some point.

C. Marechal asked whether there was any link between the steering board and the ITT for the ESATAP activity. O. Pin said that the only link was that ESA had been involved in defining the ITT and in the formation of the steering board. The ESATAP statement of work had been produced before the steering board ever existed. C. Stroom said that the ITT for ESATAP was under the full responsibility of ESA, and had not even been mentioned in the steering board.

C. Prouvost (OpenCascade) said that OpenCascade would also like to be represented on the steering board. C. Stroom said that anyone wishing to join should contact the secretary of the steering board. E-mail addresses would be provided later.

A. Crutcher (FSC) said that if the open source activity was being run as an experiment, then the experiment was being undermined by having user involvement. He felt that open source development and user involvement were different things. He said that the concept of the experiment was good, although he did not agree with many of the assertions which had been made. He felt that the requirement for the activity to be user lead would kill the initiative. He wondered how many users would turn up for steering board meetings. He said that the purpose of most businesses was to make a profit, and wondered how a company could submit its work to everyone else free of charge. HP. de Koning said that the key phrase here was “free of charge”. A. Crutcher said that everyone wanted to benefit from the work of other people, but it was necessary to have real projects to work on in order to make money. HP. de Koning responded that people were already doing open source software development in commercial companies. A. Crutcher asked who would pay for the space open source development, and was told that ESA could be a source of funding.

C. Stroom (ESA/ESTEC) commented that the best example for open source development was the field of science, which was completely open and people were able to build on top of the work of others and develop science further. He said that the payment for doing the open source software development was disjunct from the open nature of the software itself: it was on a different axis. HP. de Koning said that software development could be characterized by different axes: there was the axis from completely open to completely closed proprietary source code; there was another axis describing intellectual property rights from public domain to restricted use; and so on.

A. Crutcher was still dubious about the question of user involvement: his own experience with the ThermXL development had shown that nobody had come to the user requirements meetings that had been organized. C. Stroom countered that users tended to behave differently in open source software development, which typically needed far more user involvement because they were doing the development as well.

M. Molina (Carlo Gavazzi Space) wanted to answer the question about whether they would participate. He said that Carlo Gavazzi Space didn’t have the relevant skills in the software areas, and in fact he felt that the space industry did not have the critical combined users and developers required. He felt that it would still be necessary to use more dedicated software companies.

M. Molina commented on the issue of data exchange using STEP-TAS. He felt that nobody was going to certify whether a particular software tool complied. Would Thermal Desktop be certified? Who would do it? HP. de Koning said that ESA had now made the first robust release of the STEP-TAS converters and was now looking to provide verification tools. If these independent verification tools could be used to determine whether there was a conflict between vendors’ implementations it would then be possible to arbitrate between them.

M. Molina repeated his call from the previous workshop for improved communication via the mailing lists. He said that the mailing list already existed. He knew that it would be a violation of the rules about ITTs if all announcements were made to the whole community, but he felt it would be helpful if the community could be kept up to date with some of the developments within the running contracts. C. Stroom said that this was a difficult area, and he would need to verify whether it would be possible to bypass the official channels in order to provide information in this way.

3. Wednesday 22 October 2003: Morning Session

3.1. Simulation of Furnace Inserts and Sample Cartridge Assemblies using the Thermal Modelling tool CrysVUn

M. Hainke (Fraunhofer) described the CrysVUn system for simulating the physics of crystal growth within a furnace, and the extensions being made under ESA contract to allow the user to model individual experiment cartridges. He then gave a demonstration of the software. (See Appendix N)

M. Molina (Carlo Gavazzi Space) asked whether the CrysVUn software was available to other users, and how. He also wanted to know whether the software provided windows and doors to allow it to communicate to external software packages. M. Hainke said that the Institute sold the program commercially, and that there were currently about 50 licences. He said that there were no links to other systems.

3.2. Plant Growth Chamber Simulation using EcosimPro

L. Ordóñez (ESA/ESTEC) described to use of EcosimPro to simulate the growth of various food plants as part of an regenerative life support system for long duration space missions. (See Appendix O)

H. Peabody (TMS) asked whether plants grew taller in low gravity conditions, and whether this would lead to volume constraints. L. Ordóñez said that the differences between plant responses on Earth and in space were not well known yet. He was waiting to see experimental data.

3.3. Thermal and fluid dynamic analysis of the air cooling/conditioning system on board the MDS (Mice Drawer System) facility

A. Sgambati (Laben) presented details of the Mice Drawer Facility, an experiment to be flown on the ISS involving the study of mouse development and behaviour during a hundred day period in micro-gravity. She described the solution to the different thermal constraints imposed during the transfer to the ISS compared to the main operation. (See Appendix P)

M. Molina (Carlo Gavazzi Space) asked whether it had been possible to check the results obtained using FHTS against any experimental measurements. A. Sgambati said that they had a breadboard system in Genoa, and also a laboratory at Laben for checking system components, such as the fans, etc. They used TMG/IDEAS to check the components and to model the hybrid cold plate. The results had been consistent.

M. Molina asked how much heat was contributed to the system by each mouse. A. Sgambati said that each mouse represented a 1W heat source, so the system had to handle 6W from the mice. The actual heat produced was related to the family of mouse being used.

3.4. Thermal Aspects of Long Term Operations on a Comet Surface.

HP. Schmidt (DLR) described the parameters for the Rosetta mission and the constraints imposed by its new target of Comet 67P/Churyumov-Gerasimenko. He gave details of the different operating scenarios available as the battery temperature could be maintained for longer with comet orbit approached the Sun. (See Appendix Q)

There were no questions.

3.5. Access to ESA funded developments

O. Pin (ESA/ESTEC) gave an unscheduled presentation about doing business with ESA, and the access to information on ESA funded developments. (See Appendix R)

O. Pin said that some of the discussions during the previous day had shown that there was a lot of confusion about how the “ESA system” worked, especially over who had access to the ITTs. He said that ESA had to be very strict in applying the rules, and he wanted to make this point absolutely clear to everyone. All new developments were usually published as open tenders except for some very specific cases for which direct negotiation could be justified. ITTs were published on the EMITS system. The two ITTs which had been mentioned the previous day (the Thermal Concept Design Tool and ESATAP) had been visible to all companies registered with EMITS. It was the responsibility of industry to look for business and to consult EMITS regularly. ESA did not advertise the ITTs nor send out notification to companies.

He said that ESTEC/TOS-MCV maintained four different mailing lists and that these related to ICES, the Workshop, TASverter and the Harmonization activity. In total these contained about 200 e-mail addresses. He admitted that it was difficult for anyone to know whether they were missing from the mailing lists because they would never receive information.

He explained that the “planned” MCV R&D projects were funded from the GSP, TRP and GSTP budgets. The open source software and harmonization activity was only at the feasibility study stage. So far it had been for research only, with only one contract in place so far. In particular, projects and other developments funded under the GSP didn’t affect the funding for ESARAD and ESATAN.

Preparations were currently under way in ESTEC for submitting proposals for TRP and GSP funding. Users and projects had been consulted, and 17 proposals had been submitted, of which only 4 related to the open source software and harmonization activity.

Projects which were proposed for GSTP funding would need to have support from the national delegates, so it was important for companies to make sure that their national delegates were aware of any proposals which needed support. Which proposals were selected would be the result of a board decision.

3.6. HDF5 and STEP/NRF database for SINDA/G

R. Behee (Network Analysis) outlined his current ideas for using a neutral file format for storing the model database in a future version of SINDA, and the potential benefits of exchanging such a model database between tools. (See Appendix S)

R. Schlitt (OHB System) asked whether the import of CAD models into SINDA/G would be via STEP or using a direct conversion. R. Behee said that the tools supported the STEP standard, but that SINDA currently pulled the data directly from the CAD file. He wanted to let the modellers deal with the STEP side by pulling the knowledge of the finite element data out of the codes.

H. Sdunnus (eta_max) asked whether the tool offered support for configuration control of the model. R. Behee said that it did not, but recognized this as a good idea and said he would note it down.

C. Stroom (ESA/ESTEC) said that the viewgraph had shown SINDA reading data from the FE codes: this was effectively a database read, and writing would involve the same format. R. Behee said that PATRAN used PCL (Patran Command Language) to write the node data, etc. One way to continue would be by writing the PCL data into HDF files. He said that the transfer of information was currently one way, and that it would only be necessary to send back the temperature and the heat flow to PATRAN.

C. Stroom asked whether R. Behee had considered restructuring the data completely, reading information into a database and then solving directly from the database. R. Behee said that SINDA was similar to ESATAN, and that the data file contained all thermal data on nodes, conductors, etc. Another file provided the directory. He wanted to be able to preprocess all data into HDF files, and maybe to store the SINDA model itself in HDF to allow model export. This would allow similar tools to work on the preprocessed file. C. Stroom asked whether R. Behee would be prepared to publish such a data format. R. Behee said that he would. He said that if all tools could preprocess their models into the same data file format maybe everyone would be able to see that the tools are more similar than they thought. He reasoned that it may be better to store this model data file in some standard format such as STEP-NRF. HP. de Koning (ESA/ ESTEC) said that this had been the whole point of developing STEP-NRF, to have common attributes in a common format. R. Behee agreed, and said that to convert models from ESATAN to SINDA maybe it would be possible to use STEP.

HP. de Koning commented that the harmonization effort now appeared to stretch across the Atlantic, and that if people were prepared to push, the community might actually get better interfaces between the tools.

3.7. GOCE - Thermo-Elastic Distortion Analysis

L. Weimer (EADS-ASTRIUM) described a method on integrating both structural and thermal analysis using “unit load cases” for each area of interest on the model. He also gave details of the strong frequency constraints on the thermal stability. (See Appendix T)

H. Peabody (TMS) asked whether there had been any comparison of results with the more traditional “stop” analysis to see the difference with the typical thermo-elastic applications. L. Weimer said that he hadn’t used the traditional approach. He had made two models so far, the second one with 88 loops, and had compared them. The level was almost the same but with some small variations. The other analysis had been performed by the prime contractor. F. Lamela (EADS-CASA) said that CASA had passed the thermo-elastic data to Alenia. H. Peabody said he was interested to know more because he would be involved in performing a “stop” analysis soon for another project. H. Peabody asked about the restrictions in defining the model. L. Weimer said that he didn’t have large temperature gradients between areas in the model.

M. Gorlani (Blue Group) asked how the different configurations had been handled, with the loaded and unloaded cases, etc. L. Weimer said that he had made some experiments with the different linearisation. As the gravity decreases with the square of the distance, moving the masses further apart gives reduced effects in the error. The linearisation error was less than 1%. Same analysis for the gradients had revealed similar results. M. Gorlani asked about the change in configuration between cases. L. Weimer said that the GOCE configuration did not change enough to make it worth redoing the analysis.

F. Lamela questioned the applicability of this methodology. He said that he had worked on an antenna system where the PATRAN/NASTRAN run only took 15 seconds so it would have been no problem to rerun 88 cases. However, the interpolation in the mechanical model had been a disaster because the temperatures appeared within the model. The structural analysts had run so many models and had discovered gradients between the MLI and radiators, etc. The conclusion had been that it was necessary to have better models in all areas, but this was prohibitive. The question was how to select the areas of importance in order to reduce the gradients, this was the critical art.

M. Molina (Carlo Gavazzi Space) asked whether the analysis had considered both Earth temperature and albedo variation. L. Weimer said that both had been taken into account, but he had only shown one during the presentation.

M. Molina said that these new satellite and mission requirements were opening up new domains in spectral analysis, and that everyone involved really needed to agree on a new vocabulary. He gave the example of spectral density being applied to rotational spectral density. He said that his own presentation later in the afternoon would address this very subject.

L. Weimer said that the micro-kelvin variations in the frequency domains were not useful in ESATAN when most analysis was geared to a 4 or 5 degree variation

S. Appel (ESA/ESTEC) asked whether L. Weimer had been aware of the SINAS tool developed for ESA. This provided the interpolation of ESATAN temperatures to finite element nodes and handled gradients. He felt that SINAS was more robust than the technique which had been described during the presentation and had a wider range of applications. L. Weimer said that his group performed the thermal analysis, and the structural analysis had been carried out in Spain. The approach described had reduced the amount of work need to interface with the group in Spain. S. Appel commented that if both groups chose to keep the mapping between the thermal and structural models fixed, then the interfaces would remain the same.

3.8. Methodology for Thermal Model Archiving

F. Lamela (EADS-CASA) described the perennial problem of archiving and maintaining the analysis models for spacecraft projects where different parts of the analysis were handled by different tools and stored in different areas of the file system. He presented a small FORTRAN application for pulling the separate models into a single file for archiving. (See Appendix U)

HP. de Koning (ESA/ESTEC) wanted to know more about the model with the high value conductor which had been mentioned, because a problem like that really needed to be investigated. F. Lamela said that it had been a model of an antenna system, several years previously, where a structure modelled as two nodes, which should have had a temperature difference of less than 0.5 degree, actually resulted in a difference of many degrees. In the end, the structure had been reduced to a single node. O. Pin (ESA/ESTEC) suggested to use the energy balance to control the calculation. F. Lamela said that this could lead to a different set of problems. Relaxing the energy balance difference from 0.0 to 0.06 could give a lot of locally unbalanced nodes, even though the overall solution could be globally balanced.

F. Lamela said that this problem had been reduced to a model of just three nodes, two of which represented a battery and a radiator. They had calculated the power generated, and the heat rejected by the radiator. They had found 6W in the battery, but had 15W at the radiator. C. Kirtley (ALSTOM) suggested that the model could have been converging slowly to the solution in the steady state but had jumped out of the calculation before the solution had stabilized. F. Lamela remembered that there were specific requirements which meant that they were using the transient solvers.

S. Kasper (Jena-Optronik) commented that he was an ESARAD user, and he also preferred to have all related models in a single file set in order to run them via batch mode. He noted that it was possible to do this using the ESARAD language and the appropriate radiative and analysis cases. F. Lamela said that the program he had presented had been intended for their SGI/Unix environment where they were using THERMICA. He had no knowledge of ESARAD. S. Kasper said that this facility was already included in ESARAD, so no extra software was required.

3.9. The far field method for 1D conductor computation

S. Appel (ESA/ESTEC) presented a method for approximating the 1D conductance between touching shells by calculating the heat flow between the interface and the most distant parts of the shell, as seen from the thermal point of view. (See Appendix V)

M. Molina (Carlo Gavazzi Space) asked how the calculated conductance was affected by the choice of epsilon when calculating the far points. S. Appel said that he had found that the size of the far edge was important, and that there were various ways to handle it. Experiments using different values of epsilon from 0.5 down to 0.0 had shown that the method was not so sensitive to its value. The value of 0.15 appeared to be useful for most of the shapes considered, although an ‘exotic’ configuration might call for additional tuning.

J. Kanis (Dutch Space) asked whether the contact conductance had been taken into account.

S. Appel said that if you had two finite element meshes next to each other, it was possible to introduce an additional conductance between the finite element nodes using the spring type elements in NASTRAN. Therefore it was possible to represent contact conductance. HP. de Koning (ESA/ESTEC) said that the result would be a formula containing the contact conductance, and not a simple parameter.

M. Jacquiau (EADS-ASTRIUM) asked whether an approach considering only pairs of nodes was sufficient. Why not consider the whole geometry? S. Appel said that the solution had been designed to allow thermal engineers to play with individual, physically meaningful, conductances between nodes. He said that various studies had been made in the past into using 1D conductors for the 2D and 3D approach. Most star methods resulted in negative conductors, and some thermal engineers did not want to deal with negative conductors. Some methods resulted in solutions where many nodes had conductors to non-neighbour nodes, and some thermal engineers did not like that either. This method provided an easy way for the thermal engineer to work with simple shapes, and meaningful conductors between them,

M. Jacquiau asked whether this method could be extended to several surfaces sharing a common edge. He wondered whether a triangle/star reduction would be sufficient. S. Appel said that he had not investigated this yet, the current solution method was based on pair-wise comparison. M. Jacquiau suggested that a system of three nodes sharing a single edge, and solved on a pair by pair basis could overestimate the couplings in each pair. S. Appel stressed that this method offered a 1D solution, and M. Jacquiau was talking about a 2D problem. O. Pin (ESA/ESTEC) said that this method simply automated what the users were already doing. However, nothing had been said about the meshing: if the meshing was not fine enough then the conductances would not be calculated properly.

C. Kirtley (ALSTOM) asked whether there had been any validation of the method on complex real models. S. Appel said that he had run various tests with simple shapes, some with a growing hole, and with cut sections. He asked for the definition of complex. HP. de Koning (ESA/ESTEC) said that it was only possible to validate this method for pairs of shapes for which analytical solutions already existed. The method had been validated for those pairs for which analytical expressions existed, and it appeared to be mathematically well behaved.

M. Molina asked what would happen if a non-uniform power source was applied to the edge of the node. Was the method still well behaved? S. Appel said that the method assumed a uniform field from far away, and offered only a 1D solution. He said that 1D conductances could not be used as the perfect solution for a 2D temperature field. This method could only ever be an approximation, but in reality, that was all the thermal engineers were using anyway.

A. Robson (EADS-ASTRIUM) noted that the example model had shown node B having 2 far field edges and asked how the -Q value was split between the edges. S. Appel said that the -Q was the total heat for the two far field edges, and you could choose to split this valued however you wanted, using the ratio of the edge length for example. A. Robson said that you could also choose to use the distance between the far field edge and the interface between the nodes, but this would give a different conductance value.

3.10. An Excel Database for the generation of ESATAN and SYSTEMA Thermal Models

S. Barraclough (EADS-ASTRIUM) described a system for the automatic update of relevant ESATAN and SYSTEMA models based on spacecraft component location and orientation information held in an Excel spreadsheet. The use of this system had simplified the configuration of different study cases during the evolution of the AEOLUS satellite design. (See Appendix W)

H. Peabody (TMS) asked whether the orientation of surfaces with respect to the spacecraft was limited to the standard X, Yand Zor whether odd angles could be used. S. Barraclough said odd angles were permitted, the reaction wheels used a 45 degrees orientation, but were not used in general.

O. Pin (ESA/ESTEC) asked whether more than one engineer had been working on the model because multi-user access was difficult to handle in Excel. S. Barraclough said that there was the concept of one control engineer who had access to change the spreadsheet. They had experimented with having a master file which was then used to update slave copies, but this had proved too complicated. O. Pin noted that this implied manual configuration control, and said that if the system had been designed around a proper database then the configuration control could be automatic, with the export of specific model configurations to Excel.

M. Gorlani (Blue Group) noted that for the geometric mathematical model it was still necessary to input all of the data. Therefore he wanted to know where the system really helped to save time. S. Barraclough admitted that the user still needed to type in the geometrical data, but most of the time was saved in the automatic generation of the thermal mathematical model. It had previously taken several days to move a unit as it involved updating and checking all of the models by hand. The new system reduced this time to half a day.

4. Wednesday 22 October 2003: Afternoon Session

4.1. RadTherm

R. Habig (ThermoAnalytics) described a software system for calculating infra-red images and signatures of systems, and various additional packages for simulating air flow and heat transfer. (See Appendix X)

There were no questions.

4.2. Robust industrial model exchange between ESARAD and THERMICA with STEP-TAS

HP. de Koning (ESA/ESTEC) described the current status of the STEP-TAS/NRF protocol development, and the availability of TASverter from the ESA web site. He discussed possible ways forward in integrating the STEP interface into the different thermal tools. E. Lebegue (Graitec) provided additional viewgraphs showing the application of STEP in the French building industry. (See Appendix Y)

M. Jacquiau (EADS-ASTRIUM) asked what solution he should use in THERMICA to import and export STEP-TAS files: to extract modules from TASverter, or to use the C++ libraries. HP. de Koning said that it would be easiest to use TASverter. He said that it was ESA's intention to transfer the THERMICA part of TASverter to Astrium, and it would then be Astrium's responsibility to keep the interface up to date if changes were made to THERMICA. However, it was up to Astrium to decide whether to use the Python or the C++ libraries in the long term. HP. de Koning said that it would be necessary to re-implement the mapping from SYSBAS to STEP-TAS in order to migrate from the old to the new version of STEP-TAS.

O. Pin (ESA/ESTEC) suggested that HP. de Koning give details of the conversion of the Herschel and Planck models. HP. de Koning explained that TASverter had been tested against a very extensive test suite, and had also successfully provided full conversion of many industrial models, including the ISS, METOP and Herschel/Planck. It had therefore been stress-tested on very large models, and he was confident that the whole conversion chain was working correctly.

M. Molina (Carlo Gavazzi Space) asked whether there were any constraints on the ESARAD and THERMICA versions which were handled by TASverter. HP. de Koning said that the interface was with the ASCII SYSBAS file for THERMICA and the erg file for ESARAD.

C. Stroom (ESA/ESTEC) noted that HP. de Koning had given the long term objective of the STEP activities, and emphasized that the current priority was to define tools for the validation of STEP-TAS files. These would give a complete description of the STEP-TAS files, whether they were valid, and would help to characterize the files. These tools could then be used to validate STEP-TAS files, and any non-conformance could be checked back with the tool implementors in order to resolve conflicts when converting between tools. In this way it would be possible to resolve any discrepancies between vendor A and vendor B.

4.3. THER-CFD: a THERMICA/GAMBIT gateway

F. Boursier (EADS-SPACE) outlined the typical problems encountered during the thermal analysis of the combined Ariane and spacecraft configuration during the launch phase, taking into account air flow in the fairing, etc. He described the use of THERMICA and GAMBIT packages, and transferring information between them. (See Appendix Z)

C. Kirtley (ALSTOM) asked if the geometry was always updated in THERMICA, or whether it was a round trip process. He could see that in GAMBIT the engineer needed a detailed model, so what happened when the model was changed in THERMICA? F. Boursier said that the amount of information which needed to be exchanged varied on a case by case basis and the level of change required in the model.

HP. de Koning (ESA/ESTEC) noted that the VIF file only offered six digit accuracy for the numbers and wondered whether this gave rise to any problems with cumulative error.

F. Boursier said that he had not seen any. There were various criteria imposed on meshing, and therefore it was possible to tell whether the meshing was correct.

4.4. Highlights in thermal engineering at CGS: Thermal Stability in the frequency domain and THERMAL DESKTOP/ESARAD translation tools.

M. Molina (Carlo Gavazzi Space) covered the translation tools first because most of it had already been covered during previous presentations and discussions. He then described the current trend in spacecraft modelling, and the need to agree a whole new set of terminology to represent it. (See Appendix AA)

HP. de Koning (ESA/ESTEC) had a remark about data exchange when using STEP-TAS on THERMAL DESKTOP. He said that the import/export facility had been developed three years previously using the old version of the STEP-TAS libraries. The protocol had been updated since then, and therefore it would not be possible to use the current version of the THERMAL DESKTOP STEP interface with other tools using the new libraries. ESA would communicate details of the new protocol and libraries to the various tool vendors.

L. Weimer (EADS-ASTRIUM) said that the temperature flux could cause a small deformation of the optical bench and wanted to know whether the requirements related to the alignment or only to the temperature fluctuations. F. Lamela (EADS-CASA) said that the expansion coefficient for the optical bench was of the order of 10e-13.

A. Robson (EADS-ASTRIUM) had a question for ESA. He said that this frequency based thermal technology was completely new, and that most of the thermal engineers in industry were working with the old technology. Consequently each group was inventing its own technology and techniques for the new areas. He wanted to know whether ESA was planning on doing anything to harmonize such things. HP. de Koning said that it was clearly an important area, and that ESA had been thinking about it. However, he said that there was more to consider than just the area presented. There were new developments and requirements for satellites using cryogenic systems as well as the frequency based thermal systems. He suggested that it might be necessary to set up a working group to discuss the new technologies. M. Molina said that O. Pin (ESA/ESTEC) had suggested providing the background theory for frequency based thermal systems in a future document in the ECSS series.

V. Perotto (Alenia Spazio) asked whether any sensitivity analysis had been made of the results in the frequency domain. M. Molina said that there had only been a sensitivity analysis performed on the steady state solution, and not on the transient.

F. Lamela noted that there were various possibilities. One was to work in the time domain, but then the engineer did not usually know the sources of the variation. The power profile of the instrument was known. He suggested that in future, engineers should avoid the time domain and consider the thermal spectral density only. Working with heat inputs and sources for electronic units was easy, but working with the Sun was more of a problem. Every 3 minutes there was a solar flare. The LISA analysis had avoided MLI because of the sensitivity issues introduced.

M. Gorlani (Blue Group) asked what consideration had been given to the sensitivity related to the configuration of the linear model. F. Lamela said that the main architecture had been based on the optical bench, the thermal shield and another system. A three node model had been used to tune the parameters.

4.5. Designing for milli- and micro-kelvins

V. Perotto (Alenia Spazio) presented a series of questions and musings related to the new trends in satellite missions to work at or beyond the boundaries of the current analysis technology. (See Appendix AB)

M. Molina (Carlo Gavazzi Space) commented that of course Carlo Gavazzi Space needed to move from standard parameters or experiment with convergence criteria because they knew that they were working in a completely new domain. For SINDA they were not yet working at the kelvin stability level.

H. Peabody (TMS) suggested that rather than try to work directly on thermal solutions in milli- and micro-kelvin that the engineer could scale everything in order to work in the “normal” domain and so avoid number round-off and loss of precision. V. Perotto said that this had not been tried, the work had only been an exercise so far in order to see whether the solvers were capable of providing the required accuracy and precision in this temperature domain.

Y. Rubin (Open Engineering) said that it should be possible to estimate the inaccuracy of going from a natural to a 1D model. He said that it would be easy to check those cases which had a simple analytical relation. He suggested that other cases could be checked against results obtained from nature. V. Perotto argued that these other cases could only be verified by using test data, and that this would introduce other sources of inaccuracies. Y. Rubin concluded that this meant that it would never be possible to verify whether the requirements for milli- and micro-kelvin systems had been satisfied.

4.6. Conclusions and Workshop Close

C. Stroom (ESA/ESTEC) said that one of the goals of the workshop, expressed during the welcome and introduction, had been to improve the communications between the different players in the space thermal community. There had certainly been a lot of discussion about the harmonization activity as well as the general discussions. He said that he would try to let everyone know about what was happening via the e-mail list. He felt that the workshop had once again proved useful. He thanked all of the authors for sharing their experiences with the rest of the space thermal community.

Appendix A: Welcome and Introduction

Welcome and Introduction

C. Stroom
ESA/ESTEC

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
  - Free and open discussions.
- To present (new versions of) software tools and to solicit feedback for development

ESTEC
Thermal and Structures Division

ESA team

Charles Stroom	Head, Analysis & Verification Section
Harrie Rooijackers	Staff, co-organiser
Duncan Gibson	Software Support & Workshop Secretary

ESTEC
Thermal and Structures Division

Programme

- Two-day Programme
- Presentations include 5 minutes for questions and discussions.
- today - ESA Round-Table discussion (OSS and software) (Hans Peter de Koning).
- Cocktails today after round-table discussion in Space Expo
- Dinner (option) tonight in Noordwijk
- Conclusions tomorrow at end of Workshop

ESTEC
Thermal and Structures Division

Tuesday 21 October 2003 morning

9:00	Registration
10:00-10:10	Welcome and Introduction Charles Stroom (ESA/ESTEC, Netherlands)
10:10-10:35	ESATAN, FHTS & ThermXL current status Henri Brouquet (ALSTOM, United Kingdom)
10:35-11:00	THERMICA - news of the year Marc Jacquiau (EADS ASTRIUM, France)
11:00-11:25	ESARAD current status Henri Brouquet (ALSTOM, United Kingdom)
11:25-11:45	Coffee Break
11:45-12:10	Capabilities of the ThermPlot Pro Thermal Post-Processing Program Hume Peabody (Thermal Modeling Solutions, United States)
12:10-12:35	Overview of GAETAN's latest developments around ESATAN FHTS Marie Imhof (Silogic, France)
12:35-13:00	Web Support & Future Developments on ESATAN, FHTS, ESARAD & ThermXL Chris Kirtley, Henri Brouquet (ALSTOM, United Kingdom)
13:00-14:00	Lunch

ESTEC
Thermal and Structures Division

Tuesday 21 October 2003 afternoon

14:00-14:25	Harmonisation of thermal and space environment analysis software Reinhard Schlitt, OHB-System AG, Germany,Hans Peter de Koning (ESA/ESTEC, Netherlands)
14:25-14:50	Open Sourse Software for Engineering Purposes Mathias Haupt (University Braunschweig, Germany), Reinhard Schlitt, Frank Bodendieck (OHB-System AG, Germany)
14:50-15:15	Applicability of OSS to Space Thermal Engineering Reinhard Schlitt, Frank Bodendieck (OHB-System AG, Germany), Mathias Haupt (University Braunschweig, Germany)
15:15-15:35	Coffee break
15:35-16:00	Innovations in Using Finite Element Modelers for Spacecraft Thermal Design Ron Behee (Network Analysis, United States)
16:00-16:25	Application of the Open Source Approach to Space Environment Analysis Tools Holger Sdunnus (eta_max space, Germany)
16:25-17:30	Round Table Discussion, Hans Peter de Koning
17:30	Social Gathering is Space Expo
20:00	Dinner at the Thai Tjon, Albert Verweystraat 50, Noordwijk

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Thermal and Structures Division

Wedesday 22 October 2003 morning

9:00-9:25 Simulation of Furnace Inserts and Sample-Cartridge Assemblies Using the Thermal Modeling Tool CrysVUn
Marc Hainke, J. Dagner, J. Friedrich, G. Mueller (Fraunhofer, Germany)

9:25-9:50 Plant Growth Chamber Simulation using EcosimPro
Luis Ordonez Inda (ESA/ESTEC, Netherlands)

9:50-10:15 Thermal and fluid dynamic analysis of the air cooling/conditioning system on board of MDS (Mice Drawer System) facility
Giorgio Baldan, Antonella Sgambati (Laben, Italy)

10:15-10:40 Thermal Aspects of Long Term Operations on a Comet Surface
Hans Peter Schmidt (DLR, Germany)

10:40-10:55 Coffee break

10:55-11:20 HDF5 and STEP/NRF database for SINDA/G
Ron Behee (Network Analysis, United States)

11:20-11:45 GOCE - Thermo-Elastic Distortion Analysis
Lars Weimer (ASTRIUM GmbH, Germany)

11:45-12:10 Methodology for Thermal Models Archiving
Félix Lamela (EADS CASA, Spain)

12:10-12:35 The far field method for 1-D conductor computation
Simon Appel (ESA/ESTEC, Netherlands)

12:35-13:00 An Excel Database for the generation of ESATAN and Systema Thermal Models
Simon Barraclough (Astrium Ltd., United Kingdom)

13:00-14:00 Lunch

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Wedesday 22 October 2003 afternoon

14:00-14:25 Preliminary title: RadTherm
Ralf Habig (ThermoAnalytics, Germany)

14:25-14:50 Robust industrial model exchange between ESARAD and THERMICA with STEP-TAS
Hans Peter de Koning (ESA/ESTEC, Netherlands)

14:50-15:15 THER-CFD : a THERMICA/GAMBIT gateway
Frédéric Boursier (EADS SPACE, France)

15:15-15:40 Highlights in thermal engineering at CGS: Thermal Stability in the frequency domain and THERMAL DESKTOP/ESARAD translation tools
Marco Molina, Christian Vettore (Carlo Gavazzi Space, Italy)

15:40 Conclusions and closure

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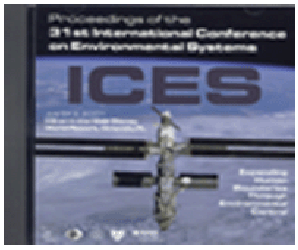

ICES 2004

- The 34th International Conference on Environmental Systems will be held 19-22 July, 2004, Colorado Springs, USA,
- Deadline for submitting abstracts: Friday 7 November, 2003
- abstracts may be submitted online at http://www.sae.org/calendar/ice/cfp.htm (preferred)
- or sent to: Olivier Pin, email olivier.pin@esa.int
- Abstracts must include paper title, author(s) name(s), mailing and e-mail addresses, phone and fax numbers.

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Practical Information

- Presenters: please leave your presentation (floppy or CD-ROM with PowerPoint file) with Duncan Gibson, Harrie Rooijackers or Charles Stroom before the end of Workshop. Please leave also a paper copy to avoid problems with embedded fonts/logo’s or Mac.
- No copyrights, please!
- Workshop Minutes will be supplied to participants, in hard copy and on the Web.

Practical Information

- Lunch: 13:00 - 14:00. The “Foyer” tables are reserved for us
- Cocktail today at 17:30 in Space Expo
- Check your details on the list of participants and inform the Conference Bureau of any modifications. Leave your email address!

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Dinner (tbc)

- "Dutch" dinner == to be paid by yourself :-(
- in "de Thai Tjon", Albert Verweystraat 50, Noordwijk a/Z, tel +31-71-364-8888
- fixed menu per table with options for 32 euro p.p., excl drinks
  - Menu is kind of table buffet
  - bill will be calculated per table (including drinks) and shared equally
- Restaurant booked today for 20:00. Please arrange your own transport
- If you would like to join, then you would have to complete the last sheet of hand-out and return it to one of the organisers (Harrie or Charles)
- ultimate time today: 14:00, to let the restaurant know.

esa

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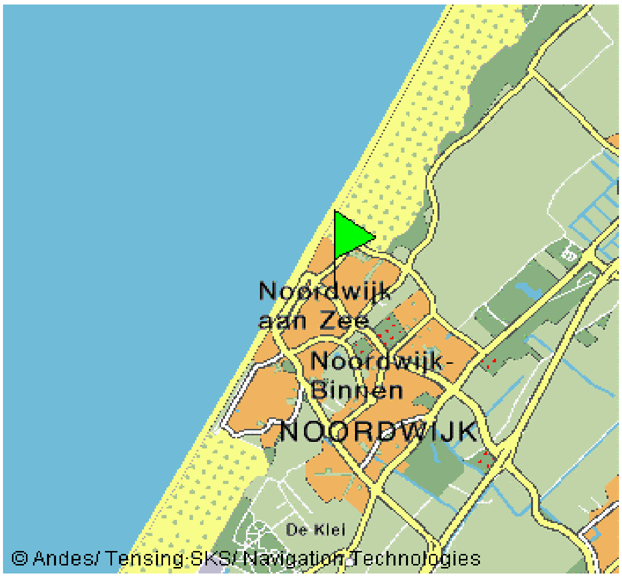
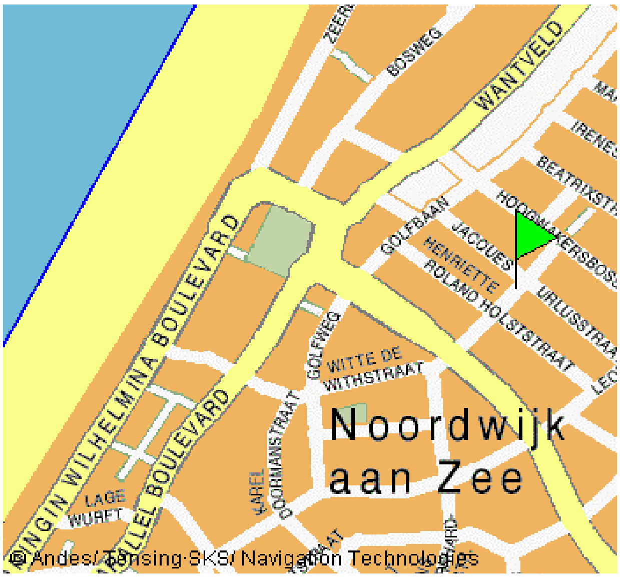
Restaurant "de Thai Tjon"





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Menu

(€ 32.00 p.p. exc. drinks.)

A selection of six different starters

xxxx

Beef dishes
Duck dishes
Chicken dishes
Tenderloin of pork dishes
Fish dishes

Served with steamed rice, fried rice and fried noodles.

Xxxx

Bavarian
xxxx

Coffee or Tea.

Appendix B: ESATAN, FHTS & ThermXL current status

ESATAN, FHTS
& ThermXL

Current Status

H. Brouquet
ALSTOM

Oct 2003

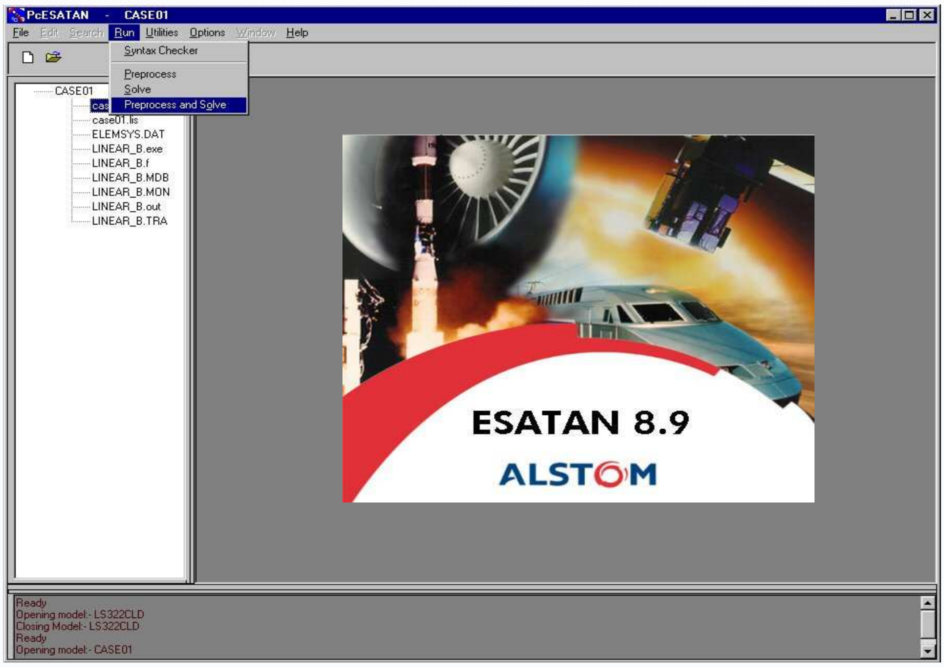
ESATAN v8.9

Henri Brouquet

ALSTOM

ESATAN v8.9

ALSTOM



- State in the Field -

ESATAN v8.9

- ESATAN v8.9
  - Released in June 2003
  - Now available on Linux
- Outstanding issues in v8.7
  - Apostrophe sign [’] in comments not supported
  - To comment the **`$INCLUDE (# $INCLUDE)`**
  - Subroutine in **`$EXTERNAL`** model not recognised
  - Reserved names not properly tested by ESATAN
  - Missing substitution data in predefined elements not tested

$\Rightarrow$ **All have been solved in ESATAN v8.9**

ESATAN v8.9 - New Developments

- Pre-Processor Improvements

Pre-Processor Improvements

ALSTOM

- Improvements on processing data
  - very large models
  - large number of conductors

- Examples from test suite & user models
  - 40,000 nodes / 100,000 GLs - **8 times faster**
  - 2,800 nodes / 5,500 GLs / 310,000 GRs - **6 times faster**

- Pre-Processor recommanded against Syntax Checker -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation

- Continuing Commitment to Development -

SOLVFM Optimisation

ALSTOM

- Improved band-width optimisation
- Improved algorithm
- Improved energy balance control
- 'Unconnected Node' support
- Near linear scalability

- SOLVFM Recommended Steady-State Solver -

New Thermal Solver SLCRNC

ALSTOM

- Performs transient thermal analysis using Crank-Nicholson method
- Unique Temperature Rate of Change criterion DTROCA used for determining the maximum time step length to be used during a transient
- Arithmetic node optimisation with new control constant ARITH

- Transient Solution -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat Balance Convergence Criteria

- Continuing Commitment to Development -

Heat Balance Convergence

ALSTOM

- Convergence can now be defined in terms of energy balance
  - INBALA (absolute nodal energy balance) vs ENBALA
  - INBALR (relative nodal energy balance) vs ENBALR
- Supported in steady state thermal solvers SOLVIT & SOLVFM

- Increased Analysis Control -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format

- Continuing Commitment to Development -

PRNCSV Subroutine

ALSTOM

- New user-callable subroutine for outputting to Comma Separated Value

```
PRNCSV(ZLABEL,ZENTS,CNAME,ORDER,FILE)
```

- Output any nodal entities and conductors

```
PRNCSV (' ', 'T', CURRENT, 'NODE', 'temperature.csv')
```

- Plotting, Archiving, Database Import, etc. -

PRNCSV Subroutine

ALSTOM

```
$MODEL H_SECTION
#
   $MODEL BAR1, NOLIST
      $EXTERNAL NON_LINEAR_BAR
   $ENDMODEL BAR1
#
   $MODEL BAR2
      $REPEAT BAR1
   $ENDMODEL BAR2
#
$NODES
#
D100, T = 20.0, C = Density * Volume * INTRP1(T100, SpecificHeat, 1);
#
$CONDUCTORS
#
GL(100, BAR1:3) = U;      # Set in VARIABLES1
GL(100, BAR2:3) = U;
#
$CONSTANTS
$REAL
#
CrossSectionalArea = 0.025 * 0.025;
Density = 2.565E03;
Volume = 0.04 * 0.025 * 0.025;
DeltaY1 = 0.02;
DeltaY2 = 0.0125;
#
$CONTROL
#
TIMEND = 500.0;
OUTINT = 10.0;
DTIMEI = 1.0;
RELXCA = 0.01;
NLOOP = 100;
#
$ARRAYS
$REAL
#
Conductivity(2, 4) = -73.33, 200.0,   37.78, 356.3,
                      93.33, 580.0,  148.89, 845.0;
#
SpecificHeat(2, 4) = -73.33, 1.3E03,  37.78, 1.7E03,
                      93.33, 2.1E03, 148.89, 2.8E03;
#
$VARIABLES1
#
      QI:BAR2:1 = 0.0
      GR:BAR2:(1, 10, 2) = 0.0035
#
      GL(100, BAR1:3) = 1 /
     & (DeltaY1 / (CrossSectionalArea * INTRP1(T100, Conductivity, 1)) +
     &  DeltaY2 / (CrossSectionalArea * INTRP1(T:BAR1:3, BAR1:Conductivity, 1)))
#
      GL(100, BAR2:3) = 1 /
     & (DeltaY1 / (CrossSectionalArea * INTRP1(T100, Conductivity, 1)) +
     &  DeltaY2 / (CrossSectionalArea * INTRP1(T:BAR2:3, BAR2:Conductivity, 1)))
#
$EXECUTION
#
      CALL SLFWBK
#
$OUTPUTS
#
      CALL PRNCSV(' ', 'T', CURRENT, 'NODE', 'temp11.csv')
      CALL PRNCSV(' ', 'L, T', CURRENT, 'ENTITY', 'temp22.csv')
#
$ENDMODEL H_SECTION
```


```
$OUTPUTS
#
      CALL PRNCSV(' ', 'T', CURRENT, 'NODE', 'temp11.csv')
      CALL PRNCSV(' ', 'L, T', CURRENT, 'ENTITY', 'temp22.csv')
#
$ENDMODEL H_SECTION
```

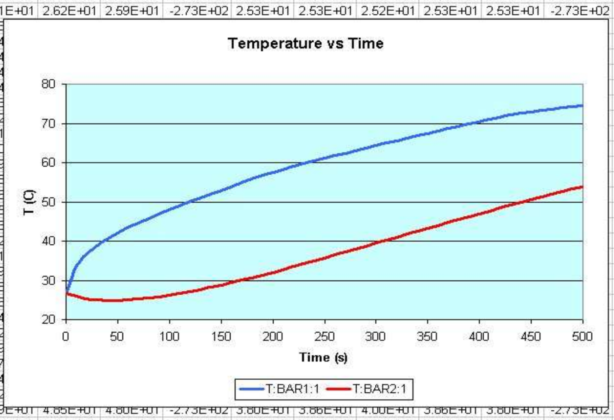

- Plotting, Archiving, Database Import, etc. -

PRNCSV Subroutine

ALSTOM

ESATAN v8.9.2; MODEL H_SECTION; TIME 16 OCTOBER 2003 15:43:03

TIME	T100	T:BAR1:1	T:BAR1:2	T:BAR1:3	T:BAR1:4	T:BAR1:5	T:BAR1:10	T:BAR2:1	T:BAR2:2	T:BAR2:3	T:BAR2:4	T:BAR2:5	T:BAR2:10
0	2.00E+01	2.67E+01	2.67E+01	2.67E+01	2.67E+01	2.67E+01	-2.73E+02	2.67E+01	2.67E+01	2.67E+01	2.67E+01	2.67E+01	-2.73E+02
10	2.38E+01	3.37E+01	2.86E+01	2.59E+01	2.60E+01	2.60E+01	-2.73E+02	2.59E+01	2.58E+01	2.52E+01	2.58E+01	2.60E+01	-2.73E+02
20	2.53E+01	3.66E+01	3.09E+01	2.71E+01	2.62E+01	2.59E+01	-2.73E+02	2.53E+01	2.53E+01	2.52E+01	2.53E+01	2.53E+01	-2.73E+02
30	2.61E+01	3.88E+01	3.27E+01	2.83									
40	2.69E+01	4.06E+01	3.43E+01	2.94									
50	2.75E+01	4.21E+01	3.57E+01	3.04									
60	2.82E+01	4.34E+01	3.69E+01	3.14									
70	2.88E+01	4.46E+01	3.81E+01	3.24									
80	2.95E+01	4.58E+01	3.92E+01	3.33									
90	3.02E+01	4.69E+01	4.02E+01	3.42									
100	3.08E+01	4.80E+01	4.12E+01	3.51									
110	3.15E+01	4.90E+01	4.22E+01	3.60									
120	3.22E+01	5.00E+01	4.32E+01	3.69									
130	3.30E+01	5.10E+01	4.41E+01	3.78									
140	3.37E+01	5.20E+01	4.50E+01	3.88									
150	3.44E+01	5.29E+01	4.59E+01	3.95									
160	3.52E+01	5.39E+01	4.69E+01	4.03									
170	3.60E+01	5.49E+01	4.78E+01	4.12									
180	3.67E+01	5.58E+01	4.87E+01	4.21									
190	3.75E+01	5.67E+01	4.96E+01	4.29									
200	3.83E+01	5.75E+01	5.04E+01	4.38									
210	3.91E+01	5.83E+01	5.12E+01	4.46									
220	3.99E+01	5.90E+01	5.20E+01	4.54									
230	4.07E+01	5.97E+01	5.27E+01	4.62									
240	4.14E+01	6.04E+01	5.35E+01	4.69									
250	4.22E+01	6.11E+01	5.42E+01	4.77									
260	4.30E+01	6.17E+01	5.49E+01	4.84									
270	4.37E+01	6.24E+01	5.56E+01	4.92									
280	4.45E+01	6.31E+01	5.63E+01	4.99E+01	4.85E+01	4.80E+01	-2.73E+02	3.80E+01	3.86E+01	4.00E+01	3.86E+01	3.80E+01	-2.73E+02
290	4.52E+01	6.37E+01	5.70E+01	5.06E+01	4.93E+01	4.87E+01	-2.73E+02	3.87E+01	3.93E+01	4.08E+01	3.94E+01	3.88E+01	-2.73E+02
300	4.60E+01	6.43E+01	5.76E+01	5.13E+01	5.00E+01	4.94E+01	-2.73E+02	3.95E+01	4.01E+01	4.16E+01	4.01E+01	3.96E+01	-2.73E+02
430	5.51E+01	7.21E+01	6.59E+01	6.01E+01	5.88E+01	5.83E+01	-2.73E+02	4.91E+01	4.97E+01	5.11E+01	4.97E+01	4.92E+01	-2.73E+02
440	5.58E+01	7.25E+01	6.64E+01	6.07E+01	5.95E+01	5.90E+01	-2.73E+02	4.98E+01	5.04E+01	5.17E+01	5.04E+01	4.99E+01	-2.73E+02
450	5.65E+01	7.29E+01	6.70E+01	6.13E+01	6.01E+01	5.96E+01	-2.73E+02	5.05E+01	5.11E+01	5.24E+01	5.11E+01	5.06E+01	-2.73E+02
460	5.71E+01	7.33E+01	6.74E+01	6.19E+01	6.07E+01	6.02E+01	-2.73E+02	5.12E+01	5.18E+01	5.31E+01	5.18E+01	5.13E+01	-2.73E+02
470	5.77E+01	7.37E+01	6.79E+01	6.24E+01	6.13E+01	6.08E+01	-2.73E+02	5.19E+01	5.25E+01	5.38E+01	5.25E+01	5.20E+01	-2.73E+02
480	5.83E+01	7.40E+01	6.83E+01	6.29E+01	6.18E+01	6.14E+01	-2.73E+02	5.26E+01	5.31E+01	5.44E+01	5.32E+01	5.26E+01	-2.73E+02
490	5.89E+01	7.43E+01	6.87E+01	6.34E+01	6.23E+01	6.19E+01	-2.73E+02	5.32E+01	5.38E+01	5.51E+01	5.38E+01	5.33E+01	-2.73E+02
500	5.95E+01	7.46E+01	6.91E+01	6.39E+01	6.29E+01	6.24E+01	-2.73E+02	5.39E+01	5.44E+01	5.57E+01	5.45E+01	5.40E+01	-2.73E+02



- Plotting, Archiving, Database Import, etc. -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format
- Model Name & Node functions

- Continuing Commitment to Development -

Model Name & Node Functions

ALSTOM

- *SUBMOD (ATTRIB)*
  returns model name of current model

```
$INITIAL
#
      CHARACTER * 20 SUBM
#
# to return 'MAIN:SUB1:SUB2'
#
      SUBM = SUBMOD('ALL')
#
# to return 'MAIN:SUB1'
#
      SUBM = SUBMOD('ROOT')
#
# to return 'SUB2'
#
      SUBM = SUBMOD('SUBMODEL')
#
```

- *SUBMDN (NODE, ATTRIB)*
  returns model name given the
  internal node number NODE

```
$VARIABLES2
#
      CHARACTER *20 SUBM
#
# to return 'MAIN:SUB1:SUB2'
#
      SUBM = SUBMDN(NCSGMN, 'ALL')
#
# to return 'MAIN:SUB1'
#
      SUBM = SUBMDN(NCSGMN, 'ROOT')
#
# to return 'SUB2'
#
      SUBM = SUBMDN(NCSGMN, 'SUBMODEL')
#
```

- Increased Modelling Flexibility -

Model Name & Node Functions

ALSTOM

- *NODNUM (NODE)*
  returns the user node number given the internal node number NODE

```
$VARIABLES2
#
      INTEGER UNODE
#
# returns the user node number where
# CSG is minimal
#
      UNODE = NODNUM(NCSGMN)
#
```

- *INTNOD (CNAME, NODE)*
  returns internal node number given user node number NODE in model CNAME

```
$VARIABLES2
#
      INTEGER INODE
#
# returns the internal node number of D100
# in CURRENT model
#
      INODE = INTNOD(CURRENT, 100)
#
# returns the internal node number of D10
# in MAIN:SUB1:SUB2 submodel
#
      INODE = INTNOD(MAIN:SUB1:SUB2, 10)
#
```

- Increased Modelling Flexibility -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format
- Model Name & Node functions
- Zero Flow Solution

- Continuing Commitment to Development -

FHTS Zero Flow Solution

ALSTOM

- Handling analytically mass-flow links with zero flow rate
- Solution formulation adapted to treat low pressure drop case
  - ΔP < MINDP : default to 1.0E-03 Pa
  - All fluid solvers address MINDP

⇒ Overcomes problem of modelling closed branches

- Increased Modelling Flexibility -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format
- Model Name & Node functions
- Zero Flow Solution
- Progress Monitoring File

- Continuing Commitment to Development -

Progress Monitoring File

ALSTOM

- A progress file is automatically created containing current state of the analysis
  - modelname.MON
  - frequency of output is controlled by PRGFBK (default 10)
- File produced in Comma Separated Value
  - easy to import to programs such as Excel
- Data available Real time, SOLVER, TIMEN, TIMEN/TIMEND %, DTIMEU, STEPCT, LOOPCT and RELXCC
  - extra data available for FHTS model (such as RELXMC…)

- Increased Modelling Flexibility -

Progress Monitoring File

ALSTOM

Realtime	SOLVER	TIMEN	%	DTIMEU	STEPCT	LOOPCT	RELXCC
08:39:45	SOLVFM	0.00E+00	0	0.00E+00	0	10	50
08:39:45	SLFWBK	20	20	2	10	2	7.52E-12
08:39:45	SLFWBK	40	40	2	20	2	7.52E-12
08:39:45	SLFWBK	60	60	2	30	2	7.23E-12
08:39:45	SLFWBK	80	80	2	40	2	7.23E-12
08:39:45	SLFWBK	100	100	2	50	2	6.80E-12

- PROGHD and PROGRS new user-callable subroutines to print out extra data
  - PROGHD(UNIT) writes out column header
  - PROGRS(UNIT) writes out one line of data for each call

```
$INITIAL
#
      OPEN(UNIT=21, FILE='feedback.cvs')
#
      CALL PROGHD(21)
#
$VARIABLES1
#
      WRITE(21, *) Variable
#
$VARIABLES2
#
      CALL PROGRS(21)
#
```

- Increased Modelling Flexibility -

ESATAN v8.9 - New Developments

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format
- Model Name & Node functions
- Zero Flow Solution
- Progress Monitoring File
- Further Developments

- Continuing Commitment to Development -

Further Developments

ALSTOM

- Control Constant DTMAX is now used in conjunction with DTMIN throughout all transient solvers

- User Constants can now be defined with MORTRAN/ other User Constants in $CONSTANTS block
  - changes in the value of the first one will propagate to the second one

- Increased Modelling Flexibility -

ESATAN v8.9 - Summary

ALSTOM

- Pre-Processor Improvements
- Thermal Solver Optimisation
- Heat balance convergence
- Comma Separated Value format
- Model Name & Node functions
- Zero Flow Solution
- Progress Monitoring File
- Further Developments

- Conclusion -

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www.techcentreuk.power.alstom.com

Appendix C: THERMICA - news of the year

THERMICA

news of the year

M. Jacquiau
EADS-ASTRIUM

THERMICA – News of the year

ESTEC Thermal/ECLS Workshop 2003

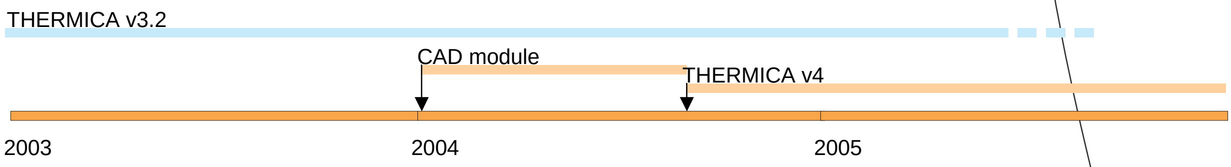
✍ engineering.software@astrium.eads.net

Content

- Schedule v3 / v4 updated
- Delivery of new « summer release » 3.2.19
- Capabilities in v3.2 not well known, but useful !
- What will follow quickly in v3.2 (still ready)
- Position of Thermica in the harmonization of thermal SW
- Financement - commercialization of Thermica

Development schedule

- Review of ASTRIUM internal users (in 2003)
  - For users, FULL PRIORITY has to be assigned for the import of **<u>CAD geometry</u>** → big change
  - The development schedule is therefore updated



  - Version 3 will continue for at least 1 year
  - CAD module available in january in Astrium
    - » Quick delivery to external users
  - Version 4 will arrive ASAP, in 2004
    - » Whole thermal application in the SYSTEMA framework

CAD module to come in january

- Import of STEP AP203 files / Catia v4 files (v5 available later)
- Export of SYSTEMA/THERMICA geometrical files

- Capabilities to define Thermica shapes with picks of points in the CAD geometry
- Organization of data in a hierarchised tree like Thermica does

- Compatible with Thermica v3

- Technical solutions : whole framework in C++, and OSS libs
  OpenCascade : data structure & memory management
  VTK : display & pre-post processing
  FLTK : graphical user interface

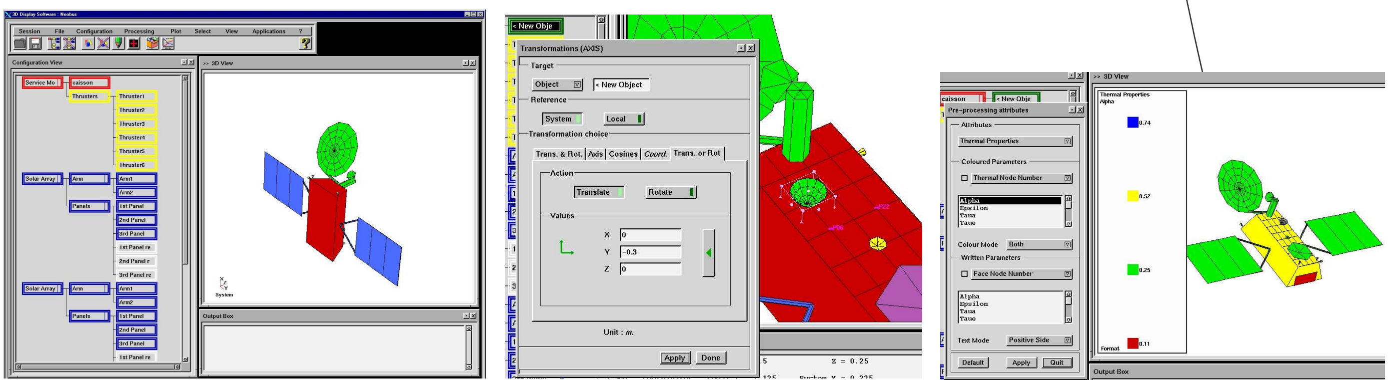
- This module will be the model builder of version 4

New release 3.2.19 (available since 08/2003)

- Globally : « same software » as the previous release …
  - Geometry import/export
  - Full user-friendly mission (orbit, pointing) with a lot of pre-defined capabilities
  - Thermal application (radiative, conductive) with user-friendly menus
  - Pre-processing – Post-processing (2D,3D,…)
- … But **new extended capabilities :**
  - T3D as an interactive model builder
  - Variable planetary fluxes (longitude, latitude, time)
  - Angle-dependant thermo-optical properties
- Full documentation available in **PDF** format

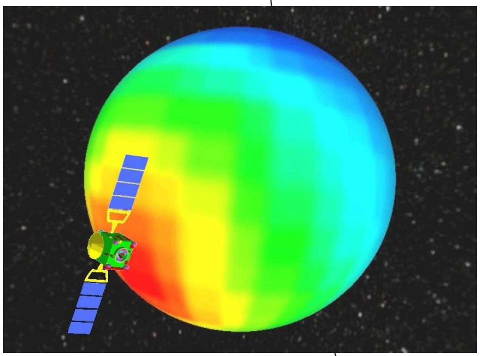
Extended capabilities in 3.2.19 : T3D model builder

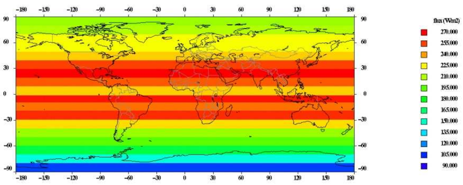
- First designed for an internal usage in Astrium, T3D is now fully available as a model builder
  - » High interactivity with mouse / keyboard
  - » High interactivity for the definition / modification / motion of shapes and objects
  - » Nice visualization of properties / results on the geometry
  - » Compatibility with the Sysbas language

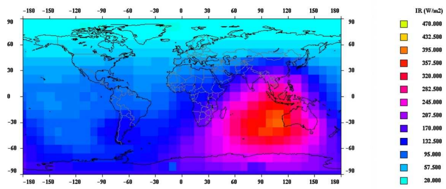


Extended capabilities in 3.2.19 : Planetary fluxes

- Planetary IR & albedo now latitude/longitude/time dependent
  - Useful for scientific missions
  - Also useful for the Earth if accuracy is needed
- Extension of the previous algorithm
  - For each orbital position, the planet has a non-uniform emission
  - The global flux level is integrated from all possible solid angles around the spacecraft

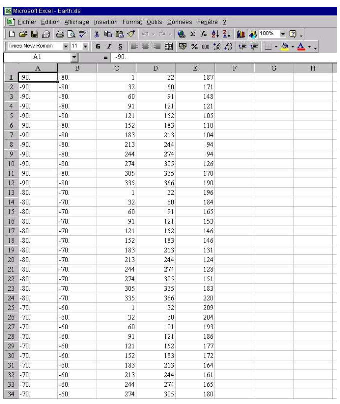






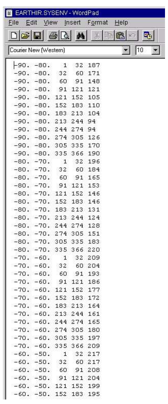
Extended capabilities in 3.2.19 : Planetary fluxes

- Easy input data for the user : use of a simple structured text file, eventually provided by any spreadsheet



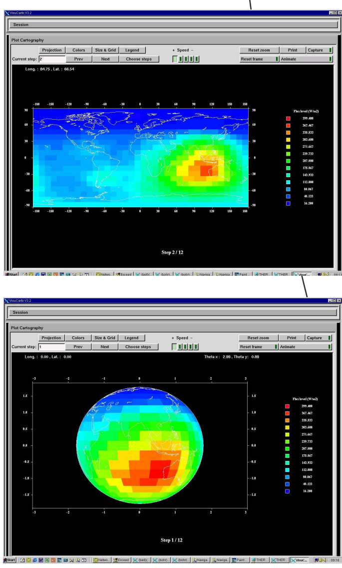
	A	B	C	D	E
1	-90.	-80.	1	32	187
2	-90.	-80.	32	60	171
3	-90.	-80.	60	91	148
4	-90.	-80.	91	121	121
5	-90.	-80.	121	152	105
6	-90.	-80.	152	183	110
7	-90.	-80.	183	213	104
8	-90.	-80.	213	244	94
9	-90.	-80.	244	274	94
10	-90.	-80.	274	305	126
11	-90.	-80.	305	335	170
12	-90.	-80.	335	366	190
13	-80.	-70.	1	32	196
14	-80.	-70.	32	60	184
15	-80.	-70.	60	91	165
16	-80.	-70.	91	121	153
17	-80.	-70.	121	152	146
18	-80.	-70.	152	183	146
19	-80.	-70.	183	213	131
20	-80.	-70.	213	244	124
21	-80.	-70.	244	274	128
22	-80.	-70.	274	305	151
23	-80.	-70.	305	335	183
24	-80.	-70.	335	366	220
25	-70.	-60.	1	32	209
26	-70.	-60.	32	60	204
27	-70.	-60.	60	91	193
28	-70.	-60.	91	121	186
29	-70.	-60.	121	152	177
30	-70.	-60.	152	183	172
31	-70.	-60.	183	213	164
32	-70.	-60.	213	244	161
33	-70.	-60.	244	274	165
34	-70.	-60.	274	305	180

Spreadsheet table



```
-90. -80.   1  32 187
-90. -80.  32  60 171
-90. -80.  60  91 148
-90. -80.  91 121 121
-90. -80. 121 152 105
-90. -80. 152 183 110
-90. -80. 183 213 104
-90. -80. 213 244 94
-90. -80. 244 274 94
-90. -80. 274 305 126
-90. -80. 305 335 170
-90. -80. 335 366 190
-80. -70.   1  32 196
-80. -70.  32  60 184
-80. -70.  60  91 165
-80. -70.  91 121 153
-80. -70. 121 152 146
-80. -70. 152 183 146
-80. -70. 183 213 131
-80. -70. 213 244 124
-80. -70. 244 274 128
-80. -70. 274 305 151
-80. -70. 305 335 183
-80. -70. 335 366 220
-70. -60.   1  32 209
-70. -60.  32  60 204
-70. -60.  60  91 193
-70. -60.  91 121 186
-70. -60. 121 152 177
-70. -60. 152 183 172
-70. -60. 183 213 164
-70. -60. 213 244 161
-70. -60. 244 274 165
-70. -60. 274 305 180
-70. -60. 305 335 197
-70. -60. 335 366 209
-60. -50.   1  32 217
-60. -50.  32  60 217
-60. -50.  60  91 208
-60. -50.  91 121 204
-60. -50. 121 152 199
-60. -50. 152 183 195
```

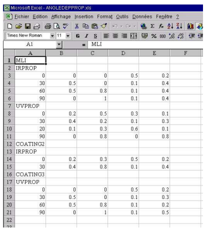
Text file



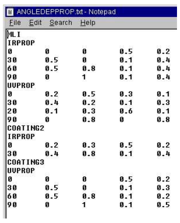
Visualization in Thermica

Extended capabilities in 3.2.19 : Angle-dependant thermo-optical properties

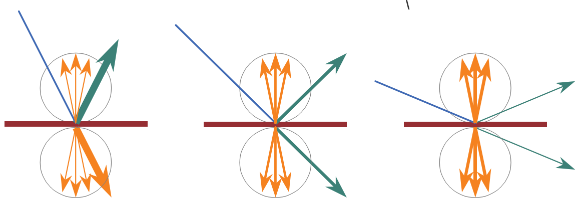
- All coatings defined in the material database of Thermica can now have angle-dependant thermo-optical properties
- No change to do in the material database : use of an external text file (can come from any spreadsheet)
- Angle-dep. Properties : α, ε, ρ_a, ρ_e, τ_a, τ_e
- Ray Tracing algorithms have been extended
- Available for both REF and Fluxes calculations



Spreadsheet table

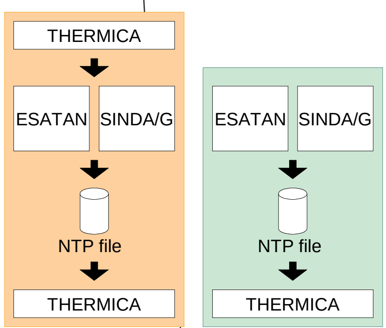


Text file

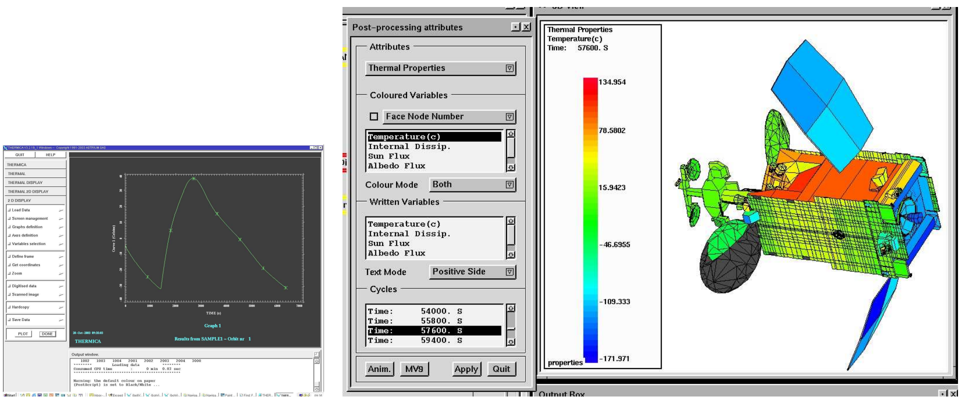


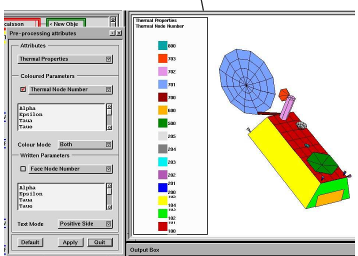
Ray tracing in Thermica

Capabilities that people usually don't know



- Display of temperatures after ESATAN or SINDA/G
  - Thanks to binary output file format NTP
  - 2D plots, 3D on the geometry (animated)

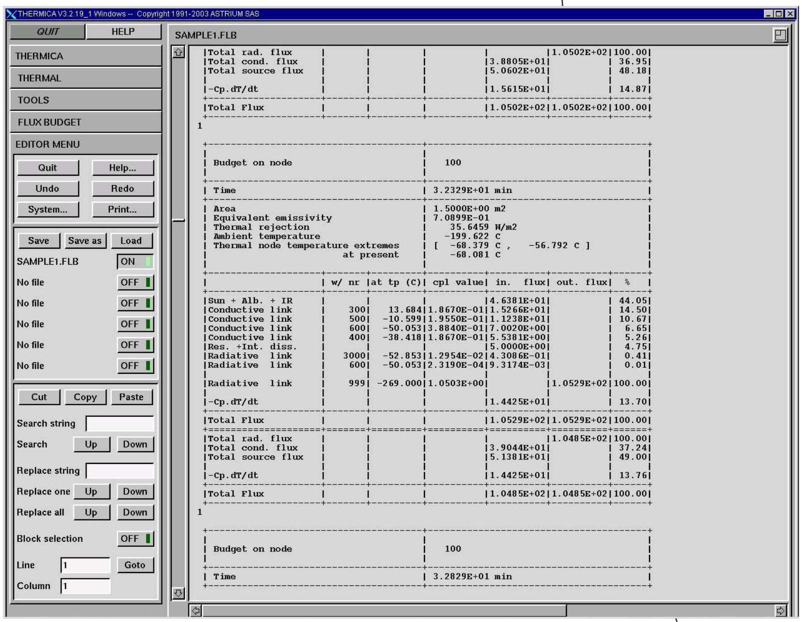




  - Available even if the ESATAN / SINDA/G process is executed outside the Thermica front-end
    - » We provide (freely) the subroutine (and support) for the output of NTP

Capabilities that people usually don't know

- Flux budget from the NTP file
  - Analysis of fluxes, sorted by importance, incoming/outcoming, radiative/conductive/…
  - Ambient temperature, thermal rejection, min/max
  - For each time step or global mean



- File conversion : NTP ↔ ASCII
  - For cross-platforms exchanges
  - For immediate import in Excel (nicely structured)

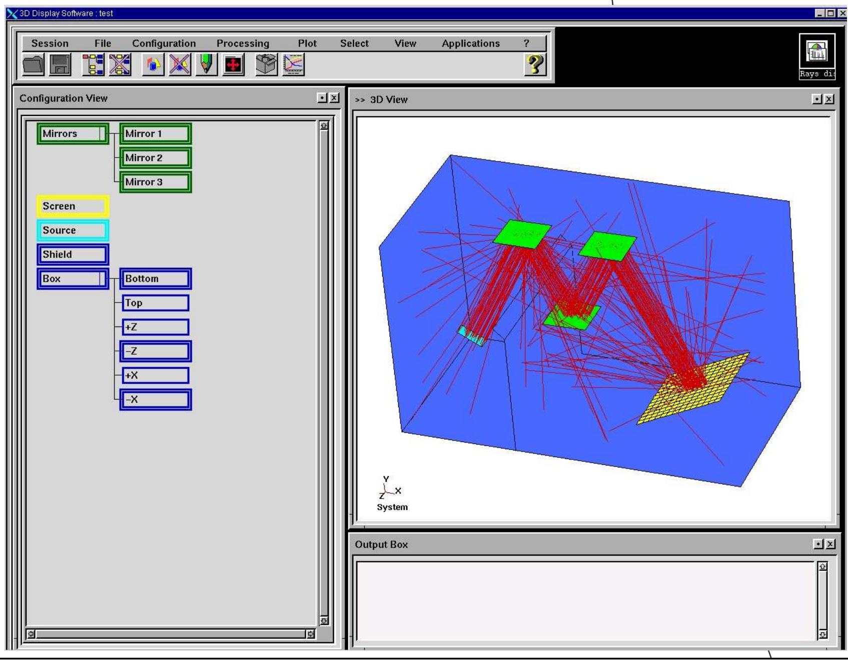
What will follow quickly in v3.2 (still ready)

- Enhanced link between Thermica and other applications of SYSTEMA
  - <u>POWER</u> : Flux & REFs are transferred into an electrical network for the design of **spacecraft electrical architecture** (still available)
  - <u>OUTGASSING</u> : **Outgassing of materials** depends on their temperature
  - <u>PERTURBATIONS</u> : A new module has been developped (in addition to others : solar/earth rad. pressure, gravity gradient, air drag, J2 effects, …), for **thermal radiation forces & torques**
    - » Each surface of a spacecraft has its own radiative emission : a force which amplitude is $\varepsilon\sigma ST^4$
    - » For specific spacecraft missions, this physical phenomena needs to be simulated
    - » The modelisation is entirely performed by Ray Tracing, with transfer of force/torque for each interaction between rays and surfaces

What will follow quickly in v3.2 (still ready)

- Display of rays for THERMICA and other applications in SYSTEMA based on Ray Tracing

  (Selection of nodes)



Useful :

- to debug complex configurations
- to find rays escaping from enclosures
- to compare analytical / facetised geometries, especially with specularity
- to have a better feeling of the physical phenomena

Thermica and Harmonization on thermal software

- Requirement from Astrium users / Astrium thermal SW team in terms of harmonization :
  - Definition of standards for data exchanges
  - Definition of functionalities to be provided by any SW for a given issue

  → *No more need to impose any specific software on space projects*

- Industrials are mature enough to decide by themselves their processes in terms of SW tools
  - In each space project, no more need to provide file format X for the official deliveries
    - » <u>The official format should always be STEP-TAS or STEP-SPE</u>

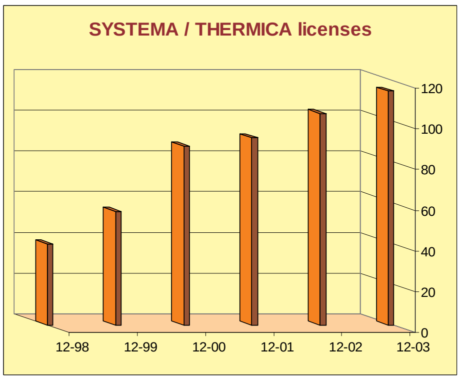
Thermica and Harmonization on thermal software

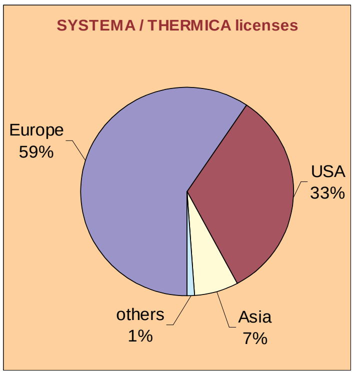
- As developer / provider of Thermica, Astrium wants to play a positive role in the standardization of data exchange
  - We want to integrate the updated STEP-TAS libraries as soon as possible
  - We want to enhance the information stored in STEP-TAS files : orbit / kinematics / results (NRF)
  - Usage of HDF files is really necessary for results
  - Great interest : worldwide user community
- Usage of TASverter or pure C++ STEP-TAS libraries
  - Short term : maybe TASverter could be sufficient
  - For extended usage, and for V4 : C++ libraries will probably be preferred

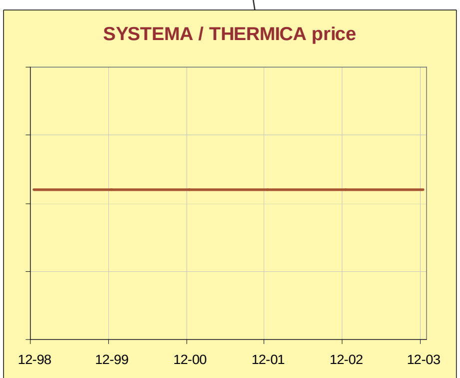
Financement of THERMICA

Thermica is financed by two main incoming « fluxes » :

- 1) Astrium internal financement : Astrium wants to invest to have thermal SW developped internally
- 2) External users : worldwide diffusion, still growing (→ but *the price never grows* !)
  → Professional structure for development / commercialization / maintenance / user support
- No objective to make profit with software but to have efficient tools developped by experts close to thermal engineers, with fast interactivity







→ Great success for european algorithms designed by **ESA / Matra** in the 80s :

a worldwide reputation for this european expertise

THERMICA – News of the year

ESTEC Thermal/ECLS Workshop 2003

✍ engineering.software@astrium.eads.net

Appendix D: ESARAD current status

ESARAD

current status

B. Castelli
ALSTOM

Oct 2003

ESARAD v5.4

Bruno CASTELLI

ALSTOM

ESARAD v5.4

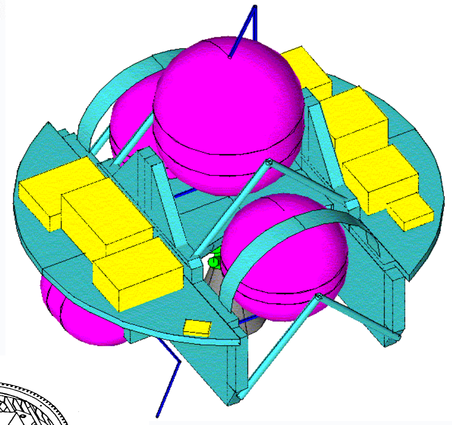
ALSTOM

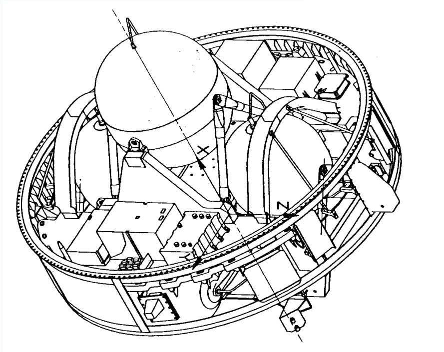
- ESARAD v5.4 released in June 2003
- Previous version released: v5.1
- Version 5.2 was used for developments
- New numbering convention:
  - odd second digit: for developments (5.3)
  - even second digit for commercial releases (5.4)

ESARAD v5.4

ALSTOM

- List of new features
  - New Combine Shell
  - Recursive Attribute Editing
  - Spacecraft Orientation
  - Simplified Kernel Language
  - ACG
  - New Custom Menu
  - NASTRAN Converter
  - New HDF Data Format





- Short demo if time permitting

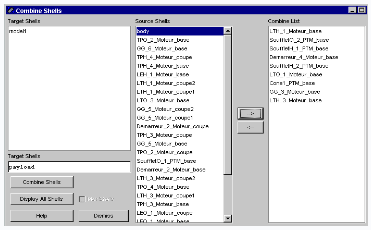
- Objectives -

ESARAD v5.4

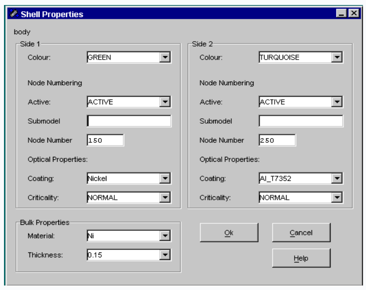
ALSTOM

Geometry - New features

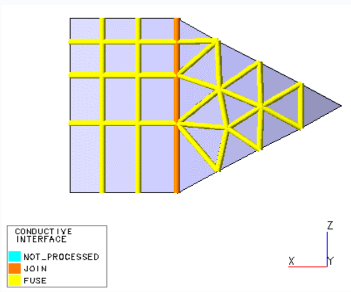
- New Combine Shell Dialog



- Recursive Attribute Editing



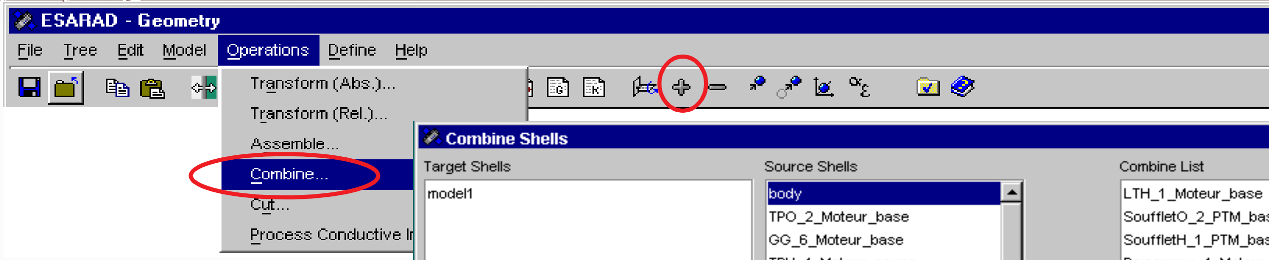
- ACG

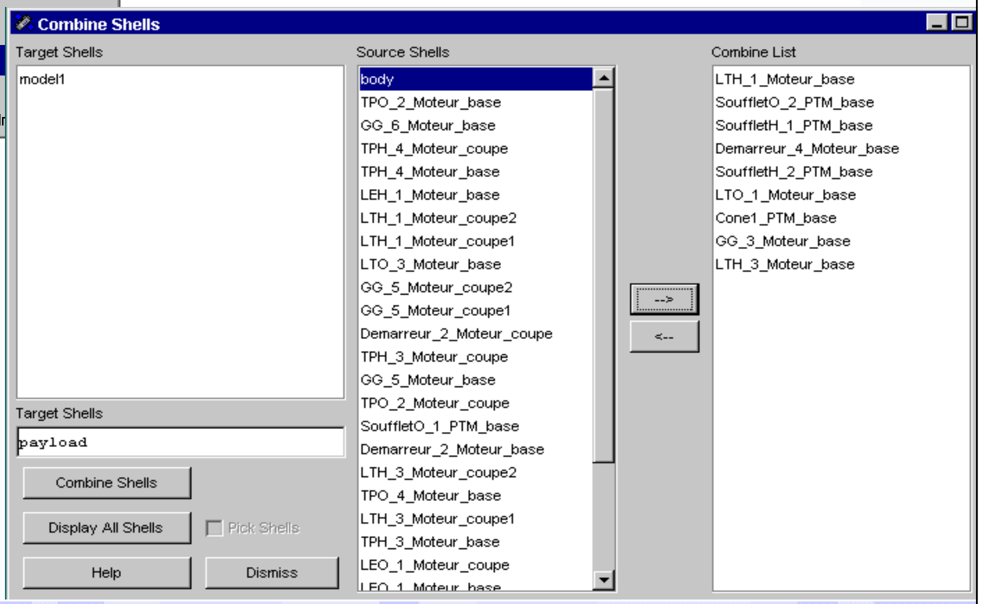


- Geometry Summary -

New Combine Shell Dialog

ALSTOM

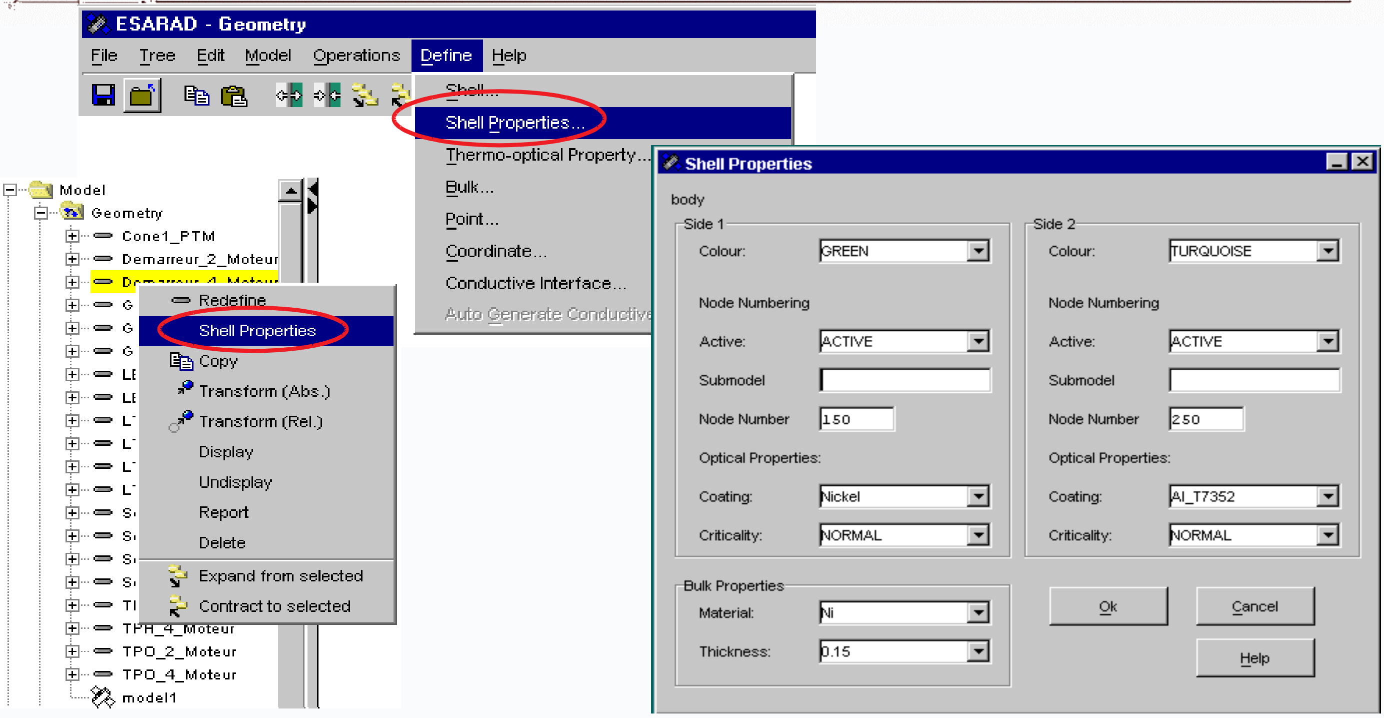




- Select shells from the left hand side list.
- Put them in the right hand side list.
- Enter a Target name.
- Click on "Combine Shells".

