Standardization Training Program Level 2 ECSS Standards

Training Course in ECSS-E-ST-31C “Space Engineering - Thermal Control General Requirements”

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Content of the training

- Introduction
  - Characteristics of the ECSS system
  - ECSS Documents for Thermal Control
  - Types of requirements
  - Application of Standard to a specific project
- Structure of ECSS-E-ST-31C general requirements document
  - #1: Scope of Document - #2: Normative References
  - #3: Terms, definitions and abbreviated terms
  - #4: Requirements
  - #5: Document requirements definition (DRD) list
  - DRD Annexes (normative)
- Tailoring
- Conclusion

Characteristics of ECSS System (1/4)

- ECSS = European Cooperation for Space Standardization
- Established in 1993, it is an organization which works to develop a single coherent set of space standards within the European space community

- Cooperative effort between **ESA**, National Space Agencies (**ASI, UKSA, CNES, DLR, NSO,** and **NSC**) and European industry (represented by **Eurospace**)

Characteristics of ECSS System (2/4)

ECSS

- Is driven by a partnership of **industries and space agencies**
- Is written in **consensus** by industry and agency experts
- Is a **consistent** set of documents
- Makes **maximum use of existing** and commonly used international standards
- Has flexibility through **tailoring**
- Is recognized by the European Space Community as:
    - the **single** developing body for European Space standards
    - the source of requirements for its Space activities
- Standards define the **requirements** rather than the means

Characteristics of ECSS System (3/4)

- Key aspect of ECSS is the documentation architecture, designed to facilitate the organisation and retrieval of information within the ECSS system (see next slides).
- Basically four main branches: Management (M), Product Assurance (Q), Engineering (E), and Sustainability (U) and three hierarchical levels

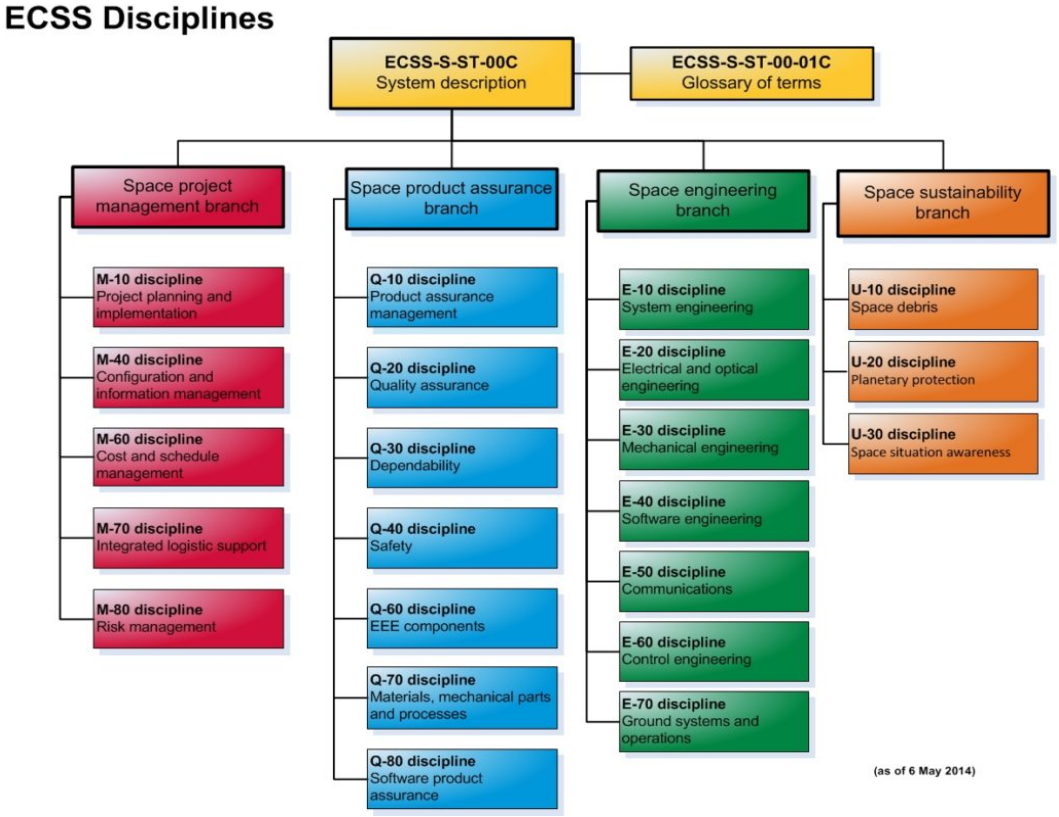
Level 1 (ECSS-S-ST-00 “ECSS system – Description, Implementation and general requirements”) - Describes the ECSS system of documents, explains its implementation in space projects, and specifies that the customer (at any level of the customer-supplier chain) shall perform the tailoring for its suppliers, and the supplier has to respond with an implementation document.

Characteristics of ECSS System (4/4)

- Level 2 (ECSS-M-ST-10, ECSS-M-ST-40, ECSS-Q-10, ECSS-E-ST-10, ECSS-E-ST-31, ...) - Describe the required objectives and functions for all aspects in the individual domain (project organization, configuration management, product assurance, system engineering, thermal control, etc.)
  - The Thermal Control Standard ECSS-E-ST-31C is located here
- Level 3 - Describe methods, procedures and recommended tools to achieve the requirements of Level 2 documents. Define the requirements for interfaces and performance of the specified product.
  - ECSS-E-ST-31-02C “Two-phase heat transport equipment” is located here.

