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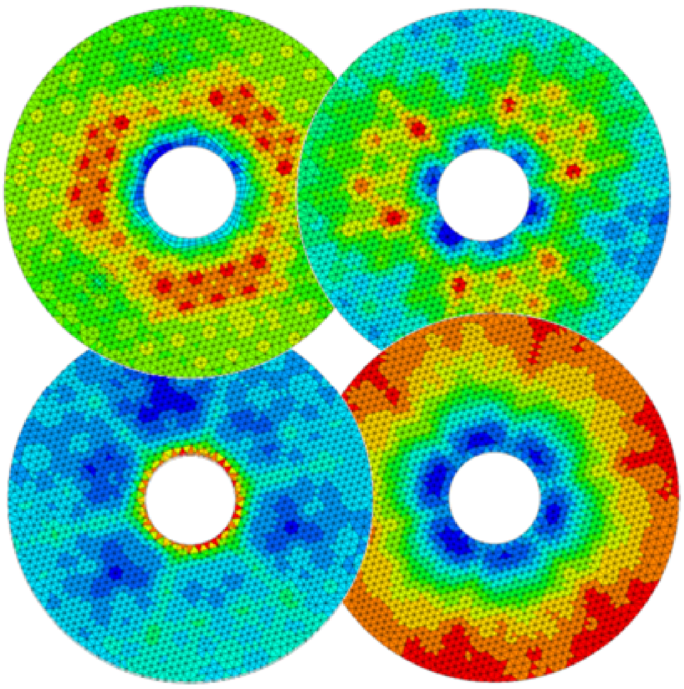

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European Space Agency
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Abstract

This document contains the presentations of the 28th European Space Thermal Analysis Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on 14–15 October 2014. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.
Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under 'Workshops'.

Please note that this document contains clickable hyperlinks which are shown as blue text.

Contents

Appendices

Programme Day 1

9:00 Registration

9:45 **Welcome and introduction**

Harrie Rooijackers (ESA/ESTEC, The Netherlands)

10:00 **Definition of Experimental Based Thermal Parameters for a Standard Thermal Architecture of Electronic Boards and Units based on modular concept and relevant Thermal Mathematical Model Validation**

Andrea Zamboni (Selex ES, Italy)

10:25 **LISA pathfinder Inertial Sensor Head thermal analysis in frequency domain**

Paolo Ruzza (CGS S.p.A., Italy)

10:50 **Fluid-selection tool**

Henk Jan van Gerner (NLR, The Netherlands)

11:15 Coffee break in the Foyer

11:45 **Development of a thermal control system for South Africa's next generation Earth observation satellite**

Daniël van der Merwe (DENEL Spaceteq, South Africa)

12:10 **GENETIK** — Optimisation tool for thermal analyses performed with SYSTEMA

Hélène Pasquier & Guillaume Mas (CNES, France)

12:35 **An overview of CHEOPS Instrument thermal design and analysis**

Romain Peyrou-Lauga (ESA, The Netherlands)
Giordano Bruno (University of Bern, Switzerland)

13:00 Lunch in the ESTEC Restaurant

14:00 **PEASSS** — New horizons for cubesat missions

Luca Celotti & Riccardo Nadalini (Active Space Technologies GmbH, Germany)

14:25 **TMRT Module Software** — Use on an Industrial Application

Michèle Ferrier & David Valentini (Thales Alenia Space, France)

14:50 **Thermal issues related to ExoMars EDLS performance**

Emilie Boulier & Grégory Pinaud & Patrick Bugnon (Airbus Defence & Space, France)

15:15 **A personal look back on Thermal Software evolution within the past 36 years**

Harold Rathjen (HRC, Germany)

15:45 Coffee break in the Foyer

16:15 **General-purpose GPU Radiative Solver**

Andrea Tosetto & Marco Giardino & Matteo Gorlani (Blue Engineering & Design, Italy)

16:40 **Insight HP3** — Thermal Modelling with Thermal Desktop

Asli Gencosmanoglu & Luca Celotti & Riccardo Nadalini (Active Space Technologies GmbH, Germany)

17:05 **Analysis Strategies For Missions Involving Comprehensive Thermal Issues**

Nicolas Liquière (EPSILON, France)

17:30 Social Gathering in the Foyer

19:30 Dinner in *Iets Anders*

Programme Day 2

9:00 **Assessment of stochastic methods for the thermal design of a telecom satellite**
Nicolas Donadey (AKKA Technology, France)
Jean-Paul Dudon & Patrick Connil & Patrick Hugonnot (Thales, France)

9:25 **Development of an automated thermal model correlation tool**
Martin Trinoga (Airbus Defence and Space, Germany)

9:50 **On using quasi Newton algorithms of the Broyden class for model-to-test correlation**
Jan Klement (Tesat-Spacecom GmbH & Co. KG, Germany)

10:15 **SYSTEMA – THERMICA 4.7.0 & THERMICALC 4.7.0**
Timothée Soriano & Rose Nerriere (Astrium SAS, France)

