esa

EUROPEAN COOPERATION FOR SPACE STANDARDIZATION

# E-10
# System Engineering Standards

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(with major inputs from Andrea Santovincenzo - ESA, SRE-FMA)

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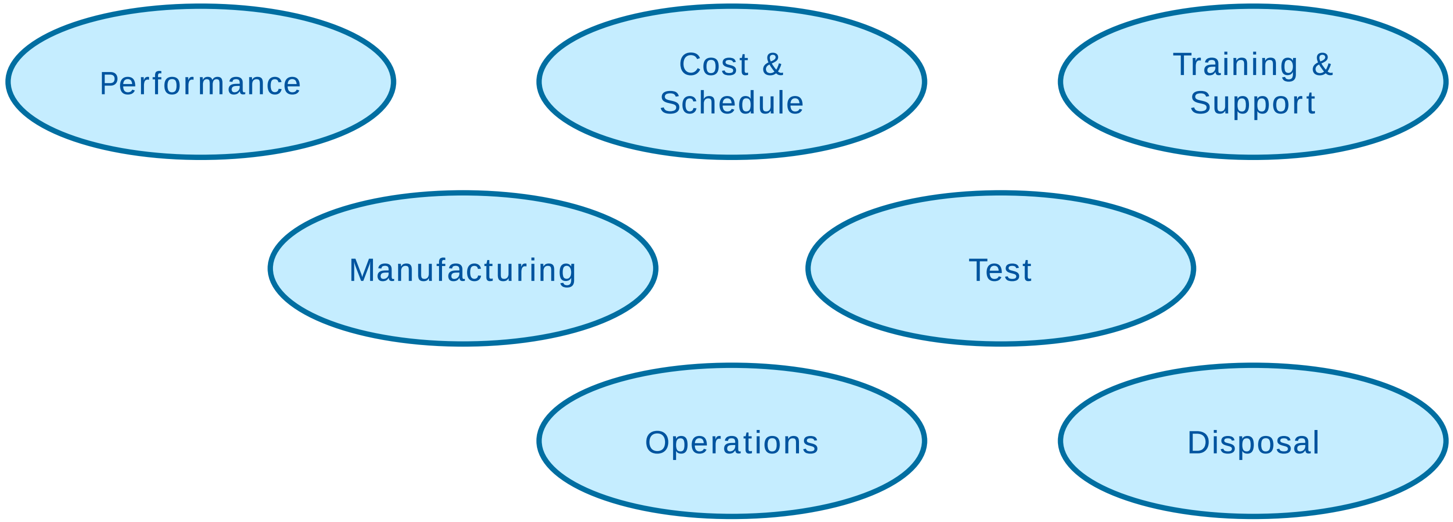
# General Background

# Background
# What is system engineering?

1. **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]
2. **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]
3. **System engineering**
   - “interdisciplinary approach governing the total technical effort required to transform a requirement into a system solution” [ECSS E-ST-10C]

# What is systems engineering? Definition by INCOSE

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem."




http://www.incose.org/AboutSE/WhatIsSE

*INCOSE is the International Council on Systems Engineering*

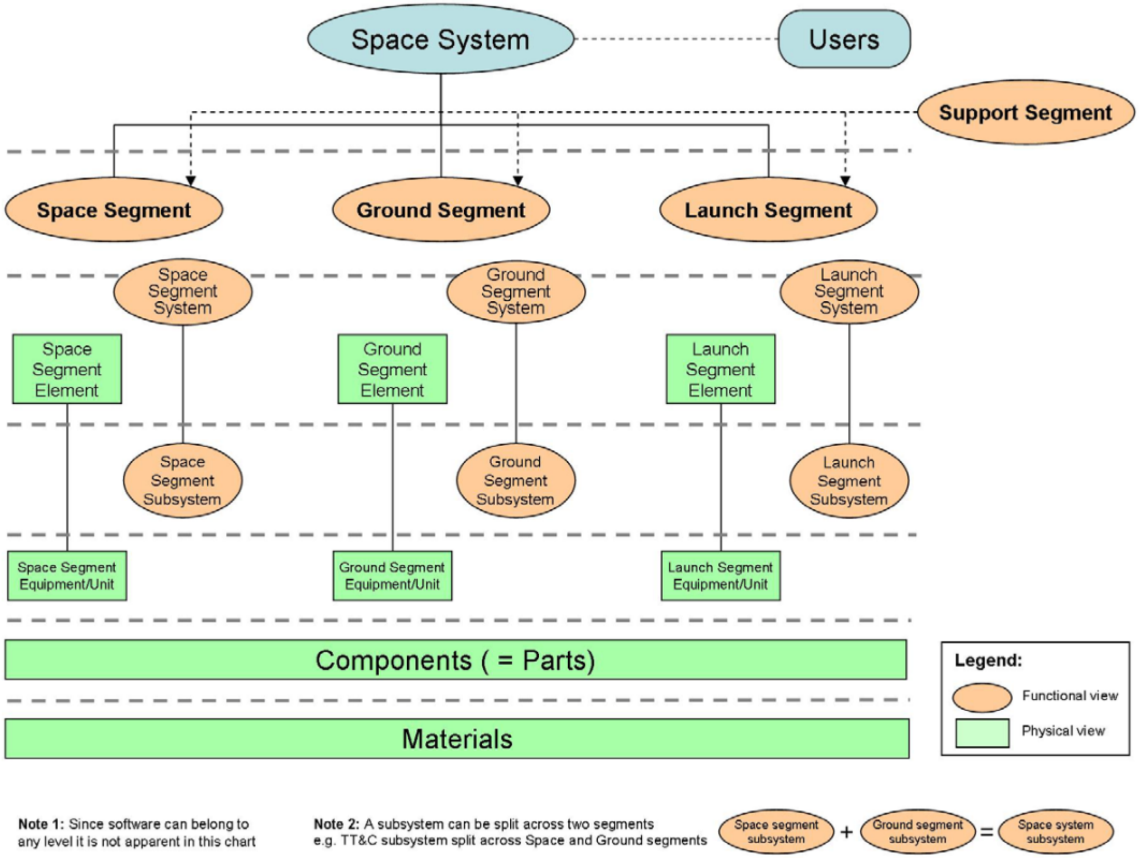
# Background – ECSS-S-ST-00-01C Space System Decomposition

