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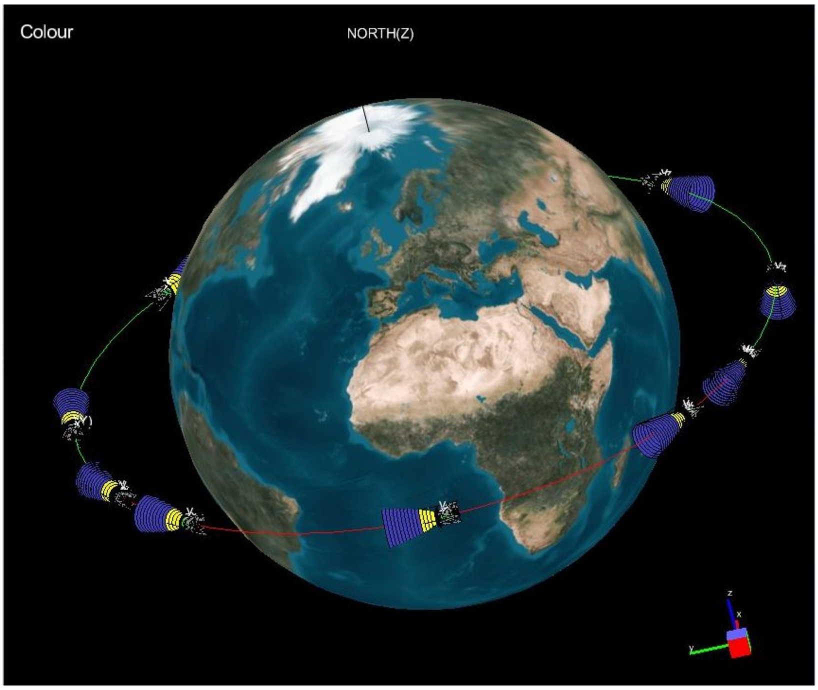

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European Space Agency
Agence spatiale européenne

Abstract

This document contains the presentations of the 29th European Space Thermal Analysis Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on 3–4 November 2015. 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 text like this are clickable hyperlinks in the document.
⇒ This document contains video material. By (double) clicking on picture of a video the movie file is copied to disk and then played with an external viewer. This has been tested with Adobe Reader 9 in Windows and Linux using vlc as external viewer. Other pdf readers may not work automatically. As a last resort the user can manually extract the movie attachment from the file and play it separately.

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Romain Peyrou-Lauga (ESA-ESTEC, The Netherlands)

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Anja Frey & Giulio Tonellotto (ESA/ESTEC, The Netherlands)

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Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Appendix B

OrbEnv
A tool for Albedo/Earth Infra-Red environment parameter determination

Alex Green
(University College London, United Kingdom)

Romain Peyrou-Lauga
(ESA-ESTEC, The Netherlands)

Abstract

OrbEnv is a tool developed for ESA missions to provide realistic and less enveloping albedo coefficient and Earth temperature range for an orbit using data measured by satellites. The tool is able to treat the most common orbit types (LEO, SSO, HEO, MEO...) and is able to calculate impinging albedo and Earth fluxes for several basic geometries and several time steps. Data comes from the CERES instrument on NASA's Terra satellite and covers more than 6 years of measurement.

Appendix C

Mercury Retro-Reflection
Modelling and Effects on MPO Solar Array

Anja Frey Giulio Tonellotto
(ESA/ESTEC, The Netherlands)

Abstract

Mercury's regolith might reflect the incident sun light preferably in the direction of the Sun, causing a retro-reflection effect. In the case of the BepiColombo Mercury Planetary Orbiter solar array this deviation from the bond albedo, which is implemented in most thermal analysis software, may cause significant temperature differences. This causes power losses since the solar array is continuously steered throughout the orbit in order to optimize its sun aspect angle (maximum sun power) without exceeded the design temperatures.

