ECSS E-10
System Engineering Standards

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Course Objectives

The objective of this course is to:

- present the E-10 System Engineering ECSS discipline
- the link between E-10 standards and the other E and M standards.
- Mention tips about their utilisation and tailoring within ESA invitations to tender and requests for quotation.

For each of the standards from the E-10 ECSS Discipline, the following is presented:

- description of the content
- guidelines for tailoring
- examples of applicability and Agency practices

Agenda

- 10:00 - 12:00
  - Background
  - Introduction to E-10 Series
  - Systems Engineering
  - Requirements Specification
  - Interface Management
- 14:00 - 16:00
  - Verification
  - Testing
  - Other E-10 Standards (Environment, Ref Coordinate Sys, Human factors, Radiation)
  - Systems Engineering Handbook mention
  - MBSE and E-10-23 and 25
  - Future Developments in Standards
- Q&A

Table of Contents

- General Background and Terminology for System Engineering
- Introduction to E-10 System Engineering sub-branch
- E-ST-10C: System engineering general requirements
- E-ST-10-06C: Technical requirements specification
- E-ST-10-24C: Interface management
- E-ST-10-02C: Verification
- E-ST-10-03C: Testing
- Other E-10 Standards
- E-10 Handbooks and Technical Memoranda
- Outlook:
  - Model-Based System Engineering
  - ESA Mission Classification
  - ECSS Tailoring
- Useful references

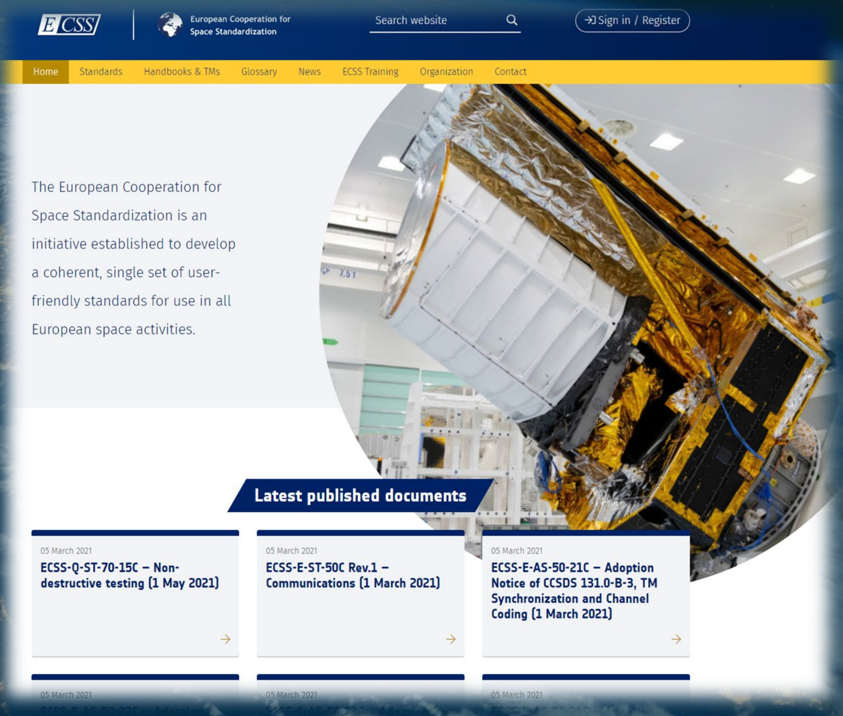
What are the Standards?

The European Cooperation for Space Standardization (ECSS) is a **collaboration among ESA**, **the European space industry** represented by Eurospace, and **several space agencies**, to develop and maintain a coherent, single set of user-friendly standards for use in all European space activities.

Established in 1993 on Eurospace request to unify space PA standardization at European level.
Officially adopted by ESA on 23 June 1994 through the resolution ESA/C/CXIII/Res to replace its own Procedures, Specifications and Standards (PSS) system.

The ECSS currently has **139 active standards**, forming the ECSS system.

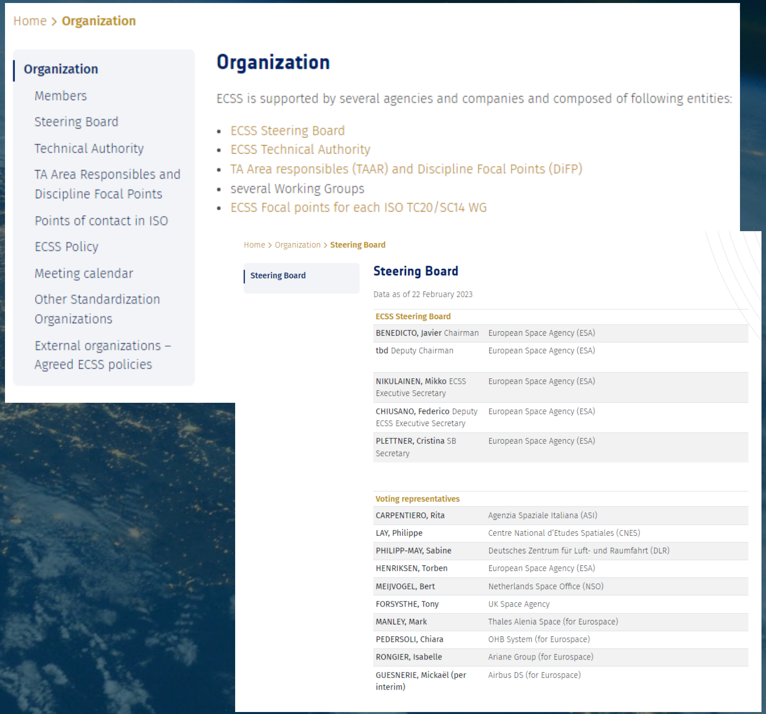
The ECSS is managed by **the ESA Requirement and Standard Division**, based in ESTEC in Noordwijk, the Netherlands. The ECSS maintains connections with multiple European and international standardization organizations, to contribute to standardization and to adopt relevant standards as part of the ECSS system



https://ecss.nl/

Roles and Responsibilities

- The Executive Secretariat provides the following functions:
  - Co-ordinate all activities leading to the development, publication and on-going maintenance of the standardization documents.
  - Provides the ESA representatives to the ECCS Steering Board (SB) and Technical Authority (TA)
  - Manages the ECSS working groups providing support and direction on how to draft standardization documents using ECSS drafting rules.
  - Maintains configuration control of ECSS documents and ECSS website, including management of New Work Item Proposals and Change Request to existing documents.
  - Support the establishment and implementation (including monitoring) of the ECSS workplan


Home > Organization

Organization
Members
Steering Board
Technical Authority
TA Area Responsibles and Discipline Focal Points
Points of contact in ISO
ECSS Policy
Meeting calendar
Other Standardization Organizations
External organizations – Agreed ECSS policies

Organization

ECSS is supported by several agencies and companies and composed of following entities:

- ECSS Steering Board
- ECSS Technical Authority
- TA Area responsibles (TAAR) and Discipline Focal Points (DiFP)
- several Working Groups
- ECSS Focal points for each ISO TC20/SC14 WG

Home > Organization > Steering Board

Steering Board

Steering Board

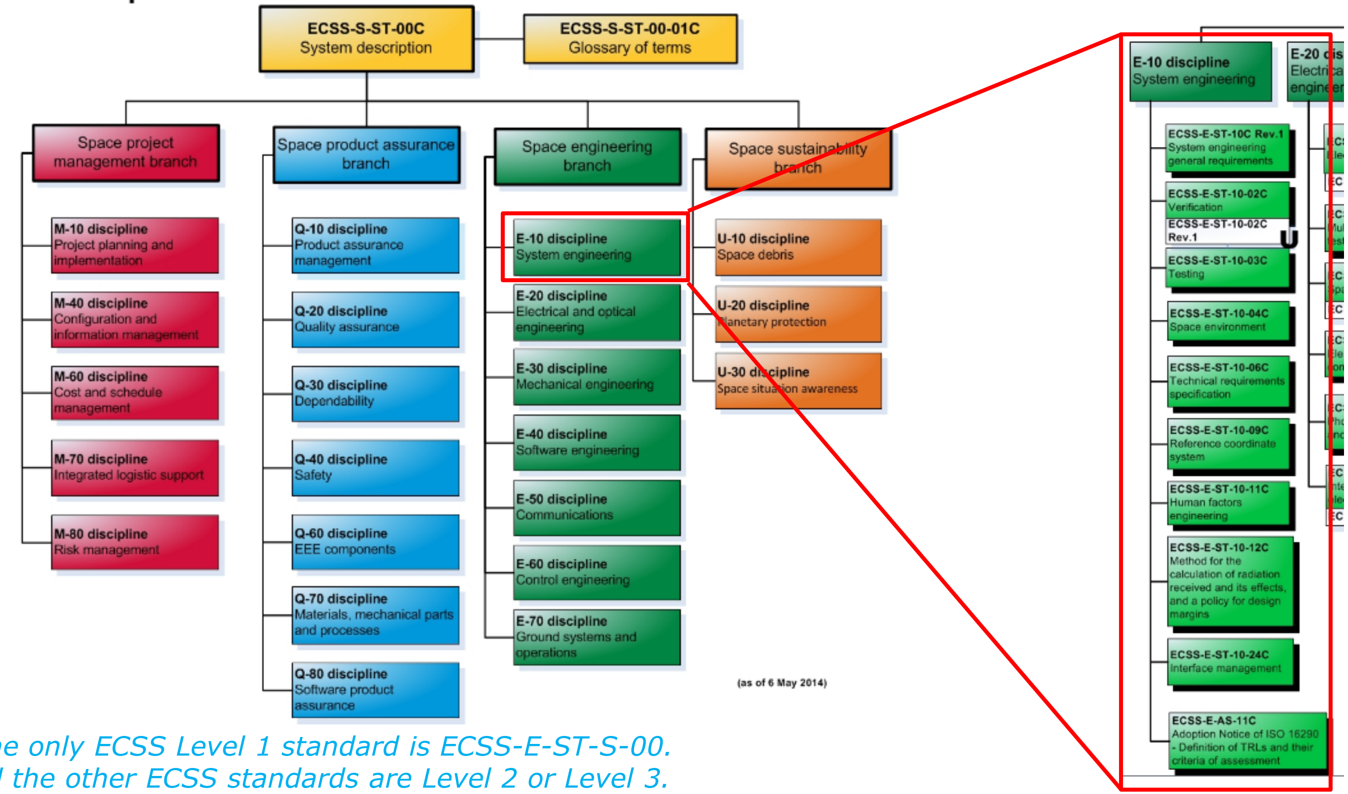
Data as of 22 February 2023

ECSS Steering Board	
BENEDICTO, Javier Chairman	European Space Agency (ESA)
tbd Deputy Chairman	European Space Agency (ESA)
NIKULAINEN, Mikko ECSS Executive Secretary	European Space Agency (ESA)
CHIUSANO, Federico Deputy ECSS Executive Secretary	European Space Agency (ESA)
PLETTNER, Cristina SB Secretary	European Space Agency (ESA)

Voting representatives	
CARPENTIERO, Rita	Agenzia Spaziale Italiana (ASI)
LAY, Philippe	Centre National d'Etudes Spatiales (CNES)
PHILIPP-MAY, Sabine	Deutsches Zentrum für Luft- und Raumfahrt (DLR)
HENRIKSEN, Torben	European Space Agency (ESA)
MEIJVOGEL, Bert	Netherlands Space Office (NSO)
FORSYSTHE, Tony	UK Space Agency
MANLEY, Mark	Thales Alenia Space (for Eurospace)
PEDERSOLI, Chiara	OHB System (for Eurospace)
RONGIER, Isabelle	Ariane Group (for Eurospace)
GUESNERIE, Mickaël (per interim)	Airbus DS (for Eurospace)

Where to find our standards?

ECSS Disciplines



The only ECSS Level 1 standard is ECSS-E-ST-S-00.
All the other ECSS standards are Level 2 or Level 3.

Link: ECSS

On the ESA Intranet

Documents from "List of ESA Approved Standards"

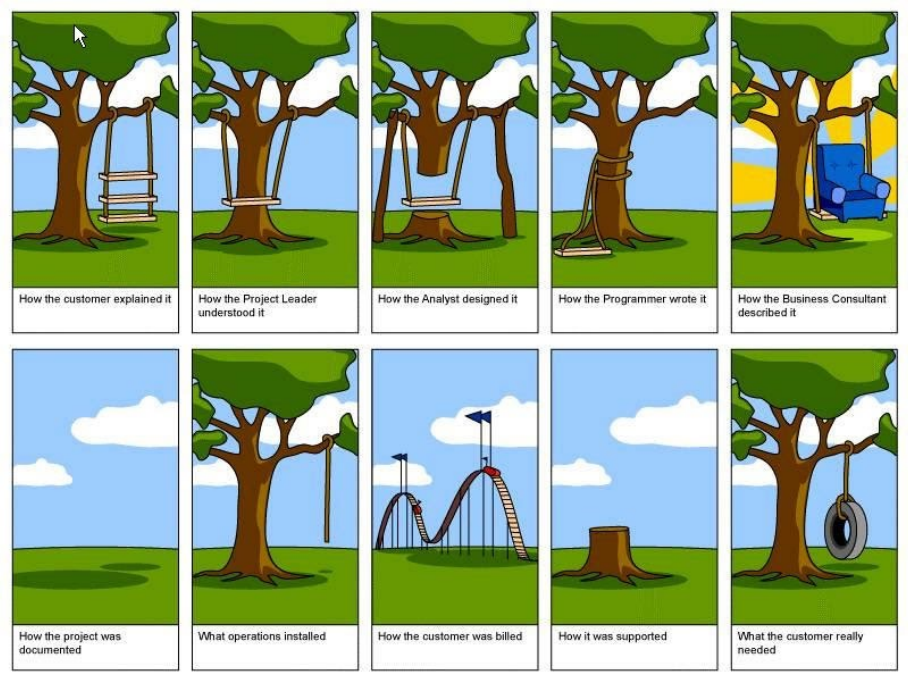
Space Engineering

Applicable Standard	Reference document	Title (including LEAS notes)	Published
Systems Engineering			
[-] ECSS-E-AS-11C		Adoption Notice of ISO 16290, Space systems - Definition of the Technology Readiness Levels (TRLs) and their criteria of assessment	01/oct/14
	ECSS-E-HB-11A	Technology readiness level (TRL) guidelines	01/mar/17
[-] ECSS-E-ST-10C Rev.1		System engineering general requirements	15/feb/17
	ECSS-E-TM-10-10A	Logistics engineering	16/apr/10
	ECSS-E-TM-10-20A	Product data exchange	16/apr/10
	ECSS-E-TM-10-21A	System modelling and simulation	16/apr/10
	ECSS-E-TM-10-23A	Space system data repository	25/nov/11
	ECSS-E-TM-10-25A	Engineering design model data exchange (CDF)	20/okt/10
	SAVOIR-HB-003 i2 r0a	SAVOIR FDIR Handbook	1/nov/19
[-] ECSS-E-ST-10-02C Rev.1		Verification	01/feb/18
	ECSS-E-HB-10-02A	Space Engineering - Verification guidelines	17/dec/10
[-] ECSS-E-ST-10-03C Rev.1		Testing	31/may/22
	ECSS-E-HB-10-03A	Testing guidelines	31/may/22
ECSS-E-ST-10-04C Rev.1		Space environment	15/jun/20
ECSS-E-ST-10-06C		Technical requirements specifications	06/mar/09
ECSS-E-ST-10-09C		Reference coordinate system	31/jul/08
ECSS-E-ST-10-11C		Human factors engineering	31/jul/08
[-] ECSS-E-ST-10-12C		Method for the calculation of radiation received and its effects, and a policy for design margins	15/nov/08
	ECSS-E-HB-10-12A	Space Engineering - Methods for the calculation of radiation received and its effects and a policy for the design margin	17/dec/10
ECSS-E-ST-10-24C		Interface management	01/jun/15

https://idc.sso.esa.int/intranet/public/standards/space-engineering.html

Why do we have standards?

To ensure that <u>what is needed</u> gets delivered



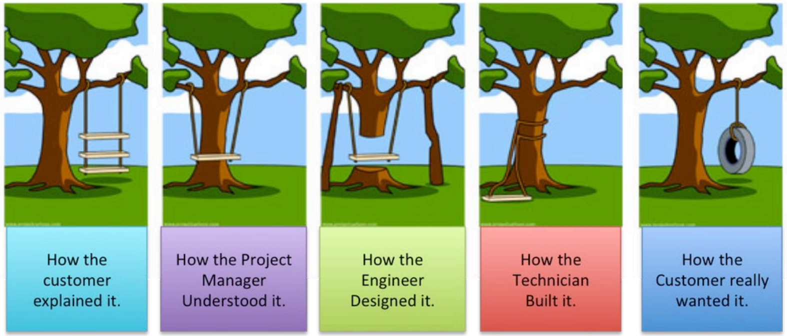
STANDARDS and REQUIREMENTS in CONTEXT

- Standards are documents created by experts.
- Experts have not legal civil authority, therefore standards are not mandatory, unless they are made mandatory by other binding legal document, for example, a contract.
- Standards are made normative by the ESA contracts
- They are of mandatory application during the execution of the project.
- ESA suppliers shall perform their work in accordance to the standards listed in their contracts, and they have to demonstrate to the ESA project team that they have met the requirements in such standards

Requirements: from definition to verification

- Requirements **set the scope** of a technical solution/commercial agreement/ delivery project
  - Requirements **have their own life-cycle**, from when they have been stated until they are delivered, passing through their implementation, verification and final acceptance
  - Consequently, a **tracking process** that controls the evolution of requirement in their life-cycle and prevents leakages is **needed**

- Requirements **involve several stakeholders** forming cross-functional team working
- It is **necessary to establish a method to make explicit all the requirements to assure they do not remain hidden**



Application of the standards in ESA projects

- Application of standards in ESA projects is defined in an ADMIN (ESA/ADMIN/IPOL(2007)11, of mandatory application in ESA.

- The ADMIN defines a document called the LEAS (List of ESA Approved Standards).

- The LEAS has two main sections:
  - Section 1 "Normative documents"
    - All ESA project shall apply all the standards is **Section 1** of the LEAS.
    - If a document is not applied, individual justification for the non-application of the document shall be provided.
  - Section 2 "Reference documents".
    - not of mandatory use by projects, use of this Section 2 is decided by each project. A project may therefore decide to use every documents in this section as normative, informative, or not use it at all, at their own judgement.

Examples of Tailoring

- Level 2 Management and Product Assurance standards in ECSS are so generic that a pre-tailoring approach for all ESA projects makes sense to account for the ESA specificities.

- The ESA MaRD (ESA Management Requirements Document) and PARD (ESA Product Assurance requirements document) templates are two ESA documents built by including, respectively, the management and the PA requirements in the ECSS M and Q standards, pre-tailored for applicability to a generic ESA project.

- ESA MARD and PARD templates still may need a final tailoring performed by each project, to account for the project specificities. Hopefully, this final tailoring will be minimum.

- The resulting documents after this final tailoring are called "Project MaRD" and "project PARD".

Knowledge of the ECSS E-10 System Engineering Discipline

Systems Engineering Role & Responsibilities vis-à-vis ECSS-E-10

What is system engineering?

- **System**
  - "set of interrelated or interacting functions constituted to achieve a specified objective" [ECSS-S-ST-00-01C]
  - "set of functional elements organized to satisfy user needs" [IEEE P1220]

- **Requirement**
  - "documented demand to be complied with" [ECSS-S-ST-00-01C]
  - "need or expectation that is stated, generally implied or obligatory" [ISO 9000:2000]

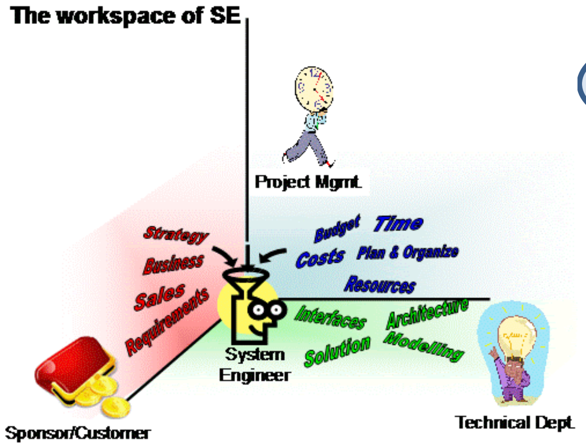
- **System engineering**
  - "interdisciplinary approach governing the total technical effort required to transform a requirement into a system solution" [ECSS E-ST-10C]

What is systems engineering?

Definition by INCOSE

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems.

It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem."



Source: https://sites.google.com/site/systemengineeringitaly/

Performance

Cost & Schedule

Training & Support

Manufacturing

Test

Operations

Disposal

http://www.incose.org/AboutSE/WhatIsSE
INCOSE is the International Council on Systems Engineering

Background – ECSS-S-ST-00-01C (Glossary of Terms)
Space System Decomposition

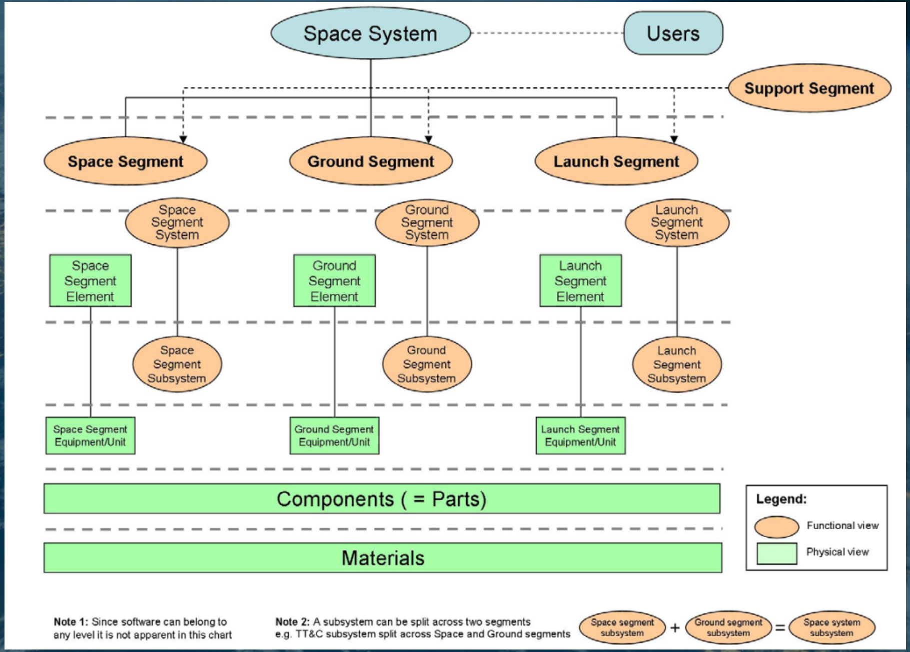
Space System: "system that contains at least a space, a ground or a launch segment"

NOTE: Generally, a space system is composed of all three segments and is supported by a support segment.

Segment:

"set of **elements** or combination of **systems** that fulfill a major, self-contained, subset of the **space mission** objectives"

4 SEGMENT GATEGORIES:
Space, **Ground**, **Launch**, **Support**



Functional vs **Physical** views

Background – ECSS-S-ST-00-01C Space System Decomposition

Functional view	Physical view
function: "intended effect of a **product**"	**product:** "implements a function" *Note: There are four generic product categories: services, software, hardware, processed materials*
system: "set of interrelated or interacting **function**s constituted to achieve a specified objective"	**element:** "combination of integrated **equipment, component**s and **part**s"
subsystem: "part of a **system** fulfilling one or more of its **function**s"	**equipment:** "integrated set of **part**s and **component**s" *Synonym*: **unit**
	component: "set of **material**s**,** assembled according to defined and controlled **process**es**,** which cannot be disassembled without destroying its capability and which performs a simple **function** that can be evaluated against expected **performance requirement**s" *Synonym*: **part**

*Warning: Outside ECSS many standards and handbooks (e.g. NASA's) use **subsystem** also as a **physical** decomposition level of a system.*

*This can be confusing in international partnerships beyond ESA member states. In ECSS a **subsystem** is always a **functional** view, usually from the perspective of an engineering discipline.*

Background - System Decomposition
Example from S-ST-00-01C Annex B

product or item

examples

space segment	space segment system	space segment element	space segment subsystem	space segment equipment (=unit)	component (=part)	material
	Data Relay Satellite System	spacecraft (physical view)	power	electronic unit (e.g. DHU, PCSU, PDU, ICU)	ASIC	Alumiunium
	Navigation Satellite System	satellite (physical view)	propulsion	thruster	hybrid	to be taken from Q60 & Q70
	spacecraft (functional view)	payload	data handling	valve	integrated circuit	
	satellite (functional view)					
		platform	thermal	battery	heat-pipe	
		instrument	structure	reflector	MLI	
		orbiter	AOCS	mechanism (when fully assembled)	structural panel	
		lander	Tm&Tc	vessel/tank	optical array	
		bay	optical	mirror/lenses/filters (assembly)	pyro components	
		module	RF	solar array (assembly)	PCB	
			communication	antenna (assembly)	mirror	
				focal plane assembly	solar cell	
				telescope (assembly)	insert	
				solar panel (equipped)	resistor	
				pressure vessels	diode	
				optical bench	transistor	
				RF filters	capacitor	
				LNA	thermistor	
				IMUX/OMUX	heater	
				OMT	propulsion fluidic	
				feeds		

ECSS "Glossary of Terms" – Mobile Apps

esa

Glossary

Pick ECSS-handbooks and technical manuals by branch, discipline and type.