**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.

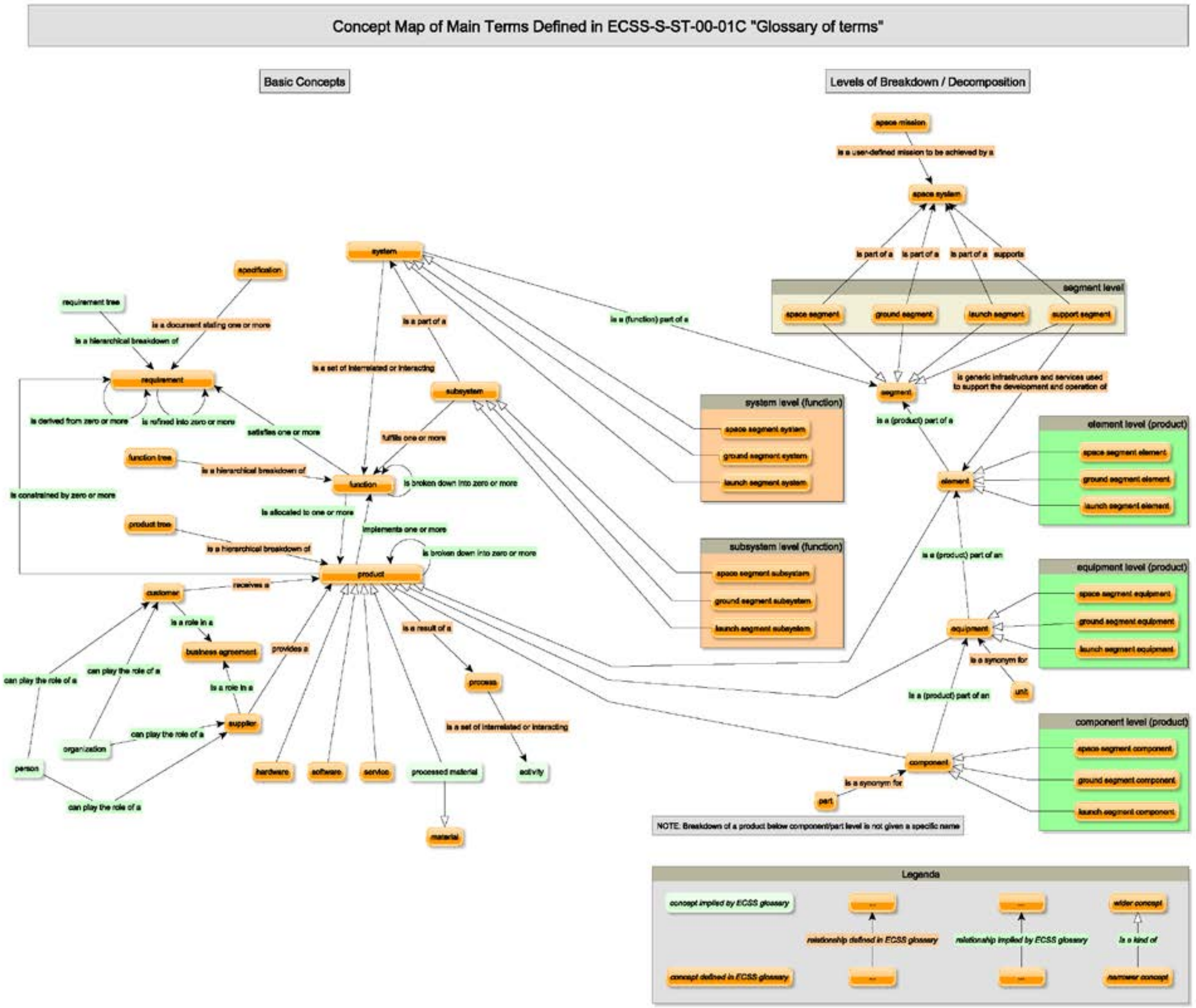
**Segment:** "set of **elements** or combination of **systems** that fulfills a major, self-contained, subset of the **space mission** objectives"

Four main kinds: **Space**, **Ground**, **Launch**, **Support**




**Functional** vs **Physical** views, see also next slide

# ECSS "Glossary of terms" Concept Map



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

| Functional view | Physical view |
|---|---|
| **function:** "intended effect of a **product**" | **product:** "result of a **process**"<br>*Note*: There are four generic product categories: services, software, hardware, processed materials |
| **system:** "set of interrelated or interacting **function**s constituted to achieve a specified objective" | **element:** "combination of integrated **equipment, component**s and **part**s**"** |
| **subsystem:** "part of a **system** fulfilling one or more of its **function**s" | **equipment:** "integrated set of **part**s and **component**s"<br>*Synonym*: **unit** |
| *Warning: Outside ECSS many standards / handbooks (e.g.) use* ***subsystem*** *as a* ***physical*** *decomposition level, of a system, and define* ***system*** *itself as both* ***functional*** *and* ***physical****. This can be confusing in international partnership beyond ESA member states.*<br>*In ECSS a* ***subsystem*** *is a functional view, usually from the perspective of an engineering discipline.* | **component:** "set of **material**s**,** assembled according to defined and controlled **process**es**,** which cannot be disassembled without destroying its capability and which performs a simple **function** that can be evaluated against expected **performance requirement**s"<br>*Synonym*: **part** |

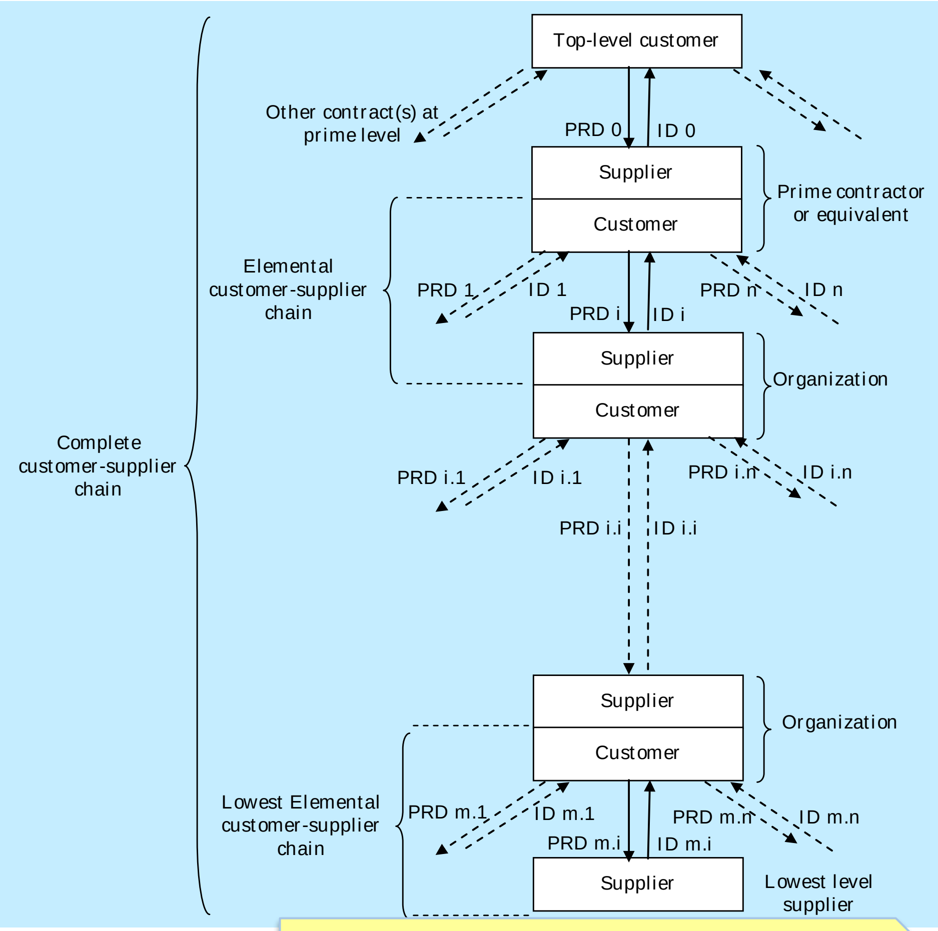
# Background - System Decomposition Example from S-ST-00-01C Annex B