11:00 Coffee break in the Foyer

11:25 **ESATAN Thermal Modelling Suite** — Product Developments and Demonstration
Chris Kirtley & Nicolas Bures (ITP Engines UK Ltd, United Kingdom)

12:10 **Tests of solids implementation in ESATAN TMS R6**
Olivier Frapsauce & Dominique Fraioli (Airbus DS Les Mureaux, France)

12:35 **Finite element model reduction for the determination of accurate conductive links and application to MTG IRS BTA**
Lionel Jacques
(Space Structures and Systems Laboratory, University of Liège & Centre Spatial de Liège, Belgium)
Luc Masset (Space Structures and Systems Laboratory, University of Liège, Belgium)
Tanguy Thibert & Pierre Jamotton & Coraline Dalibot (Centre Spatial de Liège, Belgium)
Gaetan Kerschen (Space Structures and Systems Laboratory, University of Liège, Belgium)

13:00 Closure

13:00 Lunch in the ESTEC Restaurant

Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Appendix B

Definition of Experimental Based Thermal Parameters for a Standard Thermal Architecture of Electronic Boards and Units based on modular concept and relevant Thermal Mathematical Model Validation

Andrea Zamboni
(Selex ES, Italy)

Abstract

The thermal design and development of Spacecraft, Sub-Systems or Equipments involve the establishment of a Thermal Mathematical Model (TMM), which shall be validated and calibrated by means of dedicated Thermal Survey test campaign; the thermal model calibration is then foreseen when the first representative hardware is available and typically this occurs in a project phase where the thermal design reached a certain maturity and some changes, if any, may have not negligible impact in term of schedule and cost. On the other hand, the space market is pushing for reducing schedule and typically the experimental activities verification is to be substituted with analysis whenever feasible. Defining standard thermal solution according to "re-use" and "modularity" philosophy will reduce the experimental activities and relevant risks and improve reliability of thermal prediction.
With the aid of Thermal Concept Design Tool (TCDT) and ESATAN, thermal analyses and relevant dedicated experimental test campaign have been carried out on a Standard PCB Assembly, designed for a modular concept Electronic Unit architecture
The main results obtained where

- Calibration of analysis parameter as contact resistance and PCB conductance with the aid of dedicated thermal vacuum test
- Definition of a standard PCB layout and architecture
- Issue of a (reduced) thermal model to be used for what-if analysis and for reference for future projects
- Definition of experimental based standard parameters for Thermal Mathematical Model at Board Assembly and Equipment level, reducing the effort of dedicated thermal survey and improving reliability

Appendix C

LISA pathfinder Inertial Sensor Head thermal analysis in frequency domain

Paolo Ruzza
(CGS S.p.A., Italy)

Abstract

LISA Pathfinder is the precursor of the ESA/NASA mission LISA (Laser Interferometer Space Antenna); it aims at demonstrating the feasibility of all the challenging key technologies needed by the operational mission.
CGS is responsible of the Thermal Design and Analysis of LISA Pathfinder ISH (Inertial Sensor Head). The main goal of the ISH TCS, as a part of the overall instrument TCS, is to damp the thermal disturbances coming from outside (i.e. external environment, rest of the satellite); the system performance requirements are expressed in terms of frequency-dependent allowable noise, inside the detector bandwidth (1 mHz - 30 mHz); for this reason most of the thermal analysis are not performed in the usual time domain, but in the frequency domain.
Main assumption of this approach shall be presented and the results compared with the standard time domain results and with test results, used to validate the thermal model. Finally the advantages of this method in terms of computational time and post-process capability shall also be presented.

Appendix D

Fluid-selection tool

Henk Jan van Gerner
(NLR, The Netherlands)

Abstract

Fluid selection is one of the first and most important steps for the design of a thermal control system. The usual approach to fluid selection is to manually evaluate many different fluids. However, this is a very time-consuming process, since the number of fluids to choose from is very large, and the best fluid strongly depends on the application and temperature range. Furthermore, a potentially suitable fluid can be overlooked when fluids are manually selected. For these reasons, NLR developed a systematic, automated, fluid-selection tool. This fluid selection tool is implemented in Matlab, and it uses a figure of Merit to select the most suitable fluids from the REFPROP database. In this presentation, the use of the fluid selection tool is demonstrated for 4 different applications: Heat Pipe, Loop Heat Pipe, Two-phase mechanically pumped loop, and a heat pump. For example, it is explained why CO_2 is used in the thermal control system of AMS02 (which was launched with the space shuttle in May 2011 and subsequently mounted on the International Space Station) and why isopentane is selected for an ESA Heat Pump application.

With the fluid selection tool, fluids can be selected which would have been overlooked without the use of the figure of Merit. Furthermore, the tool offers a large saving in ccosts and time since the tedious process of finding and analyzing possibly suitable fluids can now be carried out with a single push on a button.