Search glossary | Search

Branch | Discipline | Type

Popular terms

Term	Standard	Term	Standard
model factor (KM)	ECSS-E-ST-32-10C Rev.2 Corr.1	transient	ECSS-Q-ST-30-11C Rev.1
source component	ECSS-E-ST-40-07C	array antenna	ECSS-E-ST-20C Rev.1
lane	ECSS-E-ST-50-11C		

https://ecss.nl/glossary/

ECSS Glossary mobile applications

ECSS Glossary mobile apps available from iOS and Android store and ECSS Glossary Plugin for MS Word available from Microsoft Appstore

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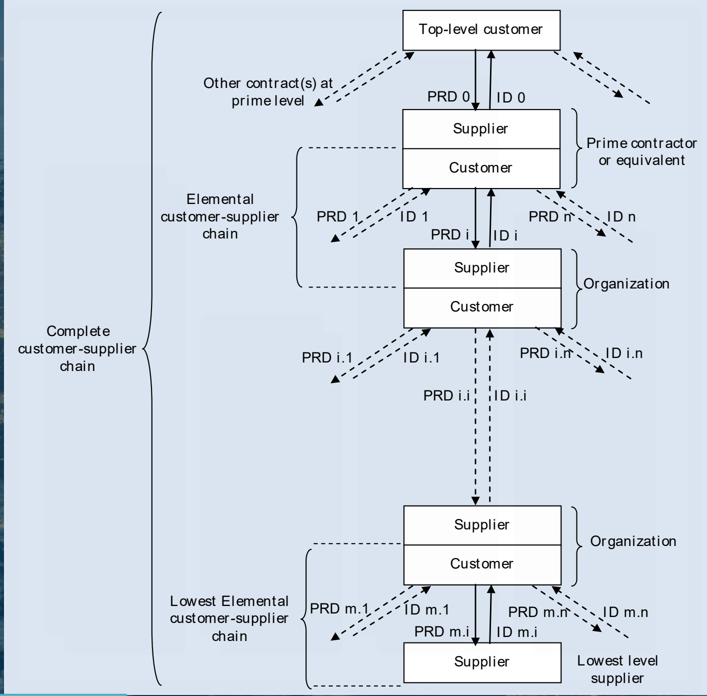
Download plugin

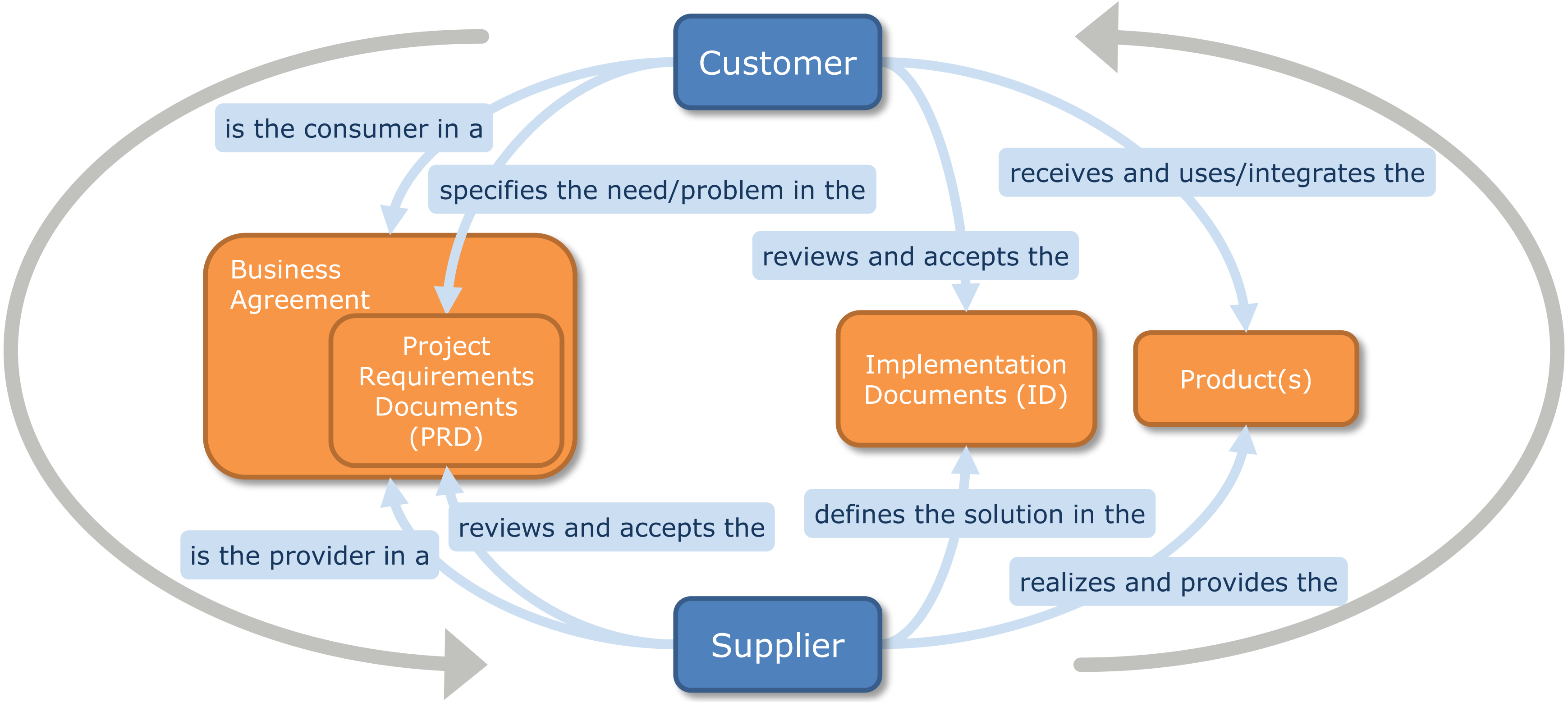
Background – ECSS-S-ST-00C The Customer-Supplier Model

- **Customer** and **Supplier** are roles played by the **Actor**s that cooperate to produce, operate and dispose a **Space System**
- One **Actor** (organization) can be a **Customer** or **Supplier** or both
- **System** is a relative concept that may appear anywhere in the **Customer-Supplier** chain:
  a **Customer**'s **Equipment** can be the **Supplier**'s **System**
- Within one **Customer-Supplier** relationship the roles of "Information Provider" and "Information Consumer" depend on the direction of the information flow, as denoted with the arrows

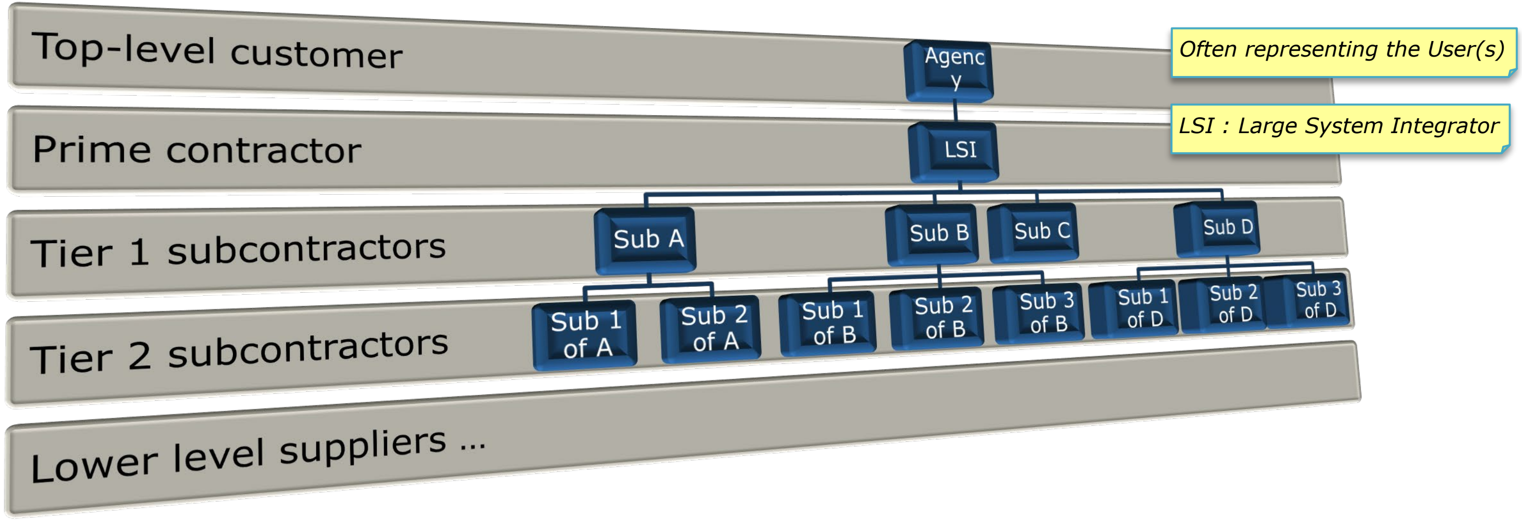


Outside ECSS the Customer-Supplier Chain is also known as the "Supply Chain" or "Extended Enterprise"

Background – ECSS-S-ST-00-01C The Customer-Supplier Model



Example of a Customer-Supplier chain for an ESA space project



Overall ECSS picture of the E-10 System Engineering discipline together with the E and M standards

Background – ECSS-M-ST-10C System Life Cycle

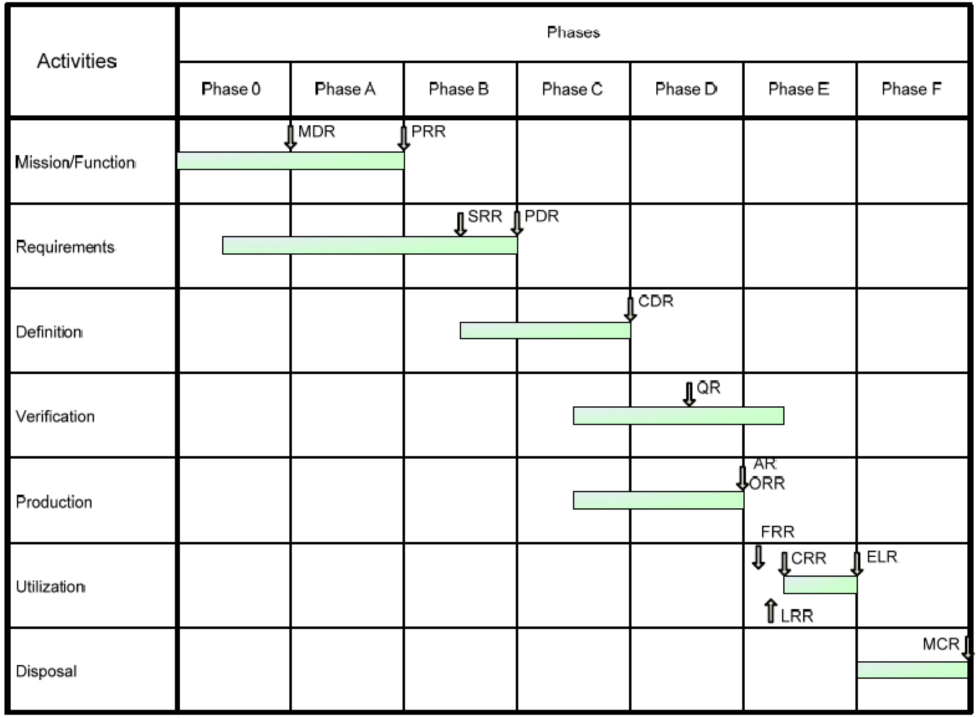
Feasibility study

Conceptual design

Detailed design

Manufacturing
Assembly
Integration
Qualification
Acceptance

Operations



T_0 : Mission Need Statement

T_F : Switch-off or burn-out / break-up

Background – ECSS-M-ST-10-01C Project reviews

- Reviews are ***examinations of the technical status*** of a project and associated issues at a particular point in time and against a pre-defined set of objectives.
- Reviews are run by a mixed group of ***insiders*** and ***outsiders*** to the project
  - but generally within the same entity the project belongs to (e.g. ESA)
- ESA Reviews assess results from all project participants/contributors including:
  - ESA project
  - Industrial contractors
  - Any external partners
- Reviews provide ***recommendations on recovery/re-direction*** in case of identified issues
- ESA Review recommendations are ***advisory***. Implementation of the recommendations is the responsibility of the ESA Project Manager.
- Number, type and objectives of the Reviews are project-dependent.
  - Generally, there is a number of reviews that are "mandatory" such as: **SRR, PDR, CDR, FAR**

Background – Main reviews

Review	Phase	Main Objectives
Mission Definition Review (MDR) / Preliminary Requirements Review (PRR)	Phase 0 / Phase A	Definition of Mission Baseline and assessment of feasibility of User requirements. Allows solid start of preliminary design.
System Requirements Review (SRR)	Phase B	Freeze of Highest level requirements
Preliminary Design Review (PDR)	Phase B	Freeze of Mission baseline and requirements down to subsystem level. Confirmation of design at System level. Confirmation of AIV plan. It forms the basis for industrial Phase C/D/E offer
Critical Design Review (CDR)	Phase C	Confirmation of detailed design at unit level. Authorisation to complete qualification/built flight units
Qualification Review (QR)	Phase D	Confirmation of System Qualification
Acceptance Review (AR)	Phase D	Acceptance of the System from the Customer
Flight Readiness Review (FRR) / Operational Readiness Review (ORR)	Phase D	Confirmation of readiness to fly NB: Launch Readiness Review is the equivalent review but for the Launcher

Introduction to E-10

System Engineering for ESA projects: Use of ECSS

- The standards shall be used (possibly after tailoring) to complement a project's own specific requirements documents, which traditionally include:
  - Mission or System Requirements Document (MRD/SRD)
  - SOW for tasks description
  - Documents for Interfaces
    - ICD with Launcher Authority, Payload, Operations, etc.
  - Specific documents
    - e.g. Planetary Protection req's, Environment definition, Regulations, etc.

- Standardization documents used by ESA include the following three categories:
  - ECSS E-10 Standards *(issued for use in ITTs, with unambiguously identified obligations, normative)*
  - ECSS E-10 Handbooks *(informative, and providing guidelines, good practices, can be made normative)*
  - ECSS E-10 Technical Memoranda *(informative, and providing useful information or data not yet mature for a standard or a handbook)*
  - ISO (for debris mitigation and TRL definitions)
  - ESSB Handbooks (e.g. ESSB-HB-E-003 ESA pointing error engineering handbook)
- Active Engineering Standards: here

More on use of ECSS for Project Managers

- The standards can undergo updates or improvements as part of their review/feedback life cycle - typically 5 yearly.

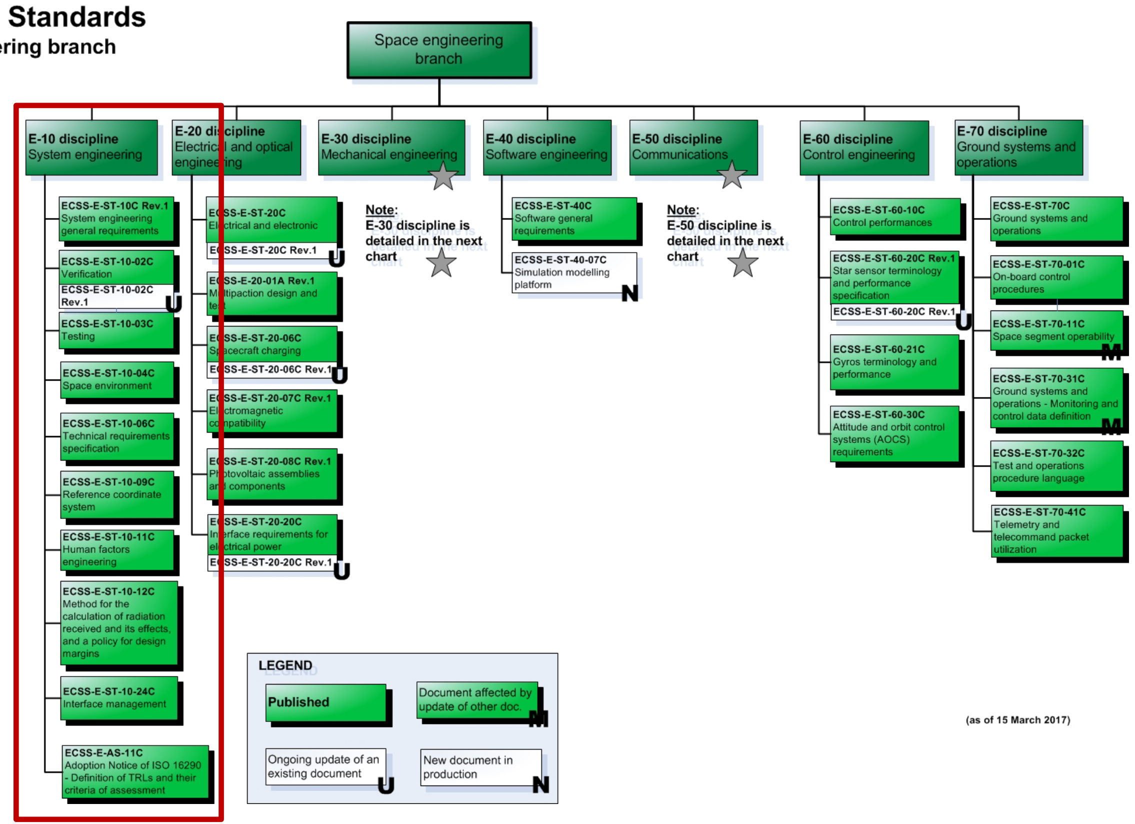
- LEAS is updated twice per year

- It is advised that Project Managers contact TEC-QES for the latest information on any possible Change Requests that may have an impact to the space project ITT phase, as well as the latest known practices from previous project(s) in the way to apply ECSS in a business agreement.

E-10 Discipline Sub-branch

Includes System Engineering itself, but also, system level disciplines:

- Space Environment
- Radiation
- Reference Coordinate System
- Human Factors Engineering



ECSS E-10 Standards Scope

- The E-10 standards cover the following System Engineering areas:
  - General principles, definitions and documentation (incl. DRDs)
  - Requirements specification
  - Interface management
  - Verification
  - Testing
  - Coordinate Systems
  - Space Environment / Radiation
  - Human Factors

- Several other areas of system engineering (traditionally) are covered by standards in other disciplines, for instance:
  - Space Segment Operability (E-ST-70-11C)
    - which defines autonomy and system requirements for operability
  - Software (ECSS-E-ST-40C) for the definition of the System inputs to SW
  - Testing at subsystem level (e.g. propulsion)
    - covered by the relevant discipline standards

The ODSI Paradigm

- ECSS standards, and specially Level 2, are intentionally generic.

Many requirements follow the ODSI Paradigm

- a. **Organize** the activity in your own way
- b. **Document** how you have organized the activity in your own way. The relevant aspects to be documented are normally covered by a DRD.
- c. **Submit** to your customer the document describing your organization, for approval. Approval of your customer is important to ensure a consistent organization through all the project actors such that your way of organizing is not conflicting with other areas.
- d. Once approved, **Implement** the documented organization. In the practical world, the organization may have been implemented before, but from a formal point of view, the implementation of a requirement applying the "ODSI" principle is considered valid only after approval by the customer.

Tailoring

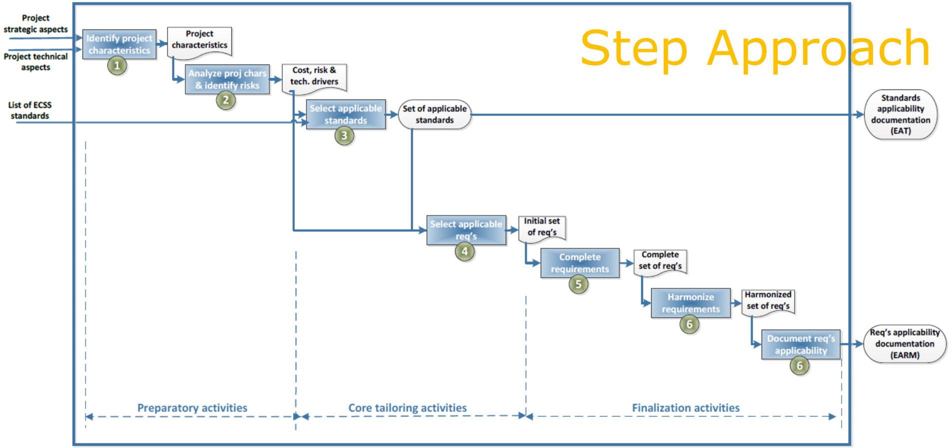


Figure 5-9: Generic tailoring process

Table 5-2: Example of EARM

THE COMPLETE SET OF REQUIREMENTS IN THE STANDARDS IN COLUMN 1 ARE APPLICABLE, WITH THE MODIFICATIONS STATED IN COLUMNS 2 TO 6

1. ECSS Standard	2. ECSS Req. identifier	3. Org. Req. identifier	4. Applicability (M/D/N)	5 Modified or New requirement (Full text)	6. Justification

NOTE: Column 3 is provided to give the users the capability of using their own requirement identification system, in parallel with the identification of the requirement in the applicable standard (Column 2).

M: Requirement applicable with Modification
D: Requirement Deleted, not applicable
N: New requirement (requirement added)

Table 5-1: Example of EAT

Standard	Applicability (A / M / /NA)	Justification (including justification of the use of other standard instead of)

A: Standard applicable without modifications
M: Standard applicable with modification. For each of these standards, the generation of a EARM is expected.
NA Standard not applicable at all

EARM (ECSS applicability Requirement Matrix)

Example of ECSS "tips"

Table 6-2: Applicability of ECSS-E Level 3 standards

#	Category and general rules for application	Subcategories	Standards
1	**Standards of generic applicability at any level of the contractual chain** *They are generally applicable to all ESA projects*	Standards for generic SE functions Applicable to any engineering activity	○ E-ST-10-02 "Verification" ○ E-ST-10-03 "Testing" ○ E-ST-10-06 "Functional specification" ○ E-ST-10-24 "I/F management"
		Generic standards, applicable at any level of the contractual chain	○ E-ST-10-12 "Radiation dose ○ E-ST-10-11 "Human factors" ○ E-ST-20-05 "ESD" ○ E-ST-20-07 "EMC" ○ E-ST-20-20 "I/Fs for electrical power" ○ E-ST-32-01 "Fracture control" ○ E-ST-32-10 "FOS" ○ E-ST-32-03 "Finite elements analysis" (to be used in conjunction with E-ST-32) ○ E-ST-32-10 "Materials"
2	**Generic standards applicable at system level** Standards imposing to make selection at agency or prime level *They are generally applicable to all ESA projects, but no need to flow them down to subcons* *The selected requirements are flowed down via Tech Specs*		○ E-ST-10-04 "Space environment" ○ E-ST-10-09 "S/C coordinate system" ○ E-ST-70-41 "PUS" ○ E-ST-60-10 "Control performances"

System Engineering E-ST-10C

ECSS-E-ST-10C “System engineering general requirements” – Content

- Provides (general) **description and guidelines** on system engineering **tasks**
- Provides SE tasks **per project phase**: it defines what should be available from system viewpoint at the end of each phase
  - *The space mission project lifecycle and its phases are defined in ECSS-M-ST-10, Space project management – Project planning and implementation*

- It provides a **list of system engineering documents + DRDs in Annexes** (*and guideline on project milestones when those shall be available*)

- Common misconception: It does **<u>not</u>** provide System Engineering “best practices” and methodologies (e.g. how to make system budgets, define margins, make trade-offs, system modes, etc.). This is left to each specific project to define.

Other tools supporting Systems Engineers

- Support Document for ESA Projects

Within ESA we have:

- ESA LESSONS LEARNED
- e.Book
- Checklists

Support documents for ESA projects

The following documents are produced for support of ESA projects.

The documents contain information concerning the Engineering, Management and Product Assurance documents to be delivered per review, the documents delivered periodically or incident triggered and incorporate the DRDs for those documents.

The purpose of these documents is to help projects to build their DRL. The documents may be used for the purpose of exploring the DRDs used in both the delivery per review and deliverable (periodic or incident triggered) document. (The DRDs have been embedded in the table in a Word Format for ease of manipulation if needed.)

The documents include all documents delivery as defined in each ECSS standards discipline per discipline in the engineering branch and sustainability branch, with reference to the corresponding DRD and the delivery schedule with regard to review when defined in the ECSS system of standards.

ID	Title	Published
ESSB-MDPR Issue 1	ESA Guideline for building project DRL from the ECSS Project Management documents	14-Apr-2013
ESSB-QDPR Issue 1	ESA Guideline for building project DRL from the ECSS Product Assurance documents	14-Apr-2013
ESSB-EDPR Issue 1	ESA Guideline for building project DRL from ECSS Engineering documents	14-Apr-2013
	Zip file containing all DRDs in MS-WORD listed in the documents above	08-May-2013
ESSB-HB-M-003 Issue 1	Generic MARD Template	18-Dec-2017
ESSB-HB-Q-010 Issue 1 Corrigendum 1	Generic PARD Template	30-Apr-2020
ESSB-HB-M-005-Issue1	ESA Lessons Learned Process Handbook	23-Mar-2020
ESSB-ST-E-006-Issue2	ESA Procedural Requirements for Frequency Assignment **Note** :This document replaces ESA/ADMIN/IPOL-PROC(2004)2 - ESA Staff shall engage in the process described in this document, at the project feasibility stage phase A of the ESA project.	23-Mar-2020

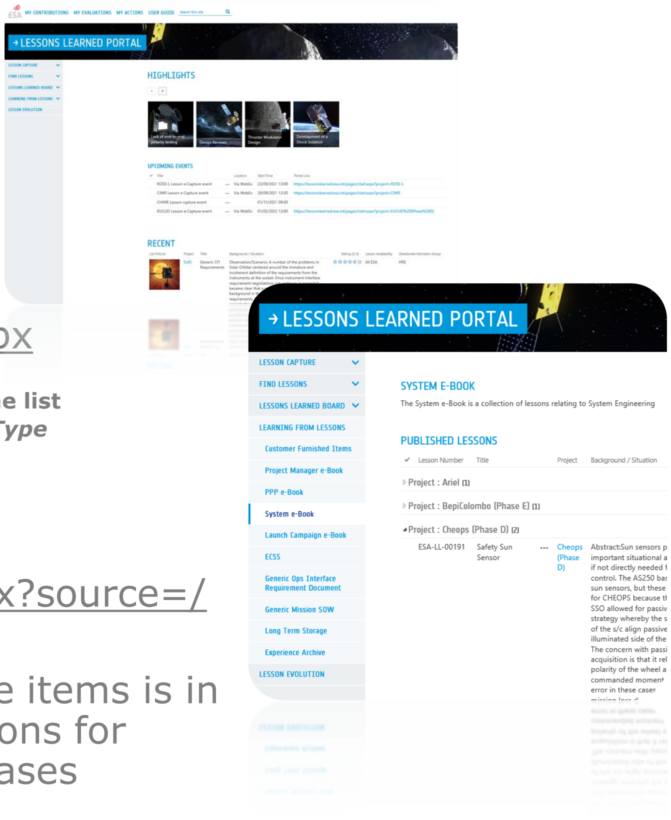
Lessons Learned Portal

- The Lessons Learned Portal can be found here:
  https://lessonslearned.esa.int/Pages/Home.aspx

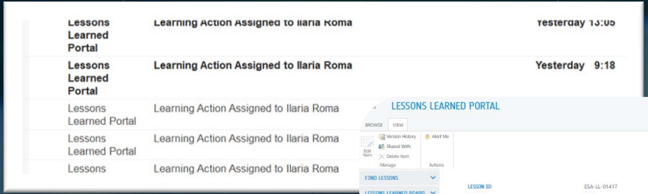
- Instructions on how to find a lesson are here:
  https://lessonslearned.esa.int/Pages/All-Lessons.aspx
  - To view a lesson, **click on the Title** of the lesson
  - You can search for lessons by typing the word you looking for in the **search box above the list**
  - You can find lessons of a specific Topic Type: **Click on the column name *Lesson Topic Type***
  - You can also select by rating (stars): **Click on the column name *Rating (0-5)***

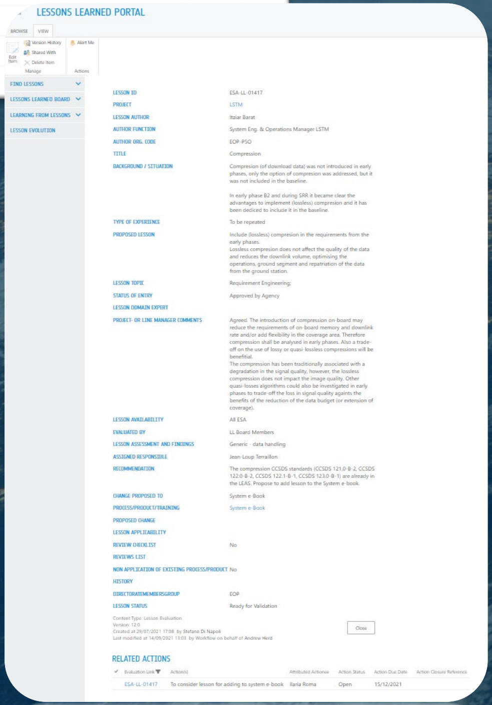
- You can also propose a new lesson here:
  https://lessonslearned.esa.int/Lists/formal/NewForm.aspx?source=/

