

ECSS E-10

System Engineering Standards

Presented by
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ESA

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& Hans-Peter de Koning (ESA)

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

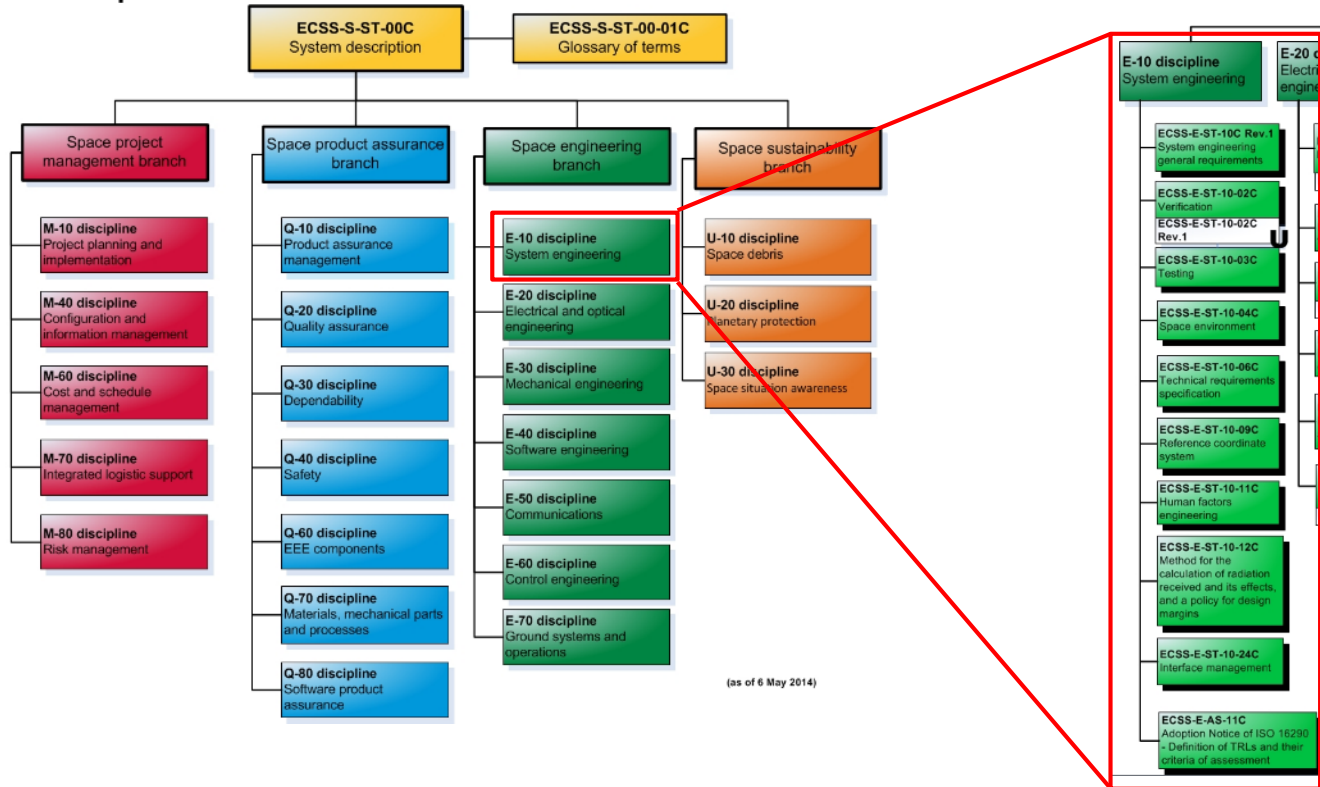
- Q&A

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- 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
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- 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
- Useful references

Where to find our standards?

ECSS Disciplines



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
	ESSB-HB-E-002-Issue1	Guidelines for the use of TRLs in ESA programmes	21/aug/13
	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		Testing	01/jun/12
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>

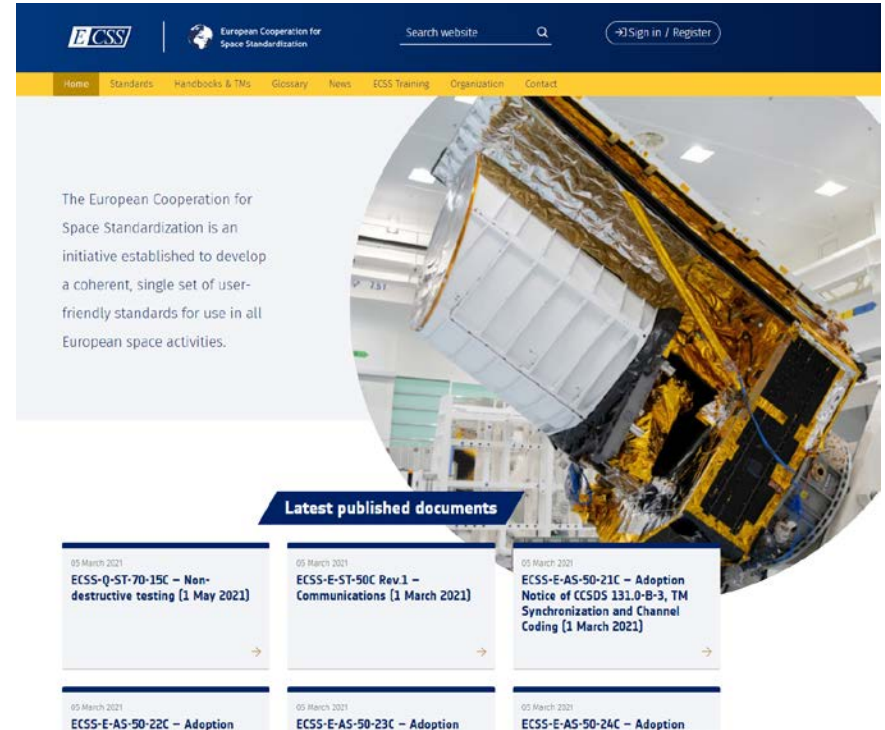
On the web

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.

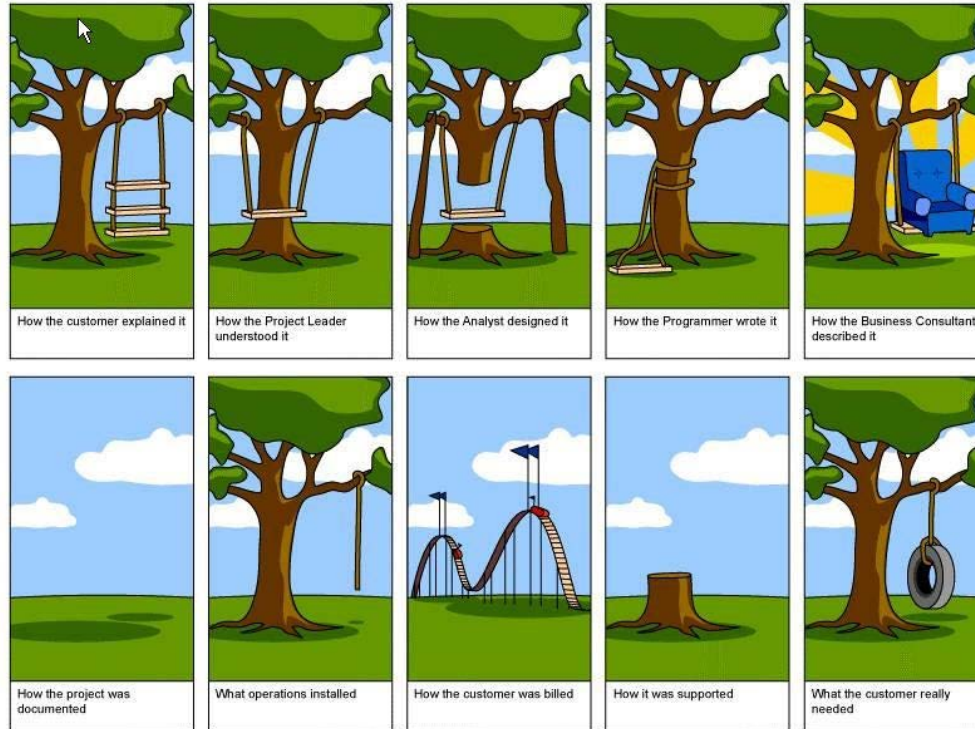
The ECSS is managed by **the ESA Requirement and Standard Division**, based in ESTEC in Noordwijk, the Netherlands. The ECSS maintains connections with multiple European and international standardization organizations, to contribute to standardization and to adopt relevant standards as part of the ECSS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



The screenshot shows the ECSS website interface. At the top is a dark blue header with the ECSS logo and the text 'European Cooperation for Space Standardization'. To the right of the header is a search bar and a 'Sign in / Register' button. Below the header is a yellow navigation bar with links for Home, Standards, Handbooks & TMs, Glossary, News, ECSS Training, Organization, and Contact. The main content area features a large circular image of a satellite in a cleanroom. To the left of the image is a text block: 'The European Cooperation for Space Standardization is an initiative established to develop a coherent, single set of user-friendly standards for use in all European space activities.' Below this is a section titled 'Latest published documents' with a grid of six document cards. Each card displays the date '05 March 2021', the document title, and the adoption date in parentheses. The titles are: 'ECSS-Q-ST-70-15C - Non-destructive testing (1 May 2021)', 'ECSS-E-ST-50C Rev.1 - Communications (1 March 2021)', 'ECSS-E-AS-50-21C - Adoption Notice of CCSDS 131.0-B-3, TM Synchronization and Channel Coding (1 March 2021)', 'ECSS-E-AS-50-22C - Adoption', 'ECSS-E-AS-50-23C - Adoption', and 'ECSS-E-AS-50-24C - Adoption'. Each card has a right-pointing arrow at the bottom right.

<https://ecss.nl/>

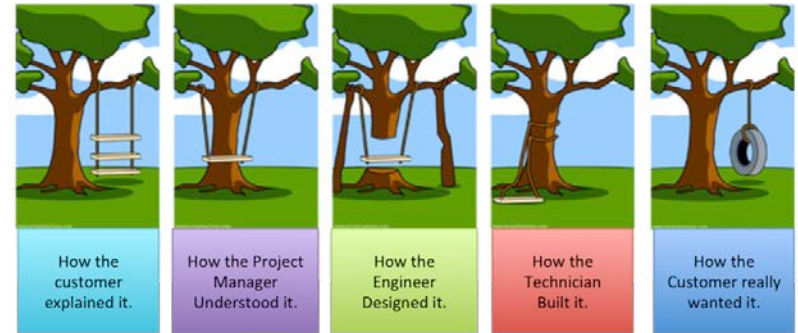
Why do we have standards?



To ensure that what is needed gets delivered

- Requirements **set the scope** of: 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** and then it is recommended a cross-functional team working
- It is **necessary to establish a method to elicit and make explicit all the requirements to assure they do not remain hidden**
- Requirements are stated at different levels following this order:
 - Business Requirements
 - Service Requirements
 - Technical Requirements, iteratively refined through all the layers of the System Architecture



General Background

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]

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

Space System Decomposition

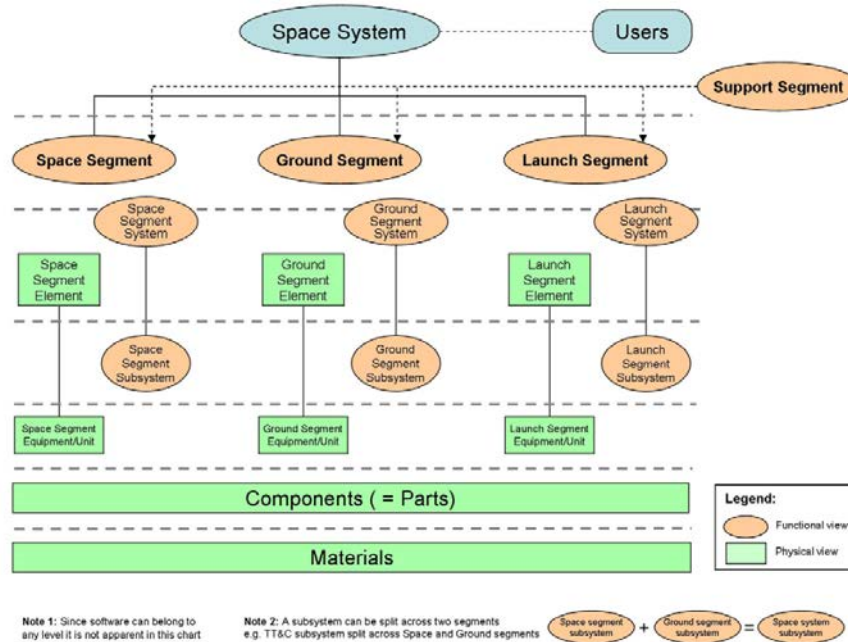
Space System: “system that contains at least a space, a ground or a launch segment”

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 fulfills a major, self-contained, subset of the **space mission objectives**”

Four main kinds:

Space, Ground, Launch, Support



Functional vs Physical views

Background – ECSS-S-ST-00-01C

Space System Decomposition

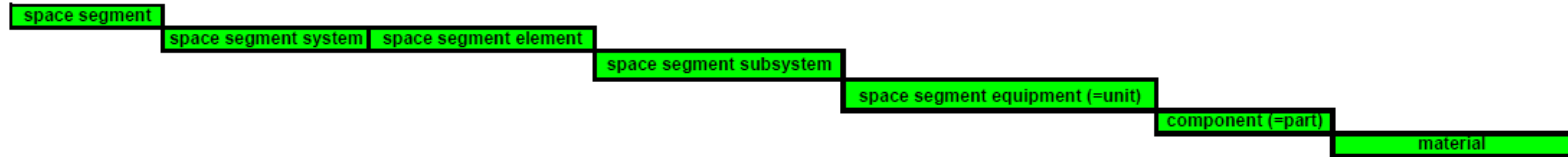
Functional view	Physical view
function: “intended effect of a product ”	product: “implements a function” <i>Note:</i> There are four generic product categories: services, software, hardware, processed materials
system: “set of interrelated or interacting functions constituted to achieve a specified objective”	element: “combination of integrated equipment, components and parts ”
subsystem: “part of a system fulfilling one or more of its functions ”	equipment: “integrated set of parts and components ” <i>Synonym:</i> unit
	component: “set of materials , assembled according to defined and controlled processes , which cannot be disassembled without destroying its capability and which performs a simple function that can be evaluated against expected performance requirements ” <i>Synonym:</i> 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					
Data Relay Satellite System	spacecraft (physical view)	power	electronic unit (e.g. DHU, PCSU, PDU, ASIC ICU)	Aluminium	
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

Glossary

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

Search glossary

Branch Discipline Type

Popular terms

① model factor (NM)	ECSS-E-ST-32-10C Rev2 Cont1	→	① transient	ECSS-Q-ST-30-11C Rev1	→
① source component	ECSS-E-ST-40-07C	→	① array antenna	ECSS-E-ST-20C Rev1	→
① lane	ECSS-C-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

→ [Search the online Glossary](#)



Download ECSS eGlossary App
Android | iOS



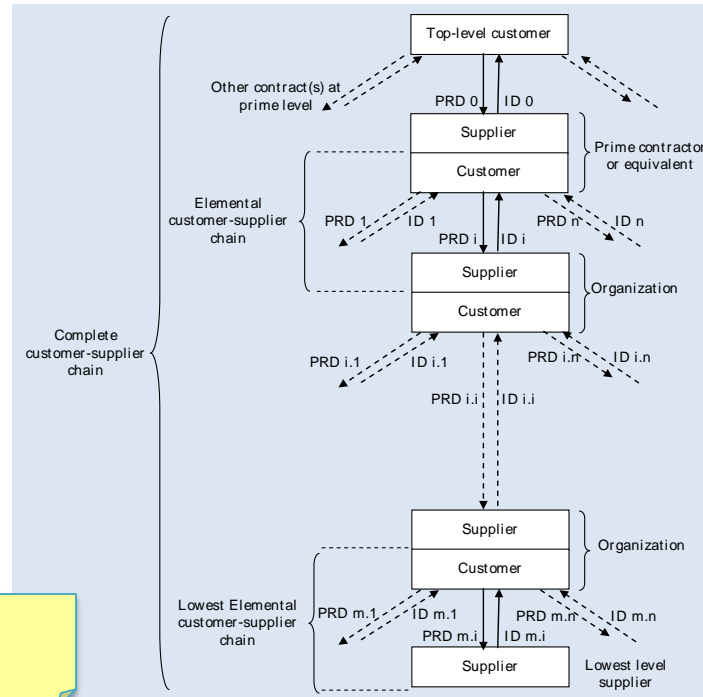
Microsoft Office Word Plugin
[Download plugin](#)

Background – ECSS-S-ST-00C

The Customer-Supplier Model

- **Customer** and **Supplier** are roles played by the **Actors** 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"

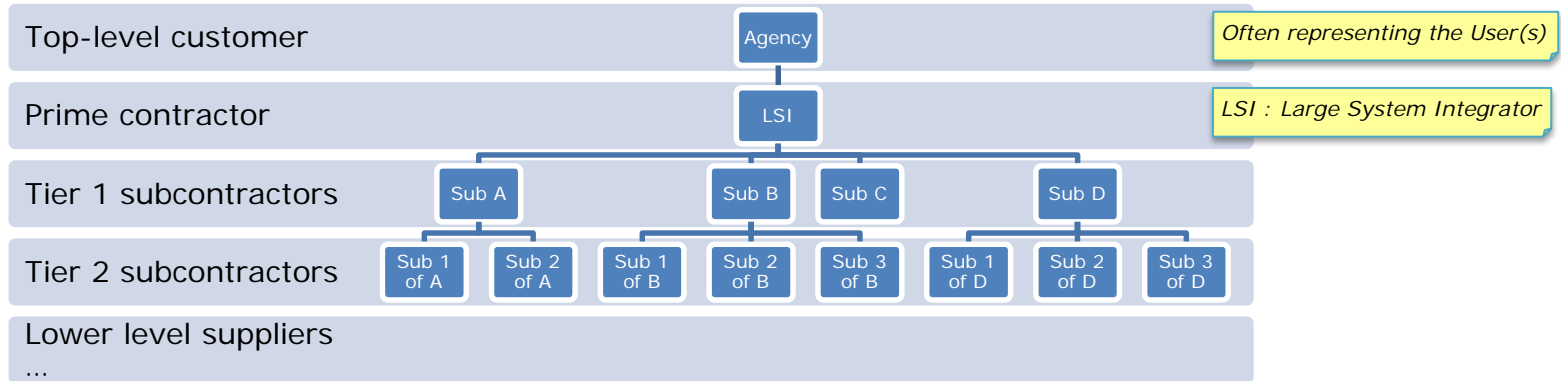


Background – ECSS-S-ST-00-01C

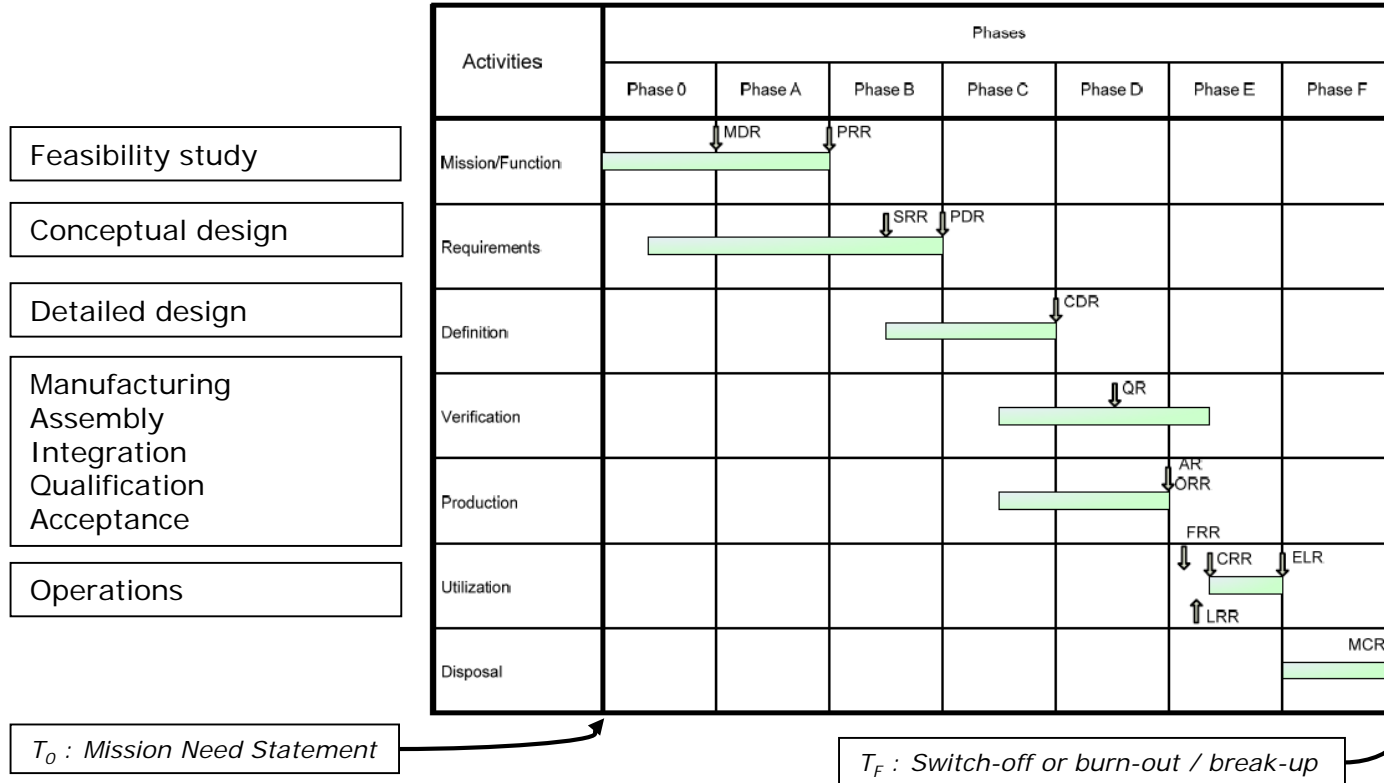
The Customer-Supplier Model



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



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



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.

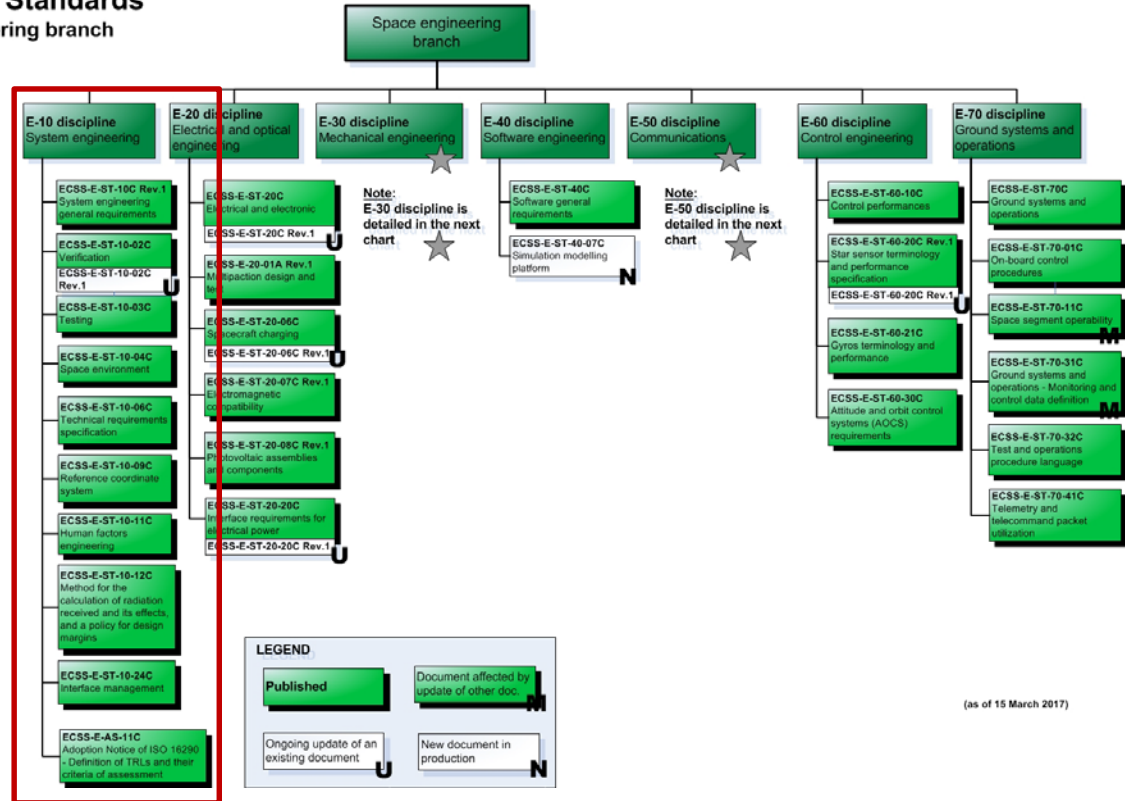
- Several categories of documents to be used at system level in ESA projects
 - ECSS E-10 Standards
 - ECSS E-10 Handbooks
 - ECSS E-10 Technical Memoranda
 - ISO (for debris mitigation and TRL definitions)
 - ESSB Handbooks (e.g. ESSB-HB-E-003 ESA pointing error engineering handbook)

E-10 Discipline Sub-branch

ECSS Standards Engineering 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

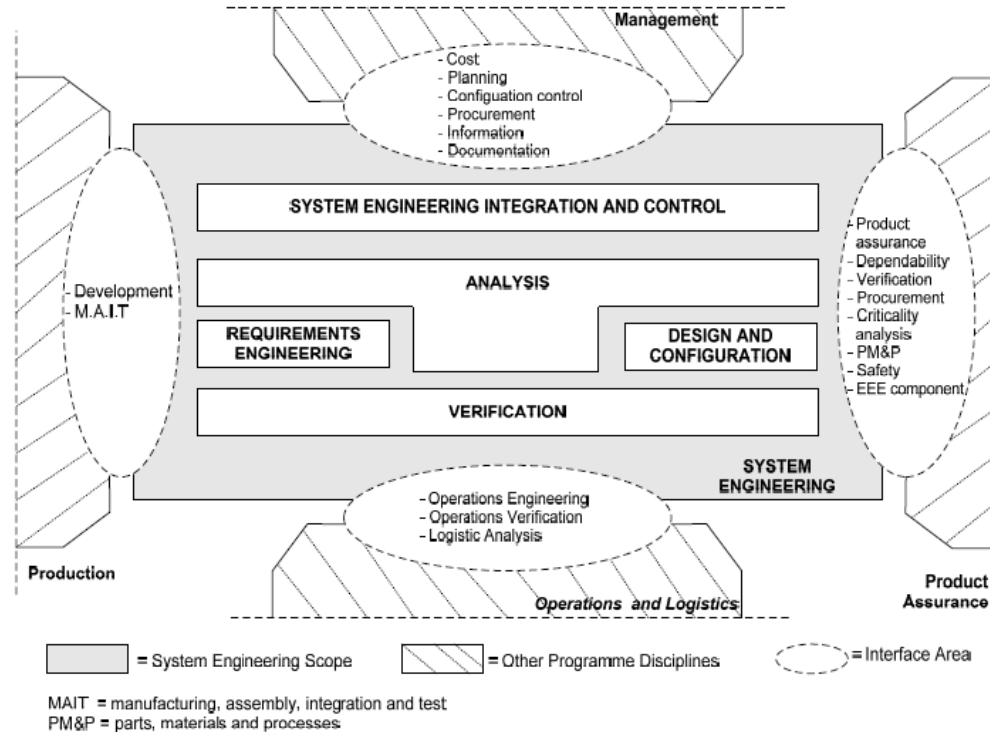
System Engineering E-ST-10C

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 **not** 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.