Appendix E

Development of a thermal control system for South Africa's next generation Earth observation satellite

Daniël van der Merwe
(DENEL Spaceteq, South Africa)

Abstract

This presentation gives an overview of the work done so far in developing a thermal control system for South Africa's next generation Earth observation satellite. Correlated thermal models of critical major components were developed based on lessons learned from SumbandilaSAT (South Africa's first national satellite). These include amongst others an electronic housing unit and a typical solar panel. In addition, the thermo-optical properties of commonly used coatings and tapes were also measured. The performance of the proposed thermal control system was evaluated using the NX^{TM} Space Systems software. During the evaluation different satellite orientation modes were considered, as well as different mission scenarios. The results show that the suggested thermal control system creates a relatively low, uniform temperature inside the satellite.

Appendix F

GENETIK

Optimisation tool for thermal analyses performed with SYSTEMA

Hélène Pasquier Guillaume Mas
(CNES, France)

Abstract

GENETIK is a software developed by CNES to facilitate the detection of thermal sizing cases. It is based on genetic algorithm to explorate solution space and to determine the worst environmental conditions (solar, albedo and earth fluxes).
With some improvements on thermal study management in SYSTEMA V4, and particularly the possibility to perform parametric analyses, the coupling of optimization tool to SYSTEMA is made possible.
The objectives of the presentation are to:

- Present GENETIK functionalities
- Develop the possibilities of this optimisation tool

Appendix G

An overview of CHEOPS Instrument thermal design and analysis

Romain Peyrou-Lauga
(ESA, The Netherlands)

Giordano Bruno
(University of Bern, Switzerland)

Abstract

CHEOPS (CHaracterizing ExoPlanet Satellite) is the first ESA S-class mission and is dedicated to search for planet transits by means of ultrahigh precision photometry on bright stars already known to host planets. The University of Bern is in charge of the CHEOPS instrument, which is a single aperture, high accuracy photometer operating between 0.4 and 1.1 micron. The focal plane detector consists of a single CCD operated at -40 °C and requires a thermal stability better than 10 mK. The presentation will provide an overview of the thermal design and of the thermal analysis of the instrument.

Appendix H

PEASSS
New horizons for cubesat missions

Luca Celotti Riccardo Nadalini
(Active Space Technologies GmbH, Germany)

Abstract

A cubesat is a type of miniaturized satellite for space research with external volume starting from 10x10x10cm3 (1U) and multiples of it (2U, 3U...). The cubesat platform is well-known to the academic researchers, small space companies and space amateurs, because of:

- standardized parts and interfaces;
- off-The-Shelf Components usage;
- "group" launches.

For these reasons, universities, small companies and space-enthusiasts have been the main users of this platform in the recent years. On the other hand, cubesat losses because of internal failures, not detailed design and analysis have been common.
PEASSS is a 3U cubsat under development as part of a FP7 European Commission project involving Active Space Technologies GmbH, TNO and ISIS (Netherlands), SONACA (Belgium), Technion and NSL (Israel). The main objective of the project is to develop, manufacture, test and qualify "smart structures" which combine composite panels, piezoelectric materials, and next generation sensors, for autonomously improved pointing accuracy and power generation in space. The system components include new nano satellite electronics, a piezo power generation system, a piezo actuated smart structure and a fiber-optic sensor and interrogator system.
The approach chosen for the design of PEASSS allows to combine the advantages of the cubesat platform to the complexity of the mission (technological demonstrator), achieving the mission success, technologies TRL step-up, while reducing the risk of the mission. This objective is achieved by increasing the level of analysis/verification of the whole satellite and the payloads/subsystems "like a non-cubesat mission", including:

- detailed thermal modelling with orbital and satellite life-time cases analysis;
- design of heaters and other active/passive thermal control solution;
- acceptance on breadboard and qualification on flight model for vibration tests;
- thermal vacuum functional tests;
- correlation and automatized correlation models;
- qualification thermal vacuum tests at payload level;
- acceptance thermal vacuum tests at satellite level.

The whole satellite thermal design and analysis are performed in Esatan-TMS and using AST's internally developed "model runner" and results "post-process" module.

Appendix I

TMRT Module Software
Use on an Industrial Application

Michèle Ferrier David Valentini
(Thales Alenia Space, France)

Abstract

Reduction thermal model activity is a recurrent activity on a majority of space program. The reduction is usually done manually. This activity can also take a lot of time if the DTMM (Detailed Thermal Mathematical Model) to be reduced has a lot of nodes and thermal couplings. Moreover, the fact that the reduction is done manually increases the error risk on the RTMM (Reduced Thermal Mathematical Model) and so increases therefore the difficulty of the correlation activity between DTMM and RTMM. In order to optimize reduction activity, an initial module software (so called TMRT, Thermal Model Reduction Tool) has been developed by Airbus Defence & Space (ADS) and Thales Alenia Space (TAS) under ESA contract. This module has been afterward implemented in TAS Thermal Internal Software (E-THERM) and several evolutions have been done under TAS self-funding, in order to implement typical ESATAN-TMS parameters and functions and so to permit the reduction of an ESATAN-TMS DTMM. The objectives of the presentation are to :

- describe briefly the TMRT Module of E-THERM
- define limits and constraints of TMRT module for an ESATAN-TMS DTMM reduction
- present the reduction results obtained on an industrial application.

