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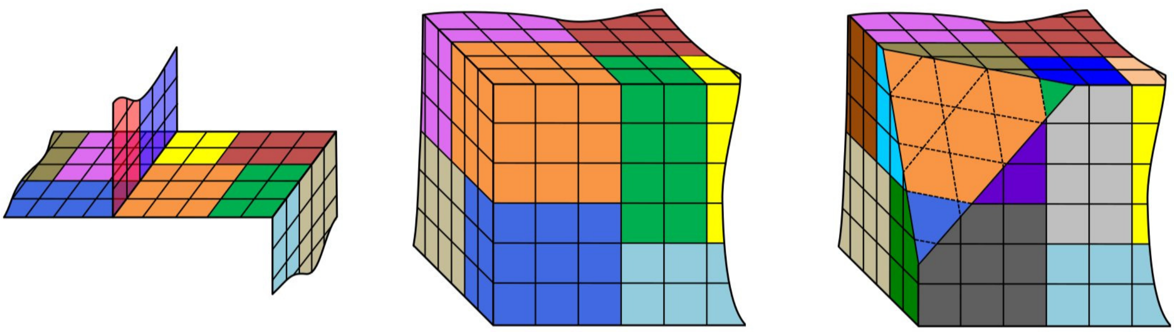

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European Space Agency
Agence spatiale européenne

Abstract

This document contains the presentations of the 30th European Space Thermal Analysis Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on 5–6 October 2016. 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.
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13:00 Closure

13:00 Lunch in the ESTEC Restaurant

Opening address

Good Morning Ladies and Gentlemen
Dear Colleagues and Friends

On behalf of the European Space Agency, I have the pleasure to welcome all of you to this 30th edition of the Space Thermal Analysis Workshop here at ESTEC and I would like to express a warm welcome to all participants coming from various ESA Member States and a number of other countries.

30th anniversary ! That is quite an achievement and also a sort of record.

It started out as the ESATAN workshop in 1985 with 38 attendants and was promoted and organized by my now retired colleague Charles Stroom with the aim

- to introduce the ESATAN space thermal analysis tool to the European thermal community as a replacement for SINDA
- and to create a forum to exchange information and experience between users and developers

The second workshop was held in 1987 and called "ESATAN Users Meeting". After the third one in 1989, the workshop has been taking place every year since that time.

I unfortunately did not attend the first two workshops in 1985 and 1987 - as I only joined the Agency in December of 1987. But then I had the pleasure to attend many of the 28 workshops over the years.

Looking back at the development of space thermal analysis there has been quite some changes and a lot of progress.

From tools like CBTS, VWHEAT (with VUFACT, RADCON, ROHCAT), VUVU, MATRAD, Manip, Polytan, ESABASE, ESARAD to today's ESATAN-TMS, EcoSim, Thermica/Thermisol, TMG and others with powerful pre- and post-processing tools and advanced GUI's make the life of the thermal engineer easier.

However, a word of warning from an old thermal engineer - any software tool is only as good as the engineer sitting on the other side of the terminal. Experience and thermal engineering knowledge is still very much needed prior to switching on the computer and using any of these tools. And the experience and knowledge is even more needed when looking at the results!

Over the years, the scope of the workshop has significantly evolved, as ESA's approach to the thermal tools also evolved.

The workshop objectives today are:

- to promote the exchange of views and experiences amongst the users of European thermal analysis tools and related methodologies
- to provide a forum for contact between end users and software developers
- to present new features of thermal tools and solicit feedback for development
- to present innovative methodologies, standardisation activities.

Let me also say a few words on statistics:

Over the last 30+ years we have had - including this year's - close to 600 presentations and almost 2000 registered external participants, some of them attending many workshops over the years. I want to sincerely thank all participants and authors, past and present.

This year again more than 100 participants have registered, which confirms the interest and important role of Thermal Software & Analysis Methods to the space community. For us, this is a clear sign of appreciation and a confirmation of the usefulness of this workshop and it also clearly demonstrates the continued need for such events to exchange information and to strengthen further cooperation on the subject as well as to provide recommendations for future developments.

I also want to take the occasion to thank all my colleagues - Harrie, Duncan and also the Conference Bureau - who have worked hard to prepare and organise these workshops.