To estimate the influence of this albedo variation the mathCAD sheet Mercury Orbital Heat Fluxes Assessment (Merflux), developed by ESTEC's D. Stramaccioni, was adapted to calculate the heat fluxes that a spacecraft experiences in orbit around Mercury when considering the retro-reflection. Different albedo modelling options were implemented and finally the diffusive reflection modelling was compared with a directional reflection case, where sunlight is reflected back into the direction of the Sun more than into the other directions. The directional reflection modelling was considered the most realistic, based on findings in literature.

The peak albedo flux, impinging on a nadir-pointing cube, calculated with this directional model, was found to be more than twice the flux calculated with the diffusive approach, while the integral remains the same (energy balance of the planet). An extensive parametric study, with different solar panel models and attitudes, concluded that the influence of the albedo modelling has a non-negligible influence on the solar array temperature. For a fixed solar aspect angle throughout the whole orbit, the biggest difference in temperature between the two albedo models was found to be +14°C/ -10°C. A more realistic approach used a steering profile provided by ESOC and found maximum ΔT of +8°C/ -5°C. These worst ΔT are local peaks, not applicable to the whole orbit, nor applicable to the most critical panel wing of the solar array, whose ΔT is only +4°C/ -4°C. Around the sub-solar point the directional albedo provides the highest temperatures, while they are lower at the poles.

This information will permit preparing the best approach for solar array in orbit steering functions definition and calibration.

Appendix D

On the thermal design and modelling of calibration blackbodies for the FCI and IRS instruments on MTG

Nicole Melzack
(RAL Space, United Kingdom)

Abstract

[1] The Meteosat series of spacecraft are meteorological satellites, providing a range of data that inform weather forecasts across Europe. First generation satellites have flown, second generation (MSG) are currently operational, and the third generation (or MTG) will provide data well into the 2030s. Two instruments going on the MTG satellites will be calibrated using the blackbody targets that are being designed at RAL Space.

The blackbody targets are required to operate at temperatures between 100–370 K. The challenge involved in this includes providing single targets that can physically achieve and operate successfully at both thermal extremes, while also meeting stringent temperature gradient requirements. This presentation will cover the thermal design solution, which involves using helium gas conduction, and how it has been modelled in ESATAN-TMS. The testing of the prototype and the limitations of modelling gas conduction in ESATAN-TMS will also be discussed.

[1] Due to severe weather conditions the author was unable to attend the workshop and present this material.

Appendix E

Development of methodologies for Brightness Temperature evaluation for the MetOp-SG MWI radiometer

Alberto Franzoso
(CGS, Italy)

Sylvain Vey
(ESA/ESTEC, The Netherlands)

Abstract

The MicroWave Instrument (MWI) is a conical scanning radiometer, which shall be embarked on MetOp Second Generation satellite. MWI will provide precipitation monitoring as well as sea ice extent information. It is now entering the detailed design phase.
Conical scanning radiometers are characterized by a continuous instrument calibration, with the sensors passing, at every rotation, below two calibration sources: a cold sky reflector providing 3K reference, and an On Board Calibration Target (OBCT) which provides an Hot temperature reference.
The high performance required to the instrument implies that the OBCT temperature is known with high accuracy, and that the gradients along its surface are suppressed. However, gradients are intrinsic to the structure of the OBCT, and driven by the day-night induced temperature cycles of its environment. Gradients can therefore only be minimized through a very extensive use of active control on the OBCT thermal environment.
The development of a Brightness Temperature computation method, i.e. the computation of the temperature sensed by the radiometer in the RadioFrequency (RF) band, was therefore a necessary step for the instrument thermal control optimization. It allowed to assign the limited instrument resources in the most efficient way, and to justify the design solutions.
In this presentation the details of the Brightness Temperature (BT) computation are provided. The OBCT temperature maps are generated by Thermica 4.6.1 using its fast-spin feature and are then post-processed with MatLab, filtering them with the Feed Horns Patterns. This results in the BT profiles along the orbit, with their associated errors. The method is then extended to the *High Frequency* analysis in order to assess the influence of each position of the rotation cycle on the BT. Results are shown, demonstrating that a passive thermal control is suitable to meet the strict performance requirements.