Recursive Attribute Editing

ALSTOM



ACG

ALSTOM

Automatic Conductance Generator

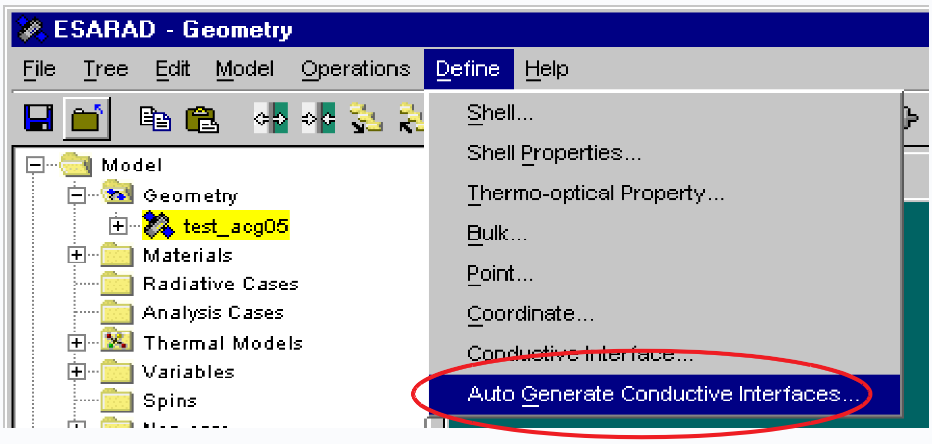
- Automate Calculations of Linear Conductances
- Recognise interface between two shells
- Output GL value to ESATAN file
- Works on uncut shell primitives
- Contact on common straight edge
- All intra GLs computed
- Inter GLs between Quads and Triangles only

ACG

ALSTOM

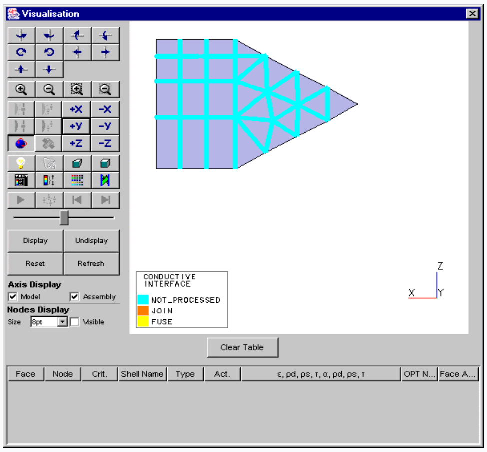
1st Option: Automatic

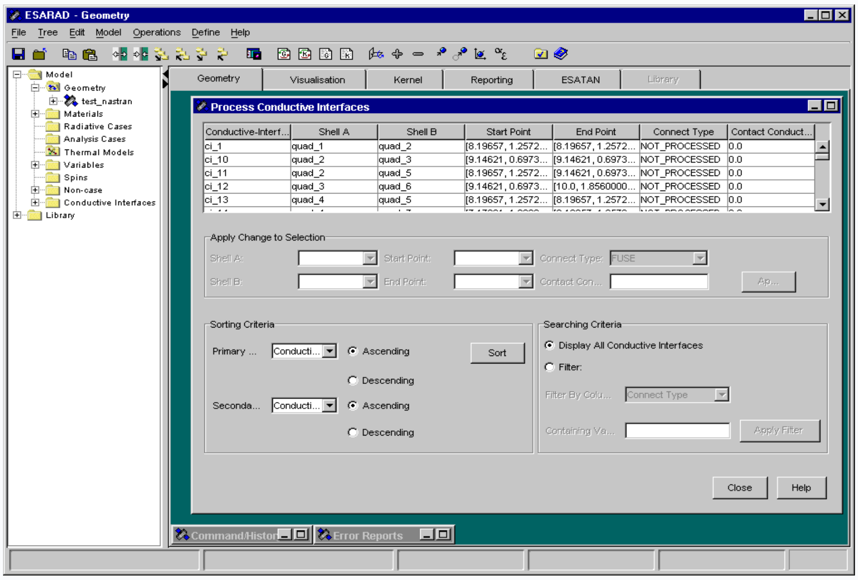
After having assigned the model, still in the Geometry workspace:



ESARAD will automatically detect the conductive interfaces, display them in the visualisation window and pop the dialog to process the interface type

1st Option: Automatic





The interfaces are default to NOT_PROCESSED

1st Option: Automatic

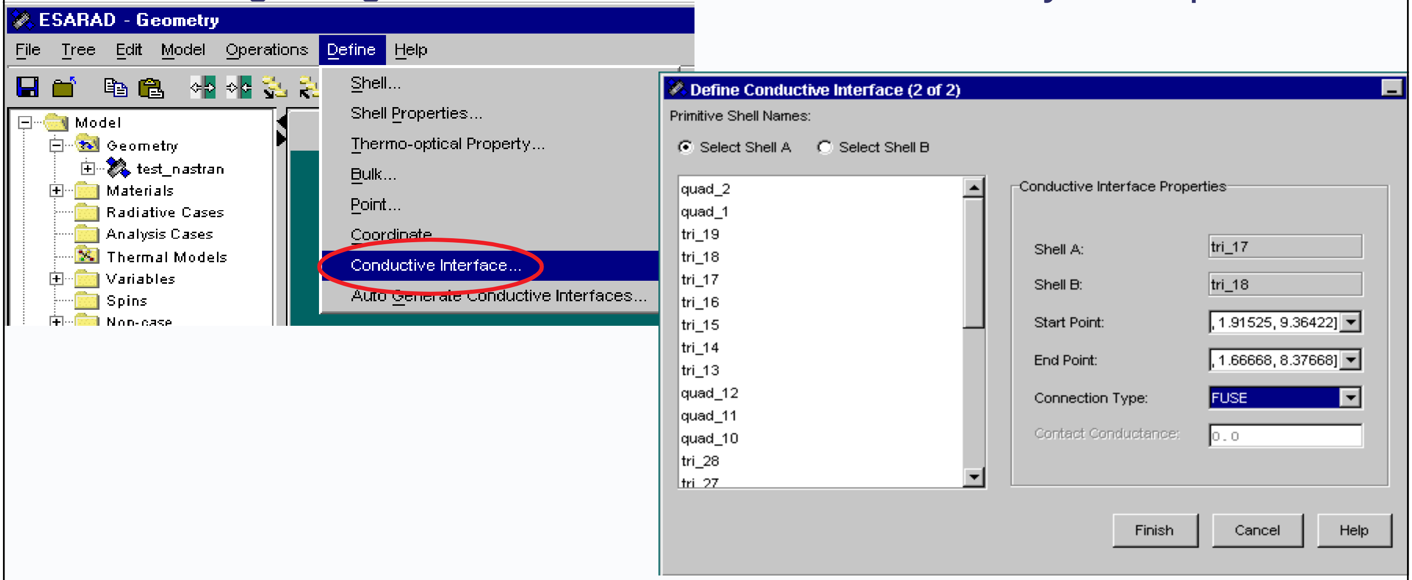
- The Connection type can then be changed to one of the following:
  - FUSE: two shells form a single continuous surface
  - JOIN: two surfaces are linked by a contact conductance
  - NOT_PROCESSED: default
  - NOT_REQUIRED
- The Connection type can then be changed by either:
  - Clicking in the visualisation window on a conductive interface
  - Selecting the interface from the list in the dialog

ACG

ALSTOM

2nd Option: Manual

After having assigned the model, still in the Geometry workspace:

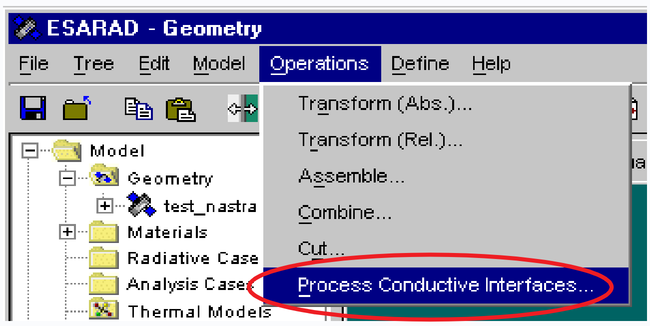


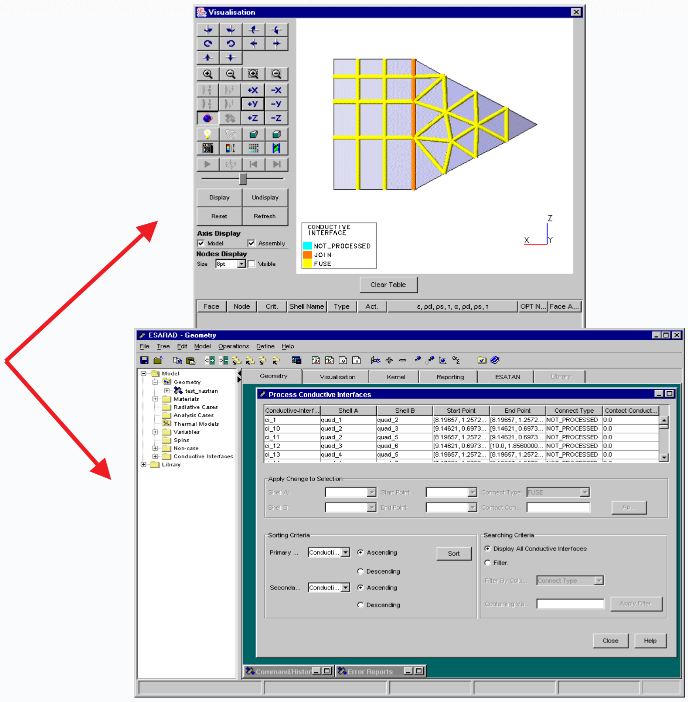
ACG

ALSTOM

2nd Option: Manual

To visualise the Conductive Interfaces
and their parameter:



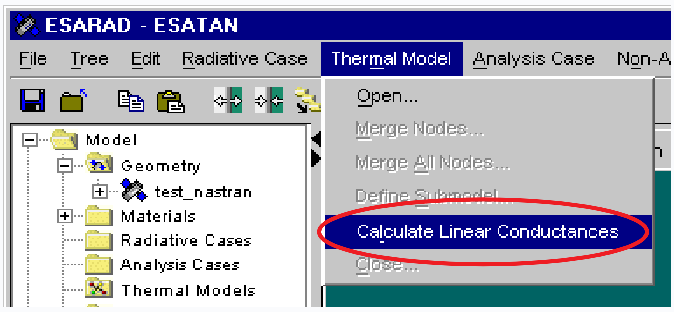


ACG

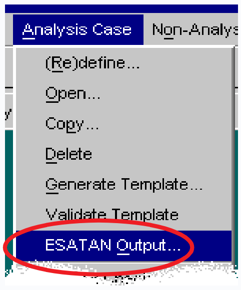
ALSTOM

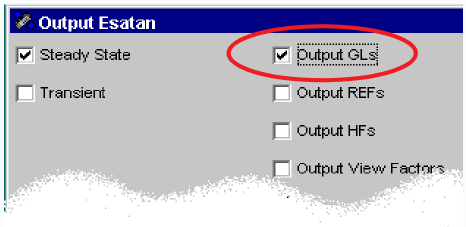
Outputting GLs to ESATAN

1. Calculate Linear Conductance in the Thermal Model Menu:



2. Click Output GL in the Analysis Case:





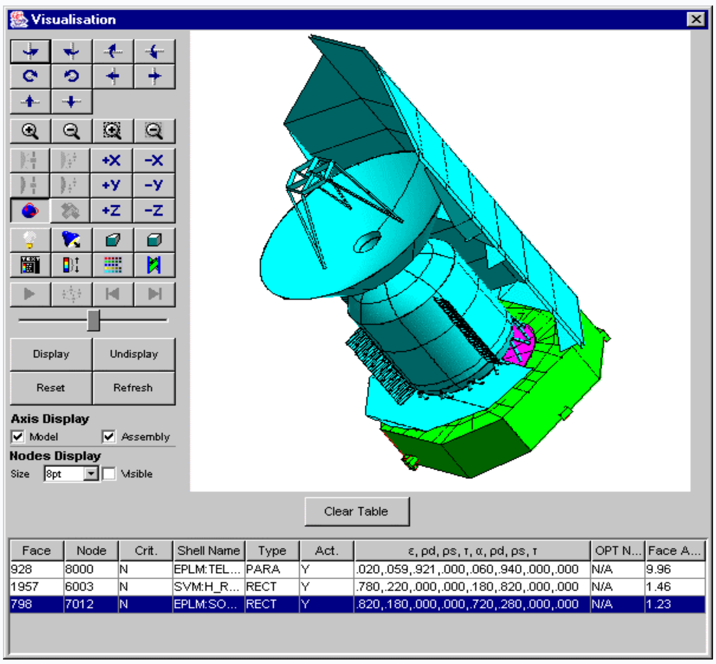
ESARAD v5.4

ALSTOM

Visualisation - New features

Background defaults

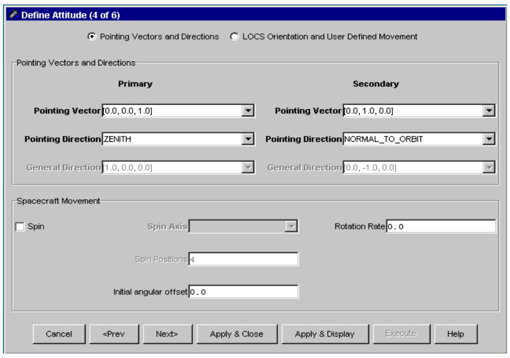
to White



ESARAD v5.4

Kernel - New features

- New Spacecraft orientation



- Simplified Kernel Language

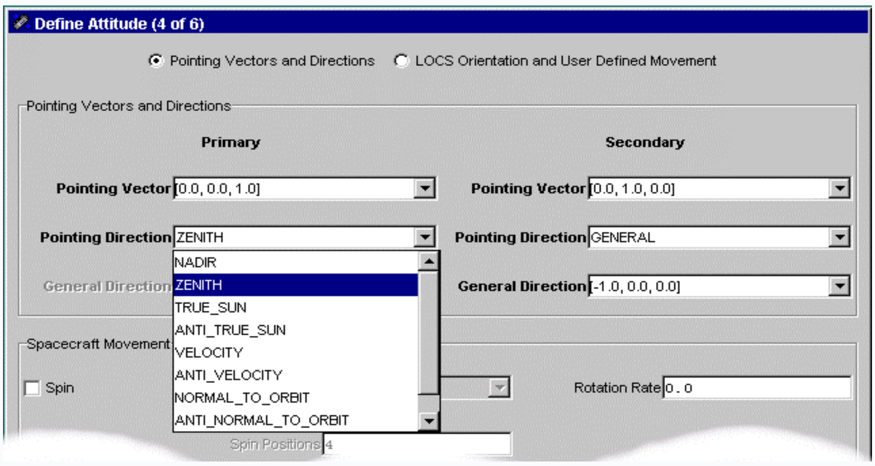
```
FOR (orbit_index = 1;
    orbit_index <= rcase.NUM_ORBIT_POSITIONS;
    orbit_index = orbit_index + 1)

    CALCULATE (
        radiative_case = rcase,
        calc_types = "REF, SDF, SAF",
        pos_index = orbit_index,
        eclipse_check = TRUE);
END_FOR
```

- Kernel Summary -

New Spacecraft orientation

- Primary and Secondary vectors make it easier to define the spacecraft orientation within the orbit

- Select vectors from the GUI



- Old LOCS Orientation method still working

- Kernel New Features -

Simplified Kernel Language

ALSTOM

All the previous calculate functions have been replaced with one new calculate method

CALCULATE_ORBIT_POSITION
CALCULATE_ORBIT_POSITION_WITH_SPIN
CALCULATE_PLANET_ABSORBED_FLUX_MATRIX
CALCULATE_PLANET_ABSORBED_FLUX_RAYTRACING
CALCULATE_PLANET_DIRECT_FLUX
CALCULATE_SOLAR_ABSORBED_FLUX_MATRIX
CALCULATE_SOLAR_ABSORBED_FLUX_RAYTRACING
CALCULATE_SOLAR_DIRECT_FLUX
CALCULATE_VIEW_FACTORS
CALCULATE_RADIATIVE_EXCHANGE_FACROTRS_MATRIX
CALCULATE_RADIATIVE_EXCHANGE_FACROTRS_RAYTRACING

} CALCULATE (…,…)

Simplified Kernel Language

ALSTOM

Example of a new CALCULTE method for a moving geometry:

```
FOR (orbit_index = 1;
     orbit_index <= rcase.NUM_ORBIT_POSITIONS;
     orbit_index = orbit_index + 1)

     CALCULATE (
          radiative_case = rcase,
          calc_types = "REF, SDF, SAF",
          pos_index = orbit_index,
          eclipse_check = TRUE);
END_FOR
```

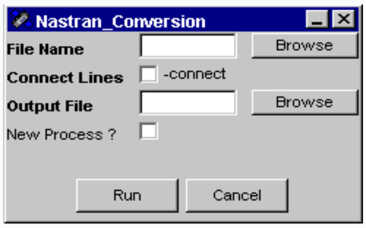
ESARAD v5.4

ALSTOM

Library - New features

- New Custom Menu

- NASTAN Converter



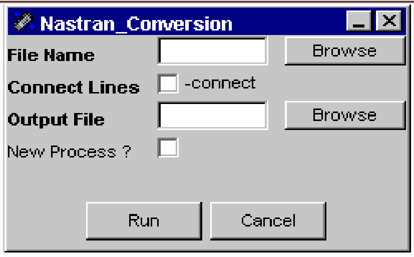
New Custom Menu

ALSTOM

- Allows external process to be called from within ESARAD
- Can integrate user’s application to work with ESARAD
- Can launch program or access system functions without needing to leave ESARAD
- Call NASTRAN converter
- Call STEP-TAS converter
- In the Library workspace

NASTRAN Converter

ALSTOM

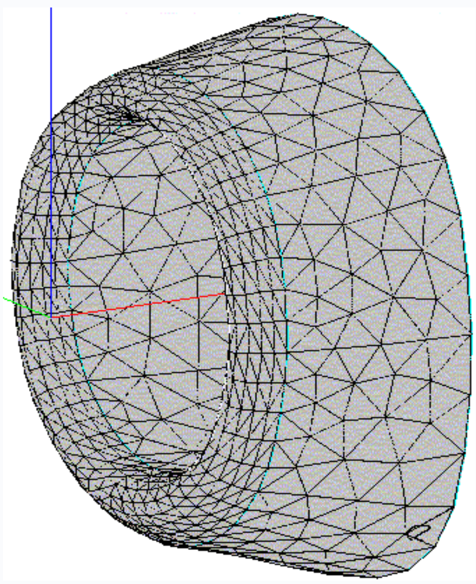


- Converts MSc/NASTRAN input files into ESARAD
- Only supports thin shells and elements (TRIA and QUAD)
- Maps GRID points ⇨ ESARAD Points Variables
- Maps FE elements ⇨ ESARAD shells
- Does not translate Material data yet
- Can be used with Combine Shells & Recursive Attribute

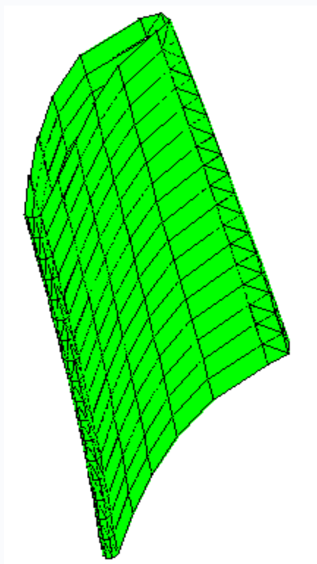
NASTRAN Converter

ALSTOM

Examples



Nacelle Air-Inlet



Turbine Blade

Data Format - New features

- New Data Store HDF (Hierarchical Data Format)
- Neutral Binary
- Platform Independent
  - same model can be opened from any platform
  - can transfer a complete model (with all data) to another site
- Only compatible with ESARAD v5.4 onwards

Conclusion

Chris KIRTLEY will present future developments after the break.

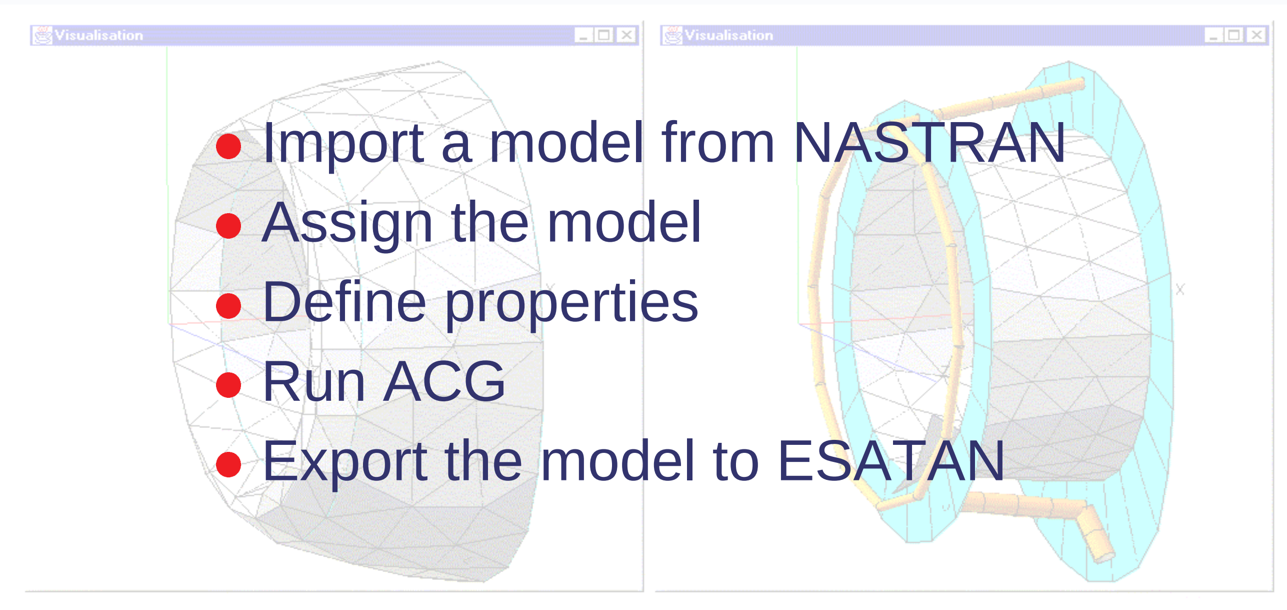
ESARAD Demo

Bruno CASTELLI

ALSTOM

ESARAD v5.4 Demo

ALSTOM

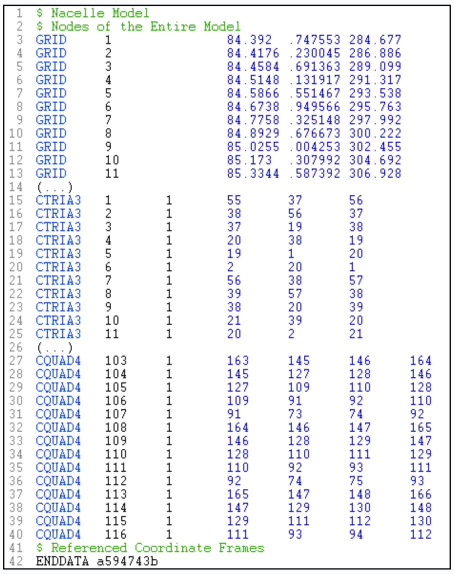


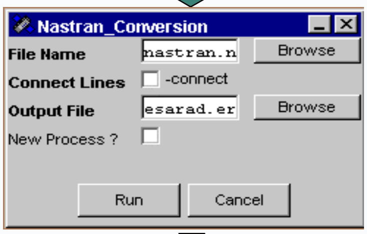
- Import a model from NASTRAN
- Assign the model
- Define properties
- Run ACG
- Export the model to ESATAN

- Demo Objectives -

Import from NASTRAN

ALSTOM





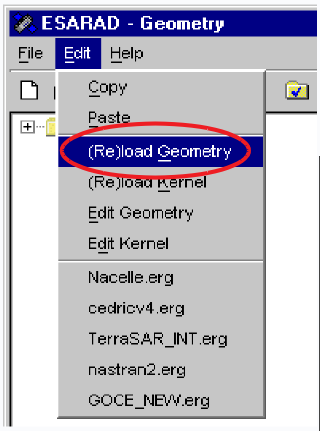
NASTRAN .ns file

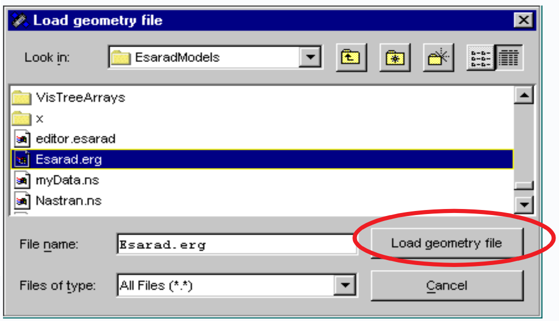
ESARAD .erg file

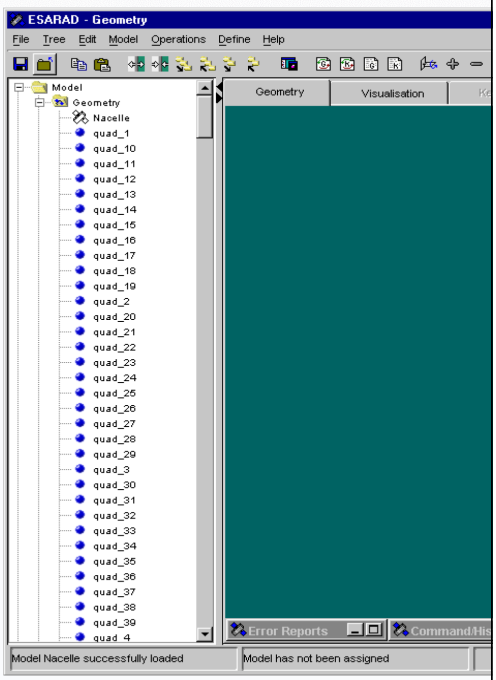
- Demo -

Import .erg file

ALSTOM







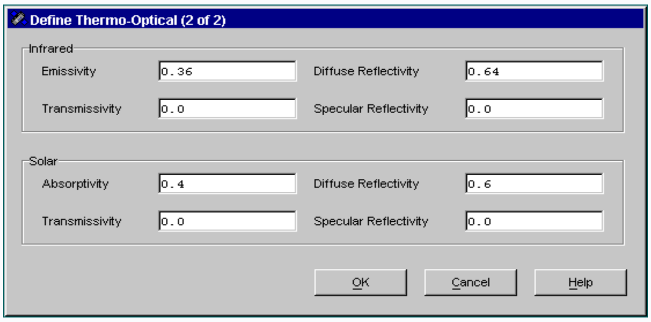
Create et open the model in ESARAD

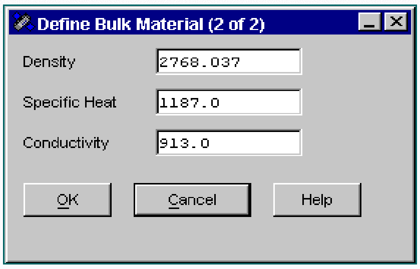
- Demo -

Assign the model

ALSTOM

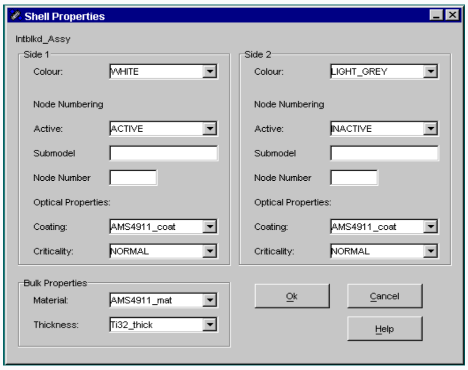
1. Define Optical Properties





2. Define bulks

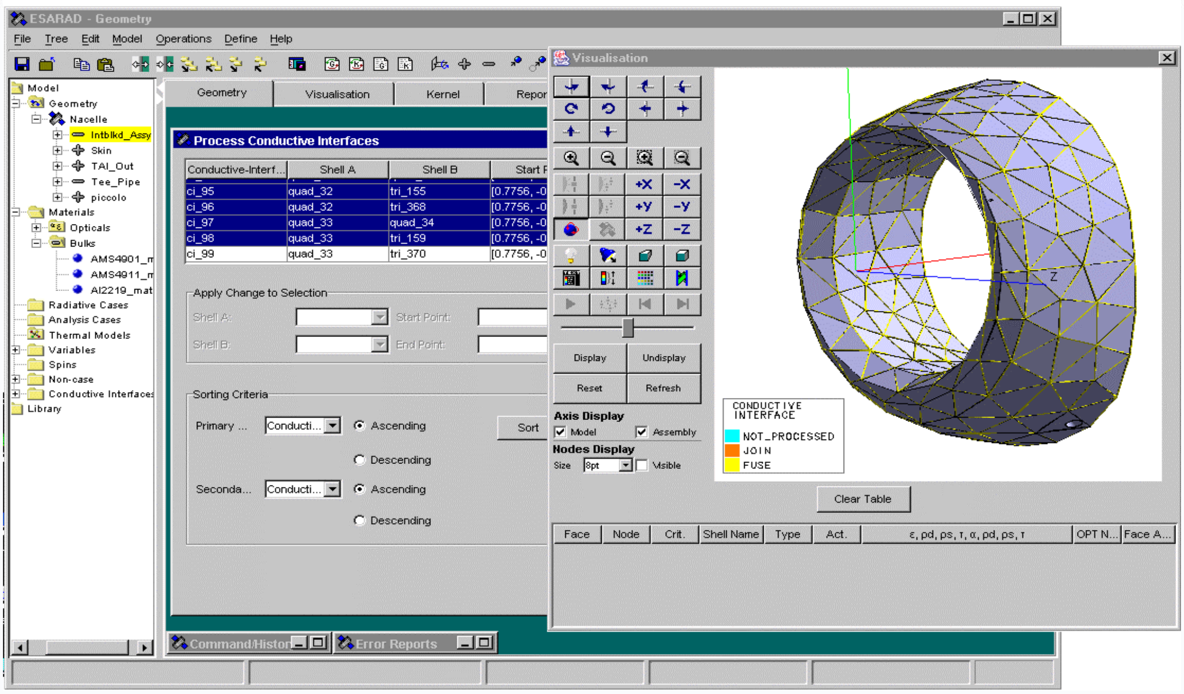
3. Assign properties



- Demo -

Run ACG

ALSTOM

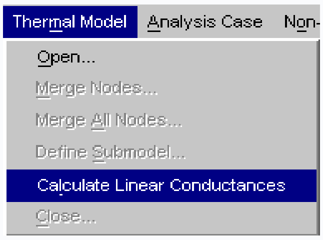


- Demo -

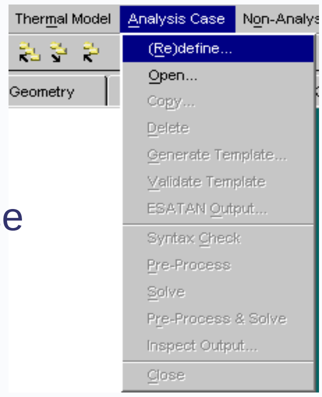
Export model to ESATAN

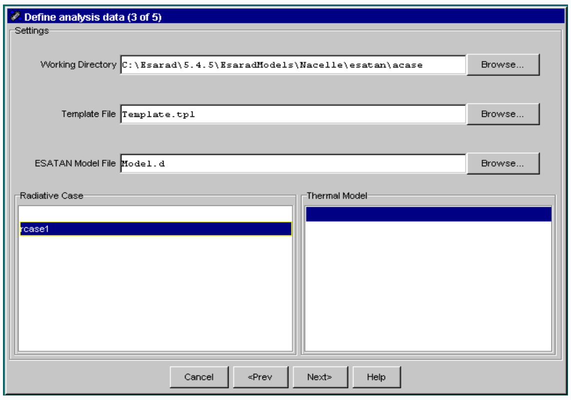
ALSTOM

1. Run a kernel



2. Calculate Linear Conductances



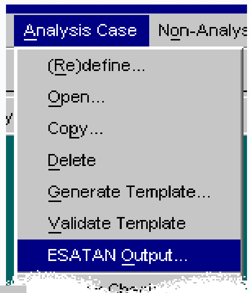


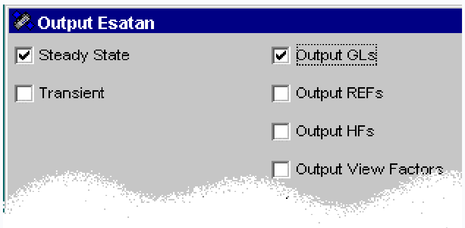
3. Open an Analysis Case

- Demo -

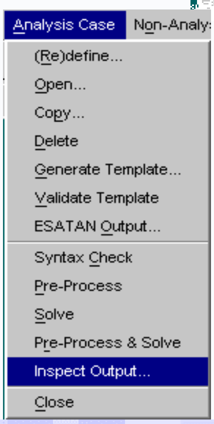
Export model to ESATAN

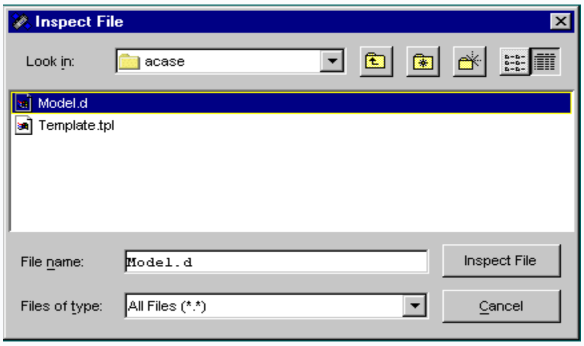
ALSTOM





4. Output to ESATAN





5. Inspect Output

- Demo -

Inspect ESATAN Input File

ALSTOM

```
# Esarad version 5.4.5, run date 11:40 Mon 20 Oct 2003
# Model name: Nacelle          Analysis case: acase
$MODEL Nacelle_acase
  $LOCALS
  $NODES
    D1 =  'Piccolo', T = 0.000000,
     A = 0.021944, ALP = 0.400000, EPS = 0.360000;
    D2 =  'Piccolo', T = 0.000000,
     A = 0.021944, ALP = 0.400000, EPS = 0.360000;
(...)

  $CONDUCTORS
    GR(204, 205) = 0.000447918;
    GR(204, 206) = 0.000167911;
    GR(204, 207) = 0.000107477;
(...)

    GL(203,204) = k_Al2219_mat * 0.00744496;
    GL(267,287) = k_Al2219_mat * 0.00426211;
    GL(281,290) = k_Al2219_mat * 0.00555827;
(...)

  $CONSTANTS
    $REAL
      # Material data for 'AMS4901_mat'
      Cp_AMS4901_mat = 0.000000;
      Dens_AMS4901_mat = 4511.900000;
#
      # Material data for 'AMS4911_mat'
      Cp_AMS4911_mat = 0.000000;
      Dens_AMS4911_mat = 4428.859000;
#
      # Material data for 'Al2219_mat'
      Cp_Al2219_mat = 0.000000;
      Dens_Al2219_mat = 2768.037000;
#
      # Conductivity from bulk 'Al2219_mat'
      k_Al2219_mat = 120.000;

  $ARRAYS

  $SUBROUTINES
      SUBROUTINE QCYCLC LANG = MORTRAN
        RETURN
      END
      SUBROUTINE QAVERG LANG = MORTRAN
        RETURN
      END
      SUBROUTINE RCYCLC LANG = MORTRAN
        RETURN
      END

  $INITIAL
      C101 = 0.000019 * Cp_AMS4901_mat * Dens_AMS4901_mat
      C102 = 0.000038 * Cp_AMS4901_mat * Dens_AMS4901_mat
      C103 = 0.000037 * Cp_AMS4901_mat * Dens_AMS4901_mat
 (...)

  $VARIABLES1
        IF (SOLVER(:2) .EQ. 'SS') THEN
          CALL QAVERG
        ELSE
          CALL QCYCLC
          CALL RCYCLC
        END IF
  $VARIABLES2
  $EXECUTION
  # Steady State Solution
        RELXCA=0.001
        NLOOP=1000
        CALL SOLVIT
  # Transient Solution
        TIMEND=PERIOD
        DTIMEI=TIMEND/100.0
        OUTINT=TIMEND/10.0
        CALL SLFWBK
  $OUTPUTS
        CALL PRNDTB(' ','L,T,QS,QE,QA,C',CURRENT)
        CALL DMPGFF(' ',CURRENT)
$ENDMODEL #Nacelle_acase
```

- Demo -

ALSTOM

www.techcentreuk.power.alstom.com

Appendix E: ThermPlot Pro

Capabilities of the ThermPlot Pro Thermal Post-Processing Program

H. Peabody
Thermal Modeling Solutions

Use of ThermPlot Pro Software for Quick Evaluation of Thermal Model Results

Hume Peabody
Thermal Modeling Solutions

- **Few tools exist to allow a thermal analyst to quickly filter thermal model output to areas of interest.**
- **Often thermal analysts write additional logic to output specific information. If new data is needed, the model must be rerun to generate the new information.**
- **ThermPlot Pro uses standard output files and allows the user to define Objects (DataSet, Plot, Table, Parameter, Group) and Options (e.g. Include Descriptions, Selected Nodes Only, HeatMaps)**
- **ThermPlot Pro then processes the input and generates a Microsoft Excel® workbook containing the data and objects specified by the user**
- **All data is then available in Excel for further study**

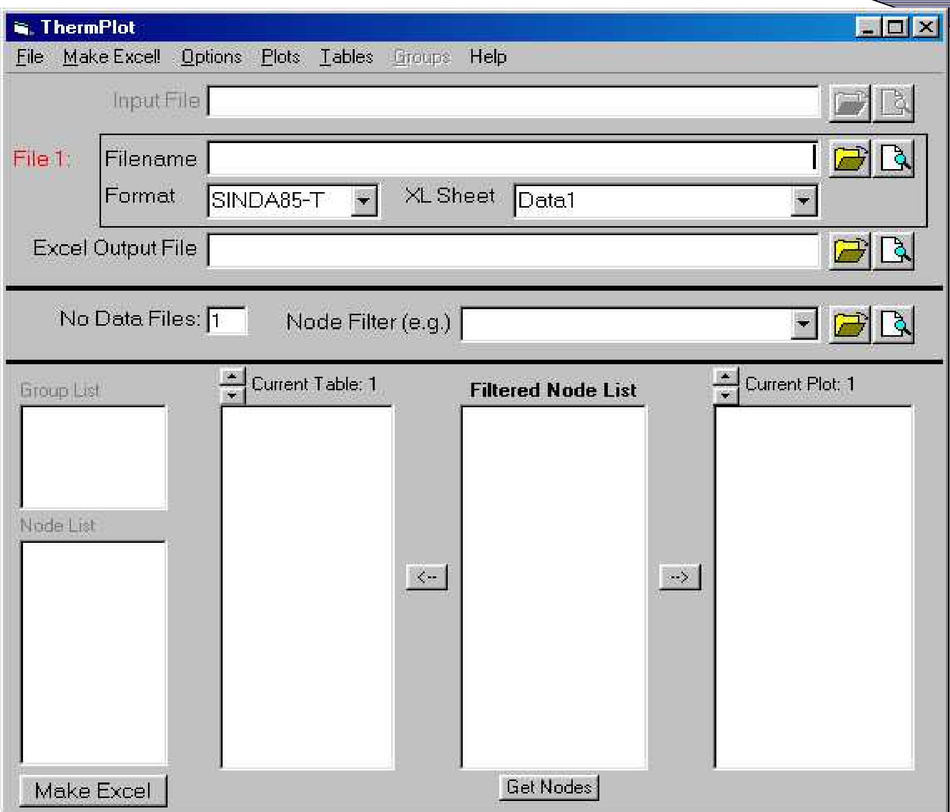
ThermPlot Pro – Features

THERMAL MODELING SOLUTIONS

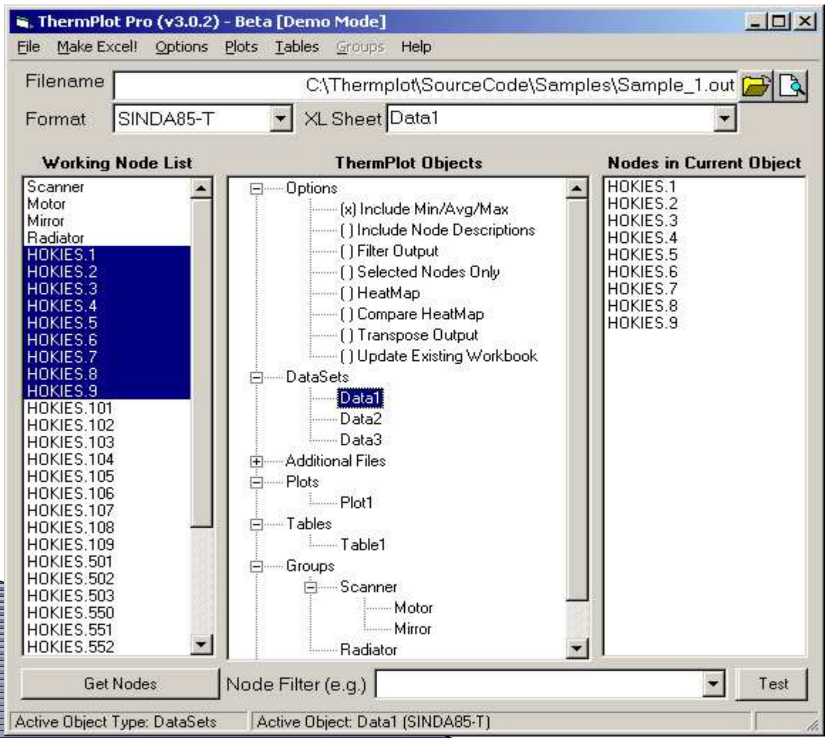
- **Process wide range of thermal solver formats and multiple files (allowing for comparisons and trend studies)**
- **Options to output only particular nodes of interest**
- **Include Node Descriptions from Input File**
- **Transpose output for dense timestep models**
- **Plot transient data with complete control over line and marker characteristics and axes properties**
- **Tabulate simplified parameters (e.g. Min, Max) including limits and conditional formatting**
- **Group nodes to simplify complicated models**
- **Create interactive HeatMaps or Compare Heatmaps**
  - **Data for any Node/Group or Timestep available**
- **Additional utilities to calculate Backloads/EqSinks and Process Radks**
- **Save settings to session file**

ThermPlot Pro – Main Screen (Classic)

THERMAL MODELING SOLUTIONS



ThermPlot Pro – Main Screen (New)



- Options set by user
- Objects created by user
  - DataSets
  - Plots
  - Tables
  - Groups
  - Parameters
- Data added to Objects from "Working Node List"
- Excel® Workbook created based on requested data and objects

ThermPlot Pro – Supported Formats

- **Many formats and parameters are supported in ThermPlot Pro including:**

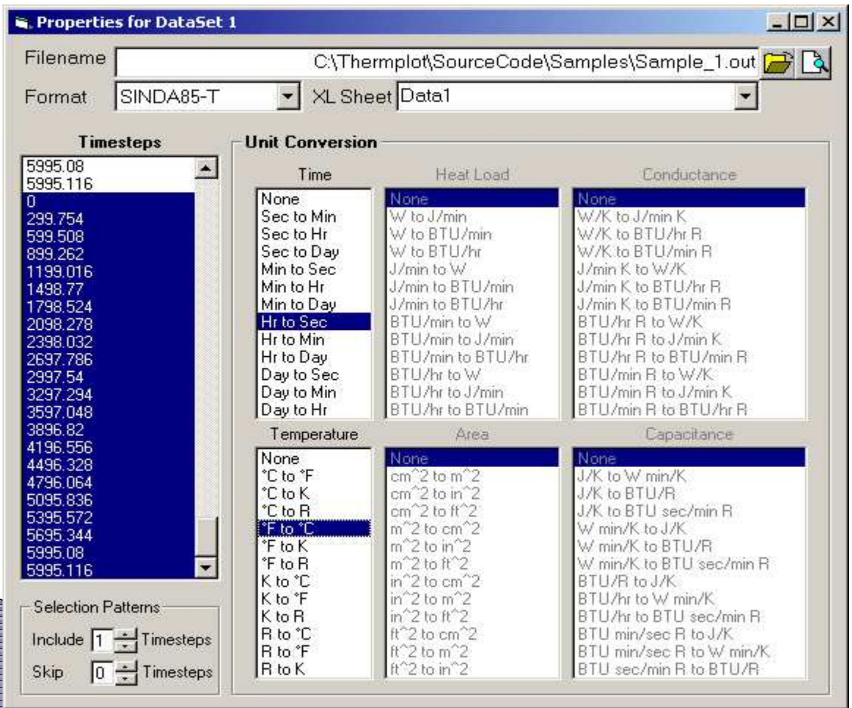
Format	*Parameters*
SINDA85 & SINDA/FLUINT®	T, Q, G, C*
SINDA/G®	T, Q, G, C, F
ESATAN (PRNDBL)	T, Q, QS, QA, QE, QI, QR, G, GL, GR, C*
ESATAN (PRNDTB)	T, Q, QS, QA, QE, QI, QR
TMG®	T, Q (QNODEF), Q (REPF), G
TAK2000®	T, Q, G, C*
TSS®	Q, G*
ThermalDesktop®	Q*, G*
Comma Separated Value	N/A
Space Delimited	N/A

** Planned*

ThermPlot Pro – Options

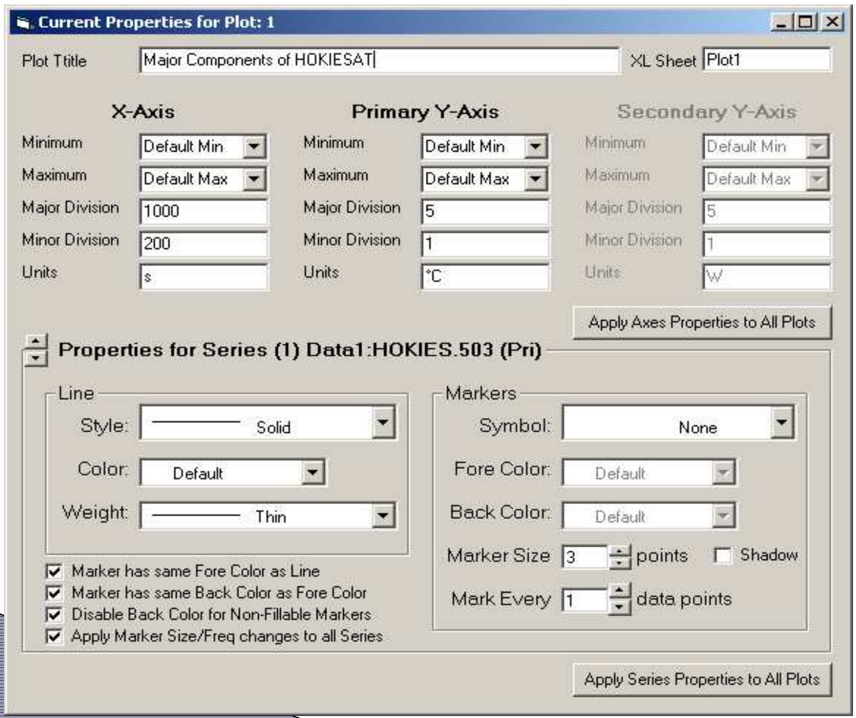
- ***Include Min/Avg/Max*** **– Automatically appends Minimum, Average, and Maximum over *Last Orbit* period to end of data**
- ***Include Node Desciptions*** **– Adds node descriptions from input files to Tables**
- ***Filter Output*** **– Output only data meeting the user specified filter criteria (e.g. 1-100, MAIN.1000-1100)**
- ***Selected Nodes Only*** **– Outputs only nodes referenced by a ThermPlot object (e.g. Group, Plot, etc.) or selected in the "Working Node List" at the time of creation**
- ***HeatMap and Compare Heatmap*** **– Specialized workbook with macros to calculate heat flow between Nodes and Groups**
- ***Transpose Output*** **– Outputs data with Nodes across and Timesteps down, used for output with many data points (Excel limit of 256 cols)**
- ***Update Existing Workbook*** **– Append data to existing Workbook, rather than creating a new Workbook**

ThermPlot Pro – DataSet Properties



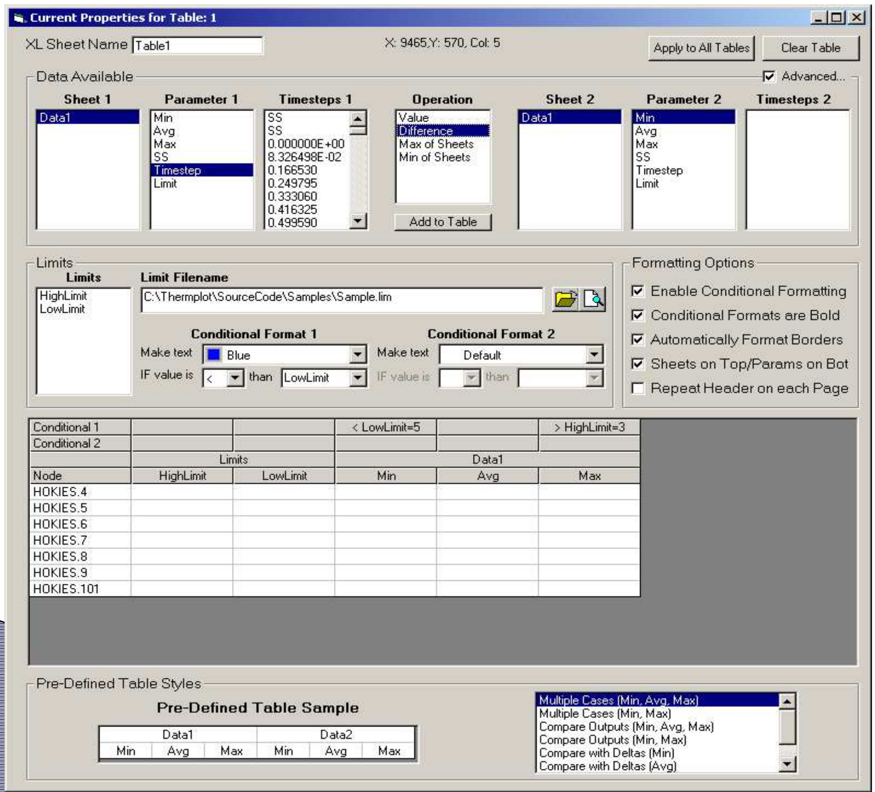
- **Select File, Format, and Data Sheet Name**
- **Specify Timesteps to output**
- **Convert Units**
  - **Time**
  - **Temperature**
  - **Heat**
  - **Area**
  - **Conductance**
  - **Capacitance**
- **Unit conversion options loaded from user-defined file**

ThermPlot Pro – Plot Properties (New and Classic)



- **Complete control over Axes Properties**
  - **Minimum, Maximum, Divisions, Units**
  - **X, Y (Pri), Y (Sec)**
- **Complete control over Series Properties**
  - **Line Color, Style, and Weight**
  - **Marker Color, Style, Size, Frequency**
- **Apply properties from one plot to all other plots for consistency**

ThermPlot Pro – Table Properties (New)



- **Select Tabular Data**
  - **Minimum, Maximum, and Average**
  - **Specific Timestep**
  - **Limits**
  - **Differences between DataSets**
  - **Minimum/Maximum of multiple DataSets**
- **Conditional Formatting to Highlight Out-of-Limit Conditions**
- **Predefined tables for quick creation**

ThermPlot Pro – Working with Groups

THERMAL MODELING SOLUTIONS

- **Groups are a method for simplifying results from large, complicated models.**
- **They allow up to three levels of sub-grouping: Major, Minor, and Sub (Instrument:Region:Component) and may be renamed, modified, or deleted.**
- **Options exist to automatically created groups from submodels and to display nodes in sub-groups when parent group is selected.**
- **When combined with HeatMaps, user may examine heat flow at various levels throughout a model. (e.g. spacecraft to instrument, panel to motor, etc.)**
- **Plan to add "Dynamic Groups", where a user may expand or collapse groups within Excel to examine areas of interest, without the need for detail in other groups. For example, a particular major group for an instrument may be expanded to its sub groups, while all other major groups remain collapsed.**

ThermPlot Pro – Working with HeatMaps

THERMAL MODELING SOLUTIONS

- **HeatMaps allow the user to examine heat flow through a model. They are similar to QDUMPS or QMAPS, but do not require massive outputs of data at each call.**
- **To use this feature, a user must have output for all Temperatures, Heat Loads, and Conductors at *EVERY* output timestep and in the same order. In addition, the input data file must also be specified in order to determine the two nodes connected by each conductor. (ESATAN and TMG are exceptions to this rule.)**
- **To enable HeatMaps, *Include Heatmaps* must be checked under *Options*. Upon enabling HeatMaps, the number of files will default to 3 and the format will automatically select *–T for File 1, *-Q for File 2, and *–G for File 3. Selecting a file for any of the three will automatically select the same file for all three cases.**
- **Many of the options for filtering output are disabled since ALL data is needed to calculate the heat flows. The *Include Max/Min/Avg* option is by default unchecked when *Include Heatmaps* is selected.**
- **HeatMaps are a powerful capability when combined with Groups. Heatflow may be examined between two nodes, a group to nodes, a node to groups, and between two groups.**
- **A user must exercise caution when outputting data from the thermal solver since HeatMap files can get very large with T, Q, and G output at every timestep. It is the responsibility of the user to use common sense; it is not uncommon to have a 50+ MB Excel® file, depending on model size.**

ThermPlot Pro – Working with HeatMaps (cont'd)

THERMAL MODELING SOLUTIONS

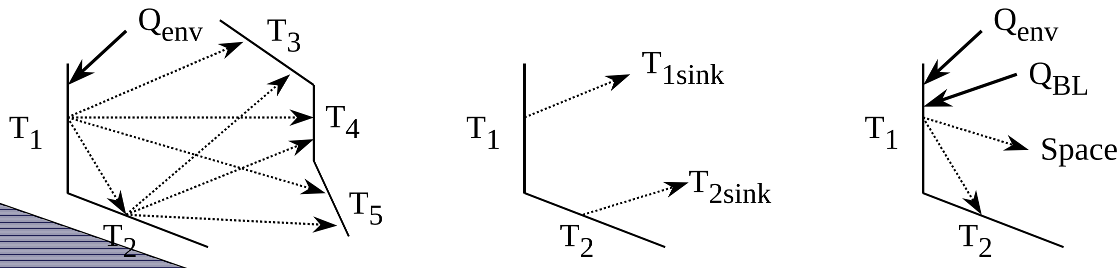
- Once the Workbook is created, the user will specify the Temperature Offset to Absolute Zero (T_{offset}), the Stefan-Boltzman constant (Sigma), the timestep of interest, and the node/group of interest. User entered data is highlighted in Red.
- Once T_{offset}, Sigma, and the timestep have been selected, heatflow through all conductors and between groups and nodes is calculated. Once a Node/Group is selected, data specific to the selection is output and sorted according to the header.
- The user selects the type of heatflow (e.g. Group-to-Node) by selecting the proper *Heat To* (either Group or Node) and entering a Group or Node as *Node i*.
- A Minimum heat value to output may be specified to eliminate negligible heat flows.
- A summary of Heatflow into or out of the Group/Node by mode (i.e. Radiative or Conductive) is displayed, as well as the Heat Applied to the Node/Group.
- A sample HeatMap Workbook is shown below.

	A	B	C	D	E	F	G	H	I	J	K	L
1		Description	BASEPLATE FOOT - MX/MY						SUMMARY:		In	Out
2		Node i	55701		Temp	11.20			Conduction		0.462	0.462
3		Time	6000		Time Col	Y			Radiation		-	-
4		Sigma	5.67E-08		Min Heat	0.0			Source		0.000	-
5		Toffset	273.15		Heat to	Node			Sum		0.462	0.462
6												
7	*Low (Out) to High (In):*						*High (In) to Low (Out):*					
8												
9	Description j	Node j	Type	Cond	Temp j	Heat j	Description j	Node j	Type	Cond	Temp j	Heat j
10	AVHRR bracket	40707	Lin	2.28E+00	11.00	-0.45	BASEPLATE UNDER SCAN CAV	55711	Lin	5.44E-01	11.73	0.29
11	SIDE EXTERNAL PANEL	55757	Lin	1.18E-02	10.88	0.00	BASEPLATE UNDER SCAN CAV	55711	Lin	1.10E-01	11.73	0.06
12	SIDE EXTERNAL PANEL	55758	Lin	3.29E-03	10.42	0.00	BASEPLATE UNDER SCAN CAV	55718	Lin	4.02E-02	11.83	0.03
13	SIDE EXTERNAL PANEL	55756	Lin	4.70E-02	11.15	0.00	BASEPLATE UNDER SCAN CAV	55712	Lin	4.36E-02	11.72	0.02

ThermPlot Pro – Backload/EqSink Calculation

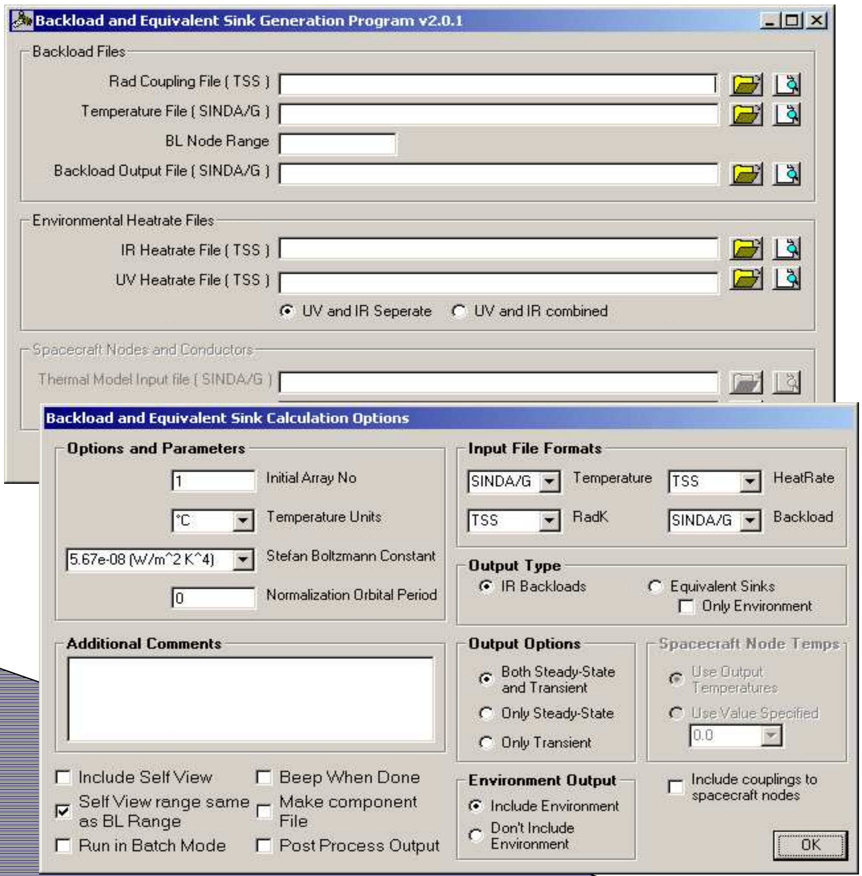
THERMAL MODELING SOLUTIONS

- Backloads are a method for providing a spacecraft environment to instrument contractors via a simple set of heat loads.
- The RadKs from any Node i (in the "Backload" Range) to any Node j are processed along with sigma and the T_j^4. All of these terms are summed for each Node i in the "Backload" range and a set of heat loads generated.
- To use the backloads, the instrument contractor simply runs the free-flying instrument model to generate a new set of radiation couplings with increased views to space (since spacecraft blocking surfaces are not present in the instrument model).
- These increased views to space are offset by the backload heat added to the surface.
- Environment heat loads are also provided to provide the complete S/C environment.
- Equivalent sinks are similar, but produce a Sink Temperature/RadK set for each node.



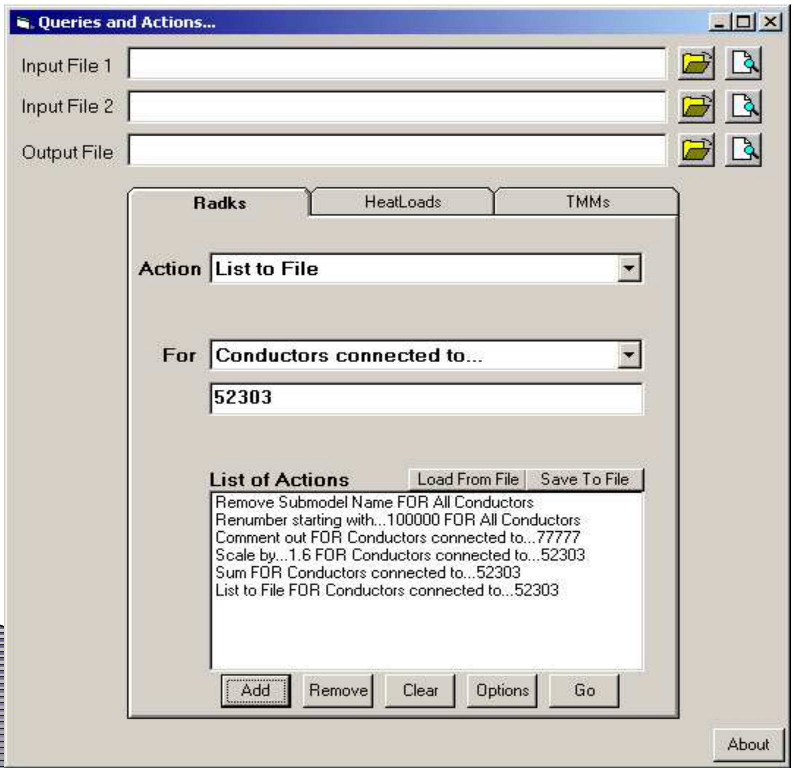
Spacecraft Environment **Equivalent Sink (TV)** **Backload (Instrument)**

ThermPlot Pro – Backload/EqSink Calculation (cont'd)



- Requires RadK and Temperature Output
- Option to include Environment (UV and IR or Combined)
- Supports SINDA85, SINDA/G, ESATAN TAK2000
- Component file for traceability
- Include Spacecraft interface couplings (e.g. mounting feet, MLI closeouts)

ThermPlot Pro – Radk/HeatLoad Post-Processing



- Variety of Options to:
  - Remove Submodel
  - Renumber
  - Scale
  - Sum
  - List
  - Comment or Delete
- For conductor sets:
  - All Conductors
  - Connected to Node i
  - Between Nodes i and j
- Currently supports TSS output only

- **Support for TSS variable conductors, and RadCad Conductor and Heat Load output**
- **Unit conversion for Conductors, Capacitances**
- **Output matrix of group-to-group heatflows for entire model within HeatMap workbook**
- **Reduction in conductor output for non-varying conductors**
- **Dynamic groups allowing user to specify complexity of grouping as needed for different areas of a model**
- **QuickPlot and QuickTable capabilities which will allow a user to preview the data within the ThermPlot environment before writing to an Excel workbook**
- **Radk Evaluation and Compare Utility**

Appendix F: GAETAN development for ESATAN/FHTS

Overview of GAETAN's latest developments around ESATAN-FHTS

M. Imhof
Silogic

SILOGIC
ingénierie pour la nouvelle informatique

Seventeenth European Thermal & ECLS Software Workshop
October 21th, 2003
Noordwijk,NL

Overview of GAETAN's latest developments

Marie Imhof

SILOGIC
Scientific software engineering Dpt

6, rue Roger Camboulives
31100 Toulouse

SILOGIC
ingénierie pour la nouvelle informatique

Overview plan

- GAETAN
- GAETAN-FHTS
- CONDOR
- Conclusions and perspectives

GAETAN 1/3

WHAT ?

GAETAN : Environment for thermal analysis

- based on ESATAN
- many pre-processing and post-processing features

WHEN ?

Developed since 1996

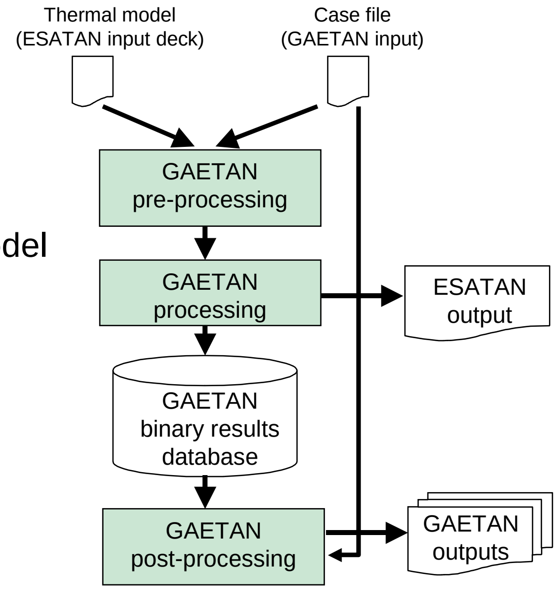
GAETAN V3.0.0 (2003)

WHO ?

CNES + 3 French industrial users

SILOGIC in charge of extensions and maintenance

GAETAN 2/3



<u>3 modules :</u>

- Pre-processing
  - Structured input data
  - Simplified programming of a model
- Processing (ESATAN)
  - Data base generation
  - Run control functions
- Post-processing

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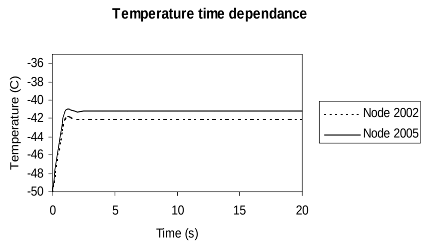
GAETAN 3/3

Post-processing tools

- Node grouping, node condensing, temperature difference calculation…
- Comparisons with calculations or tests...
- Statistic, entities values, thermal balances, average temperature…

```
Caracteristiques du modele a T0
*******************************

Modele utilisateur:     TEST
20 Noeuds thermiques
20 Noeuds fluidiques
19 Echanges conductifs
0 Echanges radiatifs
0 Couplages fluidiques


===============
Groupes definis
===============


Groupe: Noeud K

Sous-modele: TEST
Noeud(s):        1001

Groupe: Noeud J

Sous-modele: TEST
Noeud(s):        1020

Groupe: Fluides 1

Sous-modele: TEST
Noeud(s):        1002 - 1010

Groupe: Fluides 2

Sous-modele: TEST
Noeud(s):        1011 - 1019

Groupe: Paroi

Sous-modele: TEST
Noeud(s):        2001 - 2020
```

```
$bloc_de_donnees
TRANSITOIRE
$titre1
Cas de calcul TRANSITOIRE - Sensibilite :                   none
$titre2
Modèle TEST
$sous_titre1
GAETAN Version 3.0.0       ESATAN Version 8.7       09:07:27  20/10/03
$sous_titre2
Entites caracteristiques des noeuds de type DIFFUSIF
$label_identification
*          TEMPS (s )*          TEST:2002*          TEST:2005*
$label_utilisation
*          TEMPS (s )*                  *                   *
$nature_parametre
*              CALCUL*             CALCUL*             CALCUL*
$identification_parametre
*          TEMPS (s )*    TEMPERATURE (C)*    TEMPERATURE (C)*
$donnees
*                0.00 *            -50.00 *            -50.00 *
*                1.00 *            -42.02 *            -41.28 *
*                2.00 *            -42.02 *            -41.28 *
*                3.00 *            -42.02 *            -41.24 *
*                4.00 *            -42.02 *            -41.24 *
*                5.00 *            -42.02 *            -41.24 *
*                6.00 *            -42.02 *            -41.24 *
*                7.00 *            -42.02 *            -41.24 *
*                8.00 *            -42.02 *            -41.24 *
*                9.00 *            -42.02 *            -41.24 *
*               10.00 *            -42.02 *            -41.24 *
*               11.00 *            -42.02 *            -41.24 *
*               12.00 *            -42.02 *            -41.24 *
```



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GAETAN-FHTS 1/2

Updates

- Fluidic nodes and entities available in GAETAN
  - All ESATAN-FHTS fluidic nodes entities (T, P, FE, VQ…) and functions (COND, CP, RHO…)
  - Computed entities (TQ, HVF)
- Fluidic node grouping and node condensing

New features

- Mass and volume balances
- Fluid state report available for thermal balances

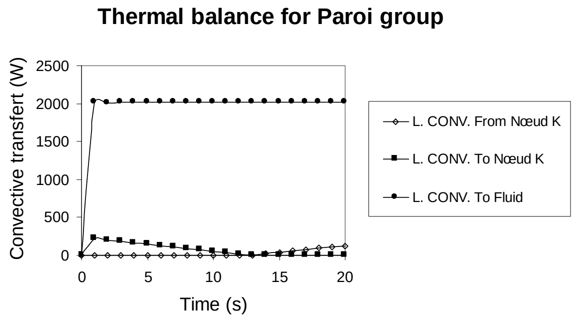
GAETAN-FHTS 2/2

Thermal Balances computing

• Conductors (GL, GR, GF) between solid and fluid nodes taken into account in solid node group detailed thermal balance

Bilans detailles par groupe de noeuds

Bilan thermique (W): Paroi Groupe de noeuds de type "Diffusif"	Entrees	Sorties
Destockage / Stockage	0.00	579.18
Dissipation electrique	4500.00	
Transfert convec.l. avec Noeud K	129.18	
Transfert convec.l. avec Fluides 1		2025.00
Transfert convec.l. avec Fluides 2		2025.00
Recapitulatif du bilan (W)	4629.18	4629.18



CONDOR 1/3

Presentation

• Software for worse-case external flux conditions evaluation
  - Fast pre-phase analysis
  - Analysis on large models for complex pointings (chaining on ESATAN)

• GUI based on a freeware XML editor
  - License free
  - Standard and light developments
  - Easy to tune

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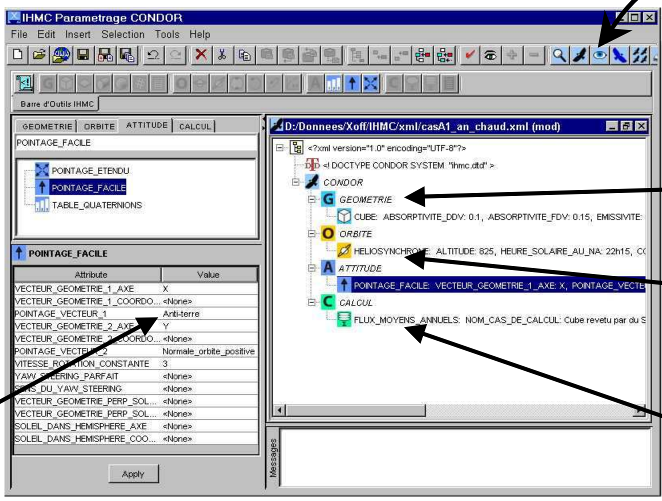
ingénierie pour la nouvelle informatique

CONDOR 2/3

Example of a GUI screen view



Visualise orbit through Esarad

On a cube

Sunsynchronous orbit

Easy pointing

Flux yearly averaged

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ingénierie pour la nouvelle informatique

CONDOR 3/3

Output example

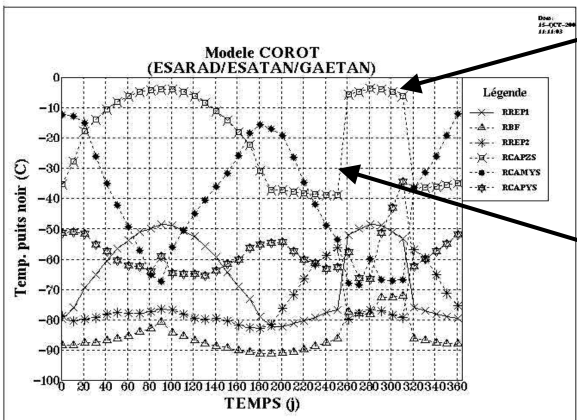

planche T-1 : Temperatures de Puits Noir

Worst case scenario for sink temperature on day 290

Attitude changes over the year

Conclusions and perspectives

Conclusions

GAETAN :

Simplifies the launching of ESATAN

Emphasises ESATAN results with advanced analysis functions

Evolutive software (users requests for improvements)

CONDOR/GAETAN/ESATAN/ESARAD :

Complete environment

Conclusions and perspectives

Perspectives

GAETAN :

Improvement of the user interface

(use of structured input files)

Improvement of the monitoring of the application

Help for model reduction

SILOGIC : thermal / GUI / model definition / output treatment...

Several skills ready to be used for the next generation of thermal tools (ESATAP)

Appendix G: Web Support and Future Developments

Web Support & Future Developments
on
ESATAN, FHTS, ESARAD & ThermXL

C. Kirtley
ALSTOM

Oct 2003

Current Product Developments & Web Support System

Chris Kirtley, Product Manager
Henri Brouquet, Support Manager

ALSTOM

Introduction

ALSTOM

Presentation in two-parts,

Current product developments

↓

New web support system

- Presentation Structure-

Introduction

ALSTOM

- Large number of developments underway
- Developments at different levels of maturity
- Present current developments
  - Detail depends upon maturity

- Scope for further suggestions to be included
  - Henri will present new web support system
  - Use it to suggest enhancements to the tools

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
- Groups, Events & Phases
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

ESATAN Developments

ALSTOM

Solver Developments

Two-phase quasi-transient solver

- FGENFI extended to handle quasi-transient
  - P & W assumed steady state
- Selected as an option via QTRSOL (=YES || **NO**)
- Need for pressure boundary removed
  - Assumes fixed fluid mass within loop
  - Mass initialised at start of each time step
- Significant speed improvements seen

- FGENDA made obsolete

- Two-Phase Solver Extended -

ESATAN Developments

ALSTOM

Solver Developments

- Single-phase transient humidity solution
  - fltntf, fltnts and fltmts being extended to handle wet air
  - Hydraulic steady state assumed (P & W)
  - Water-vapour inertia term to be included

- Fluid Loop Modelling Capability -

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
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- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

ESATAN Developments

ALSTOM

Functionality Enhancements

- Provision of new elements.
  - Flexible pipe model
  - PID Controller
  - Peltier device
- Requirements taken directly from user requests
  - Close collaboration with CNES

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- **Fluid property definition**
- Groups, Events & Phases
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

- Development Items-

ESATAN Developments

ALSTOM

Open architecture for fluid property definitions

$FLUID *WATER*
  $RHO
    $LIQUID
      definition
    $SAT_LIQ
      definition
    $SAT_VAP
      definition
    $TWO_PHASE
      definition
    $VAPOUR
      definition
  $CP

Region

Property

Fluid Type

- *fdf* File Format -

ESATAN Developments

ALSTOM

Functionality Enhancements

- Definition can take the form of,
  - a constant
  - interpolation (1D, 2D or fixed interval)
  - procedure (FORTRAN + reserved variables PROPL, …)
- No difference between system and user properties
- Easy to add new or modify system properties
- Similar approach proposed for def'n of htc's
- Additional condensation correlations provided

- Fluid Property Definition File -

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
- Groups, Events & Phases
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

- Development Items-

ESATAN Developments

ALSTOM

Functionality Enhancements

- Ability to define & refer to a group of nodes.
  - Average group data
  - Group min & max temperature
  - Heat flux between groups
  - Group data output
- Events & Phases
  - Simplify modelling control logic

IF(*Event)* THEN

do something

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
- Groups, Events & Phases
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

ESARAD Developments

ALSTOM

Functionality Enhancements

- Developments to meet BepiColombo project requirements
  - Planet temperature map (Alpha release now available to the project)
  - Removing assumption of parallel sun rays
- General implementation

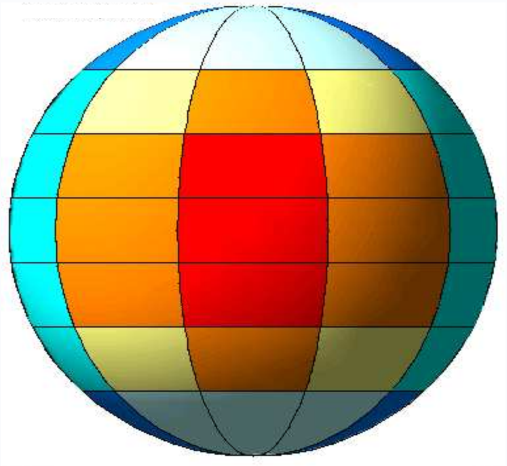
- BepiColombo Requirements -

ESARAD Developments

ALSTOM

Functionality Enhancements

- Planet temperature map
  - Used in planet flux calculation



- Matrix of temperature
  - T vs longitude/latitude
- Calculate map.