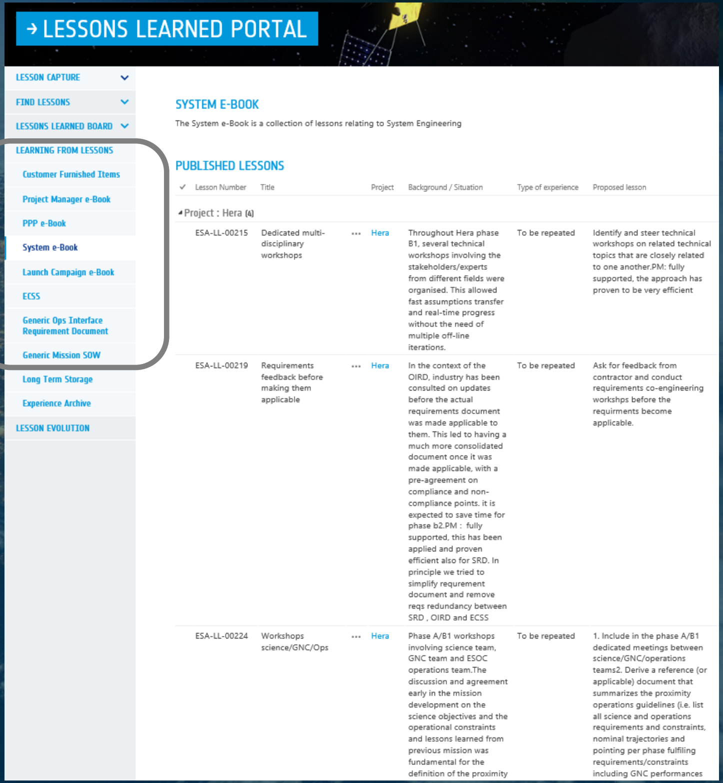
- A well establish process to transform lessons into actionable items is in place and TEC-SY contributes to it actively by injecting lessons for consideration into the new missions (e.g. CDF and early phases Systems engineering)



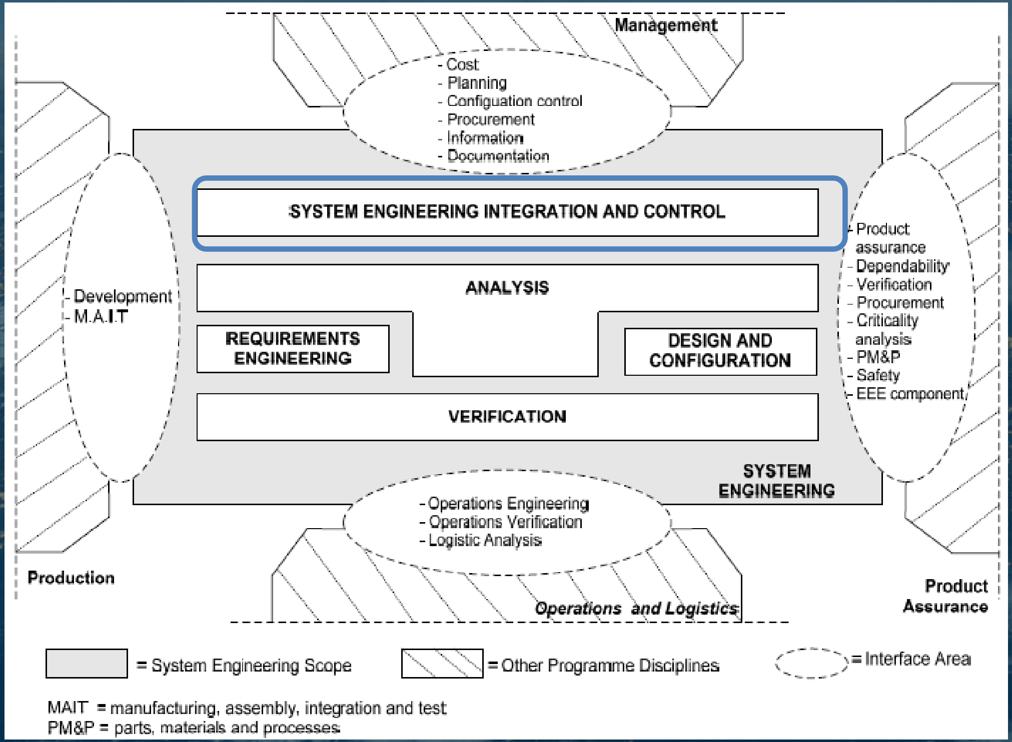
How It Looks Like







ECSS-E-ST-10C
System Engineering Functions (Fig. 4-1)



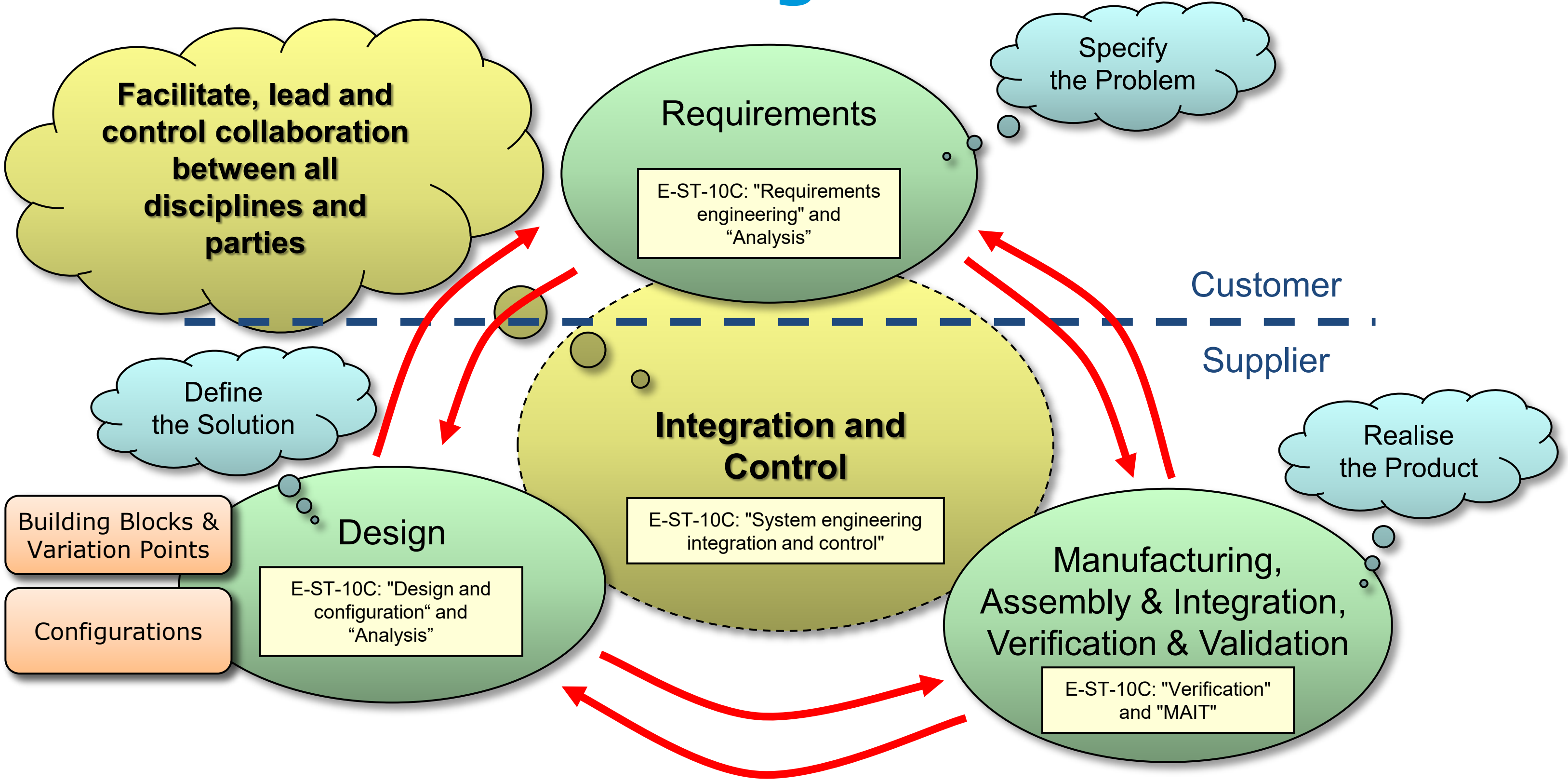
ECSS-E-ST-10C
System Engineering Functions Summary

- The system engineering function shall provide a technical assessment on any change proposal to the baseline of the product.
- The system engineering function shall provide a technical assessment on any non-conformance to the status of the product.

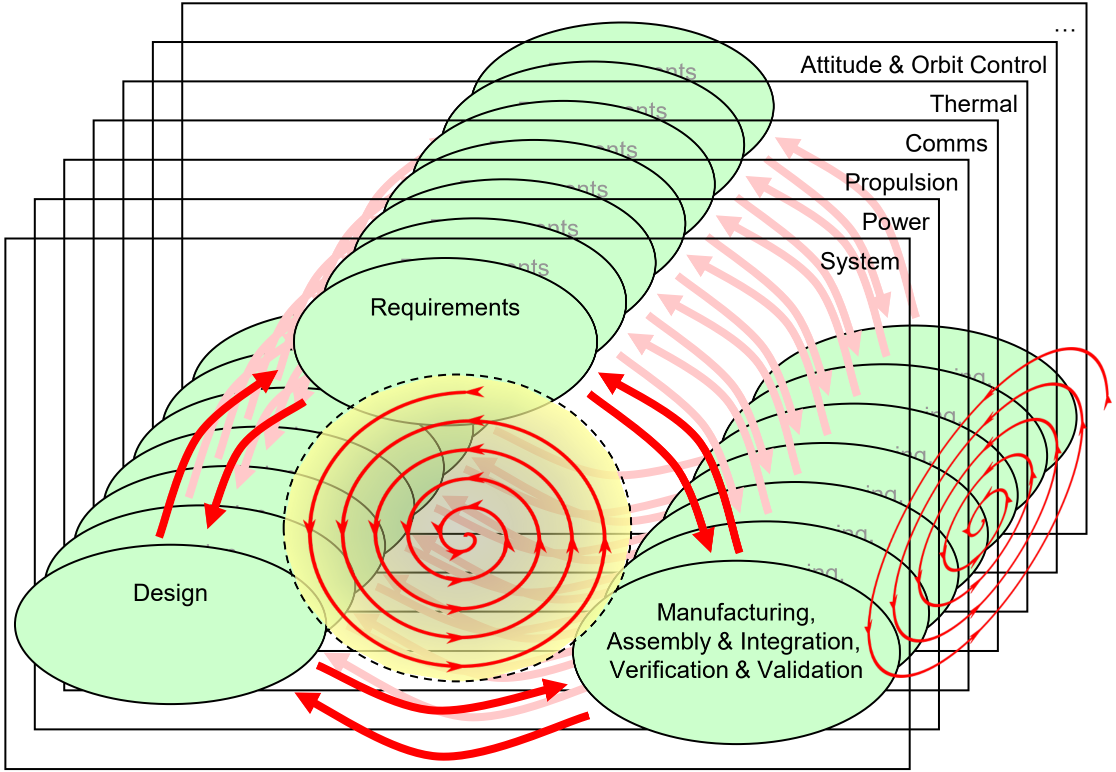
NOTE Nonconformance treatment is described by ECSS-Q-ST-10-09

Functions	Tasks
Requirements Engineering	• Elicit, write, organise, flow-down and maintain requirements • Validate top-level requirements with users (in Phase 0)
System Analysis	• Define functions / function tree • Define and justify physical architecture / product tree • Derive end-to-end performance • Analyse impacts on cost and schedule • Establish all relevant environments • Perform trade-offs • Define analysis methods, tools and models
Design and Configuration	• Elaborate system design and configurations • Define and manage interfaces
Verification	• Define and perform product verification • Ensure that the verification is successfully closed out at each stage
Integration and Control	• Define, plan and manage integrated technical effort amongst all disciplines • Define and maintain system budgets (mass, power, …) as well as margin policy • Ensure availability and exchange of all (system-level, common) engineering data • Identify and manage candidate technologies, with TRLs • Support risk, change, non-conformances control

ECSS-E-ST-10C: 3 Main Areas of Concern & SE Central Task "Integration and Control"

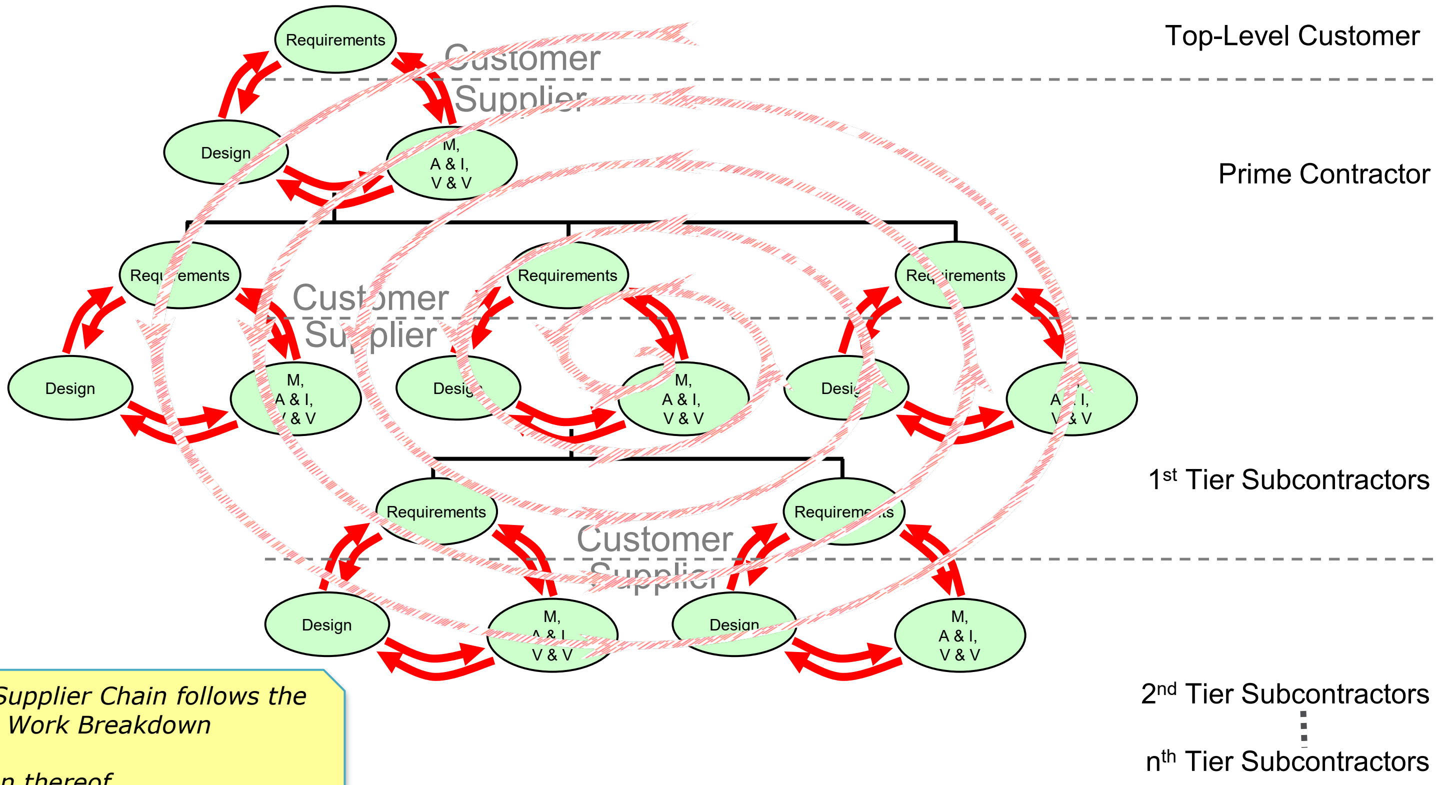


ECSS-E-ST-10C: “Integration and Control” Among disciplines



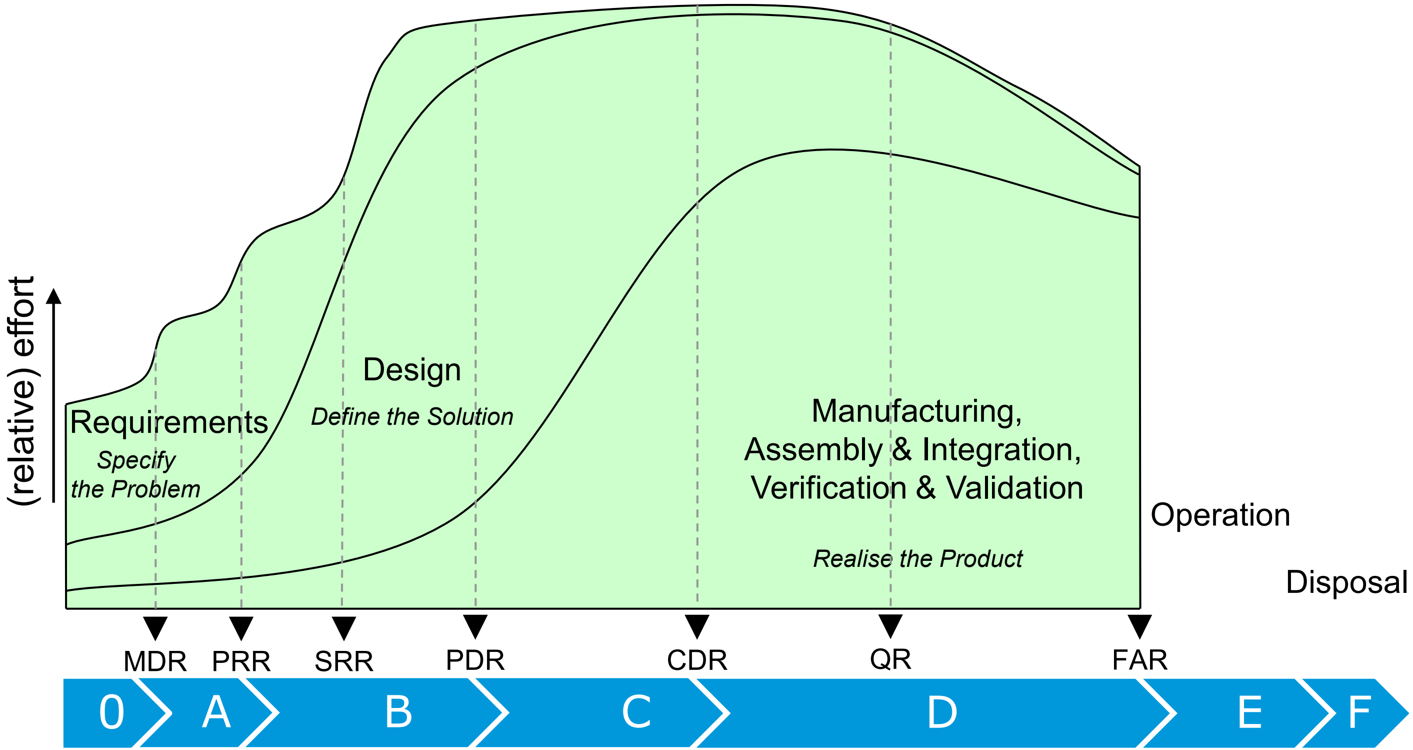
- Integration and Control (possibly concurrently in early phases)
- Iterate between
  - Requirements,
  - Design,
  - MAIV&V
- Iterate across Disciplines

ECSS-E-ST-10C: “Integration and Control” Across the Customer-Supplier Chain



The Customer-Supplier Chain follows the Product Tree or Work Breakdown Structure or a combination thereof

ECSS-E-ST-10C: “Integration and Control” Along the System Life-Cycle



ECSS-E-ST-10C
Requirements Specification Tree

Requirements shall be organized hierarchically – in a Specification Tree – that supports traceability

Typical documentation hierarchy for ESA project (NB: not in E-10):

Requirement types	***Responsible***	***Content***	***Document Name***
User requirements/ Mission objectives	User	Non-technical, high level, general. Gives rationale for the project. Contains mission need statement.	URD or Mission Objectives Document
Mission requirements	ESA	Functional, technical, overall performance. Applies to the Mission	Mission Requirements Document (MRD) (sometimes merged with URD)
System requirements	ESA	Functional, technical, overall performance. Applies to the System	System Requirements Document (SRD)
System requirements	Mission Prime / LSI	Detailed, technical, reflects the (architectural) design. Represents the interpretation of the customer requirements from the developer	System Technical Specification
Lower level (equipment, component) requirements	Lower Tier Supplier	Very specific and detailed: flow-down of system requirements.	Element, subsystem, equipment or component requirements specification
Interface requirements	ESA or Prime	Allows connecting the system with other systems	Interface Requirements Document Can be at any level where an interface needs to be managed.
Operations requirements	Operator	Technical, including constraints, for operations	OIRD

Examples - ECSS-E-ST-10C Requirements Specification Tree

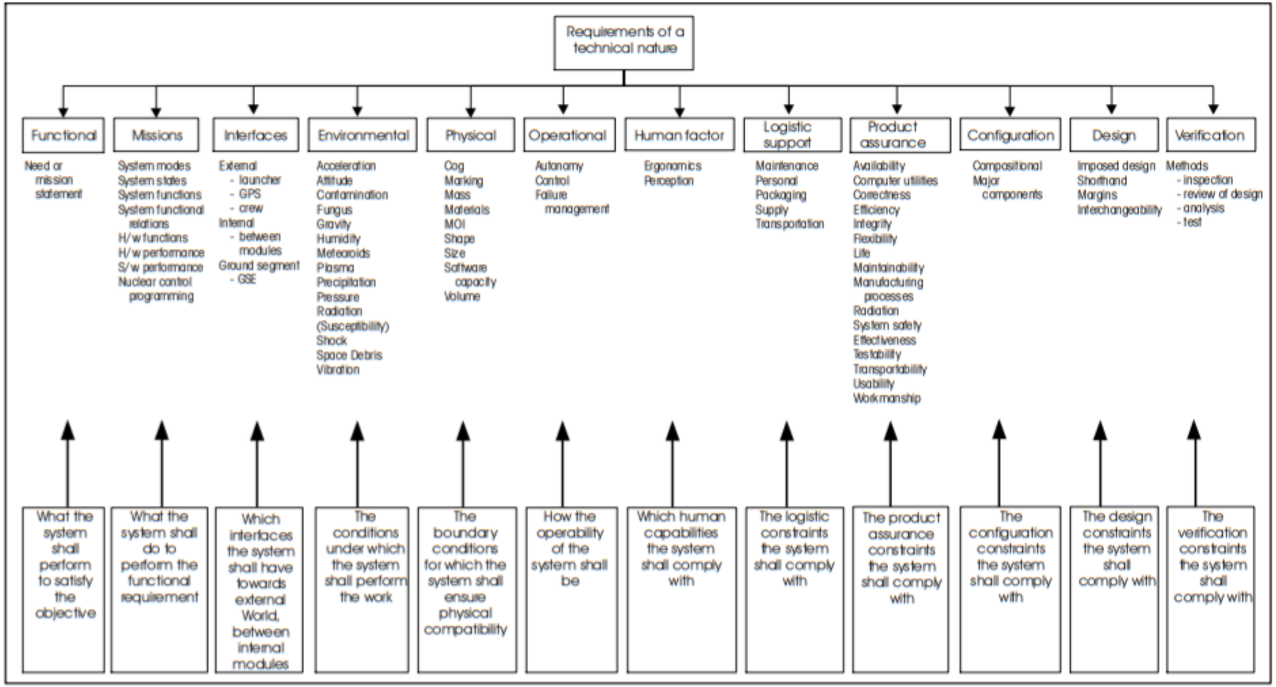


Figure 4: Space system requirement types

ECSS-E-10 Part 1B
18 November 2004

ECSS-E-ST-10C
Main SE Deliverables and Organisation

Title	Content
Mission Description Doc	high level description of mission concepts, including preferred concept
Specifications aka RB (Requirements Baseline)	preliminary TS, TS, interface requirements doc
SE Plan	tech plan, tech matrix, verification plan, AIT QM/FM plan, debris mitigation plan, coordinate systems, …
DDF (Design Definition File)	function tree, product tree, spec tree, tech budget, TS for next lower level, DDF for next lower level, interface control doc, product user manual, …
DJF (Design Justification File)	req traceability wrt next lower level, req justification file, system concept report, trade-off reports, verification control doc, test spec, analysis rep, math model description, correlation rep, test procedure, test rep, verification rep, DJF for next lower level, review-of-design rep, inspection rep, GSE spec’s, GSE data pack’s

Note 1: In DDF and DJF, “File” should be understood in the meaning of collection of documents / information containers, i.e. not a single computer file. In a digital data repository (e.g. using modern PLM or version control environment) it can be thought of as a “Top Folder” or a “Repository” or a similar concept.