Appendix J

Thermal issues related to ExoMars EDLS performance

Emilie Boulier Grégory Pinaud Patrick Bugnon
(Airbus Defence & Space, France)

Abstract

During its planetary entry, EXoMars heatshield encounters specific hypersonic environments, in terms of aerothermochemistry, radiation, particule flows... and therefore requests a specific effort, in relation to aerodynamic characterisation and quantification of thermal / thermomechanical loads, as well as demonstration of thermostructural integrity and thermal efficiency.
Airbus Defense & Space is a major contributor to both issues.
The present communication aims at emphasizing two important axes of progress :

- Performance of the vehicle & application thanks to TPS optimisation
  - Updated material data sets could be derived from dedicated tests
  - Material data sets were integrated to thermophysical modelisations
  - Improved thermophysical modelisations allowed TPS thickness reduction
- Quality of planned postflight analysis, thanks to advanced modelisation including parametric and statistic analyses, inverse methodologies, cosimulation.

Appendix K

A personal look back on Thermal Software evolution within the past 36 years

Harold Rathjen
(HRC, Germany)

Abstract

The evolution of thermal software used in European space industries from the beginning until today marks a long way from some in-house written software to the current status of today's most important packages. During almost 30 years this way was accompanied by the ESTEC annual workshop on ECLS software that started in 1986 as the Esatan workshop, but soon had to be opened for other software developments, among which Thermica has to be mentioned in first place. This presentation gives a historical look back from a personal point of view of a young thermal engineer who started working in the thermal department of ERNO in Bremen right at the time when the Spacelab project was won and the first family of commercial communication satellites (ECS/MARECS) was started. Some highlights are the decision for the cooperation between ESTEC and a little company in England to develop Esatan, and a few years later the search for an appropriate radiation software for the Columbus project. Not to forget the Esabase framework, that was used during many years as an intermediate software. Finally the problems of establishing a common thermal analysis method within the Ariane project in front of the merging of the participating companies are mentioned.

Appendix L

General-purpose GPU Radiative Solver

Andrea Tosetto Marco Giardino Matteo Gorlani
(Blue Engineering & Design, Italy)

Abstract

In the scope of the CADET project, a new radiative tool was developed in Blue Engineering. The tool can compute the extended view-factor and extended incident heat fluxes for solar, planetary and albedo contributions using the Monte Carlo Ray Tracing model. The software is implemented using the OpenCL framework, in order to take advantage of the computational capabilities of GPGPU hardware and dedicated computation hardware.
A comparison between tool results and ESATAN TMS results is performed in order to validate the tool.

Appendix M

Insight HP3
Thermal Modelling with Thermal Desktop

Asli Gencosmanoglu Luca Celotti Riccardo Nadalini
(Active Space Technologies GmbH, Germany)

Abstract

The Heat-Flow and Physical Properties Probe (HP3) is an instrument package built by Deutsches Zentrum für Luft- und Raumfahrt (DLR) as a part of NASA-JPL Insight Mission (The Interior Exploration Using Seismic Investigations, Geodesy, and Heat Transport) which will investigate the interior structure and processes of Mars. The mission will be launched on a Type I trajectory to Mars in March of 2016.
The main subsystems of HP3 includes:

- Hammering mechanism , the Mole that penetrates below the Martian surface
- Support structure that houses the Mole prior to ground penetration
- Radiometer mounted on the lander
- Back-end electronics in the lander thermal enclosure

The thermal analysis and design of the HP3 Instrument for the landed phase of the mission have been performed by Active Space Technologies GmbH using Thermal Desktop and Sinda/Fluint. In the scope of the thermal analysis and design activities, the detailed thermal and geometrical models of each subsystem as well as the integrated models are created. Being composed of subsystems which are permanently mounted on the lander, deployed on the Mars surface after landing and deployed into the Martian soil, different external thermal environments are defined for each subsystem for the different phases of the mission, including the mars heating environment modelling. The detailed models are integrated on the simplified lander model and the reduced models of the subsystems are also created to be integrated into the detailed lander model.
The features of Thermal Desktop used for the different stages of the HP3 instrument thermal modelling and analysis process are presented:

- General features;
- Generation of thermal models;
- Integration of geometrical and thermal models
- Planet heating environment modelling;
- Post-processing;
- Data exchange.

Appendix N

Analysis Strategies For Missions Involving Comprehensive Thermal Issues

Nicolas Liquière
(EPSILON, France)

Abstract

Epsilon works on projects whose complexity is expressed in different terms:

- The nature of the missions always looking for increasing performances. These induce the development of new mechanisms such as on the 3POD project, the high level of thermal stability such as on the INSIGHT mission, and high accuracy level on optical performances such as on the OTOS telescope program.
- Serious environmental constraints as for PAS instrument on the Solar Orbiter mission which directly braves the fierce Sun, and INSIGHT-SEIS instrument or Exomars-MOMA instruments which are subject to Martian environment.