- Radiative Case: Temperature Map -

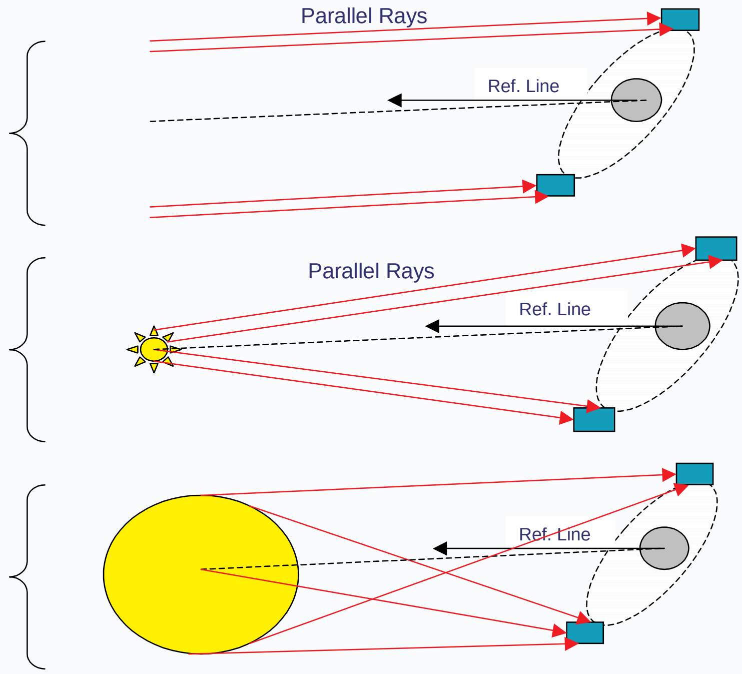
ESARAD Developments

ALSTOM

[Rays from sun at infinite distance](#)

[Rays from sun at finite distance](#)

[Rays from finite sun at finite distance](#)



- Radiative Case: Solar Rays -

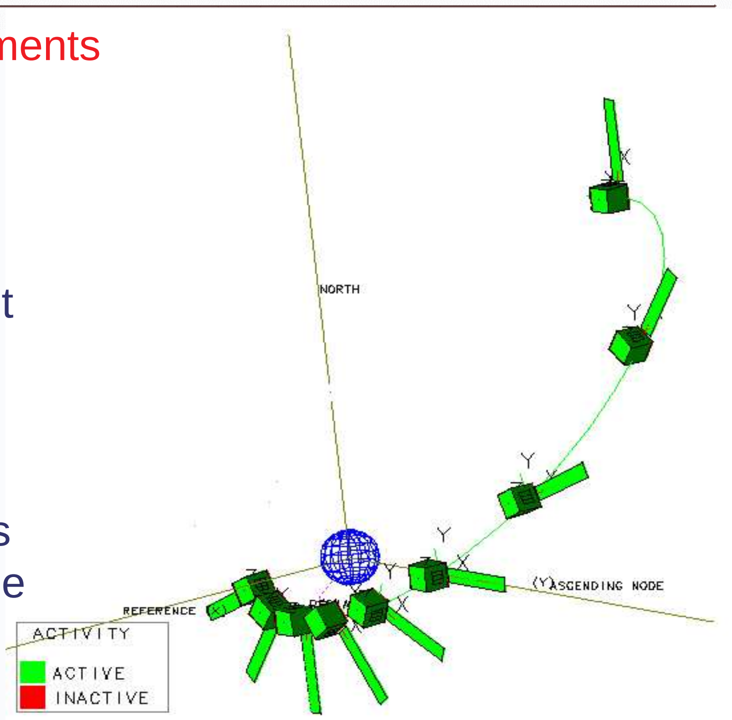
ESARAD Developments

ALSTOM

Functionality Enhancements

Orbital Arcs Development

– Orbit segment defined
– Additional options for orbit definition
– Associate orbit segment to radiative case
– An analysis case contains one or more radiative case



- Radiative Case: Orbital Arc -

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
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- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

- Development Items-

ESARAD Developments

ALSTOM

Functionality Enhancements

- 3D graphics using OpenGL
  - No third-party licence restrictions
  - Also available on Linux
  - Makes use of hardware graphics accelerator
    - Performance improvements
  - Offers much more powerful graphics capability
    - Functionality enhancements to be defined
- Tell us what you would like to see

- Visualistion: OpenGL -

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
- Groups, Events & Phases
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- ThermXL developments
- Further Developments

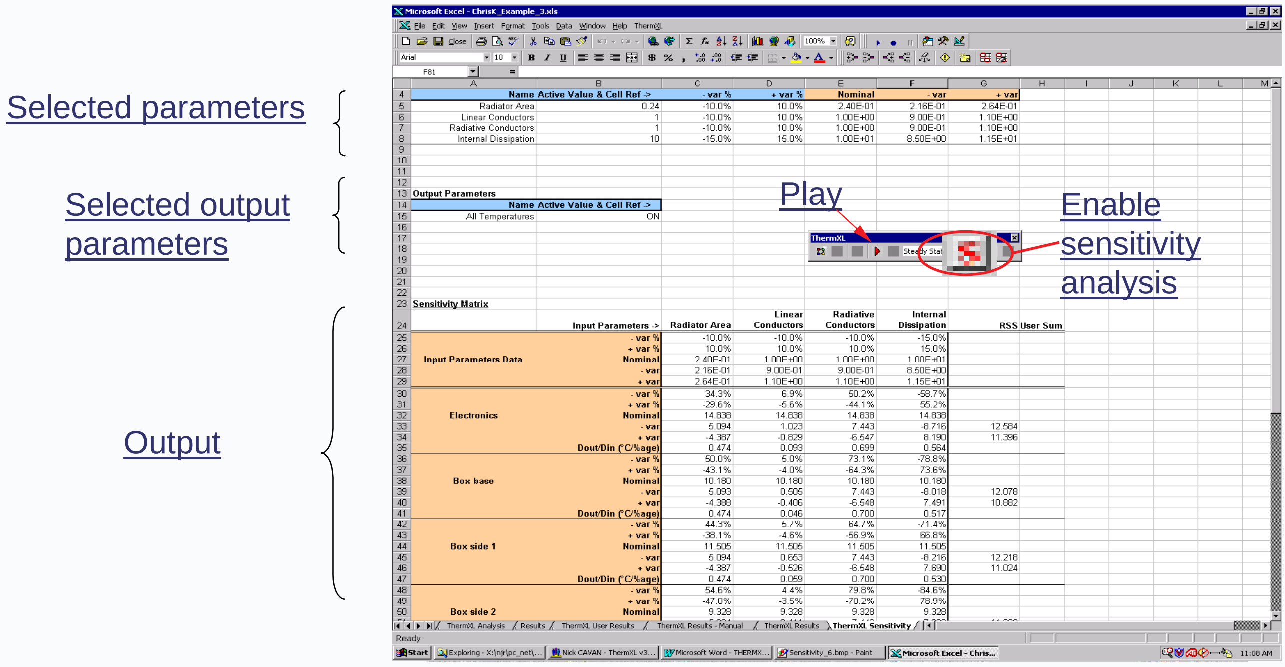
ThermXL Developments

ALSTOM

- Two development programmes underway
- First phase nearing completion
  - Additional modelling capability
    - Flexible interpolation function
    - Sensitivity analysis capability
    - Solver performance
- Further developments under definition

ThermXL Developments

ALSTOM



- ThermXL: Sensitivity Analysis -

Presentation Contents

ALSTOM

- FHTS Solver Enhancements
- New Elements
- Fluid property definition
- Groups, Events & Phases
- ThermXL developments
- ESARAD Modelling Enhancements
- ESARAD Visualisation Development
- Further Developments

- Development Items-

Further Developments

- Further development underway
- Usability of ESATAN a key area
- User survey and direct contact being made
- Results feeding into current and long terms strategy
- During 2 days I will be listening to what you want from the products

- Henri to present new web support system

www.alstom.com

Appendix H: Harmonisation

Harmonisation
of
thermal and space environment
analysis software

R. Schlitt
OHB System

Harmonization of Thermal and Space Environment Analysis Software

Reinhard Schlitt, OHB System AG

Hans Peter de Koning, ESA / ESTEC

- Overview
  - Background of ESTEC Harmonisation Activity
  - Present Situation and Need for Action
  - Inauguration of Steering Board
    - Objectives, list of members, working procedures
    - First Steering Board Meeting
    - Intended activity roadmap and actions

- Background of Harmonization Activity
  - T&SE Tools Harmonization Roadmap was presented on December 4 + 5, 2002 to National Delegations (A, CND, DK, F, D, N, S, CH, GB were present)
  - Consensus reached that
    - Standardized model data exchange is of primary importance
    - T&SE tools are essential for space product development.
    - Long term availability of such tools is of strategic importance for European Space Industry.

- Conclusions / Actions
  - (1) Continue with present program of activities for data exchange standards
  - (2) Establish a „Steering Board“ involving the user community
    - Clear mandate, but following existing ESA rules
    - Study existing solutions, cost benefit of new components, Open Source S/W
    - Define architecture and interfaces of a European library of S/W components to build thermal and space environment analysis tools
    - Recommend Go / No-Go decisions for development/implementation
  - (3) Maintain existing tools until equivalent (better?) tools ate available and/or required by running / planned ESA projects

- Present Situation and Need for Action
  - Many thermal S/W tools are existing, which are sometimes similar or have overlapping functionalities
  - Obviously no easy way to counteract this development
    - Quotation from a 1994 ESA study:
      - *„There are a great many S/W tools in use for space-related thermal engineering, but many of them are monolithic, not easily extendible and have overlaps in functionality, leading to a lot of functional redundancy and extra maintenance effort“*

The situation 10 years later has not changed or is even worse

- Selection of existing und future tools:
  - *ESATAN*, *THERMICA*, *ALTAN*, *TOPIC*, *ARTIFIS*, *CORATHERM*, GAETAN, *Condor*, *ThermXL*, *Cat (CAP and Power*) and many more…
  - And more to come: *Concept Design Tool, ESATAP, THERMOSS* …
  - Immediate consequence: Data exchange tools are needed and under development: *STEP-TAS*, *STEP-NRF*, *STEP-SPE*, *SET-ATS*, *TASVERTER*…
  - Interesting to observe: A mandatory exchange tool between *SINDA and ESATAN* is yet missing

– This situation is very surprising and not easy to understand
– T&SE tools are more or less non-commercial in nature due to the small user group (specialization in space engineering)
– In many cases they are developed and maintained by public funding. But then: Why so many tools??
– There are probably two main reasons for this situation:
  • System companies develop own tools (sometimes supported by national agencies) with the intention to reach a competitive edge in the space market
  • Developments in ESA and national agencies sometimes not sufficiently based on user requirements

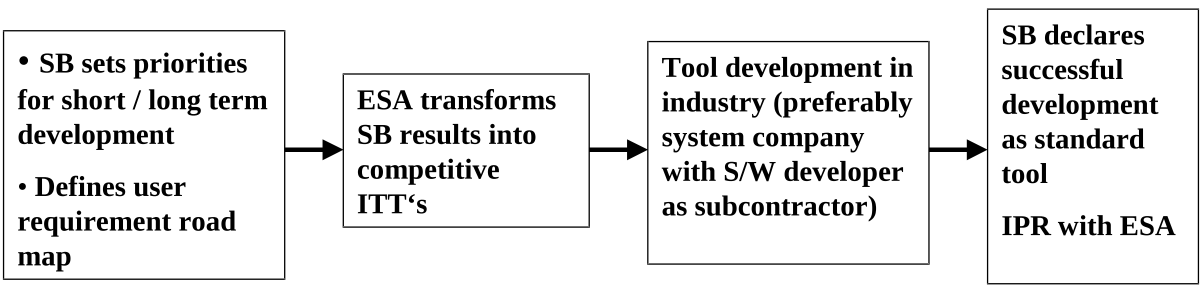
– Development at System Companies
  • Development of own engineering tools is based on a wide-spread misconception that own tools improve an industry‘s competitiveness. The contrary is the case:
    – Development of engineering tools cost invest budget and development resources
    – Maintenance difficult and costly, developers may leave the company
    – For tools developed for a certain project: What happens after termination of the project?
    – More important: System companies need to share data and recourses with subcontractors, which would not have the same software (also system companies are currently merging)
    – As consequence data conversion tools need to be developed, which again are costly and use valuable resources

- Automotive industry as a good example: Competing companies are sitting together in an effort to harmonize true commercial engineering tools, in order to facilitate data exchange with common suppliers
- European space industry moves in the opposite direction: With no realistic need different tools are produced, which need then to be harmonized by costly data exchange tools!

– Tool Development at ESA and National Agencies (public funding):
  - Several tools have been developed, which could not be successfully introduced into the user community
  - Probable reasons:
    – User community was not really involved in the beginning and during definition of requirements
    – “Marketing“ of ready products was not sufficient
    – There is a certain reluctance at companies to get involved in new S/W, because of personnel training, compatibility with existing tool infrastructure…

Let’s continue with what we have!

- The need for a “Steering Board“ (SB)
  – One important objective of the SB is to involve the user community from the beginning of a tool development



- The need for a “Steering Board“ (cont.)
  - We possibly need to change the way how we develop engineering tools

The primary rule should be:

To develop thermal engineering tools for the user community (and not solely for the customer)

- Developing contractors should therefore be requested
  - to communicate with the user community via a mailing list
  - to inform the community on the progress and ask for comments, discuss requirements
  - to have users test the S/W before delivery
  - to preferably use a web based information system, etc.

- Major board assignments
  - Increase user community involvement in S/W tool development
  - Conceive a concept for a common thermal / environmental S/W architecture, which is modular for selective application and successive development
  - Ensure modular architecture to define individual tasks for short / long term development
  - Implement existing and to be developed S/W for use by the entire community
  - Regulate maintenance
  - Convince companies to use common tools, which fulfill user requirements, in lieu of proprietary engineering tools
  - Care to avoid duplication. There should be only one tool for a certain functionality in this non-commercial environment

- Major board assignments (cont.)
    - Represent the user community (although not all users are members of the board)
    - Have the mandate to declare a certain tool as an engineering standard for the ESA user community.
    - Users shall preferably commit themselves to apply such tools
    - Ensure that relevant ESA ITT'S are based on Board decisions

- Organization of the Board
    – The SB consists of representatives of the T&SE user community from ESA member states
    – The SB has now 14 voting members and 8 observers
    – Members are balanced between Prime-Contractors (4), SME (3), Research Institutes (3), Agencies (4)
    – Observers are Prime-Contractors (3), Agencies (4), S/W Developer (1)
    – S/W developers are non-voting members and have status of observes
    – Voting members shall not be guided by company interests, but by the overall objective to establish autonomous European capabilities to improve competitiveness and quality
    – Members have selected *R. Schlitt* as Chairperson and *H. P. de Koning* as ESA Secretary
    – Board decisions are taken by majority voting of present voting members

- Board Tasks
  - The SB analyses and decides on major strategic items, including
    - User requirements
    - Development options
    - Strategy and coordination
    - Priorities
    - Interfaces
    - Maintenance
    - Distribution and support
  - The SB extends and/or amends board rules by a 2/3 majority of the voting members

- Executive Team
  - The SB has nominated an Executive Team (ET) consisting of three SB members (Hans Peter de Koning [ESA], Eric Werling [CNES], Darius Nikanpour [CSA])
  - The ET performs the day-to-day management of running activities

- Board Mandate
  - Mandated to take all decisions concerning developments of future T&SE analysis software (based on ESA‘s infrastructure budget)
  - ESA will make best effort to ensure implementation of decisions taken by the SB (the SB has formally no budget authority)

- First Study
  - The final Harmonization meeting agreed on an initial study phase to define a development road map, which addresses the following:
    - Identify and list existing solutions and products
    - Conduct a cost benefit analysis for components and/or blocks to be developed
    - Investigate the applicability of the OSS methodology
    - Estimate total cost to completion and yearly maintenance costs
    - Establish schedule and priorities
    - Establish methodology for distribution and maintenance
  - The task shall be performed as a Business Case Study
    - SOW to be established by the ET
    - Contract in DN to ASTRIUM (D, FN) and Eta_Max (D)
  - Next meeting of the SB takes place in November 03

Board Voting Members

first_name	*last_name*	*affiliation*	*country*	*discipline*	*voting*	*remark*
Patrick	Hugonnot	Alcatel Space Industries	France	thermal	1	Prime contractor
Valter	Perotto	Alenia Spazio	Italy	thermal	1	Prime contractor
Burkhard	Behrens	Astrium GmbH (EAD S/ST from July 2003)	Germany	thermal	1	Prime contractor
Markus	Huchler	Astrium GmbH	Germany	thermal		Prime contractor
Andrew	Robson	Astrium Ltd.	UK	thermal	1	Prime contractor
Philippe	Chéoux-Damas	Astrium SAS	France	thermal + space environment		Prime contractor
Christian	Vettore	Carlo Gavazzi	Italy	thermal	1	SME
Eric	Werling	CNES	France	thermal	1	Agency
Darius	Nikanpour	CSA	Canada	thermal	1	Agency
John	Sørensen	ESA TOS-EMA		space environment	1	Agency
Hans Peter	de Koning	ESA TOS-MCV		thermal	1	Agency
Holger	Sdunnus	eta_max	Germany	space environment	1	SME
Reinhard	Schlitt	OHB System	Germany	thermal	1	SME
Jean-François	Roussel	Onera	France	space environment	1	Research institute
Peter	Truscott	QinetiQ	UK	space environment	1	Research institute
Bryan	Shaughnessy	Rutherford-Appleton Lab's	UK	thermal	1	Research institute
				total	14	

Board Observing Members

first_name	*last_name*	*affiliation*	*country*	*discipline*	*observer*	*remark*
Markus	Huchler	Astrium GmbH	Germany	thermal		Prime
Andrew	Robson	Astrium Ltd.	UK	thermal		Prime
Philippe	Chéoux-Damas	Astrium SAS	France	thermal + space environment	2	Prime
Pierre	Bousquet	CNES	France	space environment	1	Agency
Luca	Maresi	ESA IMT-TH		technology harmonisation & strategy	1	Agency
Éamonn	Daly	ESA TOS-EMA		space environment	1	Agency
Charles	Stroom	ESA TOS-MCV		thermal	1	Agency
Kevin	Duffy	Maya Heat Transfer Technologies	Canada	thermal	1	Developer
				total	8	

Appendix I: Open Source Software for Engineering

Open Source Software
for
Engineering Purposes

M. Haupt
University Braunschweig

Applicability of OSS to Space Thermal Engineering
Open Source Software for Engineering Purposes

17th Thermal and ECLS Software Workshop
21. – 22. October Noordwijk ESA/ESTEC

Matthias C. Haupt

Institute for Aircraft Design and Lightweigth Structures
Institut für Flugzeugbau und Leichtbau
Technische Universität Braunschweig

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Reinhard Schlitt (OHB)
Frank Bodendiek (OHB)

Agenda

- Background
- Open Source Software
- Tool Integration
- Application
- Conclusions

Background

Therm-OSS Project:

- Application of the **open source software** (**OSS**) development model
- Thermal design and analysis tool
- ... made of OSS existing modules

Therm-OSS Approach:

- Survey of suitable OSS for the tool and the development
- Development of the general architecture
- Implementation, test and ...

Background

Approach of the OSS survey:

- **What** we have looked for:
  - Functions for modelling and simulation
    - geometry, properties, grid,
    - mission and environment,
    - radiation, conductances,
    - solver, postprocessing
  - Engineering environment
    - scripting language, configuration control, graphical user interface
  - Development infrastructure
    - CASE (design and implementation)
    - configuration and installation
- **How** we have done the search:
  - collecting information available at team members and interested people
  - Searching in the internet at potential sites, e.g. http://sal.kachinatech.com/, http://sourceforge.net
  - keword search with seach services, e.g. www.google.com , www.google.de , www.lycos.com
  - look over the link collections of (OSS) internet pages

Background

Formal criteria of software selection:

- Initiation of the project (age) and Version development (continious development)
- License type
- Dependency on other software (language, OSS, non-OSS, complexity) and operation systems

Functional criteria:

- Provided functionalities
- Architectural features
- Algorthmical core (correctness)
- Documentation (theory reference, user manual, tutorials, examples, ...)
- Software quality (source code, configuration,version control)

Subjective criteria:

- Expected future of the project (continuation, user community,)
- Recommendation for Therm-OSS (suitable, integration)

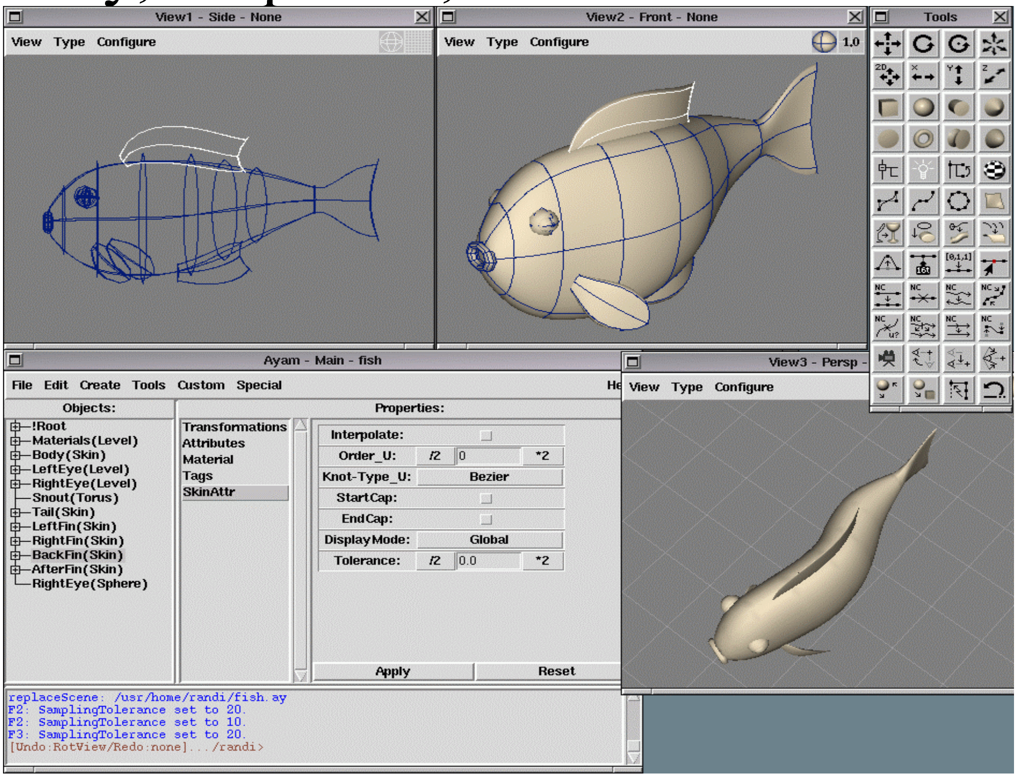
OSS: Geometry, Properties and Grid

Considered Tools: (support of primitives and structured grids)

Ayam	www.ayam3d.org	CSG, NURBS, RenderMan, tcl
Blender	www.blender3d.org	Meshes, NURBS, animation, rendering, radiosity, Python
Giram	www.giram.org	Primitives, CSG, POV, AutoCAD
innovation3d	innovation3d.sourceforge.net	Meshes, (NURBS), (RIB)
K-3D	k3d.sourceforge.net	Primitives, Meshes, CSG, RIB, animation, div. scripting
OpenCascade	www.opencascade.org	Primitives, CSG, ... CAD
VRS	www.vrs3d.org	Primitives,Meshes, Animation, library, Tcl-GUI
Chalmesh	www.na.chalmers.se:80/~andersp/chalmesh	3D overlapping grid generator
Gmsh	www.geuz.org/gmsh	3D FEM grid generator, build-in CAD, post-processing
NETGEN	www.hpfem.jku.at/netgen	3D tetrahedral mesh generator, CSG, Brep(STL), OCC, solver
QMG	www.cs.cornell.edu/home/vavasis/qmg-home.html	Geometric modelling(Brep), 2/3D mesh generator, solver, Tcl/Tk

OSS: Geometry, Properties, Grid

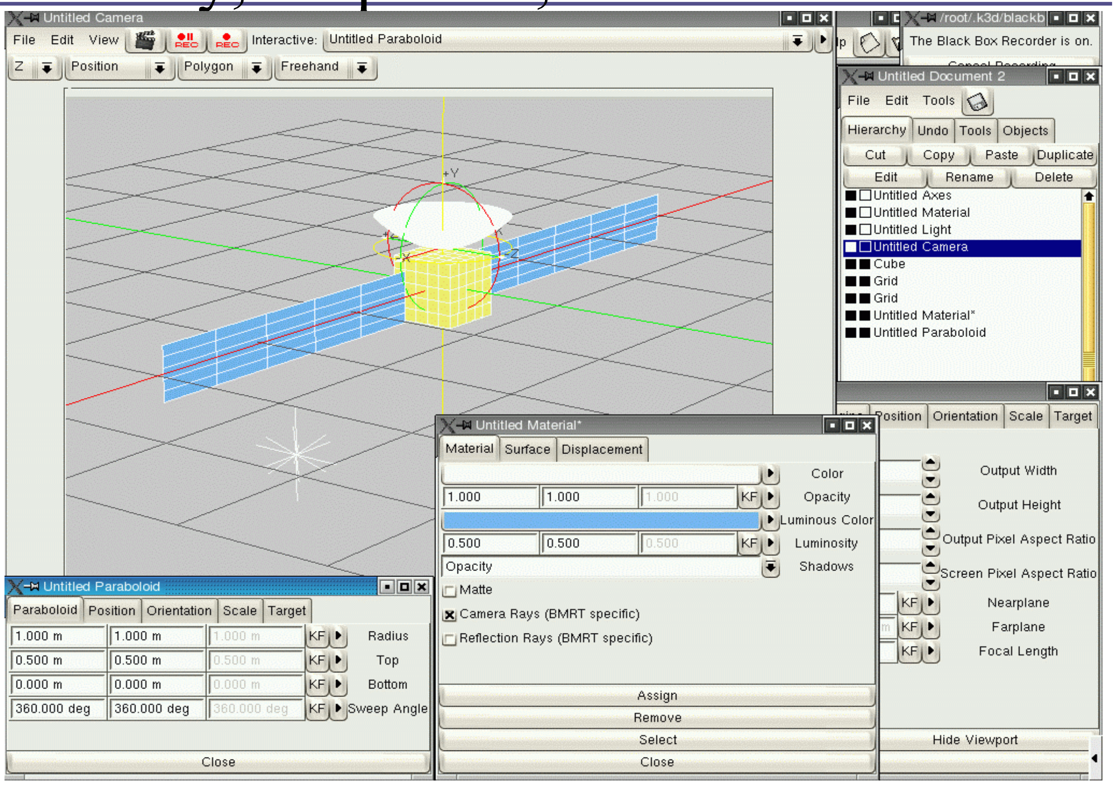
- ayam
- Primitives
- NURBS
- Editing
  - extrude
  - sweep
  - revolve
  - ...
- Material
- RenderMan
- Uses
  - tcl
  - OpenGL



IFL

OSS: Geometry, Properties, Grid

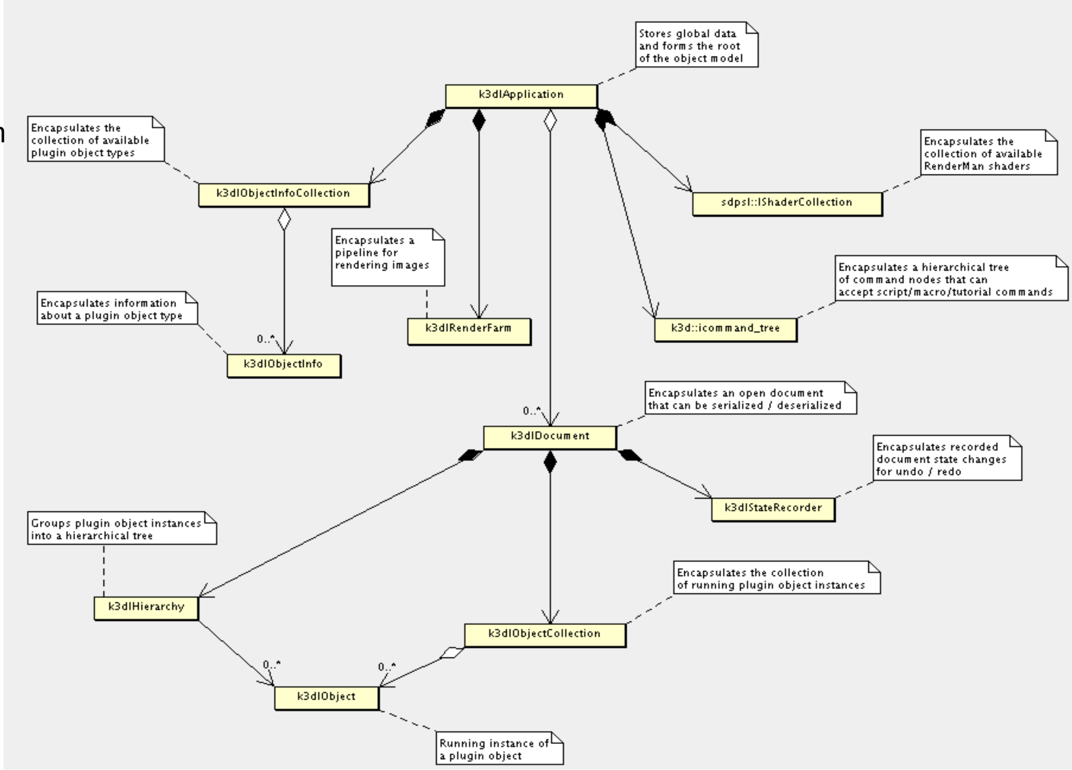
- k-3d
- Primitives
- Meshes
- Editing
- Material
- RenderMan



IFL

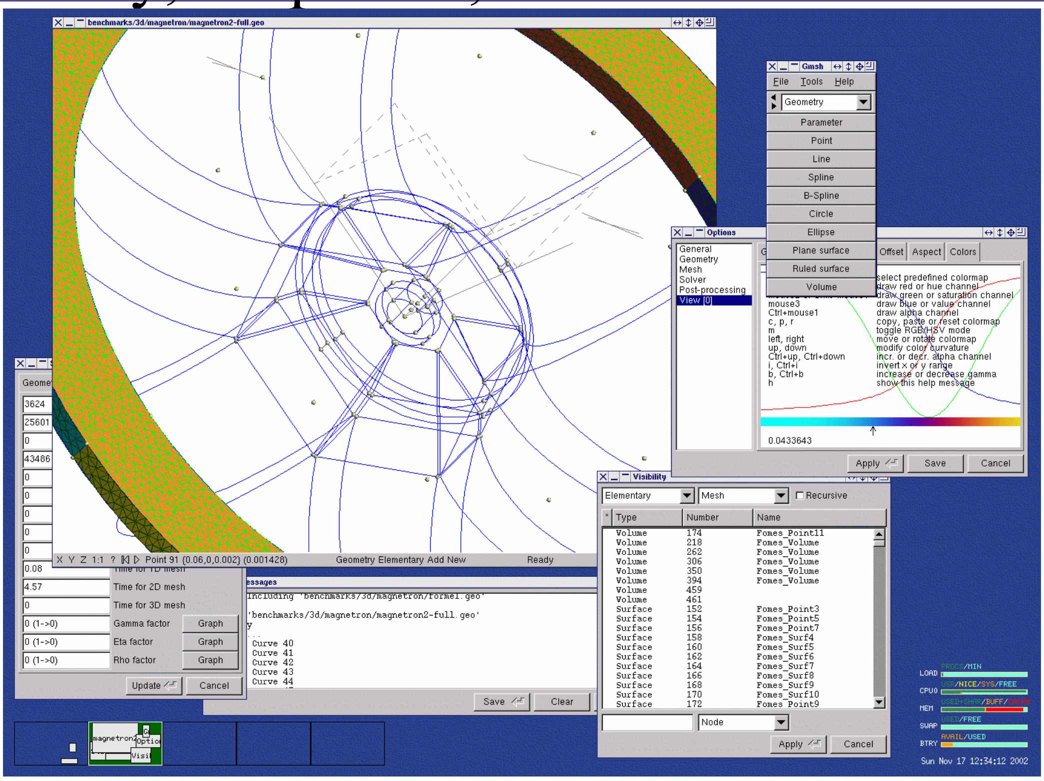
OSS: Geometry, Properties, Grid

- k-3d
- UML diagramm of Top-level
- Uses
  - GTK
  - OpenGL
  - XML



OSS: Geometry, Properties, Grid

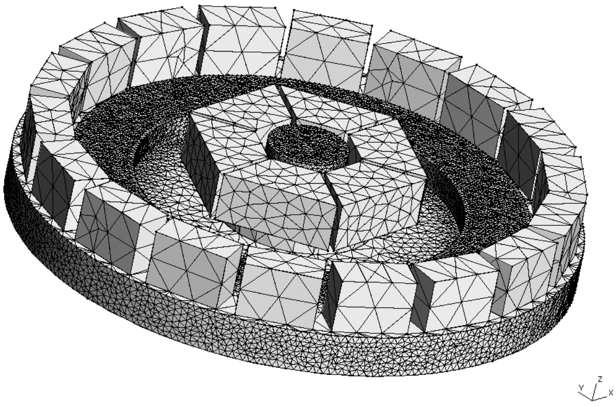
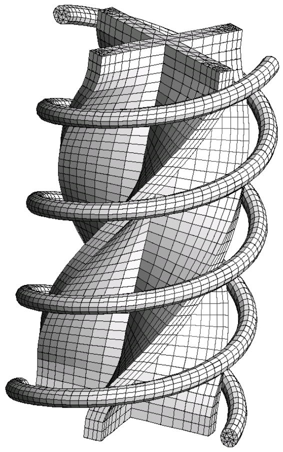
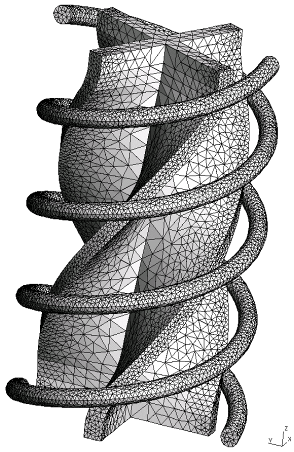
- Gmsh
- FEM environment
  - CAD
  - grid generator
  - Postprocessing
- Uses
  - FLTK
  - OpenGL



OSS: Geometry, Properties, Grid

- Gmsh

- Grid examples
  - Structured grid
  - Unstructured grid

OSS: Mission and Environment

Considered orbit propagators: **(DEIMOS Space contribution)**

- Predict - Satellite tracking and orbit prediction programm (SGP4,SDP4), additional tools (time converters, Calculate_Solar_position, Calculate_LanLonAlt, ...)
  www.qsl.net/ks2bd/predict.html

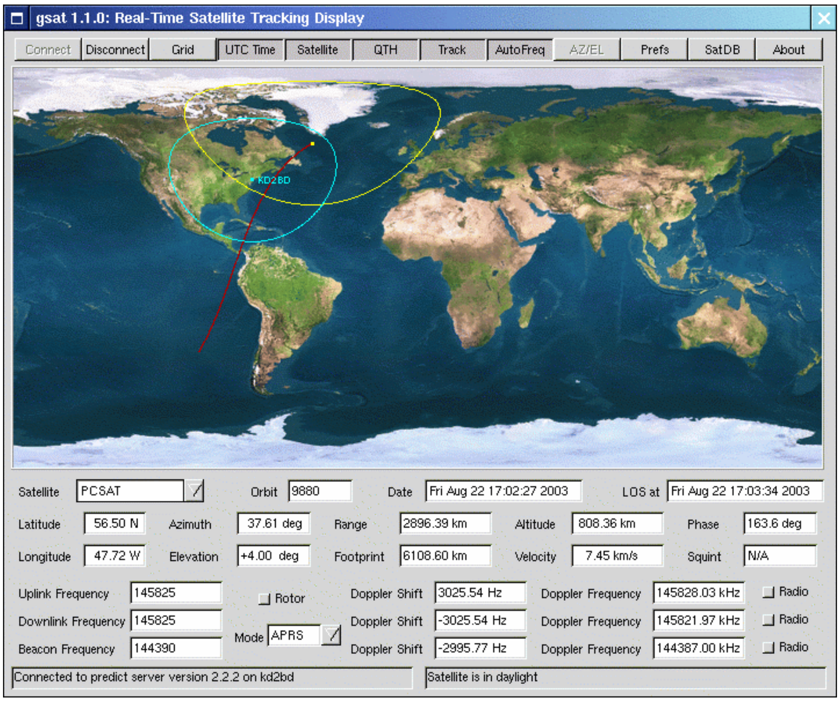
- GLSat - Satellite tracking and visualisation utility (SGP, SGP4)
  http://sourceforge.net/projects/glsat

- Project Pluto - Orbit predictor (SGP4/8,SDP4/8), additional tools (ALT_AZ, CLASSEL, EARTH2000)
  http://www.projectpluto.com/sat_code.htm

- ORSA - Orbit reconstruction, Simulation and Analysis framework for celestial mechanics.
  N-body integrators; http://orsa.sourceforge.net

OSS: Mission and Environment

- Predict
- Real-time satellite tracking and orbital prediction information
  - System console
  - Command line
  - Network socket



- Gsat client connected to Predict

- Used by
  - NASA: Goddard Spaceflight Center
  - US Naval Research Laboratory
  - Interferometrics: AMRAD-OSCAR-27
  - SUNSAT-OSCAR-35 Satellite Command Team
  - Stanford University's Space System Development Laboratory (SSDL)
  - Caltech: aligning radio telescopes against the sun position

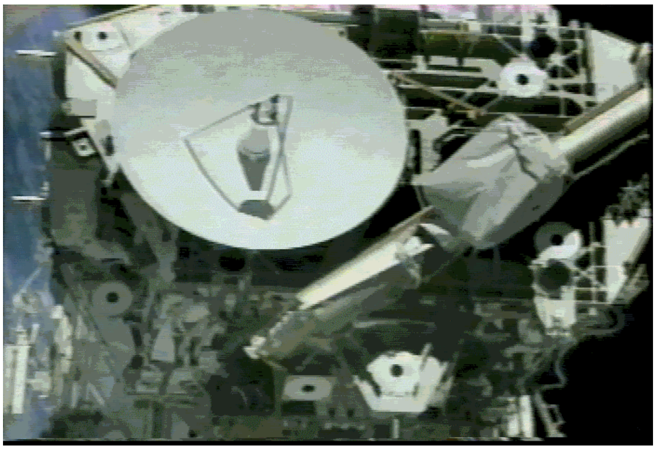
OSS: Environment and Loads

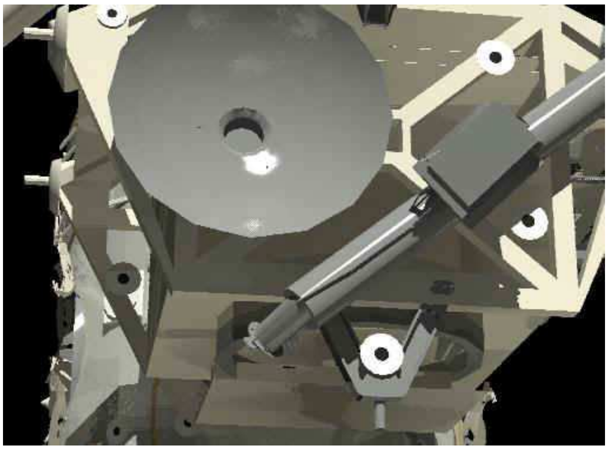
Considered radiosity tools: **(DEIMOS Space contribution)**

- POV-Ray - Renderer for photo-realistic images, radiosity method similar to Radiance;
  http://www.povray.org
- Radiance - Radiosity appoach for lighting simulation, (view dependent);
  loyd.lbl.gov.radiance.
- Blender - Integrated modeling and rendering; (hard to extract the radiosity module);
  http://www.blender.org
- Glutrad - simple and fast radiosity engine;
  http://www.cix.co.uk/~colceck/glutrad.htm
- HELIOS - C++ code of the book: Radiosity, Ian Ashdown (1994);
  http://www.cs.bilkent.edu.tr/~gudukbay/helios.tar.gz
- Raddoom - Java code of dynamic surface subdivison radiosity;
  http://perso.wanadoo.fr/psychomad/logiciels
- Radiator - Matrix, progressive and wavelet radiosity with clustering;
  http://www-2.cs.cmu.edu/afs/cs/user/ajw/www/software/
- RadiosGL - (Non-)Realtime radiosity renderer, form factor calculation using hemicube method,
  http://hcsoftware.sourceforge.net/RadiosGL/RadiosGL.html
- RenderPark - Various ray-tracing and radiosity algorithms; (Support?)
  www.cs.kuleuven.ac.be/cswis/research/graphics/RENDERPARK

OSS: Conductances and Solution

- Radiance
- Lighting Simulation and Rendering System





- Actual lighting for Z1 target array capture (video downlink)
- Predicted lighting for Z1 target array capture

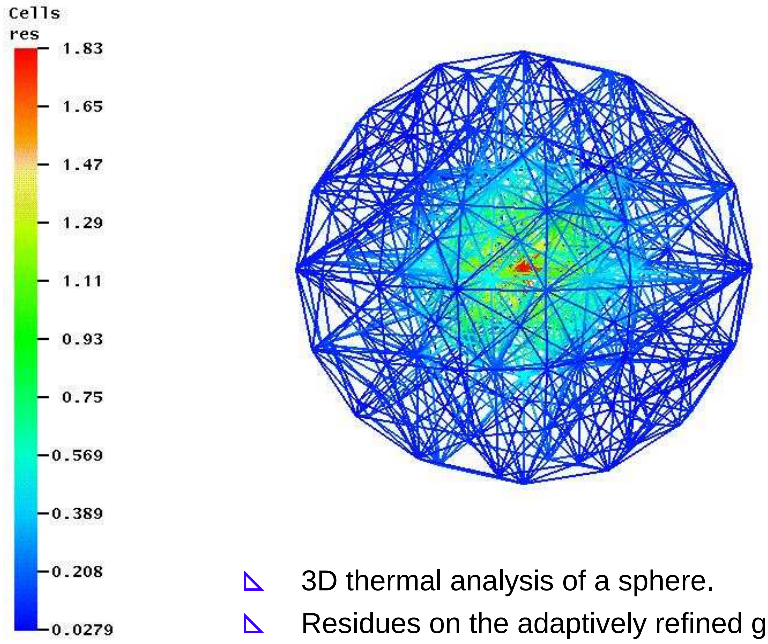
OSS: Conductances and Solution

Considered FEM/FDM solver: (support of heat transfer / structured grids)

- Deal.II - library for adaptive FEM with error estimation http://www.dealii.org/
- Feat - System for FEM (domain description, mesh generation, shape functions, loads, boundary conditions, solution, error evaluation, graphical postprocessing http://www.featflow.de/
- FreeFem - Implementation of a language dedicated to the finite element method. Http://www.freefem.org/
- MODULEF - library for FEM (automatic mesh generation, loads, boundary conditions, …) http://www-rocq.inria.fr/modulef/english.html
- Mouse - OO framework for FVM on unstructured grids http://fire8.vug.uni-duisburg.de/MOUSE/
- Ofeli - library of finite element C++ classes http://ofeli.sourceforge.net/
- Overture - object-oriented code framework for solving partial differential equations with FDM, FVM http://www.llnl.gov/casc/Overture/
- Tochnog - FEM system, http://tochnog.sourceforge.net/

OSS: Conductances and Solution

- Tochnog
- Commercial support by FEAT (NL)
- GPL.
- Equations:
  - Convection-diffusion
  - Stokes and Navier-Stokes
  - Elasticity.
  - Elasto-Plasticity.
  - Hypo-Plasticity.
  - Damage.
  - Thermal stresses.
  - Hypoelasticity.
  - Viscoelasticity.
  - Viscosity.
  - Wave equation.



- 3D thermal analysis of a sphere.
- Residues on the adaptively refined grid.

OSS: Conductances and Solution

Considered general solvers:

- LASPack - Iterative solver package (CGN, GMRES, BiCG, QMR, CGS, BiCGStab), multilevel, multigrid; www.tu-dresden.de/mwism/skalicky/laspack/laspack.html
- PETSc - Krylov subspace methods, Newton-based nonlinear solvers, timestepping (ODE) solvers; www-unix.mcs.anl.gov/petsc/petsc-2
- SUNDIALS - Solver for initial value problems for ordinary differential equation systems and nonlinear algebraic systems.
  www.llnl.gov/CASC/sundials

OSS: Postprocessing

Considered plotting tools:

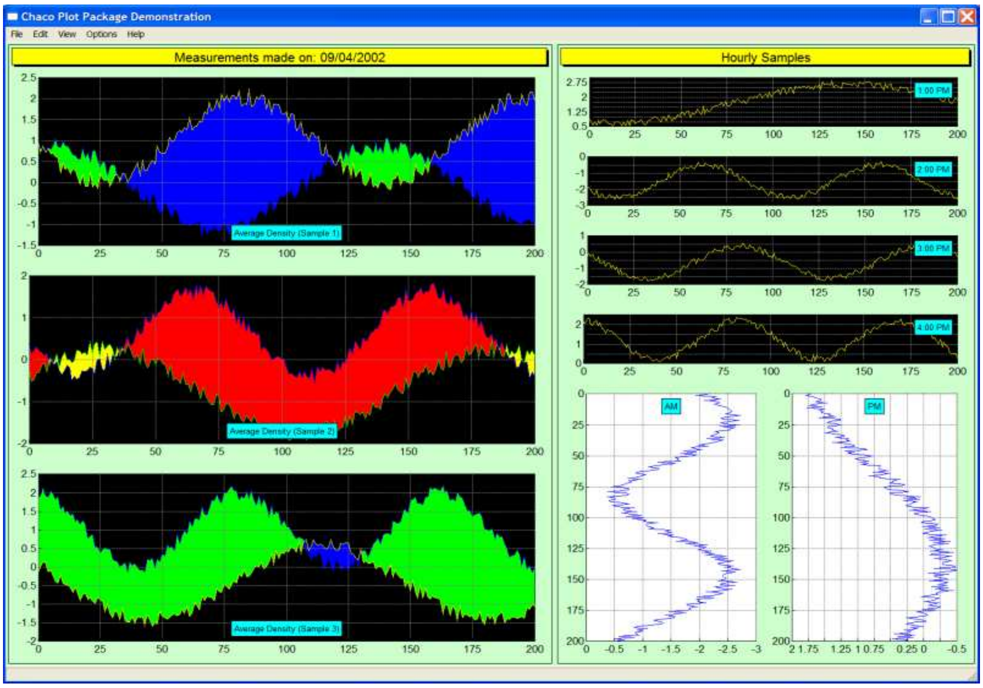
- Chaco - presentation quality scientific 2D graphics on a variety of output devices, http://www.scipy.org/site_content/chaco
- Gnuplot - command-driven interactive function plotting program, http://www.gnuplot.info/
- Grace - WYSIWYG 2D plotting tool for the X Window System and M*tif. (export of eps, pdf, MIF, SVG, PNM, jpeg, png; FFT analysis; curve fitting) http://plasma-gate.weizmann.ac.il/Grace/
- PLplot - library of scientific plot functions, can be used from C, C++, FORTRAN and Java, and Octave, Python, Perl and Tcl; http://plplot.sourceforge.net/.
- VisAD - Java component library for interactive and collaborative visualization and analysis of numerical data. https://sourceforge.net/projects/visad/.

Considered 3D visualisation tools:

- OpenDX - software package for the visualization of scientific, engineering and analytical data. Motif and X GUI, enhanced data model, advanced execution environment; http://www.opendx.org/
- VTK - C++ class library for 3D computer graphics,support for Tcl/Tk, Java, and Python; http://www.vtk.org

OSS: Plotting tools

- Chaco is a platform independent plotting library for Python
- Enthought, Inc. for the Space Telescope Science Institute (STScI)
- BSD license.
- Graphics toolkits:
  - wxPython
  - Tkinter
  - OpenGL
  - PDF
  - SVG
  - PIL



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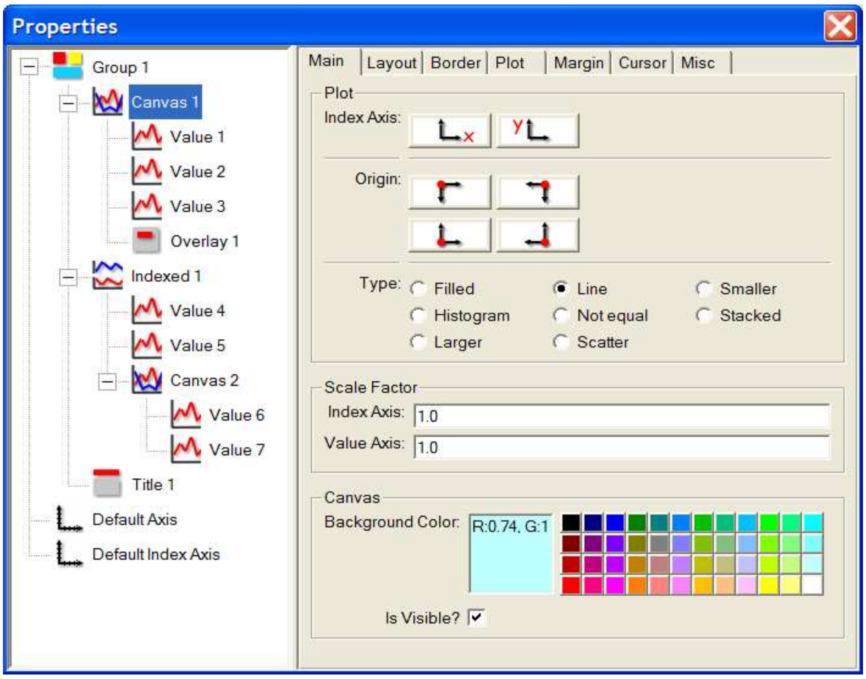


IFL

OSS: Tool Integration

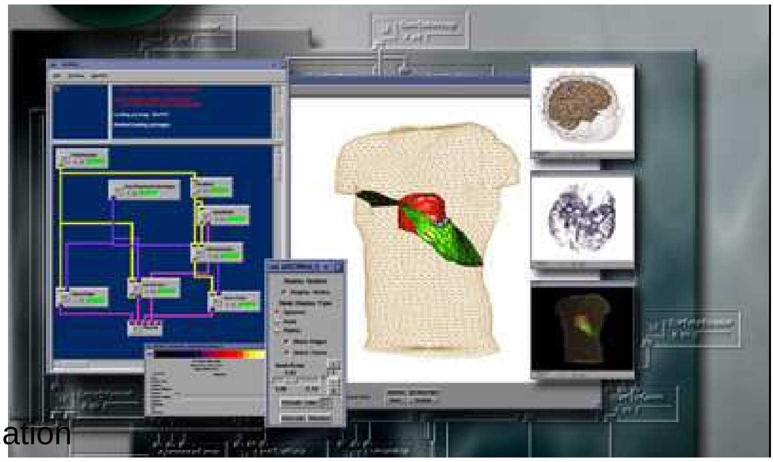
Three considered Integration Environments:

- SCIRun - Problem Solving Environment;http://software.sci.utah.edu/scirun.html
- XCAT - Common Component Architecture (CCA) of the Indiana University, Extreme Lab; http://www.extreme.indiana.edu/xcat/
- Ccaffeine - A CCA prototype framework for distributed memory message passing High Performance Computing; http://www.cca-forum.org/ccafe/.
- `ifls` - A integration environment build of OSS components, based on Python and VTK

IFL

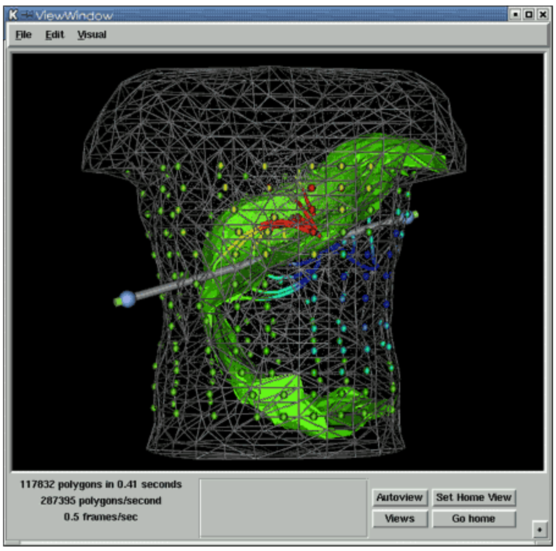
OSS: Tool Integration

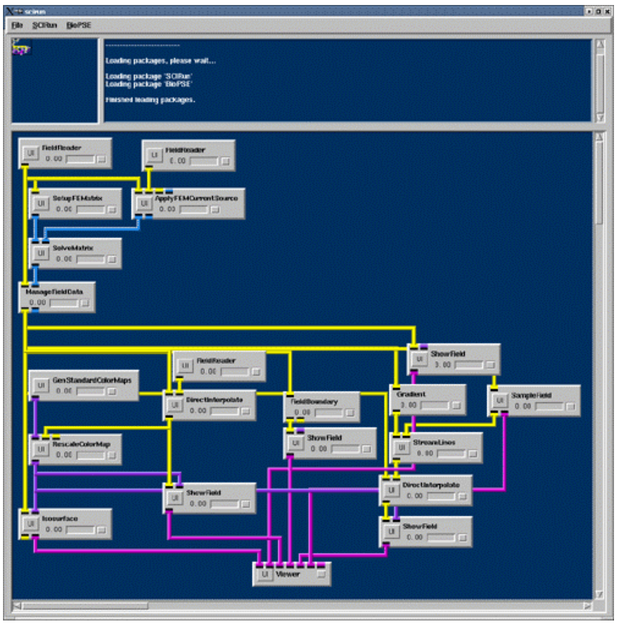
- SCIRun is a Problem Solving Environment
- Computational Workbench
  - Rapid Prototyping
  - Module Development Tools
  - Extensible: Data, Algorithms
- Visual Programming
  - Computational Steering
  - Dataflow Interface
- Modeling, Simulation and Visualization
  - Model Construction and Manipulation
  - Numerical Approximation and Solution of PDE's
  - Scalar, Vector, and Tensor Field Visualization
- High-Level Utilities
  - Scene Graph and Widget Libraries
  - Math, Geometry, and Field Libraries
- Low-Level Utilities
  - Thread, Memory and Task Management



OSS: Tool Integration

- SCIRun is a Problem Solving Environment
- Example: Bioelectric Field Simulation





OSS: Tool Integration

ifls – Objectives of our development:

- Automation and integration of the workflow
- Flexible data transfer between tools
- Integration of different source codes as well as (commercial) executables
- Simplicity, clearness, flexibility and robustness of the integration approach
- Efficient rapid prototyping for new (sub-)tasks
- Interoperability with project partners
- No monolithic tool but building blocks (build your own application)

We develop methods to solve our engineering problems

- Use of available technologies, standards and tools

. . . suitable **Open Source Software (OSS)**

Application: Airplane Design

Task in Airplane Design and Analysis:

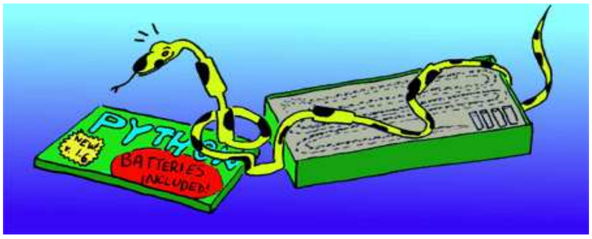
- Generic design with parametric geometry
- Use of proper design tools (e.g. CAD)
- Direct link to simulation and analysis codes with feed back
  - Derivation of corresponding analysis models (e.g. FVM, FEM, MBS)
  - Flexible postprocessing … system properties
- Mono- / Multidisciplinary studies in one environment
- Optimization w.r.t. various criteria and arbitrary design variables
- Integration into a Product Data Management Environment
- (Incorporation of knowledge based methods)

OSS: Tool Integration

Basic components of ifls:

- **Python**

  Object-orientented scripting language contains elements of traditional languages
  - Nice, simple syntax
  - Modular structure
  - Great number of books
  - Unix, Windows, ... very stable
  - Scientific computing
  - Increasing acceptance



```
Class MyClass:
    "A simple example class"
    i = 123
    def f(x):
        if x > 0:
            return 1
        else:
            return 0
```

- Standard packages of **Python**
  - **Tkinter**:
    Widgets from Tk for GUI's
  - **Numerical**:
    Vector / matrix objects
  - **Scientific Python**:
    Scientific tools, MPI, NetCDF, Optimization, ...

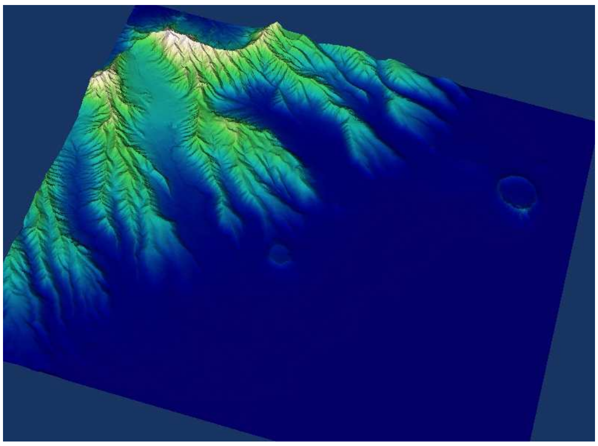
- Interface generators
  - **pyfort**: **Fortran**
  - **swig**: **C, C++**

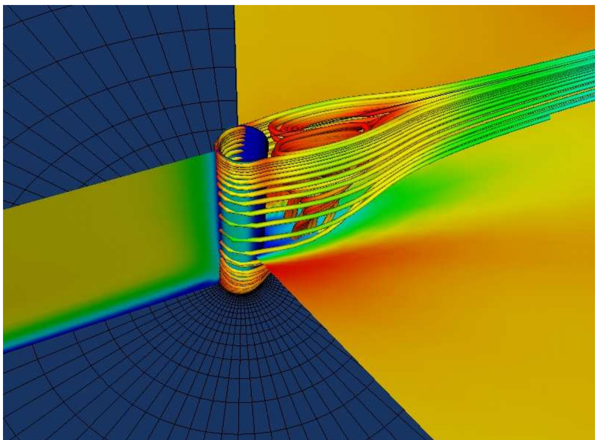
OSS: Tool Integration

- Visualization Tool Kit **vtk**

  3D computer graphic system, defines the architecture

- compiled kernel **C++**
- Wrapper for **Tcl**, **Java** and **Python**
- Render windows, renderers, actors, properties, lights, cameras
- Data objects (general, grid data), Process objects (source, filter, mapper)
- Reference books and examples
- OpenGL ... WinTel, Unix
- I/O for VRML, IGES, 3DS, HDF, …



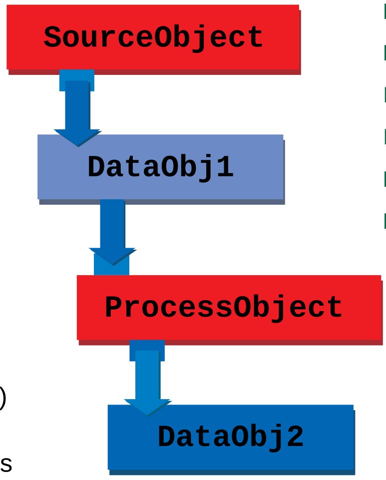


OSS: Tool Integration

Visualization pipeline of `vtk`

- **Data Objects**
  represent information
  - Methods to create, access and delete this information
  - Methods to obtain characteristic features

- **Process Objects**
  operates on input data to generate output data
  - Sources interface to external data (Reader) or generate data from local parameters
  - Filter require one or more input data objects and generate one or more output data objects
  - Mapper objects are used to convert data into graphical primitives




```
Reader = SourceObject()
DataObj1 = Reader.GetOutput()
Filter = ProcessObject()
Filter.SetInput( DataObj1 )
DataObj2 = Filter.GetOutput()
DataObj2.Update()
```

- **Pipeline Execution**
  causes process objects to operate
  - Implicit control implemented demand-driven
  - Process object execution if input change
  - Two-pass process: update and execution

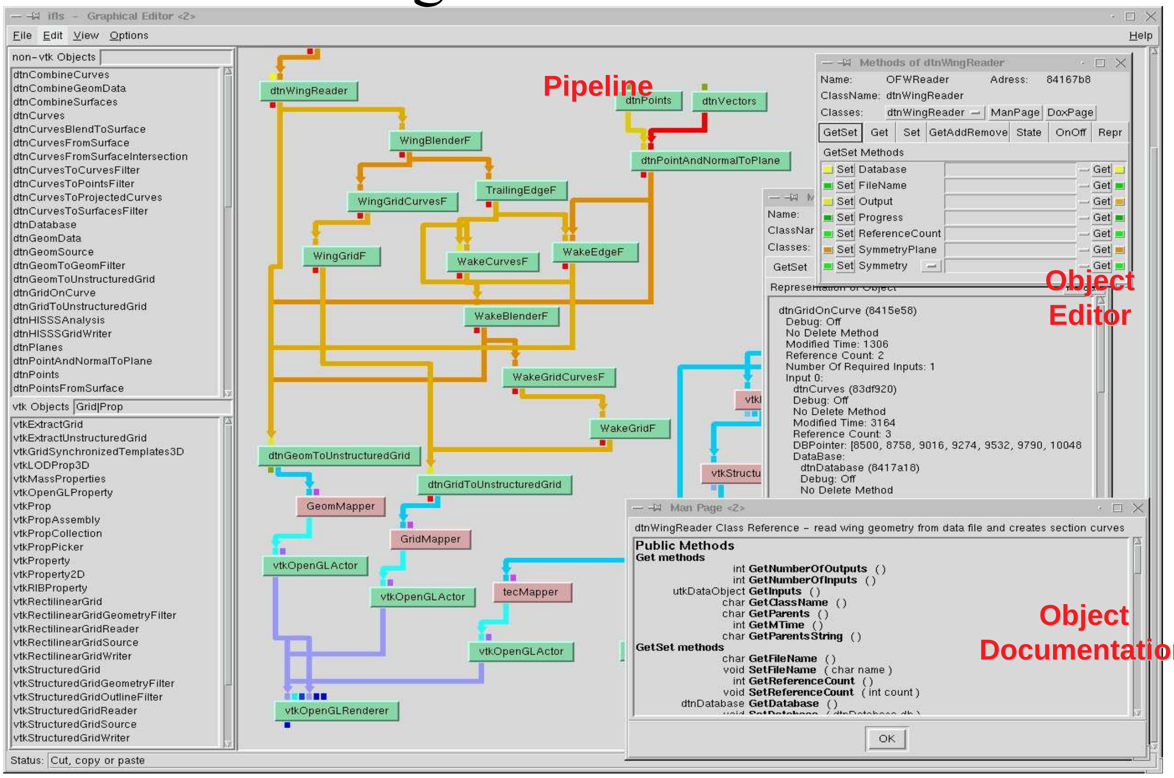
OSS: Tool Integration

Integration environment `ifls`

- **Extension modules**
  - `utk` connects `vtk` and pure `Python` objects to maintain pipeline mechanisms
  - `usr` extents the cababilities of the `vtk`-process objects
  - `dtn` with special data and process objects for geometry and grid generation based on `DTNURBS` (`IGES`) and `GridLib`
  - `stk` with process and import/export objects for analysis and simulation in a distributed environment
    (Structure: `Ansys, MSC, Abaqus`, Fluid: `HISSS, Flower, Cavecats, Tau`)

- **Graphical editor**
  - Interactive manipulation and visual programming
  - Analyses the programmed object interactions/networks
  - Visualizes the object interactions (tree / graph)
  - Coding conventions for the automatic generation of the networks, object editors and documentation (html, latex, postscript, pdf).
  - `Python` codes are executable without the graphical editor in batch mode, because the GUI is an optional feature.

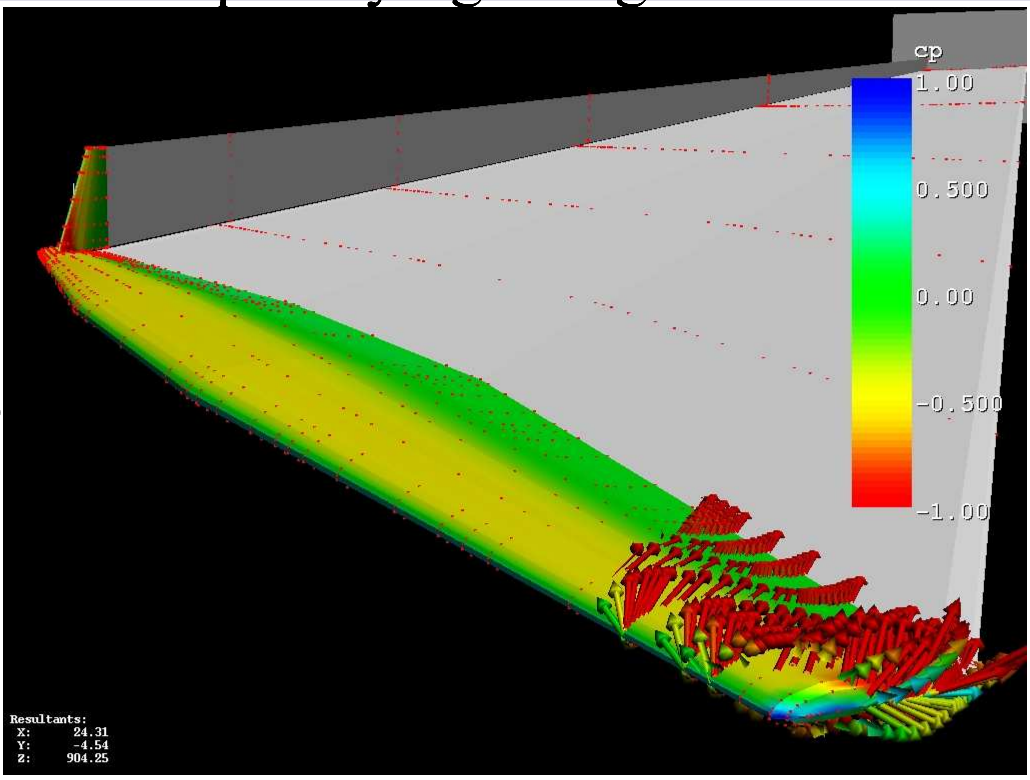
OSS: Tool Integration GUI



Application: Oblique Flying Wing

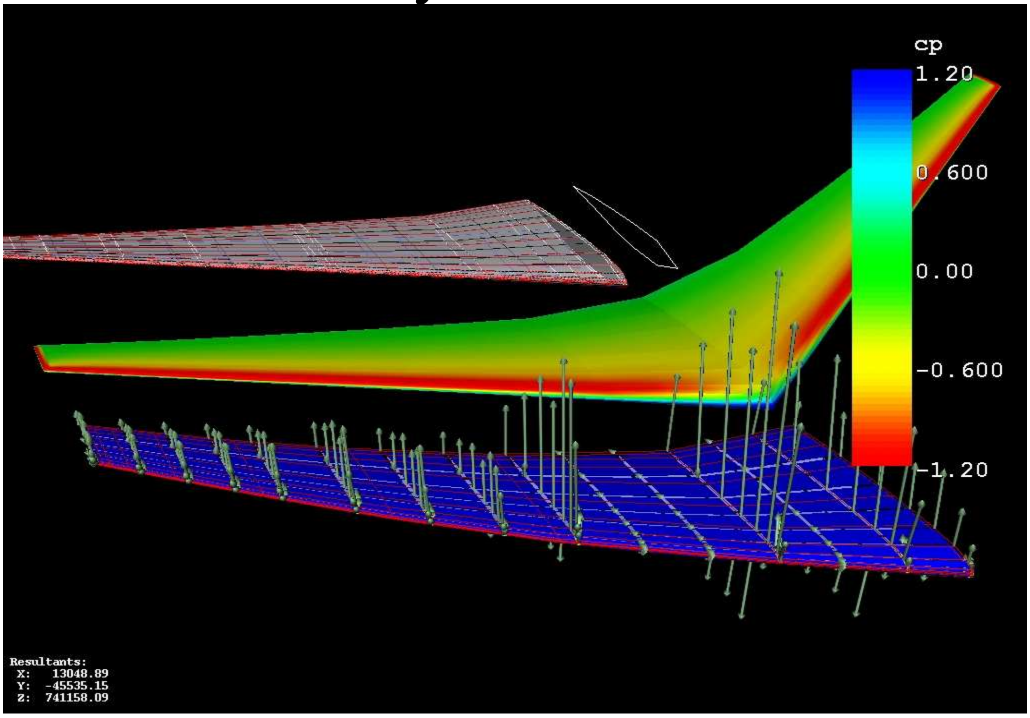
- Geometry by **DTNURBS**
  wing, fin, wake
  ***.db** (PrADO)
- Grid by **GridLib**
  ***.msh** (HISSS)
- Results
  ***.sca** (HISSS)
  ***.plt** (Tecplot)

- Aerodynamic Loads
- Derivatives
- Optimization
- Interactive variations
- Student projects



Application: Aeroelasticity

- Reference geometry
- Euler code
- MSC/Nastran
- Coupling iteration
  for the
  equilibrium state



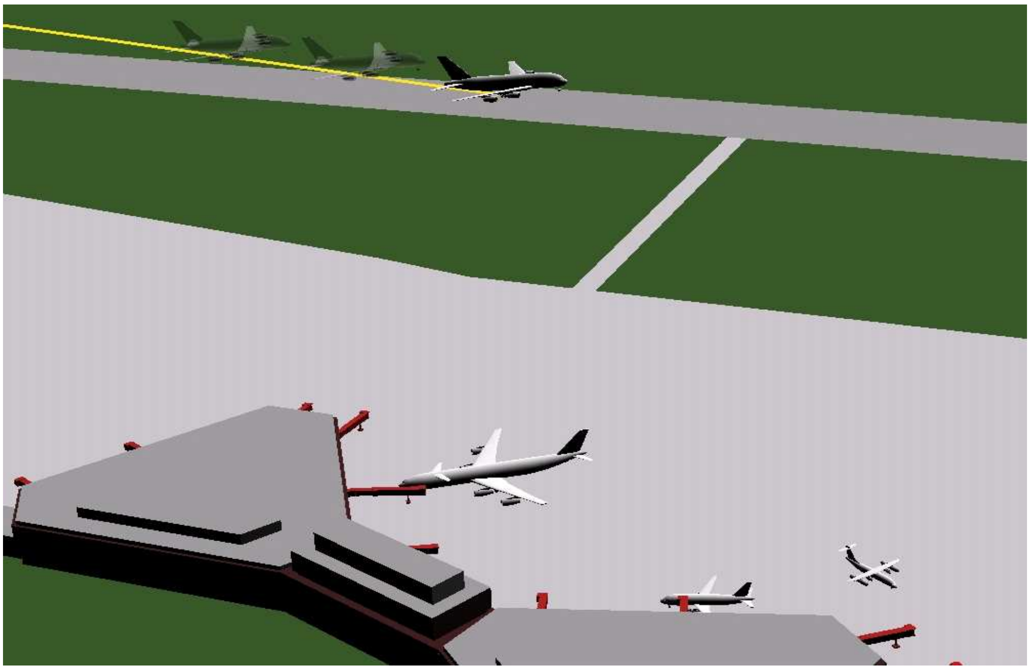
- Deflection transfer by `vtkProbeFilter` and self-developed hybride techniques

Application: Airport Environment

- Flight dynamic simulation with `JSBSim` from the `FlightGear`-Project

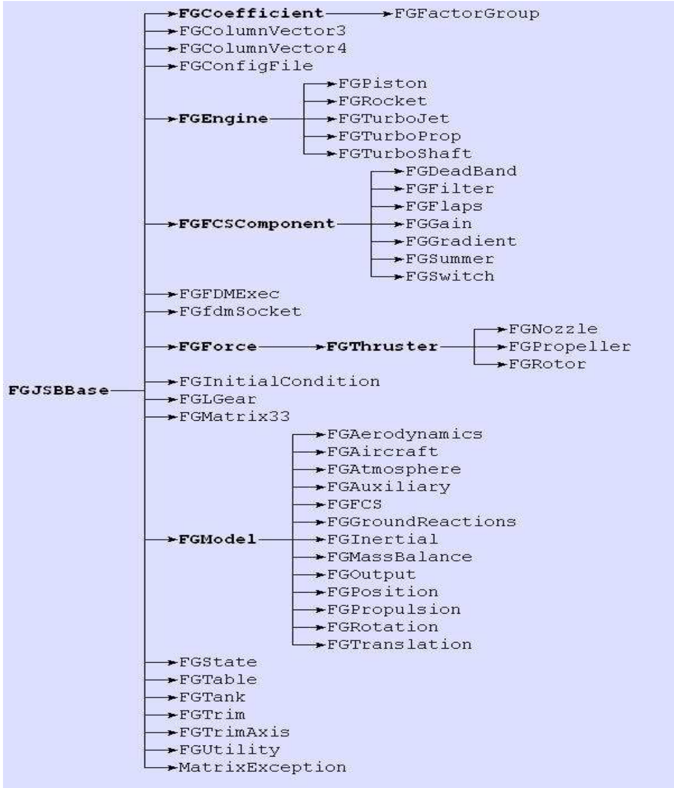
- Complete set of the equation of motion including ground forces and FCS

- `XML`-formatted description of
  - Geometry
  - Massprops
  - Aerodynamics
  - LandingGear
  - Propulsion
  - Initial state



- Servoelasticity

Application: Airport Environment



- Flight dynamic simulation with **JSBSim** from the **FlightGear**-Project

- Complete set of the equation of motion for the simulation in the time domain
- Class diagramm (end of 2001)
  - **C++** implementation
  - Wrapped by **swig**
  - **XML** generator for **HISSS** aerodynamics
  - maneuver loads
  - script or interactive use

Application: Therm-OSS

- Therm-OSS - Statement of work:

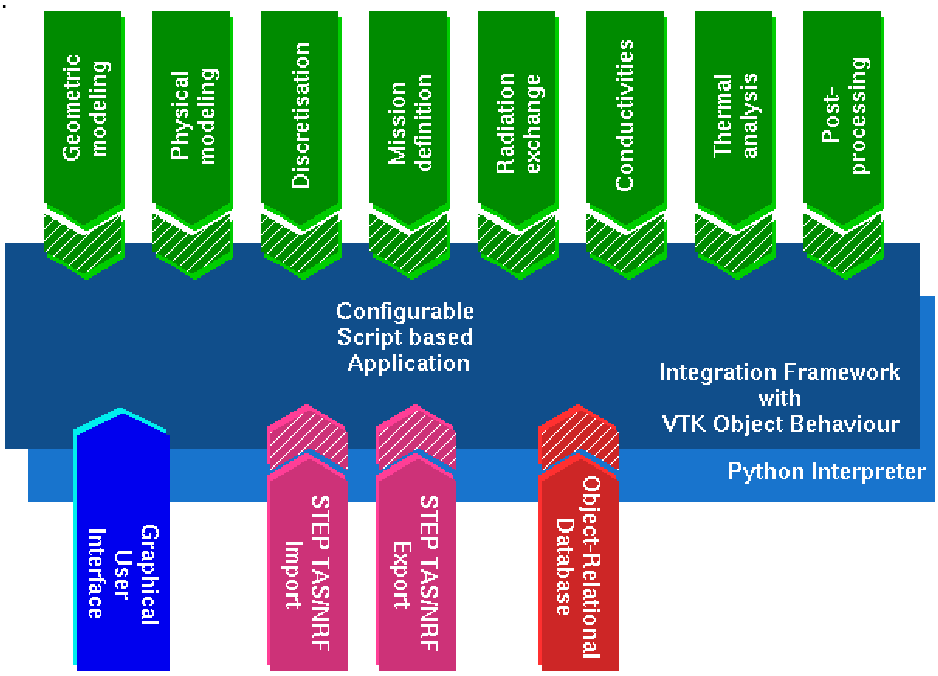
„The system to be developed, will be able to perform the complete thermal analysis of a spacecraft, or part thereof. This includes:

- the definition or modification of a model of the spacecraft or component
- the definition or modification of a model of the environment;
- the definition or modification of a model of the mission and scenario;
- the definition and execution of the analysis, defined by the above steps;
- the evaluation or assessment of the results.

To build a model of a spacecraft, or component, the user will have available a catalogue building blocks (or objects). In this first version, the geometrical forms will be limited to a few simple ones, such as plane quadrilaterals, boxes, complete cylinders and complete disks. The building blocks and the assembly tree will be stored, together with all related thermo-physical properties in an object-relational database (e.g. PostgreSQL)“

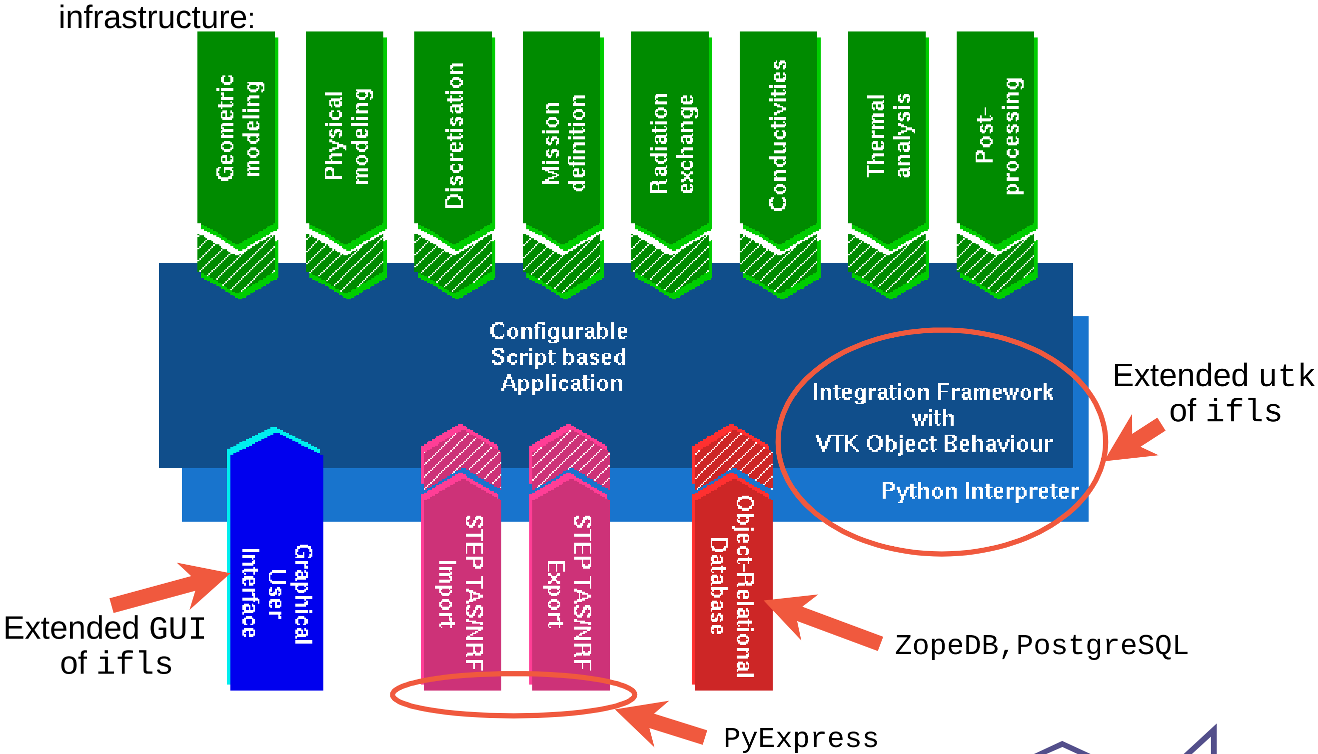
Application: Therm-OSS

- Proposed design:

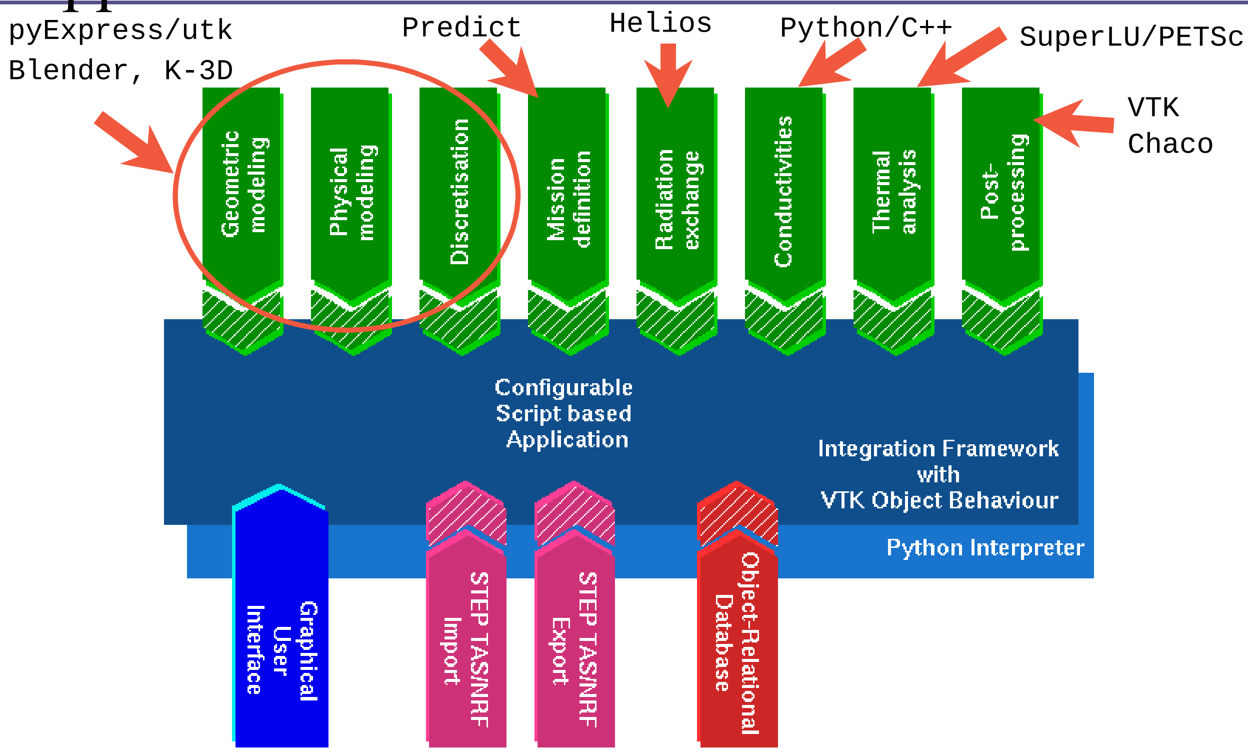


Application: Therm-OSS

- Engineering infrastructure:

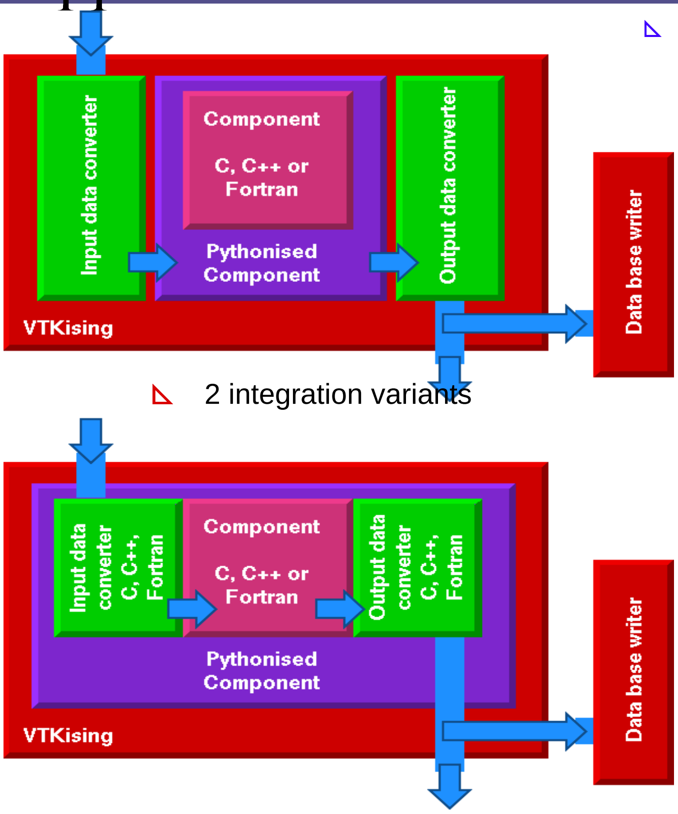


Application: Therm-OSS



- Potential functional modules:

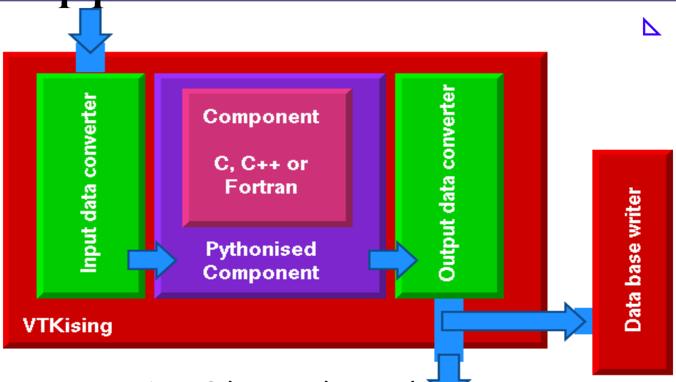
Application: Therm-OSS



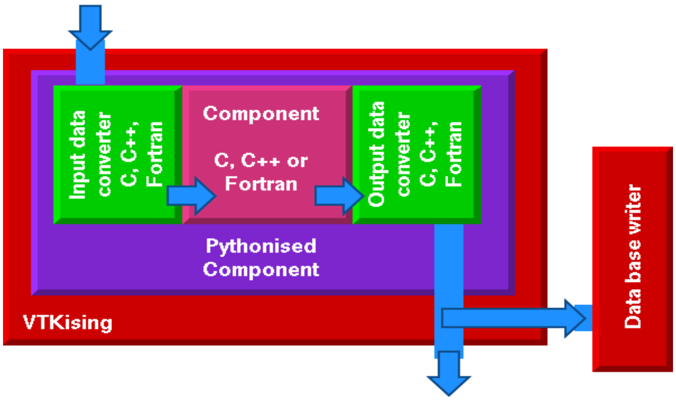
- Integration of modules/tools as ProcessObjects:
  - VTKising:
    - C++ programming: deriving classes from VTK abstract base classes, e.g. vtkProcessObject,
    - Python programming and the output will be a standards VTK data object using the vtkProgrammableSource class,
    - using the ifls extension utk, which is a reimplementation of some basic VTK classes in Python.