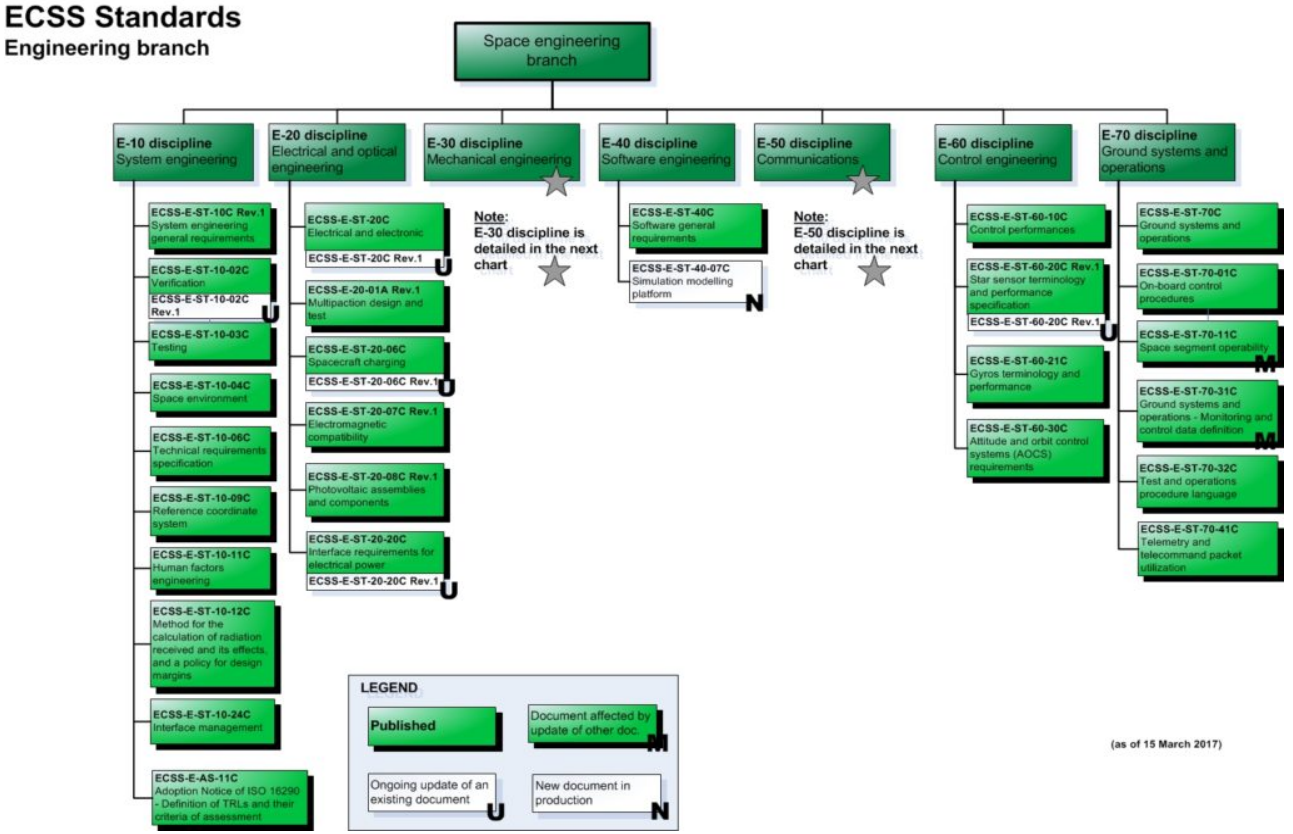
In addition, there are different handbooks providing guidelines, typical/recommended engineering methods, etc.

Characteristics of ECSS System (5)



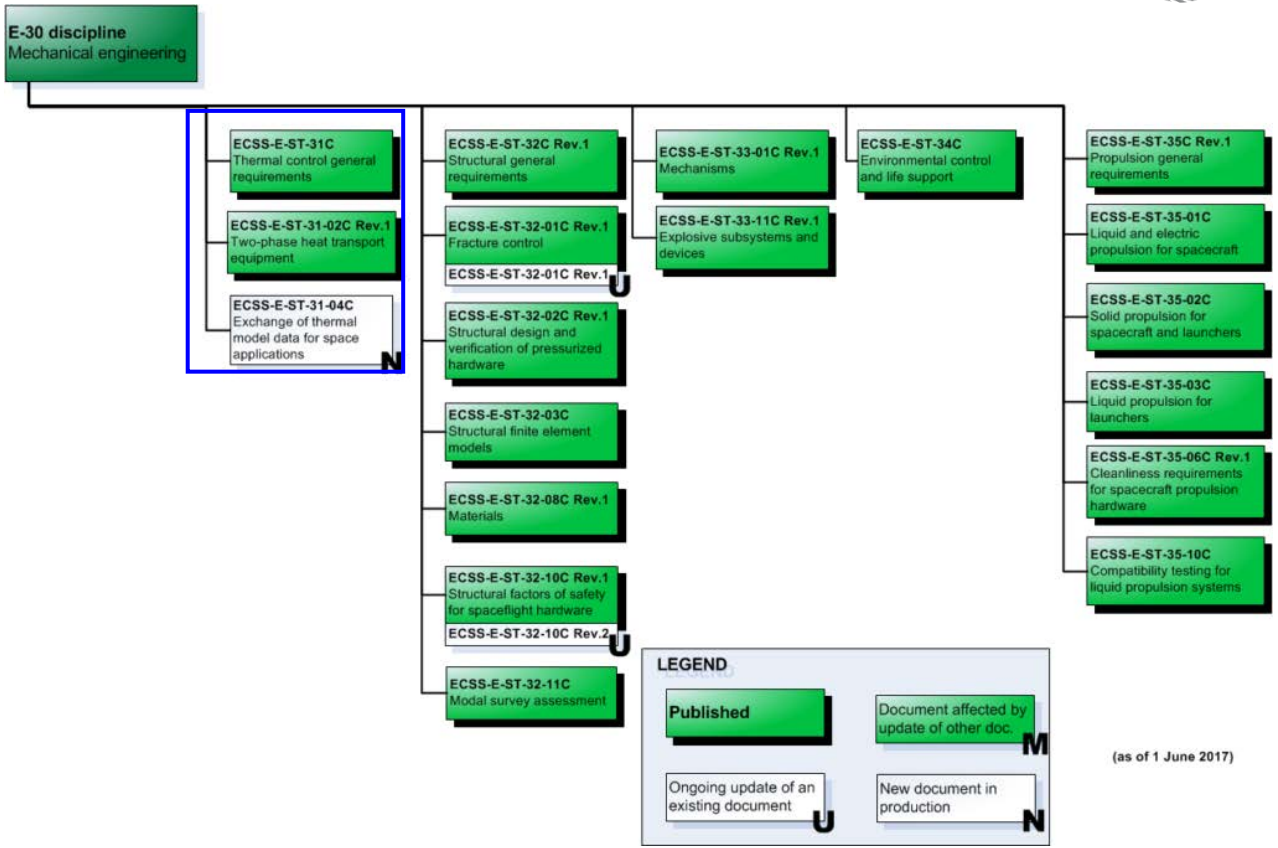
Characteristics of ECSS System (6)

ECSS engineering standards (1)