Appendix F

MASCOT thermal design
how to deal with late and critical changes

Luca Celotti Małgorzata Sołyga
(Active Space Technologies GmbH, Germany)

Volodymyr Baturkin Kaname Sasaki Christian Ziach
(DLR, Germany)

Abstract

MASCOT is a lander built by DLR, embarqued on JAXA's Hayabusa-2, a scientific mission to study the asteroid 162173 1999 JU3, launched on the 3rd of December 2014. As part of the project challenges, the short schedule for the whole development of the lander (2.5 years from PDR to launch), the strict and contrasting thermal requirements for different phases of the mission, mass&power/technology/volume limitations put the thermal design at the edge of the state of art technology solutions. As a result, the thermal system development has been on-going until the last phases of the project, on order to cope with late changes and technologies development.

This presentation focusses on the thermal control system evolution during the last months before launch and just after it and the tight schedule available to cope with late system changes. It shows the design modifications and updates, together with thermal modelling changes following intensive testing phases, in particular for the lander battery pack and the heating/pre-heating strategy for different mission phases. Many thermal vacuum campaigns, modelling re-iterations, better understanding of the main S/C thermal behaviour, together with the great team determination helped reaching a succesfull launch followed by an on-flight system verification.

Appendix G

Solar Orbiter SPICE
Thermal Design, Analysis and Testing

Samuel Tustain
(RAL Space, United Kingdom)

Abstract

[1] The Spectral Imaging of the Coronal Environment (SPICE) is one of ten instruments comprising the ESA Solar Orbiter payload. The instrument, currently being built at the STFC Rutherford Appleton Laboratory, is a high resolution imaging spectrometer operating at extreme ultraviolet wavelengths. We are currently in the build phase, with thermal testing of the flight model instrument due to commence shortly.

At an orbital perihelion of just 0.28 AU, there are numerous key design challenges that must be overcome for the instrument to survive the harsh thermal environment that it will be subjected to. In the last 18 months, the instrument has already undergone considerable thermal testing to qualify the design. The results of the tests completed thus far have provided essential inputs into the existing detailed thermal model, which is constructed using ESATAN-TMS. This presentation will discuss how the thermal analysis and testing have complemented each other for this project, while also providing impressions of ESATAN-TMS from the perspective of a relatively early user.

[1] Due to severe weather conditions the author was unable to attend the workshop and present this material.

Appendix H

Spatial Temperature Extrapolation Case Study
Gaia in-flight

Matthew Vaughan
(ESA/ESTEC, The Netherlands, Airbus Defence and Space, France)

Abstract

The project IAMITT (Innovative Analysis Methods for Improved Thermal Testing) was defined by ESA to address the issues of thermal test quality, cost and schedule reduction. One aspect of this project concerns the application of the techniques of spatial extrapolation with the aim to provide a full thermal map of a spacecraft given input temperature sensor data. This information is of particular interest during spacecraft thermal testing where a temperature may be recovered in the case of a sensor malfunction. It could also be useful in the prediction of temperatures for areas of the spacecraft that are normally difficult to instrument or to give the thermal engineer a more informed choice on the positioning of sensors.

A novel case study was proposed using the Gaia spacecraft to perform an extrapolation using the thermal model and in-flight telemetry. Firstly the thermal environment of Gaia's orbit at L2 is considered together with the requirements for an extrapolation. The algorithms behind the extrapolation are then highlighted together with the techniques used to combine in-flight telemetry with a correlated thermal model. The procedure of synchronising the time in the model with the flight data is then discussed including the assumptions made with respect to solar fluxes and internal dissipations.