All studies conducted by EPSILON on such projects require specific thermal architecture works and major modeling and simulation efforts. For each aspect, software (Systema, NX / TMG, STAR CCM + ...) is selected due to its advantages and its fit with needs.
It is proposed to walk you through some thermal problems on INSIGHT and OTOS projects, to expose how the thermal modeling and simulation problems have been managed.

Appendix O

Assessment of stochastic methods for the thermal design of a telecom satellite

Nicolas Donadey
(AKKA Technology, France)

Jean-Paul Dudon   Patrick Connil   Patrick Hugonnot
(Thales, France)

Abstract

The aim of the study is to assess the interest of using probabilistic methods and tools for the thermal design of a telecom satellite. This work has been done in the frame of system development for new satellites.
In the past the interest of such methods compared to deterministic approach leading to use of margin has been pointed locally in the system. It was concluded that these methods are useful to have a more clear and complete exploration of the design and system performances, and thus to identify easily sizing parameters among many inputs. Moreover by associating an occurrence probability to system temperatures related to the dispersion law of relevant input parameters, stochastic approach is expected to avoid a final risky or oversized design.
Here we assess the feasibility of such approach at system level on a telecom satellite by benchmarking probabilistic versus margin method for a S/C communication module. The tools used for this study is OPTIMUS (stochastic methods and computation workfow) and ETHERM (TAS thermal solver)
In this purpose the classical margin approach is compared to a deterministic uncertainty analysis (RMS of cumulative incertainties on relevant parameters of the thermal design) and to a probabilistic approach (consideration of probabilistic distribution for relevant input parameters).
Methods, tools, and results are presented and current conclusions and perspectives are given considering technical and industrial objectives.

Appendix P

Development of an automated thermal model correlation tool

Martin Trinoga
(Airbus Defence and Space, Germany)

Abstract

A generally essential part in the development of a spacecraft is the implementation of a thermal model for the temperature predictions during the operation phase. In order to achieve a good accuracy of the assessed temperatures, the thermal model has to be correlated with measurements from predetermined thermal tests. Currently this correlation is only possible in a manual way at Airbus DS GmbH. As this manual method is often a time consuming process, a new method for solving this problem is currently under development. With this newly developed MATLAB® tool (TAUMEL = Tool for AUtomated Model correlation using Equation Linearization) it will be possible to correlate restricted thermal models from ESATAN-TMS automatically. The first master thesis regarding this automated approach was finished in December 2013, whose outcome will be presented. Because of the promising potential of this new correlation method, Airbus DS in Bremen is currently working within the frame of a second master thesis. The current status will be presented as well.

Appendix Q

On using quasi Newton algorithms of the Broyden class for model-to-test correlation

Jan Klement
(Tesat-Spacecom GmbH & Co. KG, Germany)

Abstract

The correlation of a model with test results is a common task in thermal spacecraft engineering. Often genetic algorithms or adaptive particle swarm algorithms are used for this task. A different approach has been developed at Tesat Spacecom using quasi Newton algorithms of the class defined by C. G. Broyden in 1965. A study is performed with thermal space industry models showing the performance of this approach. By comparing it to the results of other studies it is shown that this approach reduces the number of iterations by several orders of magnitude.

Appendix R

SYSTEMA – THERMICA 4.7.0 & THERMICALC 4.7.0

Timothée Soriano Rose Nerriere
(Astrium SAS, France)

Abstract

SYSTEMA – THERMICA 4.7.0

The new 4.7.0 release includes new major functionalities.
A new CAD library is now embedded into SYSTEMA allowing the management of heavier CAD files. Thanks to several defeaturing options, it is possible to simplify a geometrical model with holes, chamfers and small volumes suppression. CAD shapes and SYSTEMA native shapes can then be used for thermal analysis.
A Post-Processing tab is now dedicated to the management of results. Mathematical operations, comparisons, min/max, margins, power budgets etc. can be linked together. The complete post-processing workflow can also be batched, including the generation of results into tables and graphs.

THERMICALC 4.7.0

THERMICALC is a new product of the THERMICA suite which is designed to solve small thermal problems (up to 100 nodes). It has the powerful capabilities of THERMISOL accessible from an Excel spreadsheet.
Setting and running a thermal model within THERMICALC is very easy: declaration of nodes, couplings, plus a wizard mode to help setting thermostats, temperature or time dependencies.
THERMICALC also proposes the import of THERMICA outputs (such as nodes, couplings and external fluxes) and even THERMISOL inputs.
An advanced mode may be activated so to be able to set any user's code and so to perform more complex analysis.