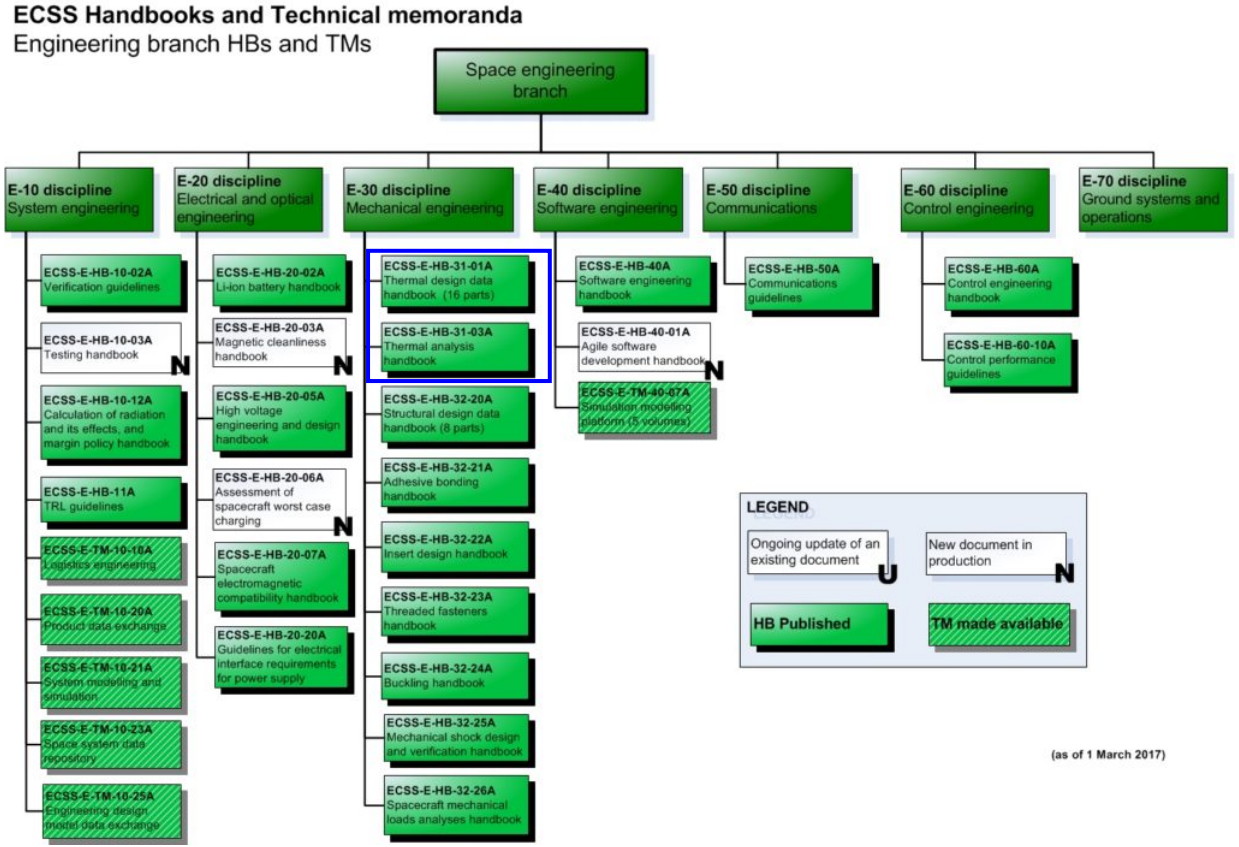
Characteristics of ECSS System (7)

ECSS engineering standards (2)



Characteristics of ECSS System (8)

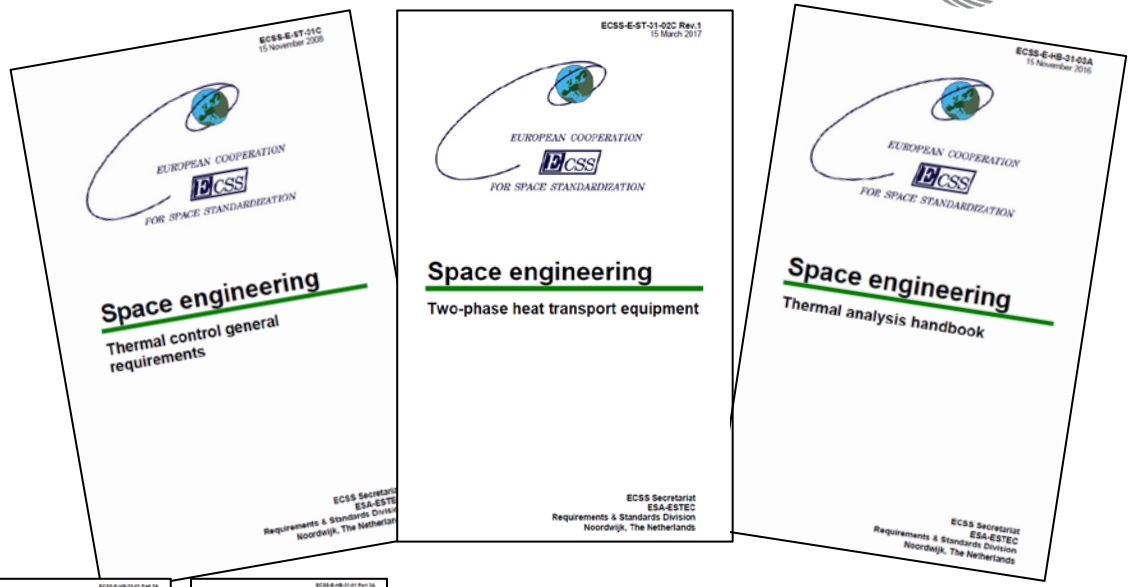
ECSS engineering Handbooks (HB) and Technical Memorandums (TM)



ECSS Documents for Thermal Control

- Existing standards:
  ECSS-E-ST-31C
  ECSS-E-ST-31-02C
- Existing Handbooks:
  ECSS-E-HB-01 and
  ECSS-E-HB-03

Standard in preparation: ECSS-E-ST-31-04C



ECSS Documents for Thermal Control

ECSS-E-ST-31C: Thermal control general requirements (2008) – to be updated

- Rather short (65 pages) and generic
- To be used on thermal subsystem level
    - Typical user: responsible subsystem engineer in a system team and thermal engineer in a thermal department
    - Useful to responsible engineers of other subsystems to understand thermal interfaces
- Document includes requirements for
    - All mission phases
    - Interfaces to equipment thermal control
    - Interfaces to other subsystems
    - The entire temperature range

ECSS Documents for Thermal Control

ECSS-E-HB-31-03A: Thermal analysis handbook (2016) – very good reference (65p)

Purpose : to provide thermal analysts with practical guidelines which support efficient and high quality thermal modelling and analysis. I.e. improve:

a) comprehension of the context, drivers & constraints for thermal analysis campaigns

b) quality of thermal models through the use of a consistent process for thermal modelling

c) credibility of thermal model predictions by rigorous verification of model results & outputs

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

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

ECSS Documents for Thermal Control

ECSS-E-HB-31-03A: Thermal analysis handbook (2016)

Modelling guidelines (configuration, version control, modelling process, modularity)

Model verification (checks)

Uncertainty analysis (sources of uncertainties, stochastic, typical values)

Model transfer, conversion and reduction (reference results, documentation)

Annex: specific guidelines for modelling (MLI, Heat pipes, layered materials, …)

Guideline 4-2

Ensure results of all production runs are traceable to a specific version of the model inside the configuration control repository.

ECSS Documents for Thermal Control

ECSS-E-ST-31-02C: Two-phase heat transport equipment (TPHTE)

- To be used on equipment level (heat pipe, loop heat pipe,…)
  - Typical user: responsible thermal design engineer for TPHTE
  - Useful to responsible thermal subsystem engineers in system teams to understand TPHTE interfaces
- Document includes requirements for
  - Design and verification of the different TPHTE
  - Qualification process of TPHTE
  - Detailed qualification test program
  - Necessary development and verification documents (DRD)

Applicable to all flight hardware of space projects, covering spacecraft and launchers

ECSS Documents for Thermal Control

ECSS-E-HB-31-01, 16 parts: Thermal design handbook (2001) – but old material!