The results are then presented comparing the differences between the model predicted and in-flight extrapolated temperatures. A heat balance on the boundary nodes is also used as an additional method to check the method against predicted values. Finally the extrapolated temperatures are visualised on the thermal model and possible benefits to the thermal engineer are reviewed.

This work has been carried out under the *Young Graduate Trainee in Industry* scheme of ESA in cooperation with Airbus Defence and Space, Toulouse, France.

Appendix I

Accelerating ESATAN-TMS Thermal Convergence for Strongly Coupled Problems

Christian Wendt Sébastien Girard
(Airbus Defence and Space, Germany)

Abstract

ESATAN-TMS Thermal solves the heat conductance differential equation (DE) for the lumped parameter thermal network node temperatures considering heat sources as well as linear (also one way) and quartic (radiative) heat exchanges between the nodes. Extensions to this modeling are available for fluid loops and ablation, namely FHTS and ABLAT. However, embedding other relevant thermodynamic phenomena, as e.g. ice sublimation during ascent of a launcher or pressurization/depressurization of a vessel, may provoke other strongly coupled heat sources and additional, segregated DE, which may impact the accuracy of the result. Even then one will usually succeed in reaching the required accuracy by choosing sufficient small time-steps, but at the cost of significantly increased CPU time. An innovative method based on a predictor-corrector-method (PCM), representing a workaround for accelerating the convergence, has been implemented and will be explained here. This method uses standard ESATAN entities only, i.e. auxiliary nodes, heat sources and one way linear conductors. For the example of ice sublimation during launcher's ascent this method is explained in detail and the benefit is demonstrated in conjunction with a specific solver option provided by ESATAN-TMS Thermal software developers in the frame of this work. Using this innovative method the time-step can be increased by nearly a factor of 100 for the given example.

Appendix J

OHB System
Thermal Result Viewer

Markus Czupalla S. Rockstein C. Scharl M. Matz
(OHB System, Germany)

Abstract

Driven by mission demands for improved performance, more precise prediction etc. a trend is observed to bigger thermal models simulated with a high transient resolution. The built-in post- processing capabilities of commercial software codes often cannot cope with the model and result file sizes. Further the necessary post-processing is split over multiple tools which are often not easy to handle.

Over the last couple of years an integral thermal post-processing tool has been developed at OHB Munich, which combined the necessary capabilities and offers a convenient and fast user I/F. The Thermal Result Viewer (TRV) has among others the following main features:

- Import of result files in different formats:
  - *.TMD
  - *.out
  - *.csv
- Import of the model structure from different sources:
  - GMM model (*.erg)
  - TMM result file (*.TMD)
  - Excel list (*.xlsx)
  - Manual setting in the program
- Simultaneous visualization of 3-D and 2-D temperature and heat flux maps and plots for selected groups
- Transient group based visualization of the internal hat fluxes in a model (conductive and radiative) – without the necessity to program it into the TMM beforehand.
- Easy and intuitive graphical user Interface (GUI)

A Demonstration of the TRV functionality will be presented and discussed in the presentation.