ECSS-E-ST-10C

System Engineering Functions (Fig. 4-1)

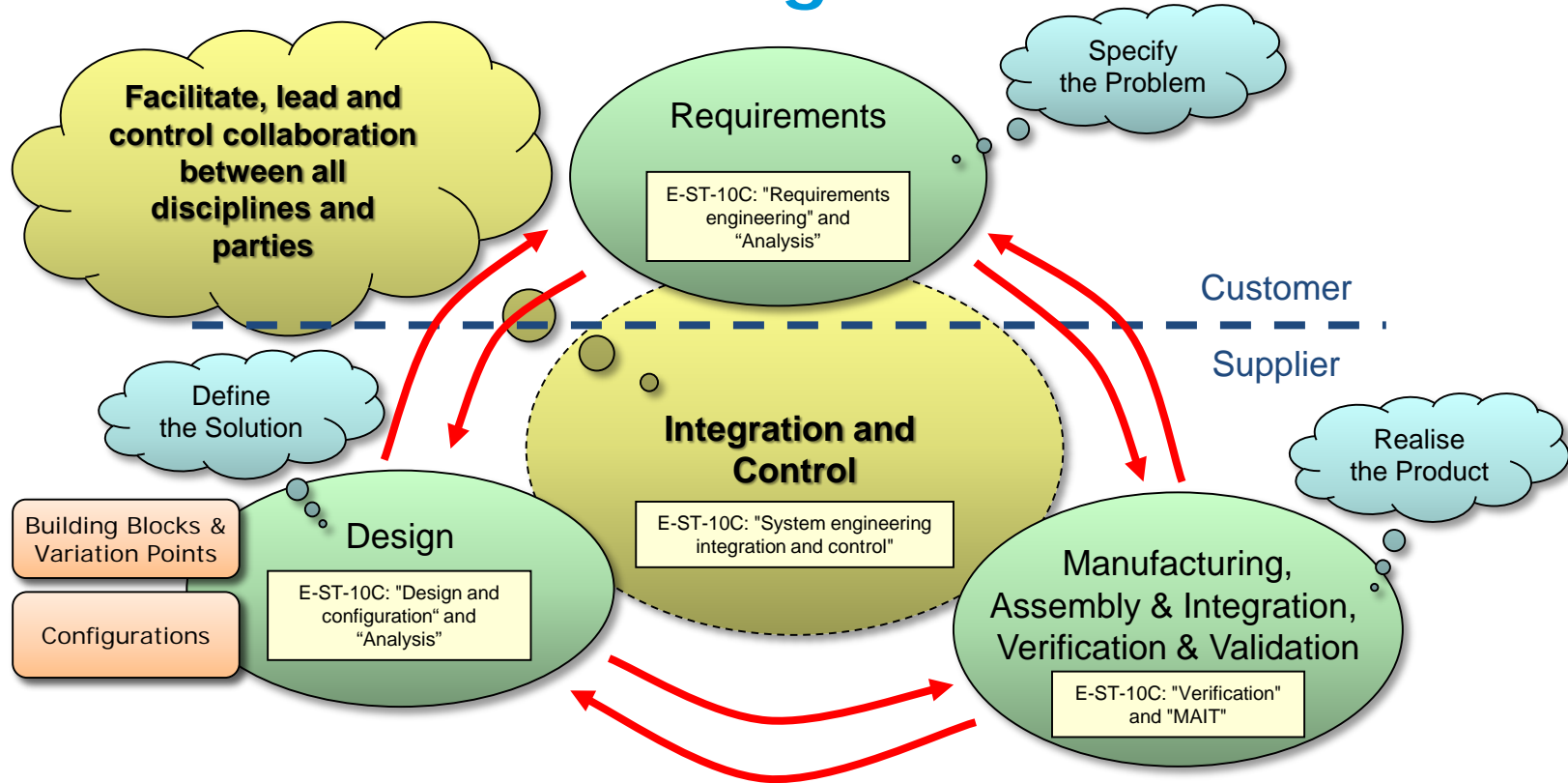


ECSS-E-ST-10C

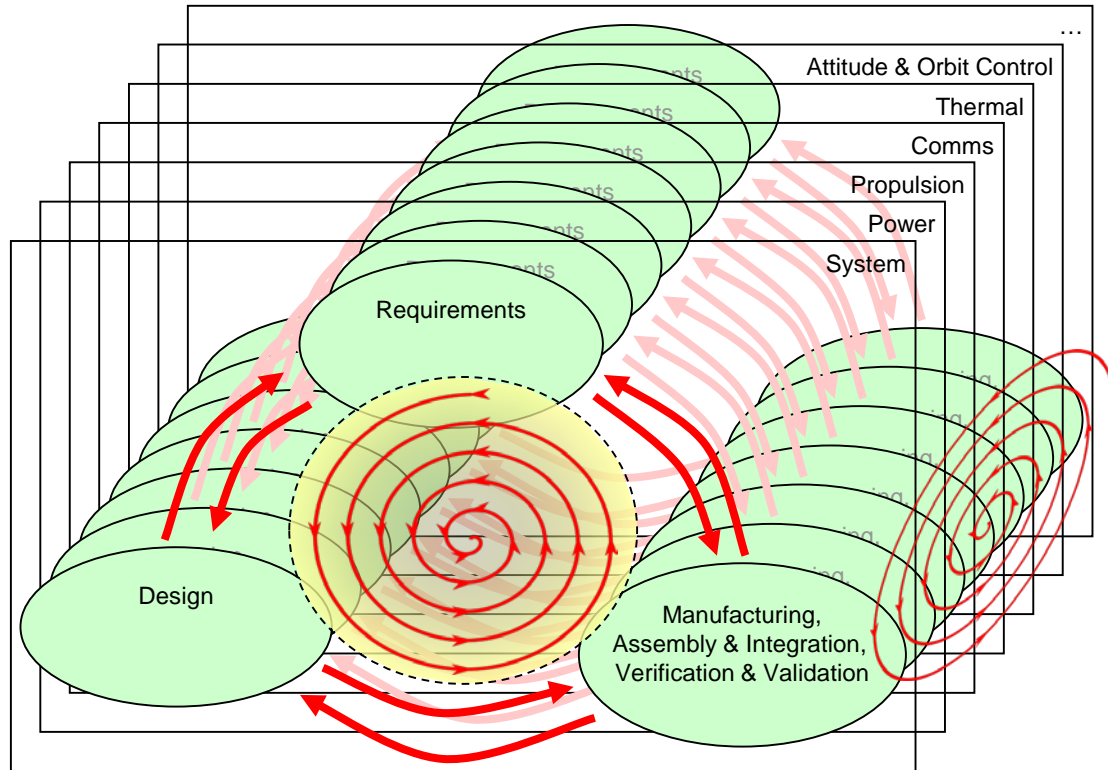
System Engineering Functions Summary

Functions	Tasks
Requirements Engineering	<ul style="list-style-type: none">• Elicit, write, organise, flow-down and maintain requirements• Validate top-level requirements with users (in Phase 0)
System Analysis	<ul style="list-style-type: none">• 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	<ul style="list-style-type: none">• Elaborate system design and configurations• Define and manage interfaces
Verification	<ul style="list-style-type: none">• Define and perform product verification• Ensure that the verification is successfully closed out at each stage
Integration and Control	<ul style="list-style-type: none">• 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"

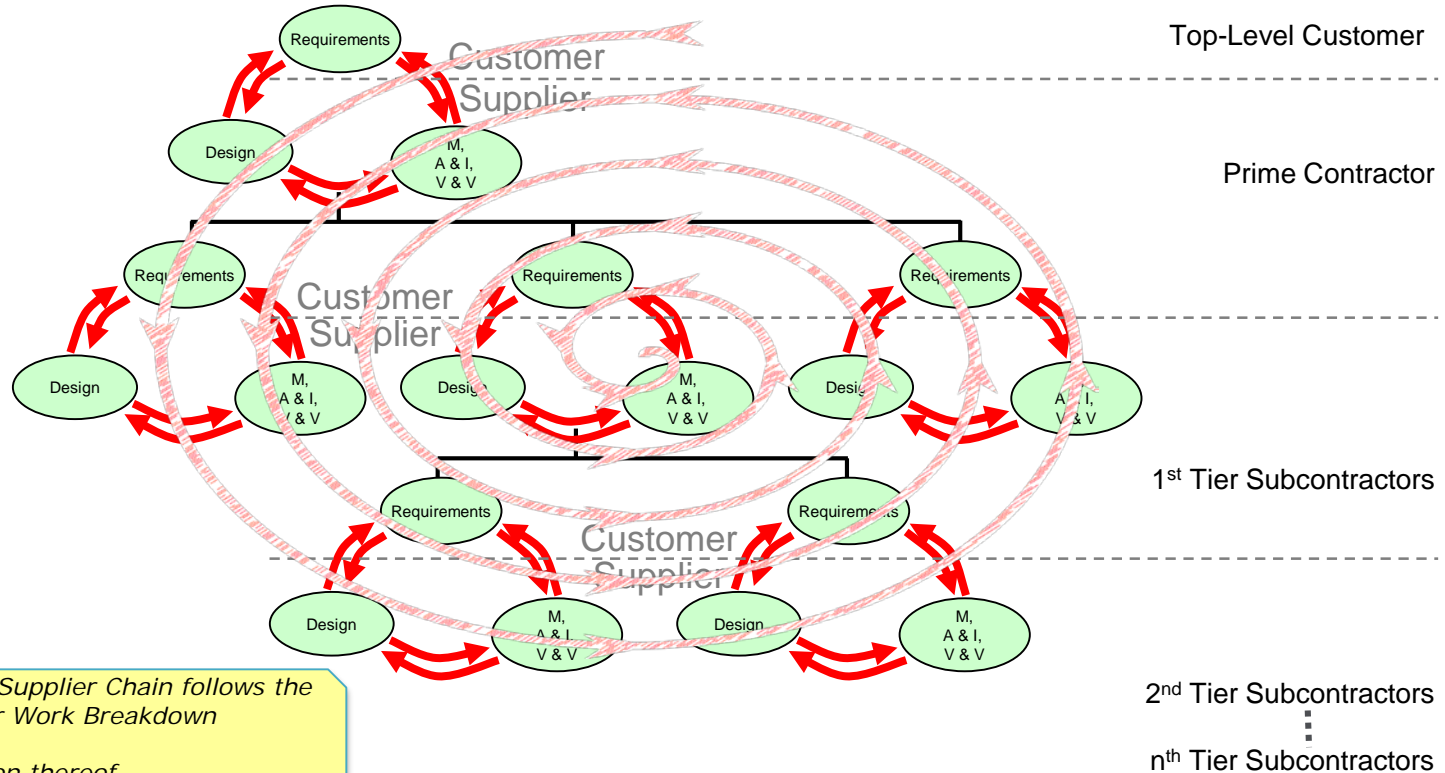


ECSS-E-ST-10C: Iterative “Integration and Control”



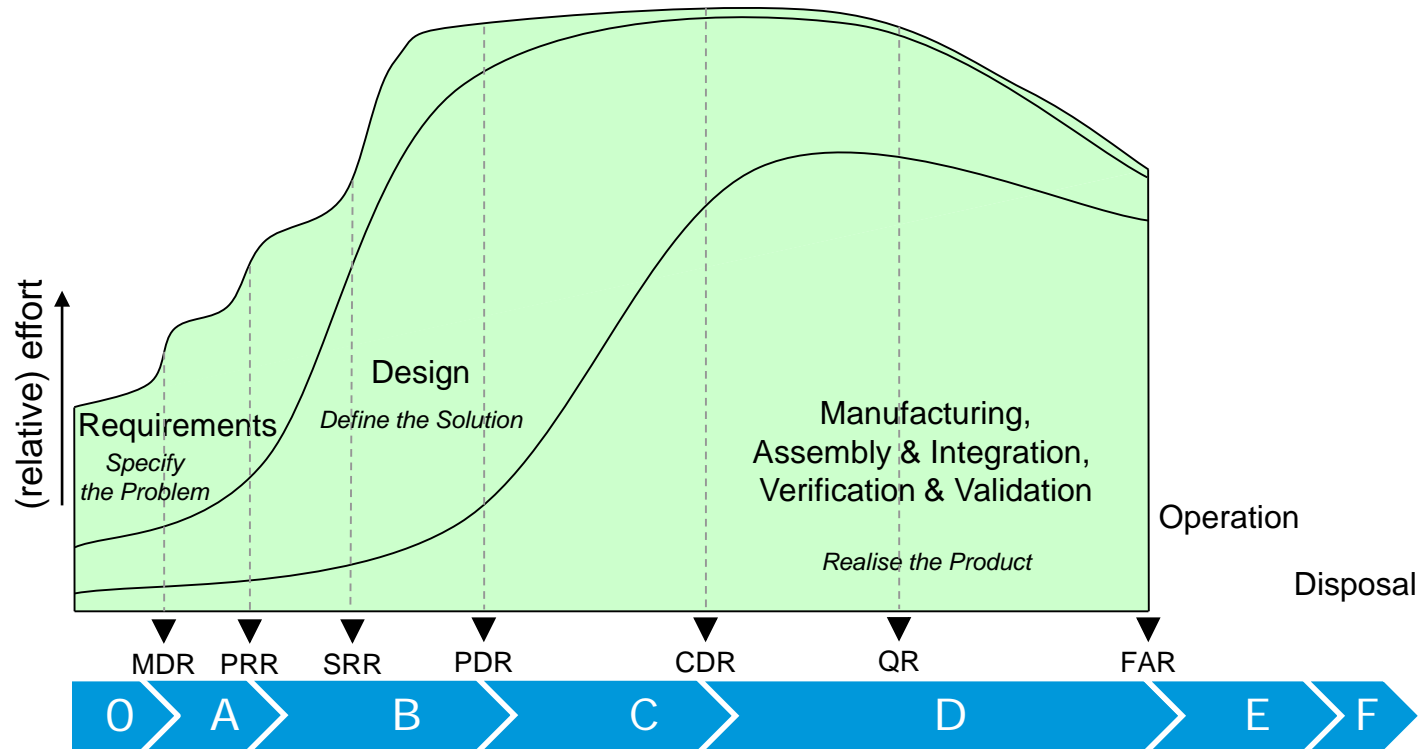
- Integration and Control (possibly concurrently in early phases)
- Iterate between
 - Requirements,
 - Design,
 - MAIV&V
- Iterate across Disciplines