Note 2: Currently many ESA projects produce instead of a DDF and a DJF a “System Design Report”

ECSS-E-ST-10C Annex D (DRD) System Engineering Plan (SEP)

The SEP was formerly often known as the "Design and Development Plan"

The System Engineering Plan defines:

- "the approach, methods, procedures, resources and organization to co-ordinate and manage all technical activities necessary to specify, design, verify, operate and maintain a system or product in conformance with the customer's requirements"
- Project objectives / constraints / phases / reviews / product evolution
- SE tasks, inputs and outputs
- SE team responsibilities and organization, including coordination between all engineering disciplines
- Procurement approach of all elements / equipment
- Technology development approach
- Verification Plan and AIT Plan, or combined AIV Plan
- Coordinate systems
- Processes, methods, facilities and tools

Depending on the size of the project, constituent plans may be integrated or be self-standing

ECSS-E-ST-10C Annex A
SE documents delivery per review (1/3)

Document title	ECSS document	DRD ref.	Phase 0	Phase A	Phase B		Phase C	Phase D			Phase E				Phase F
			MDR	PRR	SRR	PDR	CDR	QR	AR	ORR	FRR	LRR	CRR	ELR	MCR
Mission description document	ECSS-E-ST-10	Annex B	+	+											
Specifications															
Preliminary technical requirements specification	ECSS-E-ST-10-06	Annex A	+	+											
Technical requirements specification	ECSS-E-ST-10-06	Annex A			+										
Interface requirements document	ECSS-E-ST-10	Annex M		+	+	+									
System engineering plan	ECSS-E-ST-10	Annex D	+	+	+	+	+	+	+						
Technology plan	ECSS-E-ST-10	Annex E		+	+	+									
Technology matrix	ECSS-E-ST-10	Annex F		+	+	+									
Verification plan	ECSS-E-ST-10-02	Annex B		+	+	+	+	+	+						
AIT QM/FM plan	ECSS-E-ST-10-03	Annex A				+									
Orbital debris mitigation plan	ISO 24113		+	+	+	+									
Other related plans (as called in ECSS-E-ST-10 Annex D)				+	+	+									
Coordinate system document	ECSS-E-ST-10-09	Annex A		+	+	+									

This table is used to set up the planning of a project
- For big projects this is essential
- For smaller projects you might want to reduce number of deliverables to keep cost down

! ECSS asks for content and not for specific format

ECSS-E-ST-10C Annex A
SE documents delivery per review (2/3)

Document title	ECSS document	DRD ref.	Phase 0	Phase A	Phase B		Phase C	Phase D			Phase E				Phase F
			MDR	PRR	SRR	PDR	CDR	QR	AR	ORR	FRR	LRR	CRR	ELR	MCR
Design definition file	ECSS-E-ST-10	Annex G		+	+	+	+	+							
Function tree	ECSS-E-ST-10	Annex H		+	+	+									
Product tree	ECSS-M-ST-10	Annex B		+	+	+									
Specification tree	ECSS-E-ST-10	Annex J			+	+									
Technical budget	ECSS-E-ST-10	Annex I		+	+	+	+	+	+						
Preliminary technical requirements specifications for next lower level	ECSS-E-ST-10-06			+	+										
Technical requirements specifications for next lower level	ECSS-E-ST-10-06				+	+									
Design definition file for next lower level						+	+	+	+						
Interface control document	ECSS-E-ST-10-24	Annex A			+	+	+	+	+	+	+	+			
Product User manual / User Manual	ECSS-E-ST-10	Annex P					+	+	+	+	+	+	+	+	+
Design justification file	ECSS-E-ST-10	Annex K		+	+	+	+	+							
Requirements traceability matrix w.r.t. next lower level	ECSS-E-ST-10	Annex N		+	+	+									
Requirement justification file	ECSS-E-ST-10	Annex O	+	+	+	+									
System concept report	ECSS-E-ST-10	Annex C	+	+											
Trade off reports	ECSS-E-ST-10	Annex L	+	+	+	+	+								

ECSS-E-ST-10C Annex A
SE documents delivery per review (3/3)

Document title	ECSS document	DRD ref.	Phase 0	Phase A	Phase B		Phase C	Phase D			Phase E					Phase F
			MDR	PRR	SRR	PDR	CDR	QR	AR	ORR	FRR	LRR	CRR	ELR		MCR
Verification control document	ECSS-E-ST-10-02	Annex C		+(1)	+(1)	+(1)	+	+	+	+	+	+	+	+		+
Test specification	ECSS-E-ST-10-03	Annex D					+	+	+	+	+	+	+	+		+
Analysis report	ECSS-E-ST-10	Annex Q		+	+	+	+	+	+	+	+	+	+	+		+
Mathematical model description					+	+	+	+								
Correlation report							+	+								
Test procedure	ECSS-E-ST-10-03	Annex C					+	+	+	+	+					
Test report	ECSS-E-ST-10-02	Annex D					+	+	+	+	+	+	+	+		+
Verification report	ECSS-E-ST-10-02	Annex H					+	+	+	+	+	+	+	+		+
Design justification file for next lower level							+	+	+							
Review of design report	ECSS-E-ST-10-02	Annex F					+	+								
Inspection report	ECSS-E-ST-10-02	Annex G					+	+	+							
GSE specifications						+	+	+	+							
GSE Data packages							+	+	+							

Note (1) : Document limited to the verification matrix

ECSS-E-ST-10C
Guidelines for use/tailoring

- The core of the Standard shall be left as is since it gives general principles which are applicable in all cases
- Practical implementation instructions shall be included in SRD or SOW
  Examples:
  - Specific Product Tree or design constraints
  - Margin philosophy
  - Use of a tool (e.g. DOORS) to manage requirements
  - Use/definition of models
  - Operations implementation
- The documentation deliverables shall be tailored according to project needs / heritage (own project DRL), including proposed delivery dates
  - Example: System Design Report with content part of the Design Definition File and part of the Design Justification File
- DRDs as defined in annexes would typically require some tailoring

Table 7-2: Pre-tailoring matrix per "Space product types"

Table 7-2: Pre-tailoring matrix per "Space product types"

ECSS req. #	Space system	Space segment element and sub-system	Space segment equipment	Launch segment element and sub-system	Launch segment equipment	Ground segment element and sub-system	Ground segment equipment	Ground support equipment	Software	Comments
5.1a	X	X[1]	//[2]	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.1c	X	X[1]	-	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.1d	X	X[1]	//[2]	//[2]	-	-	-	-	-	[1] applicable at element level: for subsystem level - see [2] [2] applicability should be defined/tailored at each level for next lower level, depending on product heritage, engineering complexity and industrialization context.
5.2.1a	X	X	X	X	-	-	-	-	-	
5.2.1b	X	X	X[1]	X	-	-	-	-	-	[1] not applicable in case of no lower level elements in scope of engineering responsibility of supplier.
5.2.1c	X	X	X[1]	X	-	-	-	-	-	[1] not applicable in case of no lower level elements in scope of responsibility of supplier.
5.2.1d	X	//[1]	//[1]	//[1]	-	-	-	-	-	[1] depending on the applicability of ECSS-E-ST-10-06 clause 8.
5.2.1e	X	X	//[1]	X	//[1]	-	-	-	-	[1] applicability defined/tailored at each level for next lower level depending on product heritage, engineering complexity and industrialisation context.
5.2.2a	X	X	X[1]	X	-	-	-	-	-	[1] 5.2.2a.1 not applicable in the case of upper level traceability provided by the upper layer; 5.2.2a.2 not applicable in the case of no lower level requirements.
5.2.2b	X	X	X[1]	X	-	-	-	-	-	[1] not applicable in case of no lower level components in scope of engineering responsibility of supplier
5.2.2c	X	X	X	X	-	-	-	-	-	

Table A-1: System engineering deliverable documents

Table A-1: System engineering deliverable documents

Document title	ECSS document	DRD ref.	MDR	PRR	SRR	PDR	CDR	QR	AR	ORR	FRR	LRR	CRR	ELR	MCR
Mission description document	ECSS-E-ST-10	Annex B	x	x											
Specifications															
Preliminary technical requirements specification	ECSS-E-ST-10-06	Annex A	x	x											
Technical requirements specification	ECSS-E-ST-10-06	Annex A			x										
Interface requirements document	ECSS-E-ST-10-24	Annex A		x	x	x									
System engineering plan	ECSS-E-ST-10	Annex D	x	x	x	x	x	x	x						
Technology plan	ECSS-E-ST-10	Annex E		x	x	x									
Technology Readiness Status List	ECSS-E-ST-10	Annex E	x	x	x	x									
Technology matrix	ECSS-E-ST-10	Annex F		x	x	x									
Verification plan	ECSS-E-ST-10-02	Annex A		x	x	x	x	x	x						
AIT QM/FM plan	ECSS-E-ST-10-03	Annex A				x	x	x	x						
Space debris mitigation plan	ECSS-U-AS-10		x	x	x	x	x	x	x	x	x	x		x	x
Other related plans (as called in ECSS-E-ST-10 Annex D)	ECSS-E-ST-10	Annex D		x	x	x	x	x	x						
Coordinate system document	ECSS-E-ST-10-09	Annex A		x	x	x	x	x							

Useful Annexes - Examples

ECSS-E-ST-10C Rev.1
15 February 2017

Annex R (informative) Mapping of typical DDP to ECSS documents

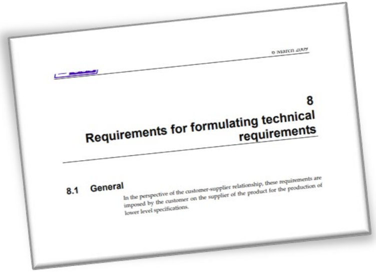
Design Development Plan (DDP) content	ECSS coverage
Introduction • General summary of the scope, objective and constraints • Definition of responsibilities and pre-requisites	ECSS-M-ST-10-PMP <3> ECSS-E-ST-10-SEP <3.1> ECSS-M-ST-10-PMP <4>
System definition including high level product tree • Identification of customer furnished products • Availability of and need to reuse existing products • Specification tree	ECSS-M-ST-10-PT ECSS-M-ST-60-9.6.2 req. ECSS-E-ST-10-SEP <4.2>.6 and <5.2.13> ECSS-M-ST-10-PT <3>.e ECSS-E-ST-10-Annex J
Technology assessment Availability of and need to develop new technologies	ECSS-E-ST-10-SEP <5.2.5> ECSS-E-ST-10-TP <4.3>
System design flow and philosophy of models • Model philosophy • Design margin philosophy for budgets - Margin philosophy for requirements as flown down from system to subsystem- assembly – and equipment level - Management of system resource allocation over the entire project phases and resource reporting to the next higher level - Rationale	ECSS-E-ST-10-SEP <4.2>.4 ECSS-E-ST-10-SEP <4.2>.5
System control and verification • Qualification and acceptance philosophy • Budget allocation philosophy • Compliance to requirements demonstration philosophy • High-level Assembly, Integration & Verification Plan, incl.: - end to end test - mission simulation and Dress Rehearsals	ECSS-E-ST-10-SEP <5.2.2> -> ECSS-E-ST-10-02-VP -> ECSS-E-ST-10-02-VCD (inc. VM)

ECSS-E-ST-10-06C
“Technical Requirements Specification"

ECSS-E-ST-10-06C
"Technical Requirements Specification"

Level 3 Standard

- Provides "requirements on requirements" – i.e. how to:
  - Identify and capture requirements
  - Write requirements
    - including how to formulate "good" unambiguous requirements
    - definitions of "shall", "should", "may", words to avoid, …
  - Classify according to type of requirement
    - functional, operational, physical, design, etc.



- **Used to write e.g. SRD and - to a certain extent - the Prime's System Specifications**
- Common misconception: **It does not provide practical instructions on how to do requirements management**
  - E.g. does not prescribe use of tools like DOORS, etc.

ECSS-E-ST-10-06C
Types of technical requirements

- Functional requirements
- Mission requirements
- Interface requirements
- Environmental requirements
- Operational requirements
- Human factor requirements
- Integrated logistics support requirements
- Physical requirements
- Product Assurance (PA) induced requirements
- Configuration requirements
- Design requirements (i.e. design constraints)
- Verification requirements
- Performance requirements

Performance usually added, currently missing from E-ST-10-06C

ECSS-E-ST-10-06C Annex A – DRD Technical Requirements Specification (TS)

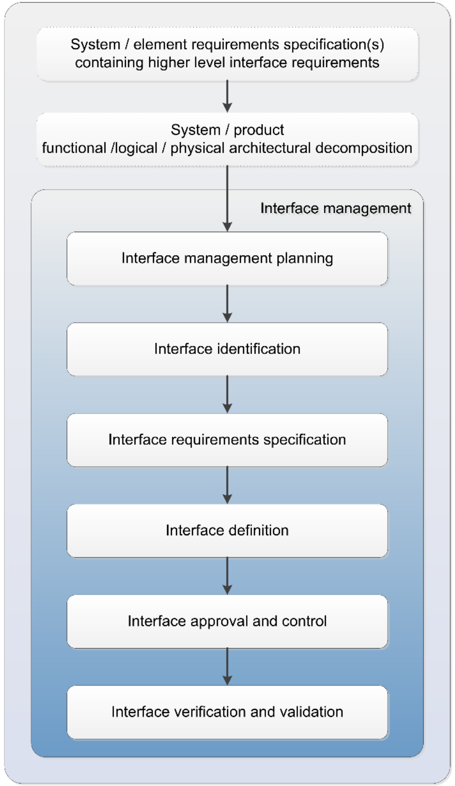
The DRD defines expected contents of a TS:

- Objective:
  - establishes the intended purpose of a product, its associated constraints and environment, the operational and performance features for each relevant situation of its life profile, and the permissible boundaries in terms of technical requirements
- User’s need interpretation description
- Selected concept / product description
- Life profile description
- Environment and constraints description
- Requirements and constraints

ECSS-E-ST-10-24C
Interface management

ECSS-E-ST-10-24C "Interface Management"

Level 3 Standard, relatively ''new'' (2015)



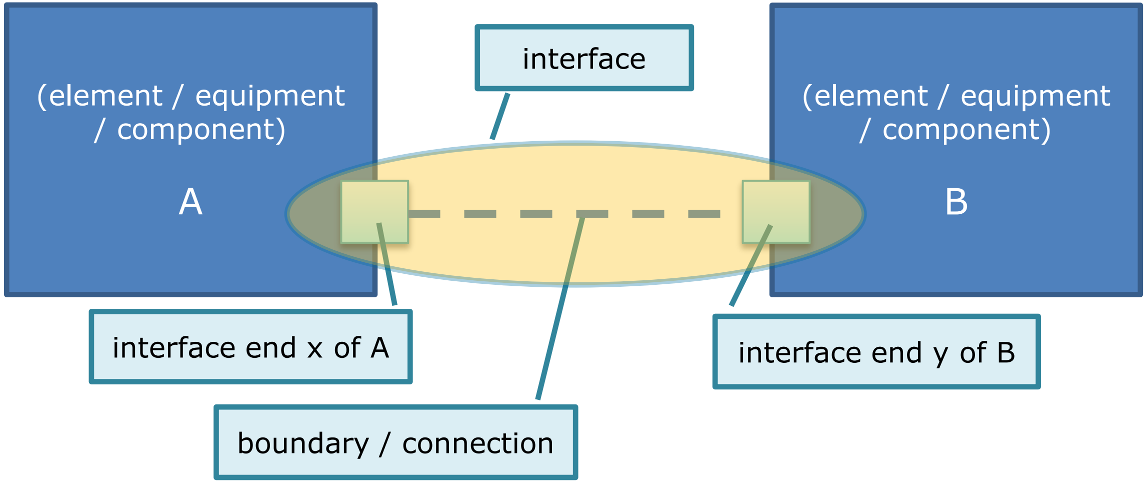
Describes the process for interface management and control, which is a **critical system activity**

- "Interface" consists of two or more "Interface Ends" plus the connection between them

It includes:

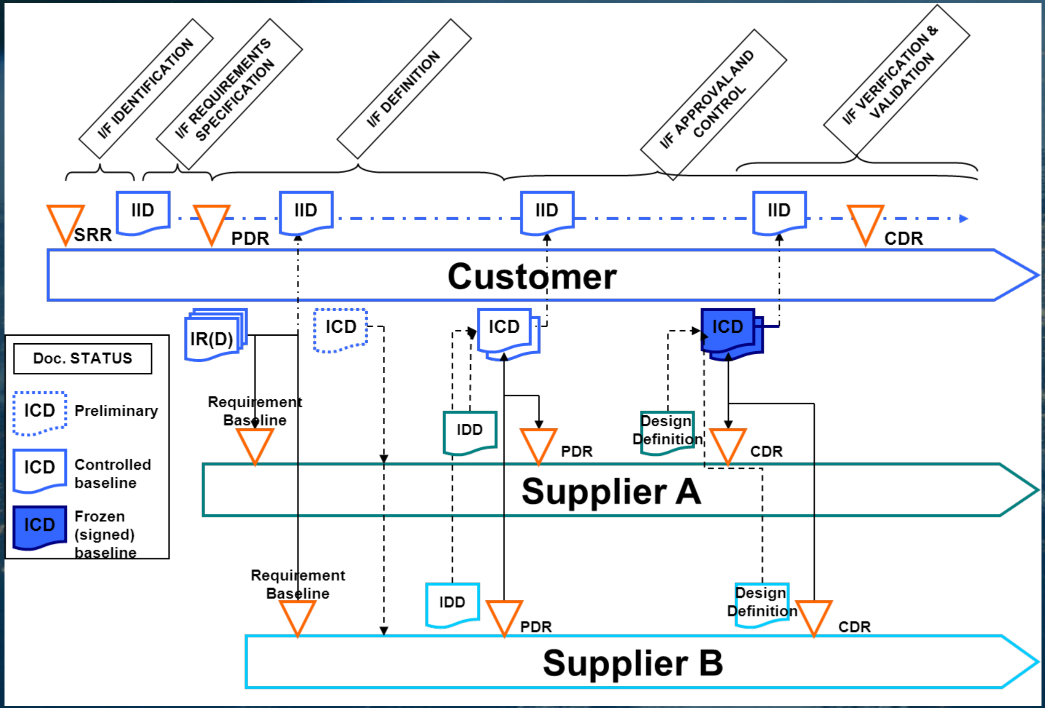
- Customer defines the req's which need to be placed on the interface (electrical, mechanical, etc.) in IRD(s)
- Supplier prepares a description of its interface end in a so-called Interface Definition Document (IDD) or Single-end ICD
- Once the interface is designed it is captured and managed via an Interface Control Document (ICD), adopted and "signed" by the managing customer and both interface end suppliers.
- Interface change management, verification and validation.
- Interface Identification Document (IID) to list all interfaces relevant to one project.

ECSS-E-ST-10-24C
“Interface Management” Definitions

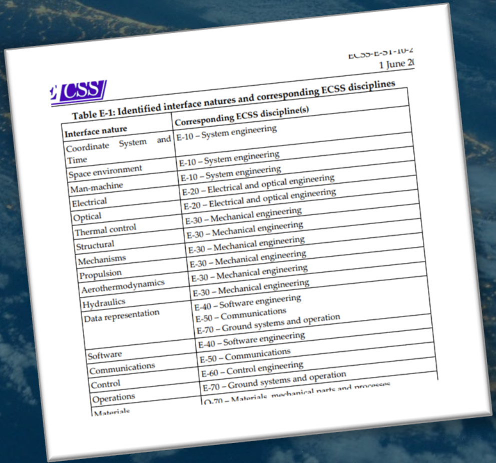


- **interface** – boundary where two or more products meet and interact
- **interface end** – one side of an interface
- **external interface** – interface between items under different programme responsibilities
- **internal interface** – interface between items within the same programme responsibility

ECSS-E-ST-10-24C – Example
Interface Management in the Life Cycle



Described for
- Generic
- Launch Segment
- Ground Segment
- Involving OTS product



ECSS-E-ST-10-24C
1 June 2015

Table E-1: Identified interface natures and corresponding ECSS disciplines

Interface nature	Corresponding ECSS discipline(s)
Coordinate System and Time	E-10 – System engineering
Space environment	E-10 – System engineering
Man-machine	E-10 – System engineering
Electrical	E-20 – Electrical and optical engineering
Optical	E-20 – Electrical and optical engineering
Thermal control	E-30 – Mechanical engineering
Structural	E-30 – Mechanical engineering
Mechanisms	E-30 – Mechanical engineering
Propulsion	E-30 – Mechanical engineering
Aerothermodynamics	E-30 – Mechanical engineering
Hydraulics	E-30 – Mechanical engineering
Data representation	E-40 – Software engineering E-50 – Communications E-70 – Ground systems and operation
Software	E-40 – Software engineering
Communications	E-50 – Communications
Control	E-60 – Control engineering
Operations	E-70 – Ground systems and operation
Materials	Q-70 – Materials, mechanical parts and processes

ECSS-E-ST-10-24C – DRDs (Document Requirements Definitions)

- Interface Requirements Document (IRD) – Annex A (normative)
  - Defines the requirements for an interface or a collection of interfaces
- Interface Control Document (ICD) – Annex B (normative)
  - Defines the design of the interface(s) ensuring compatibility among involved interface ends by documenting form, fit, and function
- Interface Definition Document (IDD) or Single-end Interface Control Document – Annex C (normative)
  - Defines the design of an interface end
  - Defines the responsibility of interface end supplier
- Interface Identification Document (IID) – Annex D (informative)
  - Proposes list of all identified interfaces to be managed
  - Live ‘document’ – can be web application / database
  - References all applicable standards to any interface

ECSS-E-ST-10-02C
Verification

ECSS-E-ST-10-02C "Verification"

- Provides definitions and general requirements on:
  - Verification process
  - Verification planning
  - Verification execution
  - Verification close-out
- Provides in Annexes DRDs several verification documents and proposes a **list of Verification documents deliverable per review**
- It is complemented by the **Verification guidelines HB** (not normative) which give explanations, advices and examples for the preparation and execution of the verification programme and provide extensive explanation on "**model philosophy**".

ECSS-E-ST-10-02C – Verification Definitions (from ECSS-S-ST-00-01C)

- **Verification**
  - **process** which demonstrates through the provision of objective evidence that the **product** is designed and produced according to its **specifications** and the agreed **deviations** and **waivers**, and is free of **defects**
  - **"building the system right"**
- **Validation**
  - **process** which demonstrates that the **product** is able to accomplish its intended use in the intended operational **environment**
  - **"building the right system"**
  - Validation demonstrates that the space system (including tools, procedures and resources) will be able to fulfil mission requirements
  - It also includes confirmation of product integrity and performance after particular steps of the project life cycle, e.g. pre-launch, in-orbit commissioning, post-landing

ECSS-E-ST-10-02C – Verification Verification vs Validation

- ECSS in general does not mandate **system validation**
  - Unlike in aeronautics for instance

- The reason is that the way system requirements are written for the **space segment** already address the suitability of the product to fulfill the needs of its intended use – therefore, in most cases **verification** encompasses **validation**

- The latter is not always true for **ground segment** elements

ECSS-E-ST-10-02C Verification Process

- The verification process shall be implemented in subsequent stages all along the program life cycle
  - The stages depend upon project characteristics and identify a type of verification
  - Usually, the verification stages are related to project milestones

- The classical verification stages and milestones are:
  - Development (PDR – CDR)
  - Qualification (CDR – QR)
  - Acceptance (QR – FAR)
  - Pre-launch (FAR – Launch) to verify after transportation / storage
  - In-orbit (Commissioning)

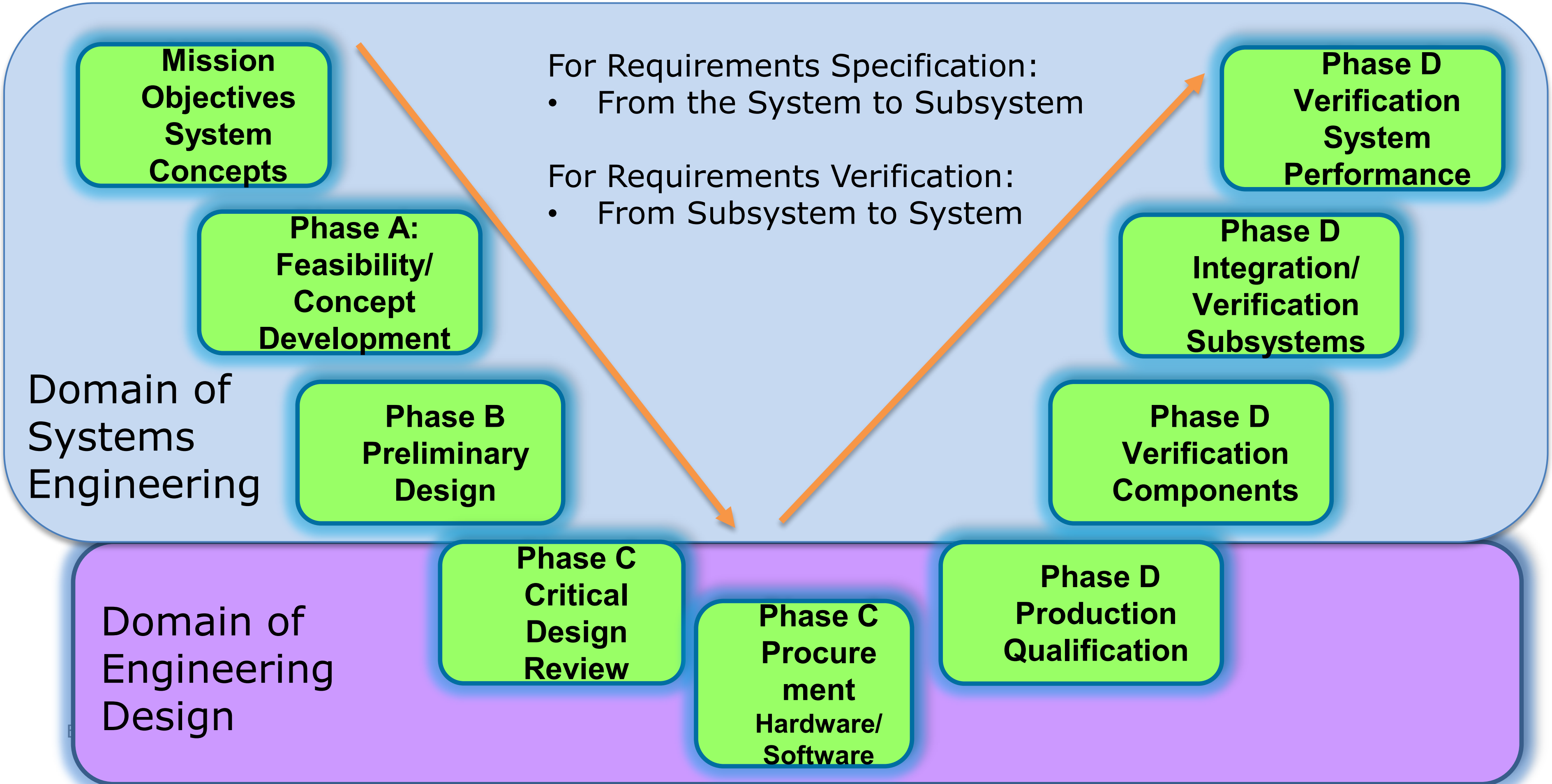
ECSS-E-ST-10-02C Verification Process

- **Qualification** - to verify the design according to project requirements;
- **Acceptance** – to ensure that the product is in agreement with the qualified design, is free from workmanship defects and acceptable for use
- **Commissioning** – verification and validation activities conducted after the launch and before the entry into operational service
  - either on the space segment elements only
  - or on the overall system, including the ground segment elements

ECSS-E-ST-10-02C Verification Process

- The verification shall be performed incrementally at different verification levels
- The number and type of verification levels depend on the complexity of the project
- Typical verification levels are:
  - Component (or Part) e.g. resistor, relay, bearing
  - Subassembly or Module e.g. printed circuit board
  - Equipment (or Unit) e.g. valve, battery, electronics box
  - Subsystem e.g. electrical power, structure, thermal
  - Element e.g. satellite
  - System e.g. manned infrastructure system

The V Model


Mission Objectives System Concepts
Phase A: Feasibility/ Concept Development
Phase B Preliminary Design
Phase C Critical Design Review
Phase C Procure ment Hardware/ Software
Phase D Production Qualification
Phase D Verification Components
Phase D Integration/ Verification Subsystems
Phase D Verification System Performance
For Requirements Specification:
• From the System to Subsystem
For Requirements Verification:
• From Subsystem to System
Domain of Systems Engineering
Domain of Engineering Design

ECSS-E-ST-10-02C
Verification methods

Verification shall be by one or more of the following verification methods (in order of higher to lower level of confidence):

- **Test**: verification method by measurement of product performance and functions under representative simulated environments
  – is the preferred method
- **Analysis**: verification method performing a theoretical or empirical evaluation using techniques agreed with the Customer – may be analysis by similarity
- **Review-of-design**: verification method using approved records or evidence that unambiguously show that the requirement is met
- **Inspection**: visual determination of physical characteristics

However:

- All safety critical functions shall be verified by test.
- Verification of SW shall include testing in the target hardware.
- For each requirement verified only by analysis or review-of-design, a **risk assessment shall be conducted to determine the impact (major/minor) of this requirement on the mission**.
  If the impact is major, two independent analyses shall be performed (in terms of model used and suppliers).