    The essential work is the implementation of the, 'Execute' method, which do the input to output transformation.
  - Data Transforming:
    - This task converts the input formats of the VTK enabled class into the individual formats of the components and vice versa if required.
    - This task can be implemented in a seperate process object as well.

Application: Therm-OSS



- 2 integration variants

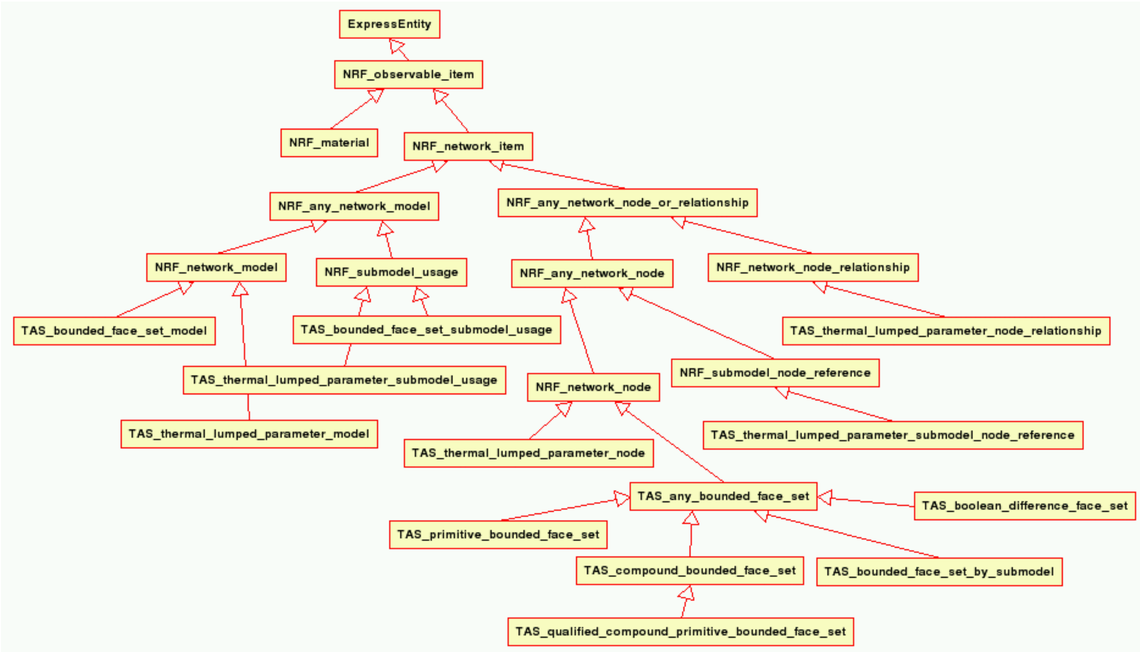


- Integration of modules/tools as Process Objects:
  - Data Transforming:
    - This task converts the input formats of the VTK enabled class into the individual formats of the components and vice versa if required.
    - This task can be implemented in a seperate process object as well.
  - Pythonising: means that the Python interpreter can communicate with the component, which is necessary in first two cases of VTKising.
    - using a shell command to execute a complete tool (Python build-in functions),
    - using a wrapper generator to build C, C++ or Fortran to Python bindings,(swig, Boost.Python and pyfort)
    - using communication protocols (e.g. Sockets, SOAP, Corba) for remote execution

Application: Therm-OSS

- Data Objects:
  - VTK includes data objects for grid based datas (structured, unstructured grids, polygonal data).
  - Therm-OSS requires the the handling of other datas (e.g. geometry, mission definition, results).
  - Implementation:
    - VTKising - map the information onto the existing VTK data objects Benefit: Reuse of existing objects, Deficit: Mapping is difficult/uncomplete/impossible
    - Pythonising - new data objects derived from utk base classes Benefit: No restrictions, Deficit: No available process objects..
  - Information:
    - Free definition - defining new data objects with properties/attributes Benefit: Enables quick prototyping, Deficit: Probably not general enough
    - STEP definition - taking STEP TAS/NRF schemas as basis for the properties/attributes Benefit: Sophisticated information model, use of existing STEP tool, Deficit: Complex model and implementation, except use of pyExpress (ESA/ESTEC)

Application: Therm-OSS

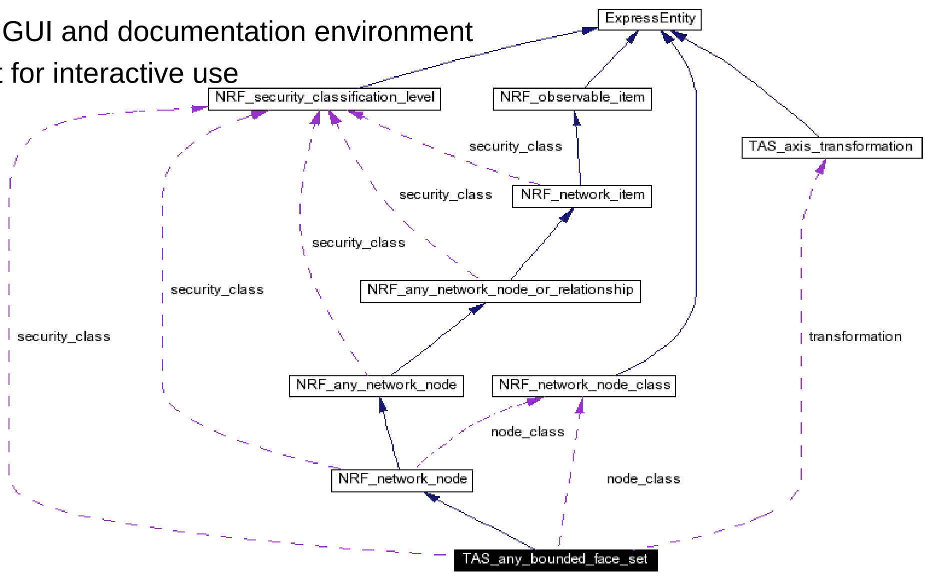


- UML class diagramm of STEP TAS/NRF observable item
- generate by Umbrello http://uml.sourceforge.net
- From pyExpress generated Python classes

Application: Therm-OSS

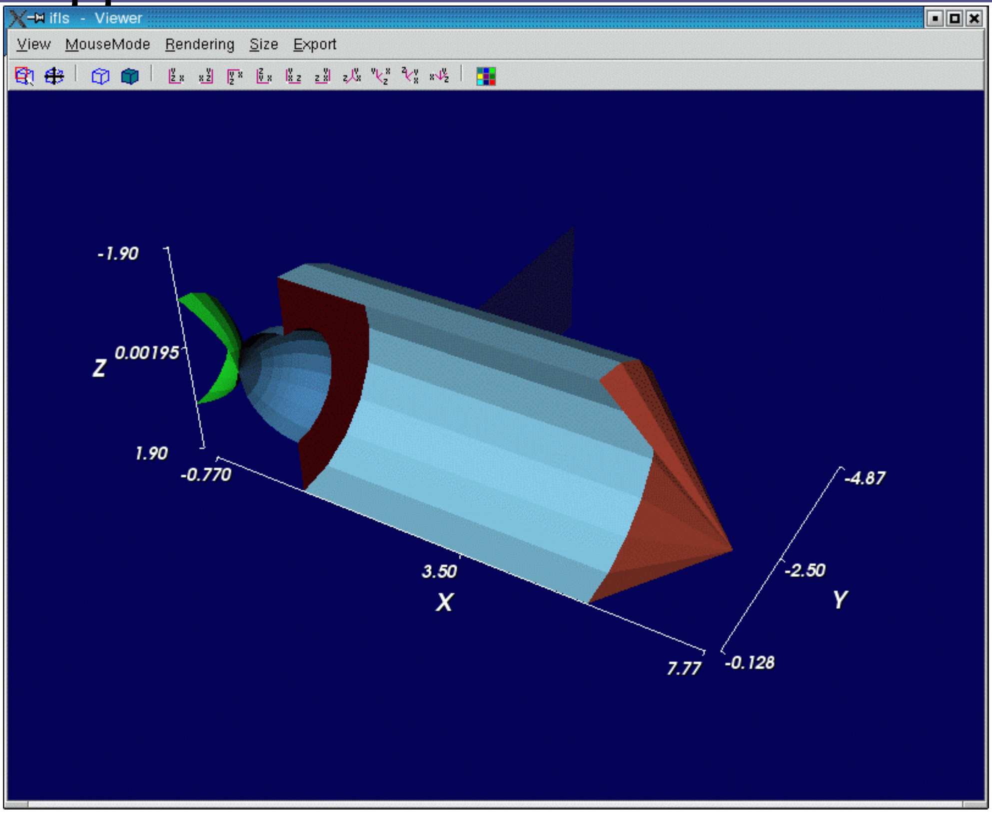
pyExpress extended with utk (Pythonizing)

- Extensions by deriving ExpressEntity from utkDataObject
- Add of 'capitalized' Methods
- Modification of ifls documentation classes
- Automatic support of the GUI and documentation environment
- Documentation important for interactive use
  - UML, DoxyGen



- Collaboration diagramm generate by doxygen

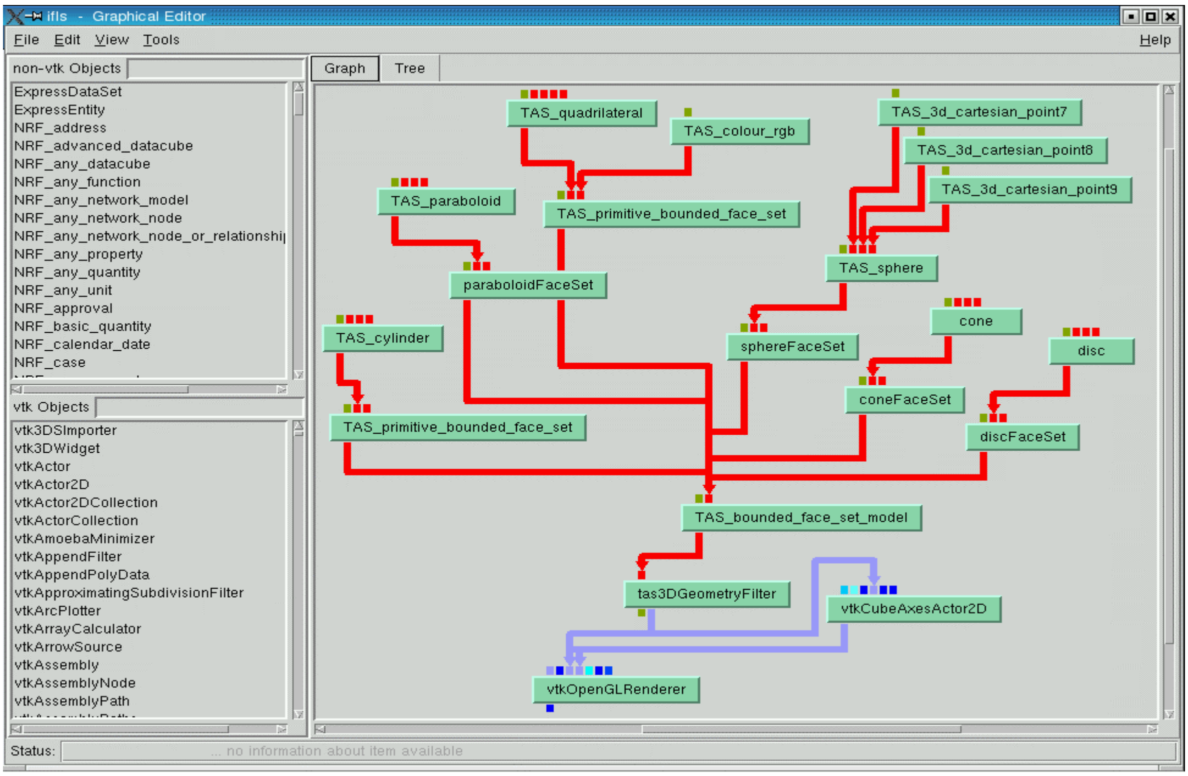
Application: Therm-OSS



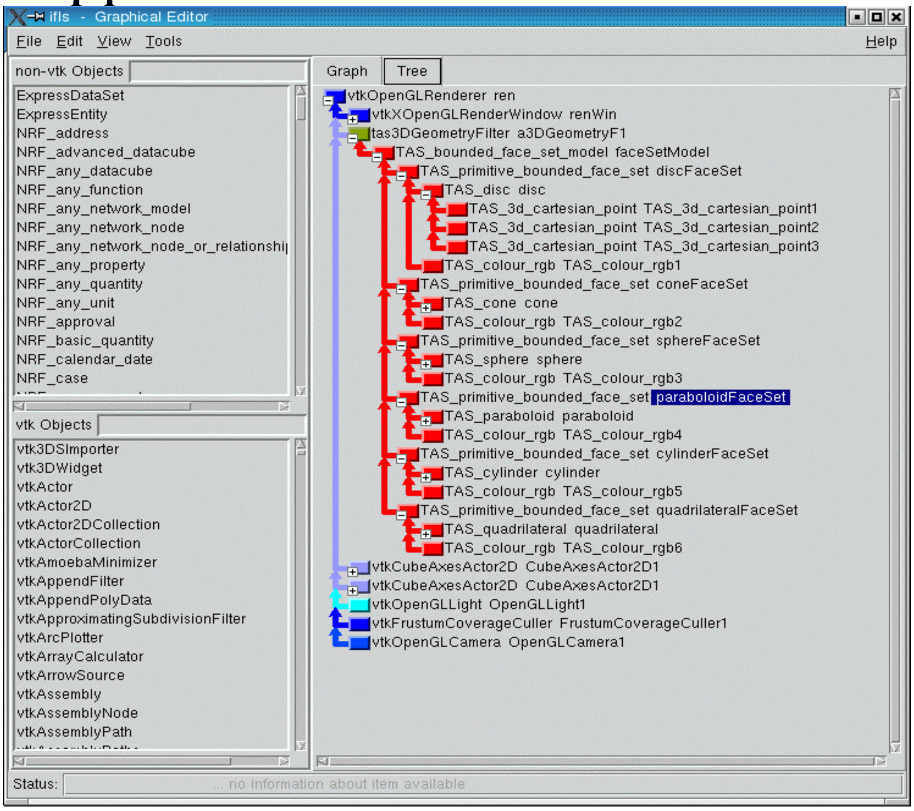
- Simple Model build from STEP-TAS primitives.
  - Cone
  - Cylinder
  - Disc
  - Sphere
  - Parabolid
  - Quadrilateral
- Visualization of the primitives with VTK
- Interactive editing

Application: Therm-OSS

Simple Model build from STEP-TAS primitives.
Graph representation in the ifls GUI



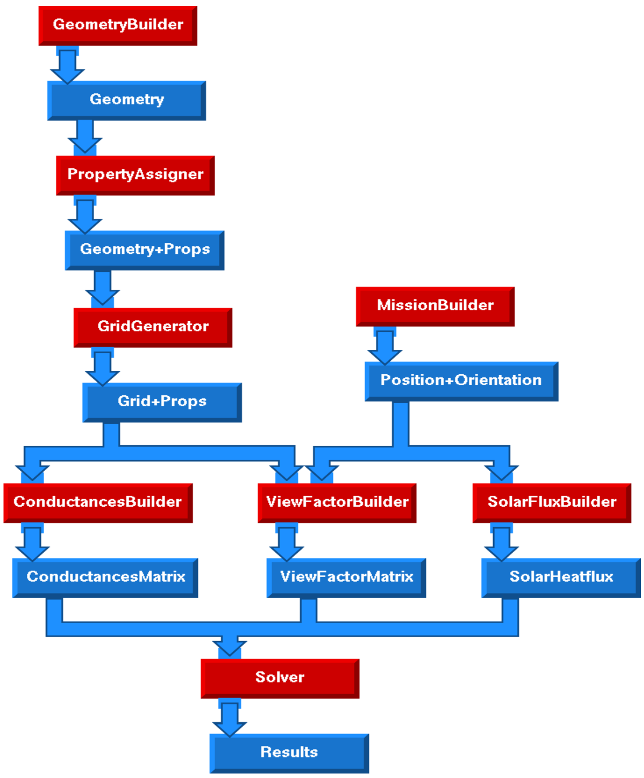
Application: Therm-OSS



- Simple Model build from STEP-TAS primitives.
- Tree representation in the ifls GUI

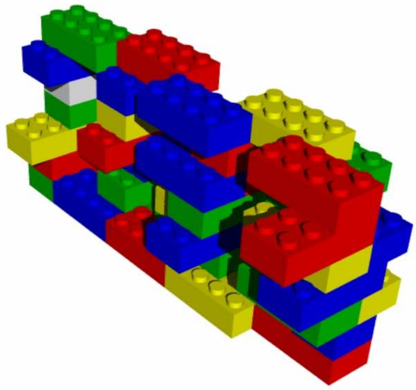
Application: Therm-OSS

- Functional modules:
  - Use case of the complete design and analysis cycle.
  - Current work:
    development in the solver region.
    - FDM matrices for the primitives
    - Load vectors and matrices
    - Building the system equations
    - Solution



Concluding remarks

- Powerful tools for design, analysis and tool integration are available as OSS
- Open Source approach of a tool integration platform `ifls` is successful . . . and makes fun
- Finding and evaluation of OSS is not easy
- License problem (free for research, not for commercial)
- Codes for the lumped parameter approach are hard to find
- Need for data and tool standards



Outlook for Therm-OSS

- First use case implementation finished in 2003
- Integration of alternative tools in 2004
- Common Component Architecture for High-Performance-Applications as one standard (?)

Appendix J: Applicability of OSS to Space Thermal Engineering

Applicability
of
Open Source Software
to
Space Thermal Engineering

R. Schlitt
OHB System

Applicability of OSS to Space Thermal Engineering

Reinhard Schlitt, OHB System AG
Frank Bodendieck, OHB System AG
Matthias Haupt, University Braunschweig
Charles Stroom, ESA/ESTEC

ESA Contract: 17162/03/NL/CP

- Overview
  - Assessment of OSS for Space Thermal Engineering
  - Establishment of an European Thermal OSS Community
  - Software Tool Development
  - Software Architecture and Elements

- Assessment of OSS for Space Thermal Engineering
  - OSS has generally a bad reputation for use as a “professional” engineering tool
    - “Free“ software not professional
    - Bad quality and thus low reliability
    - To give source code away means to loose control, to strengthen the competitor and not to gain any profit

- Principles of OSS Concept
  - Performed in a large developer community
  - Development performed by an abundance of specialists and not any more by a few persons in a single company
  - The source code will be released to anyone, who is interested. Developers catch up the code for checking, debugging, improving, extending and redistribute it to the community
  - An open source license scheme is the vehicle to regulate this approach (GNU General Public License, Sun Community Source License Principle and others)

– Advantages of the OSS Approach
- Development is shared among many (excellent) developers, which are presently out of reach for a single company
- The OSS community cares for inclusion of advancement in the software state-of-the-art
- Maintenance and implementation is shared among the users
- New features (or modules) related to specific applications can be set up on distributed codes, which avoids redoing the entire job
- S/W remains alive whatever happens to a single developing company (This is in contrast to the present closed source approach, where a single company, which owns a particular source code, could disappear from the market)

– Advantages for Space Engineering Tools
- Development, maintenance, implementation resources and associated budget can be shared between the users and thus reduced for a single company
- Approach ensures long-term availability (present risk that a developer with propriety S/W disappears from the market is deleted)
- User dependency on S/W developers is greatly reduced (development will be performed by the user himself and not by a S/W house which sometimes have reduced space system and engineering background)
- Development of specific applications is cost-effective, since it can be set up on existing source codes

- Quotation from the Open Source Initiative web page:

“Because the user can get access to the source, he can survive the collapse of the vendor. The user is no longer totally at the mercy of unfixed bugs. The user is not shackled to every strategic decision the vendor makes. And if the vendor’s support fee becomes exorbitant, the user can buy support from elsewhere. For this reason alone, every software customer should absolutely demand open source and refuse to deal with software vendors who close and shroud their code. It’s a matter of controlling the users own destiny.”

– Prerequisite for introducing the OSS approach

- **Space industry (i.e. their managers) must recognizes that**
  - Propriety closed engineering tools and the investment to establish them will not increase the competitiveness of a company (see the example automotive industry)
  - OSS will not transfer know-how to the outside – in the contrary, the company will gain knowledge through many excellent outside developers, which are now out of reach
  - A company will receive back application software modules from the community, which he otherwise needs not to develop himself
  - The OSS approach will deliver software products, which are as robust, reliable and validated as today’s propriety programs or are even superior
  - The OSS approach saves budget and manpower for a company since development, maintenance and implementation is shared within the user community
  - Companies do not engage in the risk of development discontinuity in case software developers of a certain program are no longer available to the company.

- Objective of the Present Study
  - It shall be demonstrated that a thermal engineering tool from reliable and mature OSS building blocks can created. In case building blocks are not available a specific routine can be programmed to fill the gap. (Will be presented by Matthias Haupt)
  - A user community shall be established which operates according to the principles of the OSS philosophy
  - Demonstration that the organization is capable to involve the members as active partners for testing, feedback and maintenance according to the principles of the OSS philosophy.
  - Shall be seen as pre-runner of a future membership organization

- **User Community Concept**
  - Membership limited to organizations within the ESA member states (this restriction must be in accordance with OSS license schemes)
  - Responsibilities of members:
    - Acceptance of OSS working principles by signing a license agreement
    - Distribution and re-distribution of source codes shall be the rule
    - Propriety software accepted case-by-case by the community for an interim period.
    - Members are develop new software according to OSS interfaces of the community, check new software,elaborate alterations and extensions, report bugs…
  - Responsibilities of the leading organization (OHB for the study)
    - Cares for validation of all software, performs configuration and version control
    - Decides on modifications, extensions, new software to be included
    - Decides whether propriety software shall be included
    - Provides quality maintenance, support, custom engineering, and training services

– Basically three types of members:
- Software houses, which develop software to make profit. Business shifts however from traditional software "manufacture" to support, tailoring, implementation, custom design, etc.
- System companies, who use software as tools to support development of their space products
- Academia

– Dedicated study community web site:

http://www.therm-oss.org/

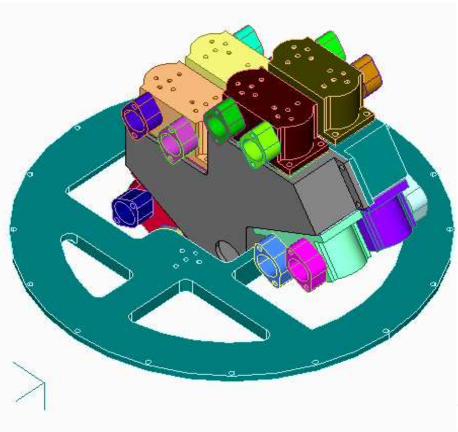
- Contains open and restricted part
- Includes:
  - Discussion forum, mailing list, S/W problem reporting system
  - Possibility to down-load / up-load source codes

Appendix K: Finite Element Modelers for Space Thermal Design

Innovations in Using Finite Element Modelers for Spacecraft Thermal Design

R. Behee
Network Analysis

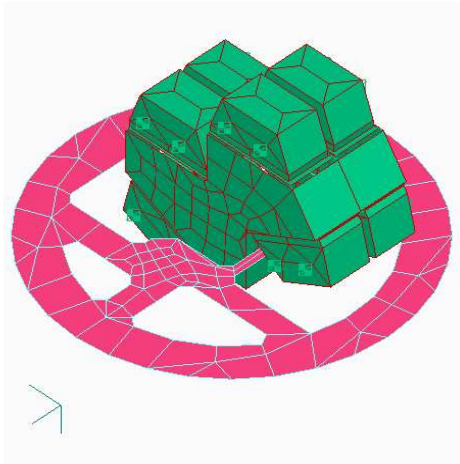
Innovations in Using Finite Element Modelers for Spacecraft Thermal Design



October 21st, 2003

Ron Behee

Network Analysis Inc



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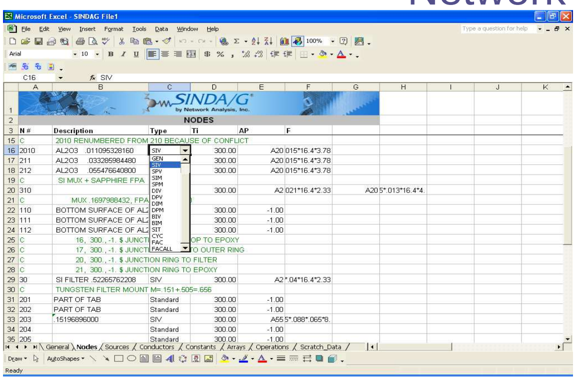
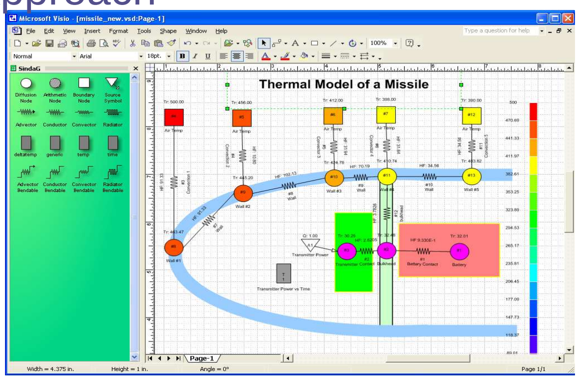
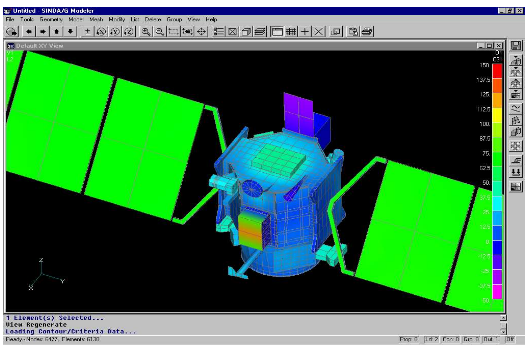
Two Basic Approaches for building Thermal Models in SINDA or ESATAN

Network Approach



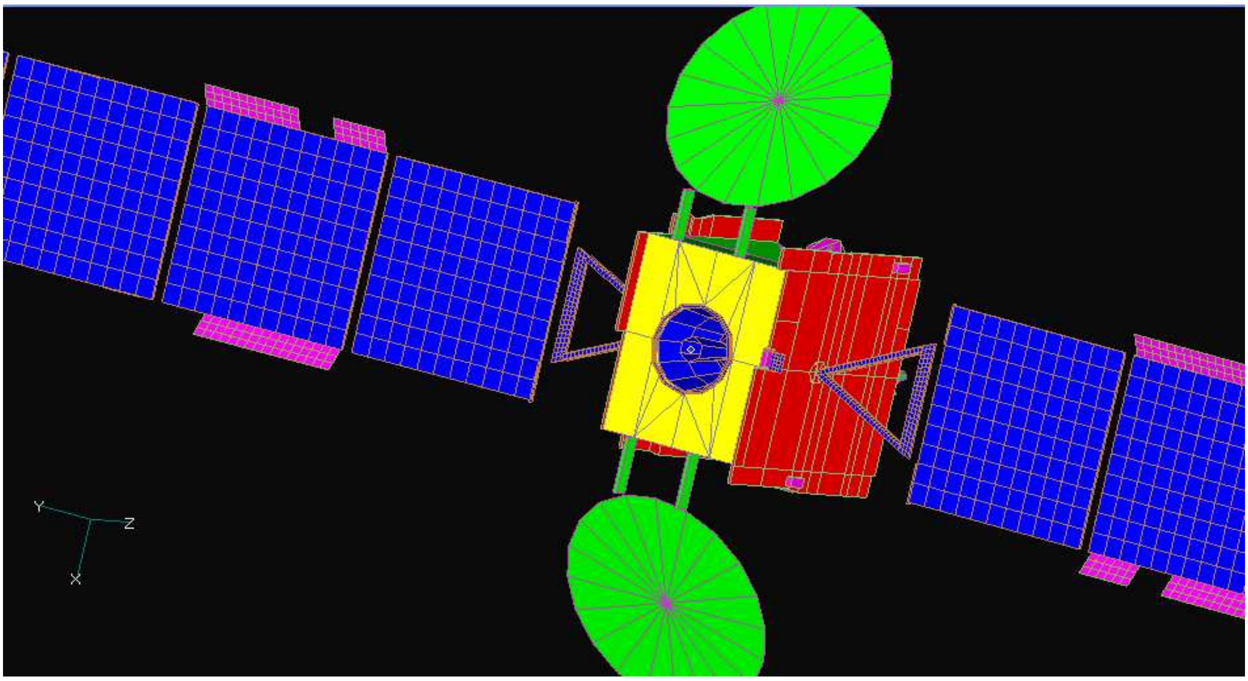


Geometric Approach



Geometric Thermal Model of Telecommunication Satellite

Mostly planer surfaces



Geometric Approach has been Implemented in Modelers Using Two Different Technologies

- FEA Meshing Based Model Builders
  - Create 3D solid geometry or import from CAD and divide geometry into finite elements using FEA meshers.
  - These model builders are general purpose and are frequently used by many different analyzers (thermal, structural, CFD).
- Radiation Shape Based Model Builder
  - Create model using several geometric shapes that are supported by the thermal radiation code.
  - These model builders are usually tied to one thermal radiation code, and will not easily work with another.

SINDA/G® by Network Analysis, Inc.

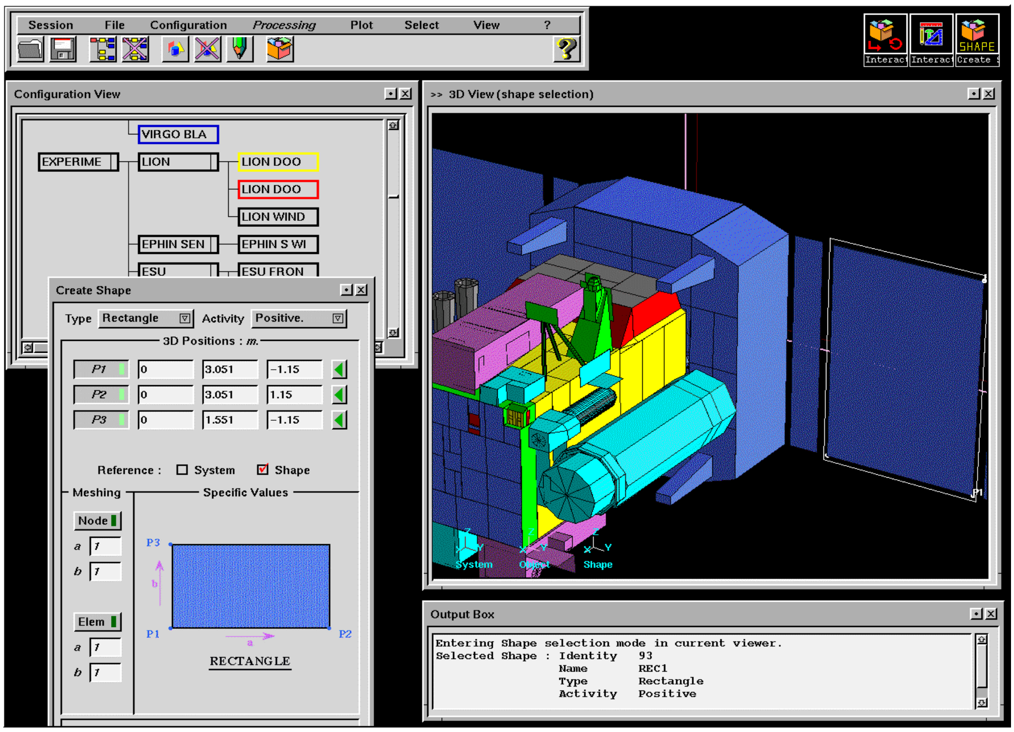
Commercially Available Geometric Modelers for *SINDA/G*

Shape Model Builder	Meshing Model Builder
THERMICA	SINDA/G For MSC.Patran
TSS	SINDA/G for FEMAP
ESARAD	MSC.Patran Thermal
NEVADA (SPARKS)	TMG for I-DEAS or FEMAP
Thermal Desktop	

SINDA/G® by Network Analysis, Inc.

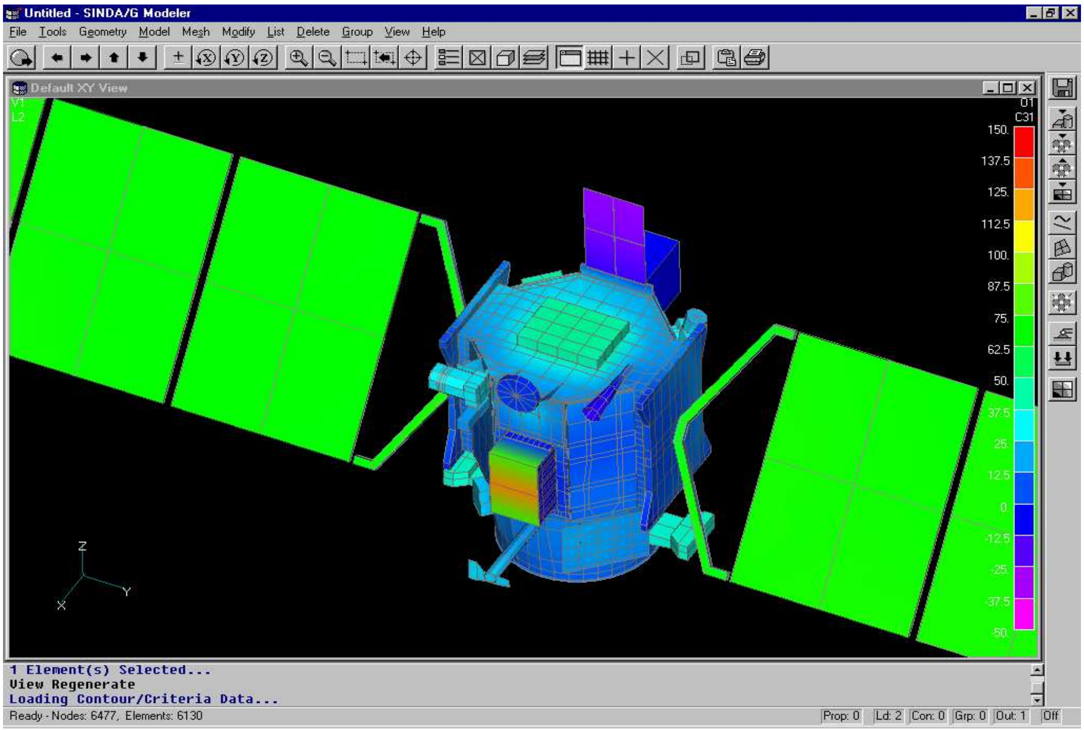
Geometric Approach

Radiation Shape Based Model Builders



Geometric Approach

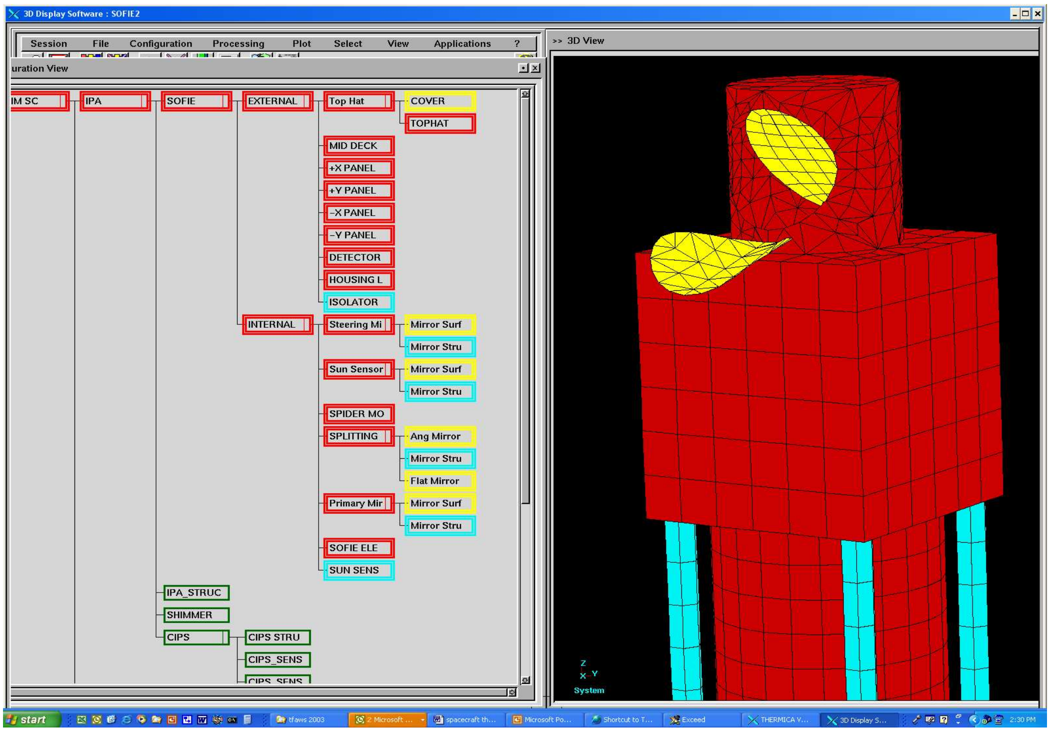
FEA Meshing Based Model Builders



Advantages and Disadvantages of the Two Types of Geometric Modelers

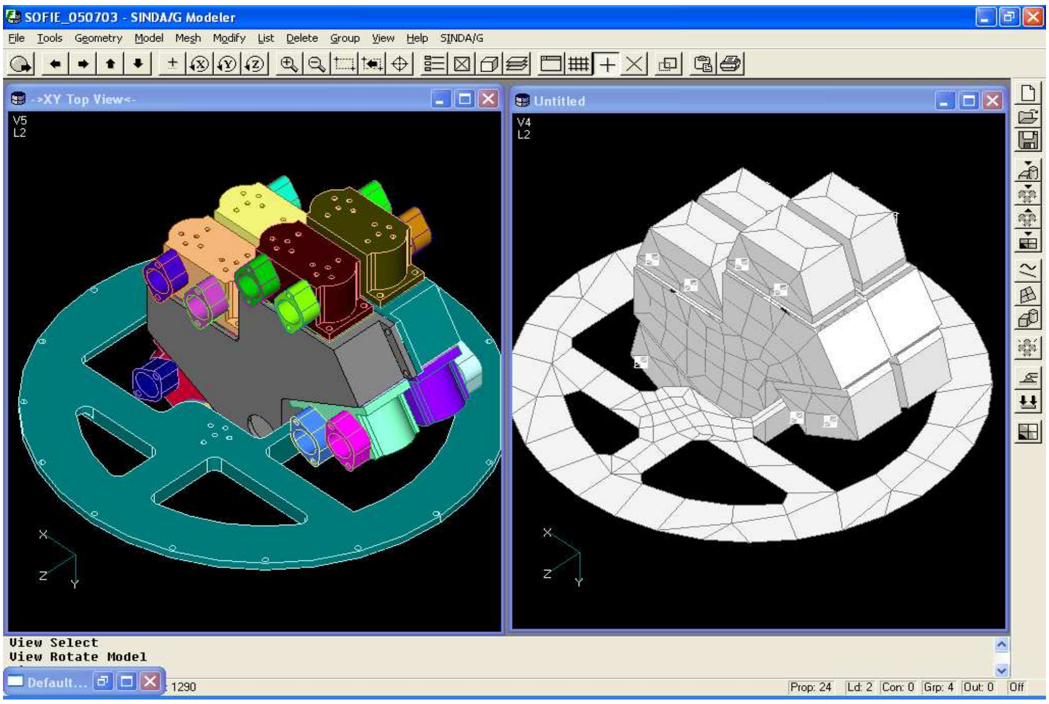
- FEA Meshing Based Model Builders
  - Good connection to CAD
  - Good connection to FEA structural/fluid programs
  - Typically have flat plat connection to radiation/orbital heating programs
  - Models solids, orthotropic materials and laminate materials
  - Thermal models with complex shapes work well.
- Radiation Shape Based Model builders
  - Poor connection to CAD
  - Poor connection to FEA programs
  - Excellent-full shape connection to radiation/orbital heating programs
  - Usually only models surfaces and use isotropic materials
  - Some Geometries are difficult to model and thermal models may contain inaccuracies in the conduction network.

Example of Difficult Geometry for Shape Based Modelers



CAD Interface

FEA Meshing Type Model Builders

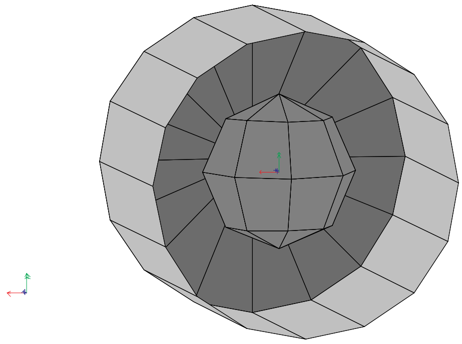


CAD geometry can be simplified

Biggest Problem of FEA Meshing Based Model Builders

Radiation Model Consists of Multiple Small Flat Plates

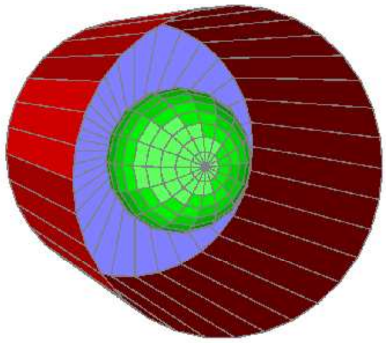
FEA Mesher Based Model Builder



Hydrazine Tank Modeled with 112 Flat Plates

Produces 6000+ radiation conductors

Radiation Shaped Based Modeler



Hydrazine Tank Modeled with 4 True Geometric Surfaces

Produces 6 radiation conductors

How to Combine the Best of Both Types of Geometry Modelers

- Use FEA Advantages
  - Good connection to CAD
  - Good connection to FEA
  - Can model complex shapes
  - Supports solids, plates, and complex conduction models
- Use Shape Advantages
  - Support full radiation shapes

Various Approaches Different Software Companies Have Taken

- Radiation shaped based approaches
  - ESA – Complex surfaces and Boolean operations on shapes in ESARAD
  - Astrium – Ability to create shapes on top of CAD geometry and Boolean operations on shapes
- FEA meshing based approaches
  - TMG – Directly use 10,000 to 100,000 small shapes (including Quad 8 curved shapes) and have a faster radiation code (hemicube method). Also supporting shapes from FEA mesher but the shapes are not integrated into the FEA modeler.

Conclusions

Radiation Shape Based Model Builders

Shape-based radiation models offer quick solutions that are helpful in performing trade studies and optimization analyses. During the early stages of satellite and instrument development programs, the thermal engineer will need to explore various surface coatings and geometry combinations. Shape-based models allow the thermal engineer to quickly change geometry and surface properties without having to re-work intricate meshes.

Example of Combining Both Technologies

As the design matures, many odd shapes will begin to appear in the spacecraft or instrument geometry that are not easily modeled with *primitive shapes*. However, the native shapes should not be eliminated altogether. For example, the conceptual design of the SOFIE instrument onboard the AIM spacecraft, the SOFIE instrument is modeled with high-fidelity using finite elements. The remaining items in the model, such as the spacecraft and other instruments, are approximated by large single-element surfaces or primitive surfaces.

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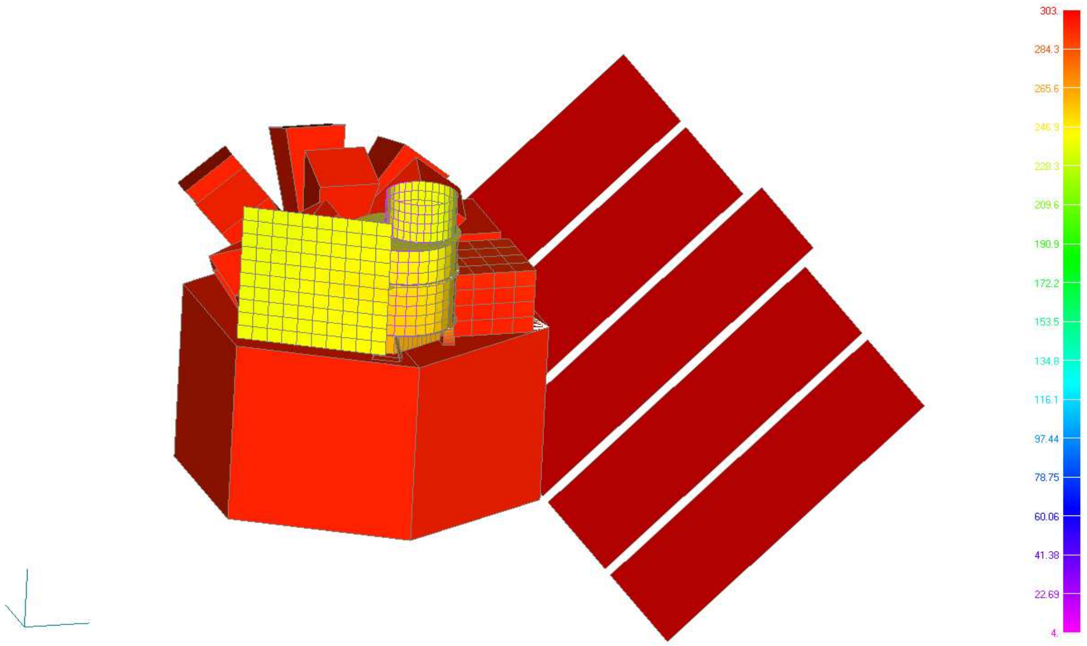
Detailed Payload and Simplified Spacecraft Using Both Technologies



SOFIE instrument aboard the AIM spacecraft

Conclusions

Possible Best Solution

- Start with FEA model builder that has excellent connection to CAD, and supports FEA flat and curved elements for radiation.
- Add curved plate elements to the radiation code to minimize the faceted errors and reduce the number of elements to model curved surfaces
- Add the ability to create common radiation shapes such as a cylinder, sphere or disk.
- It also should also have the ability to group smaller FEA type elements into larger radiation shapes to reduce the number of Radiation Exchange Factors (REF's).

NAI's New Product Development

NASA Phase II SBIR Contract

- Use the most widely accepted FEA model builder MSC.Patran (used by MSC.Nastran).
- Have MSC add common radiation shapes to MSC.Patran.
- Have at lease one radiation code developer add a curved *element type* shapes to their radiation code.
  - Quad 8 elements, Quad 16 elements (unique to Patran) or more complex surface.
- Create radiation "super elements" that group a fine conduction mesh into a larger radiation mesh

NAI will be working on these concepts during the next 2 years under a NASA research contract and we invite you to share with us your feedback, experiences and needs.

Appendix L: Open Source Approach to Space Environment Tools

Application of the Open Source Approach to Space Environment Analysis Tools

H. Sdunnus
eta_max space

Application of the Open Source Approach to Space Environment Analysis Tools

Seventeenth European Thermal & ECLS Software Workshop
21 – 22 October 2003

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Outline

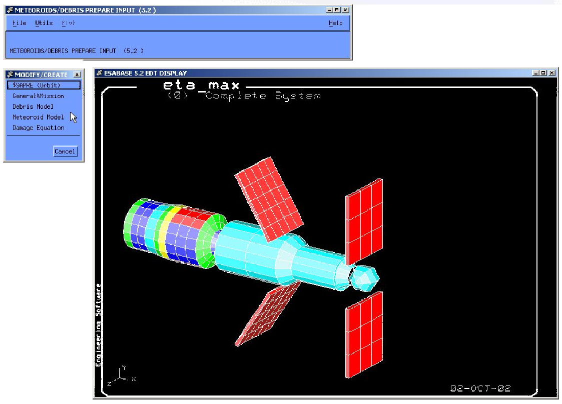
- Background
- The “Open Frontier” platform
  - Components
  - Licensing Issues
  - Data model
  - Architectural Design
- The ESABASE/Debris plugin
  - Open Frontier + ESABASE/Debris = PC ESABASE
  - PC ESABASE Online Presentation
- Summary + Outlook

Background

Background

- ESA Study
  - „Porting of the existing ESABASE/Debris Application to PC platform“
  - Study Manager: G. Drolshagen (TOS-EES)
  - Duration: 01/2003 - 06/2004
  - Usage of Off The Shelf (OTS) tools and Open Source software strongly recommended
  - Open Interfaces (STEP) is a “must”
- Approach:
  - Provide a generic platform offering everything a high level SE analysis tool needs (Open Frontier)
  - Plug in ESABASE/Debris (pre-processors, post-processors and solver)
- Open Frontier + ESABASE/Debris = PC-ESABASE
- Open Frontier plugin philosophy is open to other pre- and post processors, solvers and also to different disciplines

Background



- Problem
  - Ageing Space Environment Analysis Tools
    - Cumbersome user interfaces
    - Restricted data models
    - Platform dependence
    - Undefined or non-existent interfaces to external tools
    - Extensive Pre- and post-processing
  - Serious constraints of their acceptance and availability (ESABASE;..)

- Task (→ related to ESABASE/Debris)
  - Provide a PC based solution (Windows; Linux)
  - Replace the existing framework
  - Retain existing kernels (solver) as far as possible (ESABASE/Debris)
  - Provide interfaces to external tools (CAD → STEP)

Approach

- Usage of “Off The Shelf” (OTS) Software
  - prevents re-invention of the wheel and may save development effort

  but …
  - OTS solutions are normally far from providing ‘plug + play’ capabilities
  - Not every problem is solved by an OTS solution

- Open Source Software
  - avoids ‘proprietary’ dead-ends

  but ..
  - does not always provide a business case

Open Frontier

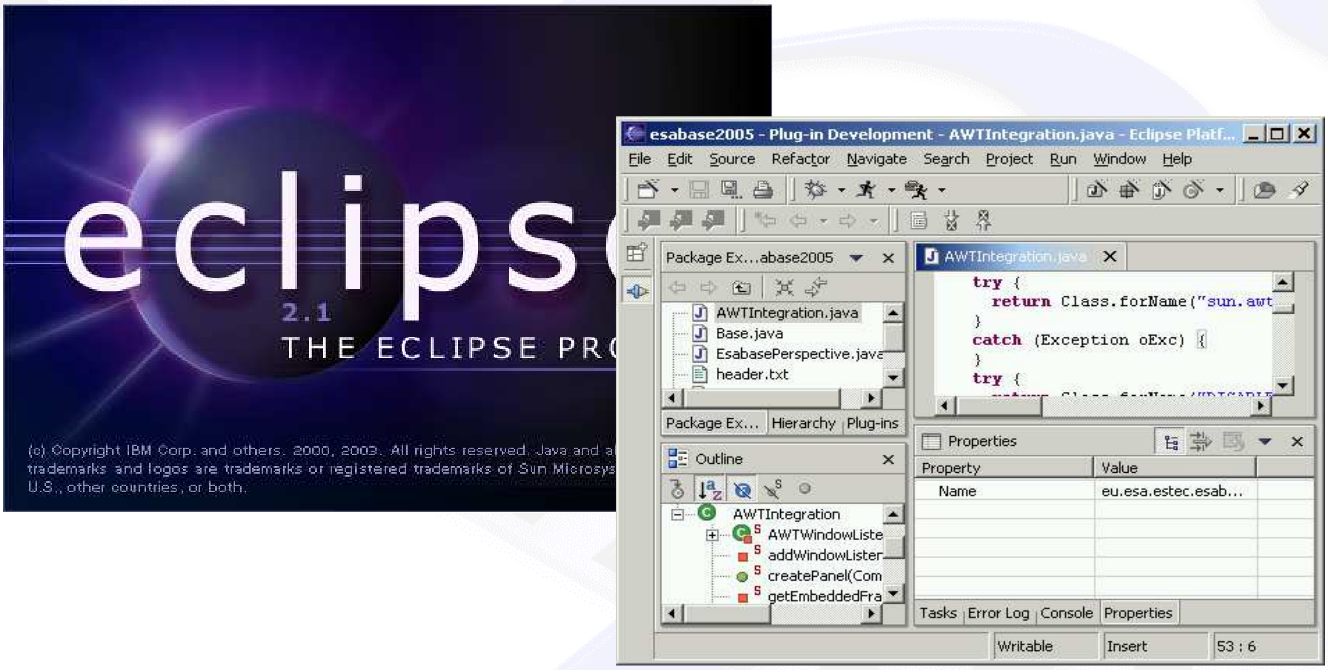
Components
Licensing Issues
Data model
Architectural Design

Identification of OTS Solutions

- What is needed ?
  - Framework Components
    - Graphical User Interface — Eclipse
    - Geometrical Model Viewer + Builder — Open Cascade
    - Result Viewer (2D; 3D graphs; 'Special Plots') — VisAD
    - Report generator — JFreeReport
  - Platform
    - Flexible, transparent + scalable data model — OCAF
    - CAD data exchange (STEP compliance) — Open Cascade

Graphical User Interface
Eclipse

eta_max space Richard-Wagner-Str.1, 38106 Braunschweig



Eclipse

eta_max space Richard-Wagner-Str.1, 38106 Braunschweig

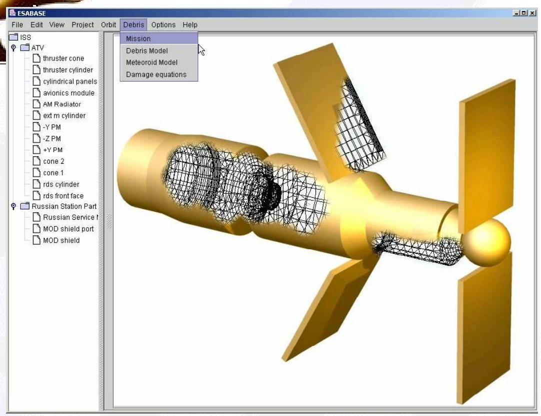
- What is Eclipse?
  - IBM states that "*Eclipse is an IDE for anything, and for nothing in particular.*"
  - Wide distribution as Java IDE, but also in the IBM commercial tool world (WebSphere)

- Eclipse is a high level GUI platform
  - Widely accepted Look & Feel
  - Native GUI components → native user experience
  - Existing framework → less components to develop
  - Primitive GUI elements → Buttons, Checkboxes, Textfields, Trees
  - complex display/edit views → Viewers, Editors
  - Always state-of-the-art in contrast to self-developed solutions

- Eclipse is Open Source
- Eclipse encourages platform building
  - Plugin model with well defined interfaces
  - Built-in plugin development environment

Geometrical Model Viewer + Builder
Open Cascade

eta_max space Richard-Wagner-Str.1, 38106 Braunschweig



Open Cascade

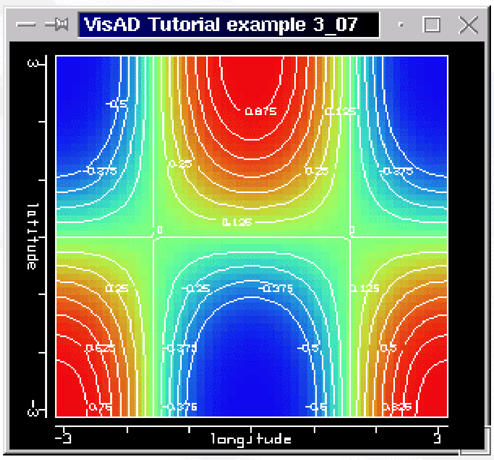
eta_max space Richard-Wagner-Str.1, 38106 Braunschweig

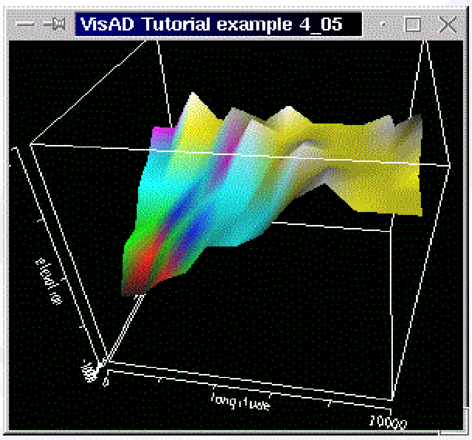
- What is Open Cascade?
  - Open Cascade is a geometric modelling toolkit
    - Create primitives such as prism, cylinder, cone and torus
    - Perform Boolean operations (addition, subtraction and intersection)
    - Compute properties such as surface, volume, centre of gravity, curvature
    - Compute geometry using projection, interpolation, approximation
  - Open Cascade is a 3D Viewer
    - ready-to-use user interaction and visualization services
    - 3D rotation, Zoom, Shading, graphical selection of geometrical objects
  - Open Cascade is Open Source
  - Based on the Swing Java 2™-based library, the Java Application Desktop (JAD → commercial) makes the application portable on all platforms running the Java 2™ Virtual Machine

Open Cascade Interfaces

- Open Cascade allows data exchange through standard interfaces
  - STEP
    - AP 203, 214
    - [209], “rough implementation” in latest release
    - SPE – PC ESABASE compatibility to be established by eta_max under ESA contract (prime:Simulog)
  - CAD
    - IGES, BREP, CSFDB
    - CATIA → free for users if bought by developer (license required)

Result Viewer VisAD





VisAD

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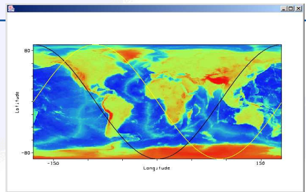

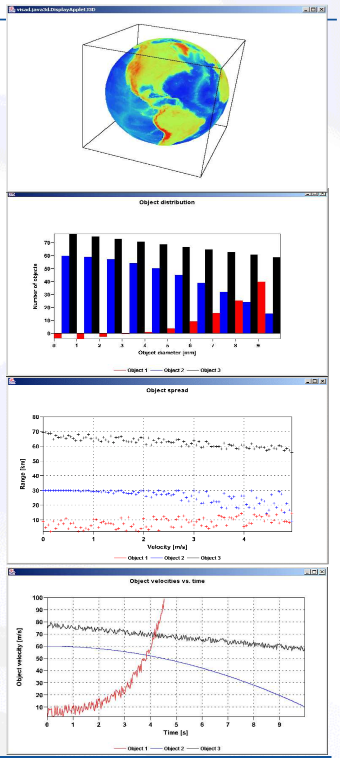

- What is VisAD?
  - VisAD is dedicated to the visualisation of scientific results
  - VisAD provides a wide range of customisation capabilities plus the possibility to extend the analysis and visualisation features.
  - VisAD is open source

- VisAD Benefits
  - highly customizable
  - huge feature range
  - supports 2D and 3D chart types
  - supports data manipulations

- VisAD is very well suited to visualise scientific data
- Geometry related results are mapped to geometry elements and displayed by means of OCC

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JFreeReport

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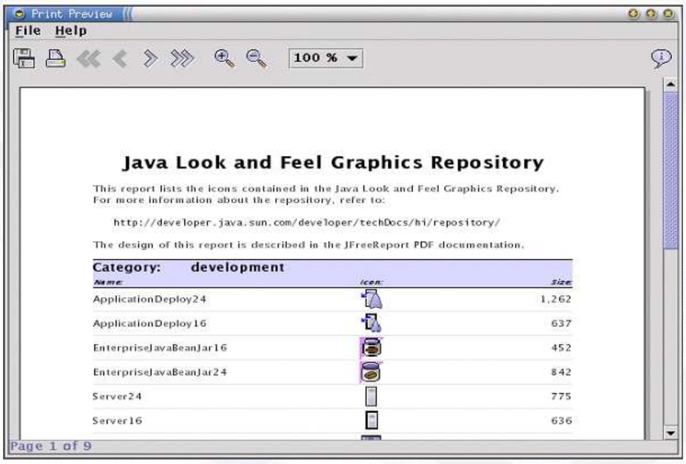


- JFreeReport supports
  - formatted on-screen display,
  - printer output and
  - PDF output.
  - XML based templates to define report formats.

Licensing Issues

- **Open Cascade**
  - being licensed under the Open Cascade Public License. It allows the distribution of „Derivative Programs“ with different licenses.
- **Eclipse**
  - Common Public License „[...] this license is intended to facilitate the commercial use of the Program [...]“

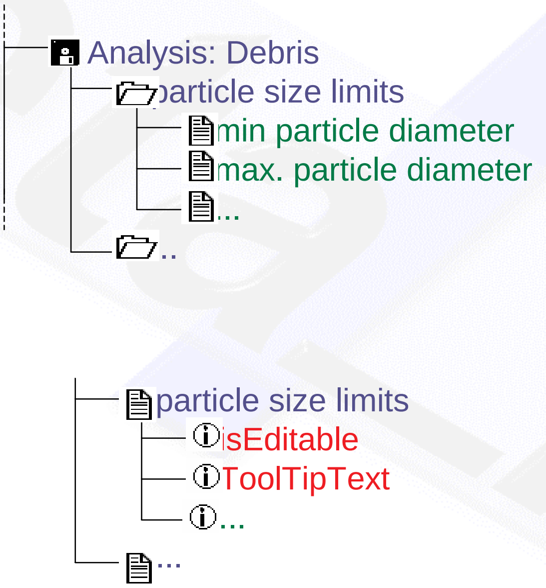
	Proprietary	Freeware	Shareware	GPL	LGPL	CPL
Zero Cost	-	x	-	x	x	x
Source available	-	-	-	x	x	x
Copying possible	-	x	x	x	x	x
Modification possible	-	-	-	x	x	x
Reselling possible	-	-	-	-	x	x

- **VisAD** →LGPL
- **JFreeReport** →LGPL
- **Open Frontier** → to be agreed with ESA
- **PC ESABASE** → to be agreed with ESA

Datamodel
The Open Cascade Application Framework (OCAF)

- **The establishment of a “good” data model is seen as a key issue**
- OCAF supports a key-driven data structure
  - Allows to use any type topological and non-topological data
  - Allows free form data model structure as well as a hierarchical structure
- OCAF allows label attributes
  - Ready-to-use attributes as well as user-defined attributes
- OCAF Features
  - Existing data browser → transparent and ‘readable’ data model
  - Open/Save functionality → allows creation and exchange of data model images
  - Undo/redo mechanism → allows data model changes at run time
  - Accessible from high level programming languages and from script languages
- Open Frontier data model as implemented by means of OCAF is flexible, easily maintainable,scalable.

Data structure



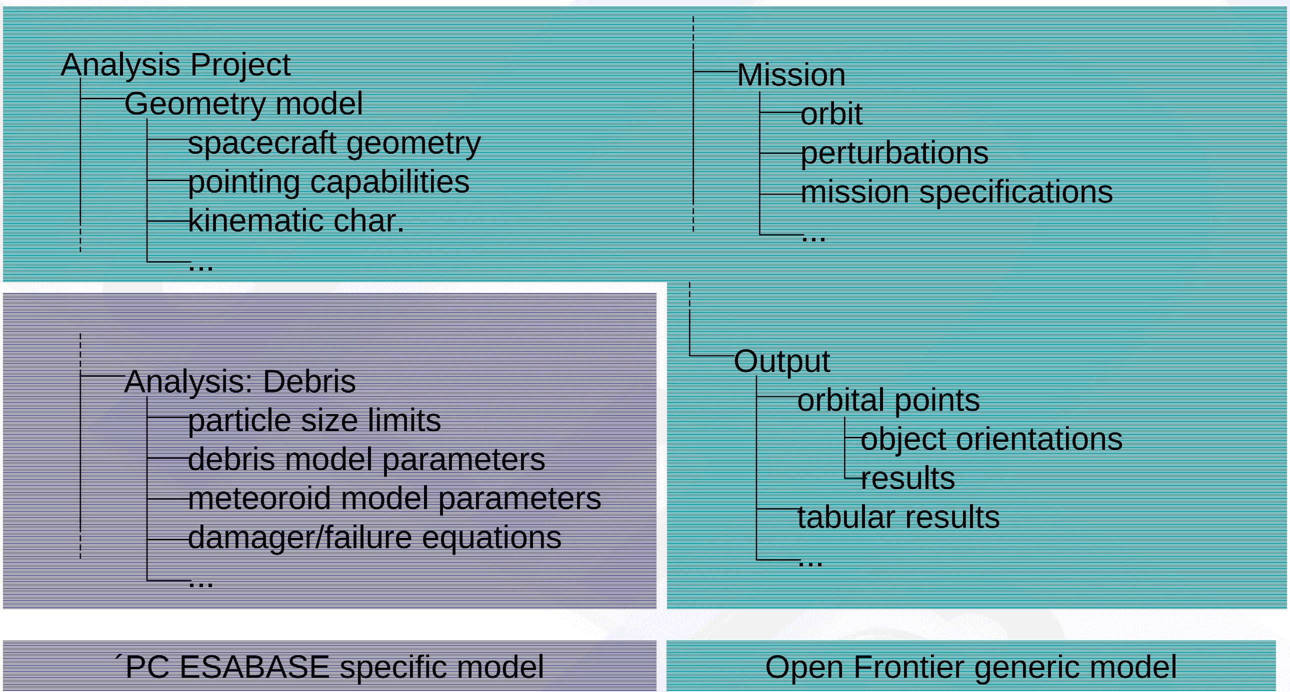
Document
- a complete data tree
- capable of loading/saving into/from files

Node/Label
- a container for data parameters

Leaf/Parameter
- a named variable containing a single value or an array of values

Property
- each leaf/parameter has assigned a list of properties that describe the parameter and its behaviour in the GUI

Open Frontier
Data model top level structure

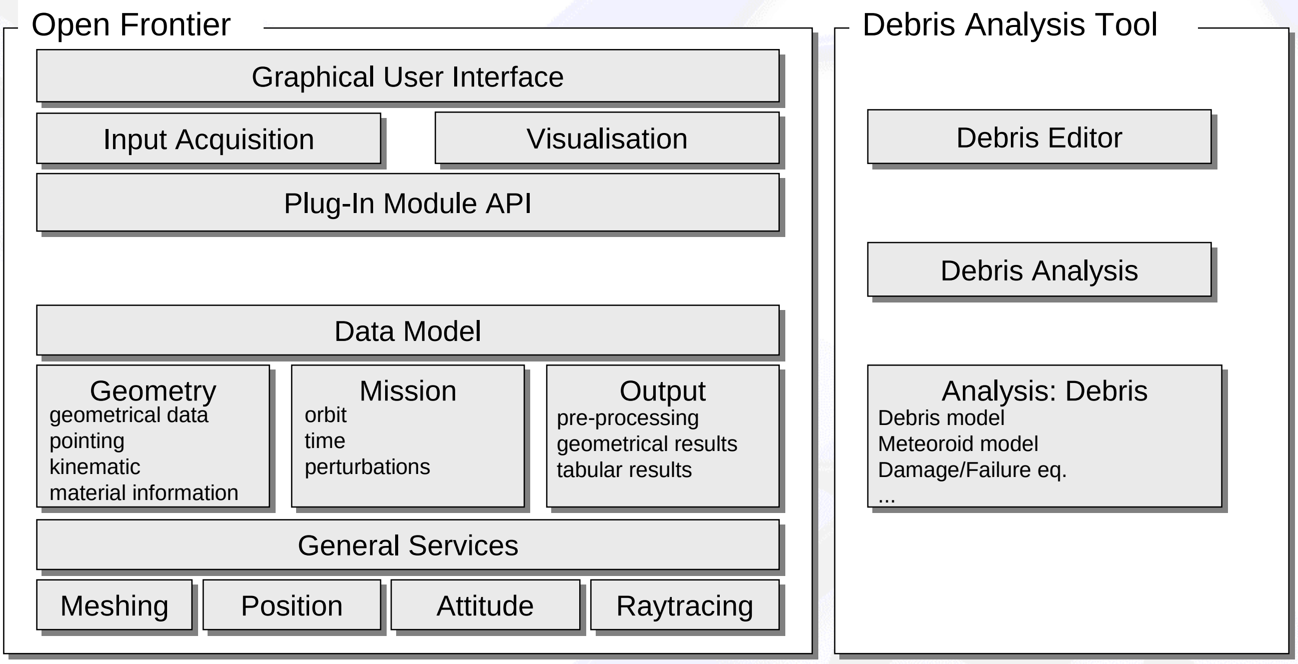


Open Frontier

+ ESABASE/Debris

= PC ESABASE

The platform concept



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Architecture

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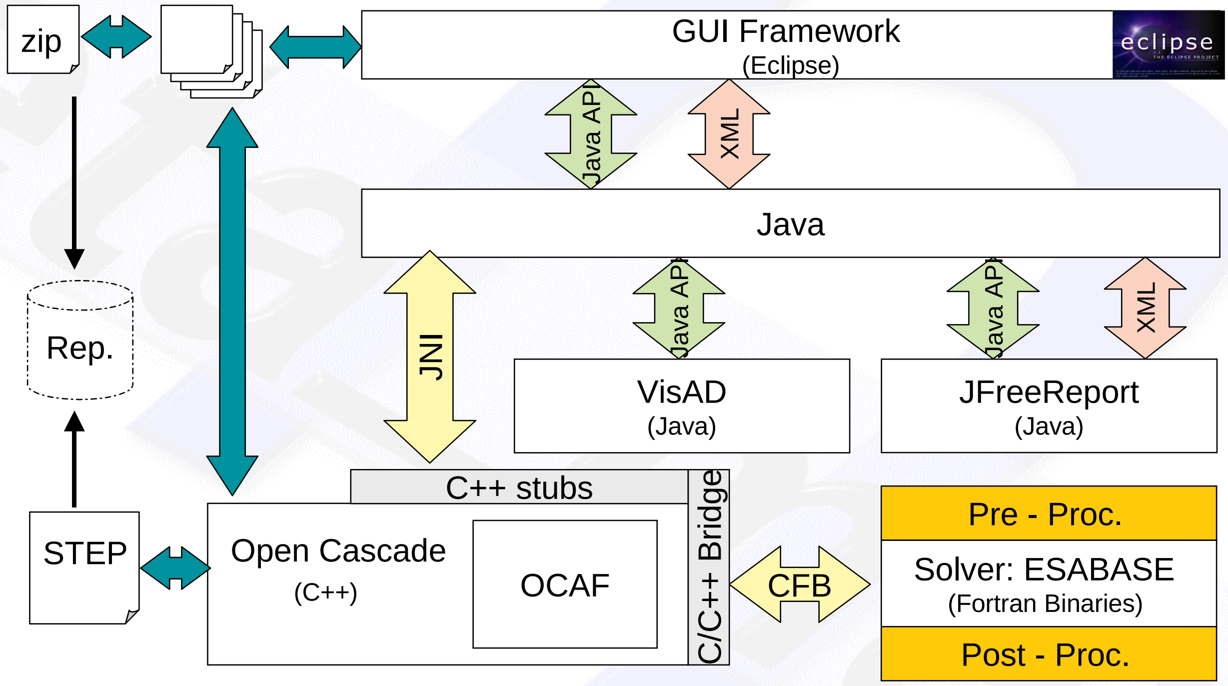

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GUI concept

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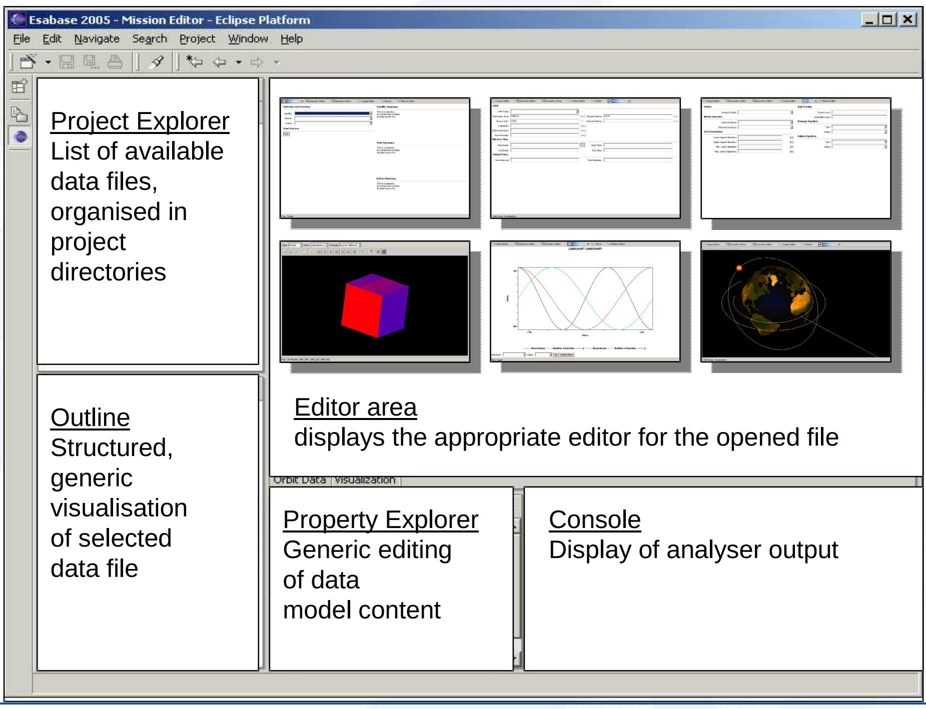
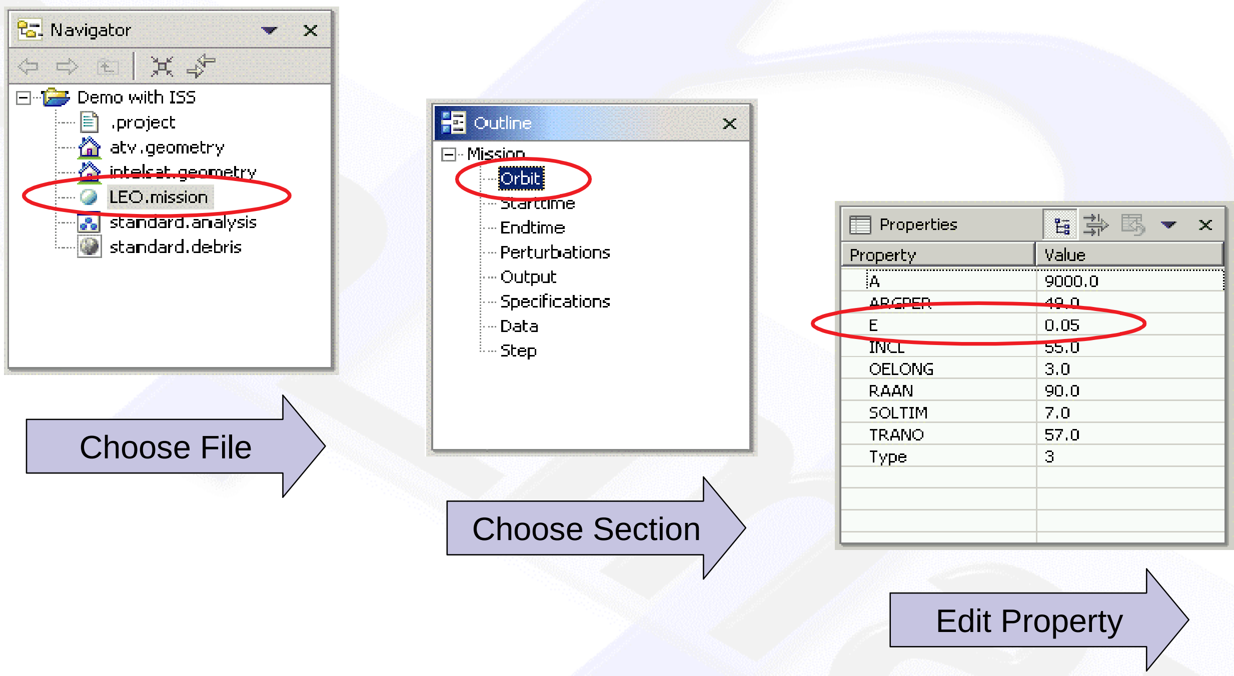


Online Presentation

Implementation Approach: Purist Workflow

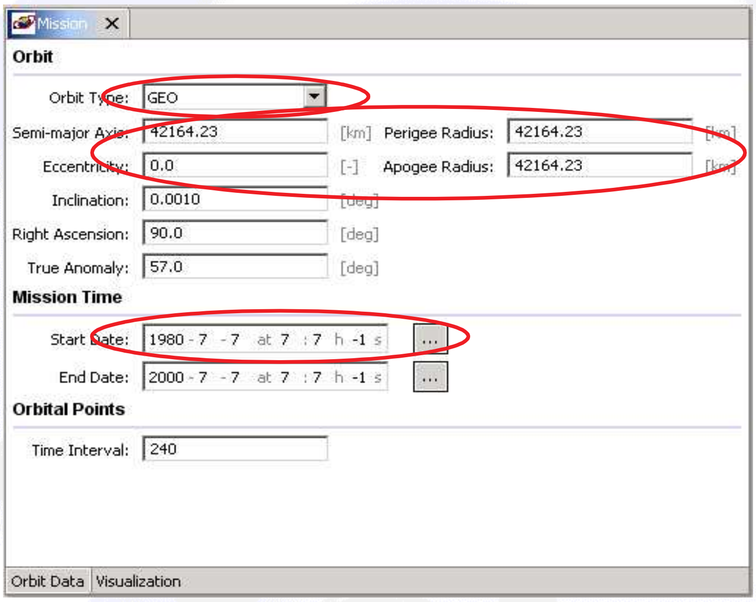


Implementation Approach: User Friendly

Cascade by Choice

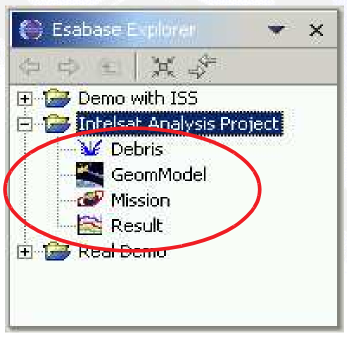
Calculation by Others

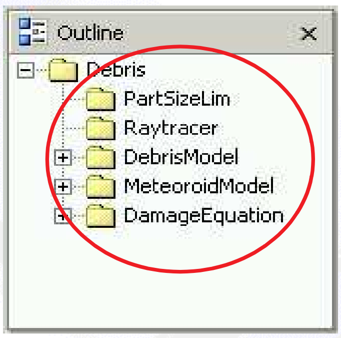
Date Editor with Dialog

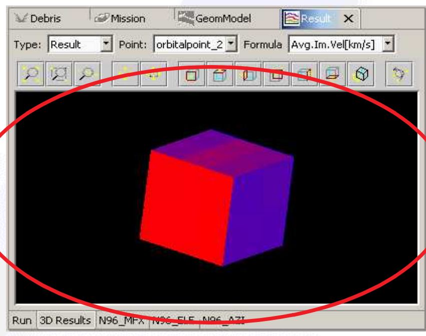


Implementation Approach: OCAF Integration

- Open Cascade is integrated by an JNI contract
  - Eclipse file matches OCAF document
  - Tree nodes match OCAF labels
  - OCC view panel is integrated into Eclipse geometry editor







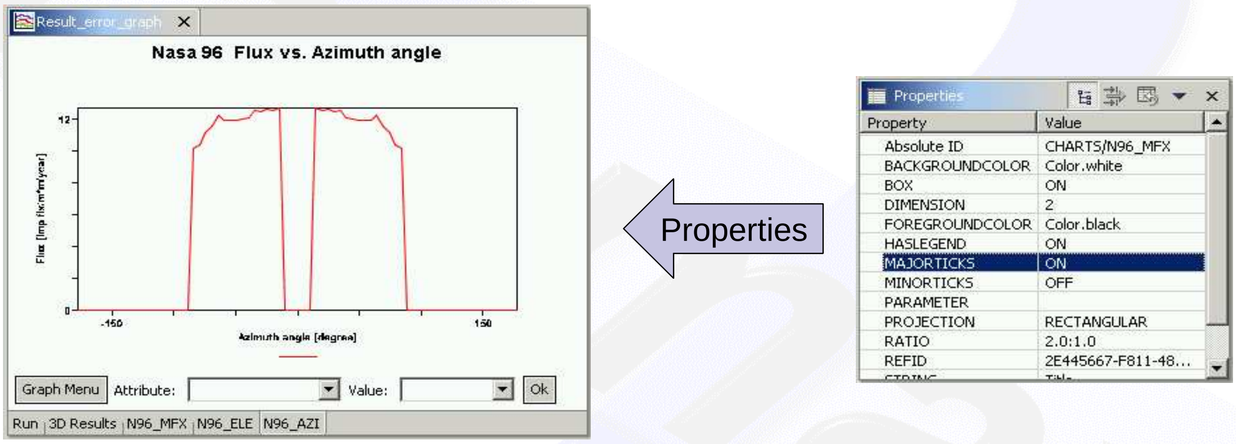
OCAF documents

OCAF labels

OCC panel

Implementation Approach: VisAd Integration

- VisAd is included via AWT/SWT integration bridge
  - VisAd panel is placed into an SWT editor panel
  - Commands are piped from OCAF to VisAd thru an automatic synchronization model



Summary and Outlook

Summary and Outlook

- Based on Open Source OTS tools the Open Frontier Platform has been created
- Open Frontier provides
  - An ergonomic framework for user input acquisition and visualisation
  - A highly flexible and scalable data model
  - An interface to external CAD tools
  - A generic plugin model for solvers from various disciplines
- The Plugin approach allows also proprietary plugins
- Open Frontier + ESABASE/Debris = PC ESABASE
  - Beta version providing most functions in principle implemented and running
  - The PC ESABASE tool providing all existing capabilities of ESABASE/Debris plus the Open Frontier advantages will be available in the second half of 2004
- Open Frontier demonstrates the applicability of Open Source software to high-profile analysis tools

eta_max

eta_max space GmbH

Appendix M: Round Table Discussion

Round Table
Discussion

HP. de Koning
ESA/ESTEC

17th European Thermal and ECLS Software Workshop Round Table

Opinions on harmonisation activity

- Open Source versus Proprietary COTS
- Community (restricted membership) versus Global public OSS
- Prescribed single toolset versus Required data format standard
- Free of charge versus Paid membership
- Representation by steering board
- Would you participate
  - As user
  - As developer

17th European Thermal and ECLS Software Workshop Round Table

FEA for thermal

- Need for FE modelling?
  - Experiences with high number of elements in radiation computation
- Need for hybrid FD/FE models?
  - FD for system/environment representation
  - FE for details (complicated geometry, critical gradients)

Need to support multi-disciplinary engineering & analysis

- How important is concurrent engineering?
- Priority of interfaces
  - Mechanical design (CAD)
  - System engineering
  - Structural
  - Optical
  - Product Data Management
  - Electrical power
  - Aero-thermo-dynamics / flow-fields (CFD)
  - Control engineering & real-time simulators
  - AOCS

17th European Thermal and ECLS Software Workshop Round Table

Computing platforms?