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” Effort 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):

<i>Requirement types</i>	<i>Responsible</i>	<i>Content</i>	<i>Document Name</i>
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

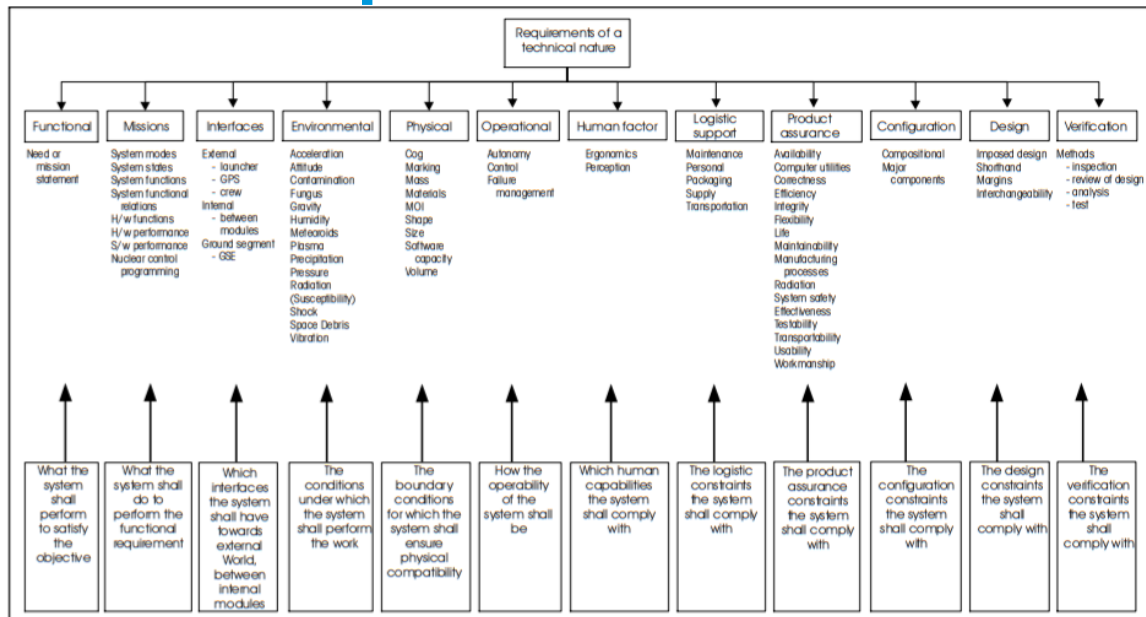


Figure 4: Space system requirement types

ECSS-E-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

Requirements

“Technical Requirements Specification”

- 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 an extent the Prime’s System Specification**
- **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

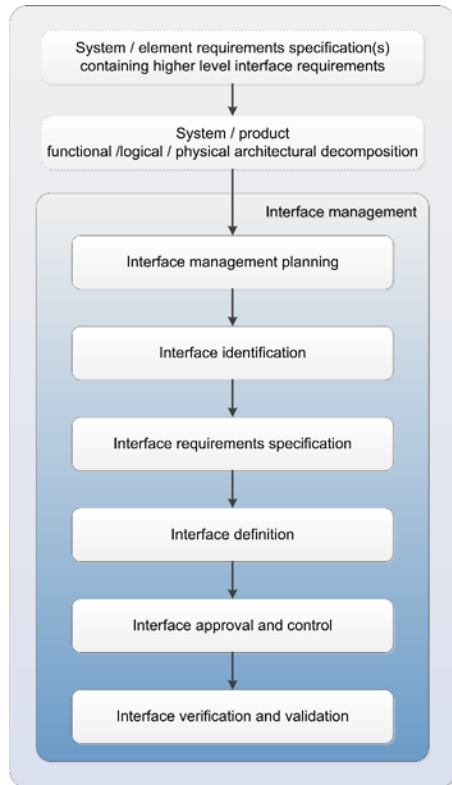
ECSS-E-ST-10-06C Annex A – DRD Technical Requirements Specification (TS)

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

Interface management

"Interface Management"



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

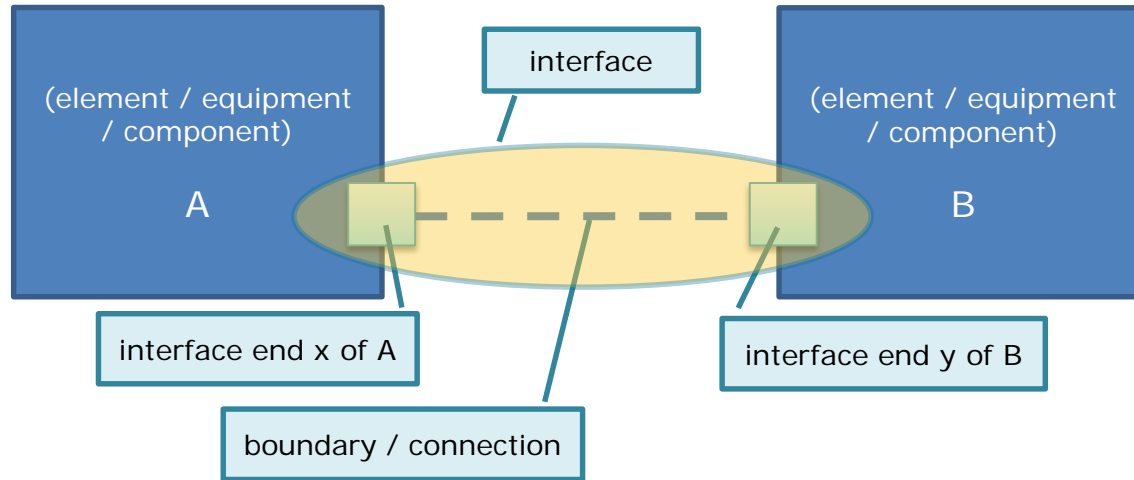
- "Interface" consists of two or more "Interface Ends" plus the connection between them

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.

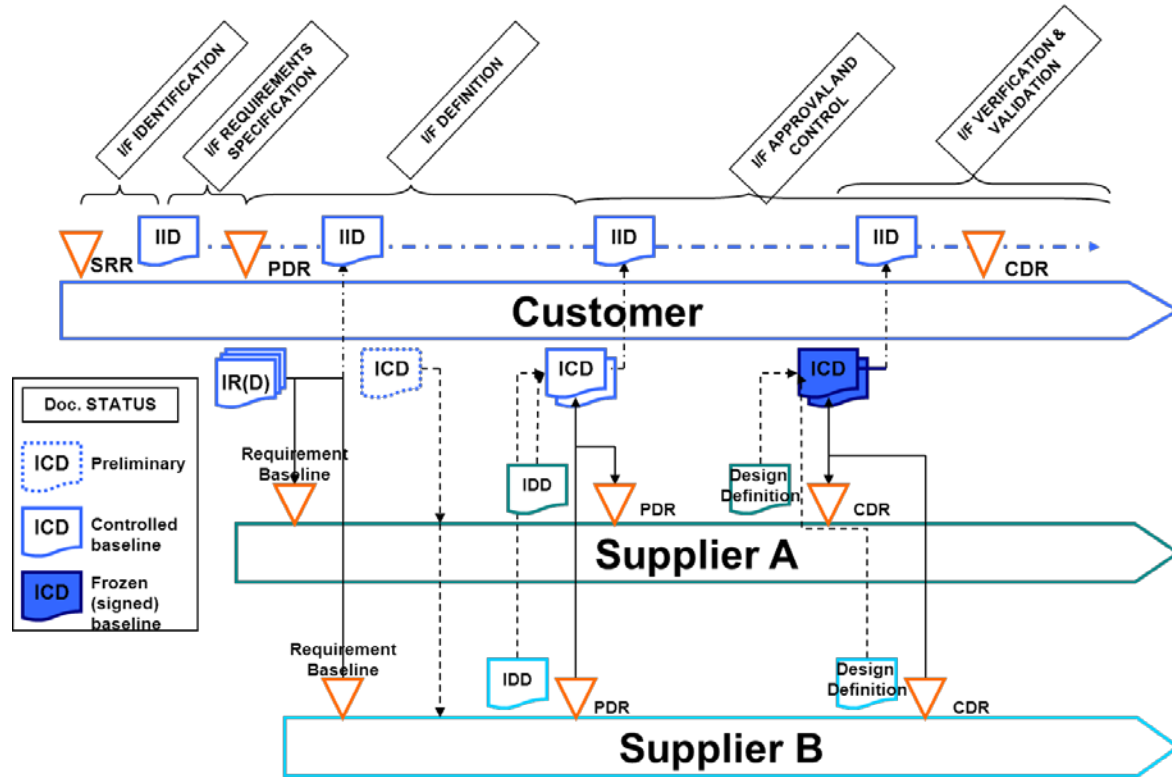
ECSS-E-ST-10-24C

“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



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

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

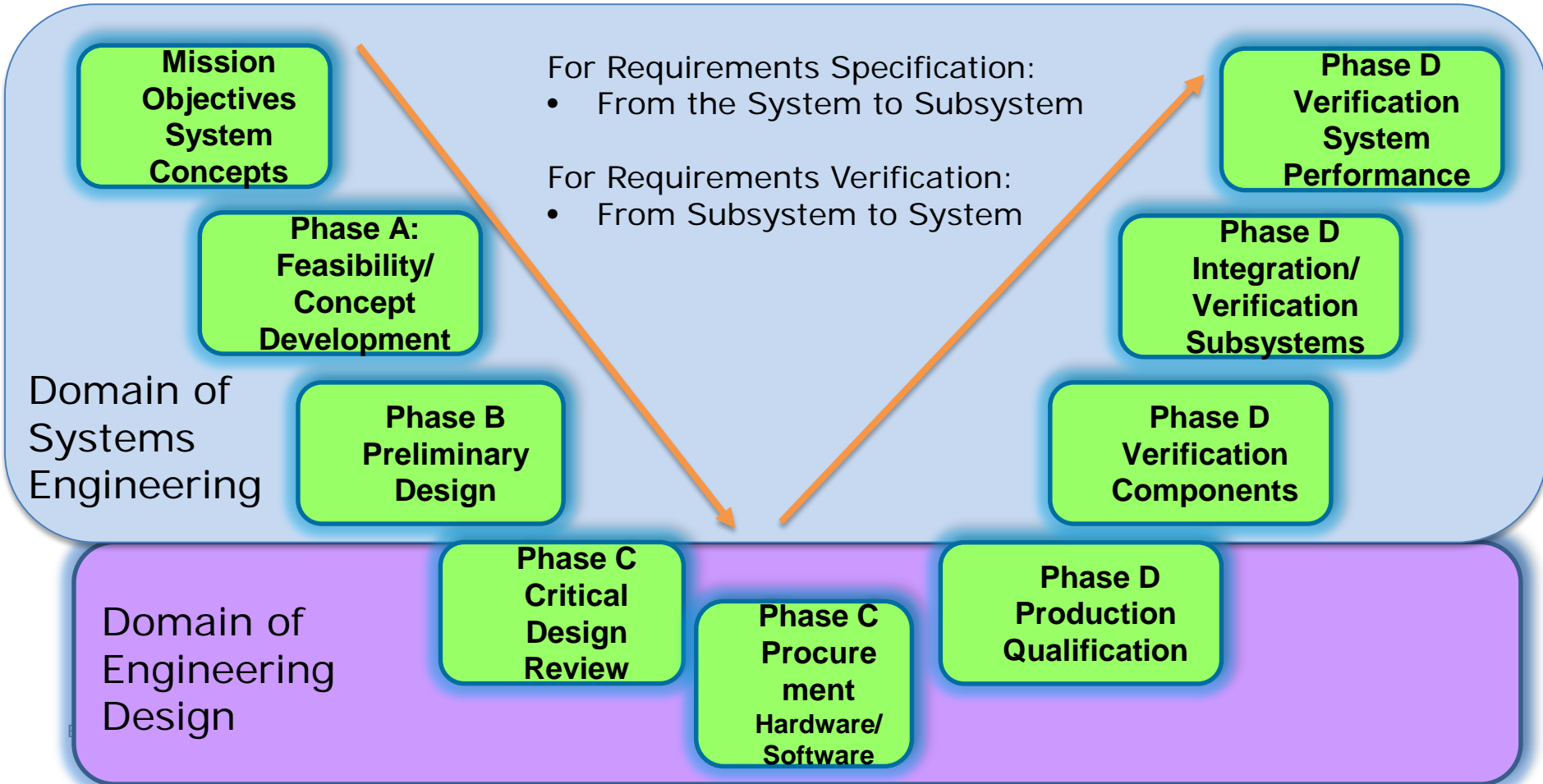
- **Qualification** - to verify the design according to project requirements;
- **Acceptance** – to ensure that the product is in agreement with the qualified design, is free from workmanship defects and acceptable for use
- **Commissioning** – verification and validation activities conducted after the 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



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).