Part 1: View factors

Part 2: Holes, Grooves and Cavities

Part 3: Spacecraft Surface Temperature

Part 4: Conductive Heat Transfer

Part 5: Structural Materials: Metallic and Composite

Part 6: Thermal Control Surfaces

Part 7: Insulations

Part 8: Heat Pipes

Part 9: Radiators

Part 10: Phase-Change Capacitors

Part 11: Electrical Heating

Part 12: Louvers

Part 13: Fluid Loops

Part 14: Cryogenic Cooling

Part 15: Existing Satellites

Part 16: Thermal Protection System

- Intended to be used as supporting material in space projects and applications
- Collection of data gathered from many projects and technical journals which provides descriptions and recommendation to be considered in the thermal design process
- Handbook has unfortunately not been updated for some time

ECSS Documents for Thermal Control

ECSS-E-ST-31-04C: Exchange of thermal model data for space applications

- Objective : to define and describe the standard protocol for Exchange of Thermal Model Data for Space Applications (commonly known as STEP-TAS protocol).
- Intended users: tools developers

Figure 1: Tool-to-tool data exchange vs open standards

3 Types of requirements (1)

- Documentation Requirements: for production and use of project documents
  - 4.9.3b: The TCS supplier shall deliver the documentation as detailed in Table 5-1

Document title	Summary	Phase								DRD ref.	Remarks
		0	A	B		C	D		E	F	
		MDR	PRR	SRR	PDR	CDR	QR	AR		MCR	
Mathematical Model Specification	Specifies requirements for development and delivery of thermal mathematical models to be used for thermal analysis at system level				X	X					E-ST-31	
Thermal and geometrical model description	Describes the TMM and GMM to be used as input for the sub-system thermal analysis cases		X	X	X	X	X	X			E-ST-31	To be updated before each analysis campaign
TCS analysis report	Contains a full mathematical analysis of the thermal control system leading to the thermal subsystem definition including redundancy strategy, operational concept and hardware definition		X	X	X	X	X	X	X		E-ST-31	Document to be updated or re-issued for CDR, AR, TBT prediction, TBT evaluation, Flight prediction
TCS interface control document	Describes the thermal control subsystem interfaces to other subsystems and to the system		X	X	X	X	X	X			E-ST-31	To be updated at CDR and AR
TCS thermal balance test specification	Describes the requirements applicable for the thermal balance test including purpose, test approach and test article					X					E-ST-31	Can be combined with the system thermal vacuum (TV) test specification
TCS detailed design description	Describes the detailed design of the thermal control subsystem			X	X	X					E-ST-31	Possible update for phase D
TCS thermal balance test procedure	Gives directions for conducting the thermal balance test in terms of description, resources, constraints and step-by-step procedure					X					E-ST-10-02	Before TBT
TCS thermal balance test report	Describes the execution of the thermal balance test and the results obtained					X					E-ST-10-02	After TBT

3 Types of requirements (2)

- Process Oriented Requirements: stating what task shall be performed
  - Usually not quantifiable, and not possible to verify on the product
  - Compliance to these requirements is performed by reviewing and accepting plans (e.g. System Engineering Plan) or analyses (e.g. thermal analysis)
  - Closure by reviewing the completed process (way of working), i.e. accepting how something has been designed, manufactured, or analysed. This can be done by reviewing the associated documentation (Plan, Analysis), or by an audit process.

Examples:

- 4.2.1a: TCS performance requirements for all mission phases shall be specified and agreed with the system authority
- 4.2.1b: The mission phases shall be represented by a coherent set of thermal design cases covering the extreme range of conditions experienced by an item during its lifetime
- 4.5.2.1a: Verification by analysis shall be performed through thermal analytical modelling and corresponding prediction

3 Types of requirements (3)

- Product Oriented Requirements
  - Requirements related to specific technically related issues, describing a product property or functionality
  - Always quantifiable, and can be verified on the product
  - Compliance of these requirements is illustrated by verification of the requirements (by Test, Analysis, Inspection or Review of Design)
  - Closure is performed by checking the actual verification of the individual requirement (i.e. Verification Control Document)

Example:

- 4.1.1a: The design of the TCS shall meet requirements of all mission phases up to the end of the operating lifetime

Types of requirements (4)

These requirement type definitions have not been systematically implemented into the ECSS system, but would have several advantages:

- Easy distinction between requirement types (when listed in dedicated sections of the Standard)
- Process requirements may be easily introduced in Statement of Work (SOW) and product requirements into technical specifications
- Requirement verification can be more easily traced. Product requirements are most often tracked through VCD (Verification Control Document) and documentation / process requirements through compliance status lists

The thermal control Standard contains only few product related requirements (temperature, environment, lifetime requirements, etc.). Most of the requirements are process related (what to for do verification, modelling, analysis, testing, etc.)

Relation of Standard to a specific project (1)

The requirements are generic -> does not constitute a TCS specification.

The procurement of a specific thermal subsystem cannot be based on this ECSS document alone.

- Documentation and process requirements, called out in this Standard, are generally introduced into the Statement of Work (SOW) of a specific project
- Technical / product requirements need to be captured in a technical specification. Standard can be seen as a “guideline” for writing a detailed, project dedicated, technical specification.

References to the need for a technical specification are already given, for example:

4.2.1a: TCS performance requirements for all mission phases shall be specified and agreed with the system authority

4.2.1g: The TCS shall conform to the following requirements to be specified in the TCS specification

4.2.2a: Temperatures… shall not exceed values … specified in the TCS specification

Relation of Standard to a specific project (2)

Examples for translation of ECSS requirement in Subsystem specification

ECSS	Specification
4.2.1e: Minimum and maximum design temperatures shall be provided (defined)	Quantitative values for design temperatures are specified for all units
4.2.1f: Acceptance and qualification margins shall be defined	Quantitative values for margins are specified for all units
4.2.1g: The TCS shall conform to required temperature gradients, stability, uniformity, heat flux, etc.	Quantitative values for temperature gradients, stability, uniformity, heat flux, etc. are specified for all units
4.2.2b3: A TPS shall support mechanical and thermo-mechanical loads	Quantitative load values are specified for relevant parts of the TPS
4.4.5a: The TCS shall conform to the total lifetime covering expected combinations of mission phases	Lifetime is quantitatively specified. Mission phases are specified in detail.

Structure of ECSS document

In order to facilitate the use of the ECSS system, the breakdown of main clauses is the same for all ECSS standards:

- Clause 1: Scope
- Clause 2: Normative References
- Clause 3: Terms, definitions and abbreviated terms
- Clause 4: Requirements
- Clause 5: Documentation requirements
- DRDs as normative annexes

Any informative text as informative annexes

The following slides summarizes and discusses the main clauses of Thermal Standard ECSS-E-ST-031C

Clause 1: Scope of ECSS-E-ST-031C (1)

In general: The purpose of the Scope clause is to describe, in a few lines, the standard as a whole in such a way that the reader can assess if the standard is applicable or not to a particular case.

Clause 1: Scope of ECSS-E-ST-031C (2)

- defines requirements for the discipline of **thermal engineering**.
- defines the requirements for the **definition, analysis, design, manufacture, verification and in-service operation of thermal control subsystems** of **spacecraft** and **other space products**.
- requirements are applicable to the **complete temperature scale**. Some are applicable only for the cryogenic or high temperature range.

Standard applicable to all flight hardware of space projects, including spacecraft and launchers.