Appendix S

ESATAN Thermal Modelling Suite
Product Developments and Demonstration

Chris Kirtley Nicolas Bures
(ITP Engines UK Ltd, United Kingdom)

Abstract

Product Developments

ESATAN-TMS provides the Engineer with a complete and powerful integrated thermal modelling environment. Version r6 was released at the end of last year and saw a significant evolution in its modelling capability. 3D solid geometry can now be modelled, performing ray-tracing on solid surfaces and allowing selection of either lumped parameter or finite element thermal analysis on the solid structure. With ESATAN-TMS r7 the focus of work of this release has been on a number of areas, including a tighter integration between Workbench and ESATAN, improvements to the layout of the user interface and general improvements directly raised by our customers.
This presentation outlines the new features to be included in the next release of ESATAN-TMS.

Thermal Modelling Demonstration

A demonstration of the new features included in ESATAN-TMS r7 will be given, building a thermal model to demonstrate the new functionality.

Appendix T

Tests of solids implementation in ESATAN TMS R6

Olivier Frapsauce Dominique Fraioli
(Airbus DS Les Mureaux, France)

Abstract

For Airbus DS Launchers development, the modelisation of the thermal phenomena inside a space vehicle needs a 3D volumic approach, in particular to represent heat transfer inside thermal protections and cavities and complex geometries. The methods based on shell elements are not well adapted to system thermal analyses. The implementation of solids in the software ESATAN TMS aims to answer to the needs of Airbus DS Vehicles Engineering.

In the frame of the development of ESATAN TMS R6 (including solids approach), Airbus DS Vehicles Engineering has tested some new functionalities for solids: volumes generation, meshing of these volumes, conductive contacts inside and between volumes (ACG), fluid/wall contacts, fluid/fluid contacts, cavities identification, radiative computations based on cavities ...

For the 28th European Space Thermal Analysis Workshop, Airbus DS Vehicles Engineering will present the results of the close collaboration between Airbus DS Vehicles Engineering and ITP Engines (ESATAN Provider) in the implementation of solids in the software ESATAN TMS R6 based on the validation test cases.

Appendix U

Finite element model reduction for the determination of accurate conductive links and application to MTG IRS BTA

Lionel Jacques
(Space Structures and Systems Laboratory, University of Liège   Centre Spatial de Liège, Belgium)

Luc Masset
(Space Structures and Systems Laboratory, University of Liège, Belgium)

Tanguy Thibert   Pierre Jamotton   Coraline Dalibot
(Centre Spatial de Liège, Belgium)

Gaetan Kerschen
(Space Structures and Systems Laboratory, University of Liège, Belgium)

Abstract

The finite element method (FEM) is widely used in mechanical engineering, especially for space structure design. However, FEM is not yet often used for thermal engineering of space structures where the lumped parameter method (LPM) is still dominant.
The two methods offer advantages and disadvantages and the proposed global approach tries to combine both. Whereas the LPM remains very versatile and allows easy integration of user-defined components, the computation of the conductive links is error-prone and still too often computed by hand. This is incompatible with the increasing accuracy required by the thermal control systems (TCS) and associated thermal models. Besides offering the automatic and accurate computation of the conductive links, the FEM also provides easy interaction between mechanical and thermal models, allowing better thermo-mechanical analyses. From this point of view, the FEM is complementary, offering the accuracy required by the always more stringent requirements of the TCS. In this framework, a FE mesh conductive reduction scheme has been developed. The detailed FE mesh is first fitted to the ESARAD geometry. The FE mesh is then partitioned, according to the ESARAD shells definition, before being reduced in an iterative procedure. The reduced conductive network, containing all the conductive information of the detailed FE mesh, and the ESARAD radiative links are then combined to form the TMM and compute the temperatures. The reduction method further allows the recovery of the detailed FE mesh temperatures back from the reduced one, therefore bridging the gap between thermal and mechanical analysis. The method has been tested and applied on the Back Telescope Assembly (BTA) on board MTG IRS.

Appendix V

List of Participants

Bakker, Marije
National Aerospace Laboratory (NLR)
Netherlands
☎ +31 88 511 4333
✉ marije.bakker@nlr.nl

Bascheri, Olivier
DOREA
France
☎ +33 4 92 90 08 29
✉ olivier.bascheri@dorea.fr

Baturkin, Volodymyr
DLR
Germany
☎ +49 4212 4420 1610
✉ volodymyr.baturkin@dlr.de

Bernaudin, Jean-Baptiste
Airbus Defence and Space
France
☎ +33 5 62 19 64 69
✉ jean-baptiste.bernaudin@astrium.eads.net

Bodendieck, Frank
OHB System AG
Germany
☎ +49 4212 020 626
✉ frank.bodendieck@ohb.de

Bonnafous, Bastien
ESA
Netherlands
☎ +31 71 565 6288
✉ bastien.bonnafous@esa.int

Brouquet, Henri
ITP Engines UK
United Kingdom
☎ +44 116 284 5765
✉ henri.brouquet@itp-engines.co.uk

Brunetti, Francois
DOREA
France
☎ +33 4 92 90 08 29
✉ francois.brunetti@dorea.fr

Bruno, Giordano
University of Bern
Switzerland
☎ +41 79839 2249
✉ giordano.bruno@space.unibe.ch