- PC/Windows
  - XP, 2000, NT, 98
- PC/Linux
  - Redhat, Suse, Mandrake, Debian, …
  - Who is using Linux clusters for affordable high performance computing?
- Sun/Solaris
- HP/HP-UX
- HP/Compaq/Alpha/TRU64
- SGI/Irix

Appendix N: Furnace Inserts and Cartridge Assemblies in CrysVUn

Simulation of Furnace Inserts
and Sample-Cartridge Assemblies
using the Thermal Modeling Tool
CrysVUn

M. Hainke
Fraunhofer Institute

Crystal Growth Laboratory
Fraunhofer Institute of Integrated Circuits and Device Technology (IISB)
Erlangen, Germany

Simulation of Furnace Inserts and Sample-Cartridge Assemblies using the Thermal Modeling Tool CrysVUn

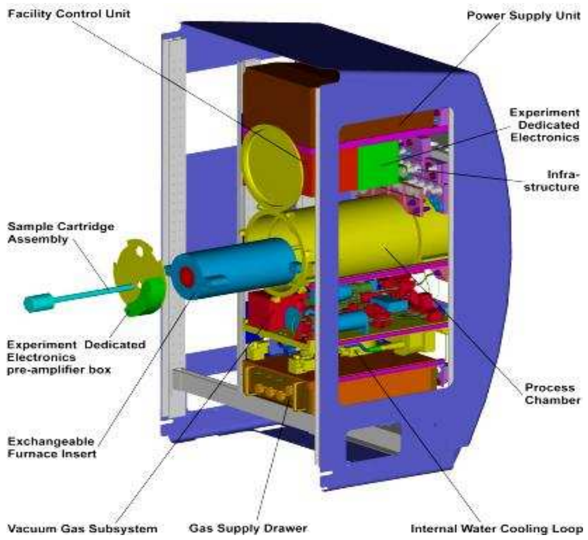
M. Hainke, J. Dagner, J. Friedrich, G. Müller

esa

ESTEC contract No. 16462/02/NL/JS

Contents

The Material Science Laboratory and Modeling Tasks



Furnace inserts (FIs)
- Low Gradient Furnace (LGF)
- Solidification and Quenching Furnace (SQF)

Several types of different sample-cartridge assemblies (SCAs), dependent on FI and specific experimental requirements.

MSL User Support Program

Support users and hardware developer with a thermal modeling tool (TMT) in
- Construction of the SCA
- Definition of the process parameters
- Evaluation of experiments

Contents

Modeling of solidification processes with the TMT CrysVUn

Working with CrysVUn:

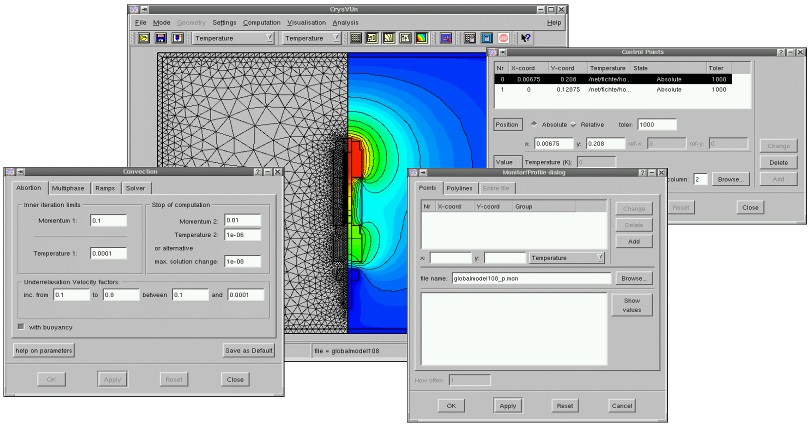
- *Inverse simulation*
- Unstructured grids
- Easy transfer of CAD-files
- Automatic grid generation
- *User-friendly graphical interface*

Physical phenomena:

- (Laminar) convection
- Radiative heat transfer (semitransparent media)
- Heat transfer by conduction (anisotropic)
- Resistance and inductive heating
- Thermal stress
- Time-dep. magnetic fields (rotating, travelling, alternating)
- Alloy solidification
  Flow in porous media
  Macrosegregation
  Microsegregation modelling

Technical details:

- Finite-volume technique
- Axisymmetric/2D-geometry
- Direct/indirect solvers
- Unix/Windows systems
- Parallelisation of view-factor computation

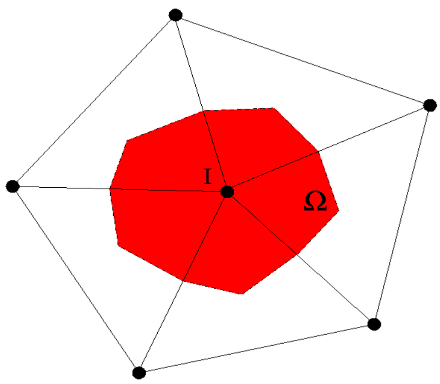


Finite Volume Technique on Unstructured Grids

Integral form of a general conservation equation:

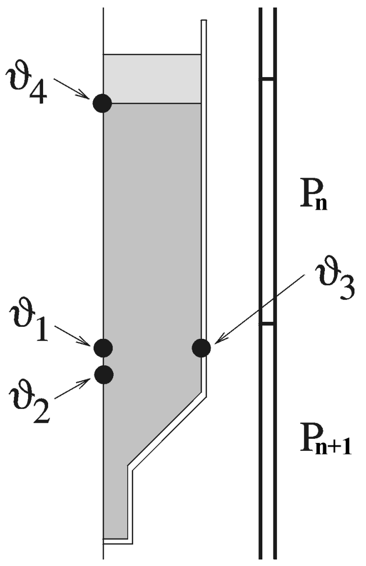
$$\int_{\Omega} \Lambda_t \frac{\partial \phi}{\partial t} dV + \oint_{\partial\Omega} \Lambda_c \phi \mathbf{v} \cdot \mathbf{n} dS = \oint_{\partial\Omega} \Lambda_d \nabla \phi \cdot \mathbf{n} dS + \int_{\Omega} s_{\phi} dV$$

unsteady term | convection term | conduction term | source term



Unstructured grid and construction of a control volume, surrounding a vertex I.

Idea of Inverse Modeling



- forward simulation: $\{P_n\} \Rightarrow T(x)$
heater powers are given, like in experiments, problem is mathematically well posed
- inverse simulation :

selection of N points $\{x_1, \dots x_n\}$
where N temperature $\{\vartheta_1, \dots \vartheta_N\}$ are given

mathematical problem:
find the heating powers P_m so that $T(x_n)=\vartheta_n$ for all n ($1 \le n \le N$),
this problem is mathematically ill-posed

strategy of solution within CrysVUn

$$\frac{1}{2}\sum_n w_n \left(T(x_n)-\vartheta_n\right)^2 + \frac{\mu}{2}\sum_m \left(P_m\right)^2 = \min$$

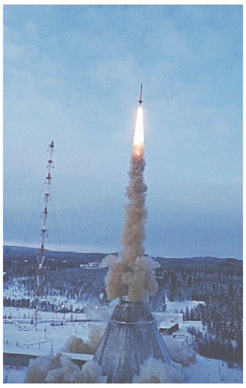
weak formulation *regularization*

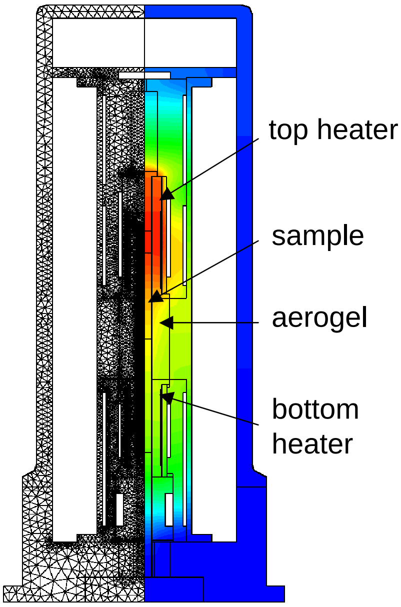
Contents

Application of CrysVUn in Microgravity Research I

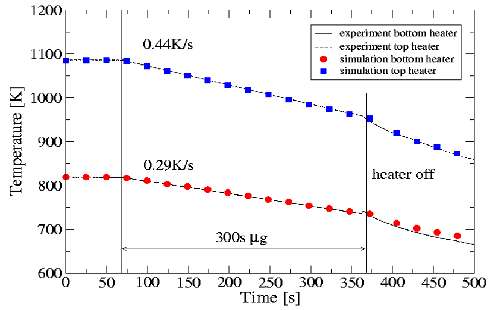
MICAST
MAP project No. AO-99-031

Thermal modeling of the ARTEX facility (IRS,DLR).

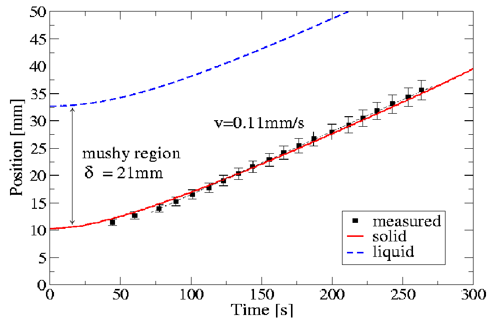




Heater temperature profiles as used on TEXUS39



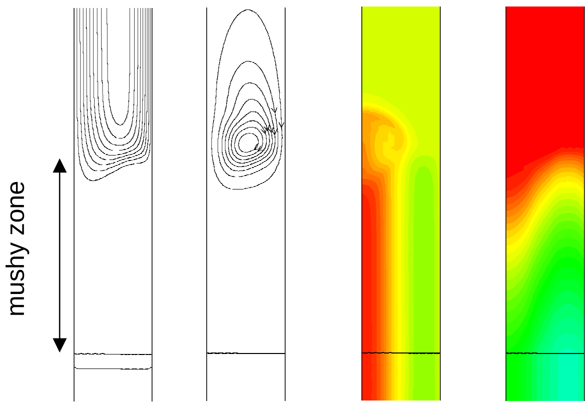
Resulting solidification process



Application of CrysVUn in Microgravity Research II

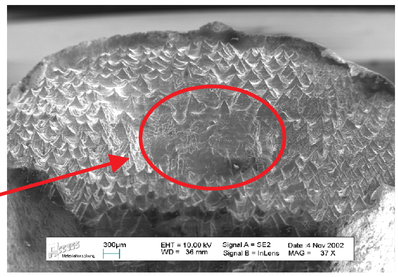
→ Modeling task: Definition of process conditions for the re-flight of ARTEX, scheduled for TEXUS41, but now equipped with an additional rotating magnetic field (RMF).

Example: Solidification of AlSi7 including a RMF



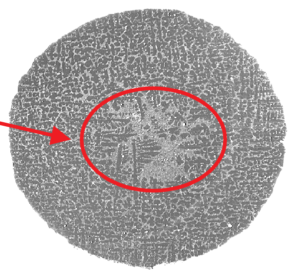
from left to right: azimuthal flow velocity, streamlines, segregation and liquid volume fraction

liquid channel formation



(source: ACCESS, e.V.)

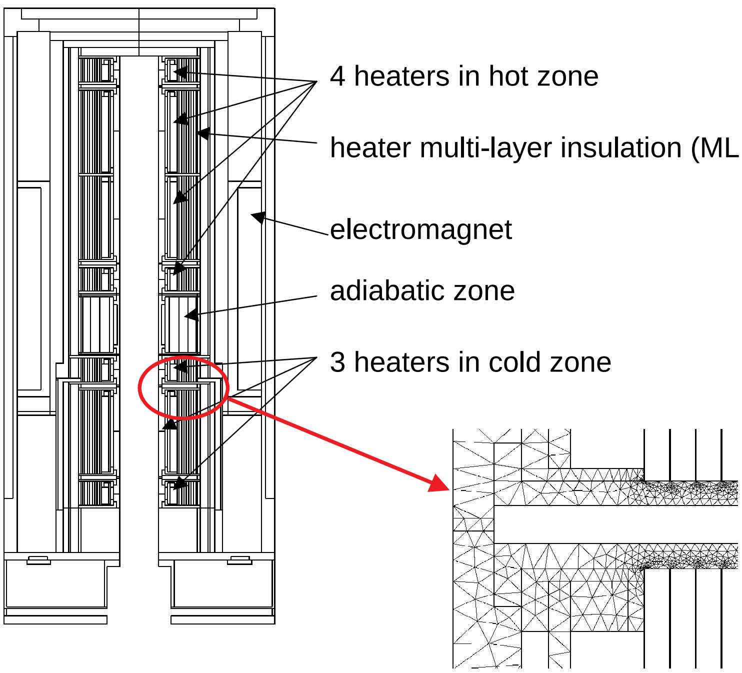
axial Si segregation



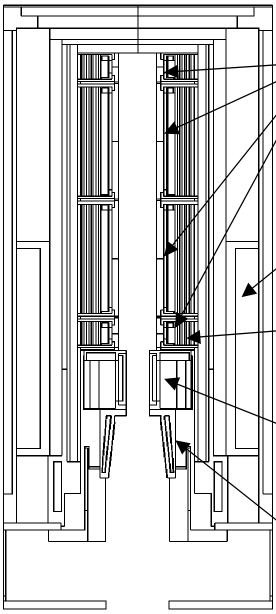
(source: IRS, DLR)

Contents

Thermal Model of LGF

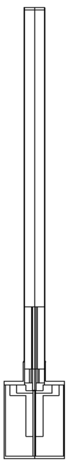


Thermal Model of SQF



Pre-Processing SCA Models Independently from FI Models

2 select appropriate FI model from a list



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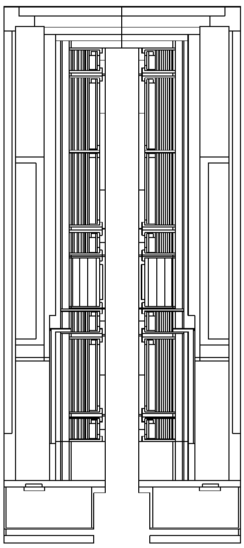

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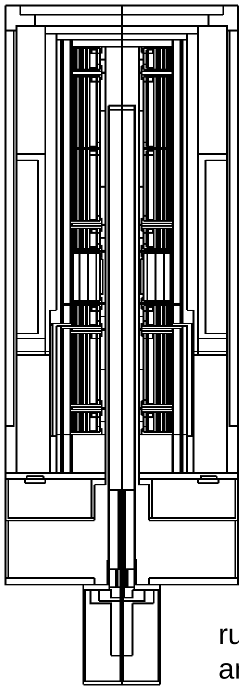


1 modify pre-processed SCA model or design SCA model from the scratch

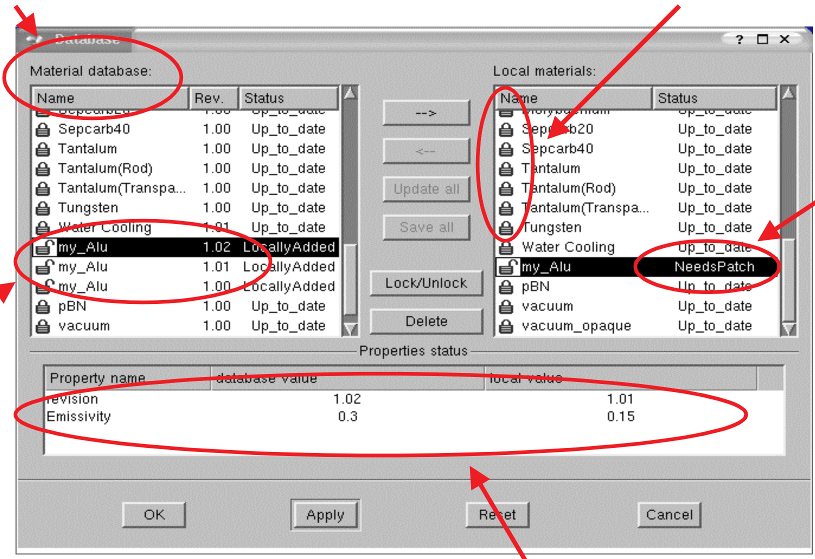
generate engineering model (EM) 3

4 run thermal analysis

Extended Material Database in CrysVUn

Materials used in the FIs and test SCAs are taken from a central material database.

FI related materials are locked for the Users.



Old material properties used in a thermal model are identified.

Revision control in the case of changed material properties.

Changed material properties are displayed in the GUI.

Contents

Conclusion and Outlook

The TMT CrysVUn was further developed according to ESA's software standard PSS05-lite to fulfill the user requirements defined by ESA.

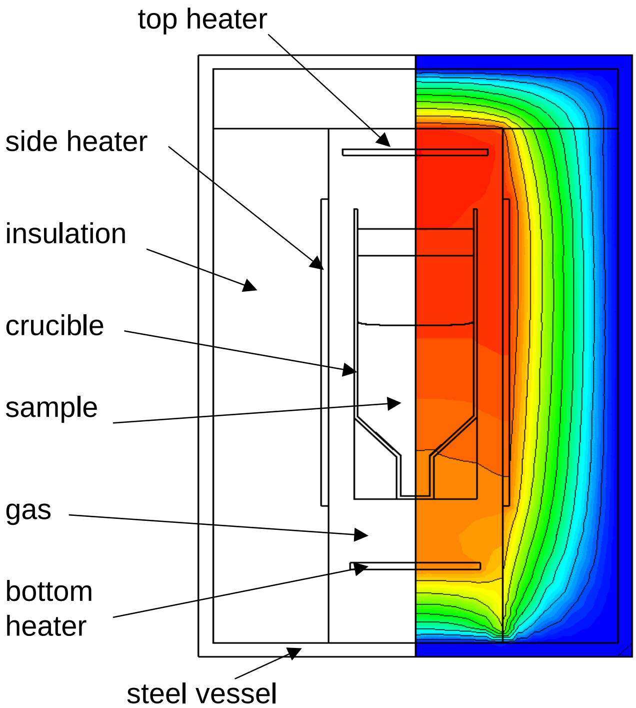
Thermal models for the FI Low Gradient Furnace (LGF) and Solidification and Quenching Furnace (SQF) were developed according to ESA's software standard PSS05-lite.

The detailed validation of the thermal models is underway.

Currently, CrysVUn is applied on behalf of EADS to support the development of the Sample-Cartridge Assemblies which shall be used by the different European MSL users.

Contents

Online Demonstration of CrysVUn using a VGF toymodel



Quick-start in CrysVUn:
- making a forward simulation
- making a inverse simulation
- evaluation of results
- changing the geometry

Appendix O: Plant Growth Chamber Simulation using EcosimPro

Plant Growth Chamber
Simulation
using
EcosimPro

L. Ordóñez Inda
ESA/ESTEC

Plant Growth Chamber Simulation using EcosimPro®

17th European Thermal and ECLS Software Workshop
Noordwijk, 21st-22nd October, 2003

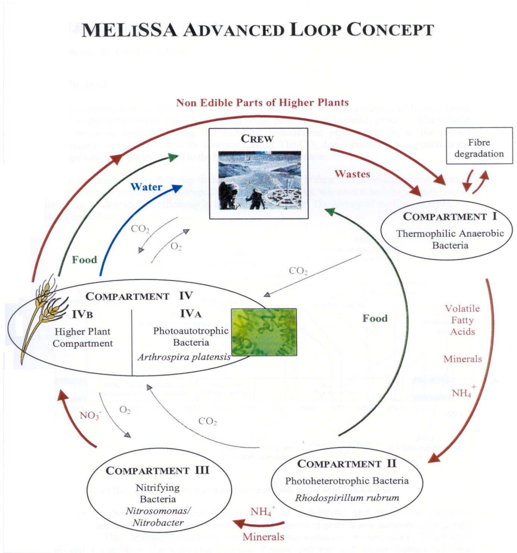
Presentation Overview

1. Introduction
2. Plant Model
3. EcosimPro® model
4. Results
5. Conclusions

Introduction (I)

✓ MELiSSA

- Stands for Micro-Ecological Life Support System Alternative
- It is a closed ecosystem intended as a tool to gain understanding of artificial ecosystems and to develop new technologies for a long term manned mission life support system
- To facilitate the study, the system is divided in five compartments: three bacteria compartments, the photosynthetic compartment and the crew compartment
- The photosynthetic compartment is as well divided in two: photo-autotrophic bacteria and **higher plants**



Introduction (II)

✓ Life Support functions of plants

- CO_2 reduction, O_2 production
- Fresh food production (lowers logistics penalty)
- H_2O regeneration

\+ Positive influence in crew psychology

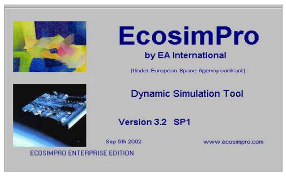
✓ Draw-backs

- High power demand
- High mass and volume penalties
- Crew time intensive

To weigh the positive effects against the penalties trade-offs are required. Multiple sources indicate plants may be favorable for long term missions

⇒ Simulations needed

Introduction (III)



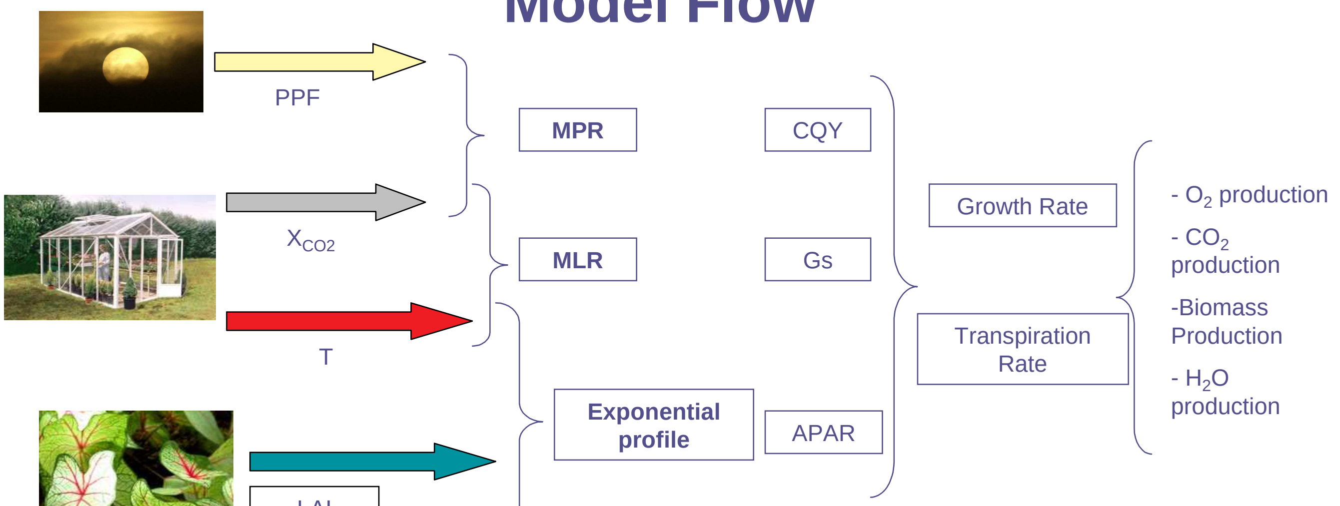
✓ EcosimPro®

- Multi-disciplinary simulation tool
- User-Friendly visual environment (similar to Microsoft Visual Studio®)
- Object oriented approach towards creating reusable libraries of components
- Allows the simulation of a given set of algebraic equations, ODEs and discrete events
- Avoids the need for the user to call the solvers, to order the equations, to handle numerical problems (algebraic loops, high index problems)
- Permits graphical modeling (drag and drop, connect components)
- Easy post-processing tool (EcoMonitor®)

Plant Growth Model

- The model selected for this investigation is the Modified Energy Cascade Model
  - It is a dynamic top level plant growth model
  - It considers:
    - Environmental conditions (light, CO_2 concentration, temperature and relative humidity)
    - Different periods in plant growth (juvenile phase, panicle initiation, heading, grain fill, canopy closure time, time of senescence)
    - Monoculture strategy
  - It does not consider:
    - Nutrient limitations
    - Water and nutrients uptake
    - Germination period of plants

Model Flow



LEGEND

LAI: Leaf Area Index

CQY: Canopy Quantum Yield

Gs: Stomatal Conductance

PPF: Photosynthetic Photon Flux

T: Temperature

MLR: Multi-variable Linear Regression

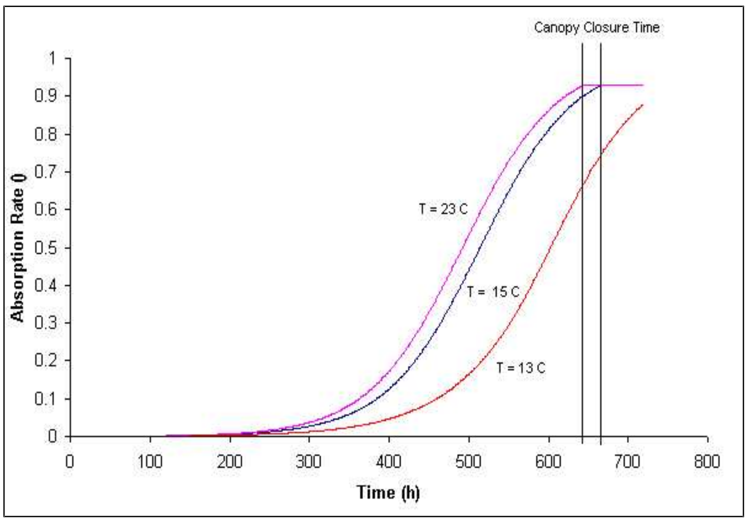
MPR: Multi-variable Polynomial Regression

APAR: PPF fraction absorbed

X_{CO2}: CO_2 Concentration

Light Absorption Model

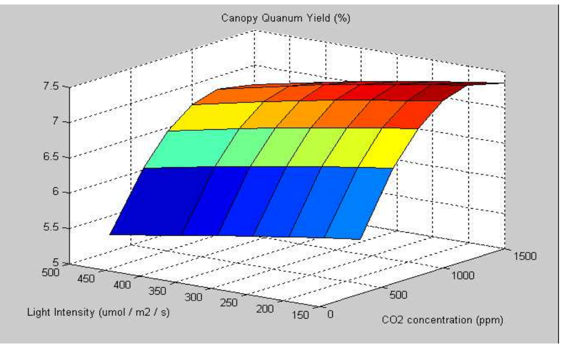
- The Absorption efficiency increases with leave area and is bound by canopy closure, which depends on the temperature of the growth environment



Growth model

- The growth model is based in an overall efficiency of carbon fixation. The Canopy Quantum Yield (CQY) is defined as the ratio of carbon fixed (C-mol) over the total light absorbed (# of photons)
- CQY is calculated using a multivariable polynomial regression based on experimental data. It depends on the total light flux (PPF) and the carbon dioxide concentration (X_{CO2})

$$CQY = CQY(PPF, X_{CO2})$$



Transpiration Model

- The driving force for transpiration is the difference in H_2O saturation vapor pressure and H_2O vapor pressure in the chamber. Hence, the transpiration rate (TR) is given by the following equation:

$$TR = \alpha \cdot Gc \cdot \frac{VPsat - Pvap}{Patm}$$

α: Units Conversion Factor

- Two conductances are defined:
  - gA: Chamber aerodynamic conductance
  - Gs: Canopy stomatal conductance
- gA is considered constant and does not pose a limitation on the transpiration
- Gs is a multivariable linear regression depending on carbon fixed, temperature and relative vapor pressure difference

Global conductance ⇒

$$Gc = \frac{gA \cdot Gs}{gA + Gs}$$

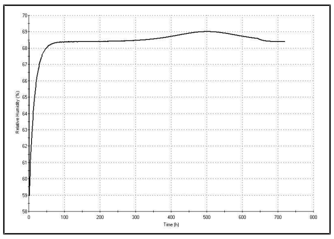
EcosimPro® Model

In the context of the previously developed MELiSSA library the model has been adapted to EcosimPro® with the following additional features:

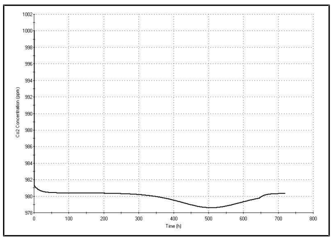
- General gas phase modeling considerations: mass balance, pressure dynamics, relative humidity
- Time events to introduce harvesting cycles and staggered culture strategy
- Conventional control strategy (PID) to maintain optimum and relatively constant values of CO_2 concentration and relative humidity

Case 1: Lettuce

- The controlled variables are maintained around the set-points of $1000ppm_{CO2}$ and 70% relative humidity



Relative Humidity vs. Time



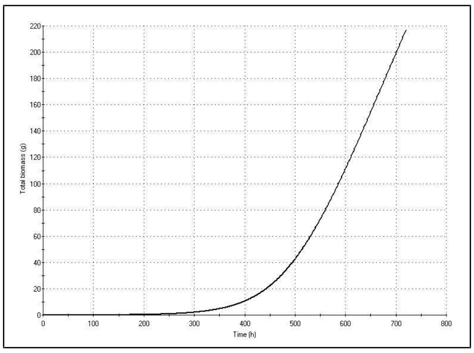
CO2 concentration vs. Time

- Mean production rates:

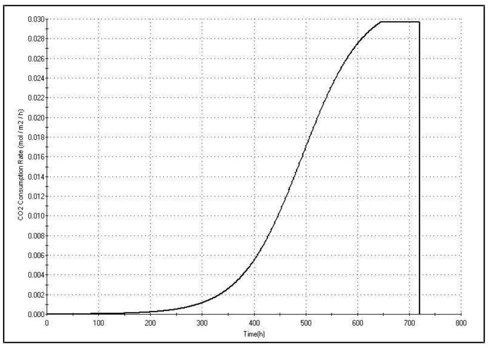
Biomass: $7.24g_{dw}/m^2/d$
O_2: $7.72g/m^2/d$
H_2O: $0.47kg/m^2/d$

- Mean consumption rates:

CO_2: $10.61g/m^2/d$



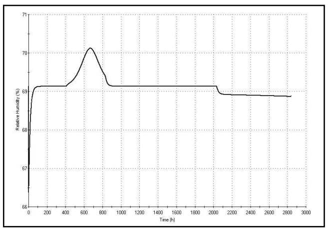
Biomass vs. Time



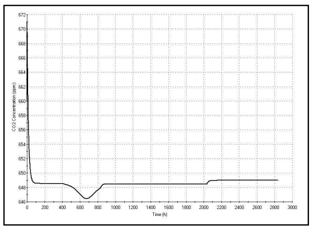
CO_2 production vs. Time

Case 2: Rice

• The controlled variables are maintained around the set-points of 660ppm$_{CO2}$ and 70% relative humidity



Relative Humidity vs. Time



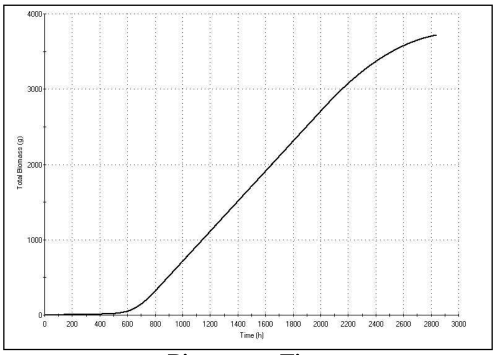
CO2 concentration vs. Time

• Mean production rates:

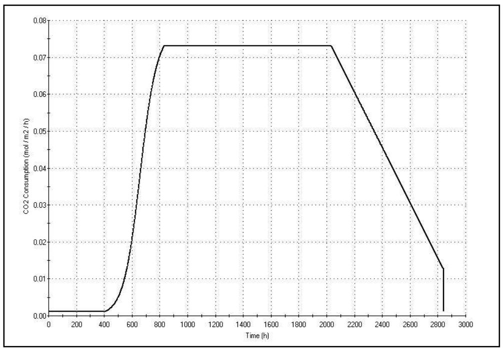
Biomass:	$31.41g_{dw}/m^2/d$
O_2:	$36.85g/m^2/d$
H_2O:	$3.50kg/m^2/d$

• Mean consumption rates:

CO_2:	$50.67g/m^2/d$

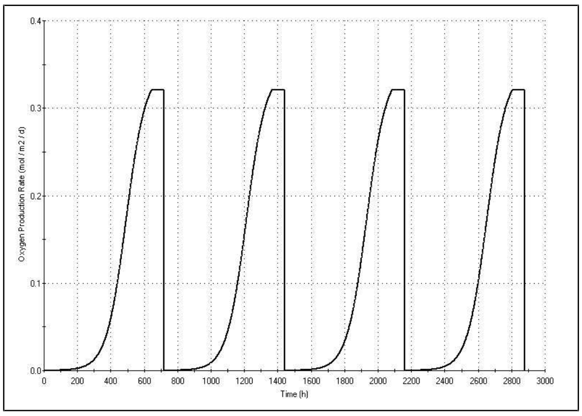


Biomass vs. Time

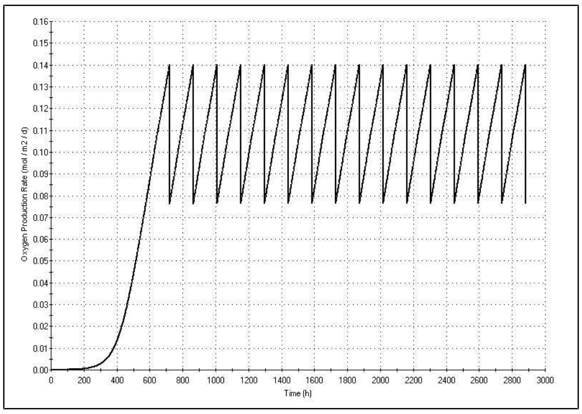


CO_2 production vs. Time

Staggered vs. Non-Staggered: lettuce



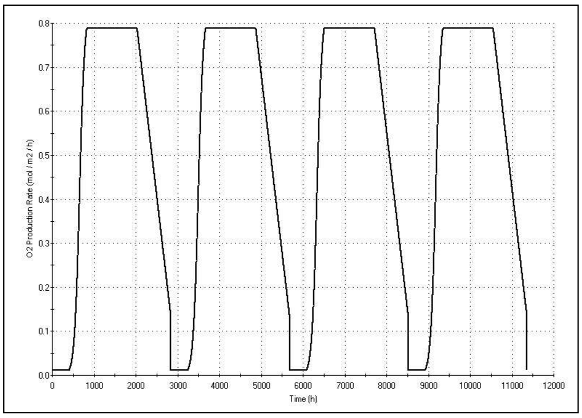
O_2 production vs. Time. Case N = 1



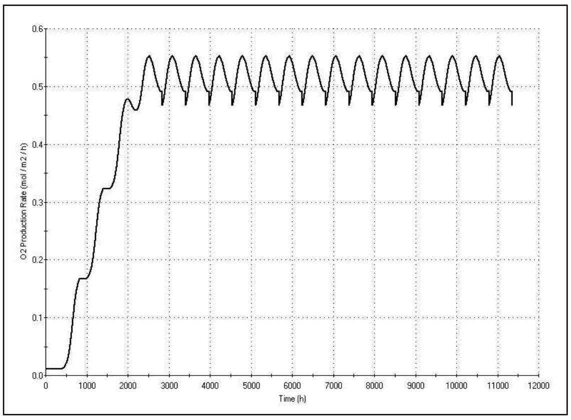
O_2 production vs. Time. Case N = 5

• The mean production rates are unchanged
• The instantaneous production rates fluctuate around the mean value.
⇒ Easier control, less buffer capabilities needed

Staggered vs. Non-Staggered: rice



O_2 production vs. Time. Case N = 1



O_2 production vs. Time. Case N = 5

- The mean production rates are unchanged
- The instantaneous production rates fluctuate around the mean value

$\Rightarrow$ Easier control, less buffer capabilities needed

Conclusions

- The model is capable of simulating plant growth under variable conditions
- EcosimPro® permits the simulation of staggered culture strategy thanks to its capability of handling discrete events
- Additional experimental data is necessary to improve and adjust the model
- Model predictions may help implementing a predictive control strategy for a MELiSSA Higher Plants Compartment
- Upon completion of data collection for the remaining candidate crops (tomato, potato, soybean, spinach, onion and wheat), the model will allow sizing the MELiSSA Higher Plant Compartment

References

- Cavazzoni, J. “Crop Modeling Task, ALS Power Reduction NRA”. Rutgers University. Department of Bioresource Engineering. September 1999.
- “MELiSSA” Yearly Report for 2002 Activity. Lobo, M. and Lasseur, Ch. ESA/EWP-2216. June 2003
- www.ecosimpro.com

Appendix P: Thermal and fluid analysis of the Mice Drawer System

Thermal and fluid analysis of the
air cooling/conditioning system
on board the
Mice Drawer System facility

A. Sgambati
Laben

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Thermal and fluid dynamic analysis of the air cooling/conditioning on board of MDS (Mice Drawer System) facility

CBA Centro Biotecnologie Avanzate
ABC Advanced Biotechnology Center

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MICE DRAWER SYSTEM

- MDS main features:
  - Facility dedicated to experiment on mice strains
  - able to host till 8 grouped mice or 6 individually
  - able to delivery dedicated quantity of food and liquids
  - able to supply air flow for mice well being
  - able to manage mice waste
  - able to sustain experiment phase for 100 days

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MICE DRAWER SYSTEM

- MDS main features:
  - Double Middeck Locker replacement payload
  - able to interface Middeck during on orbit transportation
  - able to interface Express rack in US lab on orbit
  - able to interface crew for maintenance
  - able to minimise crew time w.r.t. animal needs

M D S

- Mice Chamber (MC)
- Air Conditioning Subsystem (ACS)
- Food Delivery Subsystem (FDS)
- Illumination Subsystem (ILS)
- Liquid Handling Subsystem (LHS)
- Observation Subsystem (OSS)
- Payload Control Unit (PCU)
- External Container

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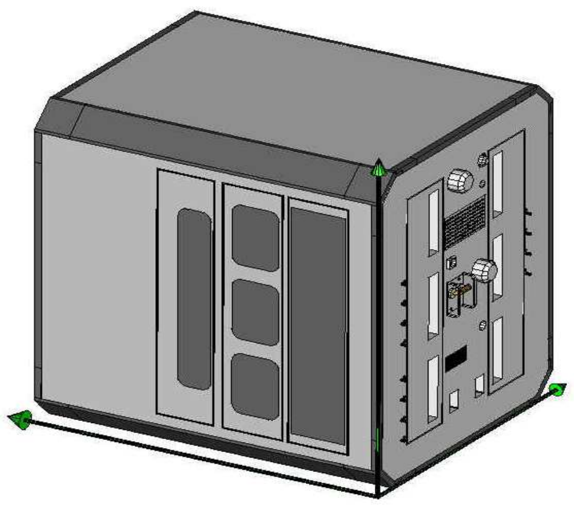
EXTERNAL CONTAINER

- The principal structural part of MDS is the External Container that supports all the subsystems and it's packaged with Pyrell Foam and inserted into DMDL



•Nodalization of EC and DMDL box

•GL conductors with Pyrell foam

•The model is defined into elemuser.dat
•and called by main programm

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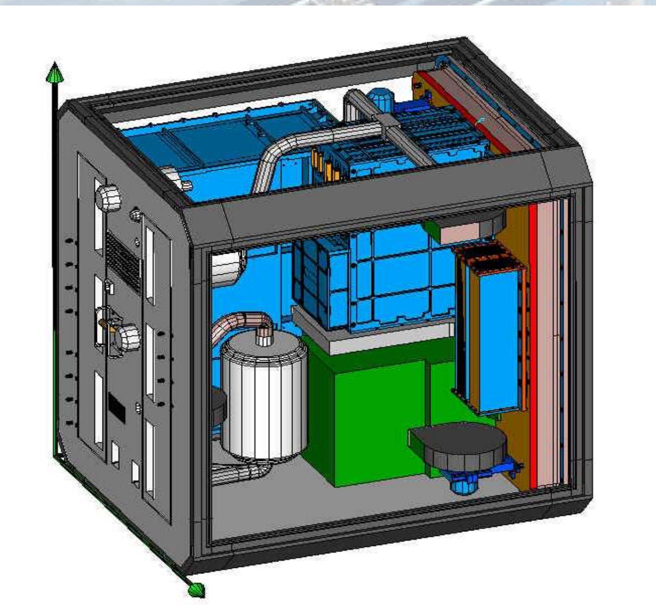
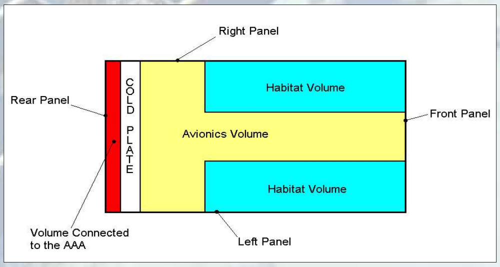
VIEW INSIDE EXTERNAL CONTAINER



- Three separated zones are present inside MDS:
  - Habitat volume
  - Avionics volume with electronic box, LHS, etc.
  - The zone connected to the AAA.



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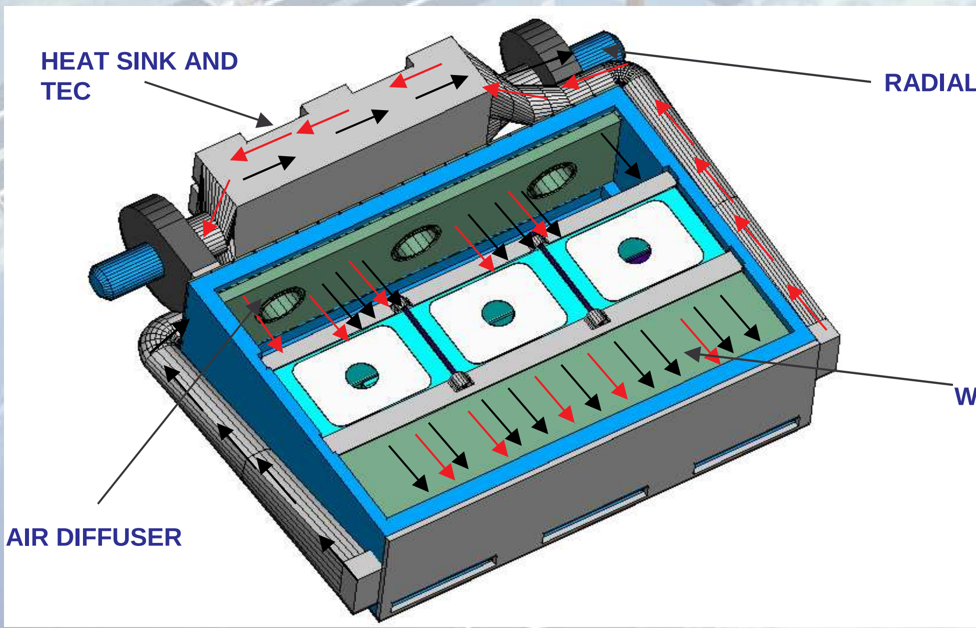
HABITAT VOLUME :Life Air Support Loop



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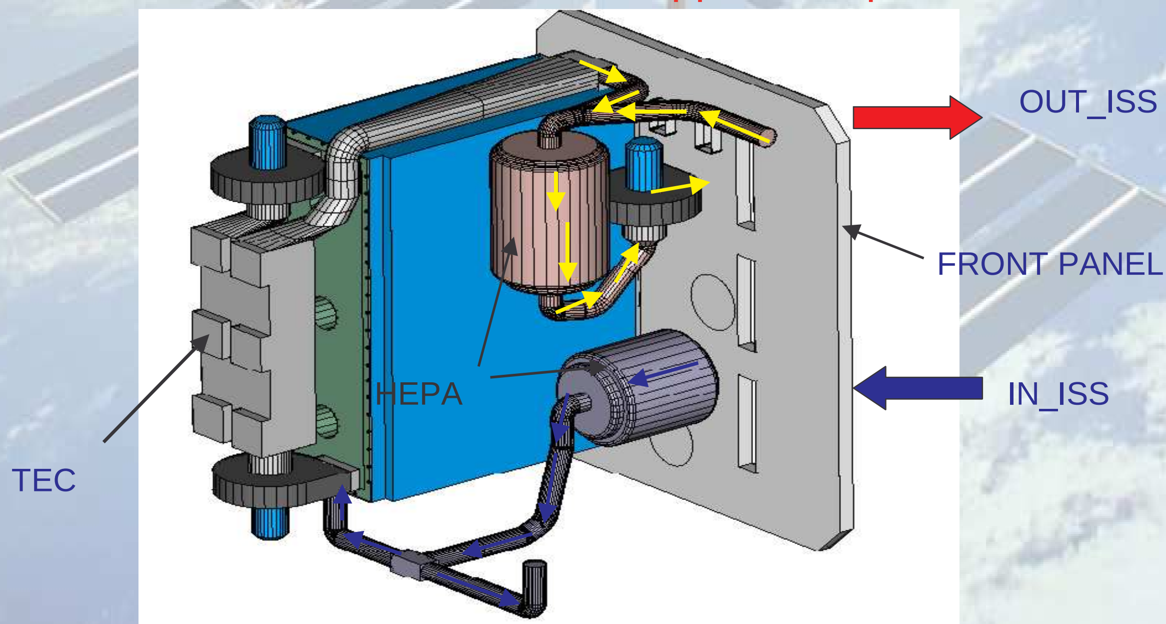
HABITAT VOLUME: Life Air Support Loop P/L-ISS



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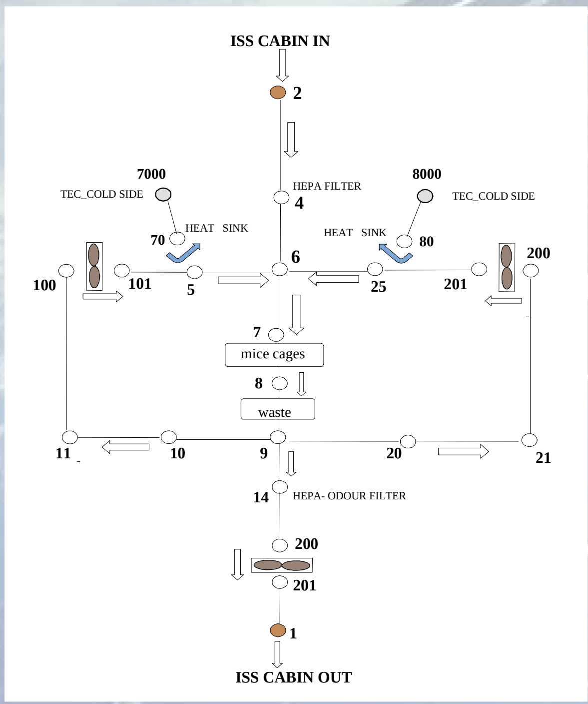

LIFE AIR SUPPORT NETWORK

Elemuser contains the fluid network to simulate the life air support loop in each habitat.

- Fan is defined using mass source/sink
- The pressure drop into the waste filter and pre-filter is defined using GP link
- Heat exchanger is connected to air loop thanks a GL =eff*S*hc
- Tec cold side is connected to HX by linear conductance GL with thermal grease characteristics and assembly by torlon screws
- Nodes:2-1 represents the boundary (Type R) of ISS Cabin conditions.

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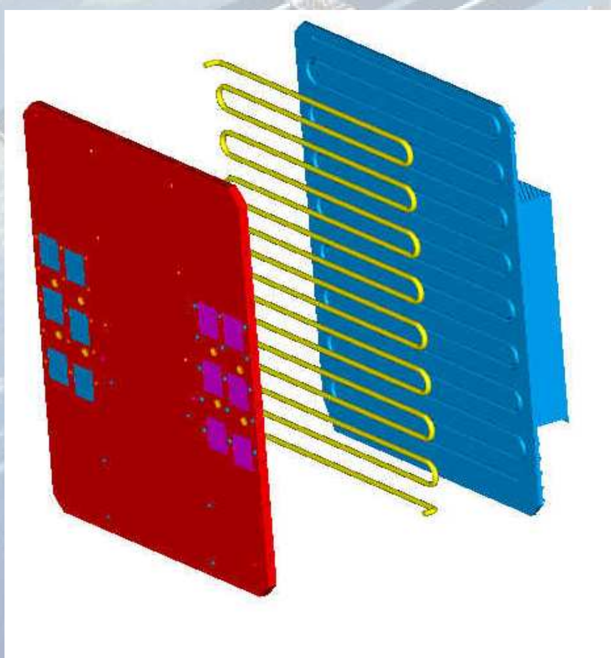
• HYBRID COLD PLATE



Cold Plate model:

- Coldplate of FHTS element
- Definition of parameters of discretization and all inputs about material property and flowrate.
- Linear conductive link between heat load and plate thermal nodes
- The cold plate is fixed by screws to the rear EC, but there is a thermal decoupling by insulating material

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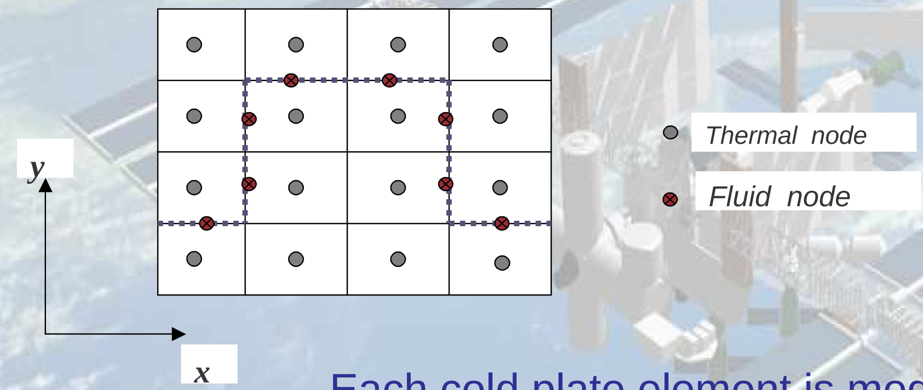
COLD PLATE ELEMENT

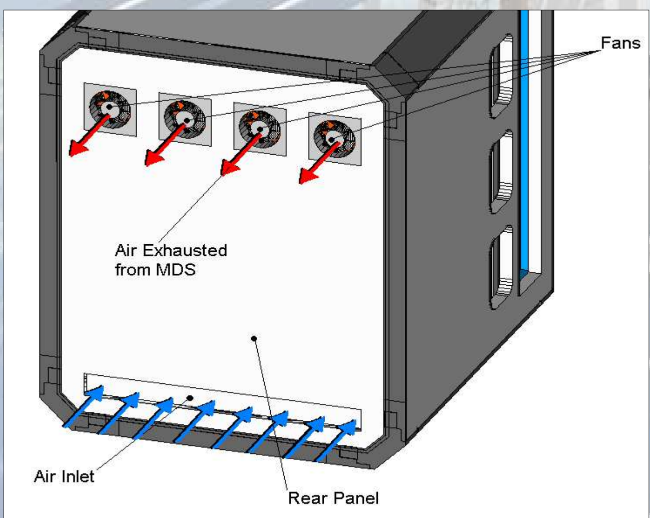


Each cold plate element is modelled as 2D plate containing a U-shaped fluid tube.

Capability to specify discrete heat source corresponding to thermal nodal within the plate

VOLUME CONNECTED TO THE AAA

- In this volume there are the cooling ribs and four axial fans.



Heat sink is modelled using a conductive and convective GL and M for flowrate through the fins.

The Avionics fans suck up the air from the Avionics Bay

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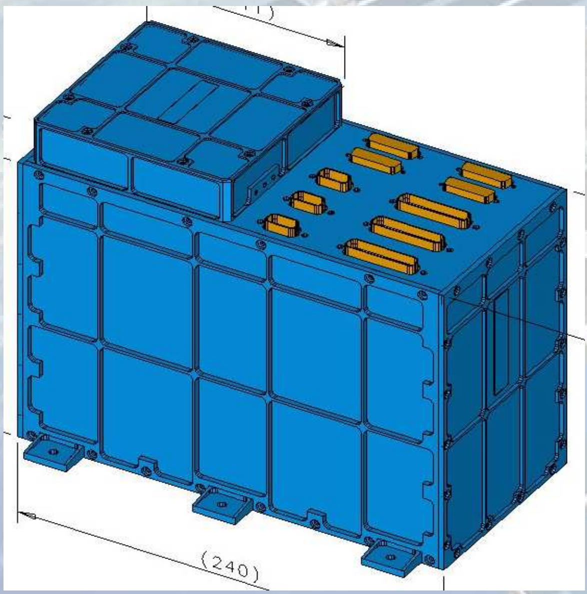
• PAYLOAD CONTROL UNIT



•Semplified model for each board (1 node)
•Link between the board and box using experimental value of GL conductors
•Link between PCU-Cold Plate nodes

output

•MaxT for all boards
•Sides' temperature of the box

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•**Thermal Design**

•Survival operational mode

- Life Air Support Loop

-Avioncs Air Loop (supplied by Avionics Air Assembly)

•Experimental operational mode

- Life Air Support Loop

-Moderate temperature water Loop (supplied by ISS)

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Survival operational mode

- All subsystem are turned off, except:
  - 4 radial fans for the air recirculation in mice volume
  - radial fan for the air blowing to the ISS
  - 12 TEC
  - ILS (electrical power reduced to 50%)
- Cooling system is AAA

Experimental operational mode

- All subsystem are turned on
- Cooling system is MTL

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THERMAL ANALYSIS

THERMAL REQUIREMENTS

The facility has to withstand the following thermal requirements:

- **The maximum return temperature from the payload to the MTL shall be less than 48.9°C**
- **The maximum return temperature from the payload to the AAA shall be less than 48.9°C**
- **The pressure drop between the inlet and outlet QDs of payload utilizing MTL shall be 19.3 ± 1.03 KPa at the desiderate flow rate**
- **The MDS habitat air temperature shall be kept between 25 - 30°C**

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THERMAL MATHEMATICAL MODEL

BOUNDARY CONDITION

Survival mode:

AAA flow rate	750 l/min
AAA pressure	101 KPa
AAA temperature (*worst case)*	29.4°C
ISS Cabin Pressure	104.8 KPa
ISS Cabin temperature	28°C
Air recirculation into mice chambers volume	480 l/min
Air blowing to the ISS	17 l/min
MDL Temperature	35 °C

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Experimental mode:

Water coolant flow rate	100 lbm/hr
Water pressure	834 KPa
Water temperature (*worst case)*	23°C
ISS Cabin Pressure	104.8 KPa
ISS Cabin temperature	28°C
Air recirculation into mice chambers volume	480 l/min
Air blowing to the ISS	17 l/min
MDL Temperature	40 °C

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Thermal budget

Survival operational mode

•T mice =29°C - TMDL=35°C

HEAT LOAD HABITAT +TEC	63.6 W	+ 15% → 73 W
PCU + ILB + ½ RADIAL FAN	39 W	+ 15% → 45 W
TOTAL HEAT LOAD dissipated into the cold plate	-	118 W

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AAA Fans (their contribut is on the AA in output)	**12 W**	**15% → 13.8**
½ Radial Fan + LED (Front panel)	**6.4 W**	**+15% → 7.4**
TOTAL HEAT LOAD dissipated out of the cold plate	**-**	**21.2 W**

THERMAL BUDGET = 139 W

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Experimental operational mode

•T mice =25°C - TMDL=40°C

HABITAT HEAT LOAD AND TEC	118 W
PCU	43 W
OSS-LHS	7 W
TOTAL HEAT LOAD Dissipated into the CP	166 W

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RADIAL FAN P/L to ISS CABIN	5 W
LED ON THE FRONT PANEL	1 W
TOTAL HEAT LOAD Dissipated out of the cold plate	6 W

THERMAL BUDGET = 172 W

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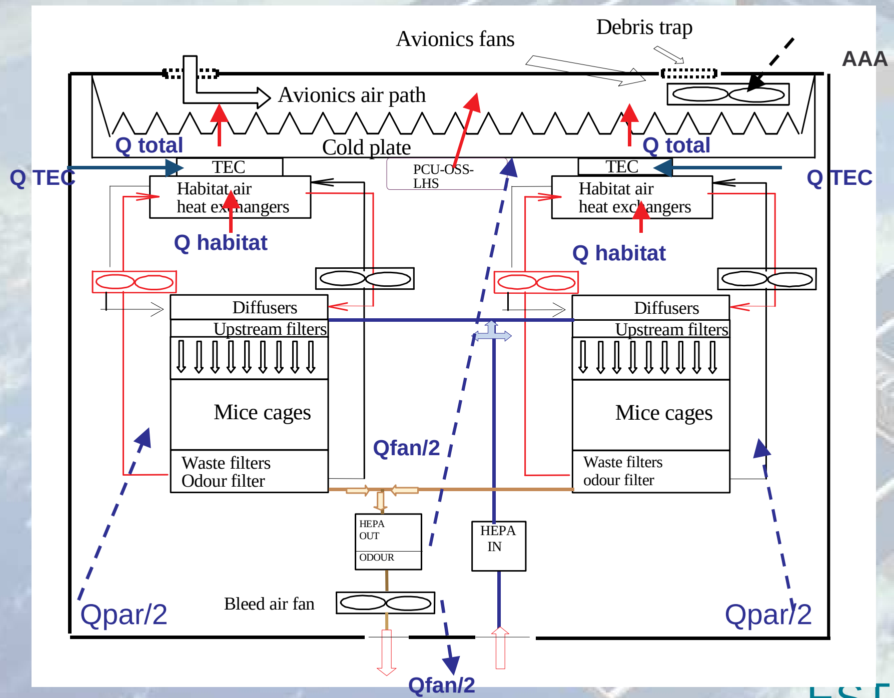
HEAT FLUX PATH



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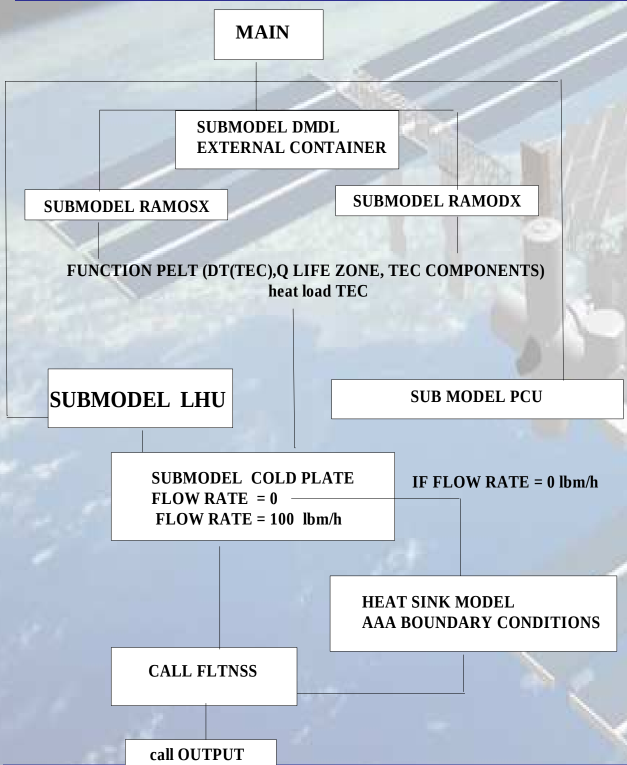

•FLOW CHART

The main sub_models are:

- Sub_model EC/DMDL
- Sub_model ramosx
- Sub_model ramodx
- Sub_model Coldplate
- Sub_model PCU
- Sub_model LHS
- Sub_model OSS Module

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Parameters and function for simulation

- Main contains the links between all subsystems in elemuser.dat and calls Elemsys.dat (coldplate) and solver routine
- Elemuser.dat contains the subsystem submodel (PCU,LHS,OSS,HABITAT,EC,DMDL)
- GP allows to define the concentrate pressure drop in the filter ,pipes and QDs
- Mass source/sink define the fans
- Peltier function simulates the real TECs behaviour and power

RESULTS

•SURVIVAL

LOCATION	NODES	T [°C]	P [Pa]
AAA_OUT	600	37.5	101288
Mice chambers	7	29	104691
Fan_Out_ISS Cabin	201	44.3	104800
PCU	1021-1044… 6021-6044	39	-

RESULTS

•EXPERIMENTAL

LOCATION	NODES	T [°C]	P [Pa]
MTL_OUT	800100	26.5	821487
Mice chambers	7	25	104692
Fan_Out_ISS Cabin	201	44.3	104800
PCU $Plate1	1021-1044… 6021-6044	29	-
LHS $Plate2	1018-1045	27	-

CONCLUSIONS

- Flexibility of the model management
- Capability to simulate the mission profile
- Easiness to change parameters of main thermal components (Fan choice,Hx efficiency,cold plate performance)
- Advanced simulation of TEC behaviour

Appendix Q: Thermal Aspects of Operations on a Comet Surface

Thermal Aspects
of
Long Term Operations
on a
Comet Surface

HP. Schmidt
DLR

Thermal Aspects of Long Term Operations on a Comet Surface

ESATAN
a simulation tool for experiment timeline optimisation

HP. Schmidt, DLR

Introduction

- Aim of Rosetta Lander:
  - In situ investigation of physical and chemical properties of a comet nucleus during the approach of the comet to the sun
    - Heliocentric distance: 3 to 1.x AU
    - Duration: about 6 months
    - Target: Comet 67P / Churyumov-Gerasimenko
    - Launch: Feb-2004
    - Landing: Nov-2014

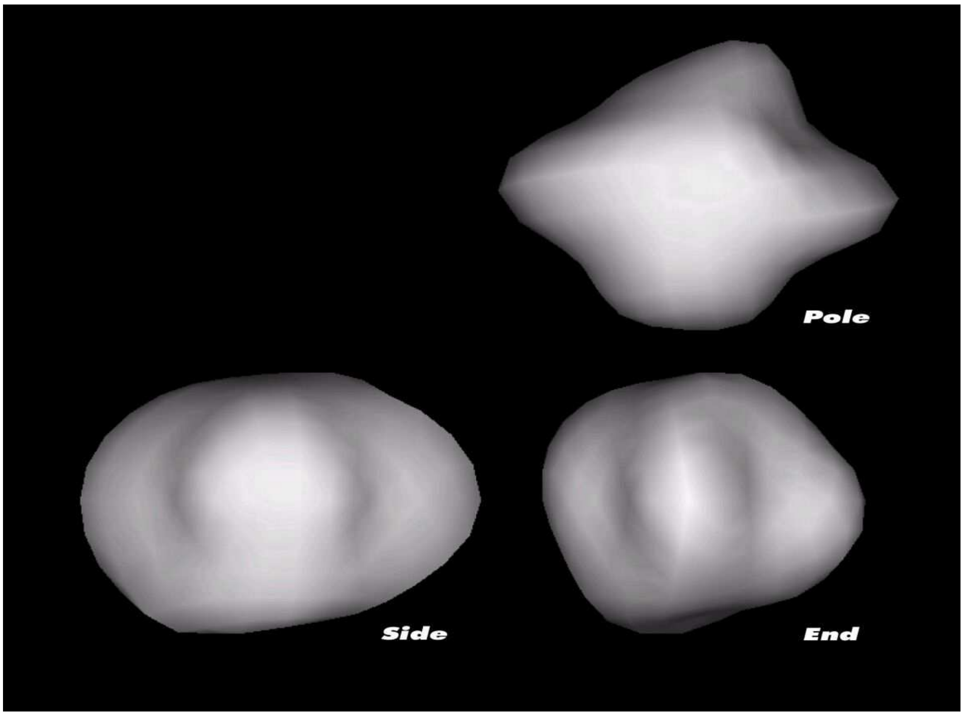
Fact Sheet

Comet 67P / Churyomov-Gerasimenko	
Perihelion	1.3 AU
Aphelion	5.7 AU
Orbital period	6.57 years
Radius of nucleus (evaluated from HST observation, March 2003) *)	1980 m
Rotational period (evaluated from HST observation, March 2003) *)	12.7 h
Albedo	0.04
Thermal emissivity	0.94

*) DPS (Division of Planetary Science) 35the Mtg, Sept 2003, Ames, Moffett Field, Cal

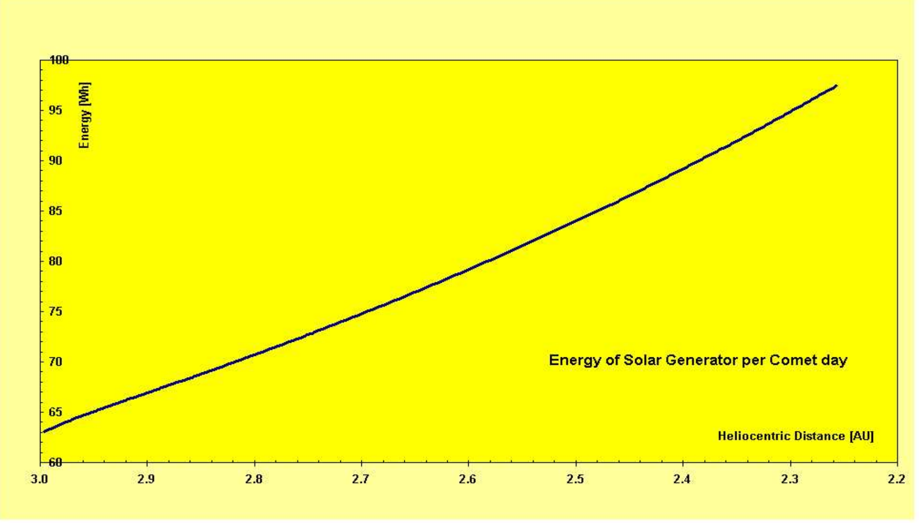
Nucleus of 67P / Churyumov-Gerasimenko

based on HST Observations



Courtesy ESA

- Problem:
  - Low energy availability for long term operations on comet surface



- Request:
  - About 9 W only for basic subsystems (power control, command and data management, telecom system) operations

- Conclusion:
  - Continuous operations impossible
- Consequences
  - Interruption of operations results in cooling down of Lander warm (electronics) compartment in particular during comet night
  - Wake-up and active temperature control requested, when power available again, before resuming operations
- Basic plan for long term operations
  - Phases of some days used for energy collection in sec battery followed by
  - Phases of experiment execution

- Thermal constraints
  - Lander operations possible, when compartment temperature above –45°C
  - Battery recharging possible, when battery temperature above Lower Limit of Charge (LLC = 0°C)
  - Battery discharging possible, when battery temperature above –30°C

➢ Thermal Control has a major impact on long term operations

Key Issues Thermal Control

- 3 independent control mechanisms
  - Hibernation Heater System
    - Activated by Orbiter during Lander and Orbiter hibernation in cruise phase
    - Hot redundant system
  - Thermal Control Unit
    - Active, when Lander is active
    - Cold redundant units for heater control and temperature monitoring
  - Wake-up Heater System in Combination with Power Enough Mode
    - Controlled by thermostat and Bus Voltage measurement
    - Active during cruise and on Comet, when Lander temperature below –47.5°C or electrical power not sufficient to operate Lander

Thermal Control Unit - TCU

- Operational Constraints
  - PSS and CDMS operating, i.e. about 6 W electrical power requested
  - Ops power request : about 130 mW per TCU unit (heater power excluded)
  - Main or/and redundant
- Tasks
  - Temperature monitoring (31 temperature sensors per TCU unit, most redundant)
  - Heating of compartment (6 individually controlled heater units per TCU unit, redundant)
  - Heater current monitoring

TCU continued

- Heater supply power (28V main bus) provided for each TCU on 3 lines for
  - Compartment heaters (4*2 W for each TCU)
  - Heater in primary battery (2.6 W for each TCU)
  - Heater in secondary battery (2.4 W for each TCU)
- Power is en/disabled by nominal CDMS/PSS ground TC
- Control of individual heaters is en/disabled by nominal TCS ground TC
- Heating control according set-point (nominal)
  - Common set-point for
    - Compartment heaters (Group A)
    - Battery heaters (Group B)
  - Set-point (–40°C default) may be updated individually for each group by nominal TCS ground TC

Wake-up Heater System
in Combination with Power Enough Mode

- Active when
  - temperature of PSS electronics below –45°C / -51°C

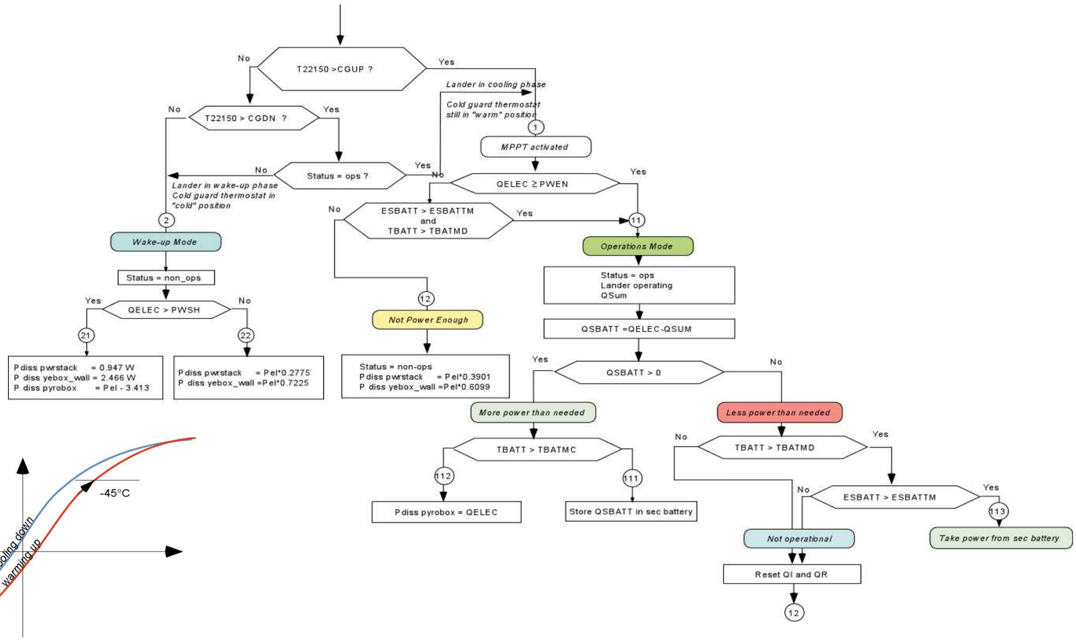
  or
  - Bus Voltage < 18.5 V
- Available Power
    - generated per solar generator (on comet)

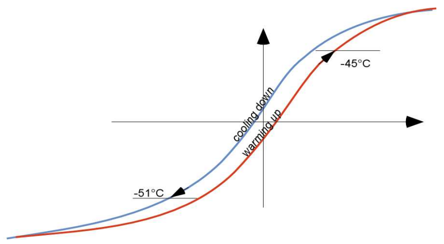
    or
    - provided by Orbiter (during cruise)

  dissipated in „wake-up“ heater

ROSETTA LANDER

Wake-up Heater System continued





ROSETTA LANDER

Implementation into ESATAN Model

$INITIAL
Define Comet / Lander parameter
Rotation period
Co-ordinates of landing point
Local time of landing
Read: Start conditions
Actual time
Heliocentric distance
Actual energy in secondary battery
Temperature start vector

$EXECUTION
Define operations mode
CALL SLFRWD

$VARIABLES1
AU = AU(t)
Comet_surface_temperature= f(t)
Thermal_power_input(t)
Solar_generator_output(t,T)
Control operations
Lander operating QI=f(t)
hibernating/wake-up QR=f(t)
battery heating / no heating QR=f(t,T)
battery charge / discharge Qelec=f(T,P)
QI=f(T,P)

$VARIABLES2
Update energy content of secondary battery

$OUTPUT
Store /print AU,T,QI,QR,Qelec,E_sec_batt

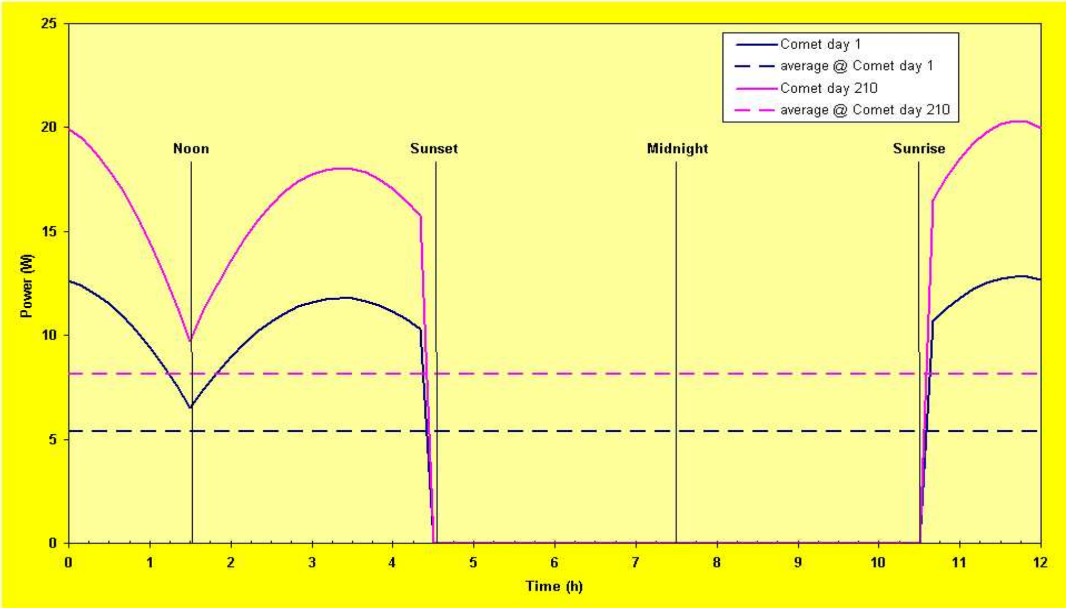
Thermal Analyses

- Long term operations
  - Start after completion of „First Science Sequence“
    - Started immediately after landing at
      - 3 AU
      - Near equator,
      - Lander Z-axis to Zenith
      - Lander X-axis to South
      - Landing time 4:30 (Comet time)
    - Duration 60 hrs
    - High power dissipation (power provided by primary battery)
    - Average compartment temperature at about 25°C
  - Primary battery exhausted
  - Operations rely on electrical power generated by solar generator, supported by secondary battery
  - Only basic subsystems (PSS, CDMS, Telecom in receiving mode) active
- Activated Thermal Control Units (only control of heater in secondary battery enabled) optional
  - Transient analyses executed for 210 Comet days (2520 h)

Thermal Analyses continued

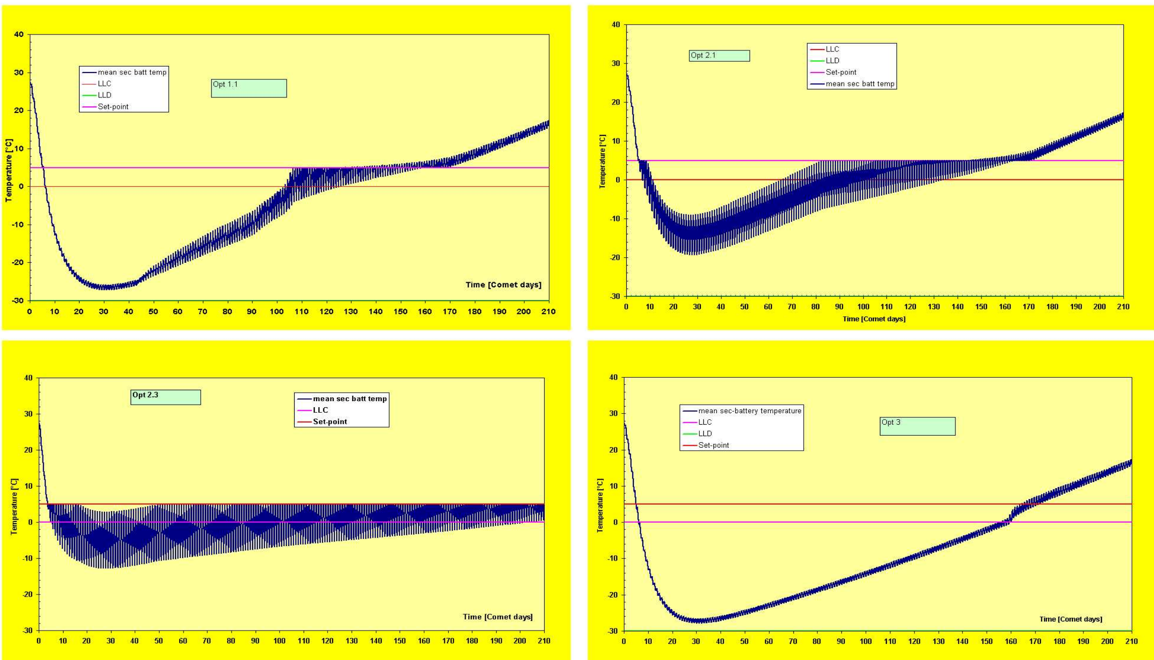
	PSS,CDMS Telecom	Both TCUs Heater in Sec Battery enabled	One TCU Heater in Sec Battery enabled	No TCU
1.1	continuously	continuously		
1.2	continuously	only during daytime		
2.1	continuously		continuously	
2.2	continuously		only during daytime	
2.3	only during daytime		only during daytime	
3	continuously			continuously

Expected Solar Generator Power



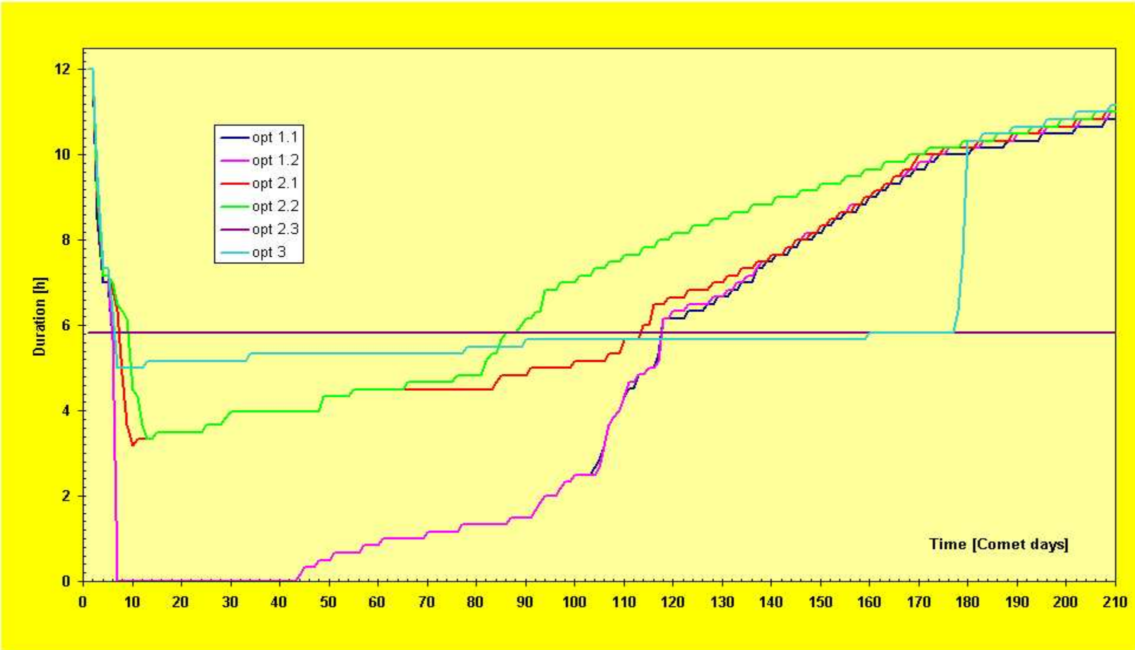
- In first order independent of operational option

Temperature of secondary Battery

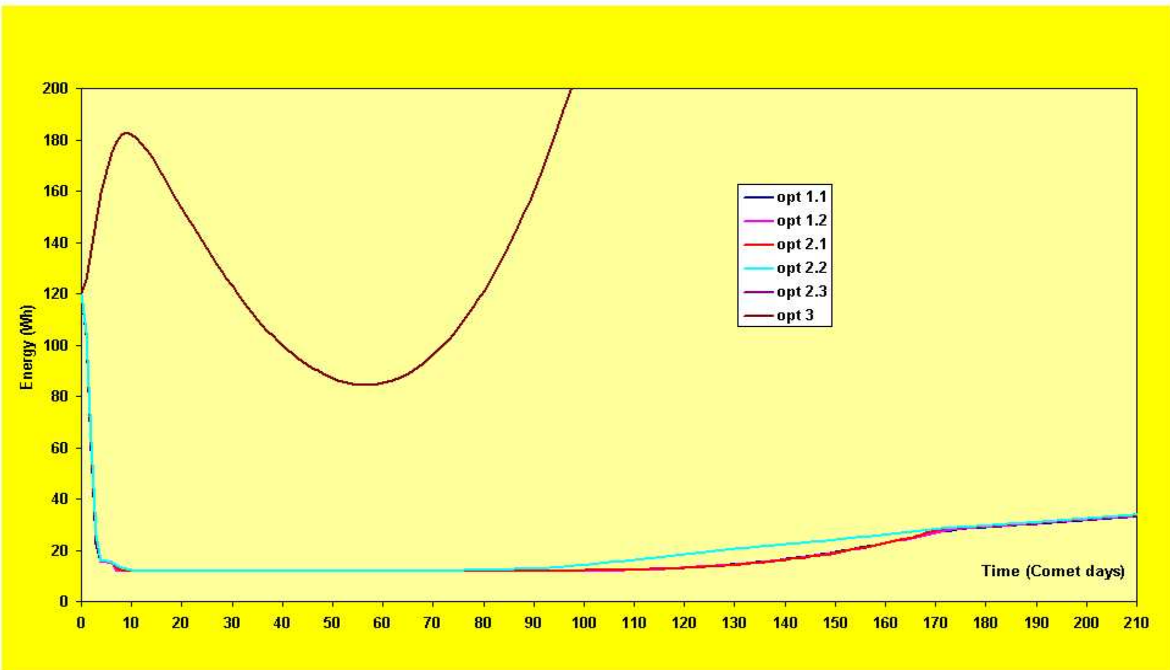


Duration of operational Phases

per Comet day



Energy Content in secondary Battery



Conclusions

- Rosetta Lander
  - On the basis of the analytical results the following recommendation for long term operations is derived
    - Schedule phases of energy collection followed by phases of experiment execution (high power consumption)
    - Inhibit night operations during phases of energy collection

- Thermal Analyser S/W
  - Esatan is an adequate tool to simulate thermal conditions of S/C operations
  - Esatan allows the implementation of relative complex operational constraints for transient analysis

Appendix R: Access to ESA funded developments

Access to ESA funded developments

O. Pin
ESA/ESTEC

Access to ESA funded developments

Olivier Pin
ESA/ESTEC D/TOS-MCV

ITTs for Space Thermal Engineering Tools

- Reminder: All* new developments are supported by Open Tenders, openly published at http://emits.esa.int
  - There were currently 2 ITTs open:
    - Thermal Concept Design Tool
    - ESATAP
- We do not advertise new ITTs via mailing lists in order to promote fair competition. It is up to you to look for business opportunities.
  - For example, all companies who had questions are already registered on EMITS and have the same level of information as any other bidder.