Standard **may be tailored** for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

Clause 1: Scope of ECSS-E-ST-031C (3)

The Standard covers requirements for the entire life cycle of the subsystem:

- Ground and pre-launch (4.1.2)
- Launch and ascent (4.1.3)
- Planetary orbital phases (4.1.4)
- Interplanetary phases (4.1.5)
- Planetary natural environment (4.1.6)
- Docking, docked and separation phases (4.1.7)
- Descent, entry and landing (4.1.8)
- Post-landing phases (4.1.9)

Clause 1: Scope of ECSS-E-ST-031C (4)

Standard applicable for the complete temperature range (as defined in the standard)

- Cryogenic temperature range (below 200 K)
- Conventional temperature range (200 to 470 K)
- High temperature range (above 470 K)

Specific requirements related to the extreme temperature ranges are called out in the following clauses (see also Annex G and H):

- 4.2.2 for requirements in the high temperature range
- 4.2.3 for requirements in the cryogenic temperature range
- 4.5.2.2 for verification by test in the cryogenic temperature range
- 4.5.2.3 for verification requirements of thermal protection system (TPS)

Clause 2: Normative References

“Normative references” list the documents referred to in requirements.

The Thermal Control Standard calls the following ECSS documents:

- Glossary of terms (S-ST-00-01)
- Verification, testing, space environment standards (E-ST-10-02, 10-03, 10-04)
- Project management (configuration and information management) (M-ST-40)
- Space product assurance:
    - Quality assurance, safety (Q-ST-20, 40)
    - Materials, mechanical parts and processes (Q-ST-70)
    - Cleanliness and contamination control (Q-ST-70-01)

All referenced documents are undated, meaning that the latest issue / revision of a referenced document is applicable

Clause 3: Terms, definitions & abbreviated terms (1)

Purpose:

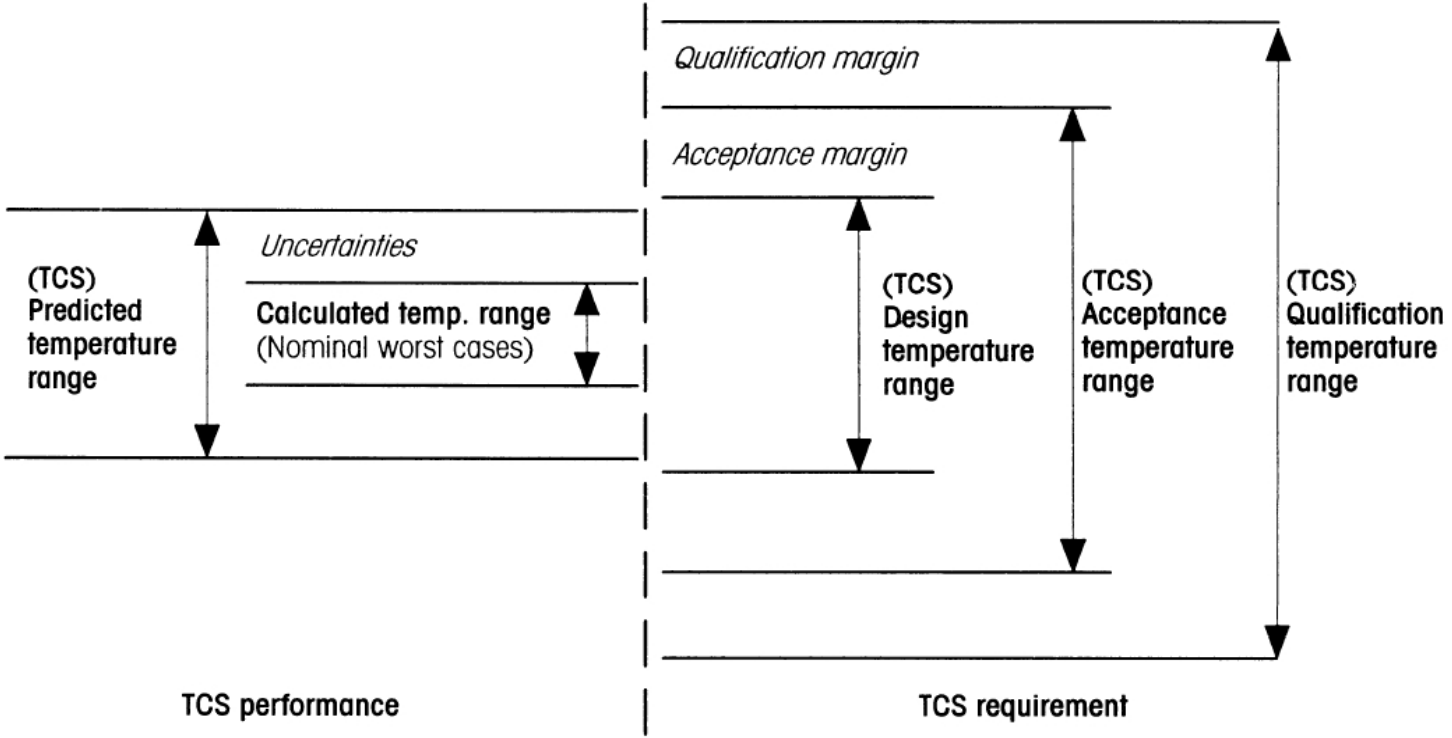
- List the terms defined in other standards which are applicable to the thermal control standard (definition of terms shall not be repeated throughout the ECSS system)
- Present the terms specific to the thermal control standard together with their definitions (these terms are unique in the ECSS system and appear only in the thermal control standard)
- List the abbreviations used in the standard, and their expanded meaning

Very important to ensure experts have the **same understanding** of specific terms used in thermal control engineering

For example the clause lists 26 temperature-related terms

Most important temperature definitions and the relation to each other are explained in the following slide (Figure 3.1 from the standard)

Clause 3: Terms, definitions & abbreviated terms (2)



Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.2 acceptance temperature range

temperature range obtained from the qualification temperature range after subtraction of qualification margins specified for the operating and non-operating mode and the switch-on condition of a unit

NOTE 1 The acceptance temperature range is the extreme temperature range that a unit can reach, but never exceed, during all envisaged mission phases (based on worst case assumptions).

NOTE 2 Temperature range used during acceptance tests to verify specified requirements and workmanship

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.3 calculated temperature range

temperature range obtained by analysis or other means for the operating and non-operating mode and the minimum switch-on condition of a unit, based on worst case considerations (i.e. an appropriate combination of external fluxes, materials properties and unit dissipation profiles to describe hot and cold conditions) excluding failure cases

NOTE The calculated temperature range plus any uncertainties is limited to the specified design temperature range. During the course of a project these uncertainties change from initial estimates into a value determined by analysis.

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.16 minimum switch-on temperature

minimum temperature at which a unit can be switched from the non-operating mode to the operating mode and functions nominally when the unit temperature is brought back to the relevant operating mode temperatures

NOTE Also referred to as start-up temperature.

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.28 temperature difference

difference in temperature of two points at a given time

3.2.1.29 temperature gradient

spatial derivation of temperature in a point at a given time

NOTE It is expressed by a temperature divided by unit length.