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

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

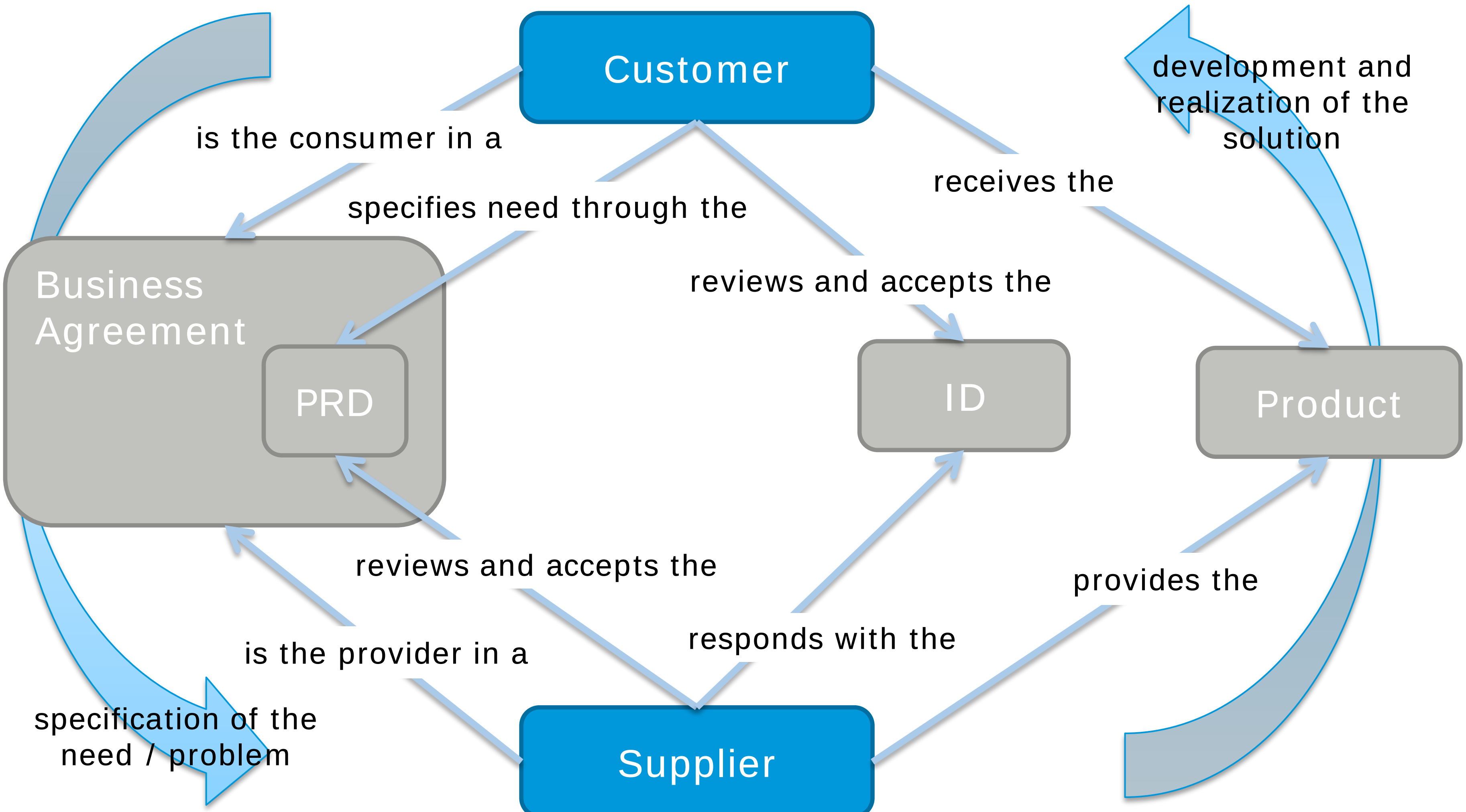
- **Customer** and **Supplier** are roles played by the **Actor**s that cooperate to produce, operate and dispose a **Space System**
- One **Actor** (organization) can be a **Customer** or **Supplier** or both
- **System** is a relative concept that may appear anywhere in the **Customer-Supplier** chain: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

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

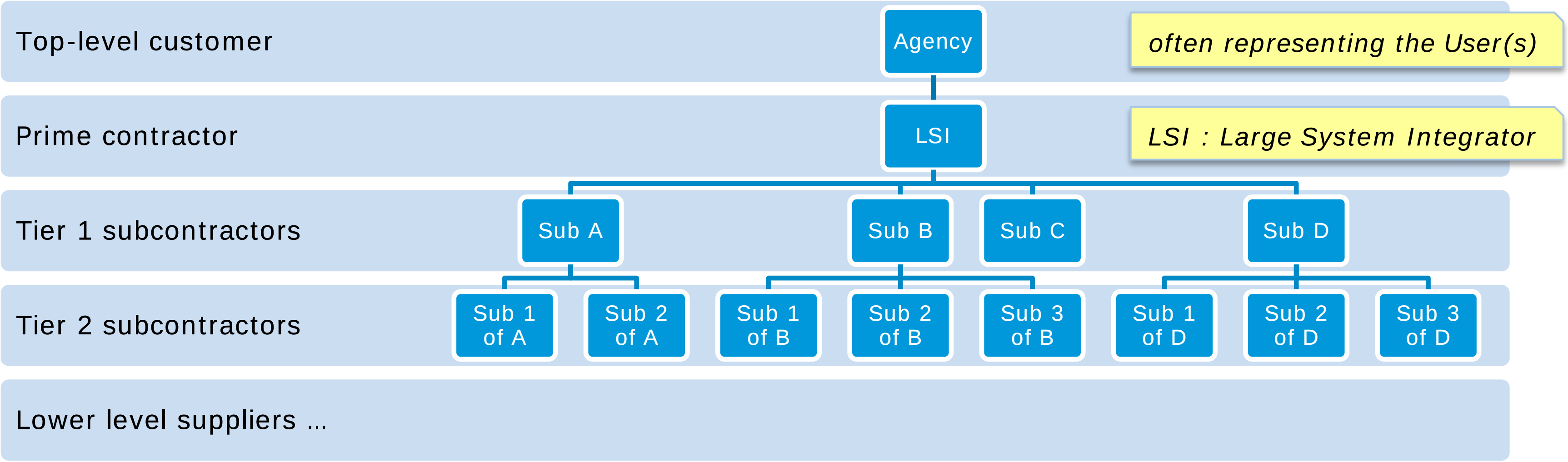



*PRD : Project Requirements Documents*
*ID : Implementation Documents*
*(Ref. ECSS-M-ST-10C)*