Bryan, Shaughnessy
STFC RAL Space
United Kingdom
☎ +44 1235 445061
✉ bryan.shaughnessy@stfc.ac.uk

Bugnon, Patrick
AIRBUS DEFENCE & SPACE
France
☎ +33 55 5657 3055
✉ patrick.bugnon@astrium.eads.net

Bures, Nicolas
ITP Engines UK
United Kingdom
☎ +44 116 284 5520
✉ nicolas.bures@itp-engines.co.uk

Celotti, Luca
Active Space Technologies GmbH
Germany
☎ +49 30 6392 6090
✉ luca.celotti@activespacetech.eu

Checa, Elena
ESA
Netherlands
☎ +31 71 565 6606
✉ Elena.Checa@esa.int

Cheriaux, Loic
AIRBUS DEFENCE & SPACE
France
☎ +33 1 3906 1535
✉ loic.cheriaux@astrium.eads.net

Dalibot, Coraline
Centre Spatial de Liège
Belgium
☎ +32 47051 4794
✉ coraline.dalibot@gmail.com

De Palo, Savino
ThalesAlenia Space
Italy
☎ +39 01 1718 0875
✉ savino.depalo@thalesaleniaspace.com

Dolce, Silvio
ESA
Netherlands
☎ +31 71 565 4673
✉ Silvio.Dolce@esa.int

Dudon, Jean-Paul
THALES
France
☎ +33 4 92 92 67 13
✉ jean-paul.dudon@thalesaleniaspace.com

Etchells, James
ESA
Netherlands
☎ +31 71 565 8503
✉ James.Etchells@esa.int

Fagot, Alain
DOREA
France
☎ +33 4 92 90 08 29
✉ alain.fagot@dorea.fr

Fernandez Rico, German
Max-Planck-Institut für Sonnensystemforschung
Germany
☎ +49 551 384 979 407
✉ fernandez@mps.mpg.de

Ferrier, Michèle
THALES ALENIA SPACE
France
☎ +33 49228 9966
✉ michele.ferrier@thalesaleniaspace.com

Fraspauce, Olivier
AIRBUS DEFENCE & SPACE
France
☎ +33 1 39 06 78 72
✉ olivier.frapsauce@astrium.eads.net

Frey, Anja
ESA
Netherlands
☎ +31 71 565 5068
✉ anja.frey@esa.int

Friso, Enrico
FRS Consulting srl
Italy
☎ +39 346 753 0867
✉ enrico.friso@gmail.com

Gencosmanoglu, Asli
Active Space Technologies GmbH
Germany
☎ +49 30 6392 6058
✉ asli.gencosmanoglu@activespacetech.eu

Gerstmeier, Michael
OHB System AG
Germany
☎ +49 89 7249 5240
✉ michael.gerstmeier@ohb.de

Hugonnot, Patrick
THALES ALENIA SPACE
France
☎ +33 6 73 56 41 10
✉ patrick.hugonnot@thalesaleniaspace.com

Hulier, Jean-Pierre
AIRBUS Defence and space
France
☎ +33 13906 1984
✉ jean-pierre.hulier@astrium.eads.net

Jacques, Lionel
Centre Spatial de Liège - University of Liège
Belgium
☎ +32 4 382 46 42
✉ ljacques@ulg.ac.be

Jahn, Gerd
Airbus DS GmbH
Germany
☎ +49 7545 8 3472
✉ gerd.jahn@astrium.eads.net

Kasper, Stefan
Jena-Optronik GmbH
Germany
☎ +49 3641 200 176
✉ stefan.kasper@jena-optronik.de

Kirtley, Chris
ITP Engines UK
United Kingdom
☎ +44 116 284 5653
✉ chris.kirtley@itp-engines.co.uk

Klement, Jan
Tesat Spacecom
Germany
☎ +49 719 1930 1689
✉ Jan.Klement@tesat.de

Laine, Benoit
ESA
Netherlands
☎ +31 71 565 3217
✉ benoit.laine@esa.int

Leroy, Sandrine
DOREA
France
☎ +33 4 92 90 08 29
✉ sandrine.leroy@dorea.fr

Liquière, Nicolas
EPSILON Ingénierie
France
☎ +33 561 001 929
✉ nliquiere@epsilon-alcen.com

Maas, Alexander
Dutch Space
Netherlands
☎ +31 71 524 5922
✉ a.s.maas@dutchspace.nl

Marach, Siarhei
Peleng
Belarus
☎ +37 52 9822 9413
✉ sergeyma@open.by

Markelov, Gennady
ATG-Europe
Netherlands
☎ +31 71579 5500
✉ Gennady.Markelov@atg-europe.com

Mas, Guillaume
CNES
France
☎ +33 56127 3102
✉ guillaume.mas@cnes.fr

Mathias, Yorick
AIRBUS DEFENCE & SPACE
France
☎ +33 1 39 06 60 58
✉ yorick.mathias@astrium.eads.net