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.22 radiative sink temperature

virtual black body radiation temperature used to define the equivalent radiative thermal load on an item

NOTE 1 The radiative sink temperature includes both the natural environment load (solar, planetary albedo and infrared fluxes) and the radiative exchanges with other items.

NOTE 2 The radiative sink temperature is typically used to provide a simplified interface for an item, to provide a means for parameter studies thus avoiding extensive calculations or to define adequate radiative boundary conditions for thermal tests.

See NOTE 3 and 4 in Standard for formula for calculation of sink temperature

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.27 system interface temperature point

physical point appropriately located on the structure of the system which can be used to evaluate the heat exchanged by conduction between a unit and the spacecraft system

3.2.1.31 temperature reference point (TRP)

physical point located on a unit and defined in the unit ICD to provide a simplified representation of the unit temperature

NOTE 1 The TRP is used for coherent verification at unit, subsystem and system level.

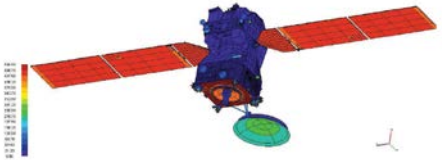
NOTE 2 Depending on the unit dimensions and interface complexity, more than one temperature reference point can be defined.

Clause 3: Terms, definitions & abbreviated terms (3)

3.2.1.8 geometrical mathematical model (GMM)

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

NOTE The GMM generates the absorbed environmental heat fluxes and the radiative couplings between the surfaces.



3.2.1.38 thermal mathematical model (TMM)

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 3 Numerical representation can be performed by lumped parameter, finite difference or finite element methods.

Clause 3: Terms, definitions & abbreviated terms (3)

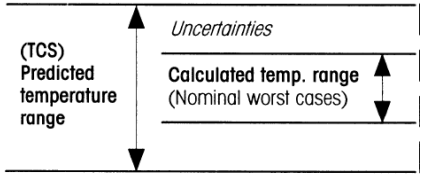
3.2.1.41 Uncertainties

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

Thermal Analysis – Uncertainties & Margins

Uncertainties in thermal modeling:

- numerical uncertainties
- 'Physical' uncertainties
  - material properties (anisotropy, batch differences)
  - optical surface properties (literature vs. real values; wavelength dependence, specularity, opacity)
  - contact uncertainties (surface roughness, pressure, interstitial medium)
  - geometrical uncertainties (simplified geometry, no harness, etc.)
  - control uncertainties (thermostat switching, PID settings, etc.)



TCS performance

- Model uncertainties are the responsibility of the thermal analyst
- Model uncertainties can be reduced through test and sensitivity analysis (typical values: +/- 15 K @ Phase 0/A, +/- 10 K @ Phase B/C.

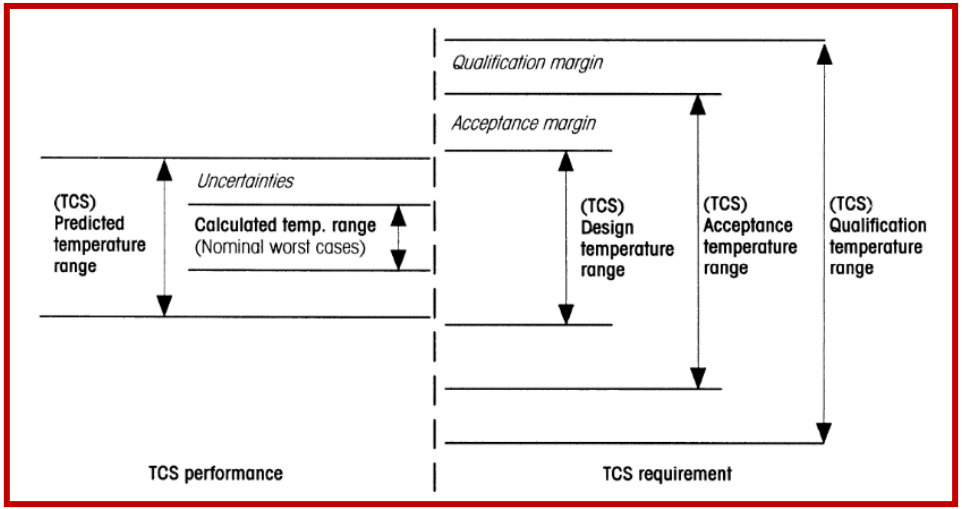
- **All results (calculated temperature) produced with computer models have uncertainties (predicated temperatures) – as each measurement has a measurement uncertainty.**

Thermal Analysis – Uncertainties & Margins

- Uncertainties:
  - Modeling Uncertainties
    - Geometry -> simplifications (holes, bolts, harness), …
    - Material properties -> bulk, anisotropy, …
    - Optical surface properties -> substrate, literature data, wavelength, opacity, specularity, …
    - Conductive interfaces -> geometry, contact conductance, …
  - Numerical Uncertainties

- Margins
  - Design Margin : project specific
  - Acceptance Margin : typical ±5K
  - Qualification Margin : typical ±5K

Uncertainty ≠ Margin
- **Uncertainty is inherent to model**
- **Margin is systematic "safety"**



Clause 4: Requirements (1)

All requirements for the TCS are listed in Clause 4 and broken down in the following sub-clauses:

- 4.1: Mission
- 4.2: Performance
- 4.3: Requirements towards other subsystems
- 4.4: Design
- 4.5: Verification
- 4.6: Production ad manufacturing
- 4.7: In-service requirements
- 4.8: Product assurance
- 4.9: Deliverables

The next slides give an overview over the requirements

Clause 4: Requirements (2)

Clause 4.1: Mission -> includes requirements for all mission phases:

- Ground and pre-launch (4.1.2)
- Launch and ascent (4.1.3)
- Planetary orbital phases (4.1.4)
- Interplanetary phases (4.1.5)
- Planetary natural environment (4.1.6)
- Docking, docked and separation phases (4.1.7)
- Descent, entry and landing (4.1.8)
- Post-landing phases (4.1.9)

Very generic related to meet the requirements for different mission phases

Clause 4: Requirements (3)

Clause 4.2: Performance – most important TCS performance requirements:

4.2.1g: The TCS shall conform to the following requirements to be specified in the TCS specification:

- Temperature gradients
- Temperature stability
- Temperature uniformity
- Heat flux
- Electrical power allocation for heating and cooling
- TM/TC allocation for TCS parameter
- Mass allocation for TCS, etc…

Specific requirements for the high and cryogenic temperature range (if different from the nominal range) as well as TCS functional requirements are given in Clauses 4.2.2, 4.2.3 and 4.2.4

Tailoring and translation into specific project requirement necessary

Clause 4: Requirements (3)

Clause 4.3: Requirements wrt other subsystems shall be captured

- from other subsystems affecting TCS
- from TCS on other subsystems

- Mechanical (4.3.2) -> requirements related to Interface Control Document (e.g. dimensions, mass, fixation, materials, heat capacities, alignment, forbidden zones, etc.); strength vs mechanical loads; issue thermal ICD
- Electrical (4.3.3) -> requirements related to heat dissipation, harness, TCS power budget, voltage, EMC
- 4.3.4.1 Propulsion -> thrusters temperature, plume interaction, heat soak back; possible modification of thruster operation, if predicted temperatures are too high
- 4.3.4.2 Attitude control -> respect attitude requirements; agreement for thermally unacceptable attitudes

