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Vesoljska tehnika - Priročnik o toplotni analizi

Space engineering - Thermal analysis handbook

Raumfahrttechnik - Handbuch für thermische Analyse

Ingénierie spatiale - Manuel d'analyse thermique

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Space engineering - Thermal analysis handbook

Ingénierie spatiale - Manuel d'analyse thermique

Raumfahrttechnik - Handbuch für thermische Analyse

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European Foreword

This document (CEN/TR 17603-31-17:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 “Space”, the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN16603-31.

This Technical report (CEN/TR 17603-31-17:2022) originates from ECSS-E-HB-31-03A.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).

1 Scope

1.1 Objectives and intended audience

This handbook is dedicated to the subject of thermal analysis for space applications. Thermal analysis is an important method of verification during the development of space systems. The purpose of this handbook is to provide thermal analysts with practical guidelines which support efficient and high quality thermal modelling and analysis.

Specifically, the handbook aims to improve:

a. the general comprehension of the context, drivers and constraints for thermal analysis campaigns;

b. the general quality of thermal models through the use of a consistent process for thermal modelling;

c. the credibility of thermal model predictions by rigorous verification of model results and outputs;

d. long term maintainability of thermal models via better model management, administration and documentation;

e. the efficiency of inter-organisation collaboration by setting out best practice for model transfer and conversion.

The intended users of the document are people, working in the domain of space systems, who use thermal analysis as part of their work. These users can be in industry, in (inter)national agencies, or in academia. Moreover, the guidelines are designed to be useful to users working on products at every level of a space project – that is to say at system level, sub-system level, unit level etc.

In some cases a guideline could not be globally applicable (for example not relevant for very high temperature applications). In these cases the limitations are explicitly given in the text of the handbook.

1.2 Context

The use of computational analysis to support the development of products is standard in modern industry. Figure 1-1 illustrates the typical thermal modelling and analysis activities to be performed at each phase of the development of a space system.

NOTE More information about the project lifecycle can be found in ECSS-M-ST-10 [RD5].

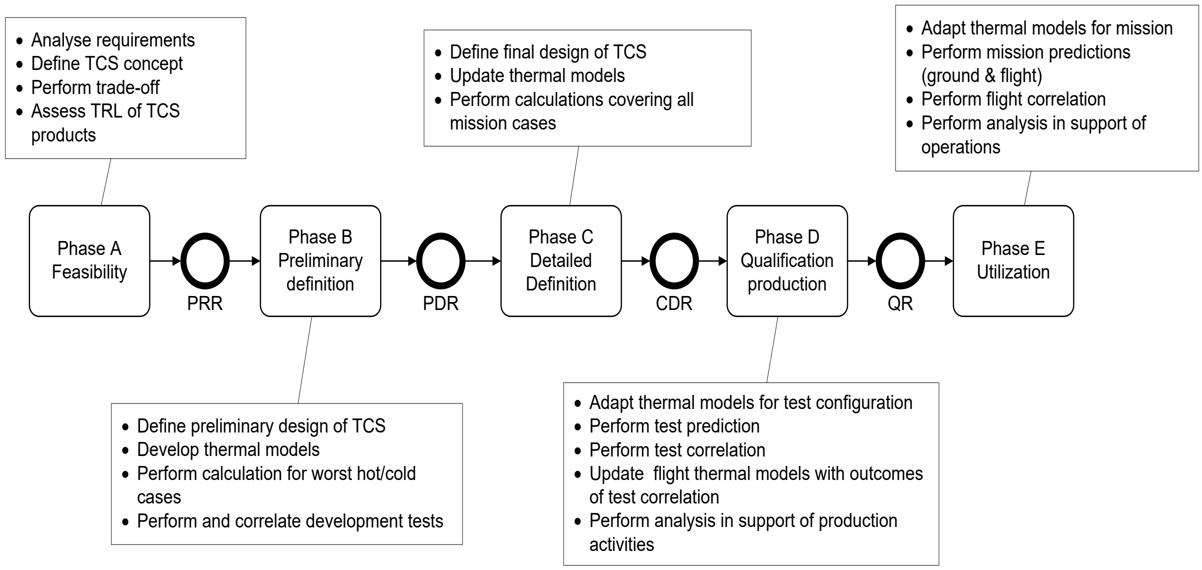

Figure 1-1: Thermal analysis in the context of a space project

It can be seen that thermal models are used during all phases of the space system development to support a large number of activities, ranging from conceptual design right through to final in-flight predictions.