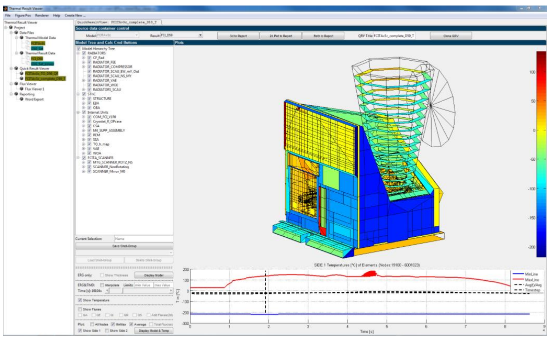

Figure J.1: Example Temperatures Visualization in TRV

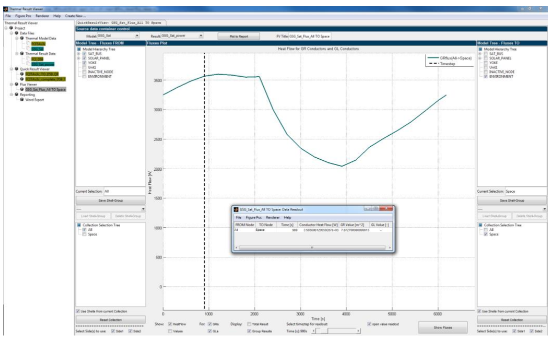

Figure J.2: Example Heat Flux Visualization in TRV

Appendix K

Overview of ECSS Activities for Space Thermal Analysis

James Etchells
(ESA/ESTEC, The Netherlands)

Abstract

This presentation will provide an overview of the two ongoing ECSS activities in the field of space thermal analysis, in particular:

- ECSS-E-HB-31-03: Thermal analysis handbook
- ECSS-E-ST-3104: Exchange of Thermal Model Data for Space Applications

The thermal analysis handbook will soon be sent out for public review and this workshop therefore provides an opportunity to make the community aware of it.
Concerning the standard on thermal model exchange, this is the formalisation under ECSS of the STEP-TAS protocol. The aims and objectives of the working group will be presented along with some discussion about the expected form of the final standard.

Appendix L

Improve thermal analysis process with Systema V4 and Python

Alexandre Darrau
(Airbus Defence and Space, France)

Abstract

When performing analyses, thermal engineers follow a methodology to ensure results quality and traceability. However, some checking or/and post-processing operations are still manually done or are performed later in the analysis process, leading to error and time wasting.
The purpose of this presentation is to introduce how the Airbus Defence & Space Thermal Engineering department in Toulouse is working to overcome these difficulties using new Systema V4 functions and Python technology. An example for each thermal analysis stage is going to be presented to illustrate.

Appendix M

Finite element model reduction for spacecraft thermal analysis

Lionel Jacques Luc Masset 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.
Both methods offer advantages and disadvantages and the proposed global approach tries to combine both methods:

- The LPM conductive links are 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.
- On another hand, due to the large number of elements composing a FE model, the computation of the radiative exchange factors (REFs) is prohibitively expensive. New methods to accelerate the REFs computation by ray-tracing are necessary. Ray-tracing enhancement methods were presented in the previous editions, providing at least a 50% reduction of the number of rays required for a given accuracy. Another way to speed up the REF computation consists in grouping the FE external facets into super-faces. Surfaces in FEM are approximated where primitives are used in the LPM. In parallel to super-faces, quadric surface fitting of selected regions in the FE mesh is therefore performed where high surface accuracy is required for the computation of the radiative links and environmental heat loads.

Last year's presentation focused solely on the first point. Developments of super-face ray-tracing with quadrics fitting will be presented. In addition to REFs, orbital heat loads computation is also implemented with significant improvement. The presentation will also address the global process involving first the detailed FE model conductive reduction, then the super-faces generation with selective quadric fitting for the computation of REFs and orbital heat loads and finally the computation of the reduced model temperatures. Detailed FE model temperature field can then be computed back from the reduced ones and the reduction matrices for potential thermo-mechanical analyses.

Appendix N

The Thermal Design of the KONTUR-2 Force Feedback Joystick

Ralph Bayer
(DLR, Germany)

Abstract

The KONTUR-2 Mission is a cooperation between the German Aerospace Center (DLR), ROSKOSMOS, RSC Energia and the Russian State Scientific Center for Robotics and Technical Cybernetics (RTC). Its purpose is to study the feasibility of using teleoperation to control robots for tasks such as remote planetary explorations. The operating human would be stationed in orbit around the celestial body in a spacecraft. For KONTUR-2, the earth is utilized as the celestial body, and the ISS as the spacecraft with the ISS crewmember as the operator. The main goals of this mission are the development of a space-qualified 2 degrees of freedom (DoF) force feedback joystick as the human machine interface (HMI), the study and implementation of underlying technologies to enable telepresence in space, and the analysis of telemanipulation performance of robotic systems. The DLR KONTUR force feedback joystick was upmassed and installed in the Russian Service Module of the ISS in August 2015. The first of a series of experiments to be completed by December 2016, were carried out successfully.