Clause 4: Requirements (3)

- Telemetry/Telecommand (4.3.5) -> command and telemetry allocation to TCS
- Data Handling and Software (4.3.6) -> TCS related software requirements (heater control, sensors)
- Launcher (4.3.7) -> launcher requirements affecting TCS (e.g. launcher envelope, venting requirements, depressurization profile, accessibility, launch pad air-conditionning, heat fluxes from fairing, etc.)
- Ground Support Equipement (4.3.8) -> requirements affecting TCS interfaces; TCS specific Ground Support Equipment requirements

Tailoring and translation into specific project requirement necessary

Clause 4: Requirements – 4.4 Design

- General (4.4.1): Use materials compatible to environment - Be documented in design description
- Budget allocation (4.4.2) -> TCS shall define budgets for mass, size, power, energy, TM/TC, operational aspects
- Parts, materials and processes (4.4.3) -> Use of space qualified parts, materials and processes
- EEE components (4.4.4) -> Use of space qualified EEE components
- Lifetime (4.4.5) -> TCS design shall conform to the total lifetime
- Predictability and testability(4.4.6) -> Design shall enable the demonstration of performance requirements (Cl. 4.2) by analysis and test

Clause 4: Requirements – 4.4 Design

- Flexibility(4.4.7) -> the design shall be able to accommodate modifications of TCS requirements and shall offer trimming capabilities
- Integration and accessibility (4.4.8) -> Accessibility to allow for integration, (de-) mounting, inspection, maintenance
- Reliability (4.4.9) -> TCS shall demonstrate required reliability figures by analysis and test, meet system requirements (i.e. single point failure avoidance)
- Interchangeability (4.4.10) -> TCS shall meet system interchangeability requirements
- Maintenance (4.4.11) -> TCS shall specify maintenance procedures, no in-orbit maintenance
- Safety (4.4.12) -> Reference to ECSS-Q-ST-40 and ECSS-Q-ST-40-02
- Availability (4.4.13) -> Plan for in-time availability of resources and items with limited lifetime

Clause 4: Requirements – 4.5 Verification

Verification requirements are process requirements (not related to product properties)

General verification requirements are contained in

- ECSS-E-ST-10-02 (Verification)
- ECSS-E-ST-10-03 (Testing)

The thermal Standard contains requirements specific to TCS

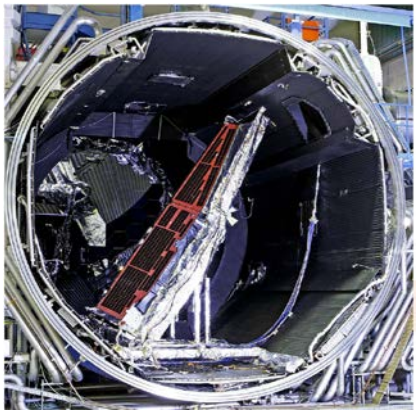
- 4.5.2.1: Requirements for analysis, modelling, TCS testing and documentation
  - Cases to be verified to be agreed with the system authority
  - Thermal balance, thermal vacuum and climatic tests are required (the latter one may be tailored away)
- 4.5.2.2: Requirements related to cryogenic control system (CCS)
- 4.5.2.3: Requirements related to High temperature TPS

Clause 4: Requirements – 4.5 Verification

4.5.3: Requirements dedicated to Thermal Balance Test (TBT)

Regarded as TCS performance verification & (when applicable) as TCS qualification test

- 4.5.3.1: Requirements related to test performance
  - Documentation: Test specification, procedures, test report
  - Purpose of TBT to verify
    - Thermal mathematical model
    - Suitability of TCS design
    - Performance of TCS hardware
    - Sensitivity of TCS with respect to parameter changes
  - Two different steady-state test cases + transient case
  - Solar simulation, when behaviour is governed by solar environment
  - Critical hardware flight representative



Clause 4: Requirements – 4.5 Verification

- 4.5.3.2: Requirements related to test success criteria
  - Steady-state conditions, when temperature sensor readings meet predefined temperature variation over a predefined time period
- 4.5.3.3: Requirements related to correlation success criteria
  - Test correlation for steady-state and transient modes based for units on unit temperature reference points (TRP)
  - Correlation is successful, when
    - Deviations between measured and predicted temperatures as specified
    - Temperature mean deviation as specified
    - Temperature standard deviation as specified
    - Deviations between measured and predicted heating / cooling power within specification

Clause 4: Requirements – 4.6 Prod. & manufacturing

- Procurement (4.6.1) ref to ECSS-Q-ST-70 (#5.6) addressing in detail procurement of materials and ECSS-Q-ST-70 (#6.6) addressing procurement of mechanical parts, ECSS-Q-ST-20 (#5.4) for QA requirements for procurement
- Manufacturing process (4.6.2) -> procedures to be approved by customer
    - Number of samples, prototypes, components to be agreed with customer
    - in accordance with QA requirements as specified in ECSS-ST-Q-20 (cl. 5.5)
- Quality management (4.6.3) -> according to ECSS-Q-ST-20 (cl. 5.1.1)
- Cleanliness and contamination (4.6.4) -> according to ECSS-Q-ST-70-01 (cl. 5.1 & 5.2)
    - TCS shall define cleanliness requirements for TCS H/W

Clause 4: Requirements – 4.6 Prod. & manufacturing

- Integration (4.6.5) -> Procedures for all levels of integration to be defined
- Identification and marking (4.6.6) -> according to ECSS-M-ST-40 (cl. 5.3.1.5)
- Packing, handling, transportation (4.6.7) -> requirements shall be defined
    - Items containing hazardous material or those subjected to special packaging, handling and transportation shall be identified
- Storage (4.6.8) ->
    - Storage conditions shall not to cause degradation to thermal H/W
    - Storage devices and storage procedures shall be defined
- Repair (4.6.9) -> Repair procedures, tools and material shall be defined

Clause 4: Requirements

- Clause 4.7: In-service requirements
    - Support the system during S/C commissioning, operational phases, special events, in-orbit anomalies; provide input to operational documentation
        - Examples: Thermal simulation of S/C
        - De-freezing of fluid systems
    - Support Cryogenic Control System (CCS) by
        - adjusting operational parameters to compensate for degradation
        - De-contamination of cryogenic areas
- Clause 4.8: Product assurance -> requirements for TCS are specified at system level and based on ECSS-Q-ST-20 Quality assurance, ECSS-Q-ST-40 Safety qand ECSS-Q-ST-70 Materials, mechanical parts and processes

Clause 4: Requirements

- Clause 4.9: Deliverables
  - All deliverables (hardware, documents, software, mathematical models) shall be specified in the Statement of Work (SOW)
  - TCS shall deliver all H/W in accordance with the specifications
  - TCS shall deliver subsystem documents as listed in Table 5-1
    - Document requirements definitions (DRD) exist for each required document
    - DRD defines the expected content for each document
  - TCS shall provide inputs to higher level system documents (AIV and test plans, DDP, drawings, interface documentation, budgets, design definition / justification, etc.)