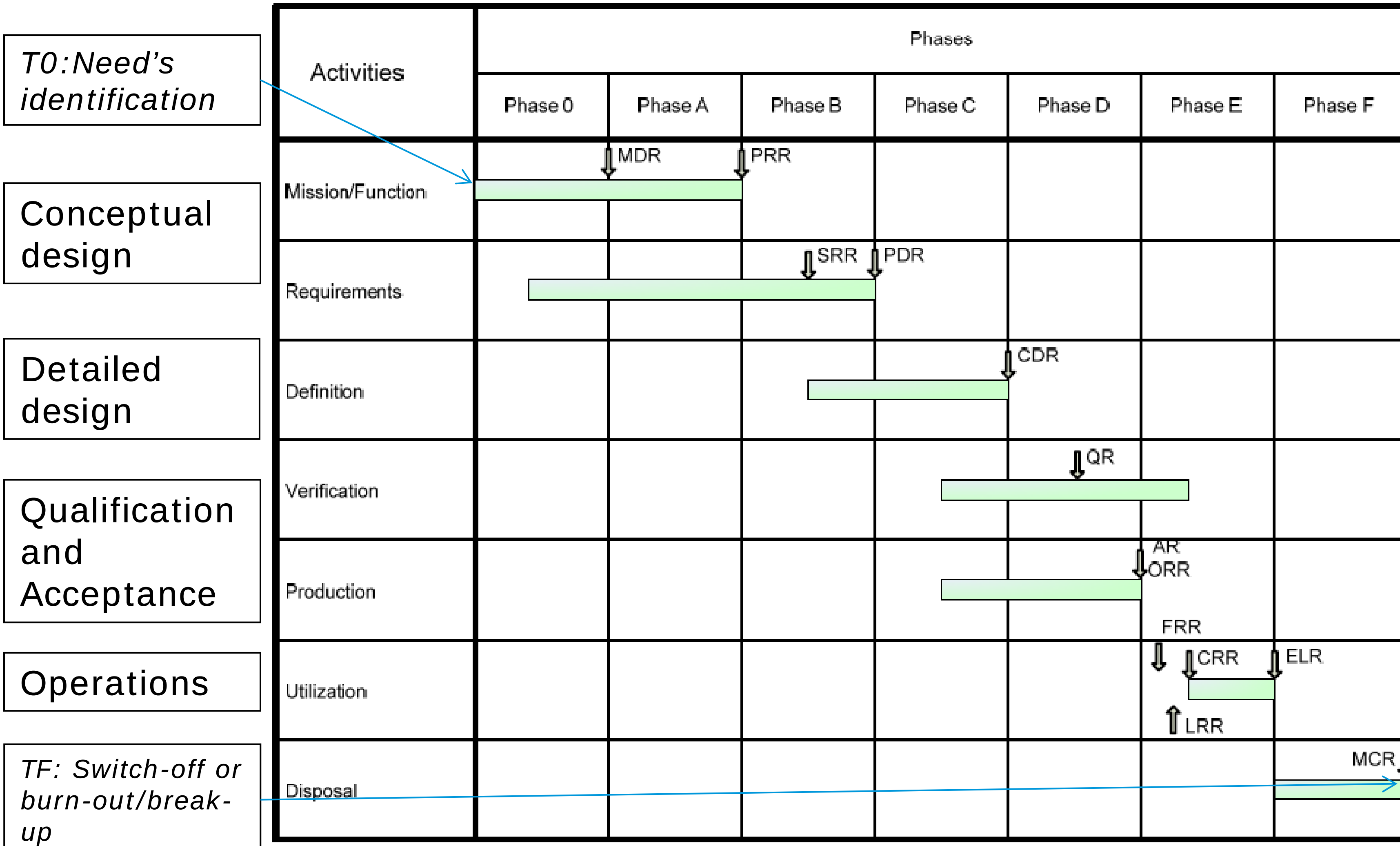
# Background – ECSS-S-ST-00-01C
# The Customer-Supplier Model
# Informal Concept Map



# 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)
- ESA Reviews assess results from all project participants 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<br>NB: Launch Readiness Review is the equivalent review but for the Launcher |

# Introduction to E-10

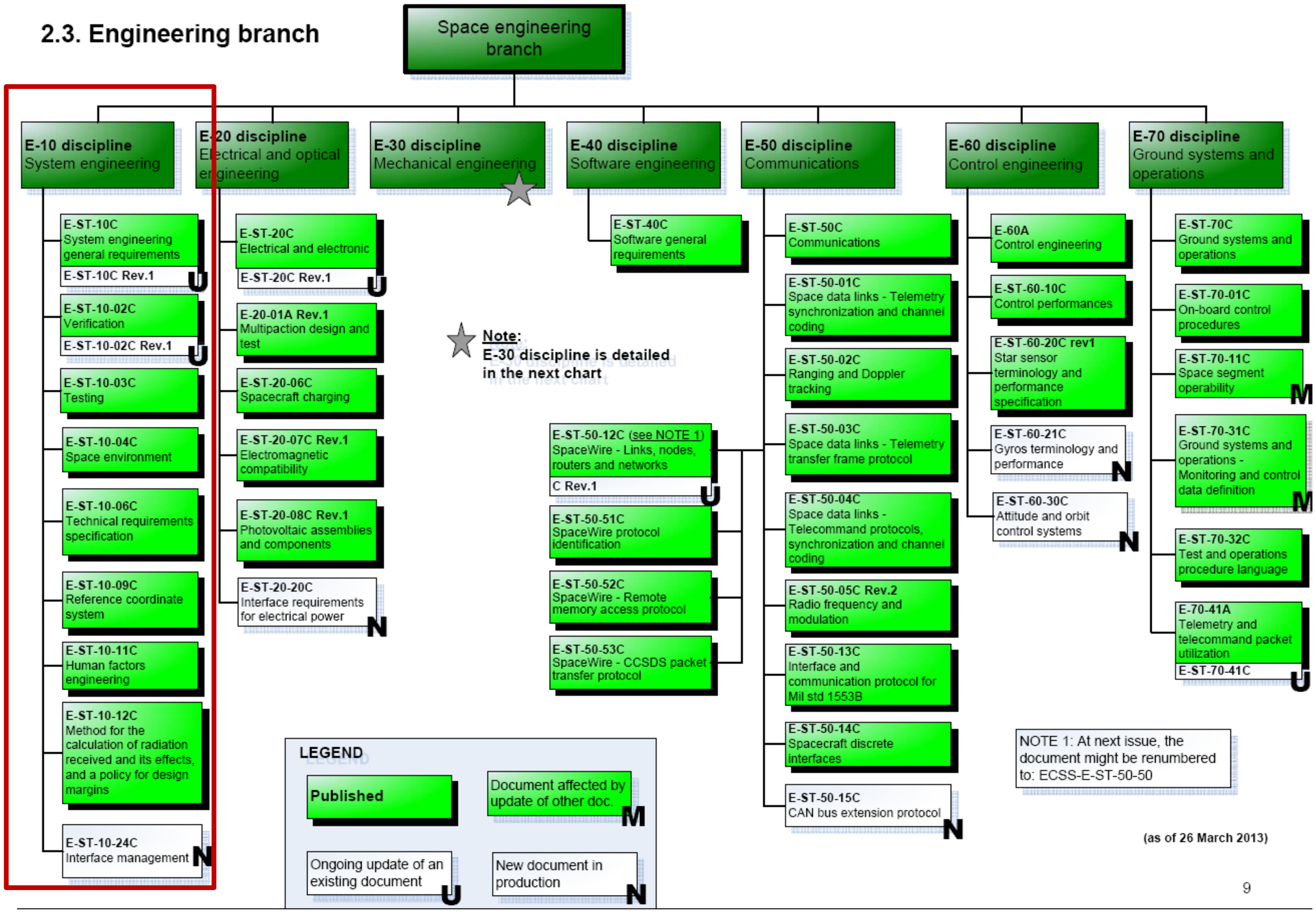
# System Engineering for ESA project – Use of ECSS