The system engineering function shall contribute to the identification of risks and mitigation measures. NOTE Details on risk management are provided in ECSS-M-ST-80

ECSS-E-ST-10-02C – Verification Stages
Qualification and Product Category (based on heritage)

Category	Description	Qualification programme
A	Off-the-shelf product without modifications and • subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment and • produced by the same manufacturer or supplier and using the same tools and manufacturing processes and procedures	None
B	Off-the-shelf product without modifications. However: It has been subjected to a qualification test programme less severe or different to that imposed by the actual project specifications (including environment).	Delta qualification programme, decided on a case by case basis.
C	Off-the-shelf product with modifications. Modification includes changes to design, parts, materials, tools, processes, procedures, supplier, or manufacturer.	Delta or full qualification programme (including testing), decided on a case by case basis depending on the impact of the modification.
D	Newly designed and developed product.	Full qualification programme.

Off-the-shelf:
procured from the market

Commercial Off-the-Shelf (COTS):
procured from the market
and not developed for space application

ECSS-E-ST-10-02C
Model Philosophy

A Model and Test Philosophy needs to be established as:

- **Qualification of the design** needs extensive testing
- Testing of the **flight model** only is not efficient as:
  - It is too late in case problems are found
    - It would be very expensive to correct the design when the system is already integrated.
  - It may be detrimental to the lifetime of the spacecraft / unit
- **Additional models** of the flight hardware are necessary, to allow early testing for effective design qualification
- The models must be **representative of the flight hardware** for all those parts that need to be tested
- It is found convenient (by experience) to separate – at system level – thermal and mechanical design aspects from functional design aspects
  - To qualify thermal and mechanical design, a Structural-Thermal Model (STM) is usually built
  - To qualify functional design, a so-called Engineering Model (EM) is usually built

ECSS-E-ST-10-02C
Model Descriptions (1/3)

Model	Objectives	Representativity	Applicability	Remarks
Mock-Up (MU)	• I/F layout optimization/ assessment • Integration procedure validation • Accommodation checks	• Geometrical configuration • Layouts • Interfaces	System/element levels	According to their representativity MU's are classified as: • Low fidelity • High fidelity (to be maintained under configuration control
Development Model (DM)	Confirmation of design feasibility	• Total conformity with functional electrical & S/W req. in agreement with verif. objectives (size, shape & I/Fs could not be representative)	All levels	• Development testing • Sometime it is also called breadboard (BB)
Structural Model (SM)	• Qualification structural design • Validation of structural mathematical model	• Flight standard with respect to structural parameters • Equipment structural dummies	• SS level (structure) • Sometime it could be considered system level if involves other SS or is merged with the system test flow	Qualification testing
Thermal Model (ThM)	• Qualification of thermal design • Validation of thermal mathematical model	• Flight standard with respect to thermal parameters • Equipment thermal dummies	• SS level (thermal control) • Sometime it could be considered system level if involves other SS or is merged with the system test flow	Qualification testing
Structural-Thermal Model (STM)	SM & ThM objectives	• SM & ThM representativity • Equipment thermo [illegible]	System level	Qualification testing

ECSS-E-ST-10-02C
Model Descriptions (2/3)

	simulation of functional & RF performances	• Flight design • Commercial parts • Functional representativity	• Equipment level • System level	Space to ground interface testing
lectrical and Functional lodel (EFM)	• Functional development • S/W development • Procedure validation • Prepare flight test programme	• Functional representativity • Commercial parts • Simulators of missing parts	All levels	• Development or qualification testing • It could be considere something in betwee a mock-up and an EN • Sometime is called also Integration Model

EM)	Functional qualification failure survival demonstration & parameter drift checking	• Flight representative in form-fit-function • without high reliability parts and usually without redundancy	All levels	Partial functional qualification testing
ingineering Qualification Model EQM)	• Functional qualification of design & I/Fs • EMC	• Full flight design • MIL-Grade parts procured from the same manufacturer of high reliability parts	All levels	Functional qualification testing
Qualification Model QM)	Design qualification	• Full flight design & flight standard	• Equipment level • SS level	Qualification testing
Life test Model (LTM)	Qualification of lifetime	• Flight representative with respect to the qualified function	Equipment level	• Model for mechanisms in a protoflight approach with lifetime requirements • Can not be used for

ECSS-E-ST-10-02C
Model Descriptions (3/3)

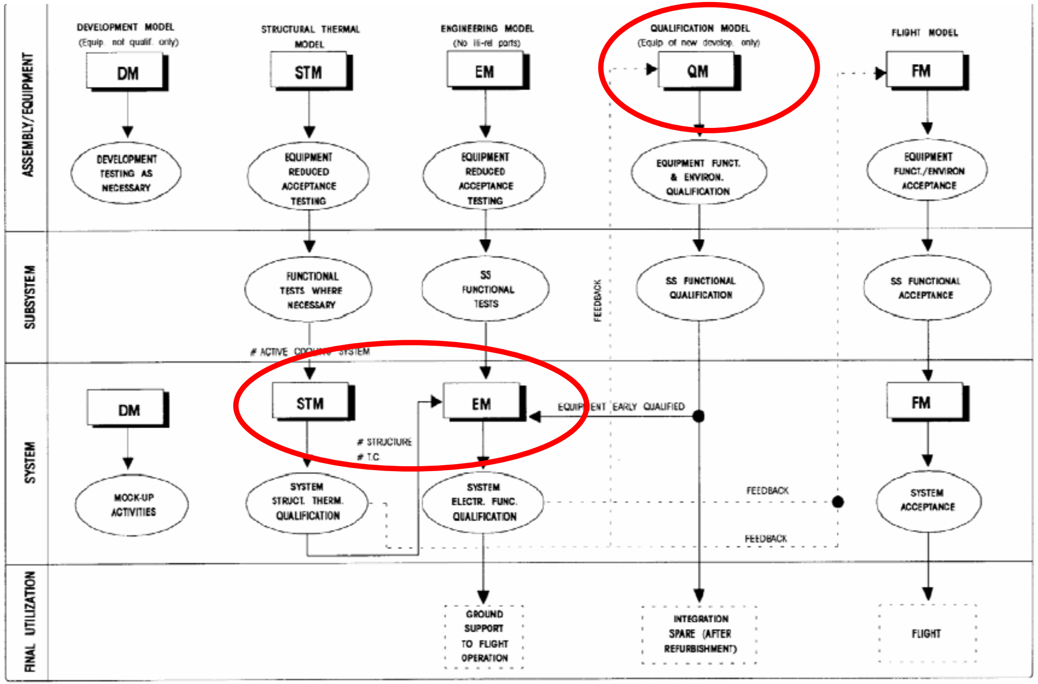
	• Flight use • Design qualification	Full flight design & flight standard	All levels	Protoflight qualification testing
Flight Model (FM)	Flight use	Full flight design & flight standard	All levels	Acceptance testing
Flight Spare (FS)	Spare for flight use	Full flight design & flight standard	Equipment level	Acceptance testing
Function oriented model	Qualification against the applicable functional requirements	Flight representative as necessary for the limited qualification objectives	All levels	Qualification testing oriented to a specific function or requirement
Training model	Flight training baseline data	Flight representative with modifications to allow for normal gravity operation	All levels	Qualification testing oriented to specific HFE requirements
Virtual and hybrid models	Development and verification of specific aspects	Virtual or physical flight representativity as necessary for the applicable verification objectives	All levels	• Composition may change in course of the project life cycle • Often replaces pure hardware models
Human related models	Qualification against the applicable HFE requirements	Flight representative as necessary for the limited qualification objectives	All levels	Qualification testing oriented to specific HFE requirements
ground segment specific models	Verification process of the ground segment and operations	Representative as necessary for the applicable verification	Ground segment	See also ECSS-E-ST-70

Prototype and Proto-Flight verification approaches (1/2)

Prototype approach:

Verification approach where **qualification is achieved on a dedicated full flight-representative system model** (generally split between STM and EM) while only acceptance takes place on the flight end item.

This applies to equipment level too.

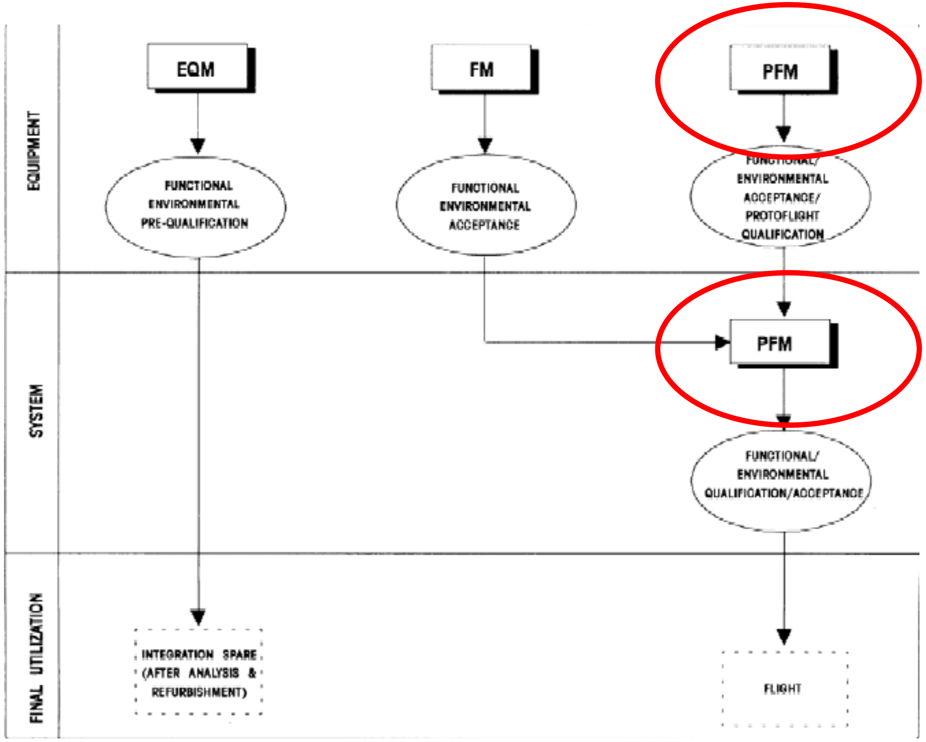


Prototype and Proto-Flight verification approaches (2/2)

Proto-flight approach:

Verification approach where qualification and acceptance take place at the same time on the flight end item.

This applies to equipment level too.



Prototype (QM+FM) vs Proto-Flight (PFM) Testing

Pro's		Con's	
Prototype	Proto-Flight	Prototype	Proto-Flight
Lower risk (issues discovered early on different model from flight)	Lower Cost (single model)	Higher Cost (additional model)	Higher risk to discover issues (too) late in lifecycle
Possibility to refurbish QM as spare	Shorter development schedule	Longer schedule	More complex spares approach
Possibility to use the QM or training, operations, etc.			No further model available for operations, troubleshooting, etc.

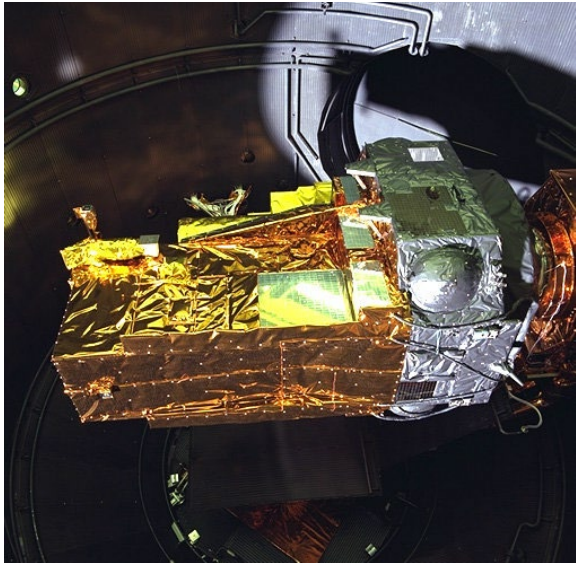
- **The cost and schedule savings of the Proto-Flight approach often overrules all other considerations**
- **Proto-Flight approach is ideal for "standard" missions with high degree of recurrent equipment**

Proto-Flight practical approach

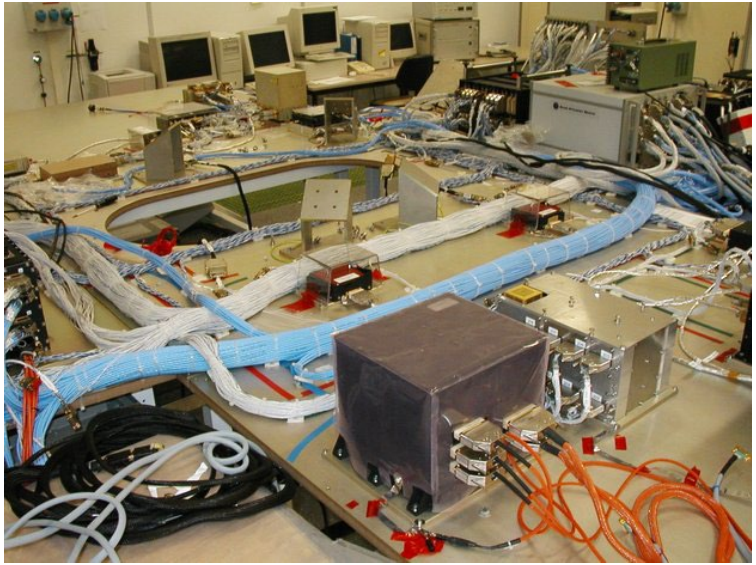
- Generally, **risk mitigation** for Proto-Flight Approach consists of:
  - enhancing development testing,
  - increasing the design margins
  - using design tools with high degree of confidence and validation (whenever possible)
  - implementing an adequate spare policy.

- In practice, the most commonly used approach is a **hybrid approach**:
  - **Qualification models** (or EQM) are **used at lower level** (subsystem and equipment level) for the most **critical or innovative parts** and **proto-flight approach is applied at space segment element level**
  - A STM (Structural Thermal Model) is defined for the mechanical part. This can then be either refurbished into the PFM (if margins are high) or discarded after use.
  - EM at system level is limited to a degree of Electrical/interfaces/functional representativeness (sometimes called ATB: Avionics Test Bench)
  - System Functional verification is carried out by SVF (Software Verification Facility)

ECSS-E-ST-10-02C - Overall Model Approach - Examples



STM: Actual structures and thermal but dummy units



EM/ATB: No structures and no thermal but assembly of EQM/EM (functionally representative) units

ECSS-E-ST-10-02C - Overall Model Approach – Examples of ESA projects

XMM-Newton

STM

EM

(composed of all the equipment EQMs)

FM

(even if it was called PFM at that time)

Cryosat

PFM

- No STM, no EM
- SW-based spacecraft functional model
- Most units recurrent, not requiring EQMs

ECSS-E-ST-10-02C Product Matrix

- For each unit on the basis of the **category**, the qualification status and the **verification needs** (a matrix of models) shall be defined.

- This forms the basis of the procurement activities

No.	Subsystem/Instrument	Qual. Status	STM	EM	PFM	SP	Remarks
1	Structure	D	1		1	*	* STM Spare
2	Thermal control	D	1	*	1	1	* STM Spare
3	AOCS						
	• Coarse sun sensor	A	2*	1	2		* Dummy
	• Star tracker	A	3*	1	3		* Dummy
	• Star tracker electr.	A	3*	1	3		* Dummy
	• Gyro package	A	1*	1	1		* Dummy
	• Gyro electronic	A	4*	1	3		* Dummy
	• Reaction wheel	A	1*	1	4		* Dummy
	• Wheel drive electronic	A	1*	1	1		* Dummy
	• Actuator gyro electronic	A	1*	1	1		* Dummy
	• Flap assembly	D	2*	1	2**		* Dummy ** PFM
	• Control electronic	D	1*	1	1**		* Dummy ** PFM
4	RCS						
	• Tanks	B(A)	8*	8**	8		* Dummy ** from STM
	• Thrusters	A	12*	1	12		* Dummy
	• Thrusters bracket	D	4*	4**	4		* Dummy ** from STM
	• Latch valves	A	11*	1	11		* Dummy
	• Filter	A	1*	1	1		* Dummy
	• Flow meter	D	1*	1	1		* Dummy
	• Fill & drain valves	A	3*	1	3		* Dummy
	• Valve brackets	D	2*	2**	2		* Dummy ** from STM
	• Pressure transducers	A	3*	1	3		* Dummy
	• Pipework	D	1*	1**	1		* Dummy ** from STM
5	Power						
	• Power control unit	C	1*	1**	1		* Dummy ** EQM
	• Battery regulator unit	A	1*	1	1		* Dummy
	• Battery mgt unit	A	1*	1	1		* Dummy
	• Pyro drive unit	C	1*	1**	1		* Dummy ** EQM
	• Power distribution unit	D	1*	1	1**		* Dummy ** PFM
	• Battery	A	2*	2	2		* Dummy
6	OBDH						
	• Central terminal unit	A	1*	1	1		* Dummy
	• Common pulsed distr. unit	A	1*	1	1		* Dummy
	• Digital bus unit	A	4*	4	4		* Dummy
	• Intelligent control unit	C(D)	2*	2**	2**		* Dummy ** EQM
	• Mass memory unit	D(C)	1*	1	1		* Dummy ** PFM
	• Remote bus interface	A	2*	2	2		* Dummy

ECSS-E-ST-10-02C - Verification Documentation and Control

- **Verification Plan** (part of System Engineering Plan)
  - Contains the overall verification approach, the model philosophy, the product matrix, the verification strategies for the requirements, the verification methods and planning, the verification tools, the verification control methodology, the verification management and organization
- **Verification Control Document – VCD** (part of DJF/SEP)
  - Lists the requirements to be verified with the selected methods in the applicable stages at the defined levels. It contains the Verification Matrix
- **Test report**
  - describes test execution, test and engineering assessment of results and conclusions in the light of the test requirements (including pass-fail criteria)
- DRDs for these documents are in Annexes of E-ST-10-02C

ECSS-E-ST-10-02C - Verification Documentation and Control

- The implementation of the verification process shall be monitored by the **Verification Control Board** (VCB)
  - a board composed of customer and supplier representatives that ultimately assesses the requirements verification close-out

- The means to monitor the verification progress are the **VCD** and the verification database

ECSS-E-ST-10-02C - Verification Guidelines for Use / Tailoring

- Guidelines for tailoring are provided in ECSS-E-HB-10-02A (verification guidelines), Annex B
- Requirements that can be tailored and requirements that are recommended NOT to be tailored are indicated
  - Per type of Mission
  - Per phase of Project
  - Per level within product tree
  - Per typical product (HW unit, SW component, Space Element, GSE, Launcher, Ground Segment, Overall System)

ECSS-E-ST-10-02C Verification Requirement	per Product/ Mission	per Phase	per Level	Specific product type						
				Space HW	Space SW	Space element	GSE	Launcher	Ground segment	Overall System
5.1 VERIFICATION PROCESS										
a. The verification process shall demonstrates that the deliverable product meets the specified customer requirements and is capable of sustaining its operational role through: 1. Verification planning; 2. Verification execution and reporting; 3. Verification control and close-out.	No	No	No	No	No	No	No	No	No	No
5.2 VERIFICATION PLANNING										
5.2.2 Verification methods										
5.2.2.1 General										
a. Verification shall be accomplished by one or more of the following verification methods: 1. test (including demonstration); 2. analysis (including similarity); 3. review-of-design; 4. inspection.	No	No	No	No	No	No	No	No	No	No
b. All safety critical functions shall be verified by test.	No	No	No	No	No	No	No	No	No	No
c. Verification of software shall include testing in the target hardware environment.	No	No	No	No	No	No	No	No	No	No
d. For each requirement verified only by analysis or review-of-design, assessment analysis (part of the VP) shall be conducted to determine the level (major/minor) of the impact of this requirement on the mission	Yes	Yes	No	No	No	No	Yes	No	Yes	No
e. If the impact of the requirement is major, a risk mitigation plan (part of the VP) shall be defined which includes, a cross check based on two independent analyses (in terms of model used and suppliers)	Yes	Yes	No	No	No	No	Yes	No	Yes	No

ECSS-E-ST-10-03C
Testing

**** NEW: 31 May 2022***

Testing

* *NEW: 31 May 2022*

ECSS

ECSS-E-ST-10-03C Rev.1
31 May 2022

Change log

ECSS-E-10-03A 15 February 2002	First issue
ECSS-E-10-03B	Never issued
ECSS-E-ST-10-03C 1 June 2012	Second issue.
ECSS-E-ST-10-03C Rev.1 31 May 2022	Second issue, Revision 1 Changes with respect to ECSS-E-ST-10-03C (1 June 2012) are identified with revision tracking. **Main changes are:** • Scope: Clarification on applicability perimeter, including not covering space vehicle constellation • Thermal Tests: o New and more clear definitions, (thermal vacuum test, thermal test at room pressure and thermal test at mission pressure, they are no more in the Glossary), o Thermal Ambient Test not used and substituted by Thermal Test at mission pressure, o Alternative methods are addressed as reference to the Handbook o "thermal" word in thermal parameters (cycles, levels, gradient and so on) changed as "temperature", o Test for switch on capability at equipment level was updated to cover test at maximum and minimum temperature, o New requirement on power status during thermal tests at equipment level and parameter monitoring. • Test on solar arrays and panel:

ECSS-E-ST-10-03C - Testing Content

- Provides requirements for testing in general and in particular at space segment element (e.g. spacecraft or instrument) and equipment level
- Defines the tests to be performed to qualify and accept for flight all equipment - sorted per “types” - and all elements
- Defines levels and pass criteria for the above tests

- Notes:
  - End-to-end System validation is not included and should be project-specific (when required)
  - Subsystem testing is not covered as normally limited to project-specific functional testing. Sometimes this is reported in the ECSS relevant to the specific disciplines (e.g. propulsion)
  - Tests at components/parts/materials level are covered by ECSS-Q-ST

ECSS-E-ST-10-03C – Test Classification

Per objective:

- **Development testing (prior to qualification)**
  - used to validate new design concepts and the application of proven concepts and techniques to a new configuration. It takes place before qualification and shall confirm performance margins, manufacturability, testability, maintainability, etc.
- **Qualification Testing**
  - is the formal demonstration that the design implementation and manufacturing methods have resulted in hardware and software conforming to the specification requirements (also called prototyping testing in other engineering fields)
- **Acceptance Testing**
  - to demonstrate conformance to building specification and to act as quality control screens to detect manufacturing defects and workmanship errors
- **Protoflight (PFM) Testing**
  - is the combination of the qualification and acceptance testing objectives on the first flight model

ECSS-E-ST-10-03C Development Testing

- It applies mostly to **equipment**
- Typical testing performed in the **early technology development** activities
- The standard does not specify which tests shall be performed for development
  - This is left to the project to define.
- Development Models are built on-purpose for development testing
  - Sometimes also called **breadboards** – a term not used in ECSS
- Qualification testing and associated levels provide a reference but often at early stage materials and components basic resistance to space environment needs to be tested
  - see ECSS-ST-Q-60- and ECSS-ST-Q-70- series

ECSS-E-ST-10-03C Test Tolerances

- Testing tolerances on the most important test parameters are specified

Test parameters	Tolerances
1. Temperature	Low High
above 80K	Tmin +0/-4 K Tmax -0/+4 K
T< 80 K	Tolerance to be defined case by case
2. Relative humidity	± 10 %
3. Pressure (in vacuum chamber)	
> 1,3 hPa	± 15 %
1,3 10-3 hPa to 1,3hPa	± 30 %
< 1,3 10-3 hPa	± 80 %
4. Acceleration (steady state) and static load	-0 / +10 %
5. Sinusoidal vibration	
Frequency (5 Hz to 2000 Hz)	± 2 % (or ±1 Hz whichever is greater)
Amplitude	± 10 %
Sweep rate (Oct/min)	± 5 %
6. Random vibration	
Amplitude (PSD, frequency resolution better than 10Hz)	
20 Hz - 1000 Hz	-1 dB / +3 dB
1000 Hz - 2000 Hz	± 3 dB
Random overall g r.m.s.	± 10 %
7. Acoustic noise	
Sound pressure level, Octave band centre (Hz)	
31,5	-2 dB /+4 dB
63	-1 dB /+3 dB
125	-1 dB /+3 dB
250	-1 dB /+3 dB
500	-1 dB /+3 dB
1000	-1 dB /+3 dB
2000	-1 dB /+3 dB
Overall	-1 dB /+3 dB
Sound pressure level homogeneity per octave band	+/- 2 dB
8. Microvibration	
Acceleration	±10 %

Test parameters	Tolerances
Forces or torque	±10 %
9. Audible noise (for Crewed Element only)	
Sound-power (1/3 octave band centre frequency)	
32,5 Hz - 160 Hz	±3 dB
160 Hz – 16 kHz	±2 dB
9. Shock	
Response spectrum amplitude (1/12 octave centre frequency or higher)	
Shock level	- 3 dB/ + 6 dB 50 % of the SRS amplitude above 0 dB
10. Solar flux	
in reference plane	± 4 % of the set value
in reference volume	± 6 % of the set value
11. Infrared flux	
Mean value	± 3 % on reference plane(s)
12. Test duration	-0/+10 %

ECSS-E-ST-10-03C Test Accuracies

- Measurement accuracy for the most important tests are specified (input to test facilities/instrumentation selection)

Test parameters	Accuracy
1. Mass	
Space segment equipment and space segment element	± 0,05 % or 1 g whatever is the heavier
2. Centre of gravity (CoG)	
Space segment equipment	Within a 1 mm radius sphere
Space segment element	± 2,5 mm along launch axis ± 1 mm along the other 2 axes
3. Moment of inertia (MoI)	
Space segment equipment and Space segment element	± 3 % for each axis
4. Leak rate	One magnitude lower than the system specification, in Pa $m^3 s^{-1}$ at standard conditions (1013,25 Pa and 288,15 K).
5. Audible noise (for Crewed Element only)	
32,5 Hz to 160 Hz	± 3 dB
160 Hz to 16 kHz	± 2 dB
6. Temperature	
above 80 K	± 2 K
T< 80 K	Accuracy to be defined case by case
7. Pressure (in vacuum chamber)	
> 1,3 hPa	± 15 %
1,3 10^{-3} hPa to 1,3 hPa	± 30 %
< 1,3 10^{-3} hPa	± 80 %
8. Acceleration (steady state) and static load	± 10 %
9. Frequency for mechanical tests	± 2 % (or ±1 Hz whichever is greater)
10. Acoustic noise	± 0,1dB
11. Strain	± 10 %
12. EMC	See ECSS-E-ST-20-07 clause 5.2.1.
13. ESD	See ECSS-E-ST-20-06 See ECSS-E-ST-20-07 clause 5.2.1 for ESD test on space segment equipment.