I hope you will find this event both enjoyable and rewarding and I want to wish you all a very fruitful and interesting workshop.

Let me now hand over to my colleague Harrie Rooijackers, the organiser of the workshop, who will provide you with some details on the logistics.

Wolfgang Supper
Head of Thermal Division

Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Appendix B

GENETIK+

Near-real time thermal model correlation using genetic algorithm

Guillaume Mas
(CNES, France)

Abstract

Using the recent improvements of GENETIK+, CNES tool that couple genetic algorithm to SYSTEMA, a new method dedicated to thermal test follow-up and explotation has been developed and validated.
This method, based on the previous development on analytical model reduction using genetic algorithm, offers the possibility to perform thermal sensors time extrapolation and near-real time thermal model correlation.
First tested on simple example, the method has been applied during real thermal test in CNES facilities.
The objective of the presentation is to:

- Present the method
- Show the potential of this method on real example

Appendix C

World Space Observatory-Ultraviolet
Thermal Analysis of Spacecraft Electronics

Samuel Tustain
(RAL Space, United Kingdom)

Abstract

The World Space Observatory-Ultraviolet (WSO-UV) is an upcoming mission led by Roskosmos that aims to provide a major space observatory operational at ultraviolet wavelengths. RAL Space is working in collaboration with e2v on the World Space Observatory UV Spectrographs (WUVS) instrument, with RAL Space being primarily responsible for the design, build and testing of the Camera Electronics Box (CEB) that drives the instrument.

This work at RAL Space follows on from previous electronics box projects on spacecraft such as the NASA Solar Dynamics Observatory (SDO) and the Geostationary Operational Environmental Satellite R Series (GOES-R). Thermal analysis of the CEB provides a difficult challenge, since in order to be meaningful the analysis must capture the hot spots within the electronics that are caused by high power dissipating components on the printed circuit boards. The thermal characteristics of these components are often poorly defined, which therefore introduces uncertainty in the results. The requirement to de-rate component temperature limits in accordance with product assurance standards such as ECSS adds additional challenge, since it significantly reduces any thermal margin within the design.

With the dissipated heat loads generated by on-board electronics expected to steadily increase as hardware becomes more sophisticated, these are issues that are likely to become more prevalent for future space missions. This talk will examine the rationale behind the modelling of the CEB, discuss possible thermal management solutions and describe the ways in which uncertainty is being defined and accounted for within the analysis.

Appendix D

Thermal mapping on Bepicolombo's Mercury Planetary Orbiter (MPO) using SINASIV

Claudia Terhes Simon Appel
(ESA/ESTEC, The Netherlands)

Abstract

Bepicolombo mission to Mercury poses complex problems in terms of environment aspects, and its effect on the structural behaviour of the spacecraft.
In order to analyse the spacecraft thermal elastic distortions cause by Mercury's harsh environment, the thermal node temperatures were mapped and interpolated on the structural finite element model using SINAS software.
This presentation will describe the work that has been done so far:

- Temperatures mapping onto the MPO finite element model;
- Challenges regarding the gradients areas and embedded heat pipes;
- Discrepancies between thermal and structural model and how they can be reduced.

Appendix E

Correlation of MLI Performance Measurement with a Custom MATLAB Tool

Lars Tiedemann Peter Lindenmaier
(HPS GmbH, Germany)

João Pedro Loureiro
(HPS Lda., Portugal)

Abstract

HPS has conducted MLI performance measurements at ESA ESTEC. The results where correlated using a custom MATLAB thermal modelling tool. With the tool it is possible to solve transient non-geometrical thermal problems allowing extremely quick parameter analyses. The tool was extremely useful for explaining unexpected test results.

MLI performance is measured with standardized test setups in a thermal vacuum chamber. The MLI specimen encloses a heater plate with controlled temperature and known heat output. The heater plate with the MLI wrapping is surrounded by a thermal shroud with controlled temperature. The thermal performance is then deduced from the temperature measurements of the inner MLI layer and the outer MLI layer assuming that the MLI is in thermal equilibrium (steady state).

The results obtained from the MLI performance measurement where not as expected and showed some irregularities which could not be explained initially. In order to verify the test results, transient simulations with a detailed model of the test setup where conducted using a custom MATLAB tool for thermal modelling.