Melendo, Ignacio
AIRBUS Defense and Space
Spain
☎ +34 65015 9486
✉ ignacio.melendo@astrium.eads.net

Morgenroth, Lutz
OHB System AG
Germany
☎ +49 89 7249 5109
✉ lutz.morgenroth@ohb.de

Moroni, David
AVIO
Italy
☎ +39 06 9728 5207
✉ david.moroni@avio.com

Muenstermann, Rolf
Airbus DS GmbH
Germany
☎ +49 421 539 5011
✉ Rolf.Muenstermann@astrium.eads.net

Nadalini, Riccardo
Active Space Technologies GmbH
Germany
☎ +49 30 6392 6071
✉ riccardo.nadalini@activespacetech.com

Nerriere, Rose
Airbus Defence and Space SAS
France
☎ +33 5 62 19 58 59
✉ rose.nerriere@astrium.eads.net

Neto, Joao
Active Space Technologies GmbH
Germany
✉ Joao.Neto@activespacetech.com

Oger, Patrick
AIRBUS DEFENCE & SPACE
France
☎ +33 39 06 24 50
✉ patrick.oger@astrium.eads.net

Persson, Jan
ESA
Netherlands
☎ +31 71 565 3814
✉ jan.persson@esa.int

Pfaltzgraff, Antoine
Jena-Optronik
Germany
☎ +49 36 4120 0227
✉ Antoine.Pfaltzgraff@jena-optronik.de

Pin, Olivier
ESA ESTEC Thermal Control Section
Netherlands
☎ +31 71 565 5878
✉ olivier.pin@esa.int

Rathjen, Harold
Private
Germany
☎ +49 421 539 4225
✉ JanneMarieke.Wendt@astrium.eads.net

Romera-Perez, Jose Antonio
ESA-ESTEC
Netherlands
☎ +31 71 565 3979
✉ jose.antonio.romera.perez@esa.int

Rooijackers, Harrie
ESA/ESTEC
Netherlands
☎ +31 71 565 3453
✉ Harrie.Rooijackers@esa.int

Ruzza, Paolo
CGS Compagnia Generale Spazio
Italy
☎ +39 02 3804 8371
✉ pruzza@cgspace.it

Schweikle, Salome
Surrey Satellite Technology Limited
United Kingdom
☎ +44 14 8334 4880
✉ j.hart@sstl.co.uk

Simonian, Sahak Menzo (Samo)
ATG Europe
Netherlands
☎ +31 6 1255 6991
✉ samo.simonian@atg-europe.com

Soriano, Timothée
Astrium satellites
France
☎ + 33 5 62 19 91 76
✉ timothee.soriano@astrium.eads.net

Stroom, Charles
CL&W
Netherlands
☎ +31 6 4284 9092
✉ charles@stremen.xs4all.nl

Theroude, Christophe
Airbus Defence and Space
France
☎ +33 5 62 19 68 85
✉ christophe.theroude@astrium.eads.net

Tirolien, Thierry
ESA
Netherlands
☎ +31 71 565 4096
✉ thierry.tirolien@esa.int

Torralbo, Ignacio
IDR/UPM
Spain
☎ +34 65194 9800
✉ ignacio.torralbo@upm.es

Tosetto, Andrea
BLUE Engineering
Italy
☎ +39 01 1950 4259
✉ a.tosetto@blue-group.it

Trinoga, Martin
Airbus DS GmbH
Germany
☎ +49 421 539 4976
✉ Martin.Trinoga@astrium.eads.net

Ucan, Meric
Tubitak Uzay
Turkey
☎ +90 210 1310
✉ meric.ucan@tubitak.gov.tr

Unses, Emre
TÜBİTAK UZAY
Turkey
☎ +90 210 1310
✉ emre.unses@tubitak.gov.tr

Valentini, David
THALES ALENIA SPACE
France
☎ +33 49292 7404
✉ david.valentini@thalesaleniaspace.com

Van Benthem, Roel
National Aerospace Laboratory (NLR)
Netherlands
☎ +31 88511 4231
✉ Roel.van.Benthem@nlr.nl

Van der Merwe, Daniël
Spaceteq
South Africa
☎ +27 21 880 8131
✉ nvdmerwe@spaceteq.co.za

Van Es, Johannes
National Aerospace Laboratory NLR
Netherlands
☎ +31 88 511 44 44
✉ Johannes.van.Es@nlr.nl

Vaughan, Matthew
ESA
Netherlands
☎ +44 79 1306 1149
✉ matthew.vaughan@esa.int

Warkentin, Viktor
OHB System AG
Germany
☎ +49 421 2020 9742
✉ viktor.warkentin@ohb.de

Winter, Daniel
ESA (TEC-MTV)
Netherlands
☎ +31 71 565 6348
✉ daniel.winter@esa.int

Zamboni, Andrea
SELEX ES
Italy
☎ +39 654 9403
✉ andrea.zamboni@selex-es.com