ECSS-E-ST-10-03C - Equipment Testing – Sequence

"Test as you Fly"

- Equipment testing (either qualification or acceptance) shall follow a pre-defined sequence

- They preserve the order in which environments are encountered during the operational life ("test as you fly"), and detect potential failures and defects as early in the test sequence as possible

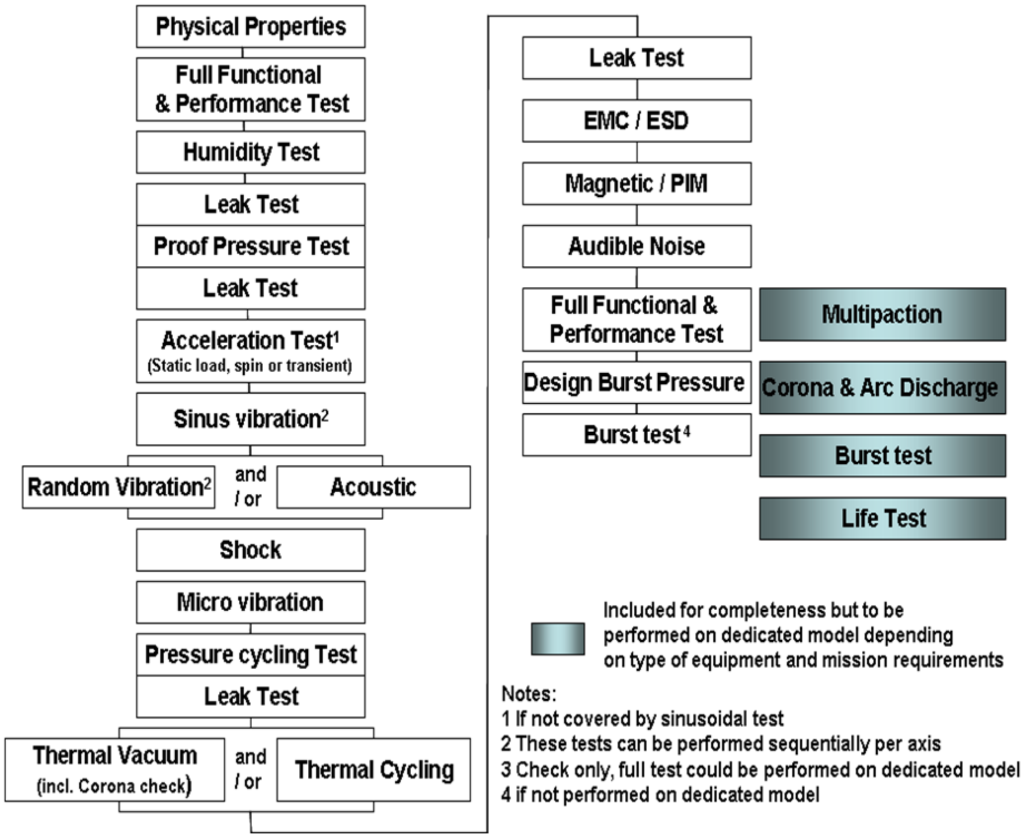


Figure 5-1: Space segment equipment test sequence

ECSS-E-ST-10-03C – Equipment Testing Types of equipment

- Required tests are different depending on "type" of equipment
  - For instance, burst pressure testing does not obviously apply to optical equipment
- Some tests need to be run only depending on specific mission requirements or characteristics
  - e.g. acoustic depending on equipment location, magnetic depending on magnetic cleanliness requirements, etc.
- Some testing may require specific models
  - e.g. burst

Types of space segment equipment			
a Electronic, electrical and RF equipment	d Valve	g Thruster	j Mechanism
b Antenna	e Fluid or propulsion equipment	h Thermal equipment	k Solar array
c Battery	f Pressure vessel	i Optical equipment	l Solar panel

ECSS-E-ST-10-03C
Equipment Qualification Testing

Qualification testing shall be conducted on dedicated QMs that are produced from the same drawings, using the same materials, tooling and methods as the flight item.

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment											
			a	b	c	d	e	f	g	h	i	j	k	l
General														
Functional and performance (FFT/RFT)	5.5.1.1		R	R	R	R	R	R	R	R	R	R	R	R
Humidity	5.5.1.2		X	X	X	X	X	X	X	X	X	X	-	X
Life	5.5.1.3	See Table 5-2 No 1	X	X	R	R	X	X	R	X	X	R	-	-
Burn-in	5.5.1.4		X	-	-	X	-	-	X	-	-	-	-	-
Mechanical														
Physical properties	5.5.2.1		R	R	R	R	R	R	R	R	R	R	R	R
Static load	5.5.2.2	See Table 5-2 No 2	X	X	X	X	X	X	X	X	X	X	X	-
Spin	5.5.2.2	See Table 5-2 No 3	X	X	X	X	X	X	X	X	X	X	X	-
Transient	5.5.2.2	See Table 5-2 No 4	X	X	X	X	X	X	X	X	X	X	X	-
Random vibration	5.5.2.3	See Table 5-2 No 5	R	X	R	R	R	R	R	R	X	X	X	-
Acoustic	5.5.2.4	See Table 5-2 No 6	-	X	-	-	-	-	-	-	X	X	R	-
Sinusoidal vibration	5.5.2.5	See Table 5-2 No 7	R	R	R	R	R	R	R	R	R	R	R	-
Shock	5.5.2.6	See Table 5-2 No 8	R	X	R	R	R	X	R	X	R	R	-	-
Micro-vibration generated environment	5.5.2.7		X	X	-	X	X	-	X	-	-	X	-	-
Micro-vibration susceptibility	5.5.2.8	See Table 5-2 No 9	X	-	-	-	-	-	-	-	X	X	-	-
Structural integrity														
Leak	5.5.3.1	See Table 5-2 No 10	X	-	R	R	R	R	X	X	-	-	-	-
Proof pressure	5.5.3.2	See Table 5-2 No 11	X	-	-	R	R	R	R	-	-	-	-	-

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment											
			a	b	c	d	e	f	g	h	i	j	k	l
Pressure cycling	5.5.3.3	See Table 5-2 No 12	X	-	-	R	R	R	R	-	-	-	-	-
Design burst pressure	5.5.3.4	See Table 5-2 No 13	X	-	-	R	R	R	R	-	-	-	-	-
Burst	5.5.3.5	See Table 5-2 No 14	X	-	-	R	R	R	R	-	-	-	-	-
Thermal														
Thermal vacuum	5.5.4.1 & 5.5.4.2	See Table 5-2 No 15	R	X	R	R	R	X	R	R	R	R	-	R
Thermal ambient	5.5.4.1 & 5.5.4.3	See Table 5-2 No 16	R	X	R	R	R	X	R	R	R	R	-	-
Electrical / RF														
EMC	5.5.5.1	See Table 5-2 No 17	R	X	X	X	X	X	X	X	X	X	X	X
Magnetic	5.5.5.2		X	X	X	X	X	X	X	X	X	X	X	X
ESD	5.5.5.3	See Table 5-2 No 19	R	X	X	X	X	X	X	X	X	X	X	X
PIM	5.5.5.4	See Table 5-2 No 19	X	X	-	-	-	-	-	-	-	-	-	-
Multipaction	5.5.5.5		X	X	-	-	-	-	-	-	-	-	-	-
Corona and arc discharge	5.5.5.6	See Table 5-2 No 20	R	R	R	-	-	-	-	-	-	-	-	-
Mission specific														
Audible noise	5.5.6.1		R	-	-	R	R	-	R	-	-	R	-	-

Key

R	Required
X	To be decided by the customer
-	Not required

ECSS-E-ST-10-03C – Equipment Qualification Test Levels and Durations

- The qualification test levels shall exceed the maximum predicted levels by a factor of safety
  - which assures that, even with the worst combination of test tolerances, the flight levels shall not exceed the qualification test levels

- Examples of qualification factors:
  - For mechanical loads: KQ = 1.25 (recommended) over the limit loads, or +3dB for shock, random and acoustic expected spectra
  - For thermal: ±10 °C on max and min design temperatures (operational and non-operational)
- Some launchers require higher qualification factors
  - E.g. Soyuz asks for KQ = 1.3 on limit loads – in such cases the KQ from launcher manual is taken as reference

ECSS-E-ST-10-03C
Equipment Acceptance Tests

- The acceptance testing shall be conducted on all the flight products (including spares)

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment												Application notes
			a	b	c	d	e	f	g	h	i	j	k	l	
General															
Functional and performance (FFT/RFT)	5.5.1.1		R	R	R	R	R	R	R	R	R	R	R	R	For k (solar array), the deployment test is mandatory before and after the environmental tests (manual deployment before the environmental tests).
Humidity			-	-	-	-	-	-	-	-	-	-	-	-	
Life			-	-	-	-	-	-	-	-	-	-	-	-	
Burn-in	5.5.1.4		X	-	-	X	-	-	X	-	-	-	-	-	To be performed, if the total duration of the acceptance test sequence is insufficient to detect material and workmanship defect occurring in the space segment equipment lifetime.
Mechanical															
Physical properties	5.5.2.1		R	R	R	R	R	R	R	R	R	R	R	R	Upon agreement with customer the CoG and MoI is not measured by test but calculated.
Static load			-	-	-	-	-	X	-	-	-	-	-	-	General structural proc higher level test (e.g. si
Spin			-	-	-	-	-	-	-	-	-	-	-	-	
Transient			-	-	-	-	-	-	-	-	-	-	-	-	
Random vibration	5.5.2.3	See Table 5-4 No 1	R	X	R	R	R	R	R	R	X	X	X	-	For k (solar array), the for fixed solar array mo bracket).
Acoustic	5.5.2.4	See Table 5-4 No 2	-	X	-	-	-	-	-	-	X	X	R	-	For b (antennas), i (opt selected depending on equipment. For k (solar array), acou second FM) can be omi testing at space segmen
Sinusoidal vibration	5.5.2.5	See Table 5-4 No 3	-	-	-	-	-	-	-	-	-	-	R	-	For k (solar array), sinu (from the second FM) c acceptance testing at sp flight heritage on desig
Shock			-	-	-	-	-	-	-	-	-	-	-	-	
Micro-vibration generated environment			-	-	-	-	-	-	-	-	-	-	-	-	
Micro-vibration suscep.	5.5.2.8	See Table 5-4 No 4	X	-	-	-	-	-	-	-	X	X	-	-	Test to be performed o

Test	Reference clause	Ref. to Level & Duration	Applicability versus types of space segment equipment												Application notes
			a	b	c	d	e	f	g	h	i	j	k	l	
Structural integrity															
Leak	5.5.3.1	See Table 5-4 No 5	X	-	R	R	R	R	X	-	-	-	-	-	For a (electronic, electrical and RF equipment) required only on sealed or pressurized space segment equipment.
Proof pressure	5.5.3.2	See Table 5-4 No 6	-	-	-	R	R	R	X	-	-	-	-	-	For c (battery) proof pressure, is performed at cell level (i.e. component level).
Pressure cycling			-	-	-	-	-	-	-	-	-	-	-	-	
Design burst pressure			-	-	-	-	-	-	-	-	-	-	-	-	
Burst			-	-	-	-	-	-	-	-	-	-	-	-	
Thermal															
Thermal vacuum	5.5.4.1 & 5.5.4.2	See Table 5-4 No 7	R	X	R	R	R	X	R	R	R	R	-	R	
Thermal ambient	5.5.4.1 & 5.5.4.3	See Table 5-4 No 8	R	X	R	R	R	X	R	R	R	R	-	-	Can be combined in thermal vacuum test. Tests not required for batteries that cannot be recharged after testing.
Electrical / RF															
EMC	5.5.5.1	See Table 5-4 No 9	R	X	X	X	X	X	X	X	X	X	X	X	For equipment without electronic test are limited to bonding test.
Magnetic	5.5.5.2		X	X	X	X	X	X	X	X	X	X	-	X	Magnetic test to be performed if justified by mission needs, in accordance with the EMCCP.
ESD			-	-	-	-	-	-	-	-	-	-	-	-	
PIM	5.5.5.4	See Table 5-4 No 10	X	X	-	-	-	-	X	-	X	-	-	-	
Multipaction	5.5.5.5		X	X	-	-	-	-	-	-	-	-	-	-	
Corona and arc discharge	5.5.5.6	See Table 5-4 No 11	R	R	R	-	-	-	-	-	-	-	-	-	For condition of applicability of test, refer to 5.5.5.6.
Mission specific															
Audible noise	5.5.6.1		R	R	-	R	R	-	R	-	-	R	-	-	Required for space segment equipment for crewed space segment element.

ECSS-E-ST-10-03C – Equipment Acceptance Test Levels and Durations

- The acceptance test shall be conducted under **environmental conditions no more severe than those expected during the mission**
- and it shall not create conditions that exceed safety margins or cause unrealistic modes of failure

- Examples of acceptance factors:
  - For mechanical loads: KA = 1. (recommended) over the limit loads or +0dB for shock, random and acoustic expected spectra
  - For thermal: ±5 C on design max and min temperatures (operational and non-operational)

ECSS-E-ST-10-03C – Equipment Proto-Flight Tests, Test Levels and Durations

- Proto-Flight tests are the same as for qualification
  - except for static loads (not required)
  - and destructive tests (burst – obviously not for the PFM)

- The Proto-Flight test levels and durations shall be as follows:
  - Proto-Flight test levels: same as qualification levels
  - Proto-Flight test durations: same as acceptance durations
    - e.g. 4 cycles for thermal

ECSS-E-ST-10-03C
Space Segment Element Protoflight Tests

- Taken as an example for Space Segment Element Testing
- Note that tests are different from the equipment ones

Test	Reference clause	Ref. to Level & Duration & Number of applications	Applicability	Conditions
General				
Optical alignment	6.5.1.1		R	
Functional (FFT / RFT)	6.5.1.2		R	
Performances (PT)	6.5.1.3		R	
Mission (MT)	6.5.1.4		R	
Polarity	6.5.1.5		R	
Launcher Interface	6.5.1.6		X	Mandatory for space segment element interfacing with launcher.
Mechanical				
Physical properties	6.5.2.1		R	
Modal survey	6.5.2.2		X	
Static	6.5.2.3	Table 6-6 No 1	X	Mandatory if not performed at structure subsystem level
Spin	6.5.2.4	Table 6-6 No 2	X	Mandatory for spinning space segment elements with an acceleration greater than 2 g or more to any part of the space segment element
Transient	6.5.2.5	Table 6-6 No 3	X	
Acoustic	6.5.2.6	Table 6-6 No 4	X	Acoustic test may be replaced by random vibration. For a small compact space segment element, acoustic testing does not provide adequate environmental simulation, and random vibration may replace the acoustic test. If acoustic test is performed, random vibration may be avoided.
Random vibration	6.5.2.7	Table 6-6 No 5	X	
Sinusoidal vibration	6.5.2.8	Table 6-6 No 6	R	Sinusoidal vibration may be replaced by transient combined with modal survey
Shock	6.5.2.9	Table 6-6 No 7	X	
Micro-vibration susceptibility	6.5.2.10	Table 6-6 No 8	X	
Structural integrity				
Proof pressure	6.5.3.1	Table 6-6 No 9	X	Mandatory for pressurized space segment elements or on pressurized equipment integrated in space segment element for which the test is feasible
Pressure cycling	6.5.3.2	Table 6-6 No 10	X	Mandatory for Pressurized space segment elements that will experience several re-entries.
Design burst pressure	6.5.3.3	Table 6-6 No 11	X	Mandatory for pressurized space segment element to be performed on a dedicated hardware
Leak	6.5.3.4	Table 6-6 No 12	X	Mandatory for pressurized space segment elements or on pressurized

Test	Reference clause	Ref. to Level & Duration & Number of applications	Applicability	Conditions
				equipment integrated in space segment element for which the test is feasible
Thermal				
Thermal vacuum	6.5.4.1 & 6.5.4.2	Table 6-6 No 13	R	
Thermal ambient	6.5.4.1 & 6.5.4.3	Table 6-6 No 14	X	Applicable to space segment elements that operate under a non-vacuum environment during their lifetime
Thermal balance	6.5.4.4		R	
Electrical / RF				
EMC	6.5.5.2	Table 6-6 No 15	R	
Electromagnetic auto-compatibility	6.5.5.3		R	
PIM	6.5.5.4	Table 6-6 No 16	X	
Magnetic	6.5.5.5		X	
Mission Specific				
Aero-thermodynamics	6.5.6.1		R	For space segment element performing atmospheric entry
Crewed Mission Specific				
Micro-vibration emission	6.5.7.1		R	
HFE	6.5.7.2		R	
Toxic off gassing	6.5.7.3		R	
Audible noise	6.5.7.4		R	

R Mandatory

X To be decided on the basis of design features, required lifetime, sensitivity to environmental exposure, and expected usage.

Note: All tests type are listed independently of their application status:

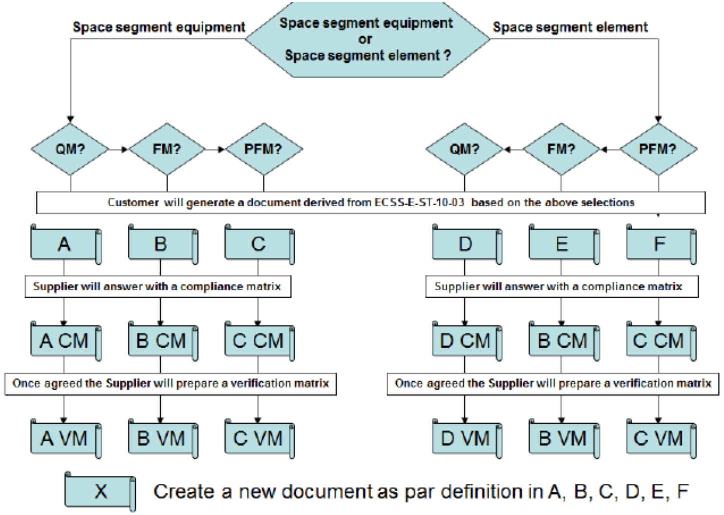
- the dark grey indicates that the type of test is never required or optional
- the light grey indicates that there is no test level and duration specified in the Table 6-6 since it is not a test where an environment is applied to the item under test

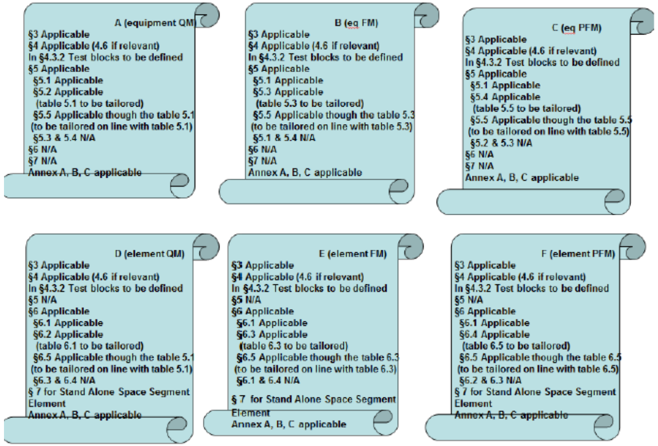
ECSS-E-ST-10-03C
Testing Documentation and Programme

- Documents:
  - AIT Plan
    - Describes the AIT process and, with the Verification Plan, gives the process for requirements verification
    - AIT / V&V process is typically a main driver for cost & schedule
  - Test specification
    - Purpose of the test, test approach, item-under-test and set-up, required GSE, test tools, test instrumentation and measurement accuracy, test conditions, test sequence, facility, pass/fail criteria, required documentation, participants and test schedule
  - Test Procedure
    - Detailed step-by-step instructions for conducting test activities
- Programme:
  - Before Test: TRR (Test Readiness Review)
  - After Test: PTR (Post Test Review) – TRB (Test Review Board)

ECSS-E-ST-10-03C
Testing Guidelines for Use / Tailoring

- Guidelines for tailoring are provided in Annex D.





Other E-10 Standards

ECSS-E-ST-10-04C – Space Environment Content

- Specifies/recommends most appropriate models and tools to define a range of space natural environments and to assess the induced environments generated by the interaction between the spacecraft and the natural environments
  - (Earth) gravity: EIGEN-GLO4C model is specified complemented by IERS models and JPL Planet and Lunar Ephemerides for perturbations
  - (Earth) Magnetic field (internal and external)
  - Electromagnetic radiation (e.g. thermal)
  - (Earth) atmosphere - NRLMSISE-00 model for altitudes < 120 km, JB-2006 model above 120 km (Annex G mentions also Planetary atmospheres)
  - (Earth) plasma (e.g. charged particles) and energetic particles radiation (Annex I gives some planetary environment data)
  - Space debris and meteoroids
  - Contamination

ECSS-E-ST-10-04C - Space Environment Documentation

- The Standard only provide requirements for the preparation of a Radiation Environment Specification and not for an overall Mission Environment Specification

- It is common practice to have a Mission Environment Specification (either prepared by ESA or the Prime) which reports the analysis performed to assess the Spacecraft environment in all phases of the mission (not only in orbit but also on-ground, on the launch pad, etc.)

ECSS-E-ST-10-04C - Space Environment Guidelines for Use / Tailoring

- Generally, for Earth-bound missions, all natural and main induced environments are well covered and within each section the standard provides tailoring guidelines
- For interplanetary missions, especially if including a surface mission (e.g. ExoMars, Lunar Lander, etc.), project own environment description and requirements are needed
- Thermal environment is usually specified in more detail by projects/primes for albedo and Earth IR (own tailoring) in comparison to what is in ANNEX F
- In most projects the prime issues as a “Support specification” the specification of all the environment (from AIV to transport to launch to orbit) applicable to the mission

ECSS-E-ST-10-09C
Reference Coordinate System – Content

- General definition and guidelines on how to define reference coordinate systems for a space project
- Mandates the preparation already from phase A of a Coordinate Systems Document explaining all the frames to be used
  - May be part of the System Engineering Plan
- Specifies need to define transformations between coordinates and define time unit (as some coordinate systems are time-dependent)
- There are three Annexes:
  - A: DRD of Coordinate Systems Document (Normative)
  - B: Transformation Tree formats (Informative)
  - C: Existing International Standard
- Hints in Annex A that at least the following systems shall be defined:
  - Inertial System (Heliocentric or Earth centered or both)
  - Orbital System (also sometimes called rotating frame)
  - Mechanically fixed System (also sometimes called body frame)
  - Instrument/Unit-fixed System (one for each unit)

ECSS-E-ST-10-09C – Reference Coordinate System – Use / Tailoring

- The Standard does not provide " recommended" Coordinate Systems definition but leaves it to each individual project to define
  - Can choose from International Standards (which are however not of much practical use)

- The Standard does specify the format for describing the coordinate systems and associated transformations (within the Coordinate System Document) and this should be tailored

- Suggest to leave applicable but tailor Annex A depending on project specific needs

Examples of commonly used Reference Coordinate Systems (1/2)

The Standard does not provide "recommended" Coordinate Systems definition but leave it to each individual project to define. Here are examples:

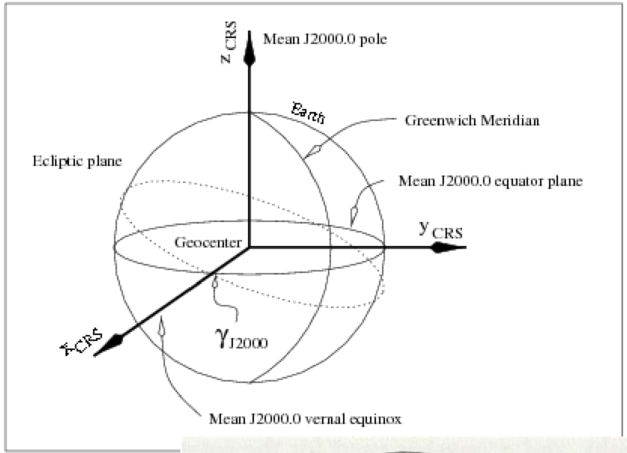
Earth Centred Inertial (ECI) used for satellite motion

Origin: Earth centre of mass

X:the intersection between the J2000.0 equatorial plane and the ecliptic plane

Z:the direction of the Earth mean rotation pole at J2000.0

Y:completes the right-handed system



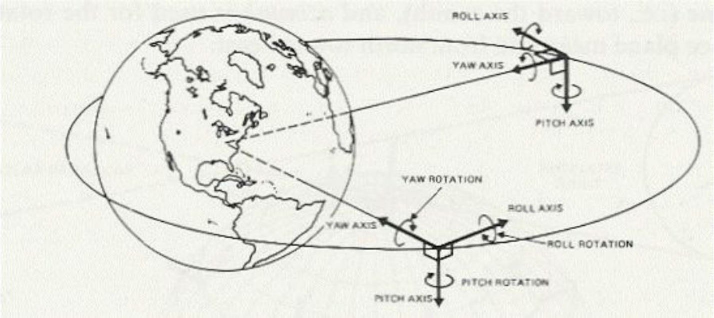
Rotating Orbital Frame used for satellite attitude with respect to mechanically fixed satellite reference frame

Origin: Satellite centre of mass

+Z: (Yaw) pointing towards the Earth centre

+Y: (Pitch) parallel to the orbit angular momentum vector, pointing in the opposite direction (i.e. orbit anti-normal)

+X: (Roll) completes the right-handed system



Examples of commonly used Reference Coordinate Systems (2/2)

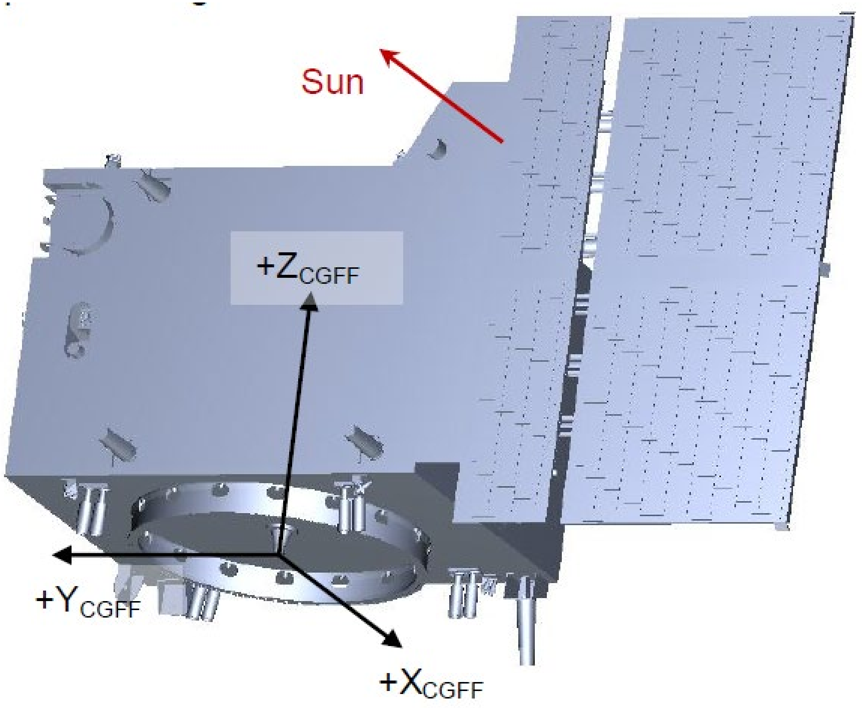
Mechanically-fixed Satellite Coordinate System used to identify attitude and locations onboard the satellite

Origin: Reference Point on the satellite Structure, often at Launcher Interface

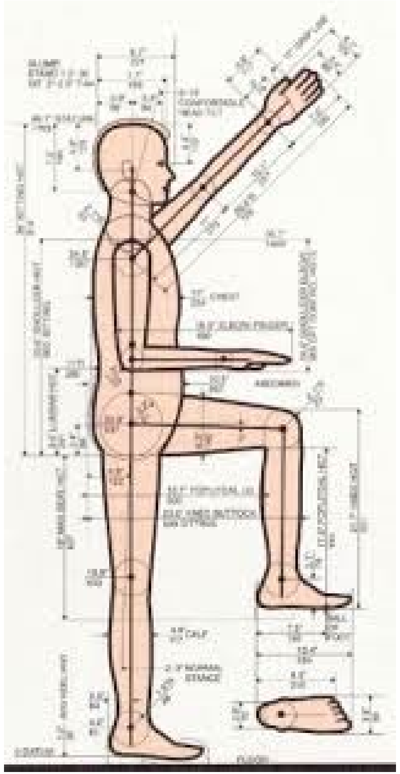
X: Typical direction linked to specific geometric or attitude features of the satellite