1. Several categories of documents to be used at system level in ESA projects
   a. ECSS E-10 Standards
   b. ECSS E-10 Handbooks
   c. ECSS E-10 Technical Memoranda
   d. ISO (for debris mitigation and TRL definition)
   e. + ESSB Handbooks
   (e.g. ESSB-HB-E-003 ESA pointing error engineering handbook)
2. The standards shall be used (possibly after tailoring) to complement a project's own specific requirements documents, which traditionally include:
   a. Mission or System Requirements Document (MRD/SRD ) – see hereafter
   b. SOW for tasks description
   c. Documents for Interfaces (ICD with Launcher Authority, Payload, Operations, etc.)
   d. Specific documents (e.g. Planetary Protection req's, Environment definition, Regulations, etc.)

# E-10 Discipline Subbranch

Includes System Engineering proper, but also:

- Space Environment / Radiation
- Human Factors Engineering



# ECSS E-10 Standards Scope

The E-10 standards cover the following System Engineering areas:

1. General principles, definitions and documentation (incl. DRDs)
2. Verification
3. Testing
4. Requirements
5. Interfaces (to be published summer 2015)
6. Coordinate Systems
7. Space Environment / Radiation
8. Human Factors

Several other areas of system engineering (traditionally) are covered by standard in other disciplines, for instance:

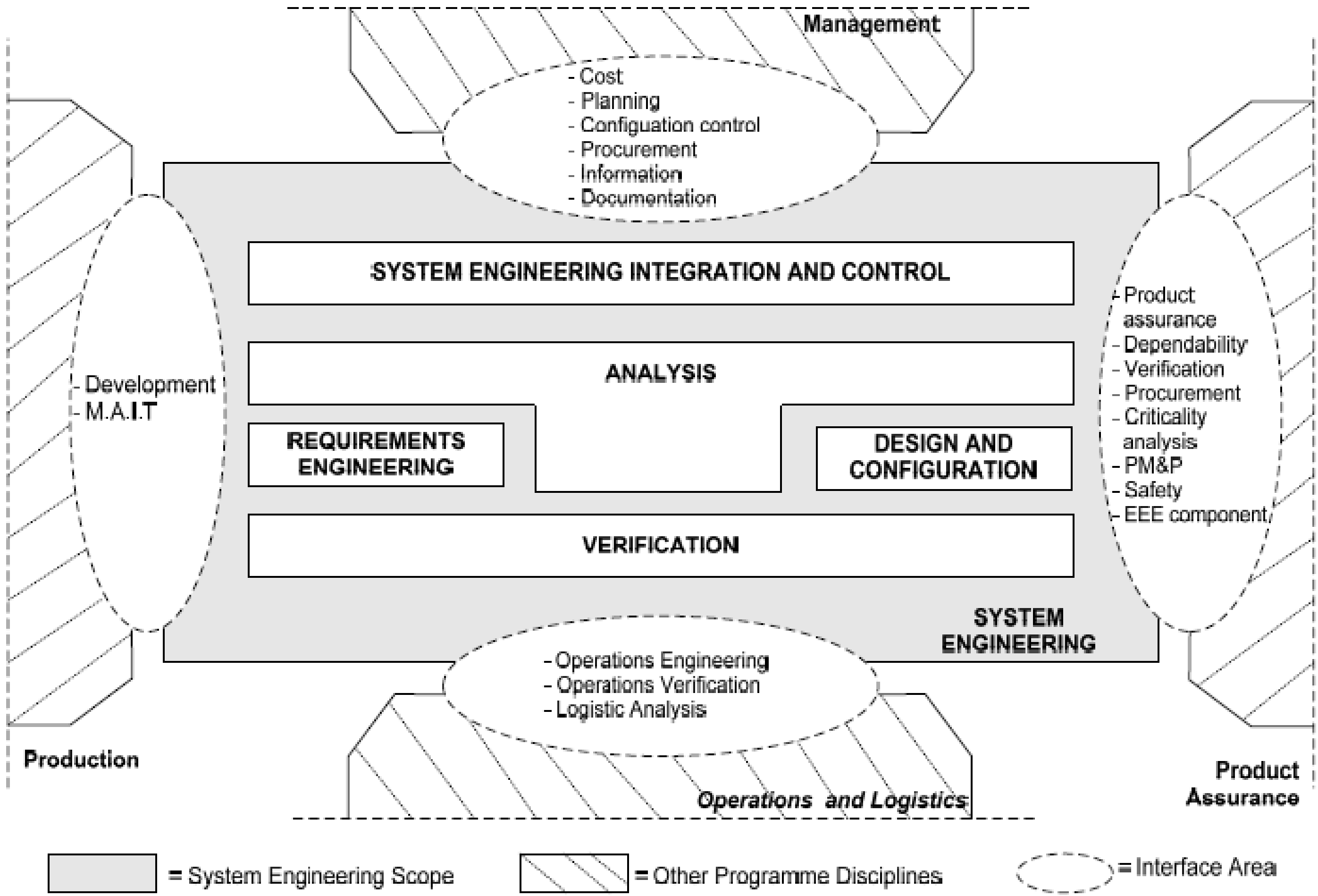
1. Space Segment Operability (E-ST-70-11C) which defines autonomy and system requirements for operability
2. Software (ECSS-E-ST-40C) for the definition of the System inputs to SW
3. Testing at subsystem level (e.g. propulsion) covered by the relevant standards