ECSS-E-ST-10-02C

Product Category (for re-use)

Category	Description	Qualification programme
A	Off-the-shelf product without modifications and <ul style="list-style-type: none">subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment andproduced 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)	<ul style="list-style-type: none"> I/F layout optimization/assessment Integration procedure validation Accommodation checks 	<ul style="list-style-type: none"> Geometrical configuration Layouts Interfaces 	System/element levels	<p>According to their representativity MU's are classified as:</p> <ul style="list-style-type: none"> Low fidelity High fidelity (to be maintained under configuration control)
Development Model (DM)	Confirmation of design feasibility	<ul style="list-style-type: none"> Total conformity with functional electrical & S/W req. in agreement with verif. objectives (size, shape & I/Fs could not be representative) 	All levels	<ul style="list-style-type: none"> Development testing Sometime it is also called breadboard (BB)
Structural Model (SM)	<ul style="list-style-type: none"> Qualification structural design Validation of structural mathematical model 	<ul style="list-style-type: none"> Flight standard with respect to structural parameters Equipment structural dummies 	<ul style="list-style-type: none"> 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)	<ul style="list-style-type: none"> Qualification of thermal design Validation of thermal mathematical model 	<ul style="list-style-type: none"> Flight standard with respect to thermal parameters Equipment thermal dummies 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> SM & ThM representativity Equipment thermo structural dummies 	System level	Qualification testing



ECSS-E-ST-10-02C

Model Descriptions (2/3)



Suitcase Model	Simulation of functional & RF performances	<ul style="list-style-type: none"> Flight design Commercial parts Functional representability 	<ul style="list-style-type: none"> Equipment level System level 	Space to ground interface testing
Electrical and Functional Model (EFM)	<ul style="list-style-type: none"> Functional development S/W development Procedure validation Prepare flight test programme Closed loop tests 	<ul style="list-style-type: none"> Functional representability Commercial parts Simulators of missing parts 	All levels	<ul style="list-style-type: none"> Development or qualification testing It could be considered something in between a mock-up and an EM Sometime is called also Integration Model
Engineering Model (EM)	Functional qualification failure survival demonstration & parameter drift checking	<ul style="list-style-type: none"> Flight representative in form-fit-function without high reliability parts and usually without redundancy 	All levels	Partial functional qualification testing
Engineering Qualification Model (EQM)	<ul style="list-style-type: none"> Functional qualification of design & I/Fs EMC 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Full flight design & flight standard 	<ul style="list-style-type: none"> Equipment level SS level 	Qualification testing
Life test Model (LTM)	Qualification of lifetime	<ul style="list-style-type: none"> Flight representative with respect to the qualified function 	Equipment level	<ul style="list-style-type: none"> Model for mechanisms in a protoflight approach with lifetime requirements Can not be used for flight

ECSS-E-ST-10-02C

Model Descriptions (3/3)



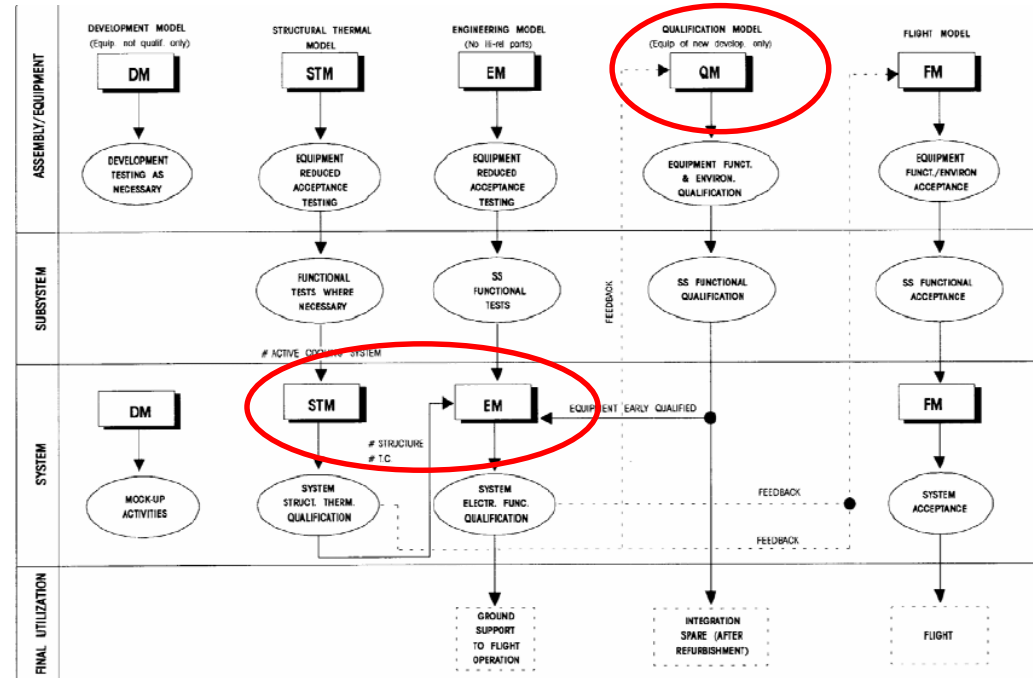
Protoflight Model (PFM)	<ul style="list-style-type: none"> • Flight use • Design qualification 	Full flight design & flight standard	All levels	Protoflight qualification testing
Flight Model (FM)	Flight use	Full flight design & flight standard	All levels	Acceptance testing
Flight Spare (FS)	Spare for 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	<ul style="list-style-type: none"> • 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 objectives	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.

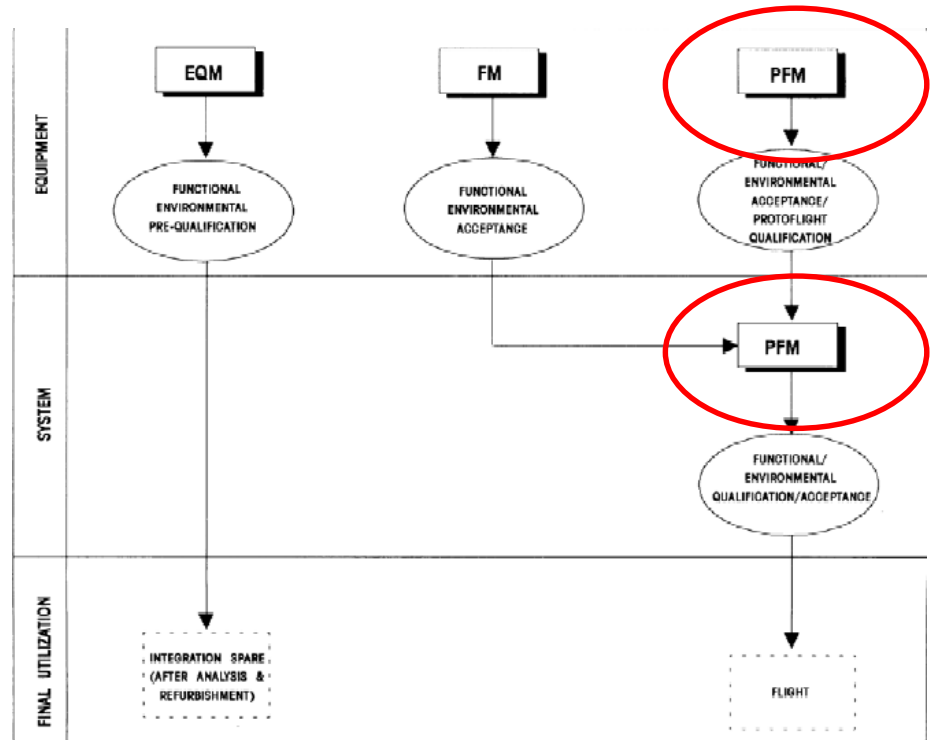


Prototype and Proto-Flight verification approaches (2/2)

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

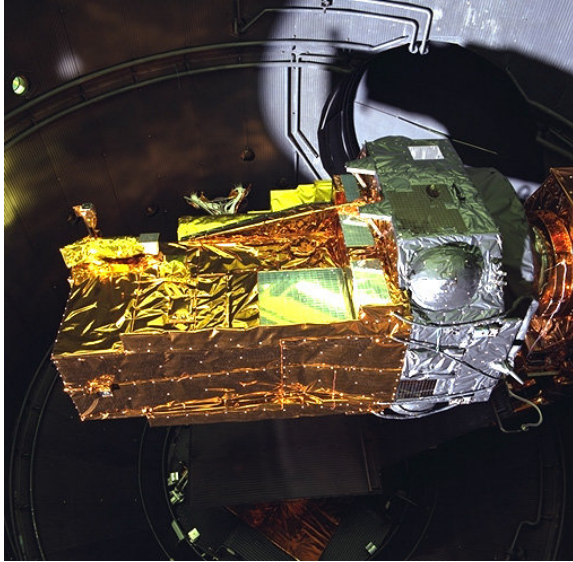
Pro's		Con's	
Prototype	Proto-Flight	Prototype	Proto-Flight
Lower risk (issues discovered early on different model from flight)	Lower Cost (single model)	Higher Cost (additional model)	Higher risk to discover issues (too) late in lifecycle
Possibility to refurbish QM as spare	Shorter development schedule	Longer schedule	More complex spares approach
Possibility to use the QM or training, operations, etc.			No further model available for operations, troubleshooting, etc.
<p>➤ The cost and schedule savings of the Proto-Flight approach often overrules all other considerations</p>			
<p>➤ Proto-Flight approach is ideal for "standard" missions with high degree of recurrent equipment</p>			

Proto-Flight practical approach

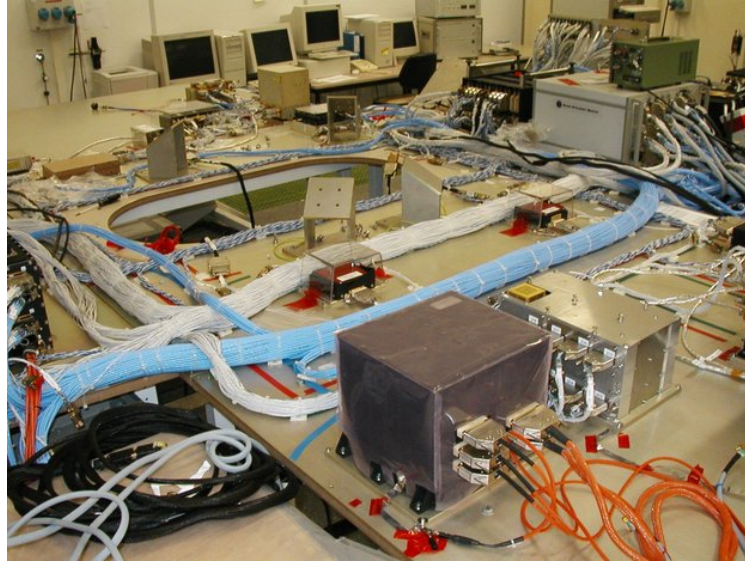
- Generally, **risk mitigation** for Proto-Flight Approach consists of:
 - enhancing development testing,
 - increasing the design margins
 - using design tools with high degree of confidence and validation (whenever possible)
 - implementing an adequate spare policy.