The tool models each MLI layer with realistic properties including surface emissivity, specific heat capacity, density, thickness and area. Spacer material in between MLI layers is considered by introducing conductive contributions between adjacent layers taking into account the compression of the MLI.

The mathematical model applied could in fact reproduce the unexpected test results. The model clearly shows that the observed effects are due to the fact that the MLI has not achieved a thermal equilibrium even after 24 hours. The simulation achieved a steady state after setting the dwell time to 10^4 hours. In steady state, the thermal performance values where as expected.

The applied mathematical model could in fact explain the measurement results which where not as expected in the beginning. The reason for the deviation could be identified to be a transient problem. Finally, steady-state values for the MLI performance measurements could be obtained by extending the simulated dwell time. However, it is worthwhile discussing whether steady-state performance values are in fact helpful for modelling realistic MLI blankets or if it would be better to create a new set of thermal performance values that also considers transient effects which MLI has in reality.

Appendix F

Solar Orbiter STM Thermal Testing and Correlation

Scott Morgan
(Airbus Defence and Space, United Kingdom)

Abstract

Solar Orbiter is an ESA mission which will explore the Sun and the heliosphere closer than ever before. One of the main design drivers for Solar Orbiter is the thermal environment, determined by a total irradiance of 13 solar constants (17500 W/m^2), due to the proximity to the Sun. As part of the thermal design and validation process, the Solar Orbiter STM platform thermal balance test was performed in the IABG test facility in November- December 2015. This presentation will describe the Thermal Balance Test performed on the Solar Orbiter STM and the activities performed to correlate the thermal model and to show the verification of the STM thermal design.

Appendix G

Automated thermal model correlation

Martin Trinoga
(Airbus Safran Launchers, Germany)

Abstract

An essential part in the development of a spacecraft is the establishment of a thermal model for the thermal design and the temperature predictions during the operation phase. In order to improve the accuracy of the temperature predictions, all thermal spacecraft models need to be correlated with measurements from thermal tests or if available thermal flight data. Since 2013 a new tool for an automated model correlation is under development with the name TAUMEL. With this newly developed tool written in MATLAB(R) programming language it will be possible to correlate thermal models from ESATAN-TMS automatically. For the validation several different thermal models from real flight hardware such as various test models were used. A first insight was already given in the 28th European Space Thermal Analysis Workshop in October 2014. Within the last two years a significant progress was mastered. Especially the functionality and user-friendliness was improved in the last period and lead to a promising tool for an effective automated thermal model correlation. On this conference the latest status, highlights and results which were treated during the past development will be presented.

Appendix H

The challenges of modelling helium gas conduction and helium seal interfaces in ESATAN-TMS r7

Nicole Melzack
(RAL Space, United Kingdom)

Abstract

The Meteosat series of spacecraft are meteorological satellites, providing a range of data that inform weather forecasts across Europe. Two instruments going on the MTG (Meteosat Third Generation) satellites will be calibrated using the blackbody targets that are being designed at RAL Space.

Modelling of the ground based blackbody calibration targets was done in ESATAN-TMS r7. The targets use a helium gas gap heat switch as the main aspect of the thermal control system. This talk will cover the challenges involved in modelling the gas conduction, and will present the current implementation.

Other aspects of the design, such as determining the conductance across a complex interface involving a helium seal will also be discussed. This presentation will also touch on the correlation of the thermal model post prototype testing.

Appendix I

Improved integrated way of post-processing thermal result data

Henri Brouquet
(ITP Engines UK Ltd, United Kingdom)

Abstract

Post-processing and reporting of the thermal results is a significant part of the overall thermal modelling process. Clear presentation of results not only helps towards the understanding of the thermal behaviour of the model, but also helps towards model validation.
This presentation focuses on how ESATAN-TMS helps the thermal engineer work efficiently, removing the burden of repetitiveness by making the process fully automatic and integrated within a single interface.