* Except when direct negotiation is justified, and this is rarely the case (used for existing products, very short time frame, etc)

TOS-MCV "planned" R&D (GSP, TRP, GSTP)

- Preliminary comment: as indicated by Hans Peter, the work on harmonisation/OSS is pretty much at the feasibility stage. So far:
  - One contract has been awarded
  - Within the frame of GSP
  - Does not affect our support for other tools, e.g. ESARAD/ESATAN
- TRP 2004-2004 and GSTP-4 are in preparation
  - Users and ESA projects have been consulted
  - 17 TOS-MCV proposals (4 linked to harmonisation)
  - Majority are GSTP
  - Waiting for TRP/GSTP board decision
  - Do not yet know which activities will be endorsed

TOS-MCV Mailing Lists

- Used for:
  - ICES
  - Workshop
  - TASverter
  - Harmonisation
- Approximately 200 e-mail addresses
  - Participants of previous workshops
  - People who replied to the harmonisation user survey, etc.
  - Includes 3 people from one of the companies with questions for example
- If you would like to be on our mailing list, please let us know!

Appendix S: HDF5 and STEP/NRF database for SINDA/G

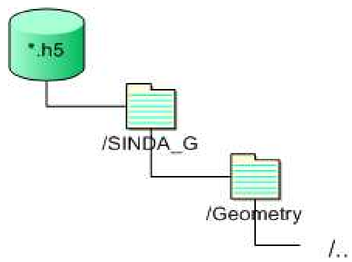
HDF5 and STEP/NRF
database
for
SINDA/G

R. Behee
Network Analysis

HDF5 and STEP/NRF Database for SINDA/G

October 22[st], 2003

Ron Behee
Network Analysis Inc



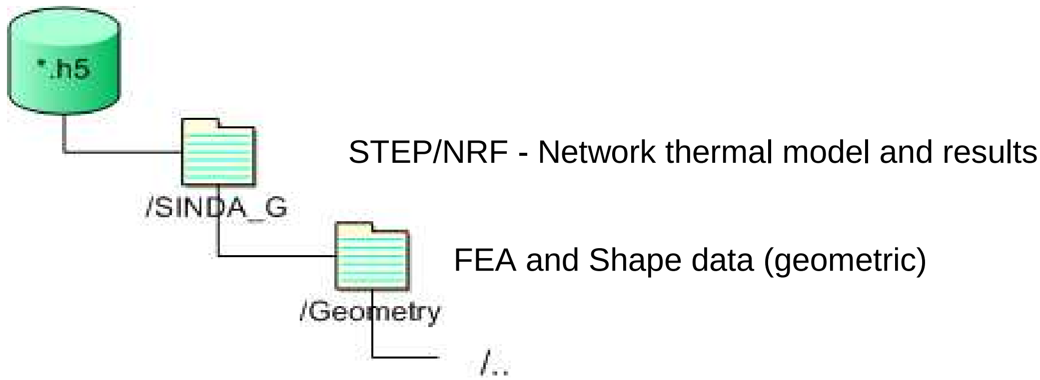
Why NAI Chose HDF5

- Widely used for scientific data
- Proposed database for STEP/NRF
- Public domain from NCSA
- Good user documentation
- Efficient, flexible and compact binary storage format
- Cross platform compatible
- API’s based on C, Fortran and Java

SINDA/G® by Network Analysis, Inc.

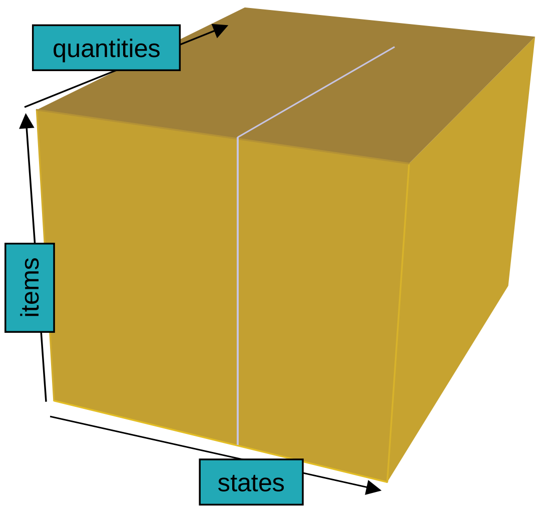
Why NAI is Implementing a SINDA/G Database based on HDF5 and STEP/NRF

- Simplifies interface to multiple FE systems
- Needed for “Next Generation” SINDA/G that is currently being designed
- Provides powerful post processing capability



SINDA/G® by Network Analysis, Inc.

STEP/NRF – Proposed by ESA



?

Can AP209 STEP FE data be stored in this data model, or will we need to create our own structure?

Central NRF data structure is the ‘data cube’

- each element of the cube is a scalar, vector or tensor property for a specific (item, quantity, state)
- state quantity is normally time or frequency

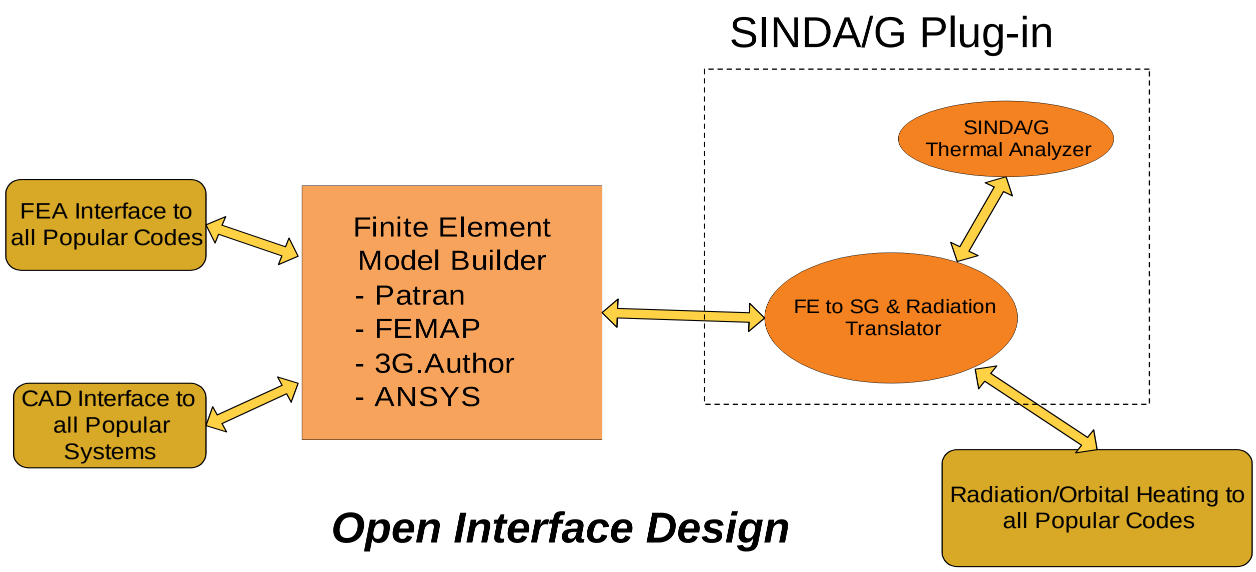
SINDA/G® by Network Analysis, Inc.

SINDA/DB Schema

- FEA data structures
  - Element, Node, Property, Load
  - Shapes
  - Materials-specific Coordinate Systems
  - Coating for Radiation Loads
  - Fluid for Convection Loads
  - Function dependant values
- SINDA Model/Sub-model hierarchy
- Results
  - SINDA/G Results
  - Ability to import results from other sources (i.e. test or computed data from another code

SINDA/G® by Network Analysis, Inc.

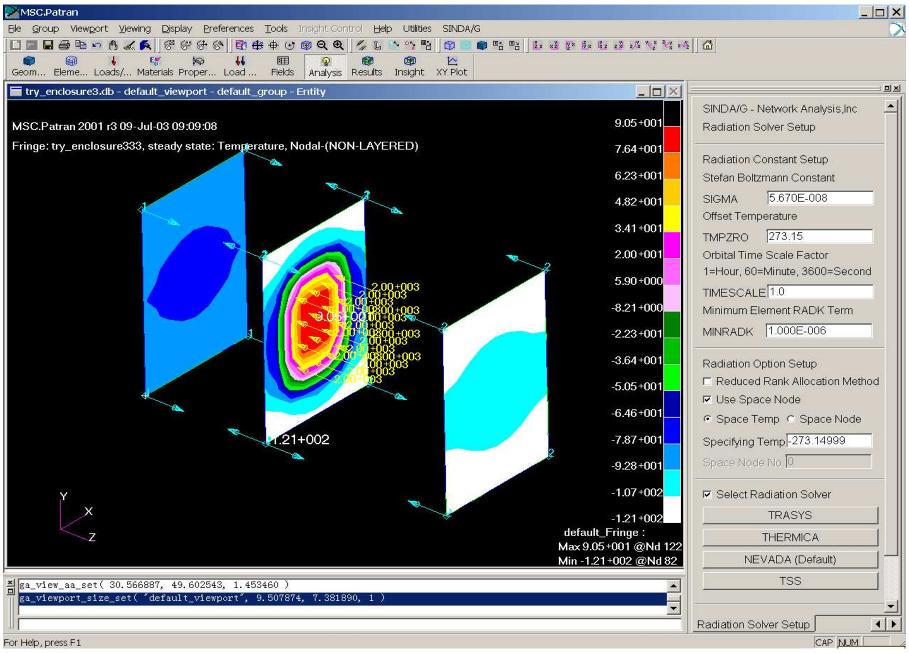
Need for Finite Element Database



SINDA/G® by Network Analysis, Inc.

SINDA/G for Patran

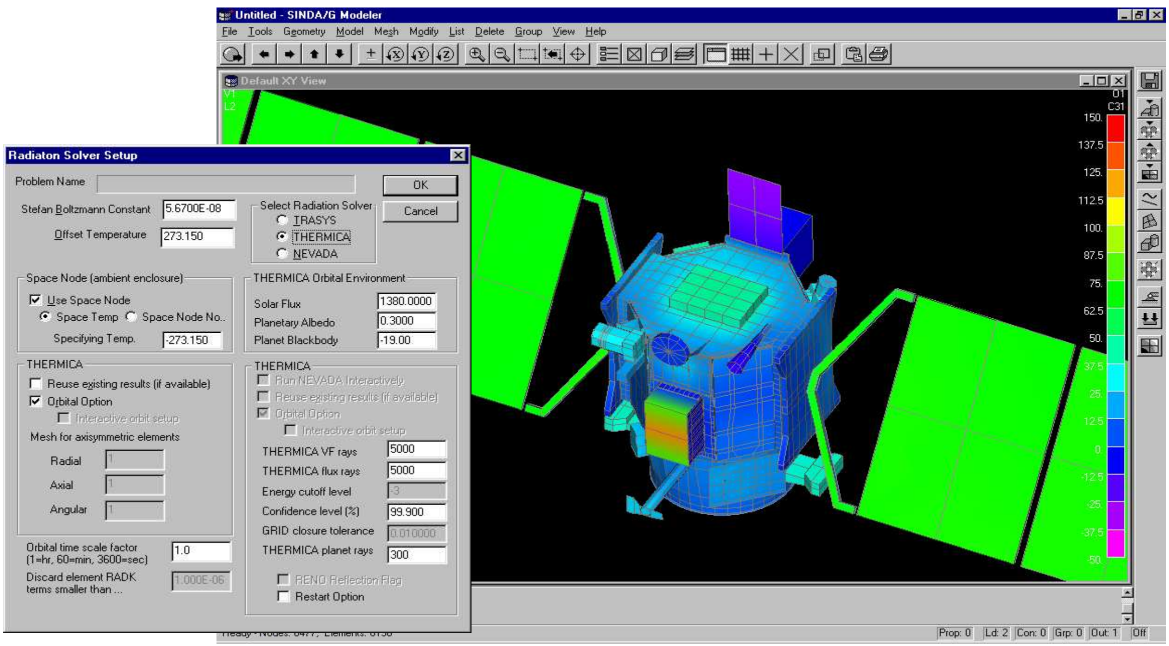
Model is independent of the radiation code



SINDA/G® by Network Analysis, Inc.

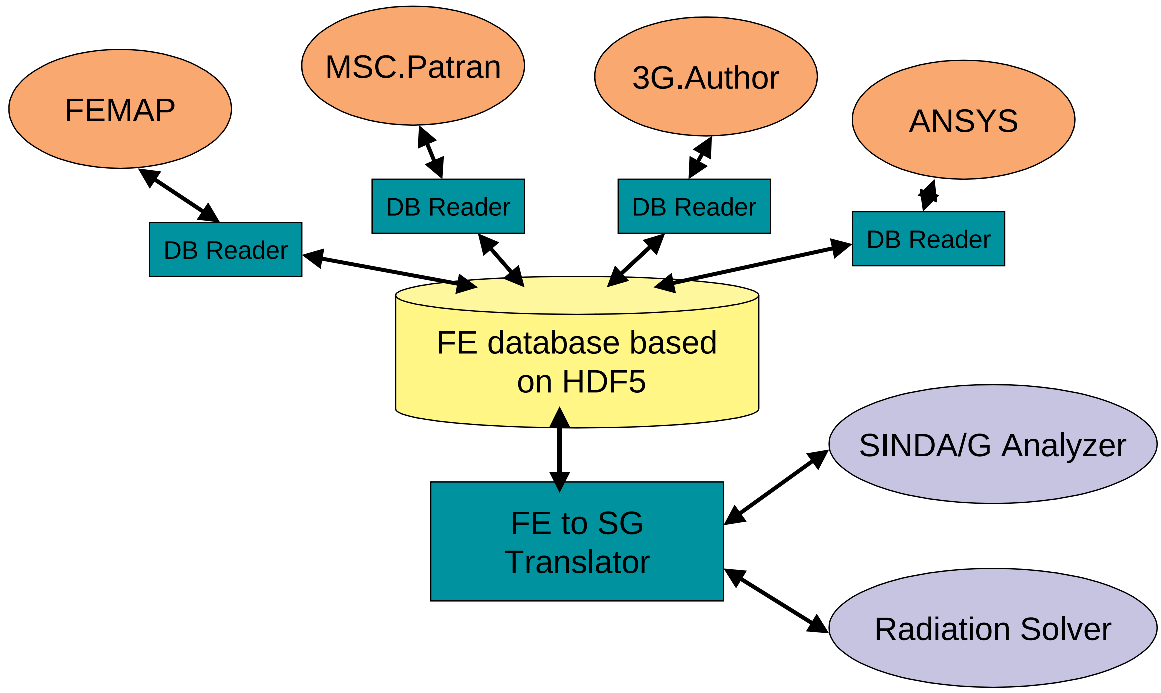
SINDA/G for FEMAP

Model is independent of the radiation code



SINDA/G® by Network Analysis, Inc.

Use of HDF5 File for FE Model Builder Interface



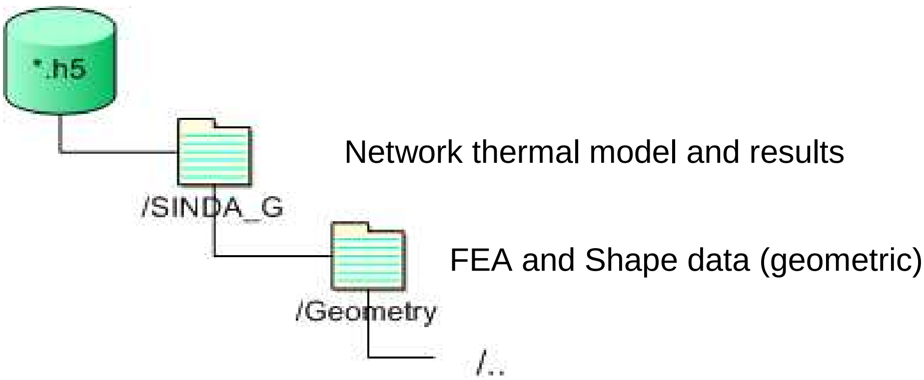
SINDA/G® by Network Analysis, Inc.

SINDA/G FE Database Implementation

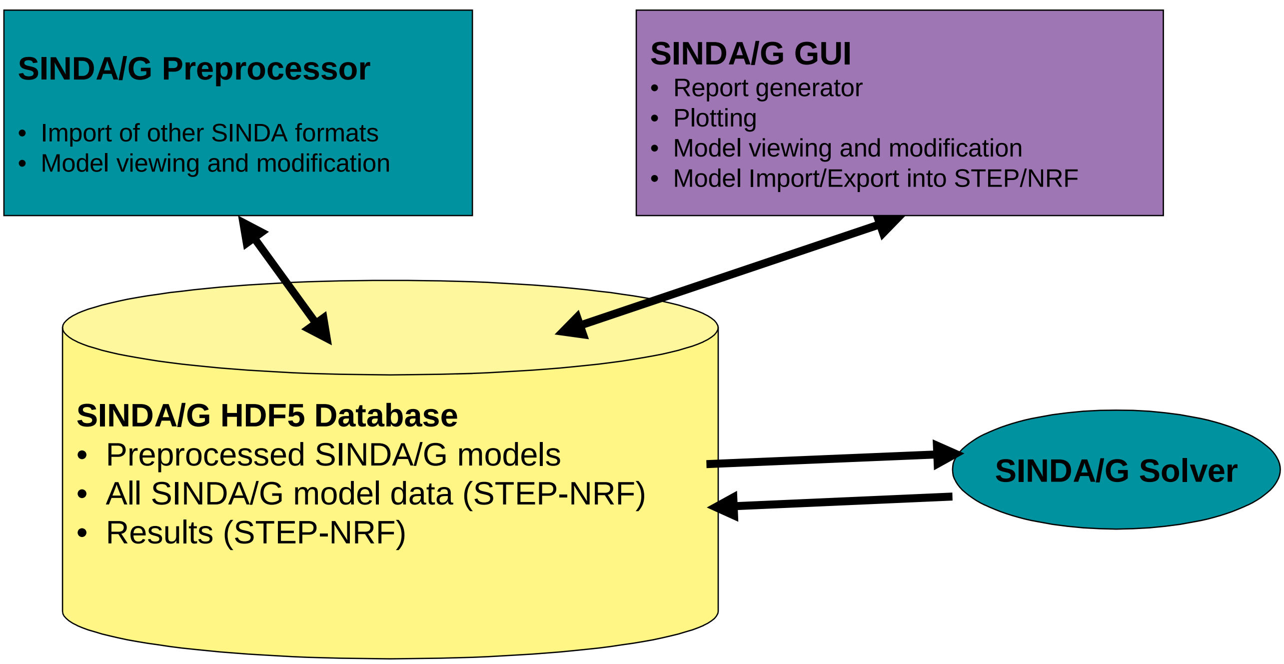
- Using existing HDF5 libraries
- Languages
  - C/C++
  - Fortran 95
- ANSYS, FEMAP & Patran file readers
- Planned release by 2004 Q1

Why NAI is Implementing a SINDA/G Database based on HDF5 and STEP/NRF

- Simplifies interface to multiple FE systems
- Needed for "Next Generation" SINDA/G that is currently being designed
- Provides powerful post processing capability



SINDA/G use of HDF5 Database



SINDA/G® by Network Analysis, Inc.

Items Needed to be Stored in Database

- Preprocessed SINDA models.
- SINDA/G Model in STEP/NRF format to facilitate model exchange.
  - Data Blocks
  - Operation Blocks
- SINDA/G Results (time dependent)
  - Temperatures, conductor values, heat flows capacitance values
  - Results from radiation codes – fluxes, REF, VF
  - Test results or results from other codes

SINDA/G® by Network Analysis, Inc.

SINDA/G Data Objects

- Network Objects
  - Node
  - Conductor
  - Source
  - Constants
  - Arrays
- Operation Objects
  - Main
  - Execution
  - Variable 1
  - Variable 2
  - Subroutine
  - Output

F & M statements in Operations Blocks that difficult to store in a non-proprietary manner

Possible Solutions

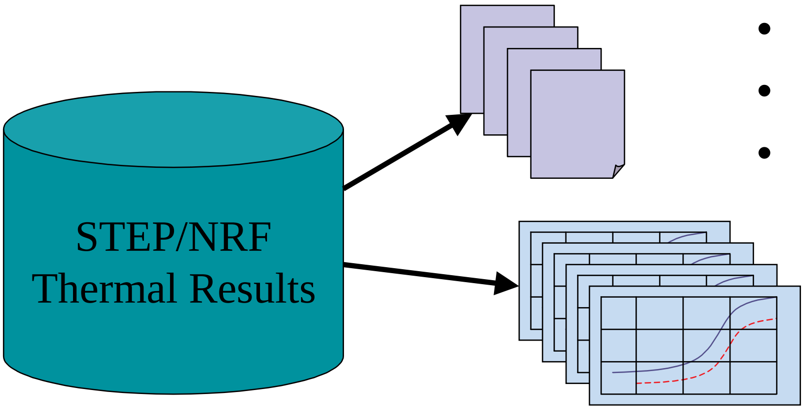
- Use option codes in the data blocks to minimize function and subroutine calls
- Develop a common language that encompasses all features of the various SINDA's and ESATAN. Encourage developers to implement this in future releases.
- Translate all Fortran into a pseudo language that can be translated back to various codes using their unique function and subroutine names.

SINDA/G® by Network Analysis, Inc.

Post Processing of STEP/NRF data

Want to change the way people look at thermal data from SINDA.

- Don't decide before the run what you want printed out.
- Plots and tables are attached to the database and automatically updated after the run.



- Plotting
- Tables
- Data reduction

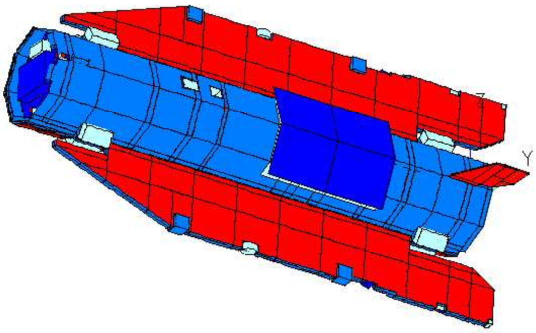
Appendix T: GOCE - Thermo-Elastic Distortion Analysis

GOCE
Thermo-Elastic Distortion
Analysis

L. Weimer
EADS-ASTRIUM

GOCE
Thermo-Elastic Distortion Analysis

22.10.2003



Lars Weimer
EADS Astrium GmbH
D-88039 Friedrichshafen
Lars.Weimer@astrium.eads.net

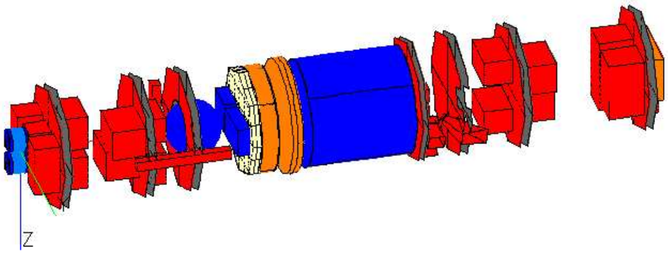
GOCE - Thermo-Elastic Distortion Analysis
Content

GOCE - Thermo-Elastic Distortion Analysis
GOCE Mission - Objectives

→ Provide global and regional models of the earth's gravity field with high spatial resolution and high accuracy

Measurement Techniques used:

- Satellite gravity gradiometry - SGG - technique (gravity gradient tensor by Gradiometer (EGG))
- Orbit determination by satellite-to-satellite tracking (SST) with GPS and GLONASS and
- Laser Ranging

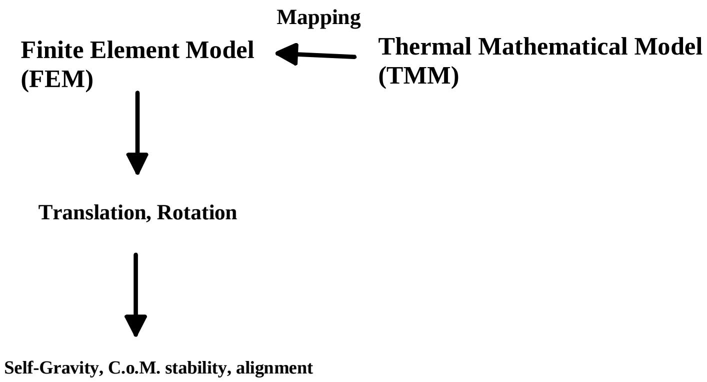


GOCE - Thermo-Elastic Distortion Analysis
GOCE Mission - Requirements

- Stringent requirements for GOCE Platform induced thermal distortions in time and frequency domain cover:
  - Self-gravity acceleration
  - C.o.M. stability
  - Instrument alignment
- MBW: 0.005 Hz to 0.1 Hz
- Thermo-Elastic Distortion Analysis to demonstrate that the requirements are not violated for all measurement phases (incorporates detailed thermal and structure analysis)
- Main distortion sources: time-dependent external heat loads (orbit height = 240-270 km) and internal dissipation of units and thrusters

GOCE - Thermo-Elastic Distortion Analysis

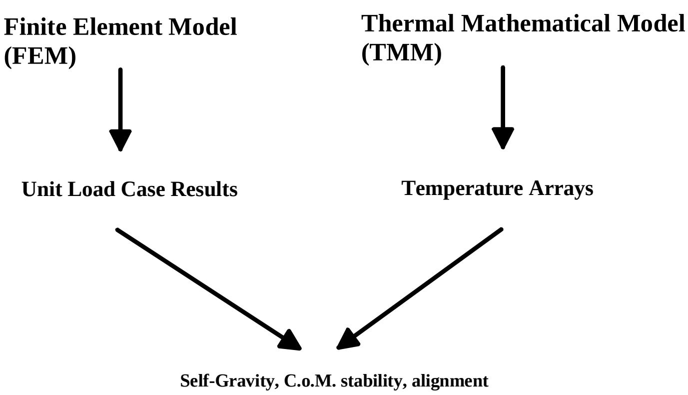
Analysis Approach - Common Approach



- Time for load case runs and re-runs
- Amount of output data/postprocessing
- Amount of data exchange between TMM and FEM (mapping)

GOCE - Thermo-Elastic Distortion Analysis

Analysis Approach – GOCE PFM Approach



+ reduced amount of output data → rapid identification of main distortion sources and design improvements

+ reduced computation time, quick re-analysis, variations and sensitivity analyses possible

+ re-analysis without new FEM analysis

o linearization error for self-gravity computations small

GOCE - Thermo-Elastic Distortion Analysis
Analysis Approach – GOCE PFM Approach

FEM (MSC/Nastran):

- GOCE platform divided into 88 thermal areas
- The thermal areas define the unit load cases
- Starting from a temperature of 20°C for the whole S/C, the temperature of all FE Model nodes of one thermal area is increased by 1°C (remaining FE Model nodes still at 20°C)
- All the required instrument alignment, C.o.M. and self gravity data is calculated per unit load case
- This step is repeated for all unit load cases (thermal areas)

GOCE - Thermo-Elastic Distortion Analysis
Analysis Approach – GOCE PFM Approach

TMM (ESATAN V 8.7, ESARAD V4.2):

- Computation of transient temperatures for the 88 thermal areas for all time steps
- All temperatures with respect to 20°C (undisturbed)

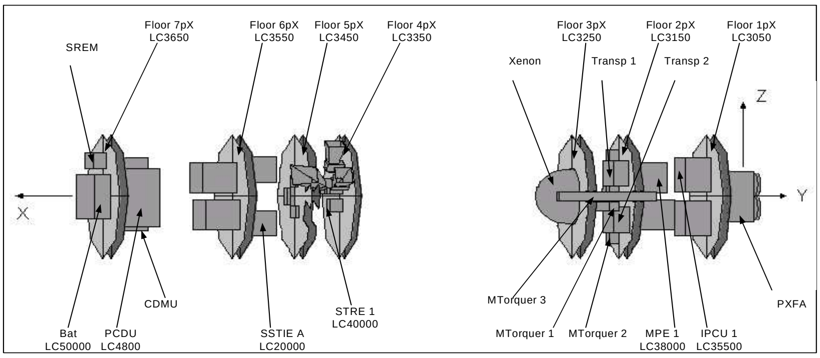
Computation of total distortions for each time step (MS Excel, Mathematica V4.2):

- Multiplication of unit load case results and temperatures (super positioning) → results in time domain
- Fourier transformation afterwards → results in frequency domain (power spectral density - PSD)

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

The unit load case results are multiplied with the in-orbit temperatures, calculated with the TMM by using the principle of superposition



GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

Unit load case count				1	2	3	4
Unit load case no.				900	940	1000	1006
Unit load case description			Basic	Launcher I/F Ring	Launcher I/F Ring	S/C Lateral Panel +Z -Y	S/C Lateral Panel +Z -Y
1	GASRF - SSARF 1	phi-xi [rad]	0	2.0450179579E-09	-1.4789500570E-09	1.3813728904E-08	1.2941527920E-08
		phi-yi [rad]	0	1.4721318705E-09	-1.1449934390E-09	9.7900846080E-09	8.1892911810E-08
		phi-zi [rad]	0	2.6024812443E-10	4.8060144420E-10	-8.4465606150E-09	5.8768478390E-09
2	GASRF - SSARF 2	phi-xi [rad]	0	1.8981965241E-09	-1.3824049455E-09	1.3442182235E-08	1.2137558393E-08
		phi-yi [rad]	0	1.4673246385E-09	-1.1424602507E-09	9.8058155040E-09	8.1885897183E-08
		phi-zi [rad]	0	2.5958083233E-10	4.8156813810E-10	-8.4686557730E-09	5.8533052100E-09
3	GASRF - SSARF 3	phi-xi [rad]	0	-1.0728666226E-10	2.1540694826E-09	-4.6104224230E-08	-3.7301955652E-08
		phi-yi [rad]	0	9.1220388973E-10	-4.8020973414E-10	-1.1629826302E-08	2.9276602748E-08
		phi-zi [rad]	0	-3.2646073895E-10	1.0454315763E-09	-3.0290053447E-08	-2.8117901591E-08
4	GASRF - SARF	phi-xi [rad]	0	-2.5743256470E-09	4.2141359027E-09	-2.5694958725E-08	-9.6586837678E-09
		phi-yi [rad]	0	2.7638708409E-08	-2.5737705421E-08	1.7840012717E-07	1.6895566178E-07
		phi-zi [rad]	0	-3.5159165961E-08	3.8763968453E-08	-3.7684338597E-07	-2.0677174323E-07
5	GASRF - GRF	phi-xi [rad]	0	-1.2301600788E-10	1.9295383606E-10	-8.1044716273E-09	-9.3657207478E-09
		phi-yi [rad]	0	1.8805552984E-10	-2.0721312731E-10	-1.7509160973E-08	-1.1105508006E-08
		phi-zi [rad]	0	-9.5468844183E-10	1.9076172623E-09	-2.2125240715E-08	-1.4961697966E-08
6	GASRF - GARF	phi-xi [rad]	0	-6.1306692827E-06	5.0379672508E-06	-4.0458430205E-06	-1.4130023329E-07
		phi-yi [rad]	0	9.2223273830E-07	6.1495512606E-05	4.2069688315E-07	1.8667657530E-07
		phi-zi [rad]	0	3.7238262550E-07	-6.2610583121E-05	1.0506284211E-06	3.4432586857E-07
7	GASRF - MTA -X-Y-Z	phi-xi [rad]	0	-3.2152642739E-07	6.5288479329E-07	-3.2545831229E-08	-3.3663528150E-08
		phi-yi [rad]	0	-2.8256988549E-07	-8.9304318431E-07	3.2077259350E-07	3.4830347968E-07
		phi-zi [rad]	0	-1.4778127199E-06	6.3306277666E-07	1.0148420464E-08	7.4979953208E-08
8	GASRF - MTA +X+Y+Z	phi-xi [rad]	0	4.7938048305E-10	-4.8995452572E-10	3.8415715892E-09	-3.7384855428E-09
		phi-yi [rad]	0	8.5557400299E-10	-1.1065694081E-09	-1.1170631120E-09	4.9037693967E-08
		phi-zi [rad]	0	-3.3377565687E-10	1.3898531150E-10	4.5893007650E-09	2.5161050589E-08
9	GASRF - ITA +Z	phi-xi [rad]	0	-5.6065490868E-09	5.8197352369E-09	-9.4749155112E-08	-4.9036693799E-08
		phi-yi [rad]	0	1.7653220094E-07	1.9014537657E-07	5.9290055225E-07	4.0962574000E-07
		phi-zi [rad]	0	-4.7973758124E-07	4.8069717289E-07	2.6413425651E-07	1.8325968256E-07
10	GASRF - GPS -X	phi-xi [rad]	0	1.4213347151E-08	-1.4017198597E-08	6.1701141282E-09	-1.3388898488E-08
		phi-yi [rad]	0	-2.4358975233E-10	-1.8357473823E-09	2.8764546377E-08	1.3532339641E-07
		phi-zi [rad]	0	-3.8384429625E-08	3.8502896767E-08	2.8500048200E-08	7.1825415137E-08
11	GASRF - GPS +X	phi-xi [rad]	0	9.0694493574E-09	-8.9662037867E-09	3.6628238642E-09	-3.9634244999E-09
		phi-yi [rad]	0	-1.5465026925E-09	-3.3030934658E-09	4.2241795371E-08	1.4769733180E-07
		phi-zi [rad]	0	4.9872752134E-08	-4.9860463895E-08	2.2761015047E-08	6.3573824187E-08

Alignment Data computed with FEM (Basic Case and Unit Load Case 1-4 shown)

GOCE - Thermo-Elastic Distortion Analysis

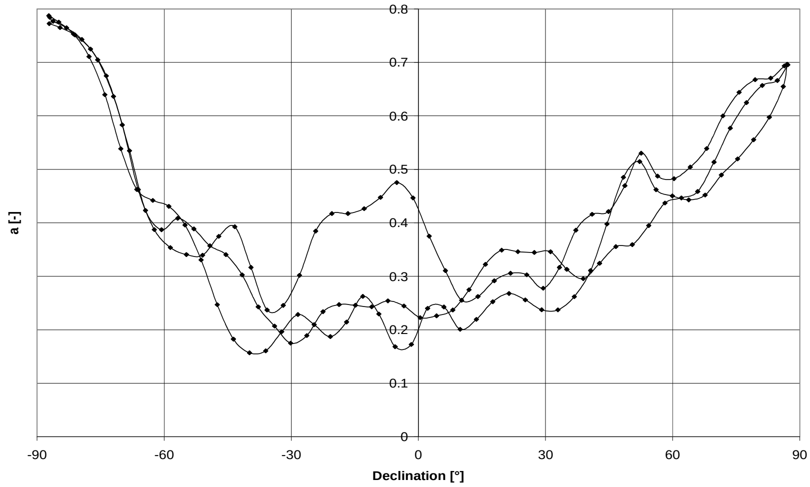
Mechanical and Thermal Model and Analysis

Transient Temperature Computations with the thermal model include:

- Eclipse/ no eclipse phases
- Fluctuation of external heat loads vs. declination (data from CHAMP mission adapted to the GOCE orbit)
- Time dependency of unit power dissipation
- Thrust Profile
- Atmospheric Heating

GOCE - Thermo-Elastic Distortion Analysis

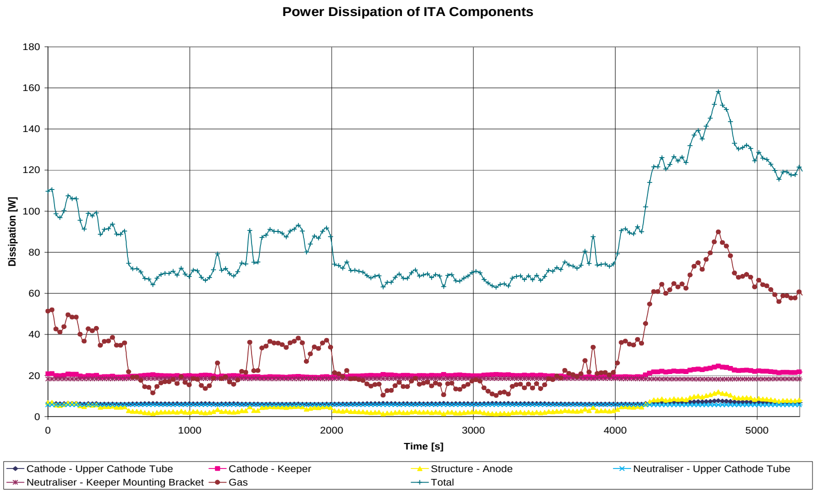
Mechanical and Thermal Model and Analysis



Albedo Factor vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

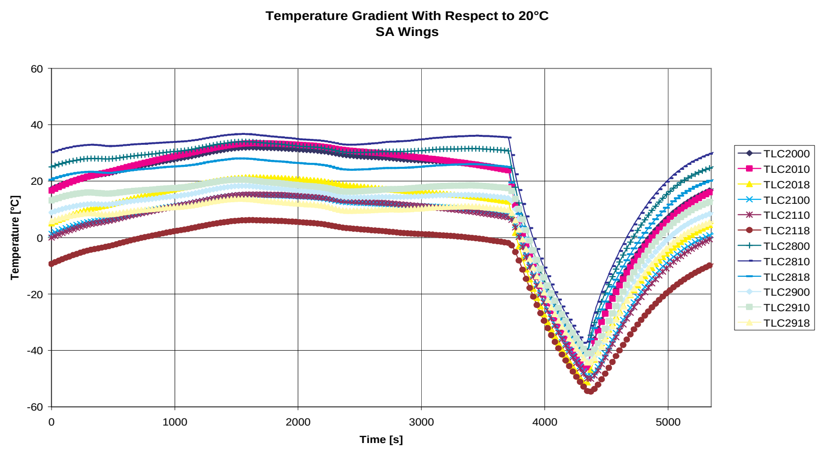
Mechanical and Thermal Model and Analysis



Ion Thruster Power Dissipation [W] per Orbit

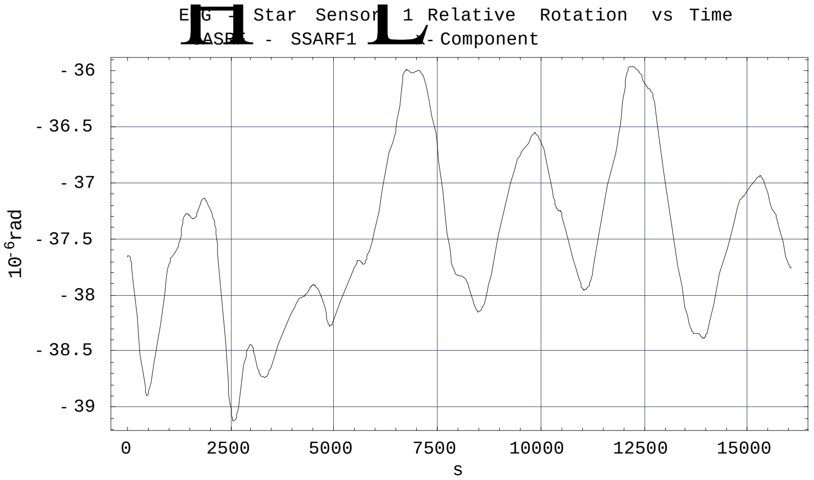
GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis



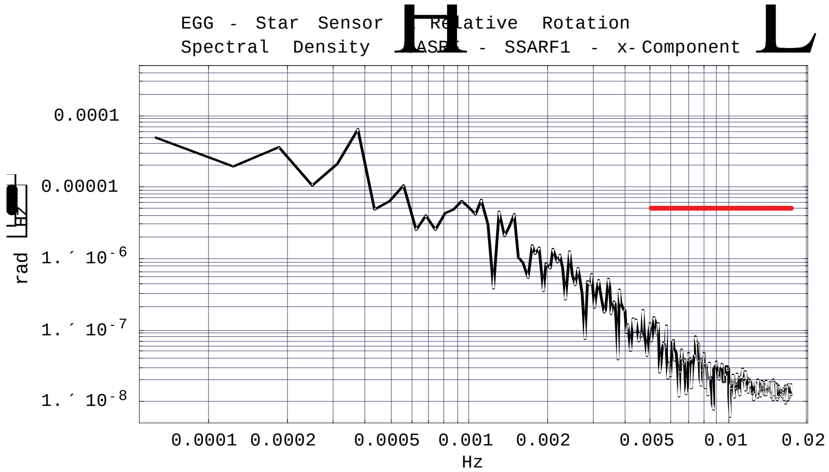
Temperatures for Thermal Areas on Wing [°C]

GOCE - Thermo-Elastic Distortion Analysis
Results



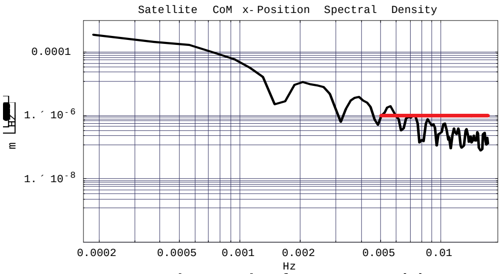
Alignment (Relative Rotation) Hot Case (no Eclipse)

GOCE - Thermo-Elastic Distortion Analysis
Results

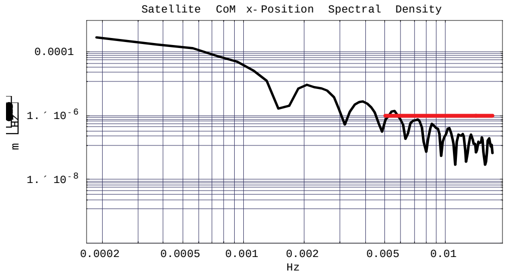


Alignment (Relative Rotation) Spectral Density Hot Case (no Eclipse)

GOCE - Thermo-Elastic Distortion Analysis
Results

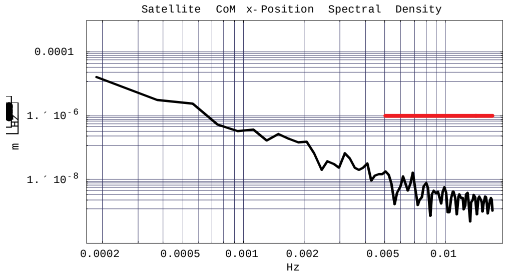


Total Results for C.o.M. (x)



Contribution of Wing

Influence of S/C Components on Total Results



Contribution of S/C Panels

GOCE - Thermo-Elastic Distortion Analysis
Summary

→ Experiences with GOCE PFM analysis approach:

- Fast and reliable check if requirements are met with high accuracy
- Easy to vary parameters and to conduct sensitivity analyses
- Quick configuration checks and determination of influence of individual components on the overall results
- No re-run of FEM required for new thermal load cases

→ Suggestiones for (Software) Improvements:

ESATAN – functionality for processing thermo-elastic distortion relevant data → routines to read ‘unit load case results‘, generate distortion vs. time output (, compute spectral density)

ESARAD – more detailed planet models required → real earth temperature and albedo factor depend on orbit position/ declination

GOCE - Thermo-Elastic Distortion Analysis

Annex

GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Orbit and Load Cases

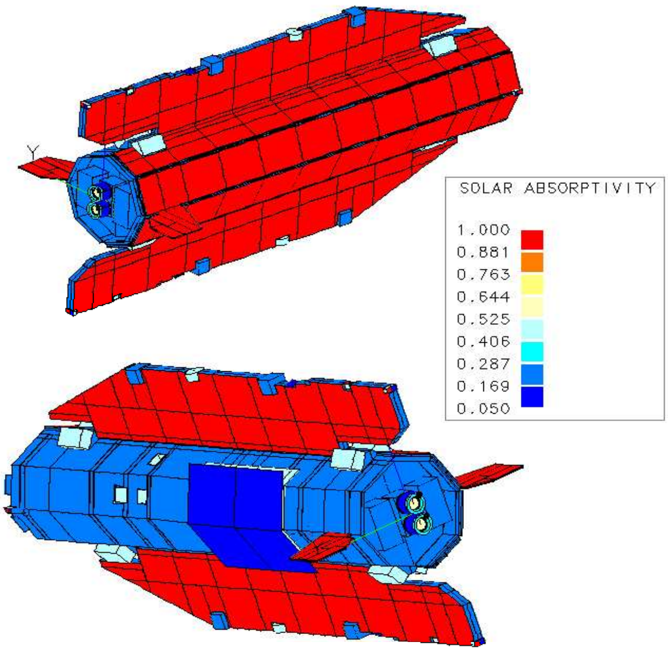
Main Orbit Parameters:

- dawn-dusk or dusk-dawn
- orbit height 240 – 270km
- inclination 96.5°

Case	HOT CASE	COLD CASE
LST Ascending Node	18:00h	6:00h
Thermo-optical Properties	EOL	BOL
Earth IR Flux [W/m²]	261 (average)	189 (average)
Albedo Coefficient	0.4 (average)	0.2 (average)
Altitude [km]	240	250
Inclination [deg]	96.5	96.5
Solar Constant [W/m²] 1)	1408	1323
Solar Declination [deg]	-13.00	23.45
Beta Angle [deg]	83.5	73.05
Eclipse Duration [min]	0	10
Ω Angle [deg]	90 deg	270 deg
Attitude	nominal	nominal
Unit dissipations	Max (EOL)	Min (BOL)
Heaters	Enabled	Enabled

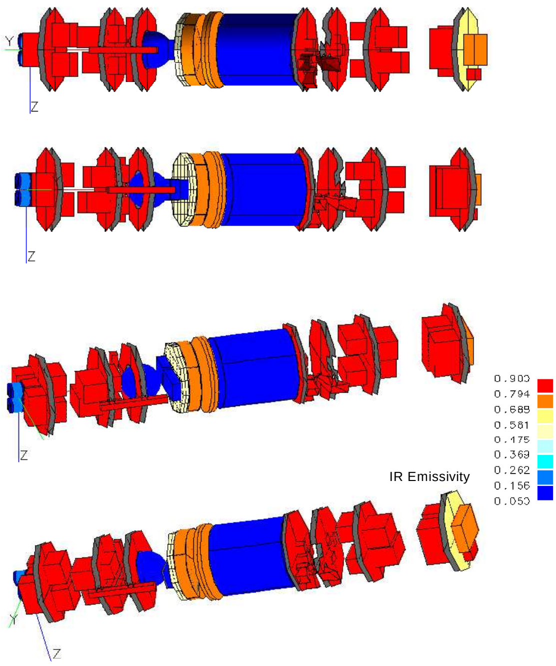
GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Configuration 1



GOCE - Thermo-Elastic Distortion Analysis

GOCE Mission - Configuration 2



GOCE - Thermo-Elastic Distortion Analysis

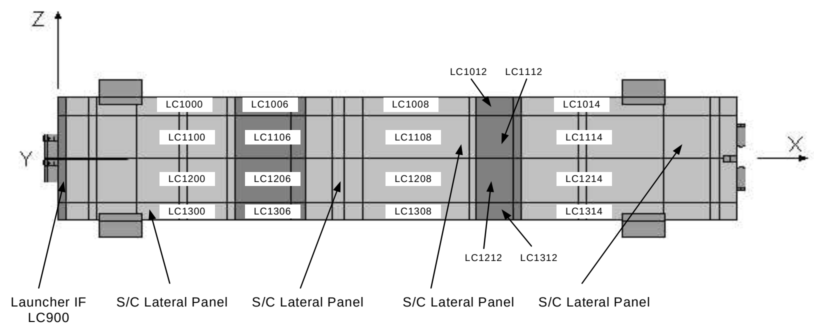
Mechanical and Thermal Model and Analysis

Unit load case count		1	2	3	4
Unit load case no.		900	940	1000	1006
Unit load case description	Basic	Launcher I/F Ring	Launcher I/F Ring	S/C Lateral Panel +Z -Y	S/C Lateral Panel +Z -Y
axi(+x) [m/s^2]	5.2244433632E-09	5.2244437744E-09	5.2244440763E-09	5.2244433262E-09	5.2244431264E-09
axi(-x) [m/s^2]	-6.1323390129E-09	-6.1323382266E-09	-6.1323375849E-09	-6.1323391596E-09	-6.1323390082E-09
ayi(+y) [m/s^2]	-6.7900107660E-09	-6.7900110939E-09	-6.7900097959E-09	-6.7900111551E-09	-6.7900113691E-09
ayi(-y) [m/s^2]	-8.1676499037E-10	-8.1676540917E-10	-8.1676442773E-10	-8.1676682072E-10	-8.1676508200E-10
azi(+z) [m/s^2]	-2.5769425791E-09	-2.5769424682E-09	-2.5769425105E-09	-2.5769425775E-09	-2.5769410747E-09
azi(-z) [m/s^2]	1.4633527638E-09	1.4633526648E-09	1.4633525573E-09	1.4633539866E-09	1.4633535272E-09

Self-Gravity Acceleration Data

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis

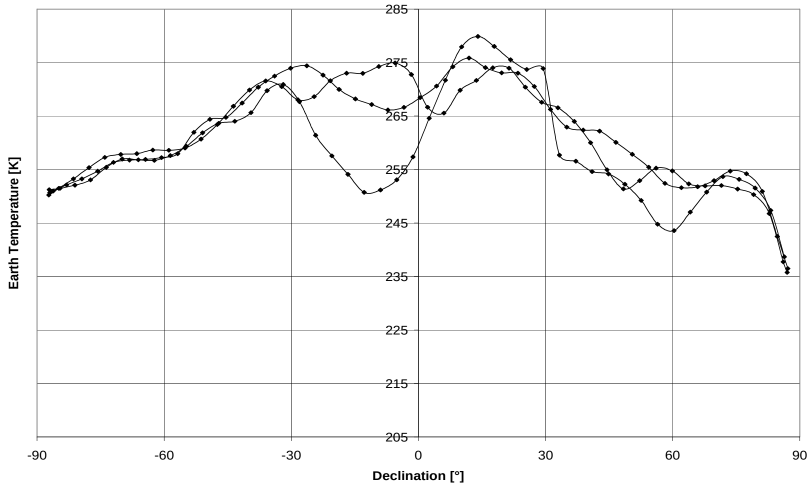


Structure Panels nY

Example - Thermal Areas → Unit Load Cases

GOCE - Thermo-Elastic Distortion Analysis

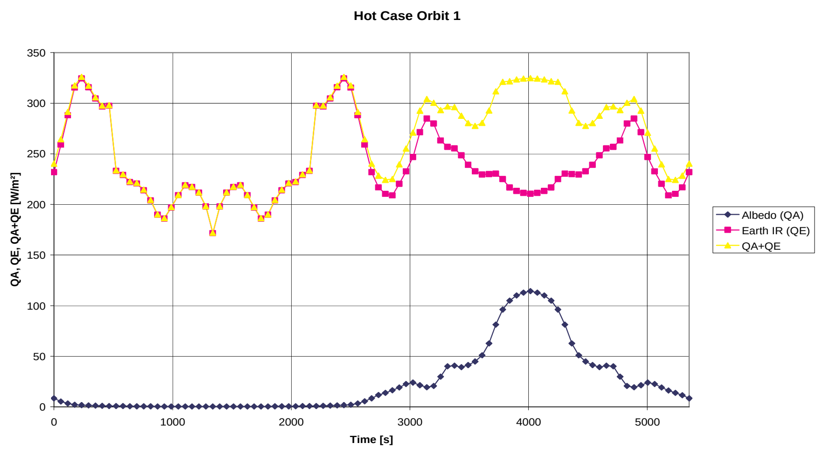
Mechanical and Thermal Model and Analysis



Earth Temperature [K] vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

Mechanical and Thermal Model and Analysis



Resulting External Heat Loads [W/m²] vs. Declination [deg.]

GOCE - Thermo-Elastic Distortion Analysis

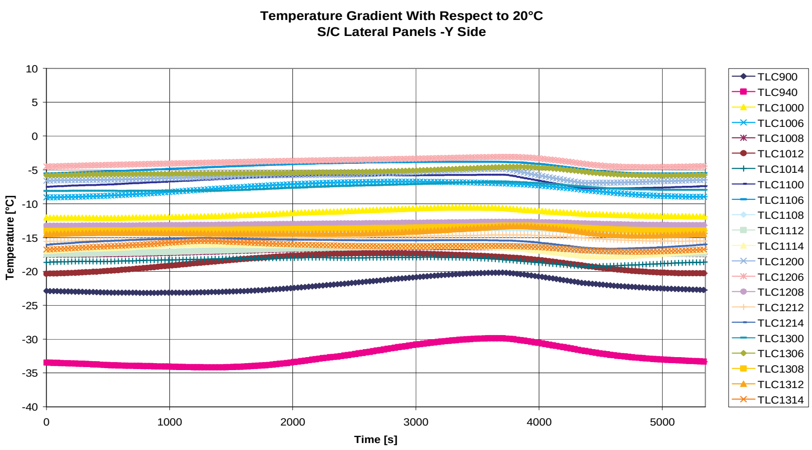
Mechanical and Thermal Model and Analysis

```
INTEGER orbit_index;

/* 97 orbit positions = 92 + 1 start=stop at equator + 4 eclipse entry/exit  */
REAL ALBEDO_FAC [97] = {
  0.14348174,
  0.13528350,
  0.09871711,
  0.05825458,
  0.03680240,
...
  0.13099252,
  0.13296514,
  0.14348174
};

    CALCULATE_PLANET_ABSORBED_FLUX_RAYTRACING (
      ir_paf = COLD_BOL_p23p45.IR_PAF[orbit_index],
      coord = COLD_BOL_p23p45.ORBIT_POSITIONS[orbit_index],
      albedo_paf = COLD_BOL_p23p45.ALBEDO_PAF[orbit_index],
      planet_rad = COLD_BOL_p23p45.ORBIT.PLANET_RADIUS,
      planet_temp = PLANET_TEMP [orbit_index],
      albedo_reflect_coeff = ALBEDO_FAC [orbit_index],
      solar_char = COLD_BOL_p23p45.SOLAR_CONST_OVERRIDE);
```

ESARAD – example albedo factor

GOCE - Thermo-Elastic Distortion Analysis

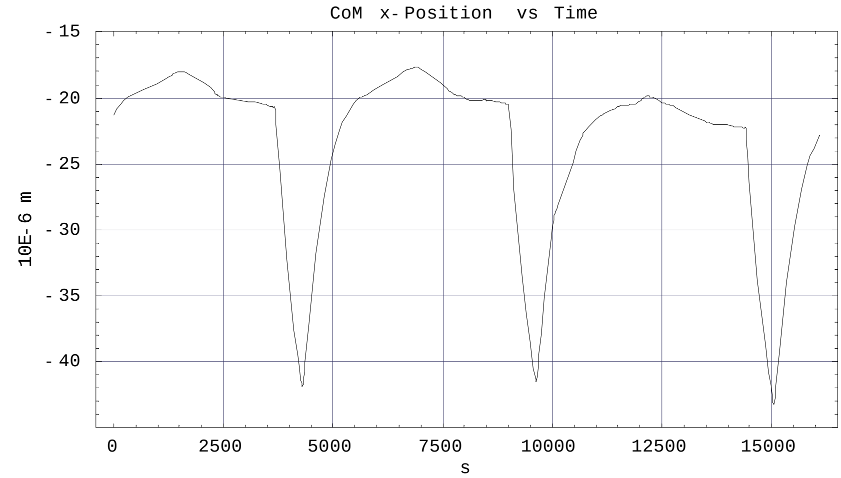
Mechanical and Thermal Model and Analysis



Temperatures for Thermal Areas on S/C Panels [°C]

GOCE - Thermo-Elastic Distortion Analysis

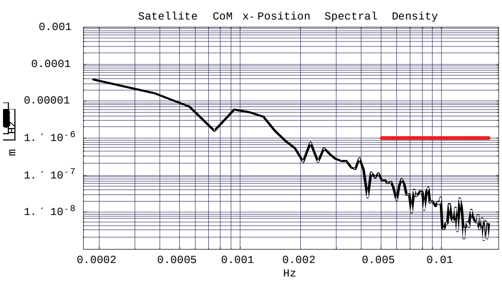
Results

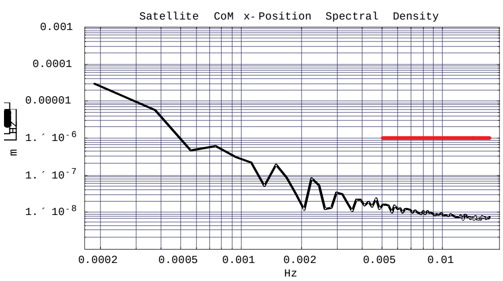


C.o.M Position Change Cold Case (Eclipse)

GOCE - Thermo-Elastic Distortion Analysis

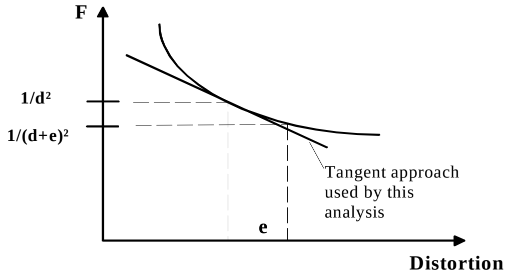
Results





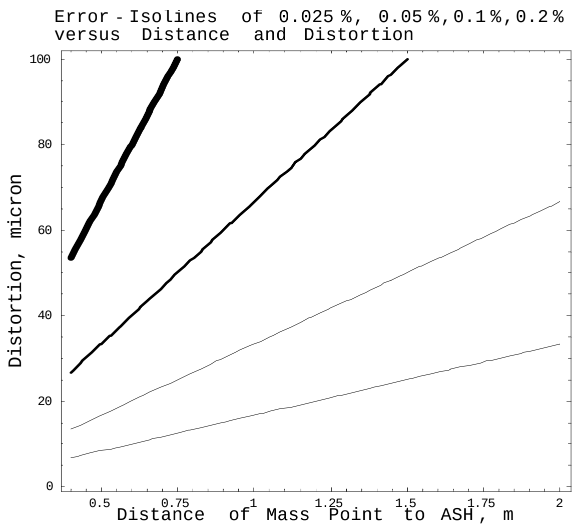
Assessment – Transient vs. Constant External Heat Loads and Unit Power Dissipation

GOCE - Thermo-Elastic Distortion Analysis
Linearization Error



- linearization error is given by the thermal unit load cases
- the gravity potential d is non-linear
- error by multiplying the unit load case result by the actual temperature swing
- error is negligibly small as long as the distortions are in the range of only a few microns and the distance of the mass points are larger than 0.5 m

GOCE - Thermo-Elastic Distortion Analysis
Linearization Error

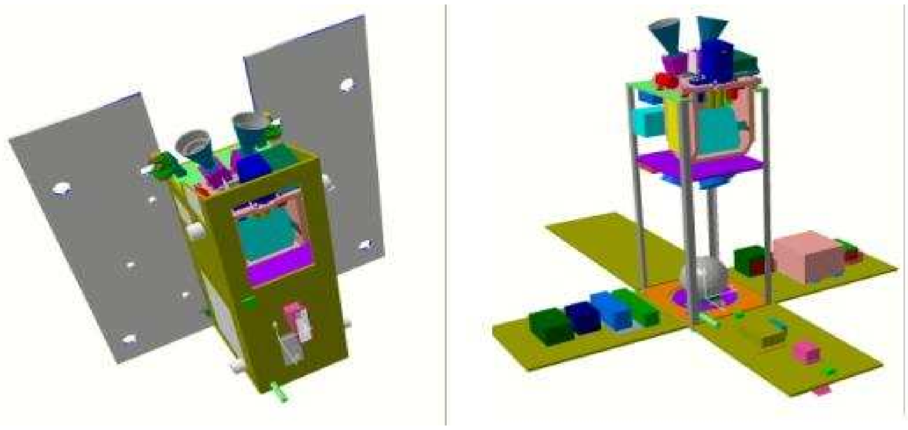


Appendix U: Methodology for Thermal Model Archiving

Methodology
for
Thermal Model
Archiving

F. Lamela
EADS-CASA

METHOLOGY FOR THERMAL MODELS ARCHIVING



OBJECTIVE:

1. To create a methodology and the associated software two archive the thermal model (THERMICA/ESARAD and ESATAN)
2. To define a thermal model delivery requirements

BENEFITS:

1. ARCHIVE THERMAL FILES IN ASCII FORMAT
   - Storing all the data
   - Possible to rerun the cases
2. DELIVERY FORMAT with trace ability of the data
3. INTERNAL AUDIT
4. BATCH RUNS

EADS CASA ESPACIO

Seventeenth European Thermal &
ECLS Software Workshop

ARCHITECTURE:

1. Pre_TERESA Fortran program
   - Generate a unique data file, called input file
   - Generate a control file with:
     - Name and number of radiative and thermal model files
2. Run_TERESA Fortran program
   - Split the input file
   - Run the Thermica models
   - Mount the ESATAN models
   - Run ESATAN models

Preprocessing: Pre_TERESA

- Input file generation

ASK about number of ESATAN models and names

ASK about total number of THERMICA models

ASK about total number of internal THERMICA models

ASK about total name of external and internal THERMICA models

MODELX.ESA
MODELY.ESA
MODELZ.ESA

MODELA
MODELB
MODELC
MODELD

Preprocessing: Pre_TERESA

- Input file generation

ASK about additional files number and names

ASK about PATH of ESATAN models

ASK about PATH of THERMICA models

ASK about PATH of Additional files

Power1.dat
Power 2.dat

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Preprocessing: Pre_TERESA

- Input file

MODELA.SYSBAS
MODELA.THER
MODELA.TRJINP
MODELA.PNTINP
TEMP.MODELA

MODELC.SYSBAS
MODELC.THER
TEMP.MODELC

Power1.dat

Power2.dat

MODELX.ESA
MODELY.ESA.

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REQUIREMENTS FOR ESATAN FILE (.ESA)

- GR´s → ?include=RMODELA99R.TAN
- ARRAY heat inputs → ?include=HMODELA99H.TAN
- Subroutine → ?include=SMODELA99H.TAN
- Average → ?include=AMODELA99H.TAN
- Additional files → ?include=power1.dat

REQUIREMENTS FOR THERMICA FILE (.ESA)

- SYSBAS, ORBIT, POINTING and SIMULATION FILE have the same name MODELA
- Run a subprocess
- Open the *.COM file and delete the execution line
    - PATH+ Thermic32SGI
- Execute the *.COM file and appears TEMP.XXX
- Rename TEMP.XXX to TEMP.MODELA

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USES:

- **One ESATAN Case**
    - **One external model**
    - **Several internal models**
- **HOT and COLD ESATAN cases**
    - **Two external models**
    - **Several internal models**
    - **HOT and COLD power files**

ESTEC, 22 Oct. 2003

USES:

- GENERAL CASE
  - Several ESATAN models (hot stowed, cold stowed, hot deployed, cold deployed, survival,...)
  - Several external models (hot stowed, cold stowed, hot deployed, cold deployed, survival,...)
  - Several internal models
  - Several power files (OFF, ON maximum, ON minimum, survival, heaters,...)

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THERMAL SOFTWARE REMARKS:

- Filtering of radiative couplings
  - Percentage or minimum value
- Don’t use formula for conductive couplings
  - Conductor value lower than 20

- Material data base
- Software for thermooptical and material degradation

ESTEC, 22 Oct. 2003

Appendix V: The far-field method for 1D conductor computation

The Far Field Method
for
1D Conductor Generation

S. Appel
ESA/ESTEC

Automated One-Dimensional Conductor Generation using the Far Field approach

Hans Peter de Koning and Simon Appel
(Hans-Peter.de.Koning@esa.int) (simon@thermal.esa.int)
(ESA/ESTEC D/TOS-MCV, The Netherlands)

17th European Workshop on Thermal and ECLS Software
ESA/ESTEC, Noordwijk (ZH), The Netherlands
21-22 October 2003

Topics

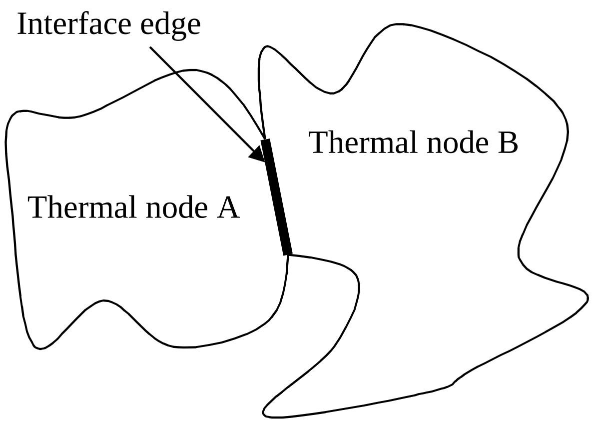
- Why automated linear conductor generation ?
- The Far Field Method
  - Assumptions
  - The method
- Conclusion

Why automated linear conductor generation ?

- 1D-Linear conductors (GLs) in thermal lumped parameter network models are generally calculated by “hand”, with spreadsheets or in some tools with shape specific formulas
- Analytical expressions are only available for a limited number of combinations of simple geometrical shapes which represent the thermal nodes
- Conductor calculation consumes a relatively large part of the thermal model preparation effort
  – In addition it is tedious and error-prone

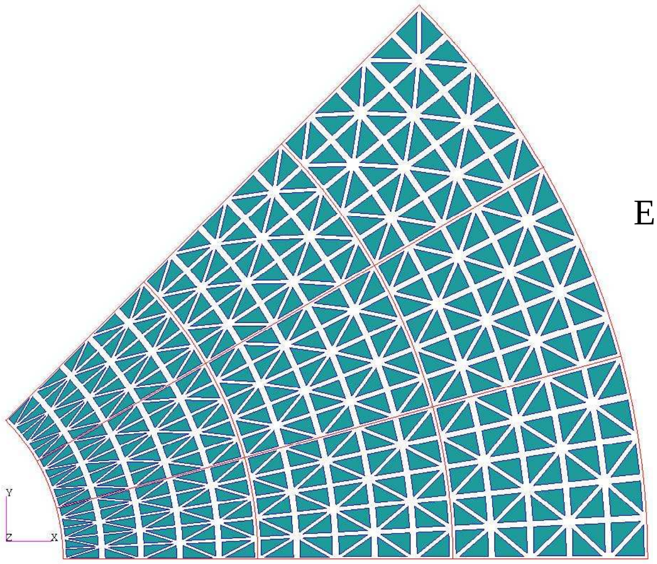
The Far Field Method: Assumptions

- Thermal nodes are considered pair by pair
- Heat is flowing through the two nodes from a remote heat source to a remote heat sink: From one “Far Field” to an other “Far Field”
- The geometry and the properties of the two thermal nodes and their interface are evaluated



The Far Field Method: Assumptions

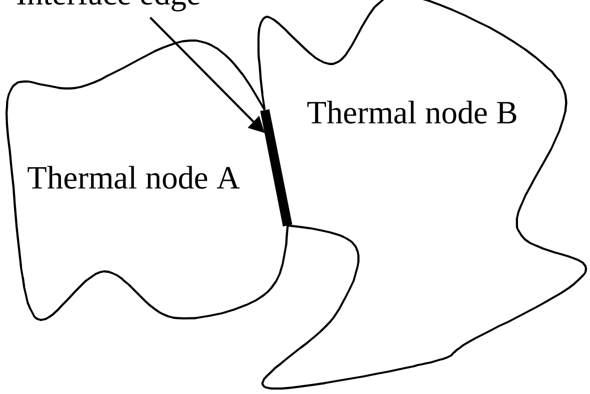
- The geometry can be meshed with a finite element mesh



ESARAD SHELL sub-divided into 9 faces/thermal nodes meshed with finite elements

The Far Field Method: Assumptions

- Adequate representation of interface conductance has to be implemented:
  - Interpolation for non-matching FE-meshes
  - Introduction of contact resistance (if any)

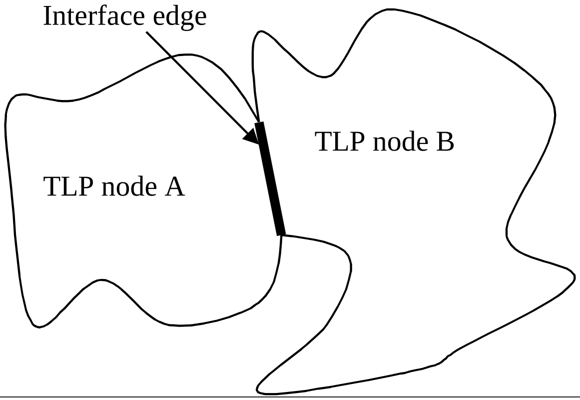


The Far Field Method: The Method

Step 1: Find the FEM-nodes at the "Far Field" edges of the thermal nodes:

"Far Field" edge =

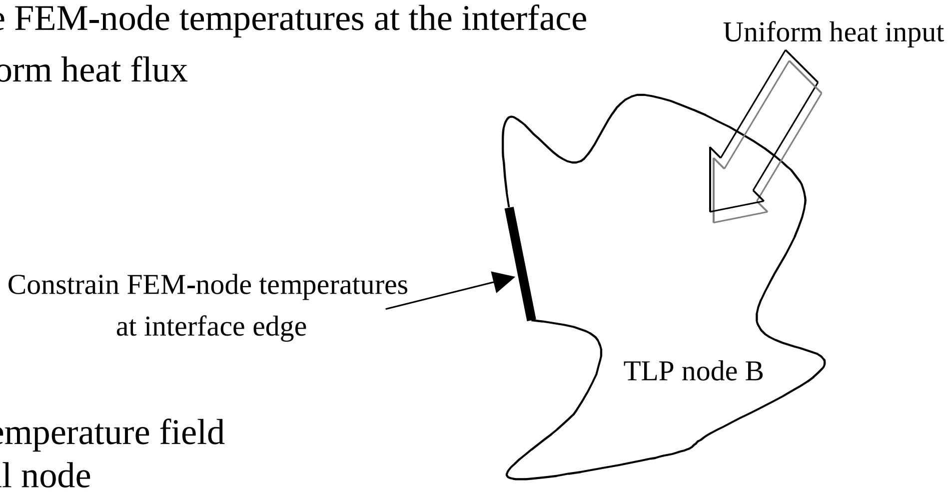
Part of the edge of the thermal node, which has the highest "thermal distance" to the interface



The Far Field Method: The Method (cont'd)

Step 1: Find the "Far Field" edges of the thermal nodes

- Consider a single thermal node and its interface:
  - Constrain the FEM-node temperatures at the interface
  - Apply a uniform heat flux



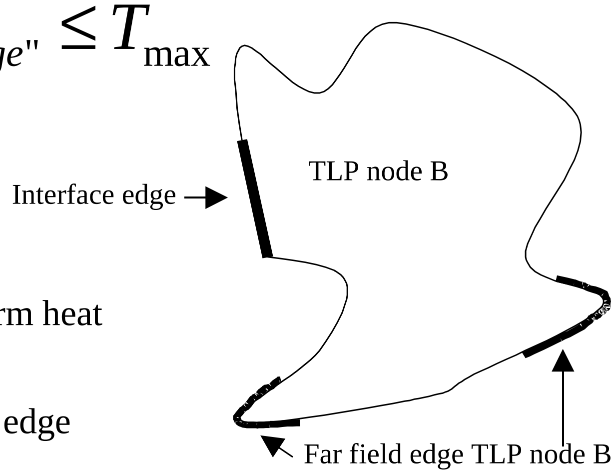
  - Produces a temperature field in the thermal node

The Far Field Method: The Method (cont'd)

Step 1: Find the "Far Field" edges of the thermal nodes

Temperature of FEM-nodes at the Far-Field edge fulfill:

$$T_{\max}\left(1-\varepsilon\right)\leq T_{\text{"}Far\ Field\ edge\text{"}}\leq T_{\max}$$



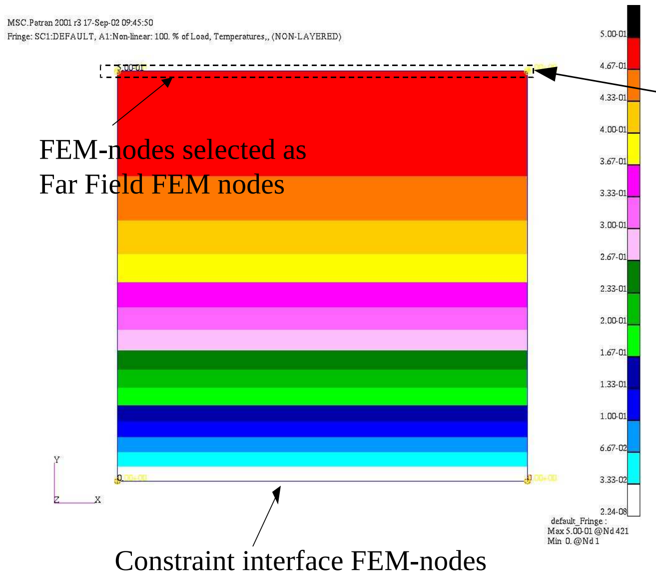
$T_{\max}$ = maximum temperature due to uniform heat flux and constraint at interface edge

ε = tolerance controlling size of Far-Field edge

The Far Field Method: The Method (cont'd)

Step 1: Find the "Far Field" edges of the thermal nodes

Example

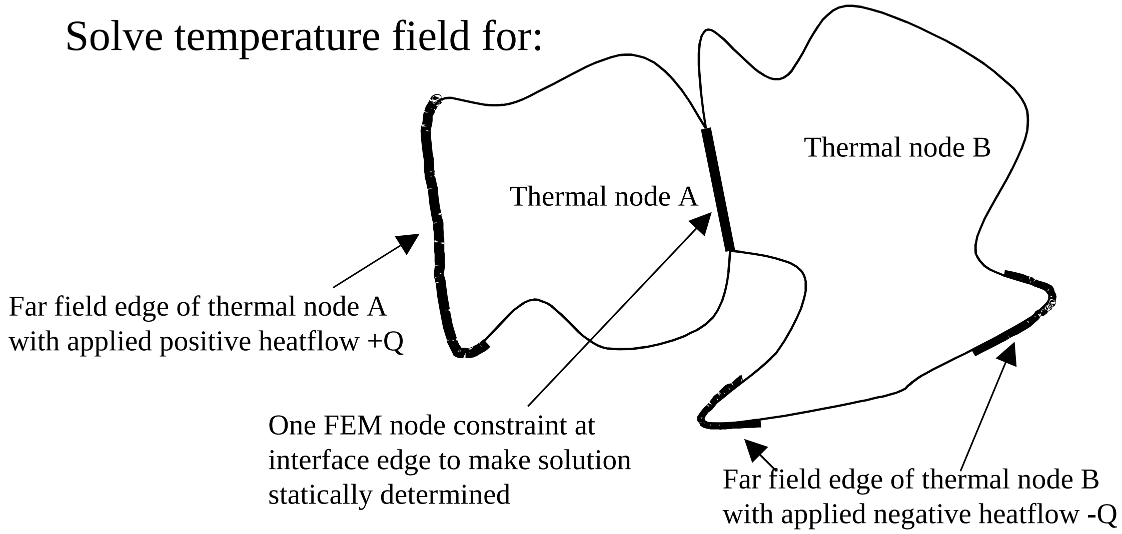


$$T_{\max}\left(1-\varepsilon\right)\leq T\leq T_{\max}$$

The Far Field Method: The Method (cont'd)

Step 2: Simulate Far Field induced temperature field in two interfacing thermal nodes

Solve temperature field for:

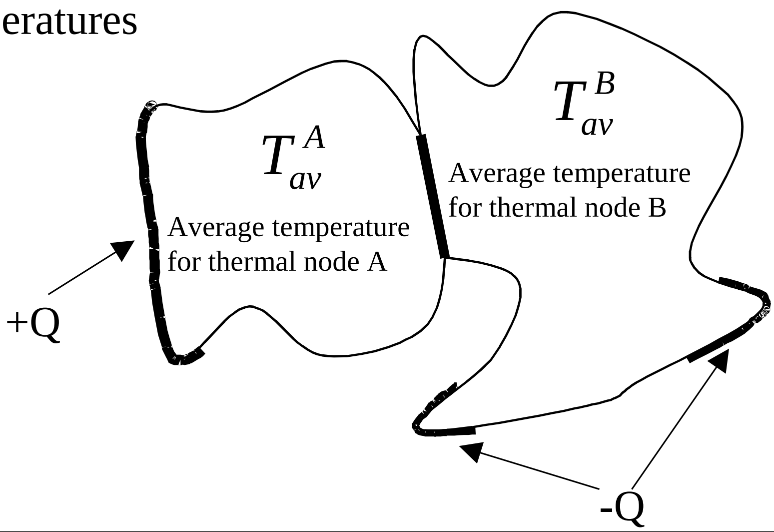


The Far Field Method: The Method (cont'd)

Step 3: Calculate average temperature and conductor value

- Weighted average temperature of the thermal nodes is computed from the FEM-node temperatures

$$GL_{AB} = \frac{T_{av}^{B} - T_{av}^{A}}{Q}$$



Conclusion

- A study has shown the robustness of the method for different geometrical shapes of the thermal nodes
- For simple shape combinations (e.g. rectangle to rectangle) the method converges to the known analytical results
- In the frame of ongoing work Alstom has been given a contract to implement the Far Field method in ESARAD

Appendix W: Excel Database for generating Thermal Models

An Excel Database
for the generation of
ESATAN and Systema
Thermal Models

S. Barraclough
EADS-ASTRIUM

An Excel Database for the Generation of ESATAN and Systema Thermal Models

Simon Barraclough
EADS Astrium UK – SM5

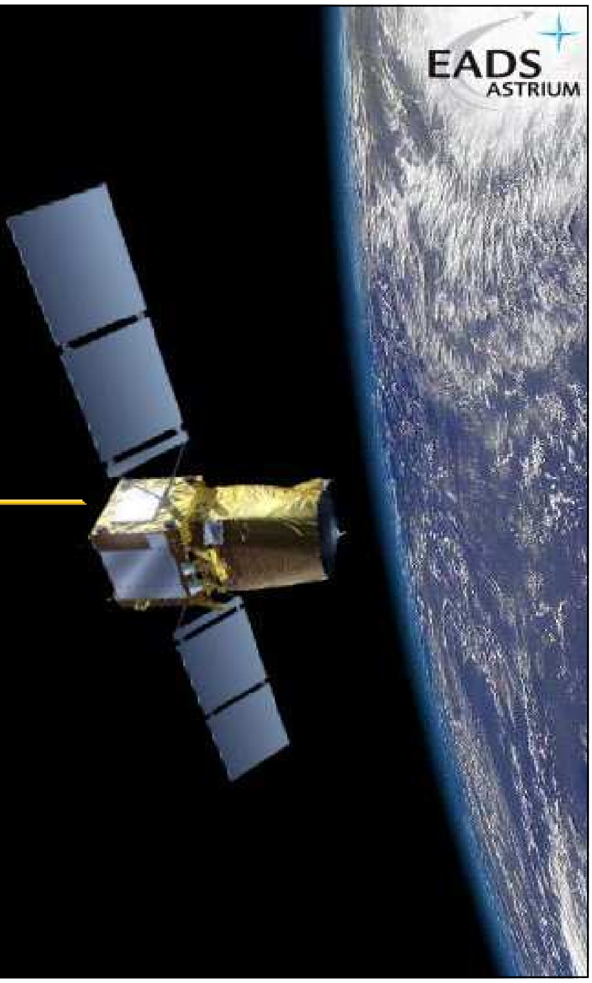
17th European Workshop on Thermal and ECLS Software

Summary

1. Introduction
2. The Thermal Model Database
3. Pre-processing
4. Post-processing
5. Summary and Future Development

Introduction

1

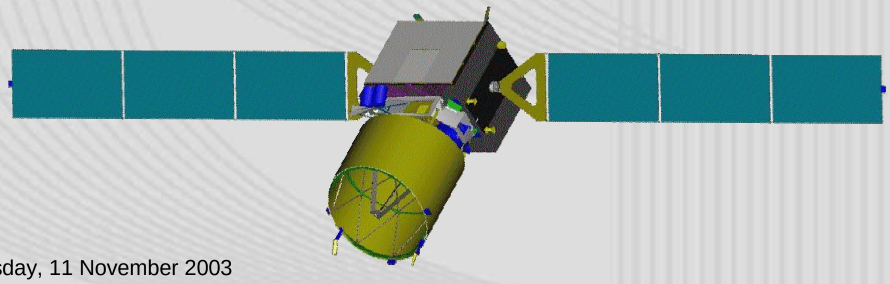


Introduction

AEOLUS
sense the wind

- Atmospheric Dynamics Mission ADM-Aeolus Program.
- Global observations of wind profiles in clear air in:
  - the troposphere.
  - the lower stratosphere.

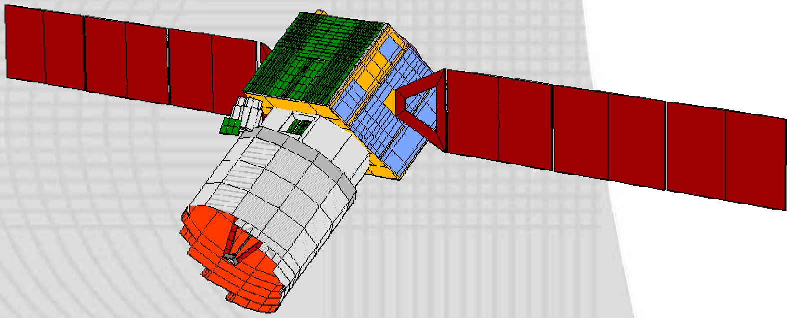
  significant improvement of weather forecasting skills.
- Atmospheric Laser Doppler Instrument (ALADIN), a Direct Detection Doppler Lidar (D3L) operating in the ultra-violet spectral region.
- Polar-orbiting Aeolus will provide ALADIN a near global coverage.