# System Engineering E-ST-10C

# ECSS-E-ST-10C "System engineering general requirements" Content

1. Provides (general) description and guidelines on system engineering tasks
2. Provides SE tasks per project phases (as defined in ECSS-M-ST-10, Space project management – Project planning and implementation): it defines what should be available from system viewpoint at the end of each phase
3. It provides a list of system engineering documents + DRDs in Annexes (and guideline on project milestones when those shall be available)
4. 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 general requirements”
# System Engineering Functions (Fig. 4-1)

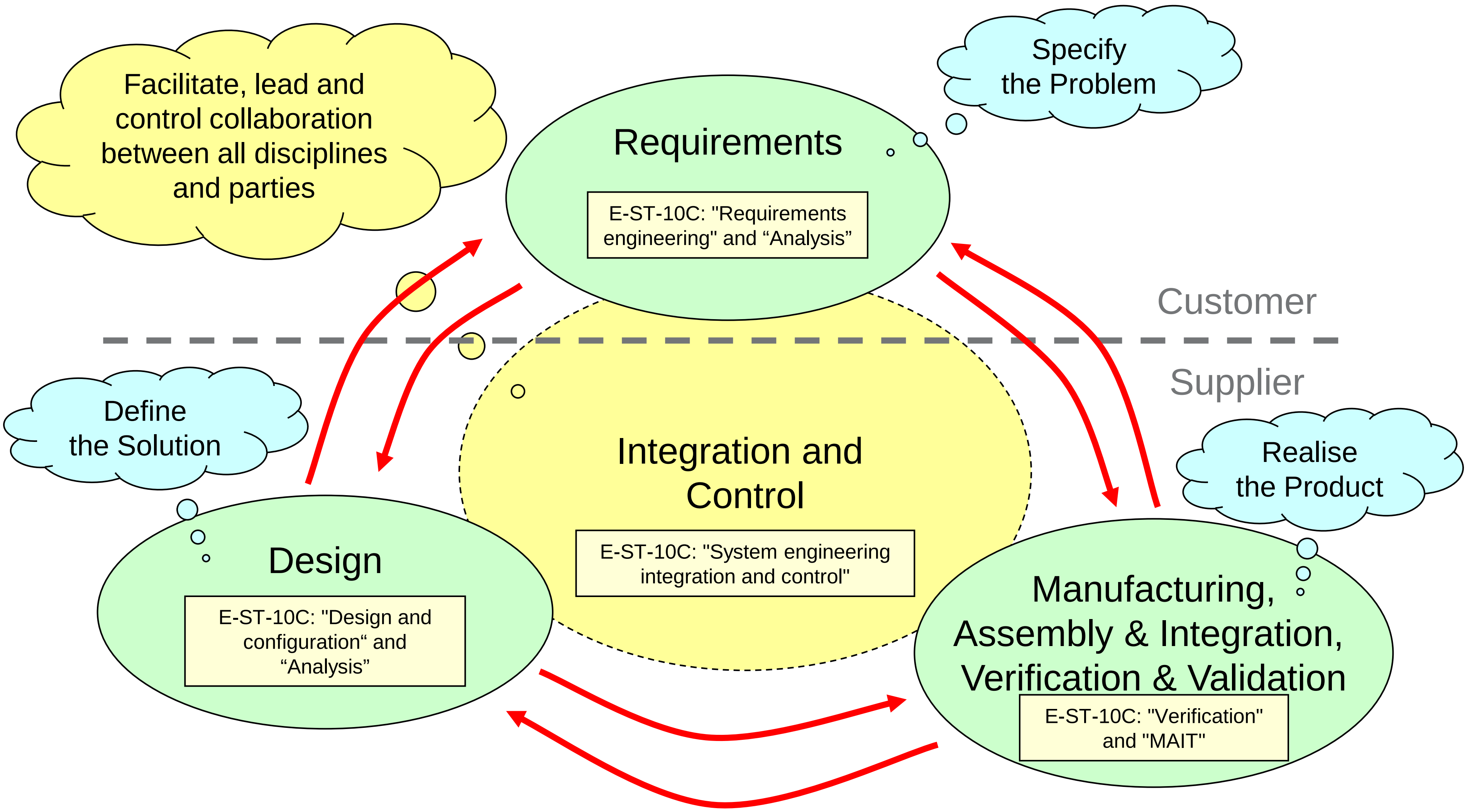



MAIT = manufacturing, assembly, integration and test
PM&P = parts, materials and processes

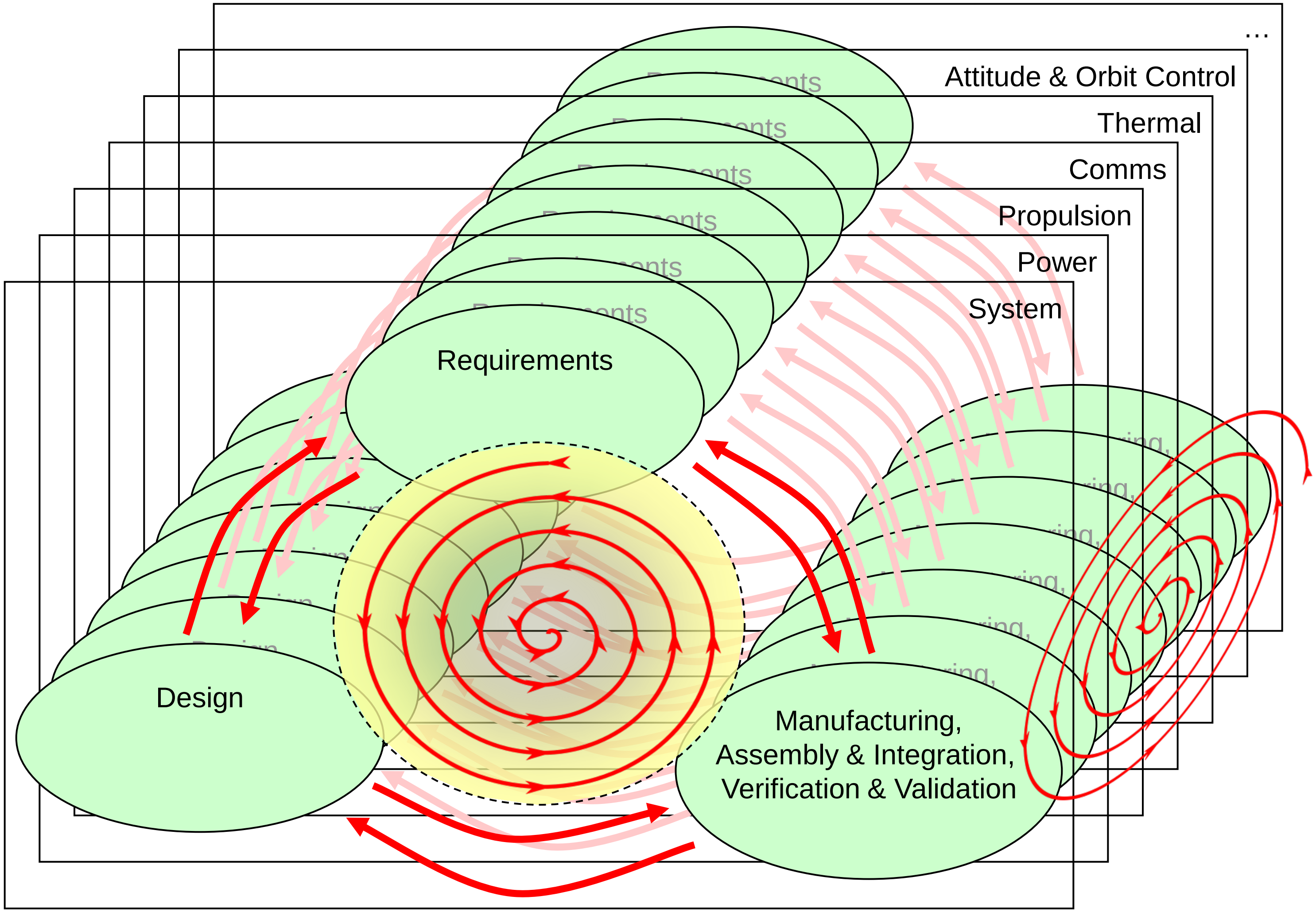
# ECSS-E-ST-10C "System engineering general requirements"
# System Engineering Functions Summary