Clause 5: Document requirements definition (DRD)

Document requirements definitions (DRD) serve to ensure:

a. completeness and consistency of information within the documents,

b. that the information contained in the document conforms to its defined scope, and correctly implements its interfaces with other documents, and

c. that portions of a document can be generated or maintained by separate organizational groups and seamlessly integrated into a coherent whole.

- Table 5-1 lists and summarizes the DRDs that are called up in the previous clauses and that are defined in annexes of this Standard or other relevant Standards.
- The first issue of a document is created in the project phase as indicated in the following list and delivered for the indicated project review.
- The document is then updated in additional issues for follow-on project phases and reviews. The creation of a completely new document shall be avoided.

Clause 5: Document requirements definition (DRD)

Document title	Summary	Phase								DRD ref.	Remarks
		0	A	B		C	D		E	F	
		MDR	PRR	SRR	PDR	CDR	QR	AR		MCR	
Mathematical Model Specification	Specifies requirements for development and delivery of thermal mathematical models to be used for thermal analysis at system level				X	X					E-ST-31	
Thermal and geometrical model description	Describes the TMM and GMM to be used as input for the sub-system thermal analysis cases		X	X	X	X	X	X			E-ST-31	To be updated before each analysis campaign
TCS analysis report	Contains a full mathematical analysis of the thermal control system leading to the thermal subsystem definition including redundancy strategy, operational concept and hardware definition		X	X	X	X	X	X	X		E-ST-31	Document to be updated or re-issued for CDR, AR, TBT prediction, TBT evaluation, Flight prediction
TCS interface control document	Describes the thermal control subsystem interfaces to other subsystems and to the system		X	X	X	X	X	X			E-ST-31	To be updated at CDR and AR
TCS thermal balance test specification	Describes the requirements applicable for the thermal balance test including purpose, test approach and test article					X					E-ST-31	Can be combined with the system thermal vacuum (TV) test specification
TCS detailed design description	Describes the detailed design of the thermal control subsystem			X	X	X					E-ST-31	Possible update for phase D
TCS thermal balance test procedure	Gives directions for conducting the thermal balance test in terms of description, resources, constraints and step-by-step procedure					X					E-ST-10-02	Before TBT
TCS thermal balance test report	Describes the execution of the thermal balance test and the results obtained					X					E-ST-10-02	After TBT

Clause 5: Document requirements definition (DRD)

Document title	Summary	Phase								DRD ref.	Remarks
		0	A	B		C	D		E	F	
		MDR	PRR	SRR	PDR	CDR	QR	AR		MCR	
TCS declared materials list	Establishes the detailed record of all the materials used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR
TCS declared mechanical parts list	Establishes the detailed record of all the mechanical parts used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR
TCS declared process list	Establishes the detailed record of all the processes used to produce the products of the thermal control subsystem		X	X	X	X					Q-ST-70	First formal delivery at PDR

Missing: delivery of thermal models

DRD's are given in normative annexes to the Standard:

Annex A, Annex B, etc.

"normative" means: these annexes are part of the list of requirements to be met

"informative" Annexes contain information

DRD Annexes (normative) (1)

The structure of each DRD is the same for all documents:

1. DRD identification
    - 1.1 Requirement identification and source document
    - 1.2 Purpose and objective
2. Expected response
    - 2.1 Scope of content
    - <1> Introduction
    - <2> Applicable and reference documents
    - <3> Definitions and abbreviations
    - <4> and following sections: Content is document specific
    - 2.2 Special remarks

DRD Annexes (normative) (2) - Example

Annex A (normative)

TCS mathematical model specification

A1. DRD identification

A1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-31, requirement 4.5.2.1d.

A1.2 Purpose and objective

The TCS mathematical model specification specifies requirements for development and delivery of mathematical models to be used for thermal analysis.

A2 Expected response

A2.1 Scope of content

<1> Introduction

a. The TCS mathematical model specification shall contain a description of the purpose, objective, content and the reason prompting its preparation.

b. Any open issue, assumption and constraint relevant to this document shall be stated and described.

DRD Annexes (normative) (2) - Example

<2> Applicable and reference documents

a. The TCS mathematical model specification shall list the applicable and reference documents in support to the generation of the document.

<3> Definitions and abbreviations

a. The TCS mathematical model specification shall list the applicable directory or glossary and the meaning of specific terms or abbreviations utilized in this document.

<4> Definition of subassemblies, interfaces and nodal breakdown

a. The TCS mathematical model specification shall specify the subassemblies, for which mathematical models are required.

b. The TCS mathematical model specification shall define conductive, convective and radiative interface nodes and their characteristics.

<5> Node number and node identification

a. The maximum number of nodes for a subassembly model shall be given.

b. A method of identification and numbering of nodes shall be presented.

DRD Annexes (normative) (2) - Example

<6> Modelling rules

a. The model hierarchy shall be described.

b. The document shall describe the applied modelling rules for thermal items

c. Control algorithms for thermal components shall be described.

<7> Software tools

a. The software tools to be used for development of the mathematical models shall be described.

<8> Test cases

a. The thermal mathematical model shall be delivered together with the definition and results of representative test cases.

A2.2 Special remarks

None

Tailoring

- The ECSS document contains requirements
    - for a variety of thermal products (spacecraft and launcher elements, equipment)
    - related to different missions (Earth orbiting spacecraft, exploration spacecraft …), different temperature ranges
- Requirements are of generic nature and therefore not defined for a specific project
- Consequently, it is necessary to select from the ECSS document a set of suitable requirements for each project case => this selection process is called tailoring

ECSS definition of tailoring (ECSS P-001B):

- Process by which individual requirements of specifications, standards and related documents are evaluated and made applicable to a specific project by selection, and in some exceptional cases, by modifications of existing or by addition of new requirements.
- Tailoring is, according to ECSS rules, a task of the customer.
- In most cases tailoring is performed by the contractor and approved by the customer
- The exact process of tailoring is not yet fully defined and is still improving.

Tailoring

- Examples for ECSS requirements tailoring
  - Project A
  - Tailoring performed by ESA (as Customer). Reference: AAA.ESA.SA.RS.0074, “Tailoring of ECCS-E Engineering Standards“

E-ST-31C Thermal control general requirements

Clauses removed	4.1.5	Interplanetary phases
	4.1.7	Docking, docked and separation phases
	4.1.8	Descent, re-entry and landing
	4.1.9	Post-landing phases
	4.2.2	High temperature range
	4.3.9	ECLS
	Annex H	High temperature range
	Reason:	Relates to events and environment not encountered by MTG

  - The table lists requirements which are not applicable for Project A
  - All other thermal requirements of E-ST-31C are then applicable

Conclusion

- ECSS-E-ST-31C defines a set of requirements, which are applicable for thermal control design and verification tasks in all spacecraft projects
- In addition technical terms are defined, which shall be used by all ECSS users to avoid misunderstandings in technical discussions
- The document covers requirements for the entire temperature range and includes requirements for all mission phases, for interfaces to equipment thermal control and other subsystems
- Requirements are mostly generic and need to be translated into project specific (quantitative) requirements
- A set of requirements specific to a project must be generated by a tailoring process