Thermal Modeling

Spacecraft thermal model consist the following elements:

- -Spacecraft structure
- -Units
- -Propulsion equipment
- -Power equipment
- -Thermal Equipment



Thermal Models:

-Geometric Mathematical Models (GMM)

↳Geometry of the spacecraft

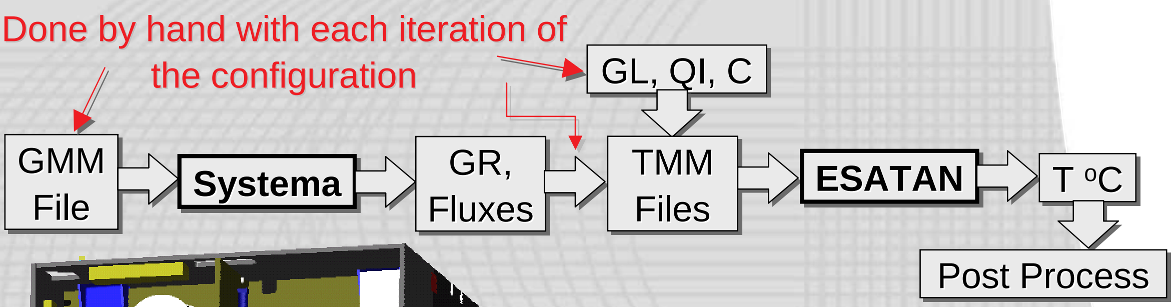
↳Radiative Exchange factors and environmental fluxes

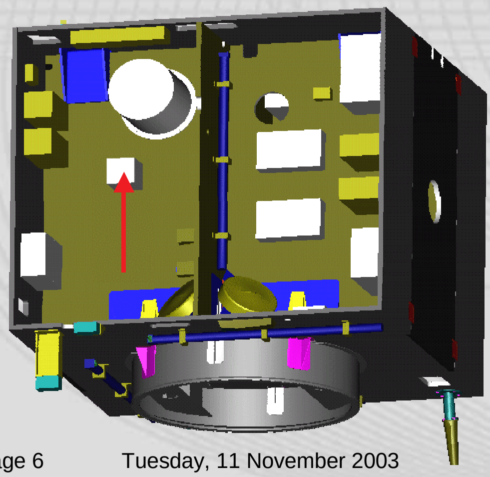
-Thermal Mathematical Models (TMM)

↳ Thermal Conduction, Capacity and Dissipation

↳Temperature Prediction

The Thermal Model





Modification to the Configuration:

- Re-build and run GMMs
- Re-build and run TMMs
  - -Internal Panel Conductances
  - -Unit interface conductances
  - -Unit properties (capacity)
  - -Cleat couplings
  - -Dissipations

Process Improvement

Many Configurations during Phase B

Method of thermal modelling can be improved:

– A central database of modelling information
– Reducing the number of data input errors
– Automatic generation of repetitive calculations

The Thermal Model Database

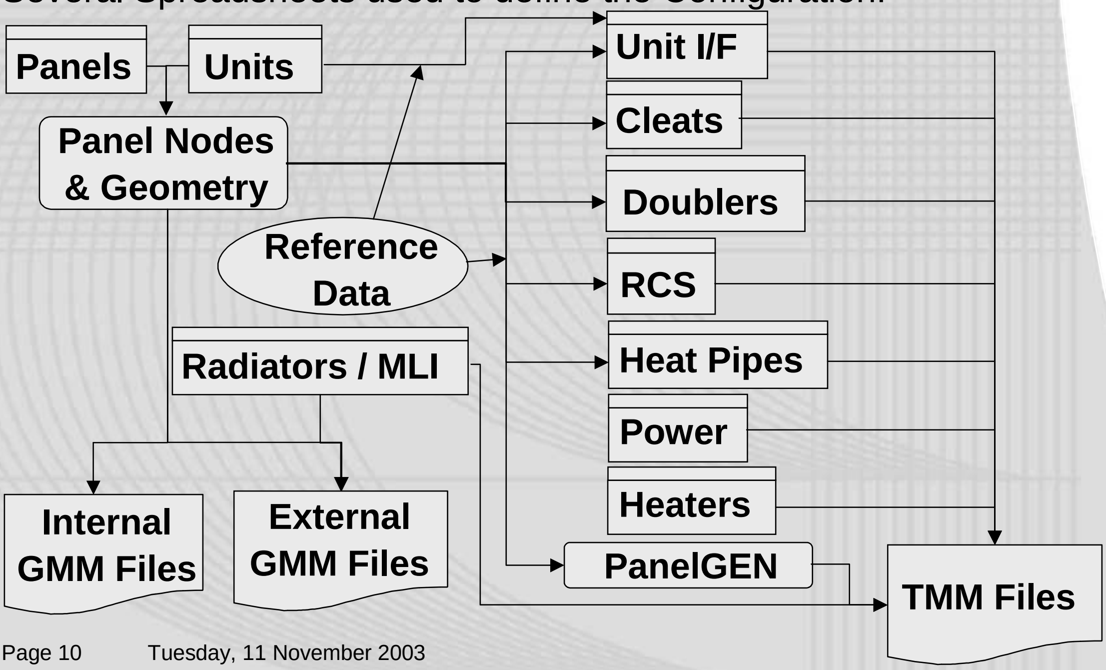
2

Excel Thermal Database

- Developed during the Phase B of the Aeolus platform
- Written using Excel 2000
- Extensive use of Visual Basic Macros and functions
- Information categorised on separate sheets broken down into the components of the spacecraft
- Spreadsheet processes the relevant information and generates text files
- Text files collated in Unix to create the TMM and GMM input files (no additional input)

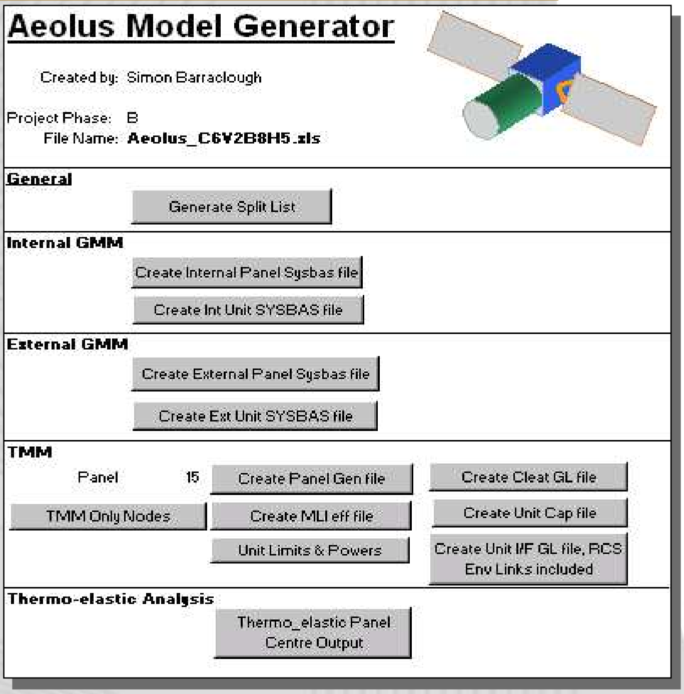
Structure

Several Spreadsheets used to define the Configuration:



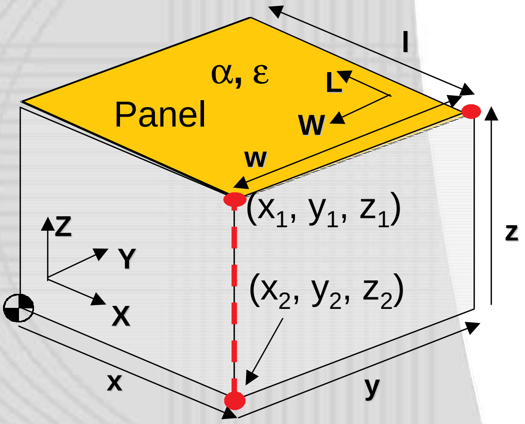
Generator Interface

- All outputs controlled from the main page
- Buttons activate the relevant macros to output the thermal data to Unix



Panels & Cleats

- Define in spreadsheet by:
  - Number and Label
  - Material
  - Node Number Series
  - Dimensions
  - Location & Orientation
  - Optical Properties
- Cleats in spreadsheet by:
  - Start & Finish points

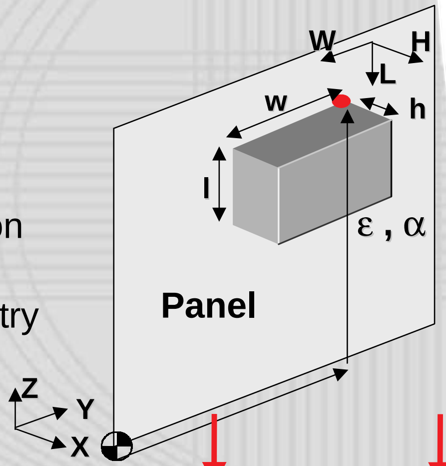


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1			Panel	Node Numbers			Dimensions (mm)		Location wrt origin			Orientation			Optical Properties		
2		Panel	Material	Inner	Outer	MLI	x	y	X	Y	Z	Unit X	Unit Y	Unit Z	Int Surface	MLI	Radiator
3		+Z Floor	Main_panel	71100	71200	71300	1600	1600	-800	-800	1621.6	+X	+Y	-Z	Black Paint	MLI	OSR
4		+X Wall	Main_panel	52100	52200	52300	680	1400	800	340	221.6	-Y	+Z	-X	Black Paint	MLI	OSR
5		+Y Wall	Main_panel	61100	61200	61300	1600	1400	-800	-800	221.6	+X	+Z	-Y	Black Paint	MLI	OSR
6		Mid Shear Wall	Shear_panel	57100	57200	N/A	1600	1400	0	-800	221.6	+Y	+Z	+X	Black Paint	MLI	OSR

Units

EADS ASTRIUM

- Define in spreadsheet by:
  - Number and Label
  - Capacity
  - Geometric type and dimension
  - Panel and location
  - Orientation of the unit geometry
  - Optical Property



TMM Only Node

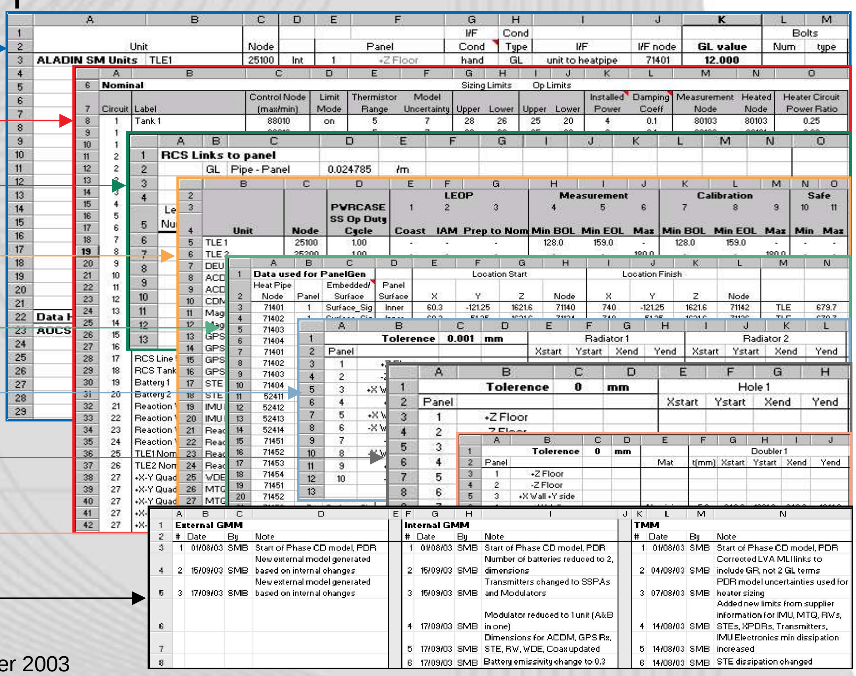
	A	B	C	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	Unit				Geo	Dimensions (mm)						Location wrt origin			Orientation			
2			Node	Capacity	Type	x	y	z	Dia		Panel	X	Y	Z	Unit X	Unit Y	Unit Z	Opt Prop
3	ALADIN SM Units	TLE1	25100	25309.2	BOX5	500	275	205			+Z Floor	110.3	137.5	1621.6	+X	-Y	-Z	Black Paint
4	Data Handling	CDMU	40100	23200.1	BOX5	500	260	280			+Y-X Shear Wall	-110.3	340.0	600.6	+Z	-X	+Y	Black Paint
5	AOCS	IMU Head	41410	4951.8		0	0	278	282		-Y-X Shear Wall	-362.4	-340.0	1400.6				Black Paint
6		IMU Head MLI	41415	0	CYL2	0	0	278	282		-Y-X Shear Wall	-362.4	-340.0	1400.6	-Z	-X	-Y	VDA MLI
7		RW Baseplate	41541	6510.7	DISCO	0	0	125	351		-Z Floor	-150.0	500.0	351.4	+X	+Y	+Z	Black Paint
8		RW Cover	41542	0	CYL2	0	0	125	351		-Z Floor	-150.0	500.0	351.4	+X	+Y	+Z	Black Paint

Different Geometry Types

Input Data

EADS ASTRIUM

- Similar type of Input is done for the:
  - –Unit Interfaces
  - –Heaters
  - –RCS
  - –Power
  - –Heat Pipes
  - –Radiators
  - –Holes
  - –Doublers
- **Changes**



Pre-processing

3

Panel Node Breakdown

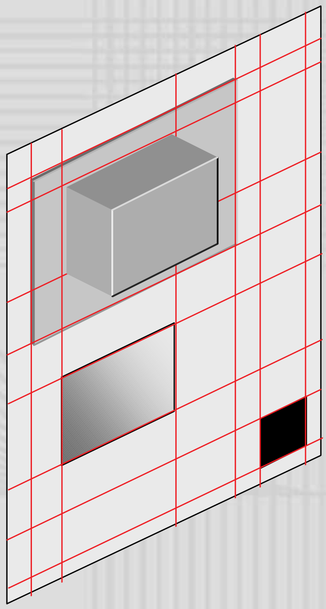
Panel Components:

- Doublers
- Radiators
- Holes
- Units

» Panel splits

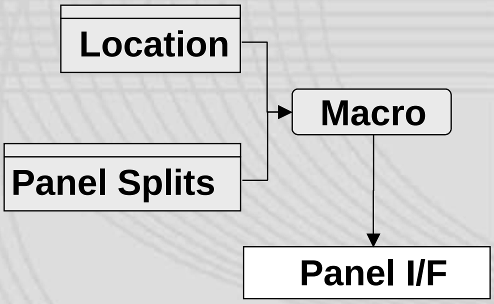
↓

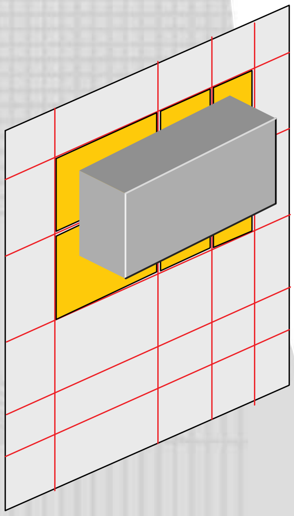
PanelGen (panel conduction)



Location Macro

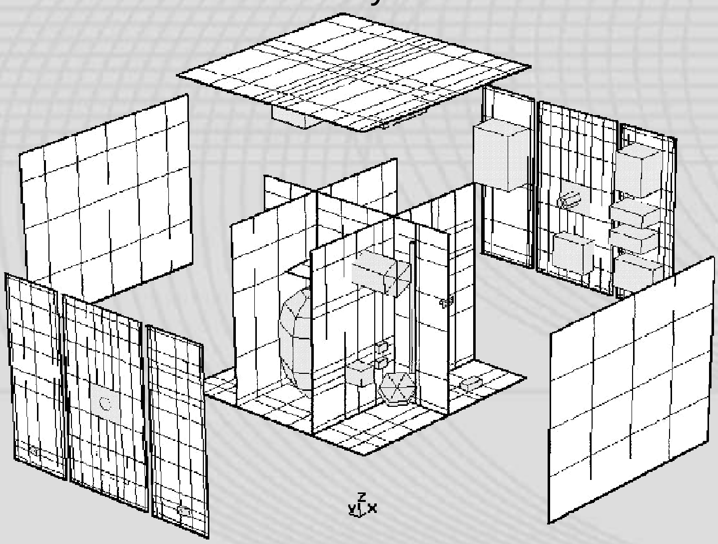
- With panel node breakdown info Excel works out the links to the relevant panel node for:
  - –Cleats
  - –Units
  - –RCS
  - –Heat pipes
  - –Holes
  - –Radiators
  - –Doublers

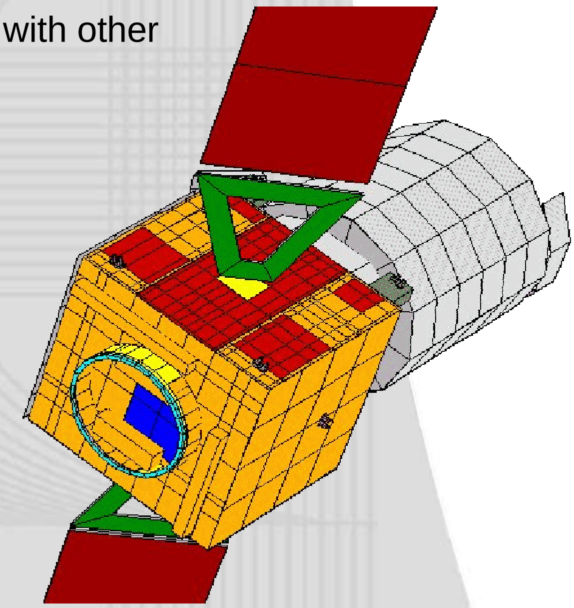




Output Files - GMM

- Geometric data from database combined with other model files in Unix
- Internal Geometry Model





- External Geometry Model

Output Files - TMM

Thermal model built using data from various different files:

TMM

- Excel Database Output
- PanelGen Results
- Supplied Model
- GMM Results
- TMM Control Inputs

```
$MODEL AEOLUS
$INCLUDE "/phase_b/Excel_out/Comments.dat"
$NODES
$INCLUDE "/phase_b/Excel_out/TMMnodes.dat"
$INCLUDE "/phase_b/PanelGen/Panelgen_nodes.dat"
$INCLUDE "/phase_b/Aladin_Model/Aladin_nodes.dat"
$INCLUDE "Systema/nodes.dat"
$CONDUCTORS
$INCLUDE "/phase_b/Excel_out/Unit_IF.dat"
$INCLUDE "/phase_b/Excel_out/Cleat_GL.dat"
$INCLUDE "/phase_b/PanelGen/Panelgen_GLs.dat"
$INCLUDE "/phase_b/Aladin_Model/Aladin_conds.dat"
$INCLUDE "Systema/GRs.dat"
$CONSTANTS
$INCLUDE "/phase_b/Constants.dat"
$CONTROL
$INCLUDE "/phase_b/Control_var.dat"
$ARRAYS
$INCLUDE "/phase_b/Excel_out/Unit_Power.dat"
$INCLUDE "/phase_b/Aladin_Model/Aladin_arrays.dat"
$INCLUDE "Systema/Ext_flux_array.dat"
$SUBROUTINES
$INCLUDE "/phase_b/Excel_out/Unit_cap.dat"
$INCLUDE "/phase_b/Excel_out/Unit_power.dat"
$INCLUDE "/phase_b/Aladin_Model/Aladin_subs.dat"
$INCLUDE "Systema/HCYCLC.dat"
```

One main TMM file used for all cases

Post Processing

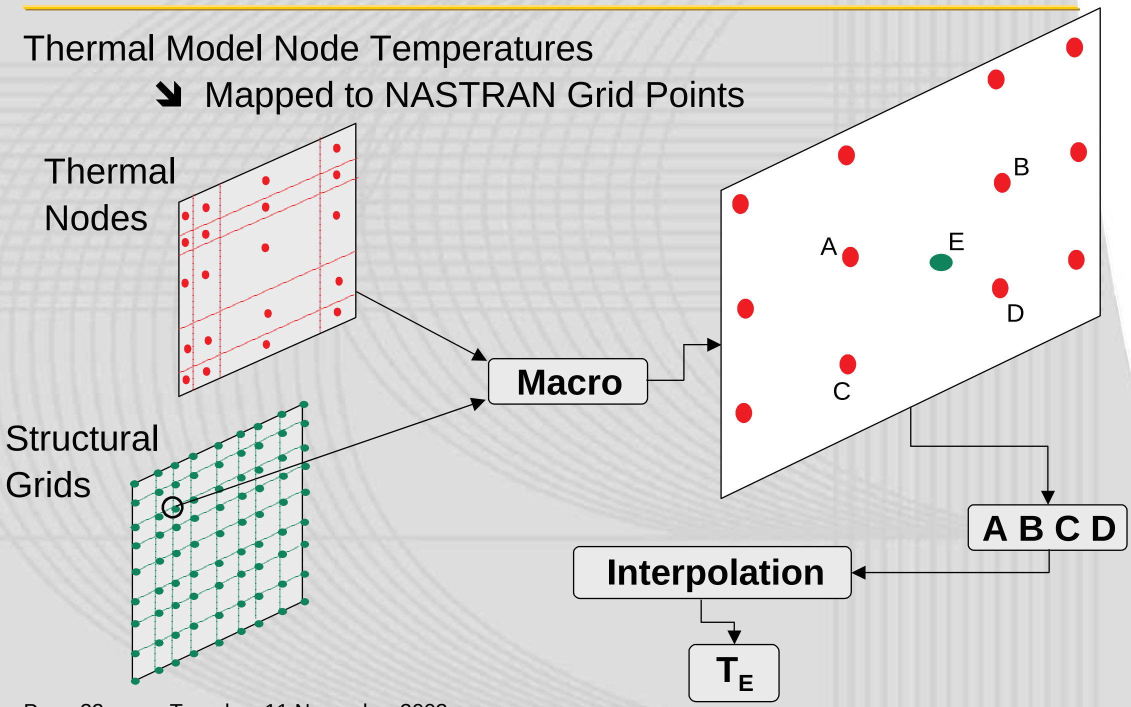
4

Post-processing Applications

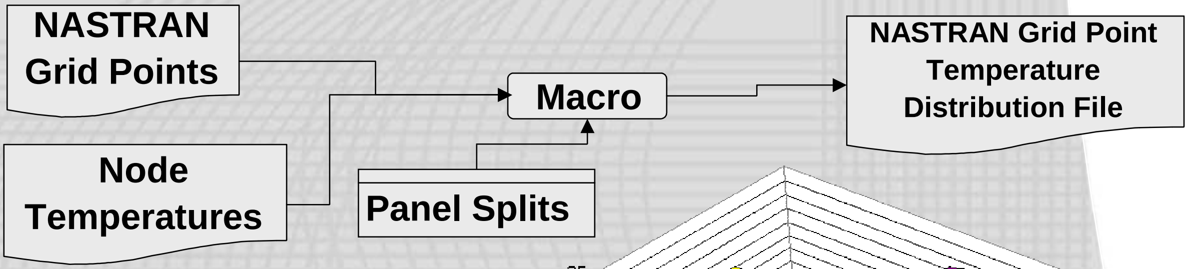
- Information within the database used for:
  - Comparisons of temperature predictions with limits
  - List of nodes for heat flow analysis
  - Locating interface node temperatures
  - Thermo-elastic analysis

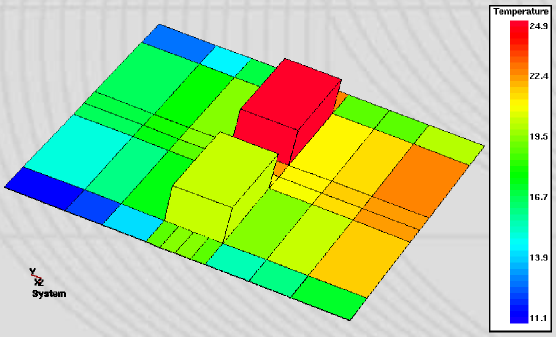
Thermo-elastic Temperatures

Thermal Model Node Temperatures
↘ Mapped to NASTRAN Grid Points

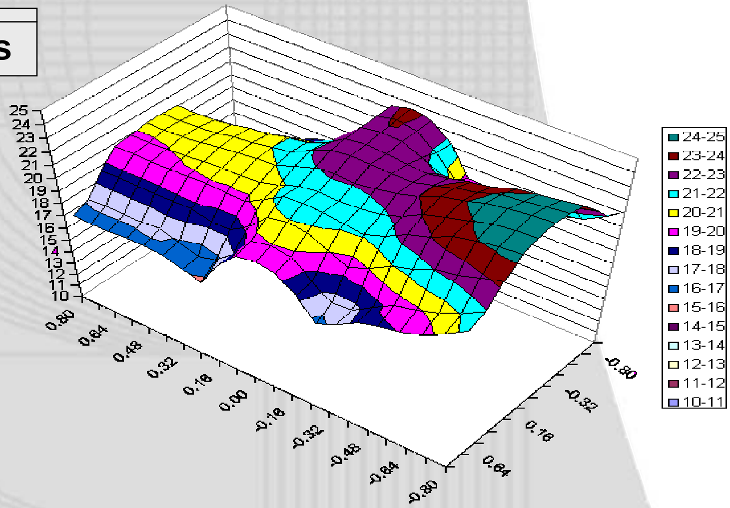


Thermo-elastic Temp Maps





Thermal Model Temperatures

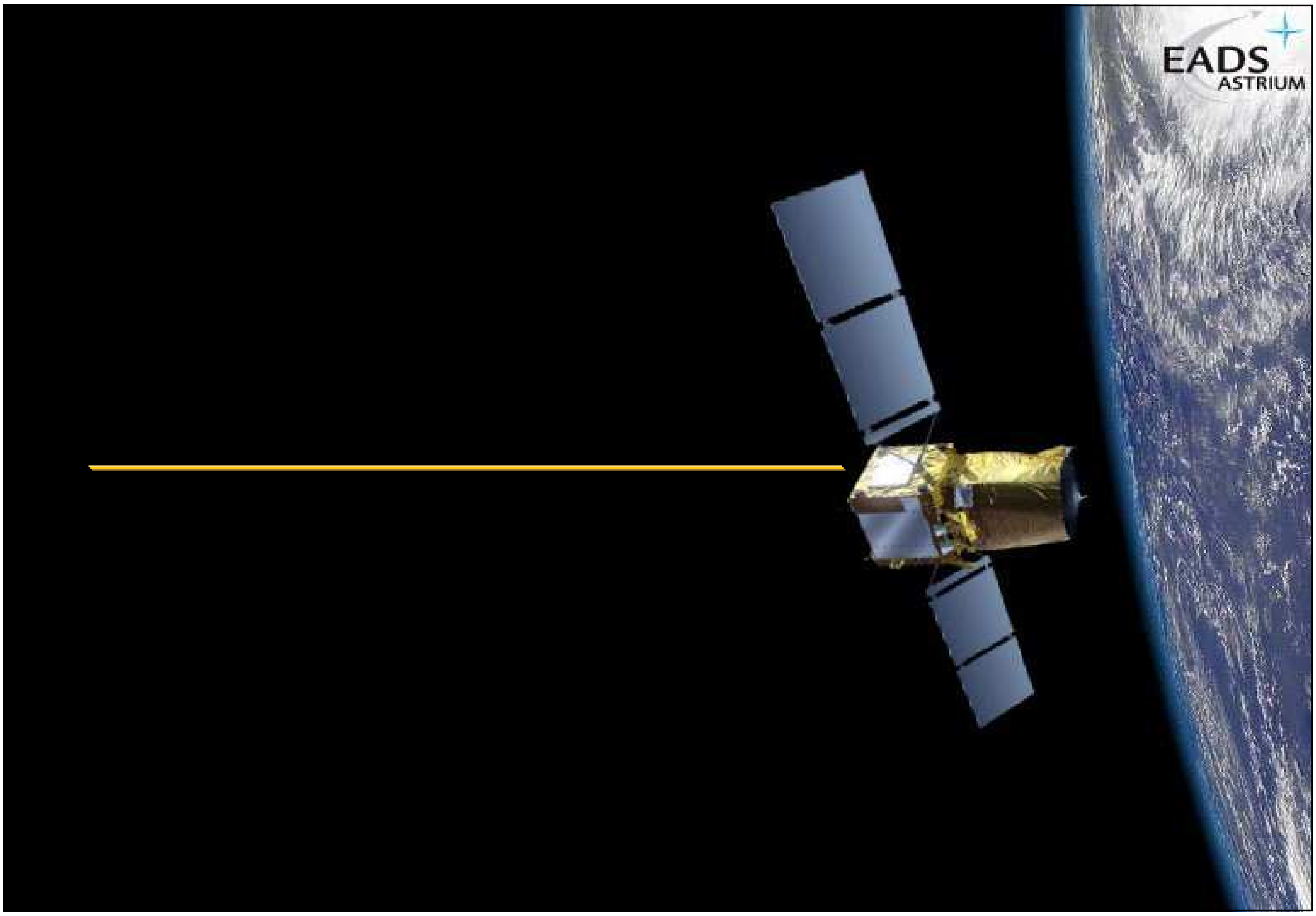


NASTRAN Grid Point Temperatures

Summary – Future Development

- Thermal Model Database for Aeolus
- Successfully applied for Phase B
- Model creation reduced to 1week
- Model modification time reduced from ≈3 days to ½ day
- Systematic updating of models
- Useful tool in post-processing applications

- Improvements
  - More generic
  - More user "friendly" (i.e. drop down menu options)
  - Ability to update from a system database


EADS
ASTRIUM

Appendix X: RadTherm

RadTherm

R. Habig
ThermoAnalytics

ThermoAnalytics Europe LLC

17th European Workshop

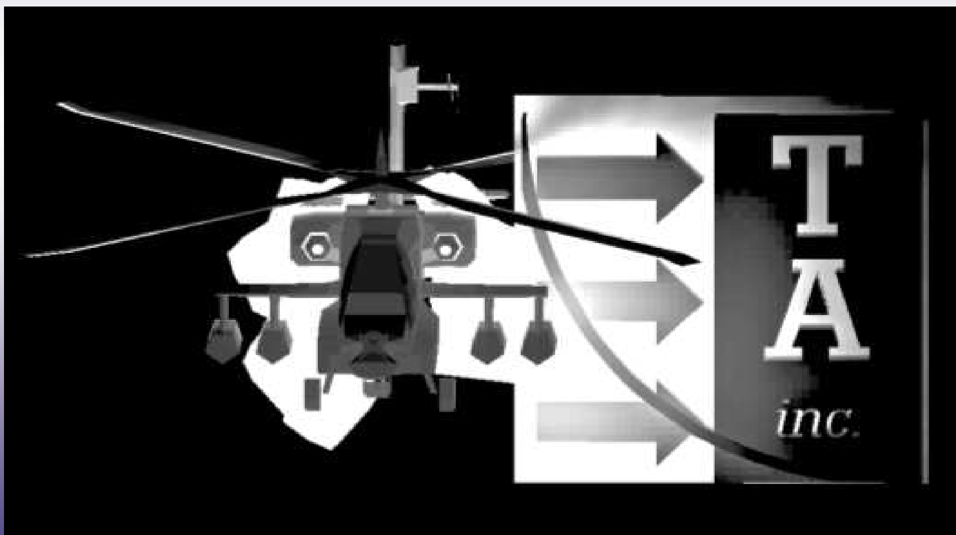
Thermal & ECLS Software

ESA / ESTEC

Noordwich
The Netherlands
October, 21th – 22th 2003

ThermoAnalytics Europe LLC

Thermal and infrared signature analysis in aerospace and aeronautics



Author: Ralph Habig
MSc for Aerospace Engineering
Managing Director Europe

ThermoAnalytics Europe LLC

Abstracts

It is more and more common to use numerical analysis software tools for aerospace and aeronautical applications. Human lives depend on these systems. Based on the wide range of activities, it is more necessary than ever before to predict the thermal behavior and protect equipment and systems from thermal damage. In many cases such systems are not fully protected against extreme thermal loads, such as intense solar impingement.

This presentation shows you the current state of software development at ThermoAnalytics, Inc. TAI's thermal and IR signature analysis software (RadTherm / MuSES) is designed to provide answers to thermal design questions and to cover these deficiencies.

A simple case study presented in this paper will demonstrate how efficiently the application RadTherm / MuSES can predict thermal and infrared behavior of any kind of system.

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Overview

- Introduction
- Procedure
- Examples
- Conclusion

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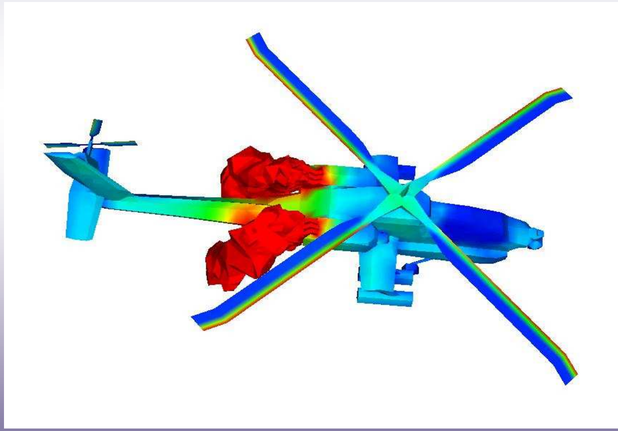
Introduction

Providing State-of-the-Art Software Products for



Commercial Thermal Analysis

Military Signature Analysis

ThermoAnalytics Europe LLC

Thermal and infrared signature prediction is more and more common and useful for

- discover heat sources
- enhanced cover of targets
- predict complexe scenarios
- find best possibilities

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History

- 1996 ThermoAnalytics Incorporates
- 1998 RadTherm 4.1 commercial release
- 1999 RadTherm 5.0 released
- 2000 TAI receives Tibbits and Army SBIR Quality Award
- 2001 TAI awarded Army Prime Contractor of the year
  RadTherm interface with CFD & Post-Processors
- 2002 TAI awarded II. Army Prime Contractor of the year

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Core Competencies

- Radiation Physics
- Computational Fluid Dynamics
- Thermal System Modeling
- Cross-Platform Software Development
- Code Optimization
- Graphical User Interface Design

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Hardware Partners

Microsoft®

hp invent

Sun microsystems

SiliconGraphics Computer Systems

- Introduction
- Procedure
- Example
- Conclusion

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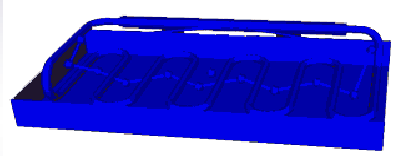
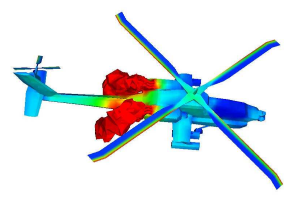
Software Partners

PTC® Enterprise Software Partner

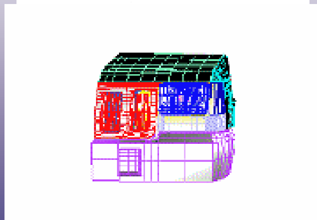
CEI Creator of EnSight

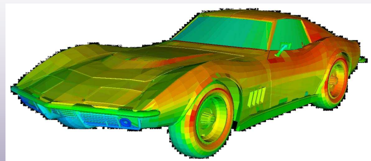


FLUENT INCORPORATED



ICEM CFD Engineering





STAR-CD

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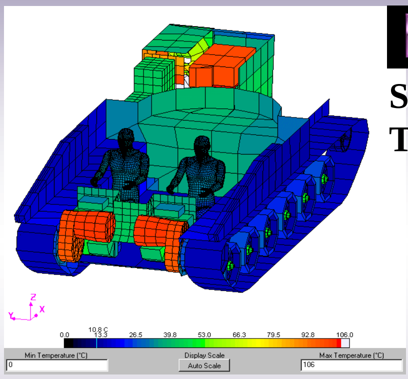
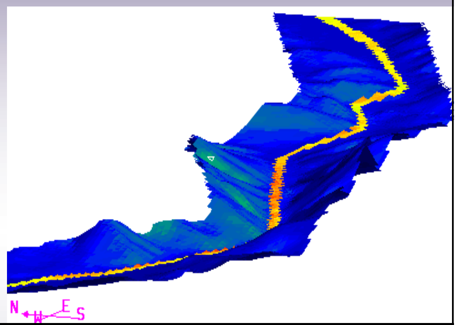
Software Products



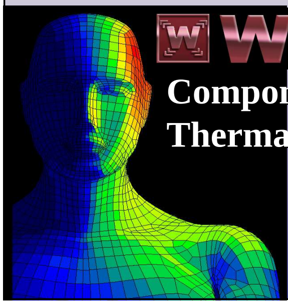
RadTherm

Systems Level
Thermal Modeling



RadThermRT

Road Surface/Terrain Modeling



WinTherm

Component Level
Thermal Modeling

InfraRed
Signature Modeling

MuSES

- Introduction
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Complete Thermal Analysis

- **Radiation**
  - Single and multibounce radiation
  - Automatic calculation of view factors and solar projected (apparent) areas, using a voxel-based ray tracer
- **Conduction**
  - Automatic Conduction Linkages
- **Convection**
  - Specify H and T_{film}
  - Automatic Convection Library
  - Calculated Wind Convection (nat. environ's)
  - 1D Fluid Flow (advection)
  - Import CFD Results

- Introduction
- Procedure
- Example
- Conclusion

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Advances

- Advanced Thermal Simulation
- Extremely Fast Thermal Solver
- Large-scale system-level Thermal Analysis
- Flexibility to manipulate your system with easy
- Rapid Prototyping
- Integration with CAD/CFD/CAE

• Introduction
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Aerospace Applications

Aircraft in standby or hovering incl. solar loading

Aircraft on mission incl. terrain on lower or upper atmosphere incl. solar loading

Infrared signature in standby, idel, hovering or on mission

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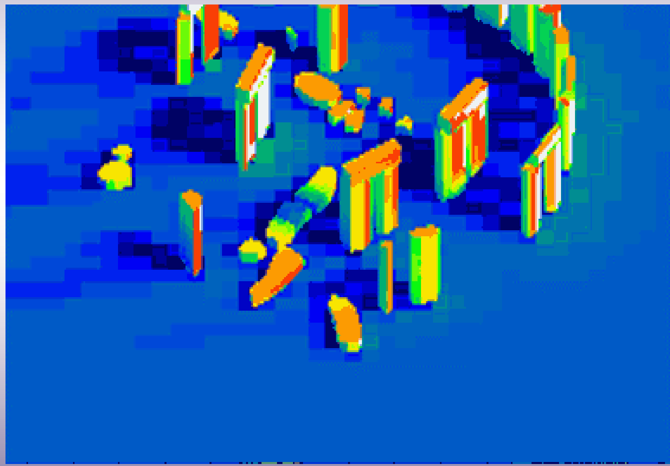
Other Applications



Automotive

Underbody, Exhaust & Underhood,
Climat Control & HVAC, Vehicle
Interior & Thermal Comfort,
Electronics & Lighting

Electronics

Architecture

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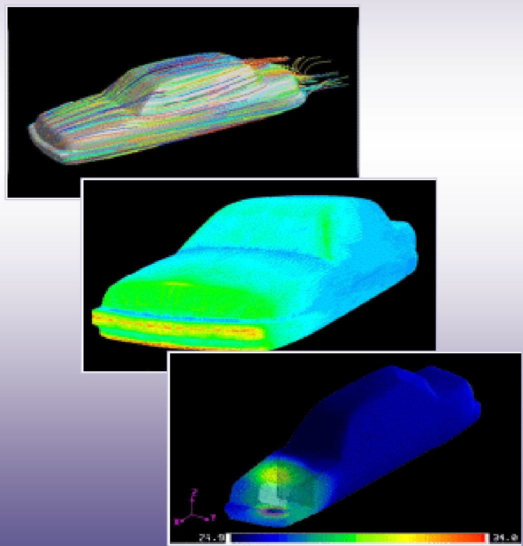
Integration with CFD

Only Surface Geometry

Convection Coefficient & Fluid Temperature

Mix with RadTherm's Other Convection Tools



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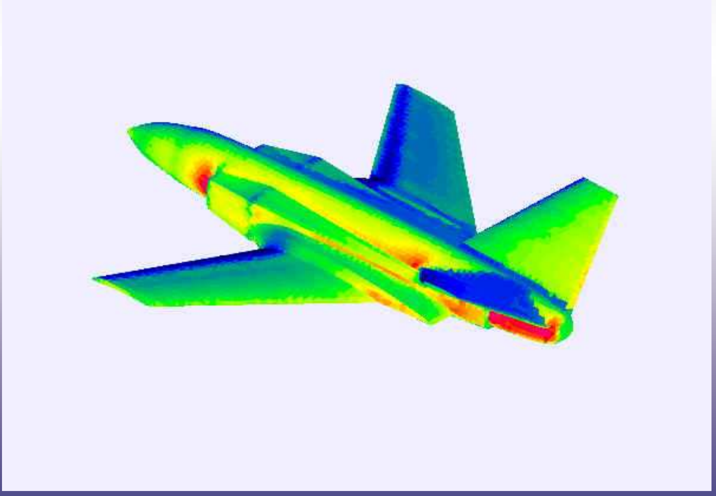
Example

The following example will discrib a project for an UAV system development on an attitute of 30000 ft



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Boundaries

MODTRAN Weather File

to predict ◘ diurnal direct solar radiance
◘ diffuse solar radiance
◘ thermal sky radiance
◘ apparent ground radiance

Direct solar radiance

to predict the solar radiance, we ran MODTRAN in “transmitted solar irradiance” mode (IEMSCT = 3) using the solar waveband (4,000 to 50,000 cm-1, 0.2 to 2.5 microns)

Diffuse solar radiance

To predict the diffuse solar radiance, we ran MODTRAN in “radiance with solar scattering” mode (IEMSCT = 2) using the solar waveband (4,000 to 50,000 cm-1, 0.2 to 2.5 microns).

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Boundaries

Thermal sky radiance

To run the thermal sky radiance simulation we used the same input deck that we used for the diffuse solar radiance except we used a thermal waveband (200 to 5,000 cm-1, 2 to 50 microns). This waveband corresponds to the spectrum typically measured in the field for thermal sky radiance.

Apparent ground radiance

To run the apparent ground radiance simulation we used the same input deck that we used for the thermal sky radiance except:

- Set the zenith to 145 degrees (ANGLE on CARD 3)
- Set the boundary temperature (TBOUND on CARD 1) to diurnal ground temperature
- Set the boundary albedo to the ground reflectivity (SALB on CARD 1)
- Set H2 to 0.0 km (CARD 3)

For the solar and sky simulations, we set TBOUND = 0.0 and SALB = 0.0 to simulate outer space.

Boundaries

MODTRAN INPUTS

- US STANDARD DAY 1976 Spring/Summer
- Without multiple scattering
- Rural extinction haze 23 km visibility
- Zenith for sky = 55 deg
- Zenith for ground = 145 deg
- Day of year = 188
- UTC = Hancock Time + 4
- Ground albedo = 0.2 (emissivity = 0.8)
- Solar band = 4000 to 50000 cm-1 (0.2 to 2.5 microns)
- Thermal band = 200 to 5000 cm-1 (2 to 50 microns)

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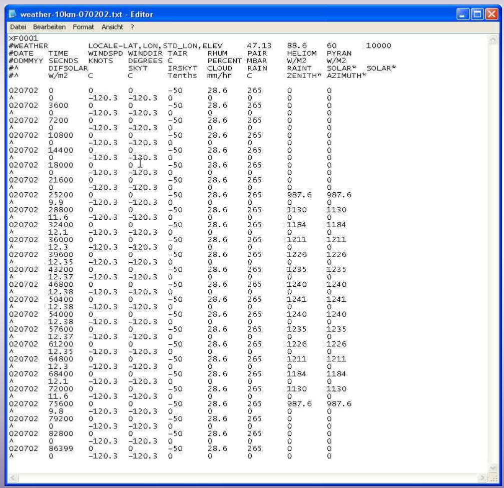
Boundaries

Weather file example



weather-10km-070202.txt - Editor

Datei Bearbeiten Format Ansicht ?

```
XF0001
#WEATHER          LOCALE-LAT,LON,STD_LON,ELEV   47.13   88.6    60      10000
#DATE    TIME     WINDSPD  WINDDIR  TAIR     RHUM     PAIR    HELIOM  PYRAN
#DDMMYY  SECNDS   KNOTS    DEGREES  C        PERCENT  MBAR    W/M2    W/M2
#^       DIFSOLAR          SKYT     IRSKYT   CLOUD    RAIN    RAINT   SOLAR*  SOLAR*
#^       W/m2     C        C        Tenths   mm/hr    C       ZENITH* AZIMUTH*

020702   0        0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   3600     0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   7200     0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   10800    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   14400    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   18000    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   21600    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   25200    0        0        -50      28.6     265     987.6   987.6
^        9.9      -120.3   -120.3   0        0        0       0       0
020702   28800    0        0        -50      28.6     265     1130    1130
^        11.6     -120.3   -120.3   0        0        0       0       0
020702   32400    0        0        -50      28.6     265     1184    1184
^        12.1     -120.3   -120.3   0        0        0       0       0
020702   36000    0        0        -50      28.6     265     1211    1211
^        12.3     -120.3   -120.3   0        0        0       0       0
020702   39600    0        0        -50      28.6     265     1226    1226
^        12.35    -120.3   -120.3   0        0        0       0       0
020702   43200    0        0        -50      28.6     265     1235    1235
^        12.37    -120.3   -120.3   0        0        0       0       0
020702   46800    0        0        -50      28.6     265     1240    1240
^        12.38    -120.3   -120.3   0        0        0       0       0
020702   50400    0        0        -50      28.6     265     1241    1241
^        12.38    -120.3   -120.3   0        0        0       0       0
020702   54000    0        0        -50      28.6     265     1240    1240
^        12.38    -120.3   -120.3   0        0        0       0       0
020702   57600    0        0        -50      28.6     265     1235    1235
^        12.37    -120.3   -120.3   0        0        0       0       0
020702   61200    0        0        -50      28.6     265     1226    1226
^        12.35    -120.3   -120.3   0        0        0       0       0
020702   64800    0        0        -50      28.6     265     1211    1211
^        12.3     -120.3   -120.3   0        0        0       0       0
020702   68400    0        0        -50      28.6     265     1184    1184
^        12.1     -120.3   -120.3   0        0        0       0       0
020702   72000    0        0        -50      28.6     265     1130    1130
^        11.6     -120.3   -120.3   0        0        0       0       0
020702   75600    0        0        -50      28.6     265     987.6   987.6
^        9.8      -120.3   -120.3   0        0        0       0       0
020702   79200    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   82800    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
020702   86399    0        0        -50      28.6     265     0       0
^        0        -120.3   -120.3   0        0        0       0       0
```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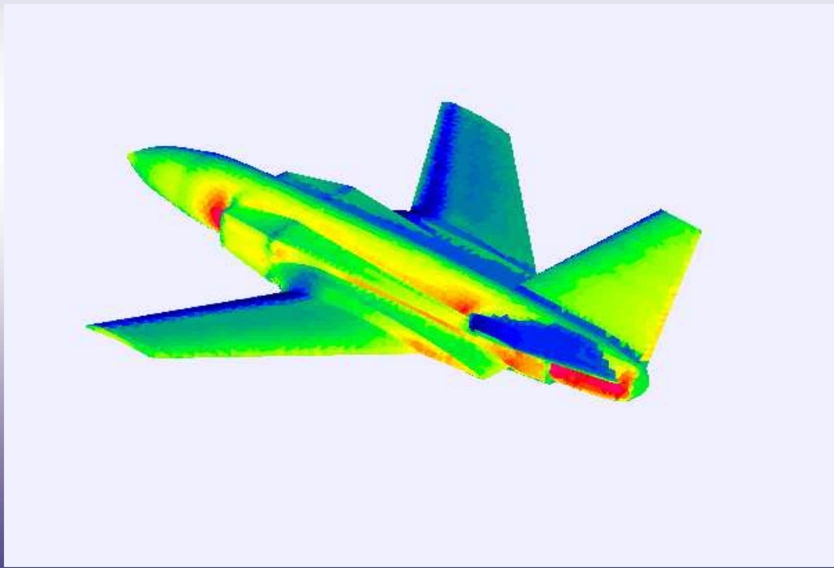
Results

Physical temperature results [time 0900-1400]



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Results

IR radiance results [time: 0900 – 1400 / 8 – 12 micron]

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Future Development

Modeling Features Scheduled After RadTherm 7

User Routines / Hook Functions
Complex BRDF
Parallel Solvers
Scene Model Interface
Exhaust Flow Interface
Plume Radiance Interface
Temperature Dependent Properties

Directional Water Model
Ship Wake Model
Spatial Sky using MODTRAN
1D Automated FF Network
3D Fluid Flow Modules
Appendable Parts Library
Mobility Module
Solid Elements

- Introduction
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Customers

- US Army, Navy, Air Force, Marines, Coast Guard, NGIC, NAIC
- Flight Safety International
- Los Alamos National Lab
- Booz Allen Hamilton
- Northrop Grumman
- General Dynamics
- Lockheed Martin
- Amherst Systems
- Teledyne Brown
- United Defense
- Sikorsky
- Textron
- Boeing
- S.A.I.C.

- DGA/ETAS - France
- FGAN / FOM – Germany
- DLR - Germany
- TNO - Netherlands
- F.O.A. - Sweden
- Bofors Missiles AB - Sweden
- NDRE - Norway

ThermoAnalytics Europe LLC

Summary

This simple case study should show you how easy it can be to predict potentional heat sources on existing systems, manned or unmanned, in atmosphere or orbital.

Also this case study shows that using **RadTherm / MuSES** makes it easy to find and discover successfully every kind of heat sources, internal and extreme thermal loads, such as intense solar impingement.

It can be used for exsiting systems as well as for new systems in development status.

• Introduction
• Procedure
• Results
• Conclusion

Conclution

Acknowledgements

I would like to thank all who assisted in the preparation of this paper, including:

- Keith R. Johnson - ThermoAnalytics, Inc., Michigan, USA
- Harrie Rooijackers - ESTEC / ESA, Noordwijk, The Netherlands

And special thanks are due to both co-authors

- Matthew Monte – ThermoAnalytics, Inc., Michigan, USA
- Craig Makens - ThermoAnalytics, Inc., Michigan, USA

Appendix

There is a seperate paper for more details about MODTRAN data files available. If you wish to receive this please contact us under service@thermoanalytics.de

Many thanks for you attention !

Your partner for successful thermal and infrared signature prediction in simulation & analysis

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Appendix Y: Model Exchange between tools using STEP-TAS

**Robust Industrial
model exchange between
ESARAD and THERMICA
with STEP-TAS**

HP. de Koning
ESA/ESTEC

Robust industrial model exchange between ESARAD and THERMICA with STEP-TAS

Hans Peter de Koning, Simon Appel, David Alsina Orra
(ESA/ESTEC D/TOS-MCV)

with some contributions from Simulog and Graitec

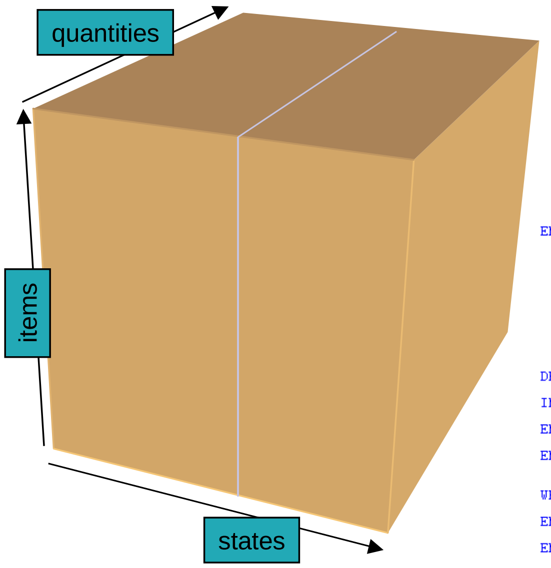
Topics

- Brief recap of STEP-NRF and STEP-TAS protocols
- Why TASverter ?
- Scope and purpose of TASverter
- Development approach
- Updates to NRF and TAS protocols
- Current status
- Outlook

Recap STEP-NRF (1)
(Network-model Results Format)

- Generic, discipline-independent exchange of models & results
  - Model definition, using a discrete network representation
    - Supports model/submodel hierarchy
  - Results data, produced in analysis, test or operation
  - Meta-data, which records details of actual analysis, test or operation performed
- Only discrete observations
  - I.e. sampled results at discrete locations for discrete states of the model / object under observation, no support for continuous fields or similar
- Any property value has explicit (physical) quantity and unit
- Data model designed to cope efficiently with large amounts of results
  - Built-in support for scalar, vector, matrix, tensor data

Recap STEP-NRF (2)
(Network-model Results Format)



Central NRF data structure is the 'datacube'

- each element of the cube is a scalar, vector or tensor property for a specific (item, quantity, state)
- state quantity is normally time or frequence
- 'simple' and 'advanced' SUBTYPEs, respectively for literal and generalised functional property values

```
ENTITY NRF_any_datacube
  ABSTRACT SUPERTYPE OF( ONEOF( NRF_simple_datacube, NRF_advanced_datacube ) );
  -- a (hyper)cubic value space in 3 dimensions: state, quantities and items
  -- the ordering of the nested list of values is determined by value_order
  id                  : NRF_identifier;
  security_class      : OPTIONAL NRF_security_classification_level;
  value_order         : NRF_datacube_order_type;
  quantity_base       : NRF_quantity_list;
  item_base           : NRF_observable_item_list;
  state_quantity      : NRF_scalar_quantity;
  state_base          : NRF_state_value_list;
DERIVE
  number_of_states : INTEGER := SIZEOF( state_base.state_values );
INVERSE
  dataset             : NRF_dataset FOR datacubes;
END_ENTITY;

ENTITY NRF_simple_datacube
  SUBTYPE OF( NRF_any_datacube );
  values              : LIST [1:?] OF NRF_real_or_integer_literal;
WHERE
  wr1: SIZEOF( values ) = quantity_base.number_of_elements * SIZEOF(item_base.items) * number_of_states;
END_ENTITY;

ENTITY NRF_advanced_datacube
  SUBTYPE OF( NRF_any_datacube );
  values              : LIST [1:?] OF NRF_any_real_or_integer_value;
WHERE
  wr1: SIZEOF( values ) = quantity_base.number_of_elements * SIZEOF(item_base.items) * number_of_states;
END_ENTITY;
```

Recap STEP-TAS (Thermal Analysis for Space)

- STEP-based application protocol
  - Initial scope: Exchange of thermal-radiative models for space, including rigid body kinematics and orbit / attitude / orientation specification
    - Geometry represented by bounded face model with minimal topology (compatible with AP 203 CC4)
  - Extended scope: Exchange of thermal lumped parameter network models
    - Targetting exchange between various SINDAs, ESATAN
  - STEP-TAS is a pure superset of STEP-NRF (Used as 'integrated resource')
  - Developed since 1996 mainly on ESA funding, supported by CNES, NASA
    - Originally full ARM / AIM according to ISO TC184/SC4 procedures
    - Accompagnying STEP-TAS library (C and F77 API) provided since 1998
    - Many tools implemented prototype or industrial beta converters

Why TASverter ?

- STEP-TAS converters did not deliver industrial solution up to now
  - Only ESARAD, THERMICA and Thermal Desktop have STEP-TAS exchange included in industrial releases
  - Exchange is slow, often not reliable, and fails for large models
- Existing STEP-TAS architecture had too many layers
  - Bad performance (CPU / elapsed time)
  - Inefficient memory usage, huge memory requirements
  - Expensive to verify and maintain
  - Difficult to distribute on multiple platform/compiler combinations
- However principle of providing protocol + library was very good and should be retained!

'STEP-TAS high level API' (C and F77)
STEP-TAS ARM
STEP-TAS AIM
SDAI-C (COTS, late binding)
Vendor specific repository handler (COTS)

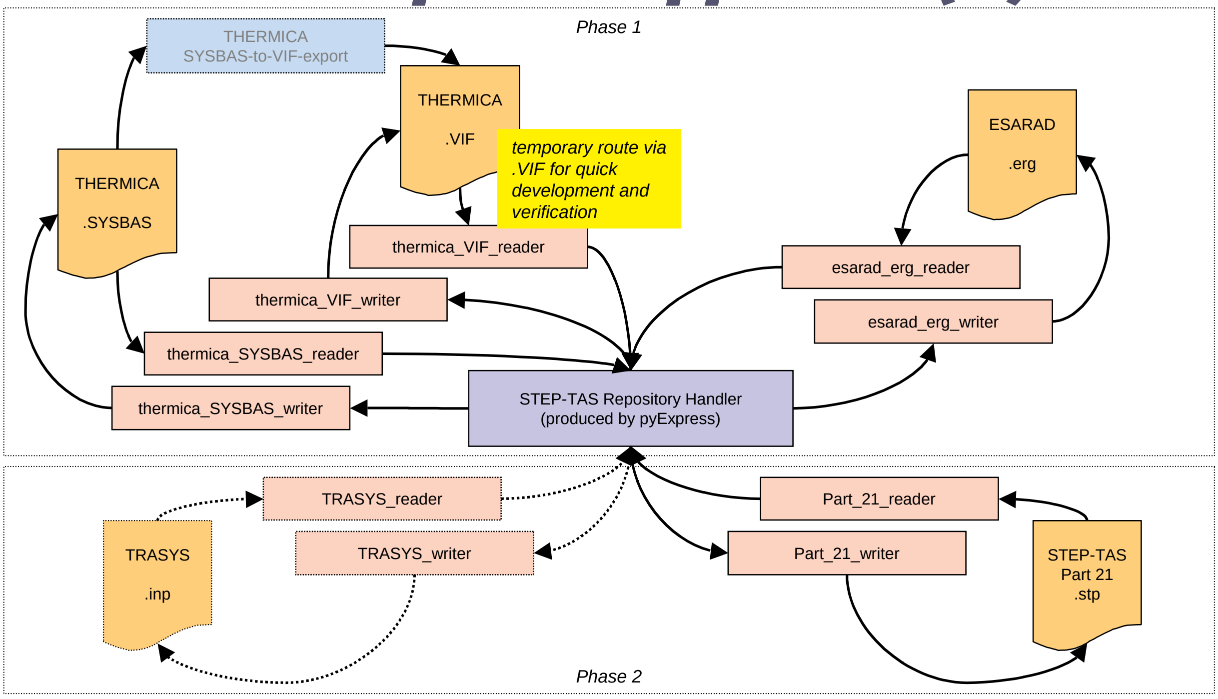
Scope and purpose of TASverter

- TASverter is an initiative of ESA/ESTEC D/TOS-MCV to:
  - Offer users finally a properly working solution for exchange of thermal models
    - First between major European analysis tools ESARAD and THERMICA
  - Remove complicated dependency on (at least) 4 developers
    - STEP-TAS and STEP library developers, Tool X and Tool Y developers
  - Produce a fully functional (open source) framework for validation and verification of STEP-based data exchange protocols and implementations
  - Lay a solid basis for the future
    - Low threshold for implementation
    - Maintainable and cost-effective
    - Ensure long term availability (no dependence on closed 3rd party software)

Development approach (1)

- Implementation in pure Python (v2.2)
  - Following positive experience with earlier ‘ad-hoc’ converter developments
- Internal data storage uses STEP-TAS (ARM) data model
  - Implemented in ‘STEP-TAS Repository Handler’, which is largely generated automatically with pyExpress from the STEP-TAS EXPRESS schema
- For each supported tool/format a ‘reader’ and a ‘writer’ is created
- Full testsuite built up alongside development
  - Unit, integration and large model testcases under configuration control
- Integrated validation and fine-tuning of STEP-NRF and STEP-TAS
  - Goal is recreation of models which are understandable and editable by humans
  - Efficient update cycle is possible with pyExpress STEP-TAS library generator

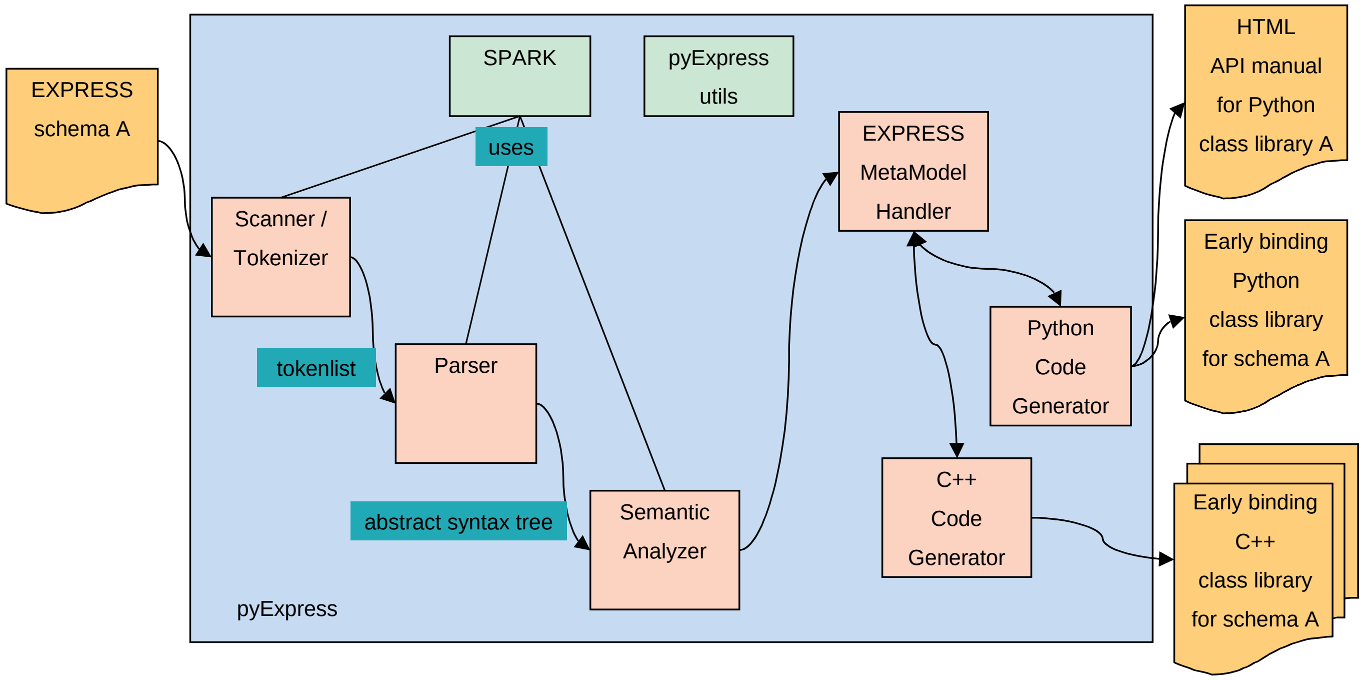
Development approach (2)



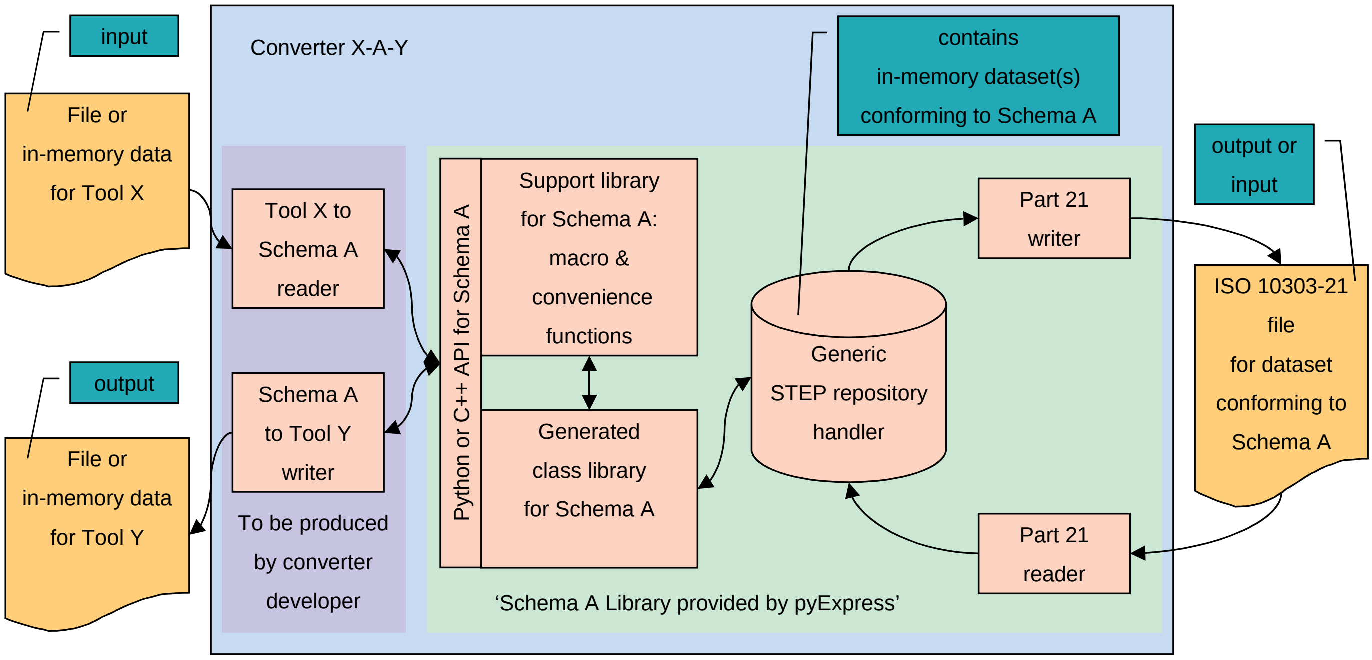
Development of pyExpress

- Provide a STEP converter development environment, that
  - can be used by converter developer with minimal STEP knowledge
  - can be used as a Rapid Application Development tool for prototyping and near-real time validation and refinement of application protocols
  - has very strong string manipulation capabilities
  - maps well onto EXPRESS object oriented data models
  - leads to industrially robust converters, with acceptable performance and memory requirements, also for large models
- pyExpress is a STEP/EXPRESS compiler / code generator
  - Generates Python class library for implementation of converter in Python
  - Generates C++ class library for implementation of converter in C++

pyExpress architecture



Outline of converter based on pyExpress

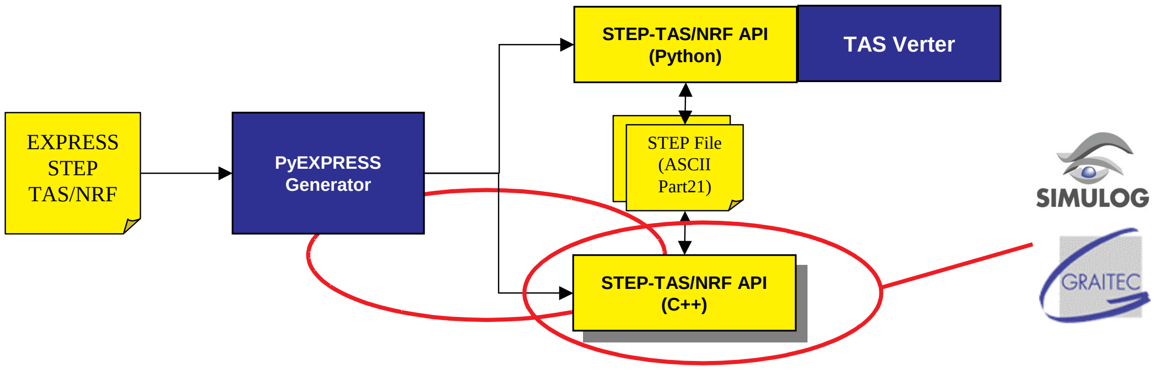


EXPRESS → Python Example (1)

```
ENTITY TAS_kepler_parameter_set;
  semi_major_axis                    : NRF_length_measure;
  eccentricity                       : REAL;
  inclination                        : NRF_plane_angle_measure;
  right_ascension_of_ascending_node  : NRF_plane_angle_measure;
  argument_of_periapsis              : NRF_plane_angle_measure;
  true_anomaly_at_start              : NRF_plane_angle_measure;
WHERE
  wr1: semi_major_axis >= 0.0;
  wr2: eccentricity >= 0.0;
  wr3: { -180.0 < inclination <= 180.0 };
  wr4: { -360.0 < right_ascension_of_ascending_node <= 360.0 };
  wr5: { 0.0 <= argument_of_periapsis < 360.0 };
  wr6: { -360.0 < true_anomaly_at_start <= 360.0 };
END_ENTITY;
```

```
class TAS_kepler_parameter_set(ExpressEntity):
    _attr_list=[
        ['semi_major_axis', 'NRF_length_measure'],
        ['eccentricity', 'REAL'],
        ['inclination', 'NRF_plane_angle_measure'],
        ['right_ascension_of_ascending_node', 'NRF_plane_angle_measure'],
        ['argument_of_periapsis', 'NRF_plane_angle_measure'],
        ['true_anomaly_at_start', 'NRF_plane_angle_measure']]
    _attr_id_maxlen=33

    def __init__(self,
        semi_major_axis                   = None,  # NRF_length_measure
        eccentricity                      = None,  # REAL
        inclination                       = None,  # NRF_plane_angle_measure
        right_ascension_of_ascending_node = None,  # NRF_plane_angle_measure
        argument_of_periapsis             = None,  # NRF_plane_angle_measure
        true_anomaly_at_start             = None): # NRF_plane_angle_measure

        ExpressEntity.__init__(self)

        assert _istype_NRF_length_measure(semi_major_axis)
        assert _istype_REAL(eccentricity)
        assert _istype_NRF_plane_angle_measure(inclination)
        assert _istype_NRF_plane_angle_measure(right_ascension_of_ascending_node)
        assert _istype_NRF_plane_angle_measure(argument_of_periapsis)
        assert _istype_NRF_plane_angle_measure(true_anomaly_at_start)

        self.semi_major_axis = semi_major_axis
        self.eccentricity = eccentricity
        self.inclination = inclination
        self.right_ascension_of_ascending_node = right_ascension_of_ascending_node
        self.argument_of_periapsis = argument_of_periapsis
        self.true_anomaly_at_start = true_anomaly_at_start

    def set_semi_major_axis(self, semi_major_axis):
        assert _istype_NRF_length_measure(semi_major_axis)
        self.semi_major_axis = semi_major_axis
        self.compute_derived_attributes()

    def get_semi_major_axis(self):
        return self.semi_major_axis
```


PyEXPRESS automatic generation



- Complete Open Source code of new STEP-TAS/NRF C++ API, including STEP-21 write/read
  - automatically generated from EXPRESS schema
- Validated on :
  - Windows NT4/2000
  - Silicon Graphics /Irix 6
  - SUN/Solaris 8

New STEP-TAS/NRF C++ API Example

```
ENTITY TAS_triangle
SUBTYPE OF
(primitive_bounded_surface);
p1 : geometric_construction_point;
p2 : geometric_construction_point;
p3 : geometric_construction_point;
END_ENTITY;
```

```
class  Tas_triangle : public  Tas_primitive_bounded_surface
{
public:
//construction destruction
Tas_triangle();
~Tas_triangle();
//attributes
Tas_geometric_construction_point* get_p1() const;
void set_p1(const Tas_geometric_construction_point *& p1)
throw (StepException);
Tas_geometric_construction_point * get_p2() const;
void set_p2(const Tas_geometric_construction_point *& p2)
throw (StepException);
Tas_geometric_construction_point * get_p3() const;
void set_p3(const Tas_geometric_construction_point *& p3)
throw (StepException);
…
```

SIMULOG

GRAITEC

Updates to NRF and TAS protocols (1)

- Removed AIM and mapping table, focussed on robust ARM
  - Interoperability with AP203 was not achieved in practice
  - Better do an executable AP203/TAS converter (retained mapping table for this)
  - Cost of full AIM implementation, verification and maintenance too high
- Major clean-up and replacement of unclear terminology
  - Resolved many issues collected over the years
  - Includes artificial constructs in ARM from original AIM/GR mapping
- Changed TAS navigational structure from bottom-up to top-down
  - Much easier / more natural to use in OO repository API
- Revalidated relationships for TAS geometry, meshing, thermal-radiative faces and made data model more consistent

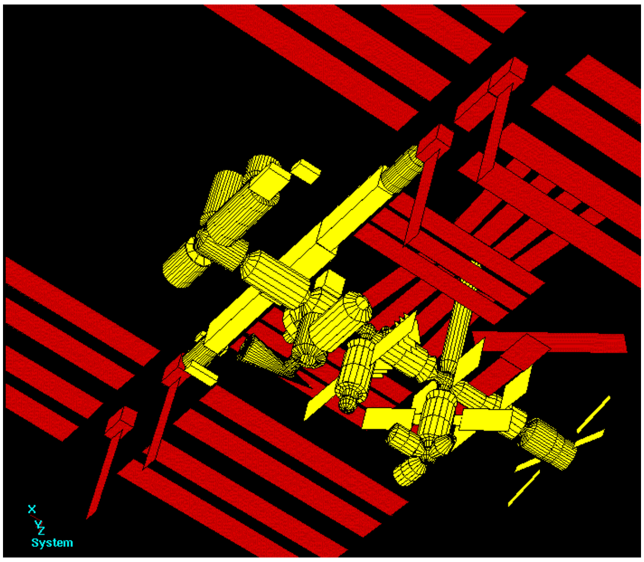
Updates to NRF and TAS protocols (2)

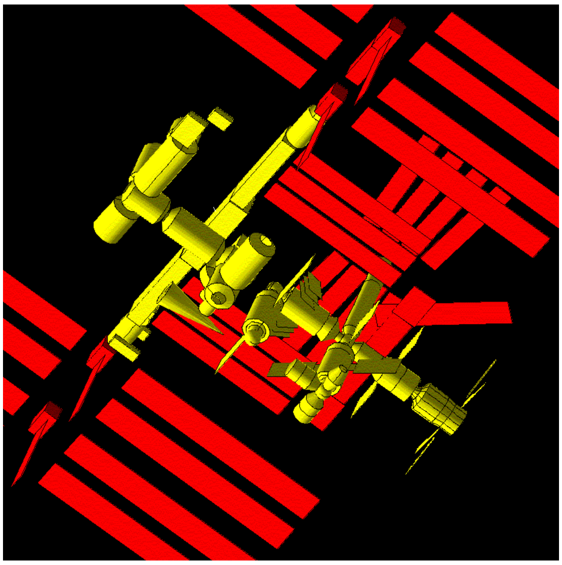
- Updated NRF definitions for 'datacube', quantities and properties
  - Permitted all permutations of ordering (item, quantity, state)
  - Added a dedicated datacube for material properties
- Started to move protocol documents from MS Word to XHTML
- Revalidated all WHERE and RULE constraints
- Made all INVERSE attribute definitions consistent
- Consequence is that new STEP-TAS (ARM) Part 21 files are not compatible with previous STEP-TAS (AIM) Part 21 files
  - Not a serious problem since STEP-TAS was not yet really in industrial use
  - Last chance for this kind of updates

Current TASverter status

- Started in October 2002; 4th release made per 10 Oct 2003
  - Self-contained Windows, Solaris, Linux, Irix executables
    - No need to install Python
  - Free download from http://www.estec.esa.int/thermal/tools/tasverter.html
  - THERMICA .VIF and .SYSBAS readers/writers
  - ESARAD .erg reader/writer
  - STEP-TAS Part 21 reader/writer
  - Configuration controlled testsuite with unit and large model testcases, including fully automated run scripts for verification and regression testing
- CIGAL-2 reader/writer in progress
  - By Alcatel Space + OpenCascade (with some assistance from ESTEC)

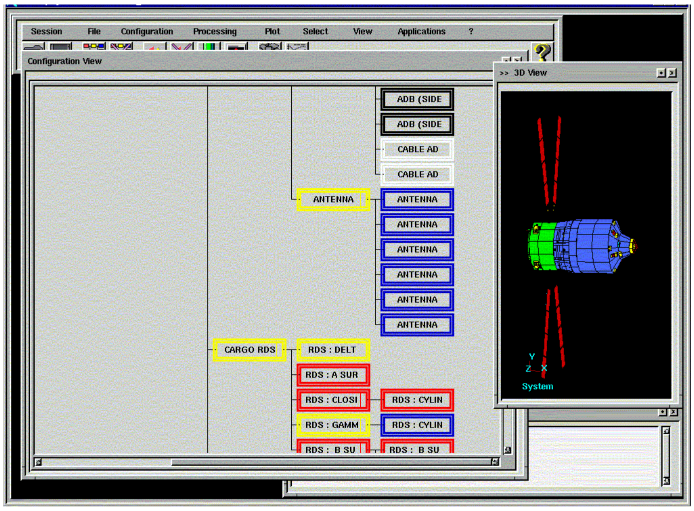
TASverter example 1: ISS_cold THERMICA to ESARAD

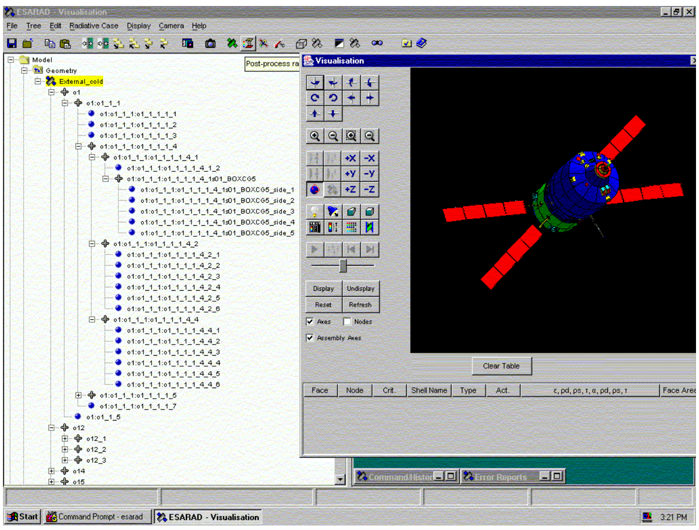




711 thermal-radiative surfaces, converted in less than 15 seconds.

TASverter example 2: ATV THERMICA to ESARAD





1700 thermal-radiative surfaces, converted in less than 25 seconds.

Model hierarchy and coordinate transformations fully retained.