Appendix J

Thermal modelling of thruster nozzles and plumes for planetary landers

Hannah Rana Andrea Passaro
(ESA/ESTEC, The Netherlands)

Abstract

Future planetary landers will embark optical sensors (e.g. cameras and imaging LIDAR) which will feed data to navigation and hazard avoidance systems, to enable safe and precise landing. These sensors may be located in proximity to thruster nozzles which, during landing, may reach temperatures around 1000K. It is therefore important to model the radiative fluxes impingent on the cameras due to the thruster as well as the plume created. Geometrically modelling the plume was achieved by establishing a mathematical model of the setup, and the emissivities of a series of truncated cones of the plume were determined. The thruster and plume were then modelled in ESATAN-TMS and the thermal impact was studied during landing phase. A preliminary engineering design was considered for the LIDAR and camera, and an overall methodology for thermally modelling thrusters and their plumes was established.

Appendix K

Thermal experiments on LISA Pathfinder's Inertial Sensors

Ferran Gibert
(University of Trento, Italy)

Abstract

LISA Pathfinder is an ESA mission with NASA collaboration aimed to test key technologies for a future space-based gravitational wave detector. The main objective of the mission is to demonstrate that two free-falling masses can be controlled inside the satellite with an unprecedented residual relative acceleration of less than 10 fm/s^2/sqrt(Hz) in the band around 1 mHz.
Among other kind of noise sources, temperature fluctuations can potentially play an important role in the experiment, since variations of temperature around the masses produce forces on them via three thermal effects: radiation pressure, outgassing and the radiometric effect. In order to keep these temperature-induced forces monitored, the instrument is equipped with series of high precision temperature sensors and with heaters that allow to inject characterization signals to the system.
Following to its successful launch in December 2015, the satellite started scientific operations in March 2016, and since then different thermal characterization experiments have been performed on the satellite's Inertial Sensors. In this presentation we will describe these experiments and report on the current status of their analysis.

Appendix L

Quasi-autonomous spacecraft thermal model reduction

Germán Fernández Rico
(Max Planck Institute for Solar System Research, Germany)

Isabel Pérez Grande Ignacio Torralbo
(Universidad Politécnica de Madrid, Spain)

Abstract

The lumped parameter method is widely used for thermal analysis of spacecraft. Often, the size of these thermal models needs to be reduced. A new method to reduce automatically the number of nodes has been developed. The reduction algorithm treats a processed conductive couplings matrix as a sparse graph adjacency matrix. Then, in order to identify the strongly connected components that define the condensed nodes, a depth-first search algorithm is used. The resulting restriction matrix serves to reduce the thermal entities, such as the conductive and radiative couplings matrices, thermal loads, etc. The method preserves the physical characteristics of the system (physical conductive paths, couplings matrices symmetry, etc.). The reduction process has been tested with a real thermal model (Solar Orbiter PHI instrument focal plane assembly). The results show a good correlation between the detailed and the reduced model, achieving a reduction in the number of nodes of about 75%. The limitations of the method and next steps are also shown.

Appendix M

Space Thermal Analysis through Reduced Finite Element Modelling

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

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.
LPM offers more accurate surfaces and fewer nodes to generate the radiative links while the FEM has automatic meshing tools and generation of conductive links. Coupled thermo-structural analyses are made straightforward if the same mesh can be used.
The proposed method brings together FEM and LPM by taking advantages on both sides. The structural FE mesh is reduced and the concept of super-node introduced. The reduction provides accurate conductive links and reduces the number of faces to compute the radiative links with Monte Carlo raytracing. The reduced model can integrate user logic in the exact same way a LPM model would do. Once the reduced model is solved using standard techniques, reduction matrices are exploited again to derive the detailed mesh temperatures for thermo-mechanical analyses.
To further reduce the computation time, quasi-Monte Carlo ray-tracing acceleration techniques were presented in the previous editions of the workshop, providing between 50% and one order of magnitude reduction of the number of rays required for a given accuracy. Combined with this acceleration technique, quadric surface fitting of selected regions in the FE mesh is performed to alleviate the FE mesh surface accuracy issue.
This presentation will summarise the research project developments carried out for the last four years. The end-to-end procedure will be detailed with actual space structures.