Meeting the thermal requirements of the joystick is one of the key challenges in the KONTUR-2 Mission. This presentation focuses on the thermal design for the force feedback joystick to cope with the unique conditions in a manned spacecraft. In order to reduce complexity, and further improve safety aspects for the integration on board the Russian segment of the ISS, active cooling has been eliminated in the force feedback joystick. Furthermore, as a safety measure, a temperature control system (TCS) has been developed and implemented able to respond to all unforeseen disturbances.

This presentation outlines DLR's approach to handle the unpredictable thermal output of the mechatronic system, resulted from a complex combination of the specific task, and the operating handling of the Cosmonaut. This in turn directly influenced the design to meet the mission's requirements, which includes the physical human-joystick interaction, storage on board the ISS, electronic components, operation time, and system performance.

Appendix O

ESATAN Thermal Modelling Suite
Product Developments and Demonstration

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

Abstract

Product Developments

ESATAN-TMS r7 was released at the end of 2014 and focused on improvements throughout the thermal modelling process, taking into account feedback received through our customer survey. The work has continued at a high-level, with a significant number of developments being finalised which centre on improving both the effectiveness of the interface and the *look and feel* of the product. Through close discussions with customers, the next release will also see a series of developments, either extending existing functionality or providing exciting new modelling features.

This presentation outlines the developments to be included within the next release of ESATAN-TMS.

Product Demonstration

A demonstration of the development version of ESATAN-TMS shall be provided, focusing on the new features of the product.

Appendix P

SYSTEMA — THERMICA

Timothée Soriano Rose Nerriere
(Airbus Defense and Space SAS, France)

Abstract

SYSTEMA, currently in version 4.7.1, is a framework for space physics applications including THERMICA, a package dedicated to thermal simulations.
The next version will be the 4.8.0 and will include a new schematic module which will allow the definition of power systems and will ease the thermo-electrical simulation process.
Besides, SYSTEMA has the ability to manage the solar system including different moons, like Ganymede, Europa and others for which orbits are approximated by Keplerian laws around a particular date of interest. A trajectory defined around a moon like Ganymede will lead to simulate fluxes both from the moon itself but also from other planets, like Jupiter in this example.
Finally, a new applicative module within Systema, called Mapping, offers the possibility to transfer data from one model to another one: fluxes from a Plume analysis to a thermal model, temperatures to an outgassing model or to mechanical mesh. For the temperature mapping, a new method based on a "backward RCN" has been set-up. This method is capable of interpolating temperatures within a re-built quadratic profile onto the thermal mesh and offers then a very accurate mapping consistent with the hypothesis of the thermal simulation.

Appendix Q

Thermal Spacecraft Simulator Based on TMM Nodal Model
Return of Experience

Sandrine Leroy François Brunetti
(DOREA, France)