TASverter example 2: ATV THERMICA to ESARAD

```
<1,1,1,1,4,4,2>    ANTENNA LAT MAIN BODY
$INFO        COLOUR=BLUE
$C_PROPERTY
     C_COATING=PSG_120_FD_cold
$TSHAPE     CYLINDER P1=(        .0,       .0,    -4.380) &
                     P2=(        .0,       .0,    -4.400) &
                     P3=(    0.155,        .0,    -4.380) &
                     DIAM=0.154
            MESH     NODE=(1,1) ELEM=(1,1) SIDE=POS
$THERM      NAME=(9966)
$AXIS       TRAX=0.04  TRAY=-0.333

<1,1,1,1,4,4,3>    ANTENNA UPP MAIN BODY
$INFO        COLOUR=BLUE
$C_PROPERTY
     C_COATING=PSG_120_FD_cold
$TSHAPE     DISC     P1=(        .0,       .0,    -4.400) &
                     P2=(        .0,       .0,    -4.480) &
                     P3=(    0.155,        .0,    -4.400) &
                     DIAM1=0.154  DIAM2=0.045
            MESH     NODE=(1,1) ELEM=(1,1) SIDE=POS
$THERM      NAME=(9965)
$AXIS       TRAX=0.04  TRAY=-0.333
```

Original THERMICA .SYSBAS

```
SHELL o1_1_1_1_4_4_2s01;
o1_1_1_1_4_4_2s01 = SHELL_SCS_CYLINDER(
    label   = "ANTENNA LAT MAIN BODY <1,1,1,1,4,4,2>",
    radius  =  7.700000000000000e-002,
    hmax    =  2.000000000000005e-002,
    hmin    =  0.000000000000000e+000,
    angmax  =  3.600000000000000e+002,
    angmin  =  0.000000000000000e+000,
    side1   = "ACTIVE",
    side2   = "INACTIVE",
    opt1    = PSG_120_FD_cold,
    nbase1  = 9966,
    ndelta1 = 1,
    colour1 = "BLUE",
    colour2 = "BLUE",
    nodes1  = 1,
    nodes2  = 1,
    ratio1  = 1.000000,
    ratio2  = 1.000000,
    thick   = 0.0);

o1_1_1_1_4_4_2s01 =
    ROTATE (object_name = o1_1_1_1_4_4_2s01,
            x_ang =  1.800000000000000e+002,
            y_ang =  0.000000000000000e+000,
            z_ang =  0.000000000000000e+000);

o1_1_1_1_4_4_2s01 =
    TRANSLATE (object_name = o1_1_1_1_4_4_2s01,
               x_dist =  0.000000000000000e+000,
               y_dist =  0.000000000000000e+000,
               z_dist = -4.380000000000000e+000);

SHELL o1_1_1_1_4_4_2;
o1_1_1_1_4_4_2 =
         (o1_1_1_1_4_4_2s01);

o1_1_1_1_4_4_2 =
    TRANSLATE (object_name = o1_1_1_1_4_4_2,
               x_dist =  4.000000000000000e-002,
```

Generated ESARAD .erg

Verification Test Suite

- More than 200 unit tests
  - Documented as a website
    - with naming convention for subdirectories per testcase
    - actual and reference results for regression testing
  - Fully scripted to run and be diff-ed automatically
- Real model tests
  - ATV model
  - METOP C/D full spacecraft model
  - ISS model
  - Herschel and Planck full spacecraft models

Short term priorities

- STEP-TAS Verification Tool (in progress)
  - Semi-automatic verification of STEP-TAS Part 21 files
  - 3D visualisation for visual inspection
  - Extraction of key characteristics of exchanged model
    - Total surface area, surface area per aggregation level
    - Overall geometric envelop
    - Materials and material properties
    - Number of faces, surfaces
    - Number of thermal lumped parameter nodes, node ranges
  - Goal is to enable ESA to verify (certify) correctness of STEP-TAS datasets produced by different converters and to isolate cause of possible errors
- Up-to-date STEP-NRF and STEP-TAS documentation (in progress)
  - Including converter implementation examples

Outlook (short term)

- Submit STEP-NRF and STEP-TAS protocols to ISO TC 184 / SC 4 for ballot as ISO PAS or TS
- Publish schemas and tools/toolkits in open source (harmonisation)
  - pyExpress and TASverter
  - develop full capability pyExpress with University of Manchester
  - STEP-TAS and STEP-NRF schemas, Python and C++ libraries
- Provide and verify pyExpress generated C++ libraries for STEP-TAS
  - If requested by thermal analysis tool vendors
- ESA development STEP-SPE (Space Environmental Analysis)
  - Contract awarded, real work starting 27-Oct-2003
  - Extends TAS for micro-meteorites/debris, contamination, atomox, radiation …

Outlook (longer term)

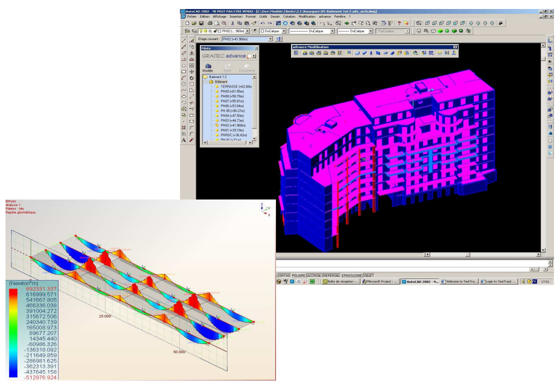
- Promote implementation STEP-TAS in US, Canadian tools
  - TMG, Thermal Desktop, TSS, ...
- Possibly extend TASverter with new reader/writer plug-ins
  - Transform existing TRASYS/ESARAD converter to TRASYS reader/writer
  - Transform existing SINDA85/ESATAN converter to SINDA85 reader and ESATAN writer
  - Add more SINDA/ESATAN-like readers / writers
  - Add AP203 reader/writer, with primitive shape recognition capability
    - Can be derived from existing AP203/ESARAD converter plus old TAS AIM mapping; possibly add facetting of remaining NURBS surfaces
  - Construct HDF5 mapping and libraries for STEP-NRF

Related: STEP in the Building Industry

- Characteristic of Building Industry
  - A lot of independent large constructors and SME involved in one (big) building
  - Building becoming more and more complex
    - Structural, thermal, acoustic, electricity…
    - Hard regulation
  - CAD : Very large objects models

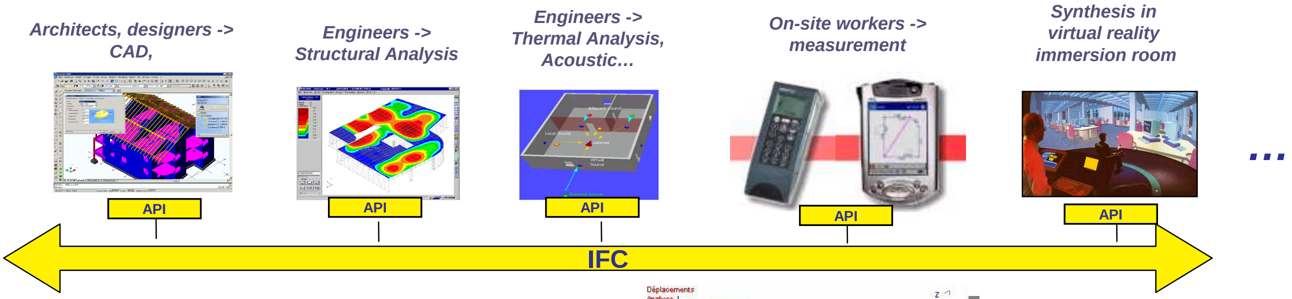
- STEP for building = IFC (Industry Foundation Classes)
  - Based on EXPRESS and STEP-21
  - Building dedicated integrated model :
    - architecture, materials, structural, thermal, HVAC…

- SIMULOG partnership, for STEP, CAD, Post-pro with GRAITEC
  - 3rd European software editor in the building industry
    - **+3500** customers
    - **+8000** licences CAD/analysis tools
    - **+100 000** buildings designed

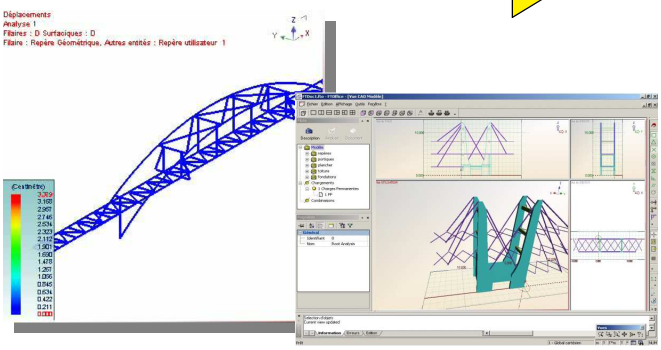


PyExpress IFC-API (C++) used in 2 major projects

- Building Design Chain (CSTB, Mediaconstruct)



- IFC-BRIDGE (SETRA)



Acknowledgements

- ESTEC team: Hans Peter de Koning, Simon Appel, David Alsina
- Contractor Simulog (France): Olivier Pailles, Arnaud Klinger
- Subcontractor GRAITEC (France): Eric Lebègue and co-workers
- ESARAD / ALSTOM Power (UK): Julian Thomas, David Scurrah
- THERMICA / Astrium SAS (France): Marc Jacquiau

Appendix Z: THER-CFD: a THERMICA/GAMBIT gateway

THER-CFD:
a
THERMICA/GAMBIT
gateway

F. Boursier
EADS-SPACE

THER-CFD :

a THERMICA/GAMBIT Gateway

F. BOURSIER

CONTENTS

EADS SPACE TRANSPORTATION

PURPOSE

THER-CFD is a Fortran/Unix Software developed by EADS SPACE Transportation in the frame of the Launch Thermal Analyses

The aim is to build quickly a geometry usable with GAMBIT meshing software based on a geometry available in THERMICA format

17th European Thermal & ECLS Software Workshop - Noordwijk, October 21-22, 2003

EADS SPACE TRANSPORTATION

LAUNCH THERMAL ANALYSIS

OBJECTIVES :

to predict the thermal behaviour of the payload during ground and flight phases

☛ To check the thermal compatibility of the spacecraft with the launch vehicle

EADS SPACE TRANSPORTATION

THERMAL ANALYSIS FLOW

SATELLITE

THERMAL MODEL DELIVERY

TEST RUNS

VALIDATION OF
DATA TRANSFER AND METHOD

MODEL INTEGRATION

- CAPACITANCES
- CONDUCTANCES
- RADIATIVE COUPLINGS
- CONVECTIVE COUPLINGS

ARIANE 5
UPPER SECTION

COMPUTATIONS
PRELAUNCH AND LAUNCH PHASES

MISSION CONDITIONS

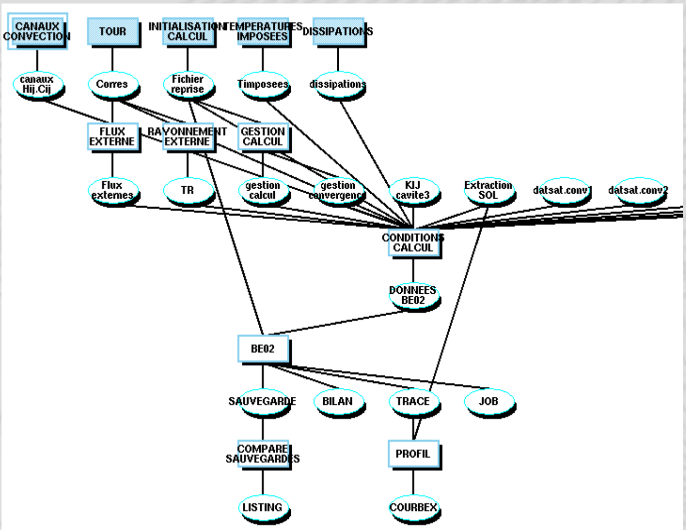
- LAUNCH TIME
- GROUND EXT. TEMPERATURE
- AEROTHERMAL FLUXES
- SPACE RADIATION

TEMPERATURE PREDICTION

COMPARISON
PREDICTIONS/REQUIREMENTS

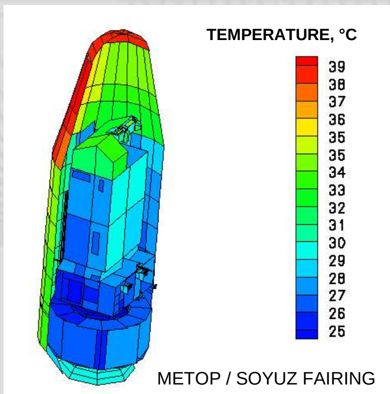
EADS SPACE TRANSPORTATION

SOFTWARES



TEMPERATURE SOLVER : **SISTHER**

(Nodal representation)



AUTOMATIC CALCULATION CHAIN : **LOGIAT**

(about 150 elementary tasks)

EADS SPACE TRANSPORTATION

SOFTWARES

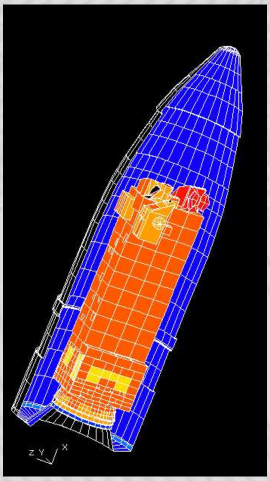
AIR FLOW CALCULATION : **GAMBIT / FLUENT**

- to refine convective coefficients determination
- to check that air velocity stays below maximal allowed levels

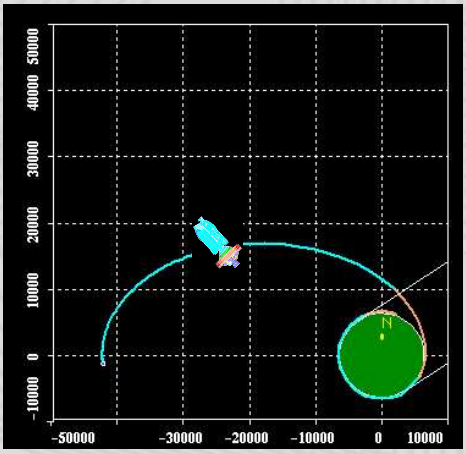
EADS SPACE TRANSPORTATION

SOFTWARES

RADIATION : **THERMICA**



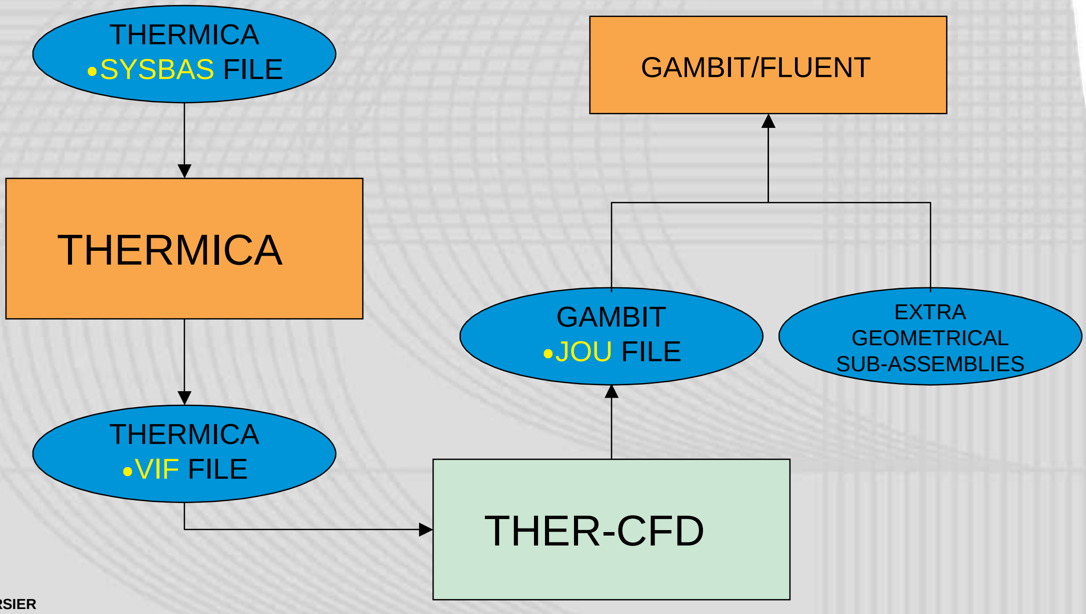
Radiative couplings inside a closed cavity



External heat fluxes during flight

EADS SPACE TRANSPORTATION

From THERMICA to GAMBIT



EADS SPACE TRANSPORTATION

From THERMICA to GAMBIT

```
<1,1,2,1> DISQUE EPAISSEUR PROTECTION AC - 26001
     4 26001     0     1     4    -1.000000         -1
   .00000E+00   .00000E+00   .56470E+01   .00000E+00   .00000E+00   .57470E+01
   .70711E+00  -.70711E+00   .56470E+01   .00000E+00   .00000E+00   .00000E+00
   .52140E+01   .51940E+01   .00000E+00   .00000E+00   .00000E+00   .36000E+03
   .10000E+01   .00000E+00   .00000E+00   .00000E+00   .10000E+01   .00000E+00
.00000E+00   .00000E+00
```

THERMICA .VIF FILE

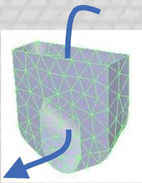
```
    vertex create « p1 » coordinates 0 0 .56470E+01
    vertex create « p2 » coordinates 0 0 .57470E+01
    vertex create « p3 » coordinates .70711E+00 -.70711E+00 .56470E+01
    coordinate create cartesian vertices « p1 » « p2 » « p3 »
    vertex copy « p1 » to « vertex.4 »
    vertex move « vertex.4 » offset 2.607 0 0
    vertex copy « p1 » to « vertex.5 »
    vertex move « vertex.5 » offset 0 2.607  0
    edge create « cerc1 » center2points « p1 » « vertex.4 » « vertex.5 »
circle
    face create « disque1 » wireframe « cerc1 » real
    vertex copy « p1 » to « vertex.6 »
    vertex move « vertex.6 » offset 0 2597 0
    vertex copy « p1 » to « vertex.7 »
    vertex move « vertex.7 » offset 2.597 0 0
    edge create « cerc2 » center2points « p1 » « vertex.7 » « vertex.6 »
circle
    face create « disque2 » wireframe « cerc2 » real
```

GAMBIT .JOU FILE

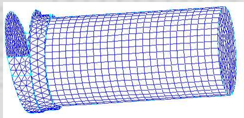
EADS SPACE TRANSPORTATION

From THERMICA to GAMBIT

EXTRA GEOMETRIES ADDED WITH GAMBIT



GAMBIT



GAMBIT

Acoustic protection

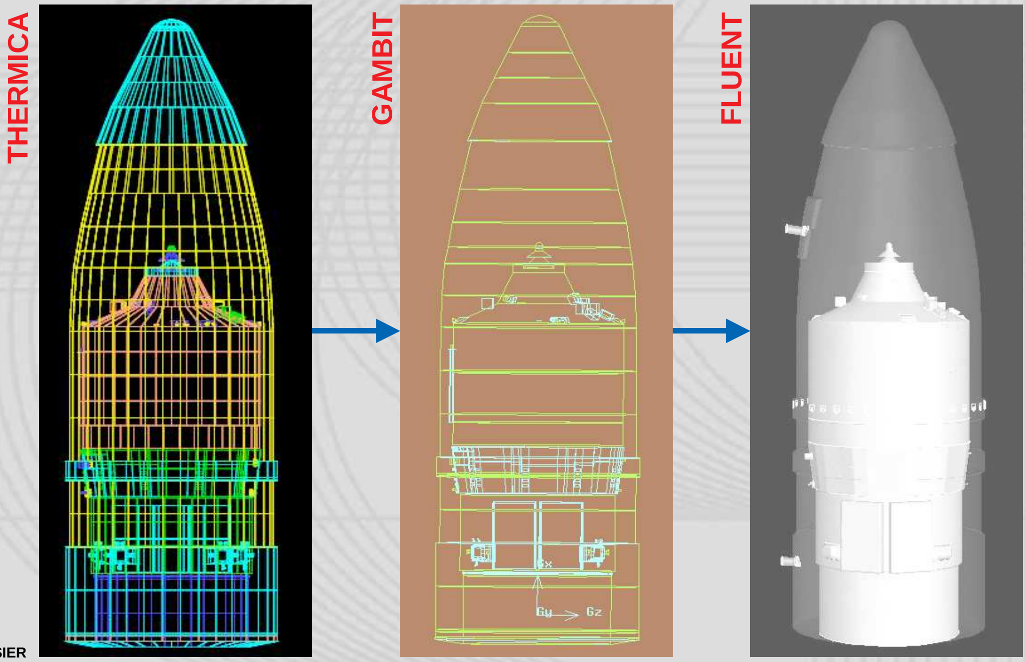
Venting hole

Air inlet deflector

17th European Thermal & ECLS Software Workshop - Noordwijk, October 21-22, 2003

EADS SPACE TRANSPORTATION

From THERMICA to GAMBIT



ATV ARIANE 5.mpeg

EADS SPACE TRANSPORTATION

CONCLUSION

THER-CFD ALLOWS A TRANSITION FROM THERMICA TO GAMBIT WHICH LEADS :

- To use a more acurate geometrical definition of the domains considered
- To lower the cost of CFD calculations thanks to shorter processes

Appendix AA:Highlights in Thermal Engineering at CGS

Highlights in Thermal Engineering at CGS:

Thermal Stability in the frequency domain
and
THERMAL DESKTOP/ESARAD translation tools

M. Molina
Carlo Gavazzi Space

Highlights in thermal engineering at CGS:

1) Thermal Stability in the frequency domain

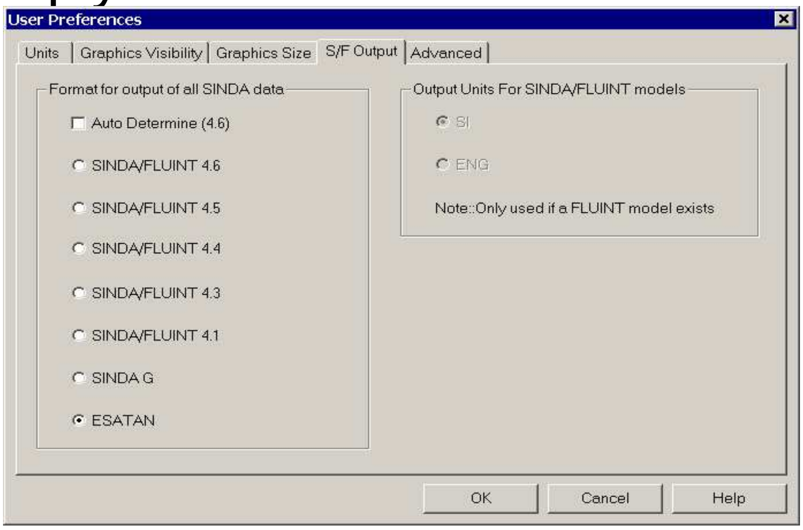
2) THERMAL DESKTOP® translation tools

Marco Molina and Christian Vettore
Mechanical and Thermal Engineering Department
mmolina@cgspace.it
Carlo Gavazzi Space SpA

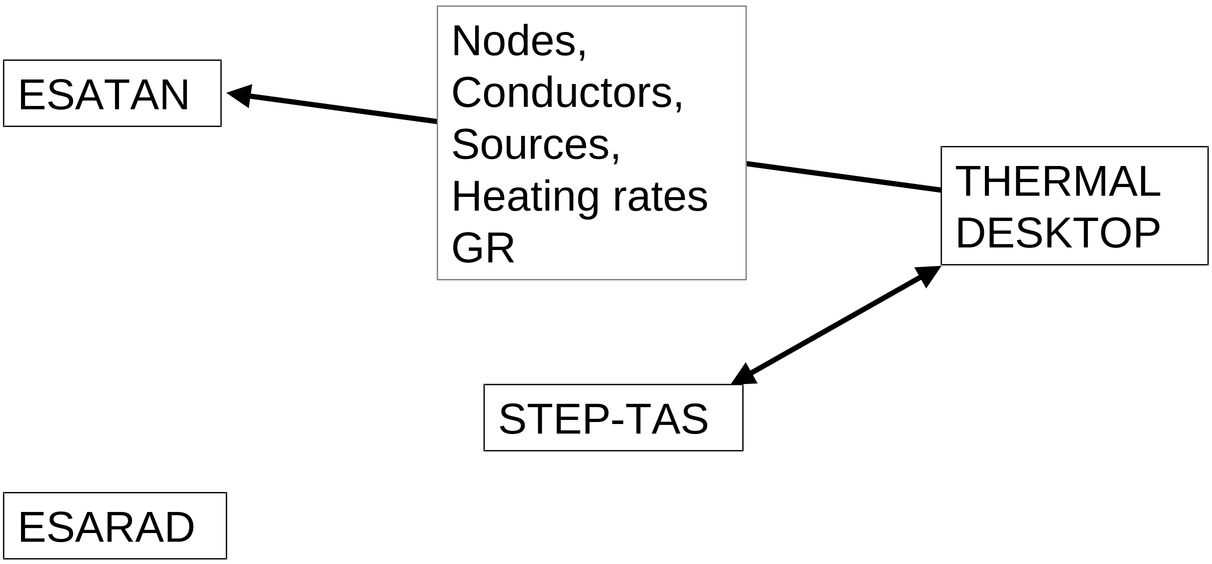
2) ESARAD (via STEP-TAS)/ESATAN translation from Thermal Desktop® 4.6

Enabling ESATAN Output

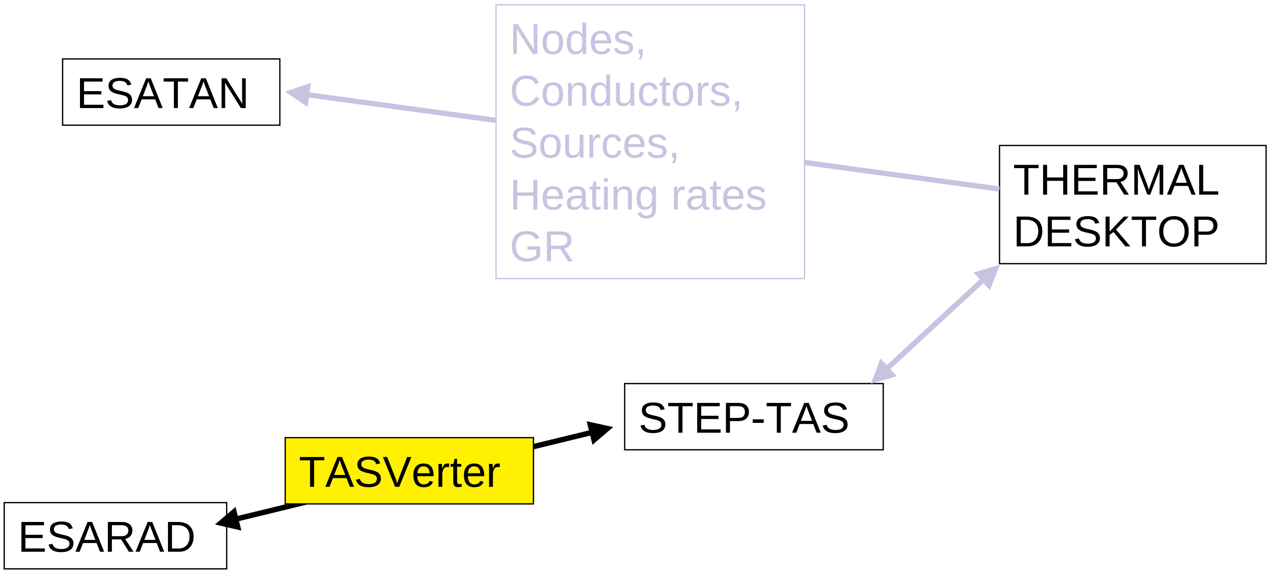
- Simply turn on the ESATAN button



Thermal Desktop® 4.6 features



How to fill the gap



Thermal Desktop ® Radiation Calculations

- Geometries built in Thermal Desktop are exported in STEP-TAS format
  - Current limitations
    - all geometry must be placed in a single submodel
- STEP-TAS can be imported into Thermal Desktop
- RADK and Heating Rate calculations are output in ESATAN format

Sample Output (RADKS)

```
C     SINDA/FLUINT data created with Thermal Desktop 4.6
C     Generated on Fri Oct 17 08:41:04 2003
C     Generated from database BASE-RcOptics.rck
C     Bij Cutoff factor:      0.0010000
C     Conductor units are: m^2
C
C    radk format:
C    node_1     node_2     Area*e*Bij $  Bij   Bji
C
          GR(      1,     999)=       0.50000;  $      1.0000
          GR(      2,     999)=       0.50000;  $      1.0000
          GR(      3,     999)=       0.50000;  $      1.0000
          GR(      4,     999)=       0.50000;  $      1.0000
C
C Summary data for nodes with Bij sums < 1.0000 or > 1.0000
C BijSum always contains Bij Self
C
C         node         area          rays    emiss      Bij     Bij     Bij   Weighted
C                                                       sum    self   inact   % Error
C         MAIN.1     0.50000       5000    1.0000    1.0000                   0.0
C         MAIN.2     0.50000       5000    1.0000    1.0000                   0.0
C         MAIN.3     0.50000       5000    1.0000    1.0000                   0.0
C         MAIN.4     0.50000       5000    1.0000    1.0000                   0.0
```


Carlo Gavazzi Space S.p.A.

Sample Output (Heating Rates)

```
#
    GENMOR
#
    IF(NSOL.GT.1.0)THEN
       QS:1=INTCYC(TIMEM,ARTIME,ARSAMAIN1,1,5676.98D0,0.0D0)
       QS:2=INTCYC(TIMEM,ARTIME,ARSAMAIN2,1,5676.98D0,0.0D0)
       QS:3=INTCYC(TIMEM,ARTIME,ARSAMAIN3,1,5676.98D0,0.0D0)
       QS:4=INTCYC(TIMEM,ARTIME,ARSAMAIN4,1,5676.98D0,0.0D0)
    ELSE
       QS:1=193.242
       QS:2=192.891
       QS:3=191.811
       QS:4=192.912
    ENDIF
```

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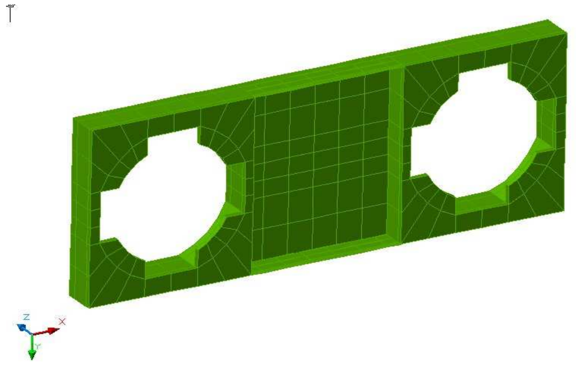
Sample Output (Heating Rates)

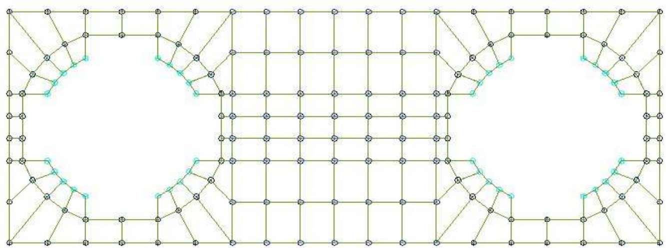
```
# Time Array
 ARTIME(17)=       0.0,4.730820e+002,9.461640e+002,1.419250e+003
        1.764227e+003,1.767633e+003,1.892330e+003,2.365410e+003
        2.838490e+003,3.311570e+003,3.784650e+003,3.909347e+003
        3.912753e+003,4.257740e+003,4.730820e+003,5.203900e+003
        5.676980e+003;
#
# solar albedo planetshine - MAIN.1 Area = 0.500000 Avg = 112.887535 31.783997 48.570499
 ARSAMAIN1(17)=4.880749e+002,4.282346e+002,2.696814e+002,5.125848e+001
          1.733135e+002,4.857050e+001,4.857050e+001,4.857050e+001
          4.857050e+001,4.857050e+001,4.857050e+001,4.857050e+001
          1.734149e+002,5.122900e+001,2.669101e+002,4.294877e+002
          4.880749e+002;
#
# solar albedo planetshine - MAIN.2 Area = 0.500000 Avg = 113.716866 31.922405 47.252102
 ARSAMAIN2(17)=4.929644e+002,4.238430e+002,2.660976e+002,4.994052e+001
          1.747323e+002,4.725210e+001,4.725210e+001,4.725210e+001
          4.725210e+001,4.725210e+001,4.725210e+001,4.725210e+001
          1.762022e+002,5.012827e+001,2.717307e+002,4.300657e+002
          4.929644e+002;

…. More Arrays…
```


ESATAN

- Node, Conductor, and Heatloads are output in ESATAN format





ESATAN Sample Output (from Thermal Desktop® 4.6)

```
#   SINDA Data generated with Thermal Desktop 4.6
#   Generated on Fri Oct 17 08:35:37 2003
#   TDUNITS,  Energy  =  J
#   TDUNITS,  Time    =  sec
#   TDUNITS,  Temp    =  K
#   TDUNITS,  Mass    =  kg
#   TDUNITS,  Length  =  m
#   TDUNITS,  Orbit   =  km
#   TDUNITS,  Pressure =  Pa
$NODES
 D1='MAIN #1', T=293.15, C=INTRP1(T1,AR2,1)*0.00025;
 D2='MAIN #2', T=293.15, C=INTRP1(T2,AR2,1)*0.00025;
 D3='MAIN #3', T=293.15, C=INTRP1(T3,AR2,1)*0.00025;
 D4='MAIN #4', T=293.15, C=INTRP1(T4,AR2,1)*0.00025;
 B999='MAIN #999', T=0.;
```

```
$ARRAYS
# DEFAULT.k
 AR1(10)=
   0., 1.
   100., 5.
   200., 7.
   300., 10.
   1000., 11.
# DEFAULT.rhocp
 AR2(8)=   0., 100.

   100., 105.
   200., 150.
   500., 175.
$CONDUCTORS
 GL(1,2)=INTRP1( (T1+T2)*.5, AR1,1)*0.001;
 GL(1,3)=INTRP1( (T1+T3)*.5, AR1,1)*0.001;
 GL(2,4)=INTRP1( (T2+T4)*.5, AR1,1)*0.001;
 GL(3,4)=INTRP1( (T3+T4)*.5, AR1,1)*0.001;
$VARIABLES1
```


Conclusions

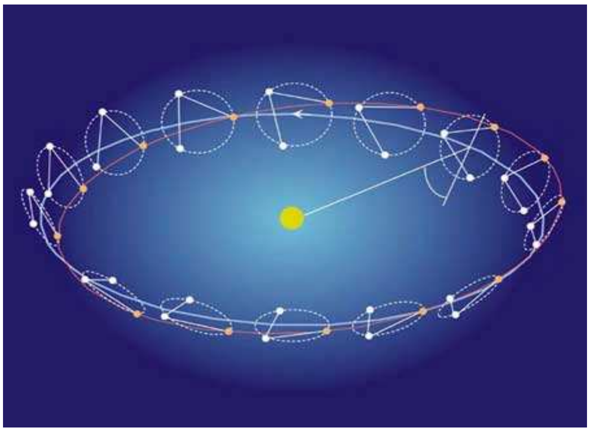
- Thermal Desktop 4.6 translates model+sources+heating rates into ESATAN
- Translation to STEP-TAS under testing
- Open point
  - How to 'certify' the compatibility with STEP-TAS?
- Important applications
  - ISS (NASA standard required)
  - Large Space Simulator (@ESTEC): GMM and TMM models now only available in ESATAN/ESARAD.

1) Thermal Stability in the frequency domain

Marco Molina, Federico Pamio,
Alberto Franzoso, Christian Vettore

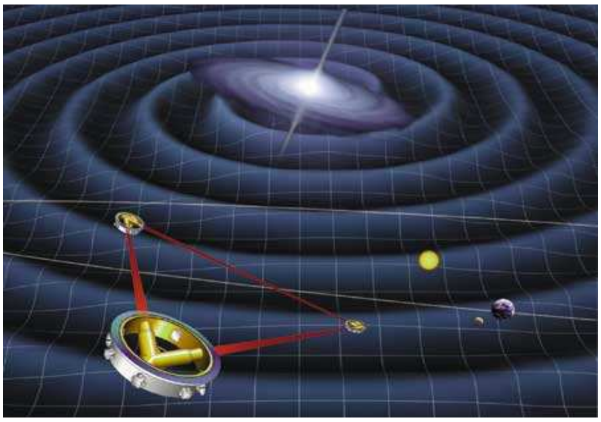
INTRODUCTION

- LISA (Light Interferometer Space Antenna)
- Constellation of 3 S/C, Heliocentric orbit, average distance $5*10^6$ km
- Scientific purpose: Gravitational Wave Detector
  - 3 couples of free-floating test masses to detect differential displacements (of the order of 10^{-12} m, 1/10 the atomic size!)
  - Laser beams bouncing between test masses, to build up a 2-3 arms interferometer



SCIENTIFIC GOAL

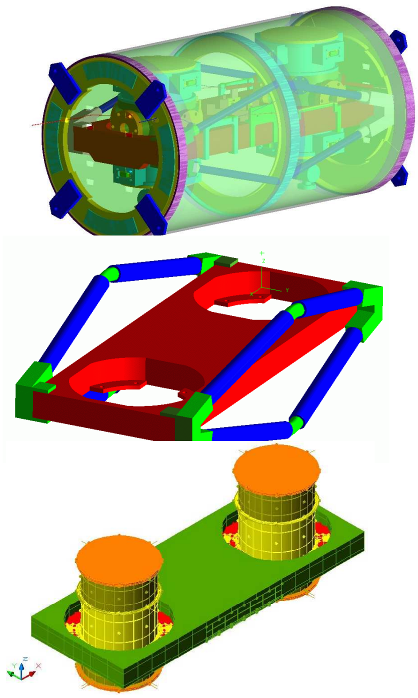
- LISA detects Gravitational Waves, Space-time distortions due to:
- Black Holes
- Supernovae
- Binary massive systems (e.g. Neutron Stars)



- A chance to test General Relativity predictions on the most energetic events in Universe

Detector Description (1)

- The scientific core of each satellite is contained in a Thermal Shield (TS), to lower the thermal noise
- Inside the TS an Optical Bench (OB) is located, hosting Laser beam optics
- A couple of Inertial Sensors (IS) lies on the OB. Each IS is a ultra-vacuum enclosure for the Test Mass, the Caging Mechanism (CM) and the Electrode Housing (EH), located around the TM.



Detector Description (2)

- Inside the Inertial Sensor:
- The Caging Mechanism
  - To block the Test mass during non-scientific phases
- The Electrode housing
  - To allow re-positioning
- The Test Mass
  - Free floating, the “mirror” at the interferometer arm ends

Thermal Analysis requirements

- Thermally driven changes of the distances on the OB will degrade the measurement accuracy if they differentially affect the two arms of the laser interferometer

- LISA detects GW within a defined frequency range => **temperature requirements given in the FREQUENCY domain**

Physical quantities DEFINITION

- TSD = Temperature Spectral Density = [K^2/Hz]

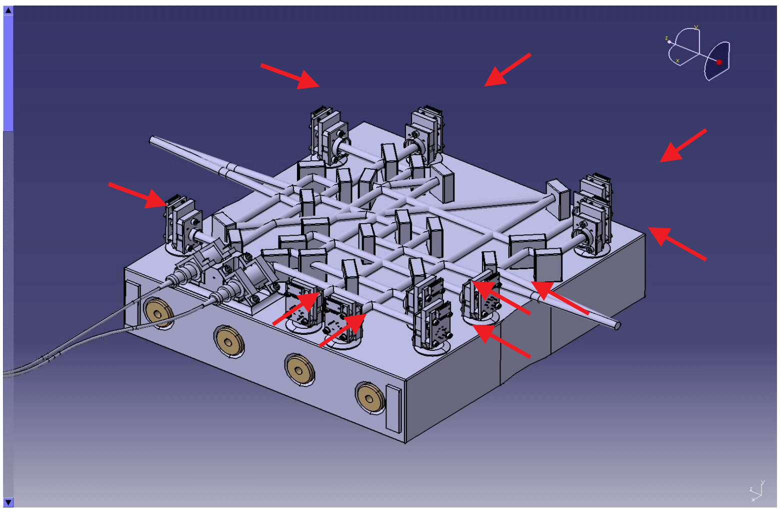
$$TSD \equiv \lim_{\Delta f \to 0} \frac{T^2}{\Delta f}$$

- TPSD = (Thermal) Power Spectral Density = [W^2/Hz]

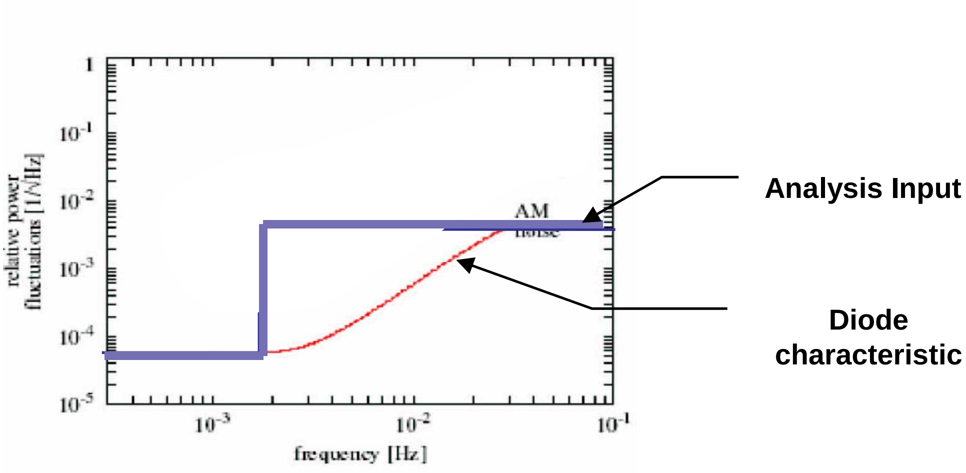
$$TPSD \equiv \lim_{\Delta f \to 0} \frac{Q^2}{\Delta f}$$

TPSD = (Thermal) Power Spectral Density Example

- Single Photo-diode (located on OB) av. dissipation : 1mW
- Overall av. dissipation power of 10mW throughout the OB



- Photo-diodes power fluctuation: two levels
  - DP/P = $4*10^{-3}$ [ ]/√Hz for frequencies ≥$1.8*10^{-3}$ Hz
  - DP/P = $6*10^{-5}$ [ ]/√Hz for frequencies <$1.8*10^{-3}$ Hz

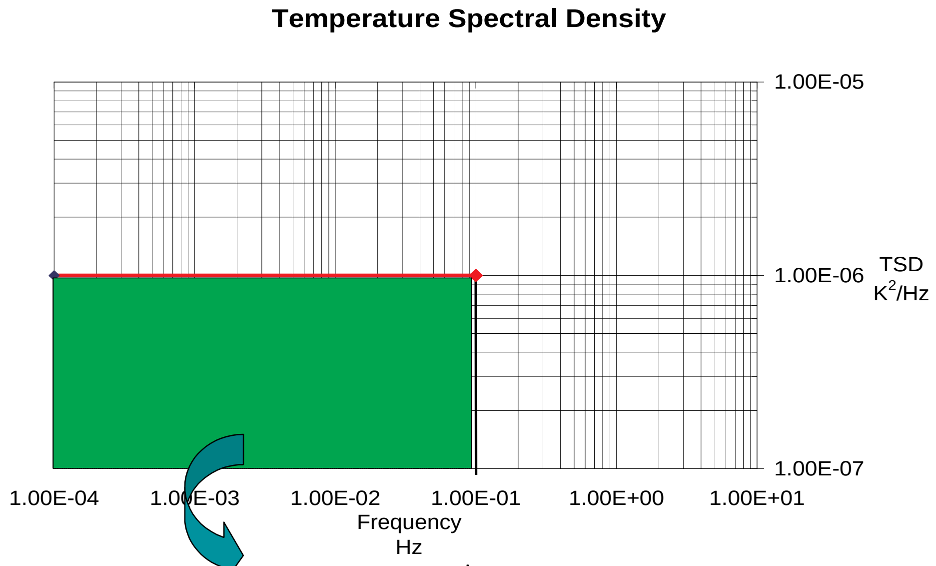


Once multiplied by the Power (W) and squared
this is really a (Thermal) “POWER” Spectral Density

Physical quantities DEFINITION

- T_{RMS} = Square root of the Area under the TSD vs. frequency curve
  - It is the root mean squared 1-sigma temperature fluctuation
    - For 68.3 % of the time, the temperature time history would have peaks no exceeding the 1-sigma temperature
    - For 99.7% of the time, the temperature time history would have peaks no exceeding the 3-sigma temperature

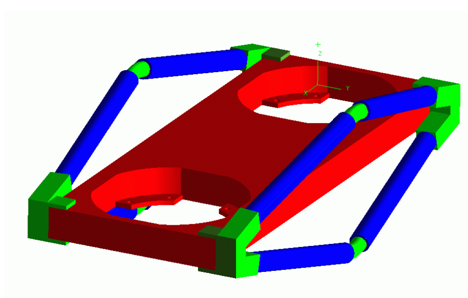
INPUT



$$T_{RMS}=\sqrt{A}=3.2\ E\text{-}5\ [K]$$

Optical Bench requirements

REQUIREMENTS	*REQ. VALUE*
OB temperature	20 ± 10°C
OB temperature stability	10^{-4} K/ $\sqrt{\text{Hz}}$
OB temperature gradient stability	10^{-4} K/ $\sqrt{\text{Hz}}$

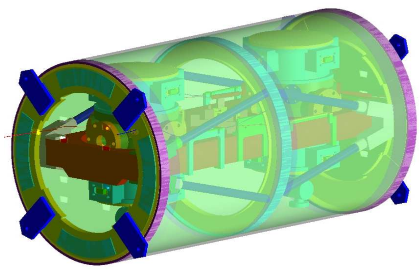


FREQUENCY RANGE:
10^{-1} ÷ 10^{-4} Hz

Boundary conditions for LTPA

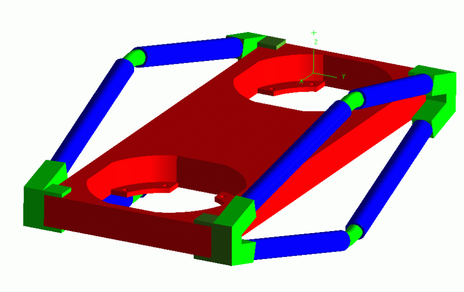
(LISA Technology Package Architecture)

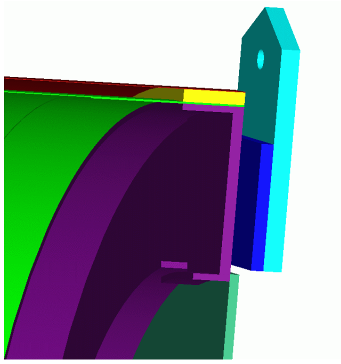
- As an input for the OB stability requirement study, temperature stability over the S/C interfaces of 10^{-3} K/√Hz was considered.
- First step: An aluminum thermal shield, made up of a cylinder with the internal and external surfaces goldized to damp the external temperature changes, was designed.



OB thermal insulation mechanical design

- The Optical bench assembly is mechanically fixed to the thermal shield by means of a system composed by pyroceram rods and titanium brackets
- An insulating washer has been foreseen under each titanium brackets attachment point; brackets are fixed to a C-shaped ring, and low emissivity coating was foreseen



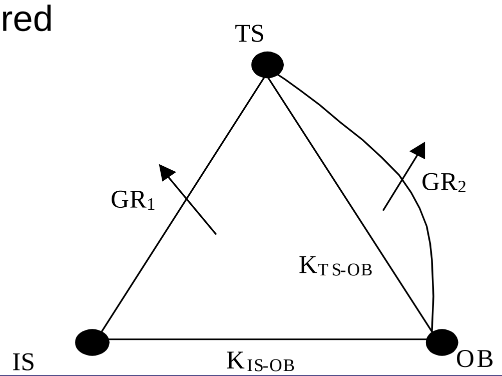


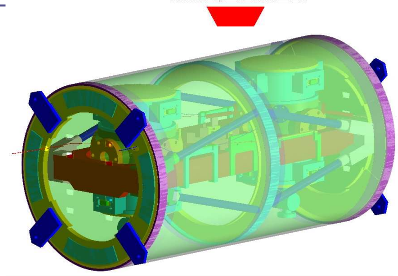
Thermal modelling steps

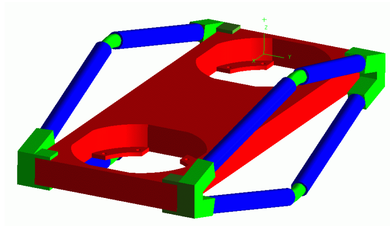
- PHASE 1: Simplified 3-nodes mathematical model
  - Test bed to get comfortable with frequency domain
  - Develop general metodology
- PHASE 2: Linearization of the 3-nodes system
  - Transfer function
  - Fast tuning
- PHASE 3: Detailed model
  - Refine and confirm preliminary results
  - Response to random boundary condition in the whole frequency range

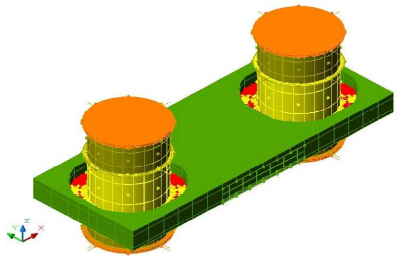
LTPA – Phase 1

- 3-nodes model: TS, IS, OB
- identify allowed conductive values provided by the OB structural supports, to satisfy the LTP thermal requirements
- provide a guideline to the structural design
- oscillating temperature was applied to the TS, no direct power introduction has been considered





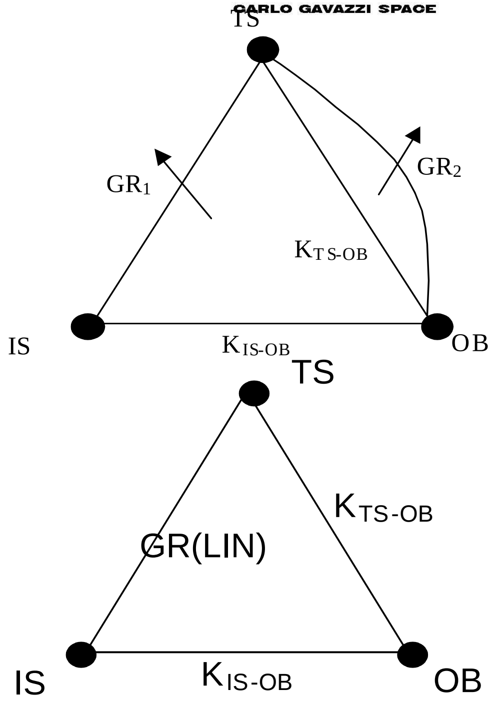




LTPA – Phase 2

Linearization of 3-nodes model

- Linearization => to use the analytic expression of the transfer function
- Linearized system:



$$\begin{cases} -k_{IS-OB}(\delta T_{OB}-\delta T_{IS})-k_{TS-OB}(\delta T_{OB}-\delta T_{S})= \\ \qquad = C_{OB}\partial\dfrac{\delta T_{OB}}{\partial t} \\ -k_{IS-OB}(\delta T_{IS}-\delta T_{OB})-\sigma A\varepsilon\left(4T_{IS\,eq}^{3}\delta T_{IS}-4T_{S\,eq}^{3}\delta T_{S}\right)= \\ \qquad = C_{IS}\partial\dfrac{\delta T_{IS}}{\partial t} \end{cases}$$

LTPA – Phase 2

- Linearization at equilibrium:
- TRANSFER FUNCTION

$$G_R=\frac{\Delta T_{IS}}{\Delta T_{TS}}=\frac{A_{IS}A_{TS}\varepsilon_{IS}\varepsilon_{TS}F_{IS-S}}{(1-\varepsilon_{IS})A_{TS}\varepsilon_{TS}F_{IS-S}+\varepsilon_{IS}\varepsilon_{TS}A_{TS}+(1-\varepsilon_{TS})A_{IS}\varepsilon_{IS}F_{IS-S}}$$

- Where: A_{IS}=IS external area
- A_{TS}=TS internal area
- ε_{IS}=IS emissivity
- ε_{TS}=TS emissivity
- F_{IS-TS}=IS-TS view factor

LTPA – Phase 2

- Requirement: attenuation of input temperature T_{TS} ($10^{-6}\ K^2/Hz$) on the output temperature T_{IS} ($10^{-8}\ K^2/Hz$), which is equivalent to require a transfer function of

$$G_{\max} = \frac{\Delta T_{IS}}{\Delta T_{TS}} = \frac{\sqrt{T_{RMS\ \ IS}}}{\sqrt{T_{RMS\ \ S}}} = \frac{10^{-4}\ K/\sqrt{Hz}}{10^{-3}\ K/\sqrt{Hz}} = 0.1$$

- Geometrical/optical/physical parameters can be adjusted accordingly

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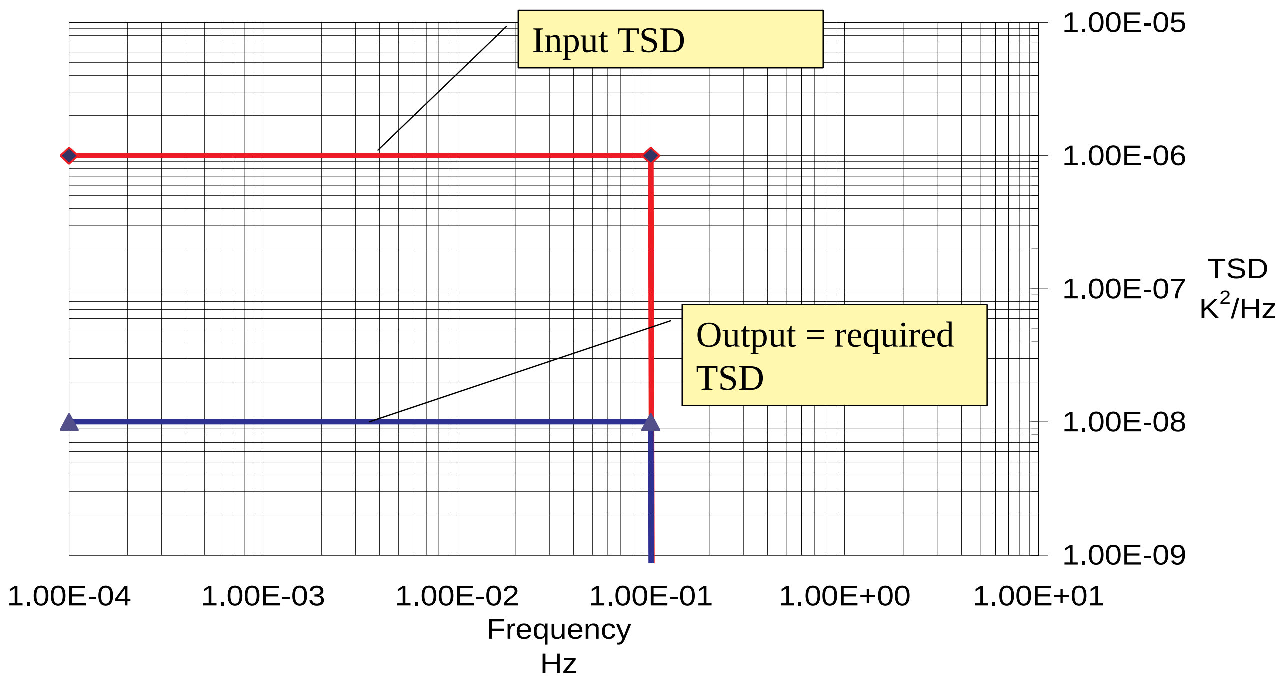
Temperature Spectral Density



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LTPA – Phase 2 results

- 3-nodes model: Applied boundary + transfer function

$$T_S = T_{S\,eq} + \Delta T sin(\omega_{TS} t) = 293 + 0.293 \sin(2\pi 10^{-4} t)$$

- Frequency of the sinusoid: 10^{-4} Hz (it is sufficient to verify the thermal requirement at the lower extreme of the relevant frequency band)

ATTENUATION FACTOR G		
	Radiative+linear	***Radiative only***
Optical bench	0,105398	0,09077
Inertial sensor top	0,105405	0,09091

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LTPA – Phase 2

- The frequency of the external perturbation was chosen to be the LOWEST in the frequency domain of interest
- The thermal models are LOW PASS FILTERS
- Once the requirements are met at the minimum frequency, then we are confident they will be respected at higher frequencies
- The three-nodes model system equation linearization led to an analytical transfer function explicitly dependent on the thermal parameters, allowing their quick tuning.

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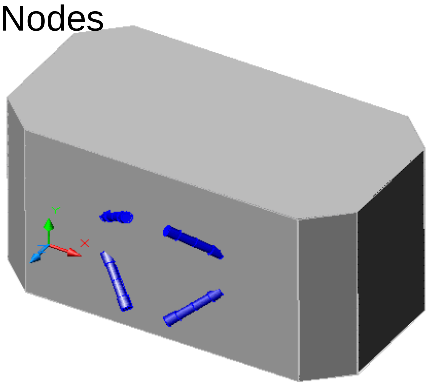
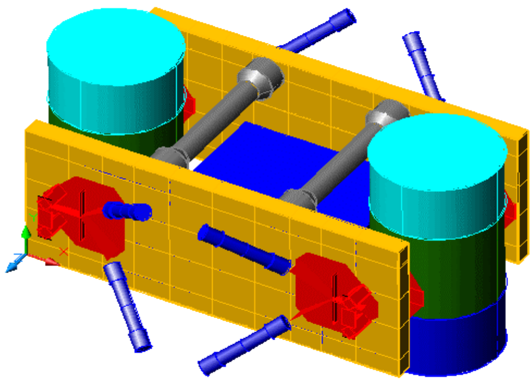
LTPA – Phase 3
Geometric model

MODEL FINAL DIMENSIONS:

• 51 Submodels

•2300 Nodes

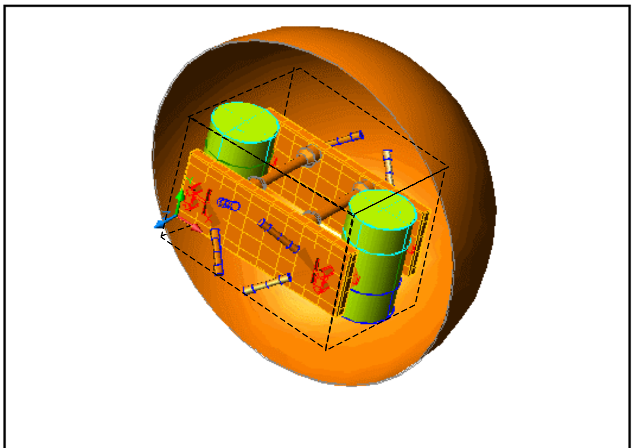




Interfaces definition (1/3)

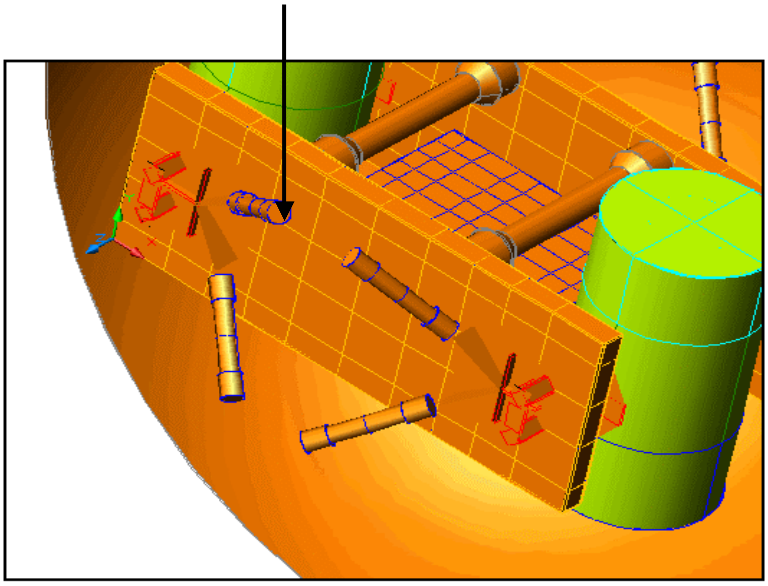
RADIATIVE INTERFACES : LTP has been wrapped by a sphere, simulating external environment

- LTP radiative environment (sphere) static T : 20°C +/- 10°C
- LTP radiative environment (sphere)
  TSD:10^{-6} K^2/Hz
- Sphere has been considered black painted



Interfaces definition (2/3)

CONDUCTIVE INTERFACES : Boundary temperatures have be assigned to the glass fiber struts end parts

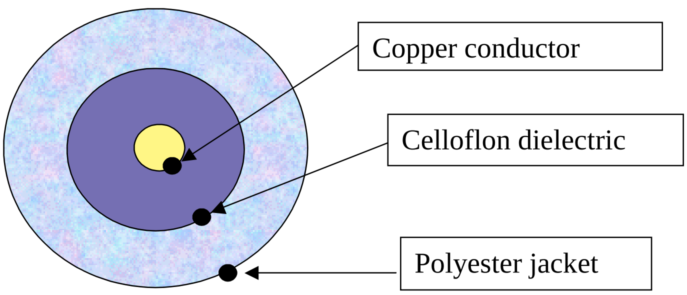


- LTP attachments points (struts ending) static T : 20°C +/- 10°C
- LTP attachments points (struts ending) T stability: TSD: 10^{-6} K^2/Hz

Interfaces definition (3/3)

CONDUCTIVE INTERFACES : Boundary temperature has been assigned also to the FEE and coupled to the Electrode Housing through coaxial cables as in IS analysis.

- FEE static T : 20°C +/- 10°C
- FEE T stability TSD: 10^{-6} K^2/Hz



No radiative coupling has been implemented
No other cables modelled

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LET'S GENERATE a time history of a known TSD signal!

SINDA → Matlab interface

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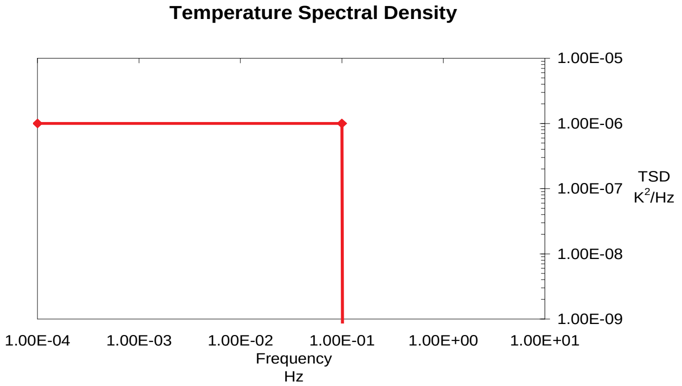
Spectral analysis

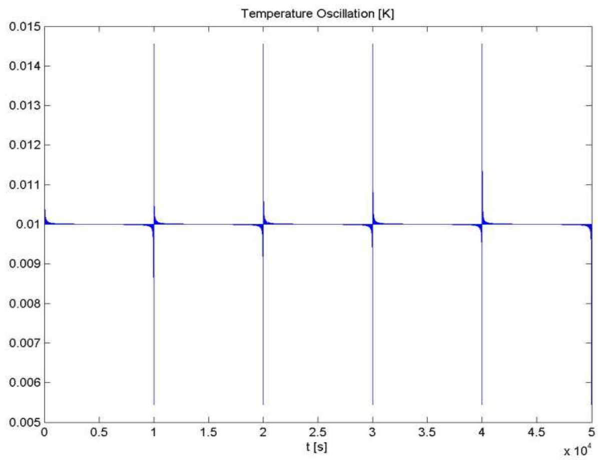
- Given a Temperature Spectral Density (TSD), the time dependent (periodic) signal is:

$$x(t) = \bar{x} + \frac{\sqrt{\mathrm{TSD}}}{\sqrt{\mathrm{P}/2}} \sum_{i=1}^{1000} \sin\left(2\pi \cdot i \cdot 10^{-4} t\right)$$

- where $\bar{x}$ is the mean value

Input signals (plots from MATLAB)

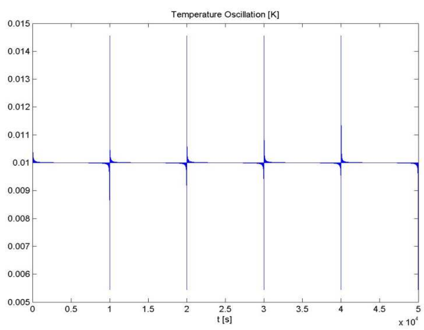




Is the plot below a RANDOM signal?

A real random signal cannot be plotted

– As soon as we plot it, it becomes deterministic!



Guidelines for the Analysis

- After the modelling phase, transient runs were made to study the temperature stability
- Sampling frequency : 1Hz (10 times higher than the higher extreme of the frequency band of interest, to avoid aliasing problems)
- Double precision calculations

Analysis results

- The TSD of the output signals was calculated as follows:

$$X(f_m, P) = \Delta T \sum_{k=0}^{N-1} x(k) \cdot e^{-i 2\pi \frac{m}{N} k}$$

- Where Δt is the sampling time (1sec), m is the index of the discrete frequency values at which the Fourier Transform is calculated:

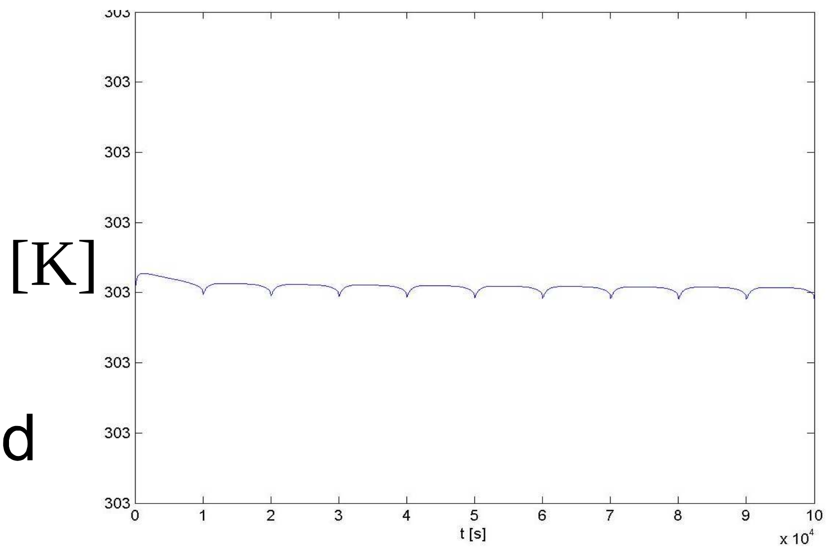
$$f_m = \frac{m}{N\Delta T}$$

- The desired output signal TSD is given by:

$$TSD(f_m) = \frac{2}{P} \left| X(f_m, P) \right|^2$$

Example: Analysis results

Time transient
for a node on the
Electrode
Housing



Thermal system damping effected

Let's go random!

In order to generate a nonperiodic input signal (more similar to what we expect as 'random') the sinusoidal signals at different frequencies where summed with a RANDOM PHASE

$$x(t) = \bar{x} + \frac{\sqrt{\mathrm{TSD}}}{\sqrt{\mathrm{P}/2}} \sum_{i=1}^{1000} \sin\left(2\pi \cdot i \cdot 10^{-4} t\right)$$

$$x(t) = \bar{x} + \frac{\sqrt{\mathrm{TSD}}}{\sqrt{\mathrm{P}/2}} \sum_{i=1}^{1000} \sin\left(2\pi \cdot i \cdot 10^{-4} t + \Delta\varphi_i\right)$$

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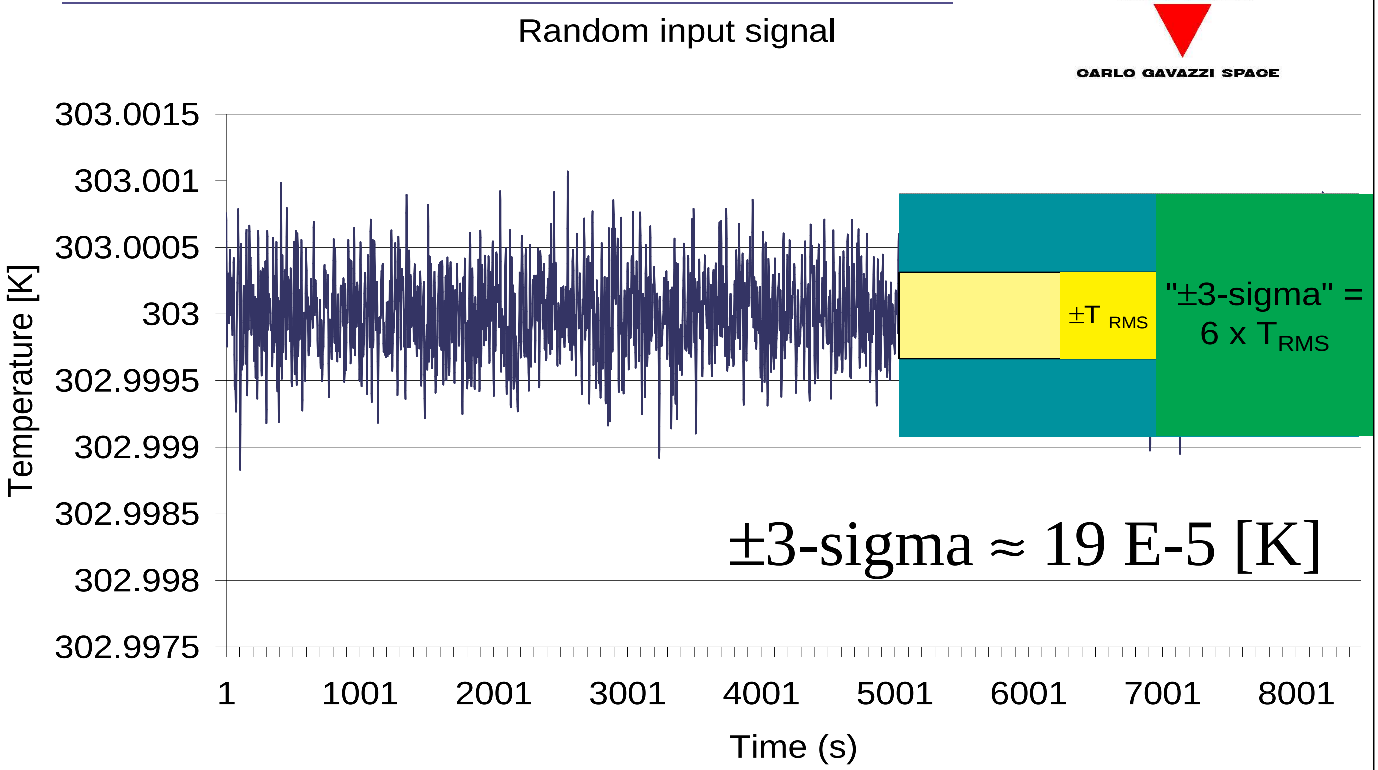

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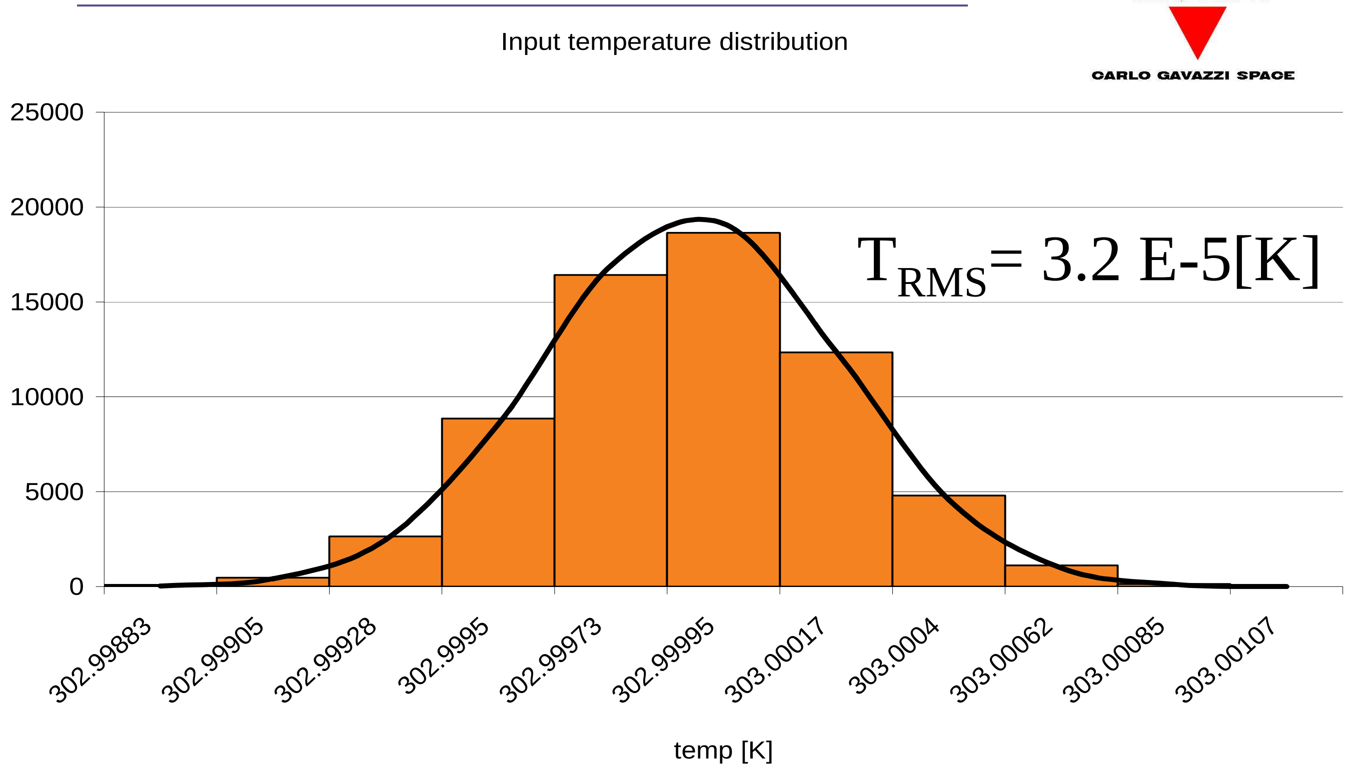
CARLO GAVAZZI SPACE



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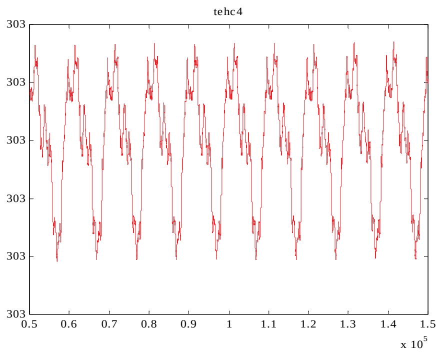
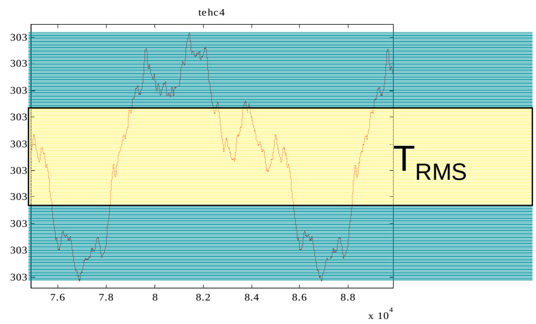
OUTPUT SIGNAL RESULTS

- Temperature profile of a internal node
- Damping effect of the thermal system



1.4E-5 [K]
(6 T_{RMS})



T_{RMS}= 2.3 E-6 [K]

RANDOM SIGNAL RESULTS

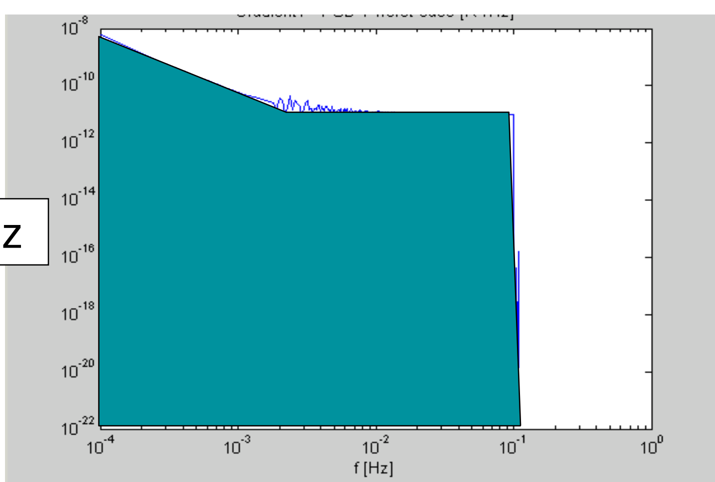
The TSD of the output signal has been computed:

TEMPERATURE STABILITY REQUIREMENT

TSD < $1*10^{-8} K^2/Hz$

•Maximum TSD : $6.6*10^{-9}$ [K^2/Hz]

K^2/Hz



T_{RMS} = 2.3 E-6 [K]

•Requirement met

COMMENTS

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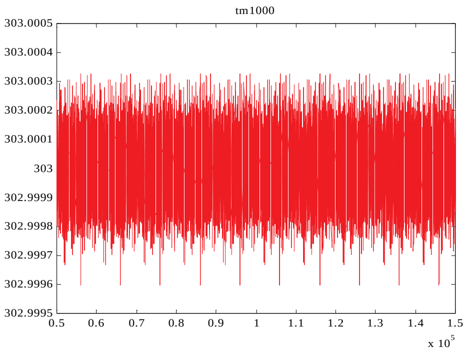
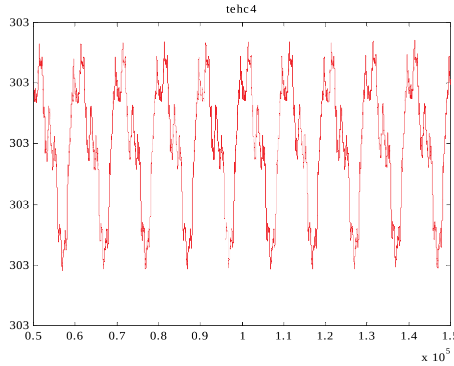
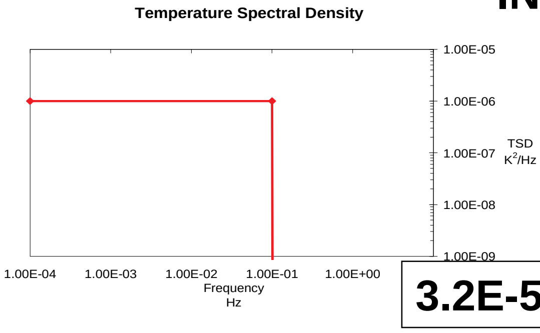
- The system act as a low-pass filter:



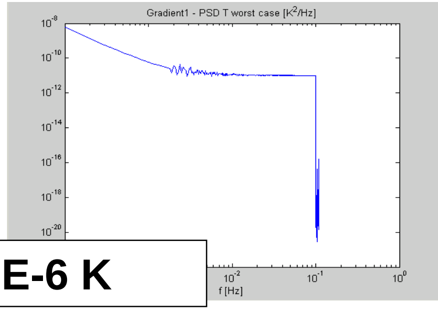


T(t)
[K]

IN → OUT



TSD
$[K^2/Hz]$



3.2E-5 K	T_{RMS}	2.3 E-6 K

Conclusions

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- Disturbing signals were created as time dependent temperature series, starting from their TPSD or TSD
- The output signals TSD was calculated and compared with max temperature fluctuations, for a cross check
- Comparison with analytical results shows good correlation
- The system meets stability requirements in terms of thermal stability and thermal gradient stability
- TSD concept must be handled with care!

Appendix AB:Designing for milli- and micro-kelvins

Designing for
milli- and micro-kelvins

V. Perotto
Alenia Spazio

Designing for mK / μK
A challenge also for thermal solvers ?

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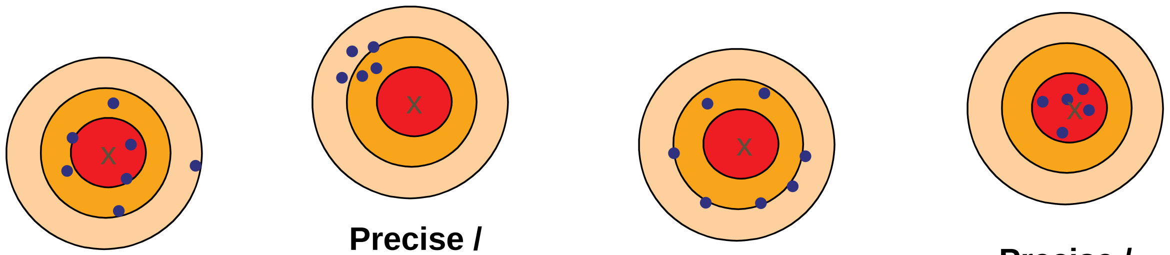
INTRODUCTION

- In some space programs *(e.g. GAIA, GOCE)* a high accuracy and precision are requested to numerical simulations, down to the levels of milli-Kelvin or even to micro-Kelvin (for temperatures and gradients).



Not precise / not accurate

Precise / not accurate

Not precise / accurate

Precise / accurate

Accuracy -> average deviation

Precision -> standard deviation

INTRODUCTION

- Are the available solvers able to guarantee adequate results in front of these requirements ?
- To verify this, a simple 2-nodes model has been built to compare the ESATAN numerical solution with the analytical one.
- This very simple problem allows to assess the ESATAN numerical precision and accuracy and also to identify the parameters which affect them.

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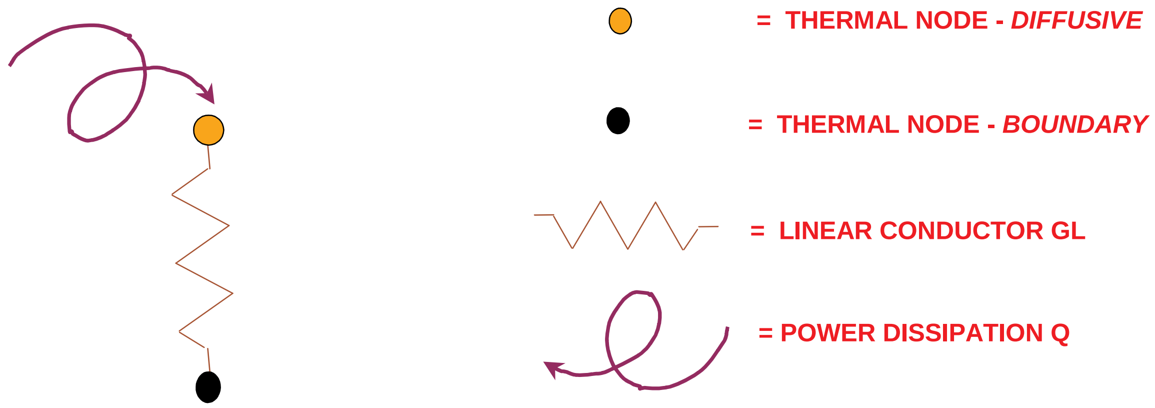
2-NODES MODEL WITH IMPOSED THERMAL POWER



Thermal balance equation:

$$C * dT(t) / dt = Q(t) + GL \cdot [\, T_{boundary} - T(t) \,]$$

with: $Q(t) = A \cdot (1 + \cos \omega \cdot t)$

2-NODES MODEL WITH IMPOSED THERMAL POWER (cont'd)

- **Analytical solution:**

$$T(t) = T_{boundary} + \left\{ \left[T_{t=0} - T_{boundary} \right] - \frac{A}{C} \left(\frac{1}{\alpha} + \frac{\alpha}{\alpha^2 + \omega^2} \right) \right\} \cdot \exp(-\alpha t) + \frac{A}{C \cdot \alpha} + \frac{A}{C} \cdot \frac{1}{\alpha^2 + \omega^2} \cdot (\alpha \cos \omega t + \omega \sin \omega t)$$

where: α = GL / C, $\omega = 2\pi$ / T

- **Several test cases have been made, each characterized by different values of parameters (linear conductor GL, specific heat, mass, boundary temperature, dissipated power)**

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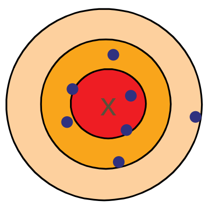
2-NODES MODEL WITH IMPOSED THERMAL POWER (cont'd)

- **For each test case several runs have been made to assess the effect of the ESATAN convergence control parameters.**
- **The difference ESATAN – analytical solution is the accuracy (actually the accuracy should be the average deviation of error for all runs with different values of control parameters, but in an analysis campaign such parameters are not explored estensively).**
- **The deviation of the accuracy with the convergence control parameters corresponds to the precision.**

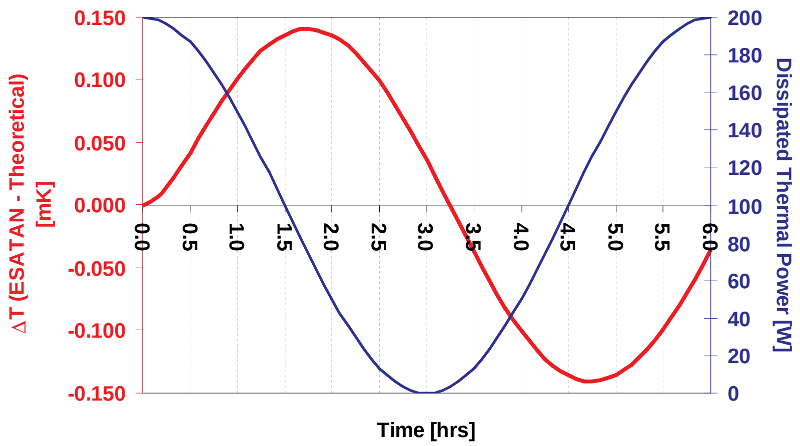


VERIFICATION OF ESATAN PERFORMANCES

Case with:

A = 100 W, m = 1 kg, c = 900 J/kg·K, Tb = T0 = 20 °C, GL = 1 W/K

Integration time step Δt = 0.01 s, Period T = 6 hrs



Time [s]	ESATAN Solution [°C]	Theoretical Solution [°C]	Difference [°C]
0	20.000000	20.000000	0.000000
1200	165.292930	165.292908	0.000022
2400	193.988628	193.988565	0.000063
3600	184.465538	184.465438	0.000100
4800	159.444963	159.444835	0.000128
6000	**127.631248**	**127.631107**	**0.000141**
7200	94.360541	94.360405	0.000136
8400	64.040898	64.040784	0.000114
9600	40.433468	40.433388	0.000080
10800	26.413110	26.413074	0.000036
12000	23.678121	23.678134	-0.000013
13200	32.560291	32.560351	-0.000060
14400	51.988800	51.988900	-0.000100
15600	79.620417	79.620545	-0.000128
16800	112.122395	112.122536	-0.000141
18000	145.574526	145.574662	-0.000136
19200	175.941990	175.942105	-0.000115
20400	199.562024	199.562104	-0.000080
21600	213.585703	213.585739	-0.000036

VERIFICATION OF ESATAN PERFORMANCES (cont'd)

Maximum ΔT [mK] ESATAN - Analytical solution	Integration time step [s]	
Relaxation Constant	*0.01*	*0.1*
1.00E-10	0.141	1.403
1.00E-05	0.141	1.403
1.00E-03	0.141	1.403

From all the test cases:

- **No effect of RELXCA on solution accuracy can be appreciated for little models**
- **Very small time steps and RELXCA not compatible with ESATAN internal limit (one million steps maximum)**

CONCLUSIONS

- For this very simple linear model (no GR) the accuracy of ESATAN is of the order of 0.1 mK
- Accuracy can be somewhat reduced (not to µK levels) using very small time steps, but <u>this is unfeasible with large models</u>
- Accuracy for complex models can not be assessed, but it is reasonable to assume it is higher than mK
- With networks containing GR instead of GL, error is expected to increase as effect of non-linearity and necessary iterations within ESATAN

CONCLUSIONS

OPEN POINTS:

- Is it possible to design a TCS with requirements in terms of mK / µK with the standard solvers ?
- Is it possible to improve the standard solvers accuracy ?
- Is it necessary to calculate also precision?
- Is it possible to achieve a TCS with requirements in terms of mK / µK with the classic procedure based on analysis (iterations design/analysis and subsequent tests) ?

Appendix AC: List of Participants

List of Participants

17^{th} European Workshop on
Thermal and ECLS Software

21-22 October 2003
ESTEC, Noordwijk, Netherlands

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