- 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	OBDAH						
	• 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 demonstrate that the deliverable product meets the specified customer requirements and is capable of sustaining its operational role through:	No	No	No	No	No	No	No	No	No	No
1. Verification planning;										
2. Verification execution and reporting;										
3. Verification control and close-out.										
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:	No	No	No	No	No	No	No	No	No	No
1. test (including demonstration);										
2. analysis (including similarity);										
3. review-of-design;										
4. inspection.										
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

Testing

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**
 - 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	
	Low	High
1. Temperature	Low High	
above 80K	$T_{min} -0/-4 K$	$T_{max} -0/-4 K$
$T < 80 K$	Tolerance to be defined case by case	
2. Relative humidity	$\pm 10 \%$	
3. Pressure (in vacuum chamber)		
> 1.3 hPa	$\pm 15 \%$	
1.3 10 ⁻³ hPa to 1.3hPa	$\pm 30 \%$	
< 1.3 10 ⁻³ hPa	$\pm 80 \%$	
4. Acceleration (steady state) and static load	-0 / +10 %	
5. Sinusoidal vibration		
Frequency (5 Hz to 2000 Hz)	$\pm 2 \%$ (or ± 1 Hz whichever is greater)	
Amplitude	$\pm 10 \%$	
Sweep rate (Oct/min)	$\pm 5 \%$	
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.	$\pm 10 \%$	
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	$\pm 10 \%$	

Test parameters	Tolerances	
Forces or torque	$\pm 10 \%$	
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	$\pm 4 \%$ of the set value	
in reference volume	$\pm 6 \%$ of the set value	
11. Infrared flux		
Mean value	$\pm 3 \%$ 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
- Try to 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

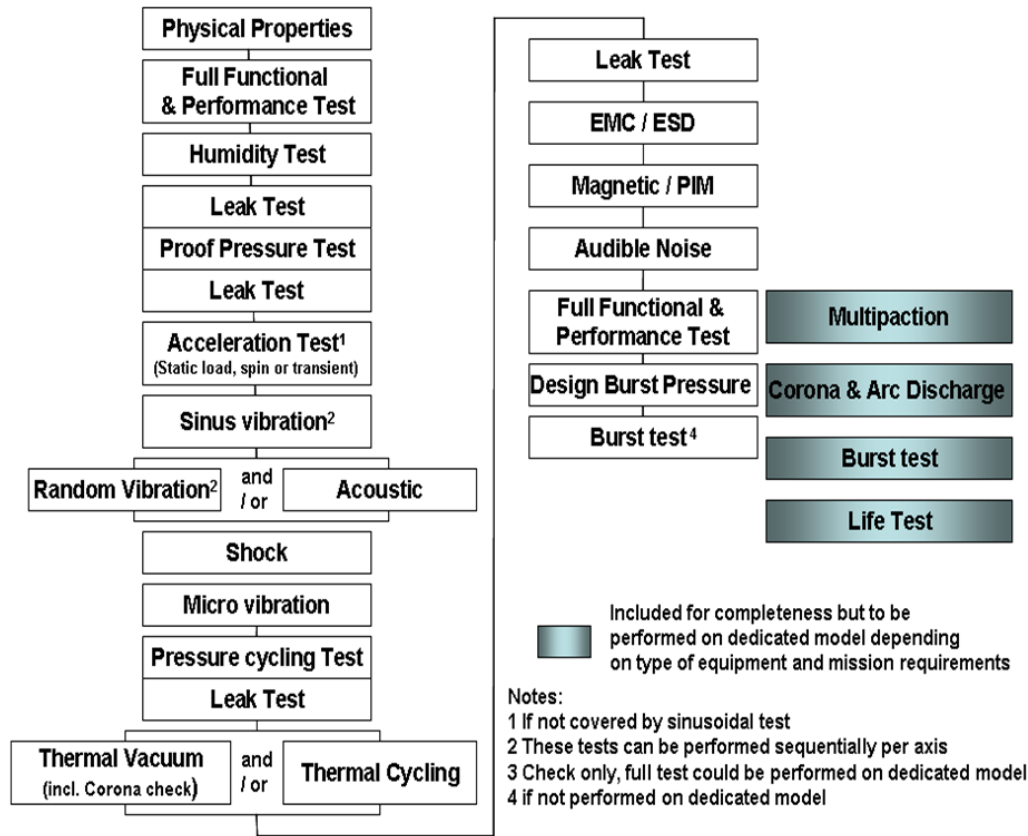


Figure 5-1: Space segment equipment test sequence

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	X	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	R	-	-	-	-	
Design burst pressure	5.5.3.4	See Table 5-2 No 13	X	-	-	R	R	R	R	R	-	-	-	-	
Burst	5.5.3.5	See Table 5-2 No 14	X	-	-	R	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	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	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	X
Magnetic	5.5.5.2		X	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	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 Mol is not measured by test, but calculated.	
Static load			-	-	-	-	X	-	-	-	-	-	-	-	General structural proof higher level test (e.g. s	
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 m 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), acc second FM) can be om testing at space segmen	
Sinusoidal vibration	5.5.2.5	See Table 5-4 No 3	-	-	-	-	-	-	-	-	R	-	-	For k (solar array), sine (from the second FM) acceptance testing at s 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		
Structural integrity																
Leak	5.5.3.1	See Table 5-4 No 5	X	-	R	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	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	R	X	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	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 / EFT)	6.5.1.2		R	
Performances (PT)	6.5.1.3		R	
Mission (MT)	6.5.1.4		R	
Polarizy	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	
PDM	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:

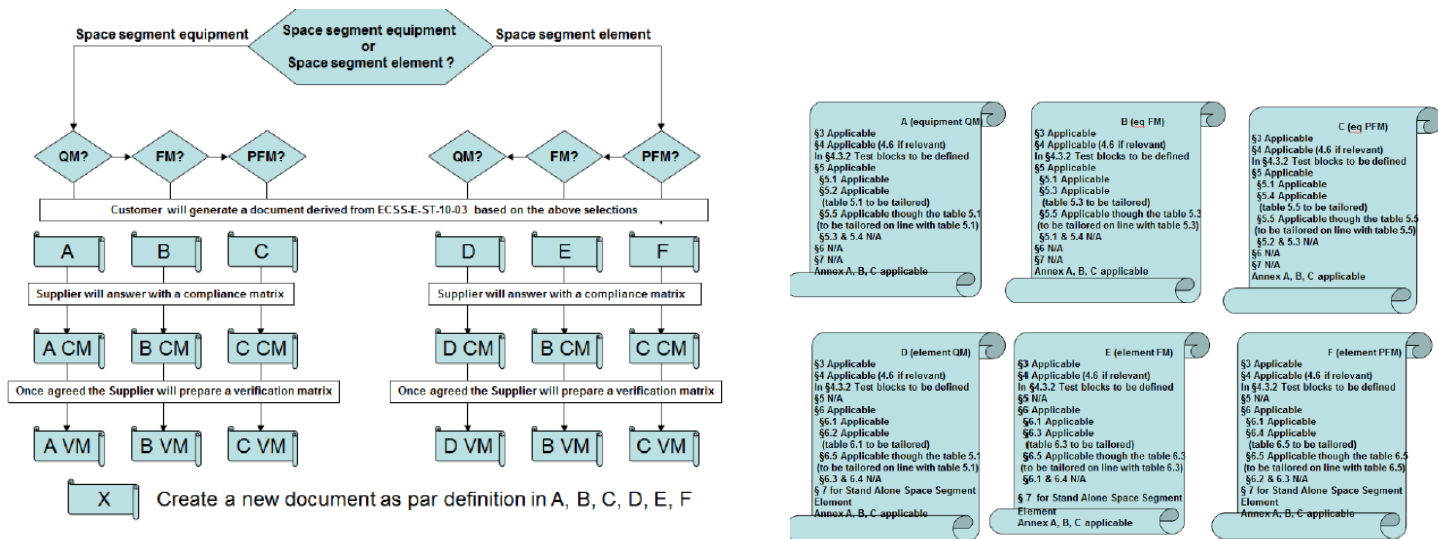
– Before Test: TRR (Test Readiness Review)

– 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:

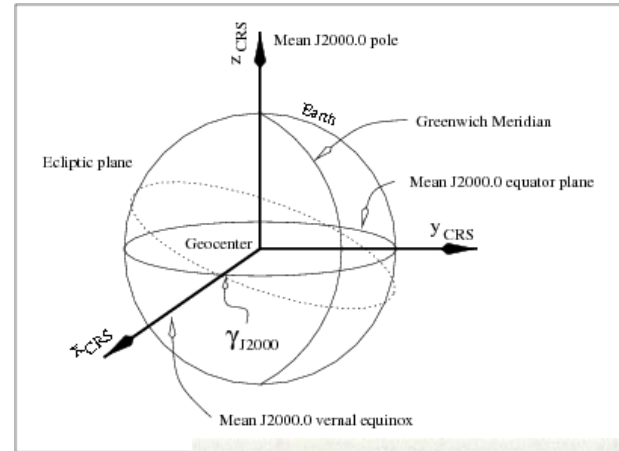
Earth Centred Inertial (ECI) used for satellite motion

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



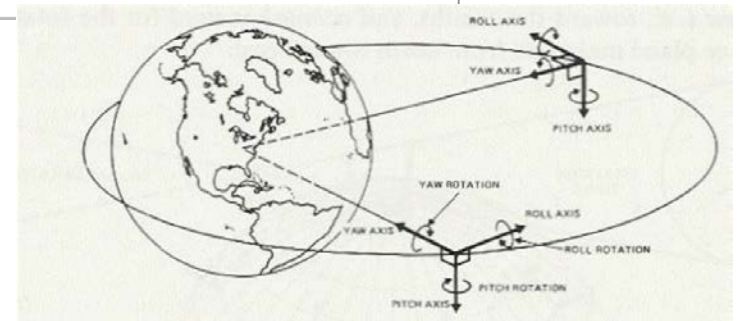
Rotating Orbital Frame used for satellite attitude with respect to mechanically fixed satellite reference frame

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)

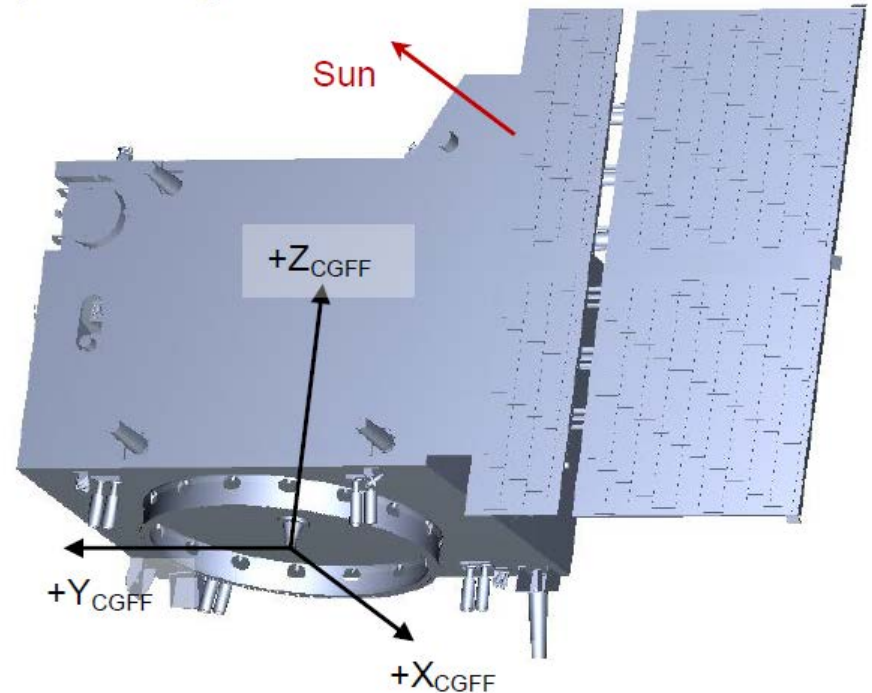
Mechanically-fixed Satellite Coordinate System used to identify attitude and locations onboard the satellite

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

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

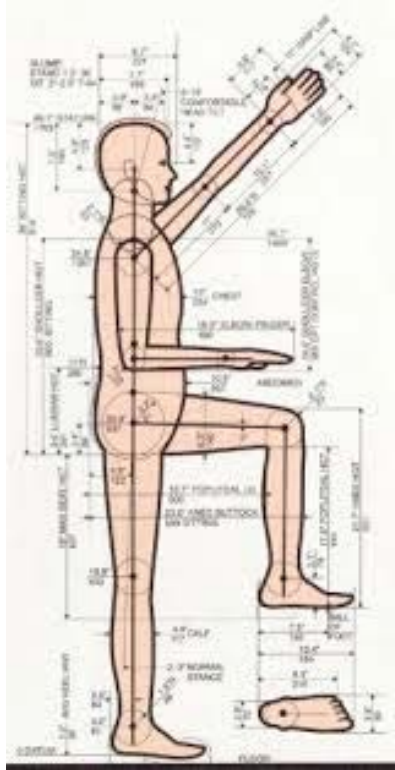
Z: often the launch direction

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)

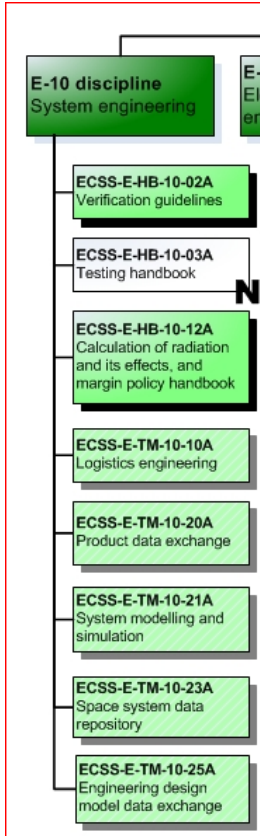
ECSS-E-ST-10-12C - Methods for Calculation of Radiation - Application

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/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 , β , 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 + CCD
	CMOS APS	TNID TID SEE (generally) Enhanced background
	Photodiodes	TNID TID SET
	LEDs	TNID TID
	laser LEDs	TNID TID
	Opto-couplers	TNID TID SET

Sub-system or component	Technology	Effect
Optoelectronics and sensors (2)	γ -ray or X-ray scintillator	TNID (alkali halides) Enhanced background
	γ -ray semiconductor*	TNID Enhanced background
	charged particle detectors	TNID (scintillator & semiconductor) Enhanced background TID (scintillator & semiconductors)
	microchannel plates	Enhanced background
	photomultiplier tubes	Enhanced background
	Other imaging sensors (e.g. InSb, InGaAs, HgCdTe, GaAs and GaAlAs)	TNID Enhanced background
Solar cells	Gravity wave sensors	Enhanced background
	Cover glass & bonding materials	TID
	Cell	TNID
Non-optical materials	Crystal oscillators	TID
Optical materials	polymers	TID (radiolysis)
	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 – currently unsure whether or when it will be finished
- 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