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

# ECSS-E-ST-10C: 3 Main Areas of Concern & 1 Central Task “Integration and Control”

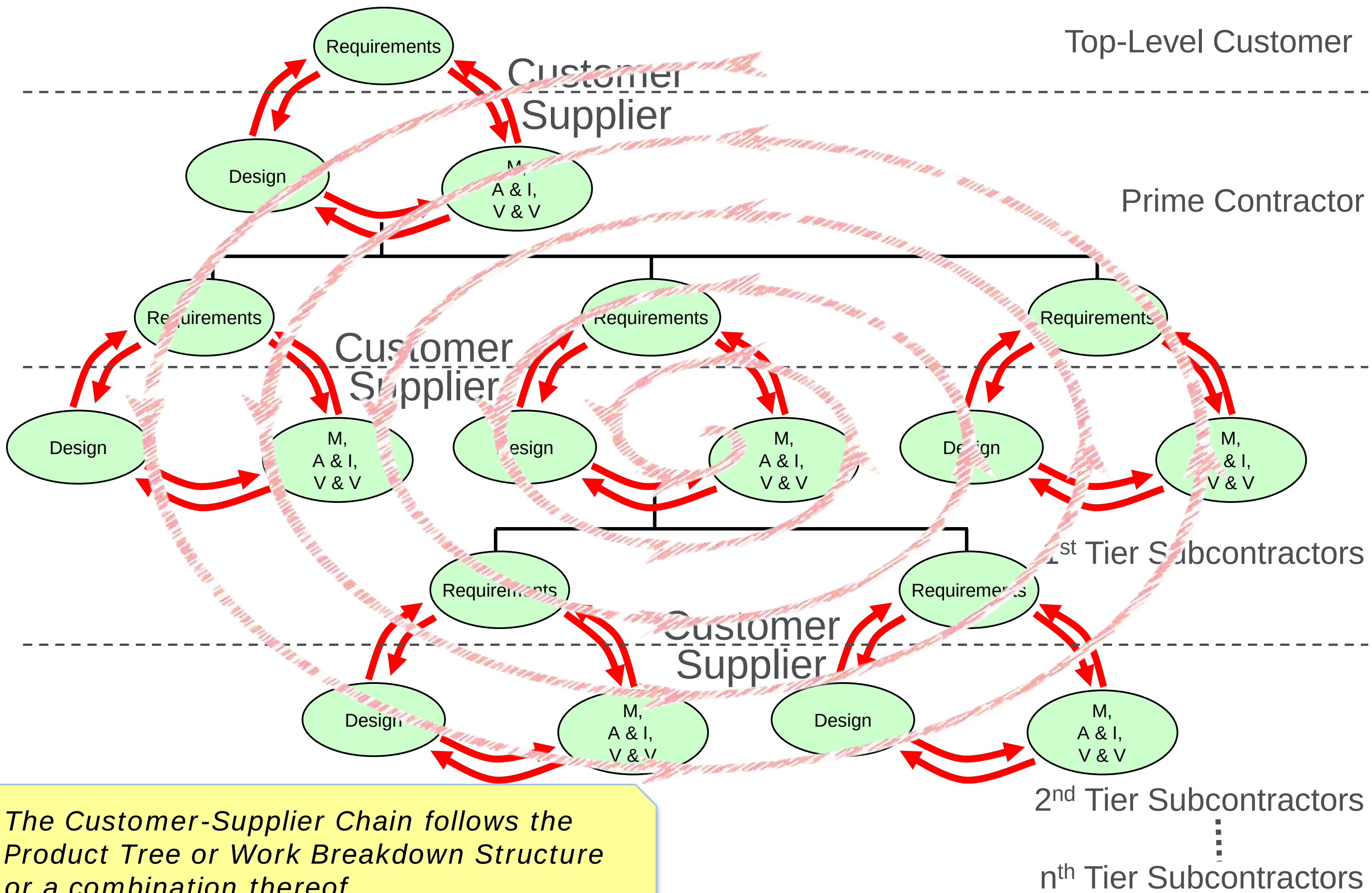


# ECSS-E-ST-10C: Iterative "Integration and Control"



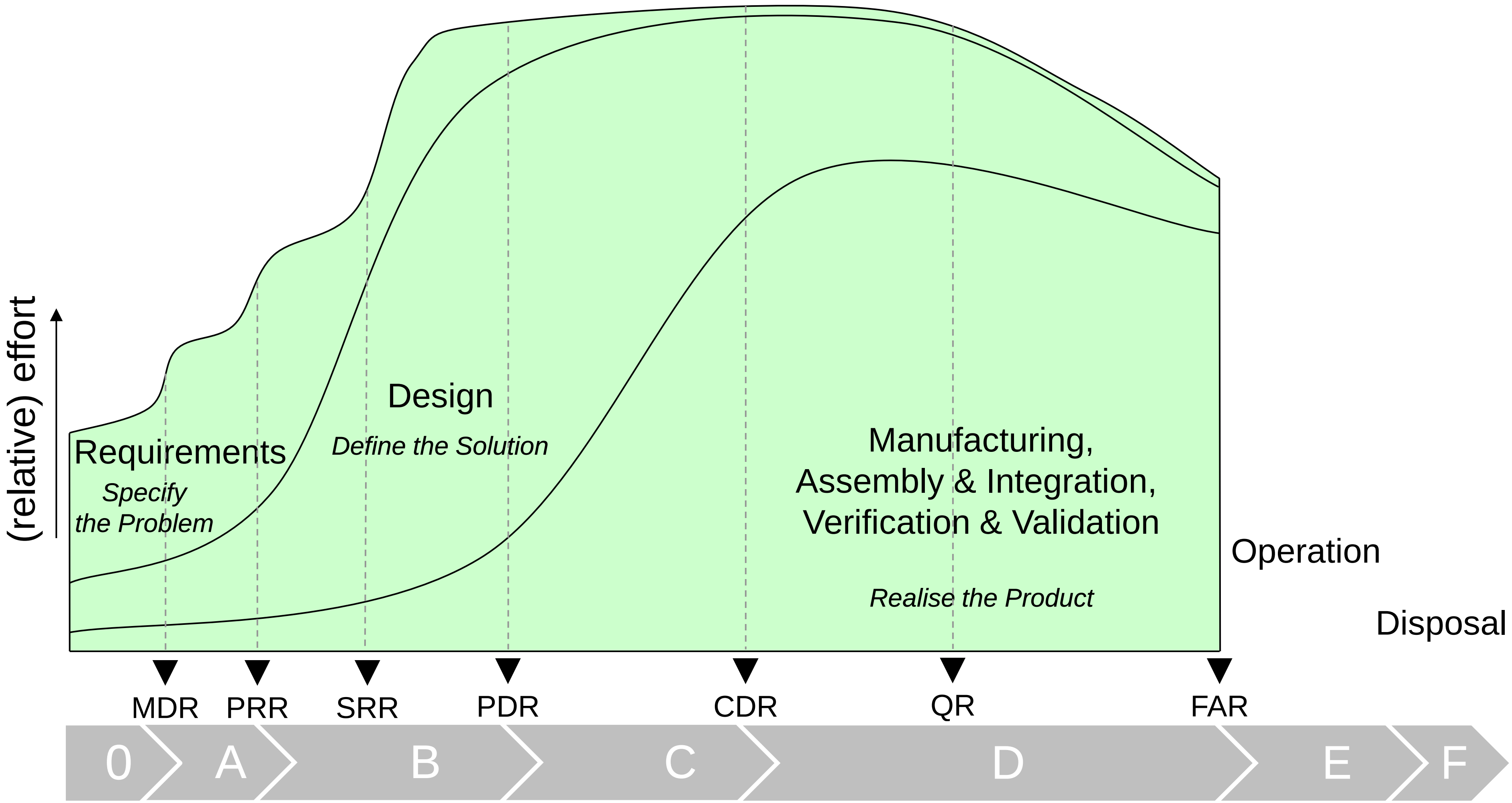

- Integration and Control (possibly concurrent in early phases)
- Iterate between Requirements, Design, and MAIV&V
- Iterate across Disciplines

# 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 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"

1. Project objectives / constraints / phases / reviews & Product evolution
2. SE tasks, inputs and outputs
3. SE team responsibilities and organization,
   including coordination between all engineering disciplines
4. Procurement approach of all elements / equipment
5. Technology development approach
6. Verification Plan and AIT Plan, or combined AIV Plan
7. Coordinate systems
8. Processes, methods, facilities and tools

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

# ECSS-E-ST-10C Requirements Engineering Specification tree

Requirements shall be organised according to a hierarchy (Specification tree) which allows their traceability

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

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

# 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 a 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 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 | | + | + | + | + | + | | | | | | | |

# 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 - System Engineering General Requirements Guidelines for use / tailoring

1. The core of the Standard shall be left as is since it gives general principles which are applicable in all cases
2. Practical implementation instructions shall be included in the SRD and/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
3. The documentation deliverables shall be tailored according to project needs/heritage (own project DRL), including proposed dates for delivery. Example: System Design Report with content part of the Design Definition File and part of the Design Justification File
4. DRDs as defined in annexes would normally require some tailoring

# Requirements

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

1. Provides "requirements on requirements" on how to:
   a. Identify and capture requirements
   b. Write requirements,
      including how to formulate "good" requirements
      (definitions of "shall", "should", "may", words to avoid, ...)
   c. Classify according to type of requirement:
      functional, operational, physical, design, etc.
2. Used to write e.g. SRD and to an extent the Prime System Specification
3. Common misconception: It does not provide practical instructions for requirement management (e.g. use of tools as DOORS, etc.)

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

# Verification

European Space Agency

# ECSS-E-ST-10-02C - Verification Content

Provides definitions and general requirements on:

a. Verification process
b. Verification planning
c. Verification execution
d. Verification close-out

Provides in Annexes DRDs of 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