Abstract

Many advantages have been depicted to use the same thermal mathematical model from early design phases to operational phases of the satellite : higher reliability of the thermal model, cost reduction by reusing the model and adaptations work load minimisation.
The dynamic spacecraft system simulator is used to validate the spacecraft control center, but also to train operators. This last user case implies the simulator to react to not predicable events, unplanned scenarios while respecting the physics of the environment.
The thermal analysis model is used to validate the satellite design by predicting temperature ranges for embedded units by calculating temperatures of thermal control elements for given configurations of the environment. Because it is also important to simulate the logic of the flight software (such as thermal regulation), an implementation of the transient state based on simulated time cannot be avoided.
The implementation of a satellite simulator connected to the real flight software using the same thermal nodal model faces many challenges such as the recalculation "on the fly" of the view factors, solar, albedo and earth fluxes impacts on the external CAD model. Another challenge is to make the loop flight software - power dissipation generator - thermal calculator not hanging. For this reason, the thermal simulator regulation must be switched off in order to let the flight software drive the thermostats and thermal temperatures time response should also be adjusted in order to fit the physics time .
Thales Alenia Space Cannes asked DOREA to implement the thermal real-time simulator based on the thermal mathematical model (TMM) provided by thermal analysis team. Thanks to the very good time performances of the e-Therm thermal core calculator (external fluxes, view factors and temperatures calculations), a real time module with parallelism features have been implemented to fit the challenge.
After the success of the O3B Networks and Alphasat dynamic spacecraft simulators in 2013, Thales Alenia Space asked DOREA to implement all the following thermal simulators such as Iridium Next, TKM, SGDC and in the future T3S, K5 and KA7.

Appendix R

Correlation of two thermal models

Marije Bakker Roel van Benthem
(NLR, The Netherlands)

Abstract

Reduced thermal models are often required in the design phase of projects. Reduced models have the advantage that they provide a reasonable level of accuracy while maintaining short calculation times. It is common to first build a detailed model, which is then reduced in the same software package. Grouping of nodes and thermal properties requires a lot of physical insight and can be a tedious job.
This presentation will offer a different approach with the same advantages, but without the tedious node grouping in the reduction step. An analytical model for the thermal analysis of wiring is correlated with a more accurate numerical model. By this correlation, the level of accuracy of the analytical model is increased, while maintaining short calculation times. The model has been developed for aircraft applications, but can be used for aerospace applications as well. After a short introduction in the model and its applications, the presentation will mainly focus on the different steps in the correlation process.

Appendix S

Experience of Co-simulation for Space Thermal Analysis

François Brunetti
(DOREA, France)

Abstract

Thermal models for space analysis are more and more complex and the idea of having one homogenous model covering different physics such as heat transfer, fluid-dynamics, thermo-dynamics and thermo-elastic is difficult to support. One solution is to open the code to others tools dedicated to bring a complementary physics. The co-simulation is a good candidate to solve the exchange of heterogeneous calculation results but many different techniques and options should be considered at software design level. According to the performances and architecture of the simulators, a co-simulation can be generic or hybrid and impact of the choice of this option may be very expensive. Depending on the physics context, the developer should determine which code would be the master or slave, depending of physics time constants involved in both codes. More depending on computer constraints, an important choice is to specify the communication protocol (such as shared memory or TCP-IP). Some standards such as FMI (Functional Mock Up Interface) are pointing and seam to be pretty candidates, but most of tools provide their own interfaces.

In this presentation we would discuss about DOREA experience and chosen strategy while mixing both CAE simulators : e-Therm (thermal analysis software) bringing the satellite system nodal model and LMS Siemens AMEsim (CFD), especially the dedicated AMErun module with the co-simulation option, to solve the fluids and thermo-dynamics (dysphasic fluxes of a fluid loop) for transient but also steady state calculations.

Appendix T

GENETIK+
Introducing genetic algorithm into thermal control development process

Guillaume Mas
(CNES, France)

Abstract

In 2014, GENETIK+, a tool that couples CNES genetic algorithm with SYSTEMA Software has been developed, showing great potential to help thermal engineers in their work.
In 2015, new functionnalities have been implemented to GENETIK+ to help analyzing physically the results of the optimization process such as visualization of the response surface and sensitivity analyses.
Thanks to these updates, GENETIK+ has been used on real application cases to show the interest of using optimization algorithm in each steps of thermal control development process.
From worst case analyses to in-flight model correlation, the results obtained with GENETIK+ open new possibilities for thermal engineers.
The objectives of the presentation are to:

- Present GENETIK+ functionalities
- Show the potential of introducing optimization algorithms into thermal control development process

Appendix U

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