ECSS-E-10 Part 1B
18 November 2004



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/>

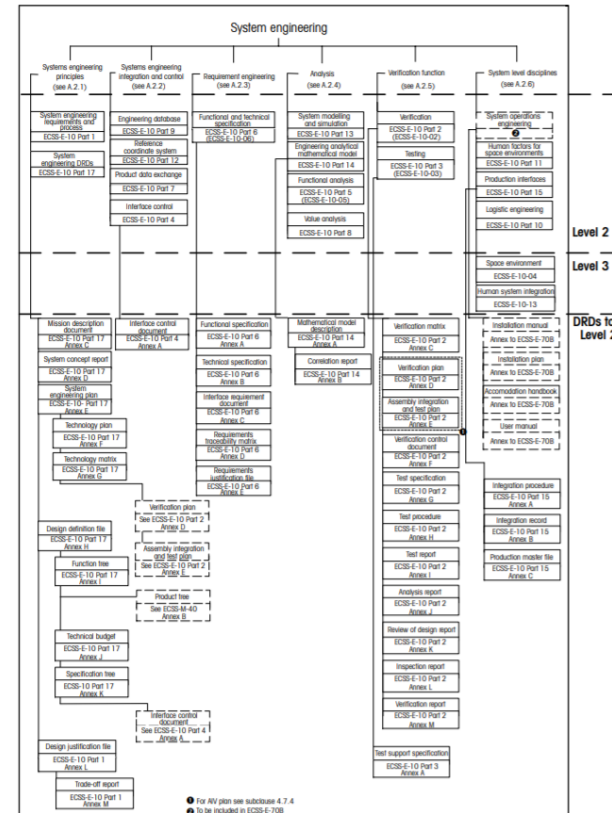


Figure A-1: Structure of the system engineering discipline

ISO 24113 (ECSS-U-AS-10C)

“Space debris mitigation requirements”

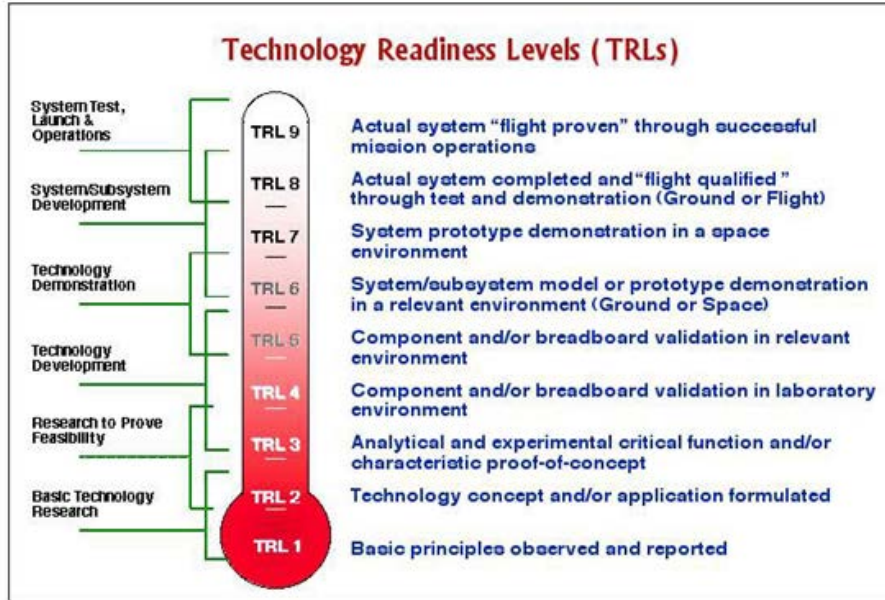
- Adopted through ECSS-U-AS-10C
- Not part of E-10 series but large impact on system design
- ECSS has adopted the international standard:
ISO 24113: Space systems - Space debris mitigation requirements.
- Only minor modifications introduced via ECSS-U-AS-10C

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

“Milestone achieved”

Level	Milestone achieved for the element
TRL 1	Potential applications are identified following basic observations but element concept not yet formulated.
TRL 2	Formulation of potential applications and preliminary element concept. No proof of concept yet.
TRL 3	Element concept is elaborated and expected performance is demonstrated through analytical models supported by experimental data/characteristics.
TRL 4	Element functional performance is demonstrated by breadboard testing in laboratory environment.
TRL 5	Critical functions of the element are identified and the associated relevant environment is defined. Breadboards not full-scale are built for verifying the performance through testing in the relevant environment, subject to scaling effects.
TRL 6	Critical functions of the element are verified, performance is demonstrated in the relevant environment and representative model(s) in form, fit and function.
TRL 7	Performance is demonstrated for the operational environment, on the ground or if necessary in space. A representative model, fully reflecting all aspects of the flight model design, is build and tested with adequate margins for demonstrating the performance in the operational environment.
TRL 8	Flight model is qualified and integrated in the final system ready for flight.
TRL 9	Technology is mature. The element is successfully in service for the assigned mission in the actual operational environment.

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.

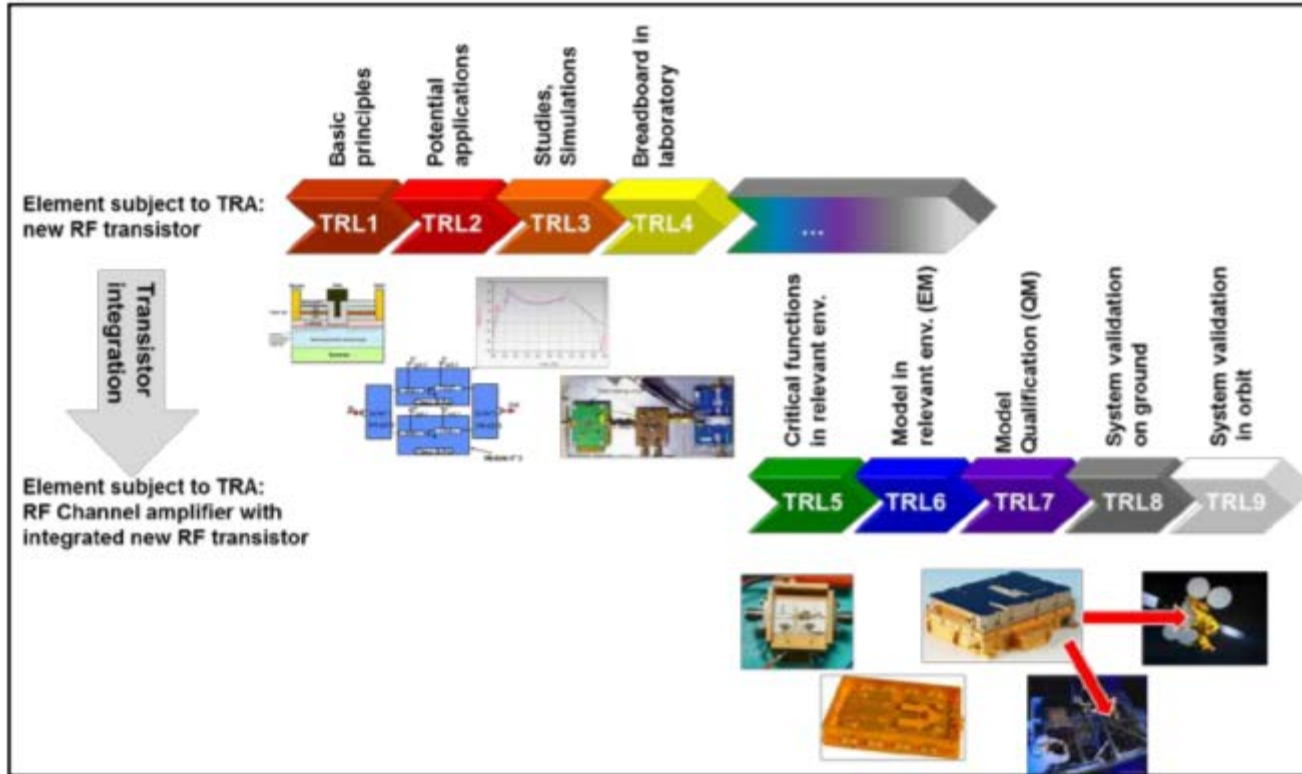
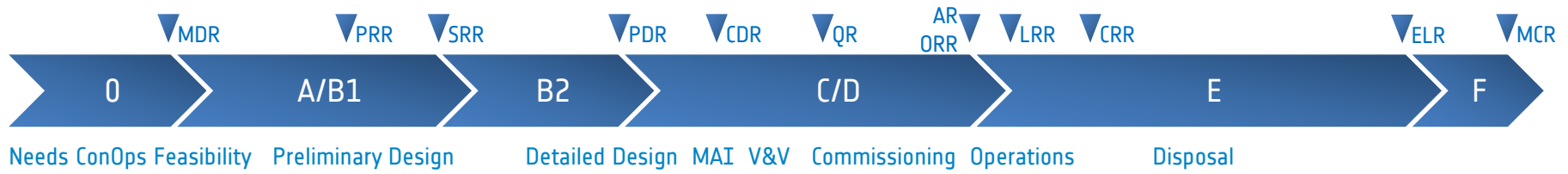


Figure 5-1: Illustration of a new RF transistor then RF amplifier progressing through TRL

Outlook: Gradually Increased use of 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
- OMG System Modelling Language (SysML) released 2010
- 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 computer 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



System Model(s)



earth return orbiter
→ mars sample return



paperless ground segment engineering

sample fetch rover
→ mars sample return



advanced digital ground segment engineering

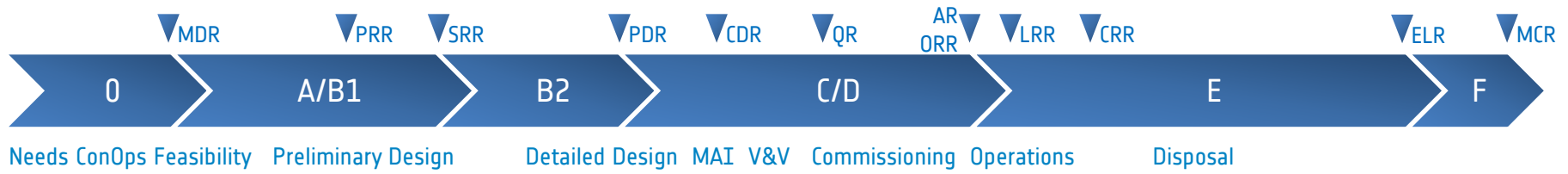
envision
→ esa-sci



adrios
→ clean space

artes sunrise
→ esa-tia





System Model(s)



earth return orbiter
→ mars sample return

sample fetch rover
→ mars sample return

envision
→ esa-sci



plato



euclid

paperless ground segment engineering

advanced digital ground segment engineering



Mixture of:

- consolidated, well established practices (e.g. OCDT in CDF)
- studies/programmes (Paperless Ground Segment, ARTES Sunrise)
- full deployment in on-going projects as pilots (Euclid, e.deorbit, PLATO)

ECSS-E-TM-10-25 based tools

Capella

Capella also used in R&D

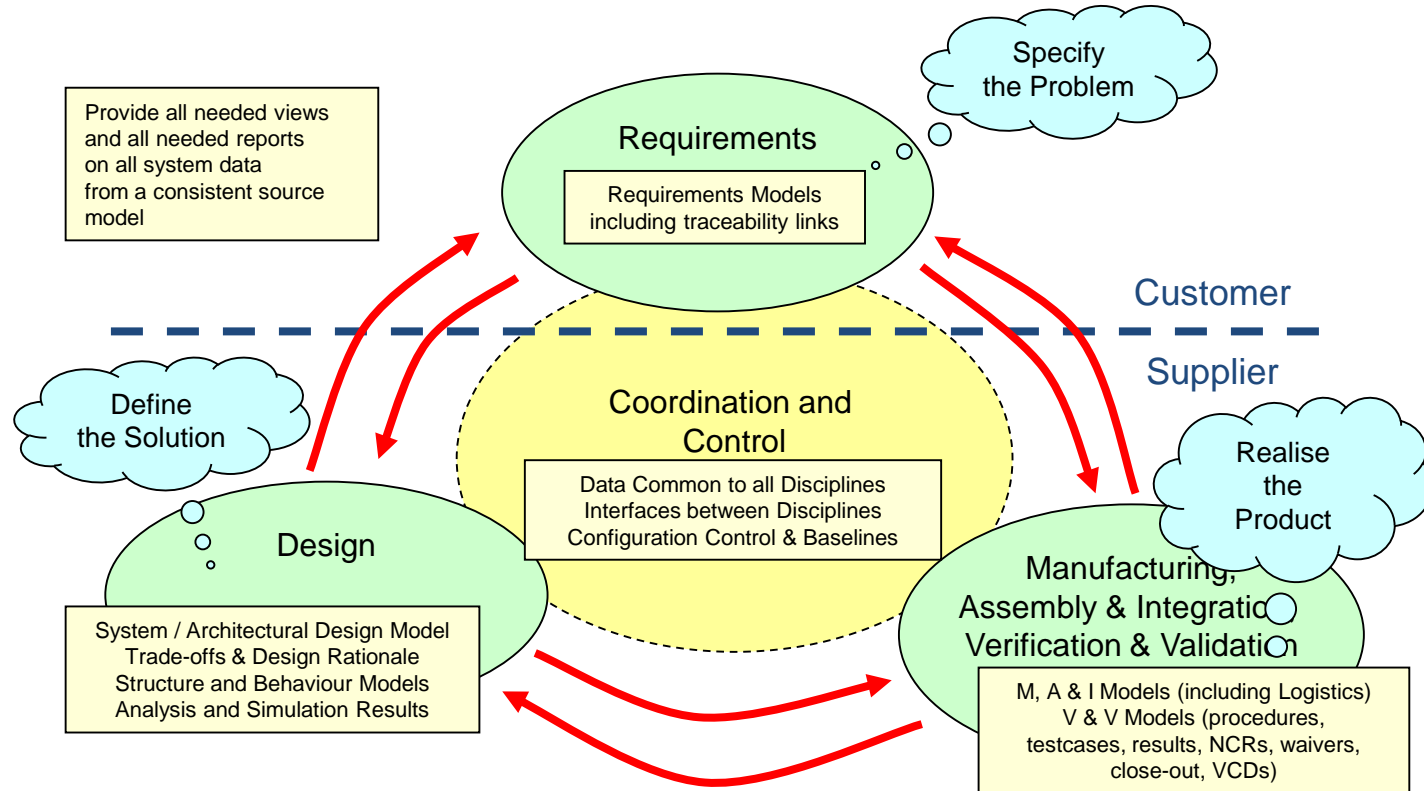
Vitech GENESYS

Cameo Systems Modeler (SysML)