Z: often the launch direction

Y:completes the right-handed system



ECSS-E-ST-10-11C
Human Factors Engineering



- It contains requirements to be taken into account when designing systems with high interaction with Humans (called Human-machine systems)
  - E.g. Human Spaceflight Vehicles
- It includes:
  - ergonomics,
  - reference for anthropometric characteristics (European),
  - EVA requirements,
  - Requirements for crew space (volume, furniture, etc.)
  - Requirements on human operations (e.g. onboard ISS)

ECSS-E-ST-10-12C – Methods for Calculation of Radiation - Content

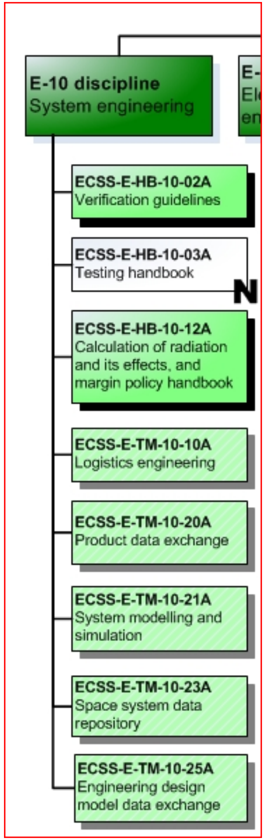
- Provides extensive description of the recommended analysis processes for definition of the expected radiation environment and effects on a space mission
- It is complemented by the guidelines in the HB (not normative) which give explanations, formulas and examples for the calculations.
- Includes:
  - Summary of radiation effects (highly recommended reading !)
  - Calculation methods and margins
  - Shielding approach
- Details on the main effects:
  - TID (Total Ionizing Dose) / TNID (Total Non-Ionizing Dose)
  - Displacement Damage
  - SEE (Single Event Effects)
  - Sensor backgrounds
  - Biological effects (for human spaceflight)

ECSS-E-ST-10-12C - Methods for Calculation of Radiation - Application

Effect	Parameter	Typical units	Examples	Particles
Total ionising dose (TID)	Ionising dose in material	grays (material) (Gy(material)) or rad(material) 1 Gy = 100 rad	Threshold voltage shift and leakage currents in CMOS, linear bipolar (note dose-rate sensitivity)	Electrons, protons, bremsstrahlung
Displacement damage	Displacement damage equivalent dose (total non-ionising dose) Equivalent fluence of 10 MeV protons or 1 MeV electrons	MeV/g cm^{-2}	All photonics, e.g. CCD transfer efficiency, optocoupler transfer ratio Reduction in solar cell efficiency	Protons, electrons, neutrons, ions
Single event effects from direct ionisation	Events per unit fluence from linear energy transfer (LET) spectra & cross-section versus LET	cm^2 versus $MeV{\cdot}cm^2/mg$	Memories, microprocessors. Soft errors, latch-up, burn-out, gate rupture, transients in op-amps, comparators.	Ions $Z>1$
Single event effects from nuclear reactions	Events per unit fluence from energy spectra & cross-section versus particle energy	cm^2 versus MeV	As above	Protons, neutrons, ions
Payload-specific radiation effects	Energy-loss spectra, charge-deposition spectra charging	counts s^{-1} MeV^{-1}	False count rates in detectors, false images in CCDs Gravity proof-masses	Protons, electrons, neutrons, ions, induced radioactivity (α, $\beta\pm$, γ)
Biological damage	Dose equivalent = Dose(tissue) x Quality Factor; equivalent dose = Dose(tissue) x radiation weighting factor; Effective dose	sieverts (Sv) or rems 1 Sv = 100 rem	DNA rupture, mutation, cell death	Ions, neutrons, protons, electrons, γ-rays, X-rays
Charging	Charge	coulombs (C)	Phantom commands from ESD	Electrons

Sub-system or component	Technology	Effect
Integrated circuits	Power MOS	TID SEGR SEB
	CMOS	TID SEE (generally)
	Bipolar	TNID SEU SET TID
	BiCMOS	TID TNID SEE (generally)
	SOI	TID SEE (generally exc. SEL)
Optoelectronics and sensors (1)	MEMS [a]	TID
	CCD	TNID TID Enhanced background (SEE)
	CMOS APS	TNID TID SEE (generally) Enhanced background
	Photodiodes	TNID TID SET
	LEDs	TNID TID
	laser LEDs	TNID TID
	Opto-couplers	TNID TID SET
Optoelectronics and sensors (2)	γ-ray or X-ray scintillator	TNID (alkali halides) Enhanced background
	γ-ray semiconductor [b]	TNID Enhanced background
	charged particle detectors	TNID (scintillator [c] & semiconductor) Enhanced background TID (scintillator [c] & semiconductors)
	microchannel plates	Enhanced background
	photomultiplier tubes	Enhanced background
	Other imaging sensors (e.g. InSb, InGaAs, HgCdTe, GaAs and GaAlAs)	TNID Enhanced background
	Gravity wave sensors	Enhanced background
Solar cells	Cover glass & bonding materials	TID
	Cell	TNID
Non-optical materials	Crystal oscillators	TID
	polymers	TID (radiolysis)
Optical materials	silica glasses	TID
	alkali halides	TID TNID
Radiobiological effects		Early effects
		Stochastic effects
		Deterministic late effects

Handbooks and Technical Memoranda



ECSS-S-ST-00C, c5.2.2:
Handbooks are non-normative documents providing background information, orientation, advice or recommendations related to one specific discipline or to a specific technique, technology, process or activity.

ECSS-S-ST-00C, c5.2.3:
Technical memoranda are non-normative documents providing useful information to the space community on a specific subject.

- ECSS-E-HB-10-02A Verification guidelines
- ECSS-E-HB-10-12A Methods for the Calculation of radiation and its effects and margin policy handbook
- ECSS-E-HB-11A Technology readiness level (TRL) guidelines
- SAVOIR-HB-003 SAVOIR FDIR Handbook
- ECSS-E-TM-10-10A Logistics engineering
- ECSS-E-TM-10-20A Product data exchange
- ECSS-E-TM-10-21A System modeling and simulation
- ECSS-E-TM-10-23A Space system data repository
- ECSS-E-TM-10-25A Engineering design model data exchange (CDF)

ECSS System Engineering Handbook

- Work on ECSS-E-HB-10 “System engineering handbook” was started but put on hold

- As part of restructuring the whole of ECSS to version C all guidelines and best practices were moved out of the standards

- However …

ECSS System Engineering Handbook

A lot of useful guidelines and best practices can still be found in the previous version of ECSS-E-ST-10: Part 1B

ECSS-E-ST-10 Part 1B can be downloaded from http://ecss.nl/standard/ecss-e-10-part-1b-system-engineering-part-1-requirements-and-process/

cancelled and superseded by ECSS-E-ST-10C Rev.1 – System engineering general requirements (15 February 2017)

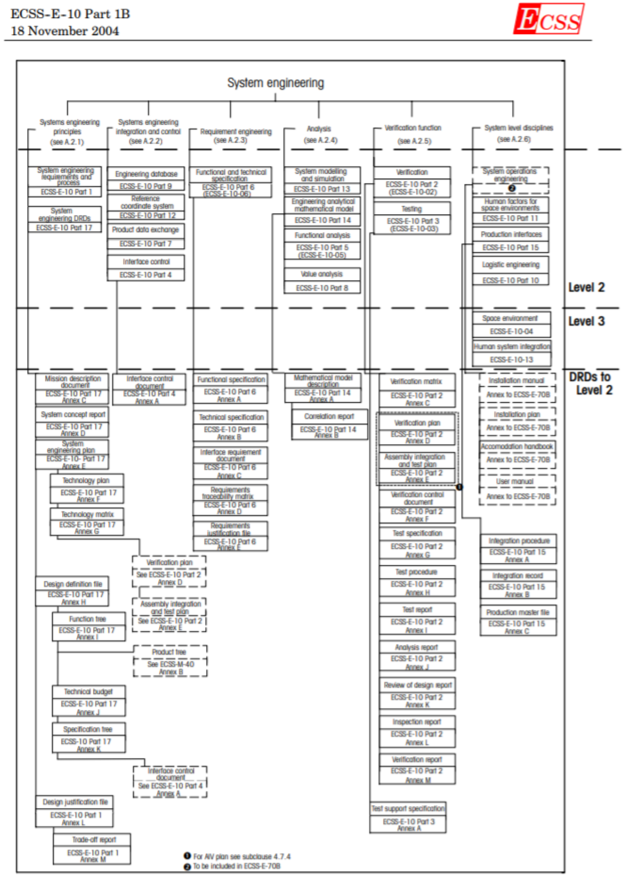


Figure A-1: Structure of the system engineering discipline

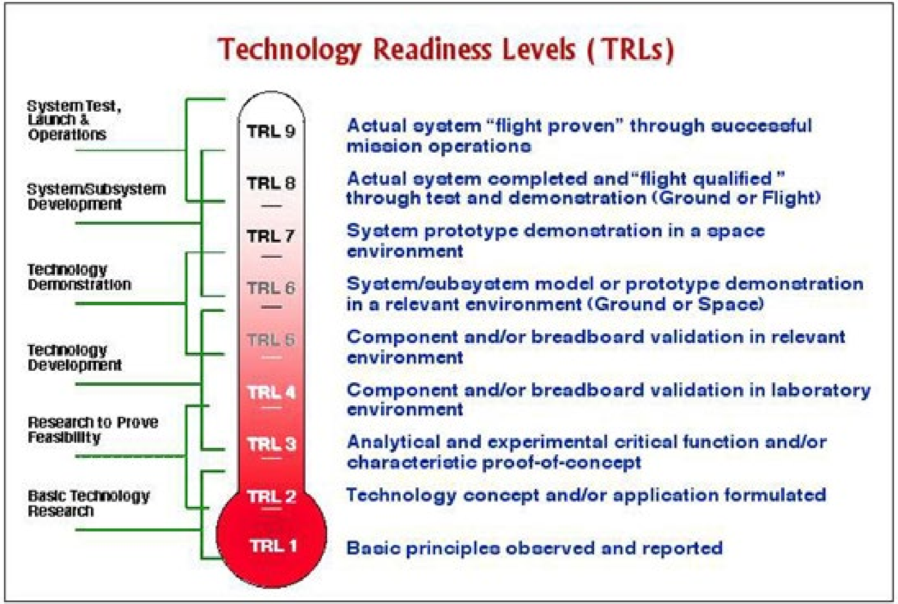
ISO 24113 (ECSS-U-AS-10C) "Space debris mitigation requirements"

- Adopted through ECSS-U-AS-10C
- Not part of E-10 series but large impact on system design
- ECSS has adopted the international standard:
  ISO 24113: Space systems - Space debris mitigation requirements.
- Only minor modifications introduced via ECSS-U-AS-10C

Policy in summary

- All ESA Space Vehicle including Satellites, Launchers and Inhabited Vehicles shall be disposed of
  - At the end of life they shall be out of "Protected regions" (LEO up to 2000 km and GEO +/-15 deg, +/- 200 km) within 25 years
  - Either moved to non-protected regions or re-entered into Earth atmosphere for break-up and burning
  - Uncontrolled re-entry not allowed if casualty risk > 10-4 (the case of ATV and possibly Envisat)
  - If drift to non-protected regions or re-entry do not happen naturally, active (propulsive) measures needs to be accounted for

Technology Readiness Levels
ISO 16290 adopted through ECSS-E-AS-11C



Note: The TRL scale evaluates a given technology **in the context of a specific application, not by itself**

If a given technology has been flying for a long time it does not mean that it is automatically TRL 9!

TRL 9 is achieved only for the ***exact same application*** with ***exactly the same requirements***, otherwise it is TRL 5

TRL definitions are applicable to both HW and SW
Accompanying **Handbook ECSS-E-HB-11A** published 1 March 2017

TRL Scale as Defined in ISO 16290

Level	Definition
TRL 1	Basic principles observed and reported
TRL 2	Technology concept and/or application formulated
TRL 3	Analytical and experimental critical function and/or characteristic proof-of-concept
TRL 4	Component and/or breadboard functional verification in laboratory environment
TRL 5	Component and/or breadboard critical function verification in a relevant environment
TRL 6	Model demonstrating the critical functions of the element in a relevant environment
TRL 7	Model demonstrating the element performance for the operational environment
TRL 8	Actual system completed and accepted for flight ("flight qualified")
TRL 9	Actual system "flight proven" through successful mission operations

TRL Scale as adopted through E-AS-11C "Work achievement"

Level	Work achievement (documented)
TRL 1	Expression of the basic principles intended for use. Identification of potential applications.
TRL 2	Formulation of potential applications. Preliminary conceptual design of the element, providing understanding of how the basic principles would be used.
TRL 3	Preliminary performance requirements (can target several missions) including definition of functional performance requirements. Conceptual design of the element. Experimental data inputs, laboratory-based experiment definition and results. Element analytical models for the proof-of-concept.
TRL 4	Preliminary performance requirements (can target several missions) with definition of functional performance requirements. Conceptual design of the element. Functional performance test plan. Breadboard definition for the functional performance verification. Breadboard test reports.
TRL 5	Preliminary definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Preliminary design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Analysis of scaling effects. Breadboard definition for the critical function verification. Breadboard test reports.
TRL 6	Definition of performance requirements and of the relevant environment. Identification and analysis of the element critical functions. Design of the element, supported by appropriate models for the critical functions verification. Critical function test plan. Model definition for the critical function verifications. Model test reports.
TRL 7	Definition of performance requirements, including definition of the operational environment. Model definition and realisation. Model test plan. Model test results.
TRL 8	Flight model is built and integrated into the final system. Flight acceptance of the final system.
TRL 9	Commissioning in early operation phase. In-orbit operation report.

Outlook to the Future

Model-Based System Engineering (MBSE)

- Since about 2006 there has been a growing trend to move to MBSE
- INCOSE MBSE Initiative started early 21st century

- MBSE tool implementations (COTS and open source) maturing and being put into industrial practice

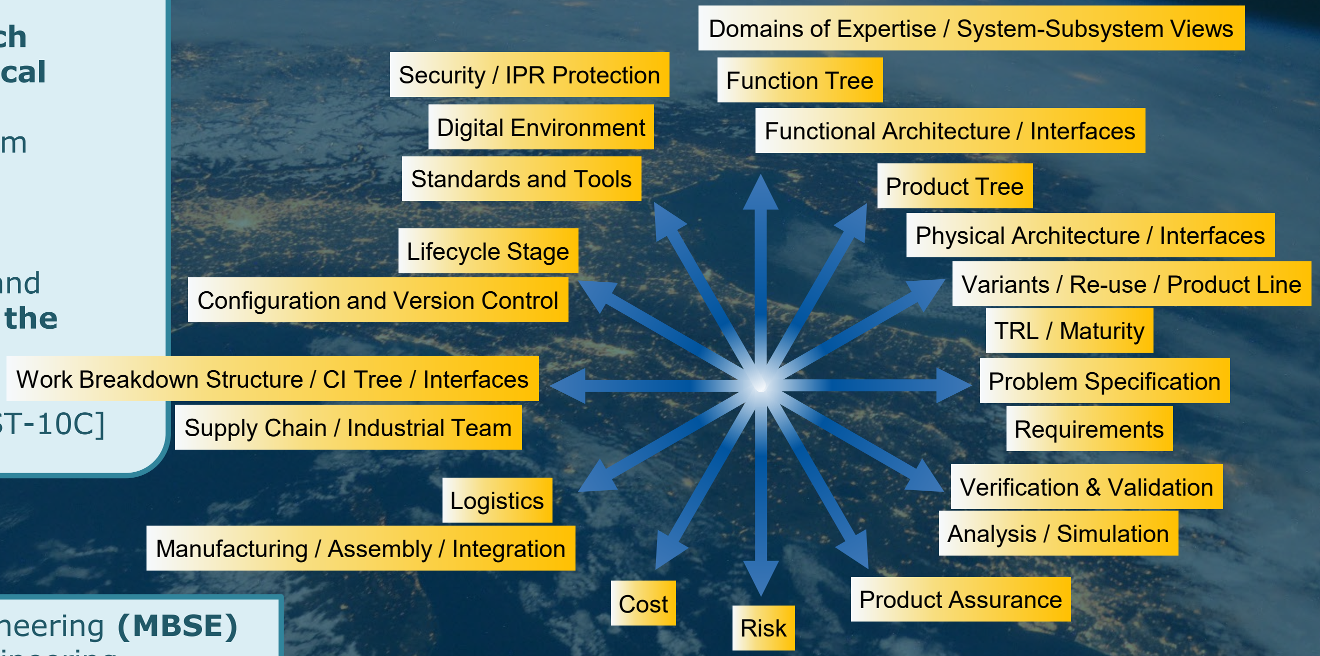
- Main goal: **more efficient and effective system engineering by moving from a document-centric to model-centric approach making use of the capabilities that modern IT tools can offer**
  - cf. transition of 2D drawings to 3D CAD over the last 30 years

- Most important expected benefits:
  - One master definition of information = "Single Source of Truth"
  - Any number of views / perspectives on the same information
  - All views are inherently consistent: "consistent by construction"
  - Integrated version, configuration and traceability control

Purpose and Challenge of System(s) Engineering

System Engineering is
- **interdisciplinary approach** governing the **total technical effort** to **transform requirements** into a system **solution**
- **integration and control**, coordinating the various **engineering disciplines** and participants throughout **all the project phases**

[from ECSS-E-ST-10C]

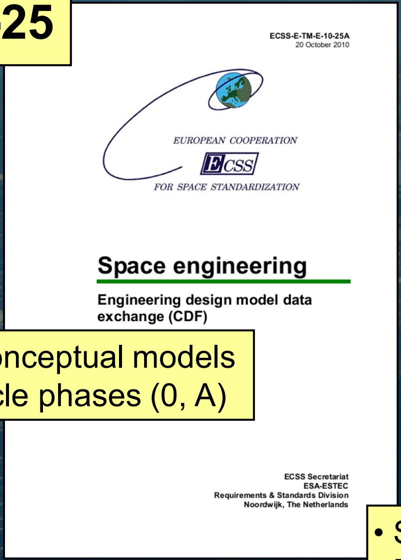


Goal of **Model-Based** System Engineering **(MBSE)** is to improve SE using a digital engineering approach

⇒ Handle huge amount of information across many dimensions

ECSS-E-TM-10-23 and E-TM-10-25
Towards fully digital engineering

E-TM-10-25



ECSS-E-TM-E-10-25A
20 October 2010

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

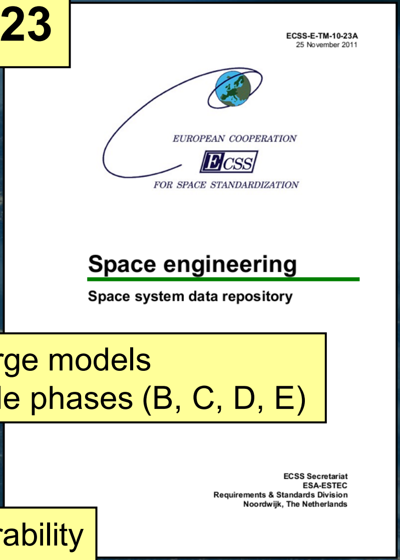
Space engineering

Engineering design model data exchange (CDF)

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

Focuses on conceptual models in early life cycle phases (0, A)

E-TM-10-23



ECSS-E-TM-10-23A
25 November 2011

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

Space engineering

Space system data repository

ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands

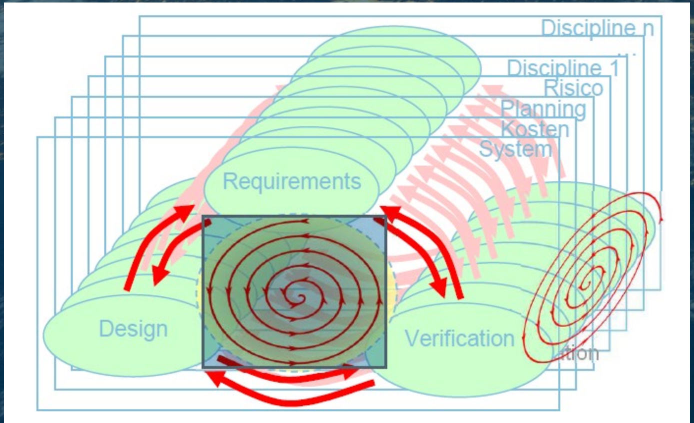
Focuses on large models in later life cycle phases (B, C, D, E)

- Semantic data models – essential for interoperability
- Developed in tandem
- Where possible uses common approach
- Where possible aligned with SysML
- E-TM-10-25A made available Oct 2010
- E-TM-10-23A made available Nov 2011

ECSS-E-TM-10-25A & MBSE

- It defines both a language and an exchange protocol to facilitate collaborative MBSE in the context of Concurrent Design (early design phases)

- Developed by the ESA CDF (Systems and Concurrent Engineering Section) and industrial partners to promote Concurrent Design, to support collaborative MBSE in CDF environments and to facilitate data exchange among between partners.



- It provides the means to express:
  - the Problem Statement in the form of requirements and
  - the solution in the form of an architecture (including a logical, functional and physical architecture)

  providing a means to create relationships between the two to perform (semi) automated requirements verification.

COMET

- RHEA open-source implementation of ECSS-E-TM-10-25 Annex A.

- Goal: having all tools implementing standard interfaces (APIs) – or developing adapters – enhancing interconnection and data exchange

Several Initiatives and Working Groups

esa

MB4SE (https://essr.esa.int/project/mb4se-model-based-for-system-engineering)

- https://mb4se.esa.int (mb4se thumbnail)
- MB4SE User Needs: MB4SE-TN-001 i2 r2
- Harmonisation Technical Dossier and Roadmap: 2020.1_THD_MB4SE_v2.2

OSMoSE

- https://mb4se.esa.int (OSMoSE thumbnail)

https://mbse2021.esa.int OSMoSE session, recorded presentations

Digital Spacecraft (https://essr.esa.int/project/digital-spacecraft)

- https://mb4se.esa.int (Digital Spacecraft thumbnail)
- White paper : White Paper on Digital Space Systems i1 r3
- User Needs: DTSC_UserNeeds_Iss1_Rev2
- Process investigation: DTSC_Process_Investigation_Iss1_Rev2

Supporting MBSE adoption in later phases

Also in ESSR:

- System factory architecture (SASyF)
  https://essr.esa.int/project/specification-and-architecture-of-a-system-factory-sasyf
- ESA SysML solution
  https://essr.esa.int/project/esa-sysml-solution

MBSE in ESA Missions Mission Overview

esa

0

concurrent design facility

COMET

Pre-Phase A (Industry)

-> esa-hre
-> esa-eop
-> ...

A/B1

saga
→ esa-tia

lunar communications and navigation services (lcns)
→ esa-tia

e.deorbit
→ clean space

adrios
→ clean space

e.inspector
→ clean space

ariel
→ esa-sci

envision
→ esa-sci

truths
→ esa-eop

argonaut (el3)
→ esa-hre

B2

earth return orbiter
→ mars sample return
→ esa-hre

galileo 2nd gen
→ esa-nav

truths
→ esa-eop

C/D

earth return orbiter
→ mars sample return
→ esa-hre

euclid
→ esa-sci

plato
→ esa-sci

ariane 6 launch system
→ esa-sts

i-hab
→ esa-hre

esprit
→ esa-hre

E

columbus
→ esa-hre

F

COMET (10-25)

Enterprise Architect (SysML)

Cameo Systems Modeler (SysML)

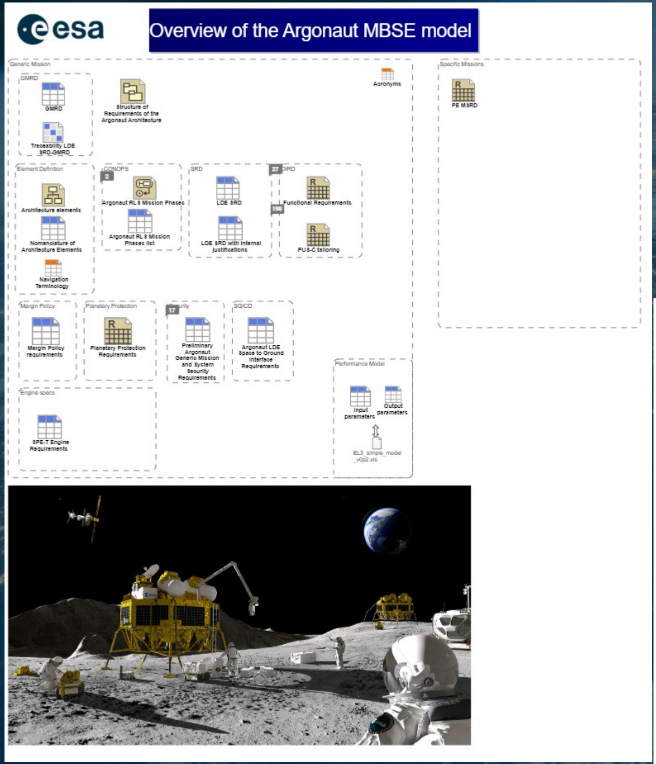
Capella

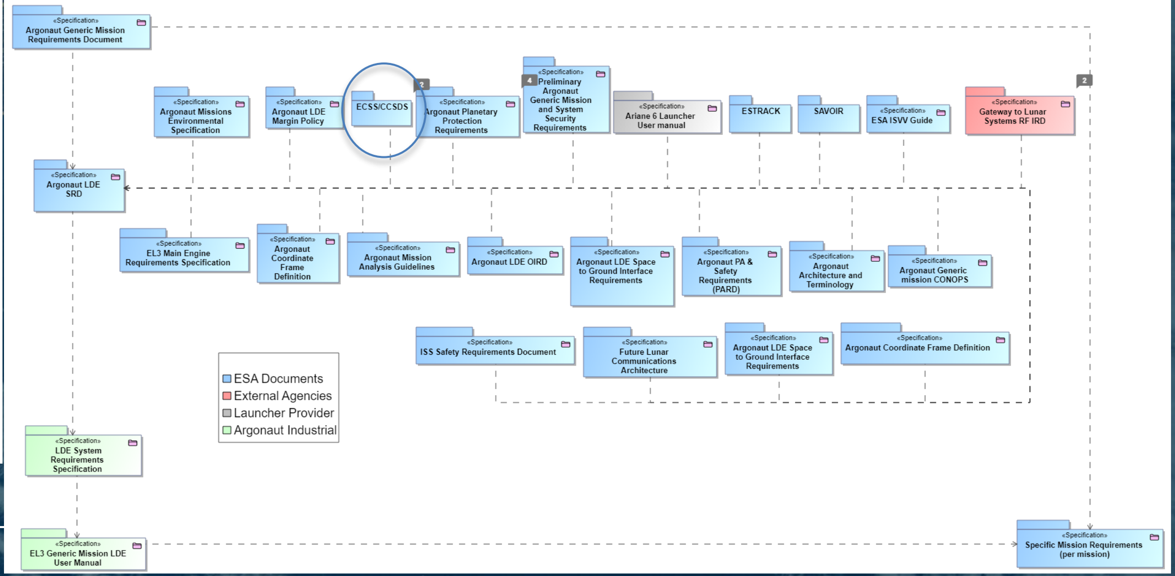
Vitech Genesys

Valispace

Example: ARGONAUT MBSE Model

- ESA requirements are managed in the MBSE tool (CSM)
- Documents are generated automatically and are used in ITTs, reviews, etc.
- The model contains the list of applicable and reference documents. ECSS are there as a link
- All ECSS are available in DOORS (downloadable)





Standardization of ESA System Requirements Documents

- Task Force on Requirements Management (RMTF) established in 2013 with representatives from ESA, national agencies and space industry including Large System Integrators (LSIs) for the **standardization of ESA System Requirements Documents**

Composition (2013)	Objectives
esa, cnes (Centre National d'Études Spatiales), ASI (Agenzia Spaziale Italiana), DLR, Thales Alenia Space (a Thales / Leonardo company), EADS Astrium, OHB, Surrey Satellite Technology Ltd, RUAG (Together ahead.), Selex ES (A Finmeccanica Company)	1. Establish **requirements management processes**, within an organization and across organizations (along the customer/supplier chain), needed to meet efficiently space projects objectives 2. Derive project **user needs** for requirements management and requirements data base exchange **3. Establish requirements for the evolution of ECSS system towards a requirements database as a reference, as opposed to a document system**

- Lessons learnt from 15+ projects considered

Generic SRD – Overview

- Initiative led by ESA Systems Department (TEC-S), with objective to:
  - Support directorates and projects in creating their own (mission-specific) SRD, starting from a reviewed baseline
  - Harmonise structure and contents of ESA System Requirements Documents
  - Facilitate handover to industry, including thanks to SRD digital model exchange (model-based)

- Key features of the Generic SRD:
  - Covering System Level (Level-1) requirements, not limited to the space segment
  - No duplication or tailoring of ECSS requirements
  - No contractor task (belong to Statement of Work)
  - No duplication of OIRD requirements for spacecraft operability

- Reviewed by Engineering Standardisation Board (ESB) panel with nominated experts and representatives from ESA directorates: DG-5X, EOP, NAV, OPS, SCI, STS, TEC, TIA

Generic SRD – Future work

- Generic SRD Issue 1.0 finalised and released to ESA Standardization Board November 2022 meeting

- Terms of Reference under approval for ESA Generic SRD governance definition → Working Group with duties to:

  - Support the handover to the project teams, including MBSE implementation, as well as tailoring process
  - Assess feedback from projects / users, including proposed evolutions
  - Assess Lessons Learnt for which Generic SRD identified as recipient
  - Monitor ECSS and other standards evolution to reflect in Generic SRD
  - Maintain and update the Generic SRD accordingly

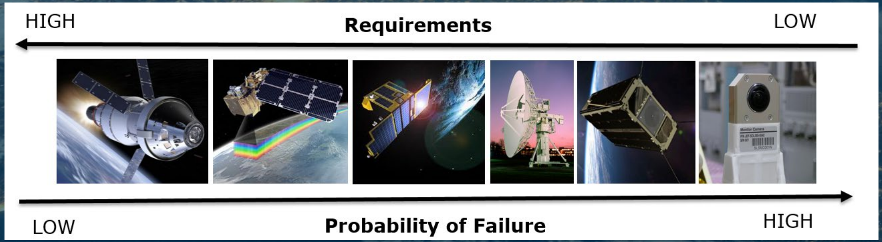
ESA Mission Classification

- During ESA Executive Board in 2019 (EB76 28/10/2019) a go-ahead was given to prepare an ESA mission classification like what is already adopted by NASA.