Appendix N

VEGA Launch Vehicle
Improved Fluidic Thermal Prediction Model

P. Perugini David Moroni Matteo Tirelli
(Avio S.p.A., Italy)

Abstract

The VEGA Launch Vehicle Thermal Prediction Model is introduced and its latest improvements described. With increased availability of sensor data from successfully performed flights it was possible to highlight the need for higher predictive accuracy, both in temperature trends and values, in some specific but crucial elements, in particular the 4^{th} stage liquid propulsion system main engine. It is in fact one of the most critical component due to the long mission requirements with respect to other stages engines, with complex attitude profiles in space environment and multiple re-ignitions.
In an upper Stage Assy, as the VEGA LV A4, the major concern is the propellant temperature, especially in the moments just before engine start-up, being related with combustion instabilities and performances. For this reason, ESATAN FHTS library capabilities were studied and fluidic network representing the engine feeding lines introduced in the Thermal Model.
Propellants properties are taken from available literature and dedicated libraries are developed to fit ESATAN required format.
Thrust Chamber cooling system is also included and complex heat exchanges between hot gases and engine structure accounted. Simulations temperature trends are compared with flight sensor data for previous flights resulting in a very good correlation.
The whole model is finally optimized in order to minimize impacts on runtime due to the new solution loop. Further improvements are foreseen both in fluid properties and model details.

Appendix O

SYSTEMA — THERMICA

Timothée Soriano Antoine Caugant
(Airbus Defense and Space SAS, France)

Abstract

Systema version 4.8.0 includes many improvements and corrections. Especially, the material database now handles different phases so to be able to set not only beginning-of-life and end-of-life properties but also for any customizable condition.
Moreover, a new ray-tracing algorithm based on a quasi-random approach has been developed and shown a very significant improvement in the accuracy of radiative couplings and external fluxes evaluations.
The python interface keeps being improved with more and more features and there are available scripts to export/import models in ASCII format or to help in the setting of parametric analysis.
Besides, the current developments are focusing on several new features. Some have already well progressed like the integration of Systema in test facilities or the management of convection so to ease the correlation with ambient testing. A particular attention is also given to the Step-Tas interface. The 4.8.0 version stabilizes a lot the export of Systema and Thermisol models (GMM and TMM). In the next 4.8.1 version, the import should also be improved thanks to an improved management of the cutters.

Appendix P

Gas conduction and convection modelling techniques for the ExoMars Rover

Joshua Katzenberg
(Airbus Defence and Space, United Kingdom)

Abstract

The operation of the ExoMars rover in the gaseous atmosphere at Mars's surface has led to several challenges in the thermal analysis. Many parameters not normally encountered in spacecraft thermal analysis - such as wind speed - have been considered. To simulate the heat transfer to the environment, the external nodes couple to a single node via a convection modelling subroutine - switching between natural and forced convection depending on the wind-speed. Due to the complex geometry inside the rover, the approach for the internal model has been to use multiple gas nodes coupled to the geometry either via conduction or convection. ESATAN-TMS tools such as; non-geometric gas nodes for visualisation, contact zones for calculating gas node coupling areas and switching flags for heat transfer method have also been used to aid analysis tasks. Modelling techniques and the choice of thermal heat transfer approach based on the geometry are discussed in this presentation.

Appendix Q

Modelling of complex satellite manoeuvres with ESATAN-TMS

Nicolas Bures
(ITP Engines UK Ltd, United Kingdom)

Abstract

Requirements from the Space industry demand performing radiative and thermal analysis combined with more complex spacecraft manoeuvres and attitudes; for example the MetOp-SG project has multiple rotating and spinning components which can prove challenging to model.
This presentation focuses on how ESATAN-TMS eases the process of defining and visualising complex kinematics as well as performing radiative simulation.

Appendix R

pyTCDT (TCDT 2.0)
A flexible and scriptable toolbox for thermal analyses.

Marco Giardino Andrea Tosetto
(Blue Engineering, Italy)

James Etchells Harrie Rooijackers
(ESA/ESTEC, The Netherlands)

Abstract

The tool provide users an integrated environment with analytical functions, ARTIFS and TOPIC integration, array function execution, editors, plotting and scripts management. As the name suggest it is implemented in Python so it will be available for different platforms and its distribution will be simplified wrt version 1.X.