MagicDraw also used in ESA-AF

Enterprise Architect (SysML)

Model Based System Engineering (MBSE) in an ECSS E-10 context

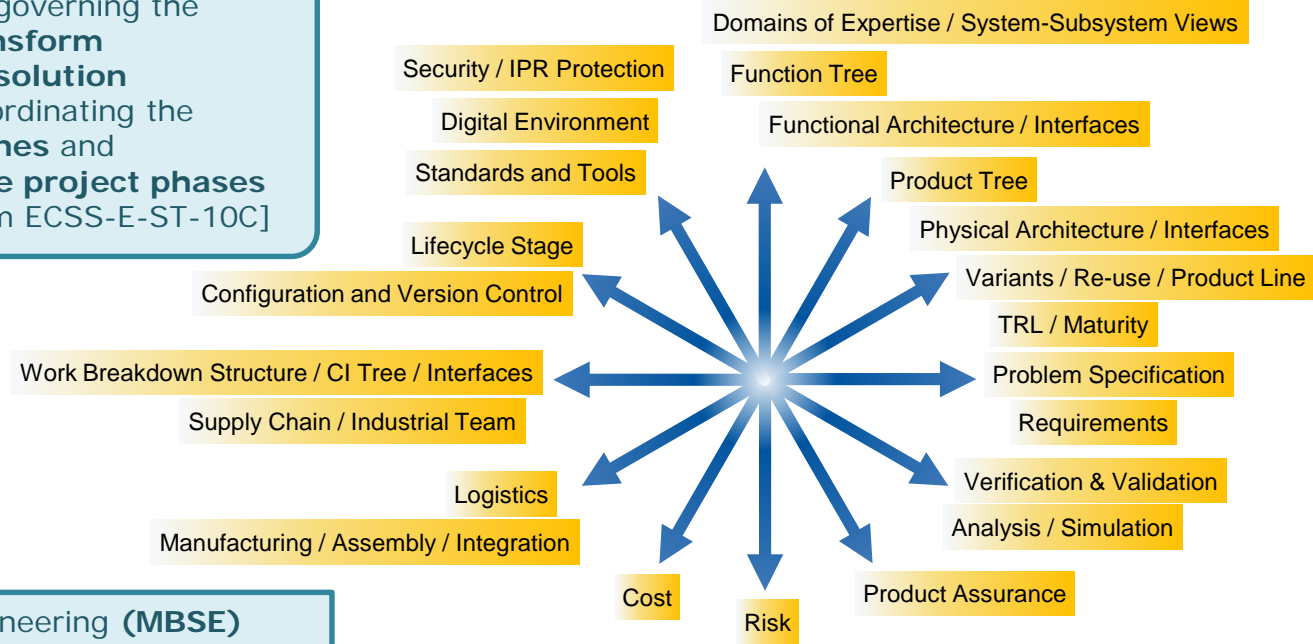


Purpose and Challenge of System(s) Engineering

System Engineering is

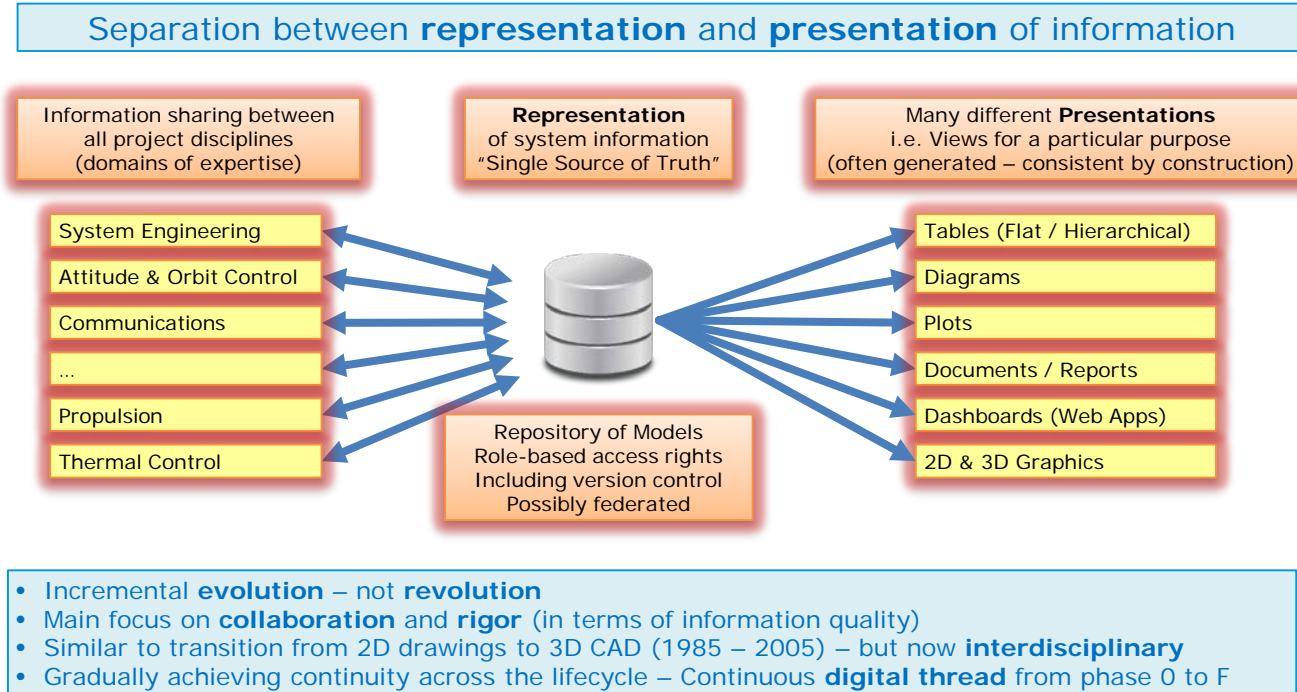
- **interdisciplinary approach** governing the **total technical effort to transform requirements into a system solution**
- **integration and control**, coordinating the various **engineering disciplines** and participants throughout **all the project phases**
[from ECSS-E-ST-10C]

⇒ Handle huge amount of information across many dimensions

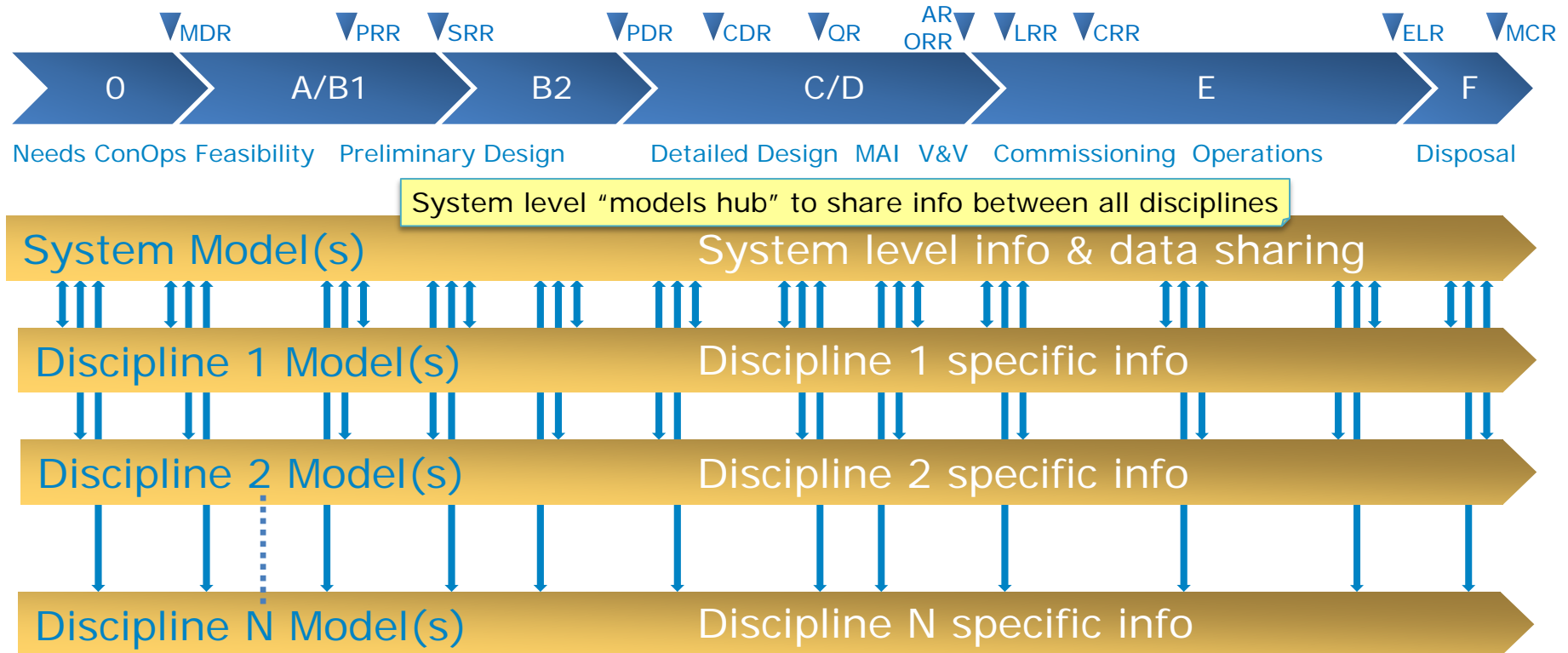


Goal of **Model-Based System Engineering (MBSE)** is to improve SE using a digital engineering approach

Essence of Transition to Model Based System Engineering



MBSE “Continuous Digital Thread”



ECSS-E-TM-10-23 and E-TM-10-25

Towards fully digital engineering

E-TM-10-25



Space engineering

Engineering design model data exchange (CDF)

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

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

E-TM-10-23



Space engineering

Space system data repository

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

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

- 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
- Future: merge to single real standard

ECSS Implementations and further development

- Proof-of-concept tool for E-TM-10-23 validation available at Virtual Spacecraft Design site: <http://www.vsd-project.org>
- Evolution of VSD used in EGS-CC (European Ground System Common Core) project
- E-TM-10-25 implemented in Open Concurrent Design Tool (OCDT) under ESA Community Open Source License, see <https://ocdt.esa.int>
 - Other commercial tools available
 - OCDT will transition to COMET as from 2022
- OCDT used in daily practice in ESTEC CDF, since 2014
- ESA contribution (in cooperation with NASA-JPL) for Quantities, Units, Dimension and Values (QUDV) accepted in OMG SysML
 - same QUDV in E-TM-10-23 and E-TM-10-25
 - further evolution into OMG SysML v2 (publication in 2020)
- Harmonisation activity “Space System Data Repository” was run in 2015, and “Model Based for Systems Engineering” in 2020 (MB4SE AG) defining a roadmap for MBSE for the European Space sector
- Since 2017 in Competence Domain CD09 “Digital Engineering for Space Missions”

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>

List of acronyms

AIT	assembly, integration and test
AIV	assembly, integration and verification
AR	acceptance review
BB	breadboard
BOL	beginning-of-life
CDR	critical design review
CI	configuration item
CIDL	configuration item data list
COTS	commercial-off-the-shelf
CR	change request
DDF	design definition file
DDR	detailed design review
DIL	deliverable items list
DJF	design justification file
DRD	document requirement description
DRL	document requirement list
EEE	electronic, electrical and electromechanical
EGSE	electrical ground support equipment
EM	engineering model
EMC	electro-magnetic compatibility
EOL	end-of-life
EQM	engineering qualification model
EQSR	equipment qualification status review
FAR	flight acceptance review
FDIR	failure detection, isolation and recovery
FM	flight model
FMEA	failure modes and effects analysis
FMECA	failure mode effects and criticality analysis
GDIR	general design and interface requirement
HMI	human-machine interface
HW	hardware

I/F	interface
ICD	interface control document
ID	implementation document
IEEE	Institute of Electrical and Electronics Engineers
IID	interface identification document
INCOSE	International Council on Systems Engineering
IRD	interface requirements document
ISO	International Organisation for Standardisation
J2000.0	epoch 2000 January 1.5 (TT)
KQ	qualification test factor
MGSE	mechanical ground support equipment
MRD	mission requirements document
NCR	nonconformance report
ORR	operational readiness review
PFM	protoflight model
PRD	project requirements documents
PRR	preliminary requirements review
QM	qualification model
QR	qualification review
RAMS	reliability, availability, maintenance and safety
RB	requirements baseline
SEP	system engineering plan
SI	système international
SRD	system requirements document
SRR	system requirements review
STM	structural-thermal model
TID	total ionising dose
TID	total ionizing dose
TIDL	total ionizing dose level
TIDS	total ionizing dose sensitivity
TM	technical memorandum
TRL	technology readiness level