- A proposal for an ESA Mission Classification scheme was presented to EB in 2020 (EB96, 26/10/2020).
- In the meeting, a go-ahead was given to establish the pre-tailoring of (ECSS) requirements for each class of mission per dedicated Working Groups, and to define the implementation rules for an EB decision by Mid 2021.

BACKGROUND

- The pre-tailoring activities on ECSS Q-Branch were carried out by 5 sub Working Groups constituted of experts from application Directorates and TEC, and coordinated by a core Working Group.
- These sub Working Groups were chaired by ESA Project Managers and co-chaired by Heads of PA&S Offices, with secretarial function performed by relevant Section Heads.



- Outcome presented to ESA Project Managers Forum and to ESA Senior Programme Managers Board before and after pre-tailoring activities respectively in May and June 2021.
- Final endorsement by ESA Executive Board (DG and Directors) took place on 19 July 2021.

MAIN ASSUMPTIONS

- ESA mission classification encompasses one-off missions (man, non-manned missions), recurring operational spacecraft, IOD/IOV and CubeSats. Satellite mega-constellations and launchers are not addressed
- A specific mission class can contain units/payloads with different classes. Namely, mission class is originally defined at project/mission level, but it's possible to conceive different classes for different mission elements on-board the same S/C. Potential differentiation between critical and non-critical equipment to be addressed by the project
- More flexibility is given to industry as a function of class of the mission (highest flexibility and associated risk for class V), but also more reliance of ESA on contractor's internal processes, more simplification of the documentation and required reporting, at the cost of the less visibility given to ESA and more delegation of responsibility and of risk is given to industry
- Some insights
  - Requirements do not necessarily depend on an equipment is recurrent or not. Heritage will be reflected in equipment category defined during EQSR (Equipment Qualification Status Review)
  - For ECSS Q-Branch, ECSS fully applicable to Class I (and most of Class II)
  - Possibility to combine deliverable documents mainly for class IV and V missions
  - Security and safety (comprising space debris requirements/policy) are not subject to tailoring
  - Additional tailoring (up and down in addition to pre-tailoring) still possible at project level

ESA MISSION CLASSIFICATION TABLE

Class type	I	II	III	IV	V
Mission Criteria and Marking					
Criticality to Agency strategy (Flagship mission, Internationnal cooperation, Impact on ESA strategic goals, and image)	Extremely high Criticality	High Criticality	Medium Criticality	Low Criticality	Educational purposes
Marking					
Mission Objectives (Directorate priority and purpose, e.g in orbit demonstration, educational)	Extremely high Priority	High Priority	Medium Priority	Low Priority	Educational purposes
Marking					
Cost (Cost at Completion, Including Phase E1)	>700 M€	200 - 700M€	50 - 200M€	1- 50M€	< 1M€
Marking					
Mission Lifetime (Nominal mission life duration)	> 10 years	5-10 years	2-5 years	1-2 years	1 year
Marking					
Mission Complexity (Design interfaces unique payloads, New technology development)	High	High to Medium	Medium	Medium to Low	Low
Marking					

I. Critical strategy/safety (e.g. manned missions) (High level of requirements and low risk)

II. Performances should be met whatever it takes

III. Finding the best compromise between risk and cost to deliver the mission

IV. Mission is designed according to a hard cost limit (affordability approach)

V. Almost full delegation to industry (Minimum requirements but increased risk)

ESA MISSION CLASSIFICATION - Marking & Classification

ESA Mission: xyz

- Extremely critical to the Agency (Criticality is then Class I)
- Mission objectives considered High Priority (Objectives in Class II)
- Cost of the mission: 300 to 400 M€ (Class II)
- Mission lifetime: 7 years nominal (Lifetime is then Class II)
- Mission complexity: medium (Complexity is then Class III)

1 <= Total <= 1,5 -------- = Class I
1,5 <Total <= 2,5 -------- = Class II
2,5 < Total <= 3,5 -------- = Class III
3,5 < Total <= 4,5 -------- = Class IV
4,5 < Total <= 5 --------- = Class V

Mission Characteristics Criteria & Related Weighting Factors:	Level >>>	I	II	III	IV	V	Input Score (1/2/3/4/5)	Weighted Score
Criticality to Agency Strategy		Extremely High Criticality	High Criticality	Medium Criticality	Low Criticality	Educational Purpose		
WF (10/20/30 %):	30	x					1	0.30
Mission Objectives		Extremely High Priority	High Priority	Medium Priority	Low Priority	Educational Purpose		
WF (10/20/30 %):	20		x				2	0.40
Cost		> 700 M€	200 – 700 M€	50 – 200 M€	< 50 M€	< 1 M€		
WF (10/20/30 %):	10		x				2	0.20
Mission Lifetime		> 10 years	5-10 years	2-5 years	< 2 years	< 1year		
WF (10/20/30 %):	10		x				2	0.20
Mission complexity		High	High to Medium	Medium	Medium to Low	Low		
WF (10/20/30 %):	30			x			3	0.90
Total % (must be 100):	100						Total (*):	2.00
Legenda:				(*)			CLASS:	II

26/10/2020: ESA Mission Classification table and ranking methodology presented to and endorsed by EB (EB96)

ECSS Pre-tailoring activities

- **26/10/2020:**

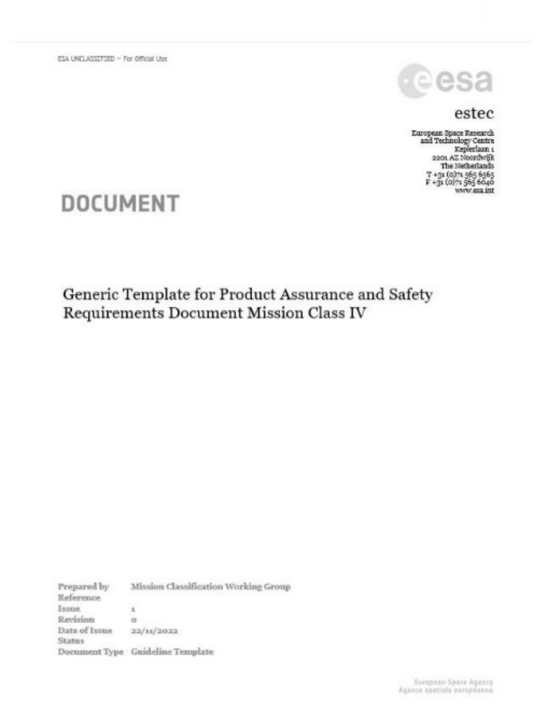
  EB (EB96) gave the go-ahead to establish the pre-tailoring of ECSS Q-Branch requirements for each class of mission per dedicated Working Groups

- **19/07/2021:**

  Final endorsement by EB of the pre-tailoring done on ECSS Q-Branch by ESA Executive Board (DG and Directors) and **approval to start ECSS-E Branch standards pre-tailoring**

- **07/2022-Today:**

  - ESA Mission Classification Q-branch pre-tailoring completed (SW PA, M&P for class V on-going)
  - 4 new PARDs + PARD for Class I (which already existed as the only template before now) made available to ESA project volunteering to use it
  - **ECSS-E branch pre-tailoring in progress**



ESA UNCLASSIFIED – For Official Use

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www.esa.int

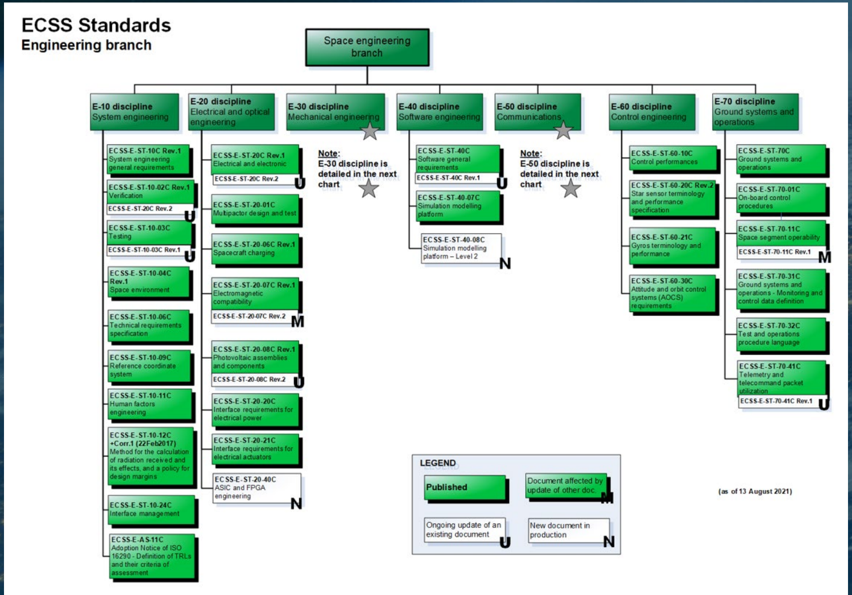
DOCUMENT

Generic Template for Product Assurance and Safety Requirements Document Mission Class IV

Prepared by	Mission Classification Working Group
Reference	
Issue	1
Revision	0
Date of Issue	22/11/2022
Status	
Document Type	Guideline Template

European Space Agency
Agence spatiale européenne

ECSS E-Branch Pre-tailoring – Work in progress



19/07/2021: ESA Executive Board (DG and Directors) authorization to start ECSS E-Branch standards pre-tailoring

E-Branch pre-tailoring activities KO on 12.2021 and aims to be completed by mid 2023

Sub-WGs as well as standards to be tailored confirmed based on selection criteria proposed by D/TEC (to start with most relevant E-Branch ECSS standards in terms of cost and "time" savings)

TEC-S	TEC-E	TEC-M
ECSS-E-ST-10-03C Testing	**ECSS-E-ST-20C Rev.2** Electrical and Electronic	**ECSS-E-ST-31C** Thermal Control **ECSS-E-ST-32C Rev. 1** Structural general requirements **ECSS-E-ST-32-01C Rev. 2** Fracture Control

Statistics post Tailoring

Class Percentages % With TOTAL	Class I			Class II			Class III			Class IV			Class V		
	A	M	N	A	M	N	A	M	N	A	M	N	A	M	N
ECSS-Q-ST-10C Rev.1	100%	0%	0%	95%	4%	2%	73%	15%	13%	9%	31%	60%	0%	29%	71%
ECSS-Q-ST-10-04C	100%	0%	0%	100%	0%	0%	100%	0%	0%	2%	6%	92%	0%	4%	96%
ECSS-Q-ST-10-09C Rev. 1	100%	0%	0%	100%	0%	0%	100%	0%	0%	13%	12%	75%	0%	1%	99%
ECSS-Q-ST-20C Rev.2	100%	0%	0%	100%	0%	0%	95%	0%	5%	24%	14%	62%	7%	13%	80%
ECSS-Q-ST-20-08C	100%	0%	0%	100%	0%	0%	100%	0%	0%	8%	6%	86%	5%	6%	89%
ECSS-Q-ST-20-10C	100%	0%	0%	100%	0%	0%	85%	5%	9%	29%	5%	66%	11%	14%	75%
ECSS-Q-ST-30C Rev.1	96%	1%	3%	95%	1%	4%	89%	2%	9%	54%	5%	41%	28%	7%	65%
ECSS-Q-ST-60-13C Rev.1	97%	2%	1%	97%	2%	1%	94%	2%	3%	73%	12%	15%	18%	13%	69%
ECSS-Q-ST-60C Rev. 3	94%	4%	1%	93%	5%	1%	92%	6%	2%	67%	12%	21%	20%	11%	69%
ECSS-Q-ST-60-15C	86%	9%	5%	86%	7%	7%	72%	21%	7%	60%	21%	19%	52%	24%	25%
ECSS-Q-ST-80C Rev.1	100%	0%	0%	100%	0%	0%	97%	2%	1%	97%	2%	2%			
TOTAL	**98%**	**1%**	**1%**	**97%**	**2%**	**1%**	**91%**	**5%**	**5%**	**40%**	**12%**	**49%**	**14%**	**12%**	**74%**

A	M	N
Applicable	Modified	Not Applicable

- There are only very few differences between Class I and Class II
- Class III still presents a high number of applicable requirements (91%)
- The most important tailoring is seen for Class IV and Class V where, respectively, about 60% and 86% of requirements are modified or not applicable
- Class III remains an “in-between” class, e.g. between a “standard” ESA -type missions (Class I, Class II) and a “NewSpace” type mission (Class IV, Class V) for which it is difficult to find a good tailoring balance from a risk perspective. It is proposed that for Class III, the majority of the tailoring is left to the project, based on the areas they decide should be monitored more or less closely, depending on the project specific risks

ESA Mission Classification implementation plan

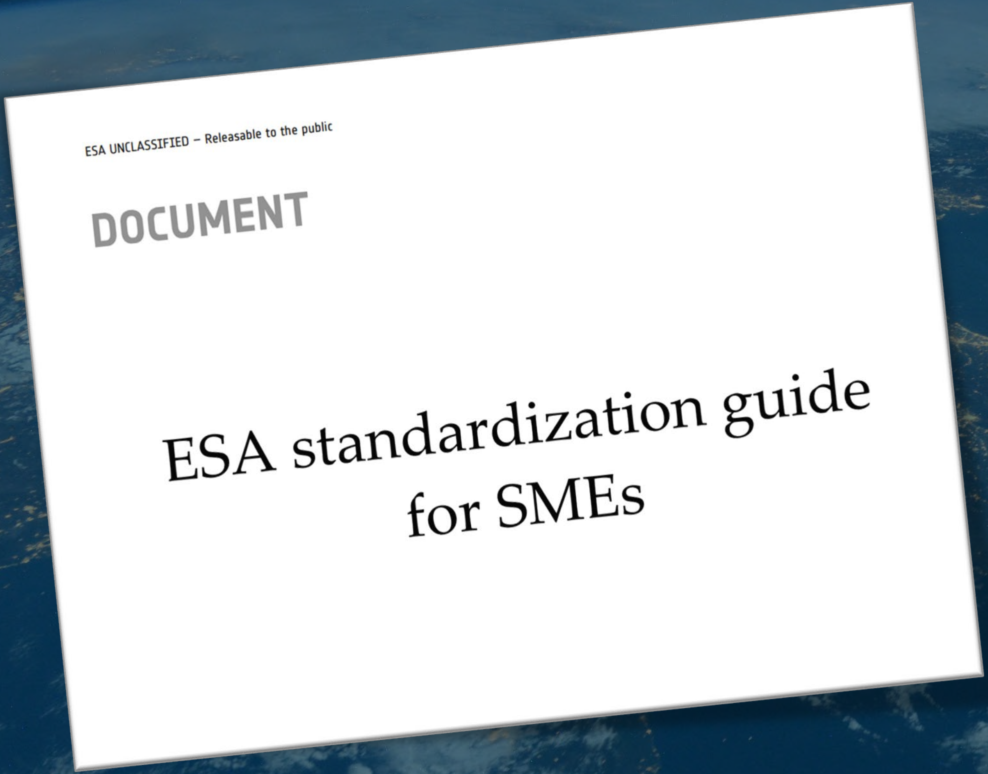
- On 19 July 2021 ESA Executive Board also decided to:
  - Endorse the ESA Mission Classification Plan which proposed to identify the class of a new mission very early in the project (phase A, e.g. it is adopted in CDF) but in all cases should be revisited and, if necessary updated, by the project team as part of the Preliminary Project Plan (PPP) presented at IPrev (prior to publishing ITT for phase B2/C/D/E1)
  - Recommended to develop associated training/awareness material
  - Advise to communicate externally (delegations, industry, etc.) on the ESA Mission Classification

Class type	Class I	Class II	Class III	Class IV	Class V
Mission Examples	ERO JUICE MTG Argonaut	PROBA III FLEX VIGIL ARIEL TRUTHS SENTINEL 2	FORUM CHEOPS Comet-I HARMONY MicroGeo	AWS SCOUTS Probe B2 on COMET-I GOMX-5 M-ARGO GX-5	YPSat

Useful references

- ECSS
  - http://www.ecss.nl
- Systems Engineering Body of Knowledge
  - http://sebokwiki.org/
- ISO/IEC 15288, Systems and software engineering — System life cycle processes
  - http://en.wikipedia.org/wiki/ISO/IEC_15288
- NASA/SP-2007-6105 Rev1, NASA Systems Engineering Handbook
  - http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008301.pdf
- International Council on Systems Engineering (INCOSE)
  - http://www.incose.org
- INCOSE / OMG Model Based Systems Engineering (MBSE) Initiative
  - http://www.omgwiki.org/MBSE/doku.php

Back-Up


ESA UNCLASSIFIED – Releasable to the public

DOCUMENT

ESA standardization guide for SMEs

Correspondence between ESA contract and ECSS documentation

- Vast majority of the documents required by ESA/REG/001 Annex IV to accompany any tender are also required by ECSS Standards.
- Large overlapping between the contract requirements, and the requirements in ECSS.
- Larger overlapping with standards in the S and M branches, but in a lower extent, also with some few requirements in E10 (System engineering) and some Q (product assurance) standards.
- Table 4-4 is a comparison between the documentation requirements in a generic response to an ITT, and the corresponding ones in the S and M standards.

* As it can be seen, most of the requirements in the S and M branches are also required by the contract itself.

Table 4-4: Correlation between the requirements in the ESA General Condition of Tender and the requirements in ECSS

Table 4-4: Correlation between the requirements in the ESA General Condition of Tender and the requirements in ECSS

	#	Requirement	General conditions of tender (ESA/REG/001 Annex IV)	Standards
ITT	1.	Preparation by the customer of a SRD/PRD, as a result of tailoring, and including a tailoring or applicability matrix	#A.5 (The draft contract of the ITT)	ECSS-S-ST-00C, # 9.2 & Annex A ECSS-M-ST-10C(R1), #5.1.2
TECHNICAL PROPOSAL	2.	Specification tree	Annex B (Technical proposal)	ECSS-E-ST-10C, #5.2.3.1c & Annex J
	3.	Mission assessment	Annex B (Technical proposal)	ECSS-E-ST-10, #5.3.1a
	4.	System analysis & system budget	Annex B (Technical proposal)	ECSS-E-ST-10C, # 5.3.1a
	5.	System budget	Annex B (Technical proposal)	ECSS-E-ST-10C, # 5.4.1.2a & Annex I
	6.	Concept of design	Annex B (Technical proposal)	ECSS-E-ST-10C, #5.3.3c & Annex C
	7.	Design definition (mech., electr., …)	Annex B (Technical proposal)	ECSS-E-ST-10C, # 531c, 5.3.1f, 5.4.1.1b, 5.4.1.4a & Annex G
	8.	Integration & test logic	Annex B (Technical proposal)	----
	9.	Operations logic	Annex B (Technical proposal)	----
	10.	GSE	Annex B (Technical proposal)	----
	11.	Technical requirement compliance matrix	Annex B (Technical proposal)	ECSS-S-ST-00C # 9.3 & Inf. Clause 7
	12.	Cost drivers	Annex B (Technical proposal)	----
	13.	Critical path	Annex B (Technical proposal)	ECSS-M-ST-60C, #8.1b
	14.	Identification of other critical developments & contingencies	Annex B (Technical proposal)	----
	15.	TRL	Annex B (Technical proposal)	ECSS-E-ST-10C
	16.	Identification of risk factors <<25>>	Annex B (Technical proposal)	ECSS-M-ST-80C, #7.2.4a
	17.	PA/QA/safety aspects	Annex B (Technical proposal)	Single point failure
MANAGEMENT & ADMINISTRATIVE PROPOSAL	18.	Project management Plan (PMP)	Annex C.A (Management & admin proposal)]	ECSS-M-ST-10C(R1), #5.1.3a & Annex A
	19.	Configuration management plan (CMP)	Part of the PMP	ECSS-M-ST-40C(R1) Annex A
	20.	Cost & Schedule Management Plan (CSMP)	Part of the PMP	Part of the PMP
	21.	ILS approach	Part of the PMP	Part of the PMP
	22.	Risk management policy and plan (RMPP)	Part of PMP	ECSS-M-ST-80C, Annexes A & B
	23.	SRD/PRD to the lower tier suppliers NOTE: This req makes <<1>> recursive	Annex C.B (Management & admin proposal)]	ECSS-S-ST-00C, # 9.2 & Annex A ECSS-M-ST-10C(R1), #5.1.2
	24.	Evidence of subcon compliance with reqs above	Part 3.D.1.ii	----
	25.	Project organization breakdown structures, referred to the WBS	Annex C.C (Management & admin proposal)	ECSS-M-ST-10C(R1) #5.2 & Annex A (part of the PMP)
	26.	Key personnel	Par 3 D.2 (2nd bullet)	----
	27.	Geo and company breakdown (Country/Company grouping CCG)	Annex C.D	ECSS-M-ST-60C, #9.2.6a, 9.3.5a & Annex E
	28.	Business agreement structure (BAS) or Contract structure	Annex C.E	ECSS-M-ST-60C, 7.1.2a & b

Summary of the requirements in ECSS-E-ST-10 "System engineering"

Table 9-1: Summary of the requirements in ECSS-E-ST-10 "System engineering"

Clause & Req			Requirements subject	DRD (Annex)	Supporting guidance
5.1 SE plan			SE plan (SEP)	Annex D	Clause 4
5.2 Requirement engineering	5.2.1		Derivation of requirements. Consistency and robustness	E-ST-10-06 Ann A	E-ST-10-06
	5.2.2		Up and down requirements traceability		
	Process	5.2.3.1	Technical spec (-> *E-ST-10-06*)		
		5.2.3.2 – 5.2.3.8	Consolidation, analysis, verification & validation and maintenance of requirements		
		5.2.3.9	Requirement baseline, to be established		
5.3 Analysis	5.3.1 System analysis		In phase 0, Analyse MSD to produce an **MDD (mission def. doc)**	Annex B	
			Functional analysis to produce a **Function Tree**	Annex H	
			Produce a **DDF**, and justify it in a **DJF**	Annexes G&K	
			Produce physical architecture and the Product Tree (-> *M-ST-10*)	M-ST-10 Ann B	
			All analysis documented in an Analysis report	Annex Q	
	5.3.2 Environment		Establishment of the environment(s), qualification&acceptance criteria, design&test factors and margins, account for design induced effects		
	5.3.3 trade-off analysis		Perform trade-off for: system concept, design, processes, make-or-buy, technologies, architecture, CIs, planning, verification methods		
			Document all **trade-off reports**	Annex L	
			Alternative system concepts, in the **System Concept Report**	Annex C	
	5.3.4		Methods tools & models, in the SEP, and validated & maintained	Part of the SEP	
5.4 Design & configuration	Design	5.4.1.1	Establish the design (incl. interfaces,-> *E-ST-10-24*)		
		5.4.1.2	Establishment and apportioning of **Technical budgets**	Annex I	
			Margin policy	Part of the SEP	
		5.4.1.3	Design methods, tools & models	Part of the SEP	
	Configur.	5.4.2.1	Configuration coverage (physical, functional, SW, I/F, budgets, lower level), to be included in DDF		
		5.4.2.2	Configuration baseline, under configuration control		
		5.4.2.3	Definition of the Assembly hierarchy and sequence		
5.5 Product verification			Verification performed i.a.w. -> *E-ST-10-02*		
			Verification to cover all product (HW, SW, MITL, Ops, scenarios)		
5.6 SE Integration and control	5.6.1		General requirements on management of SE activities		
			Make compatible the SEP and project schedule		
			Engineering data: ensure exchange and define repository		
			Interfaces i.a.w. -> *E-ST-10-24*		
			Coordinate system, to be defined in the SEP i.a.w. -> *E-ST-10-09*	Part of the SEP	
			Technology plan management & technology maturity -> *E-ST-11*	Annex E	E-HB-11
			SE contribution to risk management		

CI = Configuration item	I/F = Interface	MITL = Man-in-the-loop	SEP = System engineering plan
HW = Hardware	SW = Software	DDF = Design definition file	DJF = Design justification file