Indeed, in some cases, thermal analysis is the only way that certain thermal requirements can be verified; as physical tests are either too expensive or unrealisable. It is therefore vital for the credibility of the predictions made that the quality of the models is as high as possible.

2 References

RD #	EN Reference	Reference in text	Title
[RD1]	EN 16603-31	ECSS-E-ST-31,	Space engineering - Thermal control general requirements
[RD2]	EN 16603-32-03	ECSS-E-ST-32-03	Space engineering - Structural finite element models
[RD3]	EN 16603-31-02	ECSS-E-ST-31-02	Space engineering - Two-phase heat transport equipment
[RD4]	TR 16603-31-01	ECSS-E-HB-31-01	Space engineering - Thermal design handbook
[RD5]	EN-16601-10	ECSS-M-ST-10	Space project management - Project planning and implementation
[RD6]	EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
[RD7]			Gilmore, D., G., "Spacecraft Thermal Control Handbook – Volume 1: Fundamental Technologies", 2002
[RD8]			Anderson, B. J. and Smith, R. E. "Natural Orbital Environment Guidelines for Use in Aerospace Vehicle Development", NASA Technical Memorandum 4527, June 1994
[RD9]			Anderson, B. J., Justus, C. G., and Batts, G. W. "Guidelines for the Selection of Near-Earth Thermal Environmental Parameters for Spacecraft Design", NASA Technical Memorandum 2001-211221, October 2001
[RD10]			Anderson, B. J., James, B. F., Justus, C. G., Batts "Simple Thermal Environment Model (STEM) User's Guide, NASA Technical Memorandum 2001-211222, October 2001
[RD11]			Sauer, A. "Implementation of the Equation of Time in Sun Synchronous Orbit Modelling and ESARAD Planet Temperature Mapping Error at the Poles ", 22nd European Workshop on Thermal and ECLS Software. October 2008. https://exchange.esa.int/thermal-workshop/attachments/workshop2008/

RD #	EN Reference	Reference in text	Title
[RD12]			"Feasibility of Using a Stochastic Approach for Space Thermal Analysis", Blue Engineering & Alenia Spazio, 2004, https://exchange.esa.int/stochastic/
[RD13]			"Guide for Verification and Validation in Computational Solid Mechanics," The American Society of Mechanical Engineers, Revised Draft: 2006
[RD14]			Remaury, S., Nabarra, P., Bellouard, E., d'Escrivan, S., "In-Flight Thermal Coatings Ageing on the THERME Experiment" CNES, Proceedings of the 9th International Symposium on Materials in a Space Environment, 2003 Noordwijk, The Netherlands
[RD15]			M. Molina & C. Clemente, "Thermal Model Automatic Reduction: Algorithm and Validation Techniques", ICES 2006.
[RD16]			F. Jouffroy, D. Charvet, M. Jacquiau and A. Capitaine, "Automated Thermal Model Reduction for Telecom S/C Walls", 18th European Workshop on Thermal and ECLS Software, 6–7 October 2004
[RD17]			Gorlani M., Rossi M., "Thermal Model Reduction with Stochastic Optimization", 2007-01-3119, 37th ICES Conference, 2007, Chicago
[RD18]			M. Bernard, T. Basset, S. Leroy, F. Brunetti and J. Etchells, "TMRT, a thermal model reduction tool", 23rd European Workshop on Thermal and ECLS Software, 6–7 October 2009
[RD19]			STEP-TAS Technical Details http://www.esa.int/TEC/Thermal_control/SEME7NN0LYE_0.html
[RD20]			CRTech, "How to Model a Heat Pipe", http://www.crtech.com/docs/papers/HowToModelHeatpipe.pdf
[RD21]			Juhasz, A., "An Analysis and Procedure for Determining Space Environmental Sink Temperatures with Selected Computational Results", NASA Technical Memorandum 2001-210063

3
Terms, definitions and abbreviated terms

3.1 Terms from other documents

a. For the purpose of this document, the terms and definitions from ECSS-ST-00-01 [RD6] apply, in particular for the following terms:

1. **validation**

   NOTE Validation is the process of determining the degree to which a computational model is an accurate representation of the real world from the perspective of the intended uses of the model.