Appendix S

A comprehensive integration methodology based on cosimulation

Integration of thermal management in early phases of an electronic / electrical design

Benoit Triquigneaux M.Bareille Julien Pouzin Laurent Labracherie
J.Vidal
(ALTRAN Technologies, France)

Abstract

Thermal management is becoming a critical issue in electronic systems design due to the high dissipated power in electrical architectures and to the environment to which they are submitted.
Multi-physics simulation is an efficient way to solve some of the raised problems at various development steps. It helps designers in their choices by giving them more realistic predictions from the earliest stage of their development process.
The objective of this presentation is to demonstrate the benefits of thermal integration at the predesign stage of an electrical system. This integration is performed through a cosimulation technique which couples two dedicated simulation tools:

- SABER (SYNOPSYS®) for electrical / electronic modelling,
- IDEAS NX (SIEMENS®) for 3D thermal studies.

Coupled by a communication bus (COSIMATE, CHIASTEK®), they improve significantly the understanding of the system. Cosimulation becomes then a differentiating practice during the development phase.
This approach will be applied here to the predesign of an autonomous water search drilling system embarked on a spatial probe for MARS exploration. The objective is to develop a multi-physic Virtual Test Rig in order to validate technological choices and anticipate integration issues in the probe working environment (MARS atmosphere).
The methodology tested during this test case is generic and can be successfully applied to any system design for which the account of heat dissipation is mandatory.
The conclusion of this work is that, if it is generalized at various stages of the system development V-cycle, the "bus" cosimulation technique represents an efficient way to increase the designer confidence in his architecture. It provides a realistic virtual test rig gathering all the most important thermal phenomena influencing its piece of equipment functioning so that an early design error or integration issue can be anticipated in a cost effective way.

Appendix T

THERM3D / e-Therm GMM (conductive) and TMM generation of thermo-mechanical antenna support designed for ALM

Patrick Connil Jean Paul Dudon Thierry Basset Patrick Hugonnot
(TAS, France)

François Brunetti
(DOREA, France)

Abstract

Additive Layer Manufacturing (ALM) becomes more and more in the wave of spacecraft pieces manufacturing (i.e. antenna support). Experiences in aeronautics and medical implants bring opportunities for innovation, lower costs and make ALM a modern fabrication process.
However, 3D printing needs 3D models that fit mechanical and thermal constraints. The main objective is to converge to a single model iterating through CAD, mechanical and thermal expertises. CAD constraints evolved from classical manufacturing to ALM by increasing the complexity of CAD model, not in the size but by the use of a complex mix of shapes largely depending on B-Spline surfaces, extrusions and cuts.
For the thermal point of view, and as the 3D conduction optimisation always depends on material characteristics, fluxes direction, shape optimisation, the thermal expert is still needed for such calculation and a push-button CAD software is not sufficient.
For these reasons, THALES ALENIA SPACE (TAS) decided to improve the actual existing 3D conductive session within e-Therm in order to provide CAD import, meshing facilities, automated nodal breakdown that fit ALM constraints. In this presentation we would discuss about TAS needs and progress on ALM design for thermal analysis, the actual THERM3D research and development that has been integrated into e-Them since 2007, but also how DOREA solved major technical issues on importing raw CAD models for meshing to finally conductivity calculation and temperatures cartography. We will show in this presentation an example on an antenna support but is also used for heat-pipe 3D section modelling.

Appendix U

Development towards 3D thermography

Gianluca Casarosa
(ESA/ESTEC, The Netherlands)

Abstract

The presentation reports on an activity aimed at solving the biggest issue of existing IR camera thermography, i.e. the temperature measurement of objects with significant 3D surface variability (wrinkles and folds). Such variations can alter the interpretation of images where the surfaces have significant directional emissivity variations and hot sources are brought in the field of view of the test surfaces. The latter is especially critical when measuring cold objects.
The activity covered the development of a method using IR cameras for 3D geometrical mapping of the test specimen and IR flux measurement. Correction of measured apparent temperature is based on a ray tracing approach. The method developed was validated by test.

Appendix V

Data exchange for thermal analysis
a status update

James Etchells Duncan Gibson Harrie Rooijackers Matthew Vaughan
(ESA/ESTEC, The Netherlands)

Abstract

This short presentation will give a factual overview of the current status for thermal analysis data exchange. A summary of current known issues and lessons learned will be presented at a practical level. Additionally the status with STEP-TAS and interfaces inside the thermal tools will be covered. Finally the STEP-TAS based TMM converter "TMMverter" will be introduced along with some usage examples.

Appendix W

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