2. **verification**

   NOTE 1 Verification is the process of determining that a computational model accurately represents the underlying mathematical model and its solution

   NOTE 2 The topic of V&V is well known in the context of quality assurance and systems engineering (including software systems). There has also been some work in other domains such as Computational Fluid Dynamics (CFD) and structural mechanics to develop processes for V&V of simulation models. In the particular context of computational analysis the formal definitions usually apply [RD13].

   NOTE 3 More informally the following questions are often used to explain V&V in the context of computational analysis:

   - Verification "did we solve the equations correctly?"
   - Validation "did we solve the correct equations?"

b. For the purpose of this document, the terms and definitions from ECSS-E-ST-31 apply, in particular for the following terms:

1. **geometrical mathematical model**

   mathematical model in which an item and its surroundings are represented by radiation exchanging surfaces characterised by their thermo-optical properties

2. **thermal mathematical model**

   numerical representation of an item and its surroundings represented by concentrated thermal capacitance nodes or elements, coupled by a network made of thermal conductors (radiative, conductive and convective)

   NOTE The current trend is towards integrated thermal modelling tools, in which case the distinction between Geometrical Mathematical

Model (GMM) and Thermal Mathematical Model (TMM) becomes ill-defined. Nonetheless the terms GMM and TMM are still used in the everyday language of thermal engineers and so the terms are retained in this document.

3. **thermal node**

representation of a specific volume of an item with a representative temperature, representative material properties and representative pressure (diffusion node) used in a mathematical lumped parameter approach

NOTE The current document is written to be, as far as possible, tool and method independent. It is therefore useful to generalise the concept of thermal node to cover other numerical methods (e.g. the finite element method). Mathematically speaking a thermal node represents a "degree of freedom" in the equation system. More practically, the purpose of a thermal node is to provide a temperature evaluation (and output) at a selected location.

4. **uncertainties**

inaccuracies in temperature calculations due to inaccurate physical, environmental and modelling parameters

NOTE This definition of uncertainty refers specifically to temperature calculations. In the context of this document this is widened to calculations of other key model outputs such as heater power or duty cycle.

3.2 Terms specific to the present document

3.2.1 accuracy

degree of conformance between an output of a thermal analysis and the true value

NOTE The true value is usually a measurement from a physical test, for example a thermal balance test. The purpose of the verification and validation effort is thus to improve and quantify modelling accuracy.

3.2.2 arithmetic thermal node

thermal node with zero thermal capacitance

NOTE 1 Arithmetic nodes are normally treated specially by thermal solvers and a quasi-steady state solution is obtained for them during transient runs. This is useful to avoid excessively small time steps when lightweight items need to be represented in large models.

NOTE 2 Additionally arithmetic nodes are often used to represent thermal interfaces or the edges of region

3.2.3 computational model

numerical implementation of a mathematical model

NOTE 1 This is usually comprises numerical discretisation, solution algorithm, and convergence criteria.

NOTE 2 This definition is taken from RD11, where a more detailed discussion of the relationship between mathematical and computation models can be found.

3.2.4 CSG

ratio of capacitance to sum of connected conductances for a thermal node

NOTE No specific acronym is available for CSG, most likely the C represents capacitance, the S represents the sum, and the G represents the conductors.

3.2.5 error

<CONTEXT: thermal analysis> difference between an output of a thermal analysis and the true value

NOTE 1 High accuracy analyses therefore produce outputs with small associated errors.

NOTE 2 This is a typical dictionary definition of error and generic. More specific and formal definitions occur in a number of other sources, for example ASME [RD13].

3.2.6 key model output(s)

output(s) from the thermal model having high level of importance

NOTE Examples of key model outputs are TRP temperatures, heater duty cycles, and any other output form the model with special significance for the verification of the TCS.

3.2.7 radiative cavity

collection of radiative surfaces of the thermal-radiative model, having the property that its surfaces cannot exchange heat through thermal radiation with the surfaces belonging to another cavity

NOTE This term is synonymous with "radiative enclosure".

3.2.8 radiative enclosure

See "**radiative cavity**".

3.3 Abbreviated terms

For the purpose of this document, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	**Meaning**
BOL	beginning-of-life
CCHP	constant conductance heat pipe
CFD	computational fluid dynamics
CLA	coupled launcher analysis
CNES	Centre National d'Etudes Spatiales
COTS	commercial off-the-shelf
DGMM	detailed geometrical mathematical model