1. **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")
2. **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 the confirmation of product integrity and performance after particular steps of the project life cycle (e.g. pre-launch, in-orbit commissioning, post-landing).

**Verification vs validation**

ECSS does not mandate the need for 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 validation is enveloped by the verification. This is not always true for the Ground Segment.

# 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 and storage
- **In-orbit** (Commissioning)

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:

a. (Component or Part) e.g. resistor, relay, bearing
b. (Subassembly or Module) e.g. printed circuit board
c. Equipment (or Unit) e.g. valve, battery, electronic box
d. Subsystem e.g. electrical power, structure
e. Element e.g. satellite
f. System e.g. manned infrastructure system

# ECSS-E-ST-10-02C - Verification Process -2

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

# 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):

a. **Test** – verification method by measurement of product performance and functions under representative simulated environments
**– is the preferred method**

b. **Analysis** – verification method performing a theoretical or empirical evaluation using techniques agreed with the Customer – may be analysis by similarity

c. **Review-of-design** – verification method using approved records or evidence that unambiguously show that the requirement is met

d. **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 - Qualification and Product categories

| Category | Description | Qualification programme |
|---|---|---|
| A | Off-the-shelf product without modifications and<br>• subjected to a qualification test programme at least as severe as that imposed by the actual project specifications including environment and<br>• produced by the same manufacturer or supplier and using the same tools and manufacturing processes and procedures | None |
| B | Off-the-shelf product without modifications.<br>However:<br>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.<br>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. |

Notes:

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:

1. Qualification of the design needs extensive testing.
2. Testing of the flight model only is not efficient as:
   a. it is too late in case problems are found. It would be very expensive to correct the design when the system is already integrated.
   b. It may be detrimental to the lifetime of the spacecraft / unit.
3. Additional models of the flight hardware are necessary, to allow early testing for effective design qualification.
4. The models must be representative of the flight hardware for all those parts that need to be tested.
5. It is found convenient (by experience) to separate at system level, thermal and mechanical design aspects from functional design. 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 - Models Description - 1

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

# ECSS-E-ST-10-02C - Models Description - 2

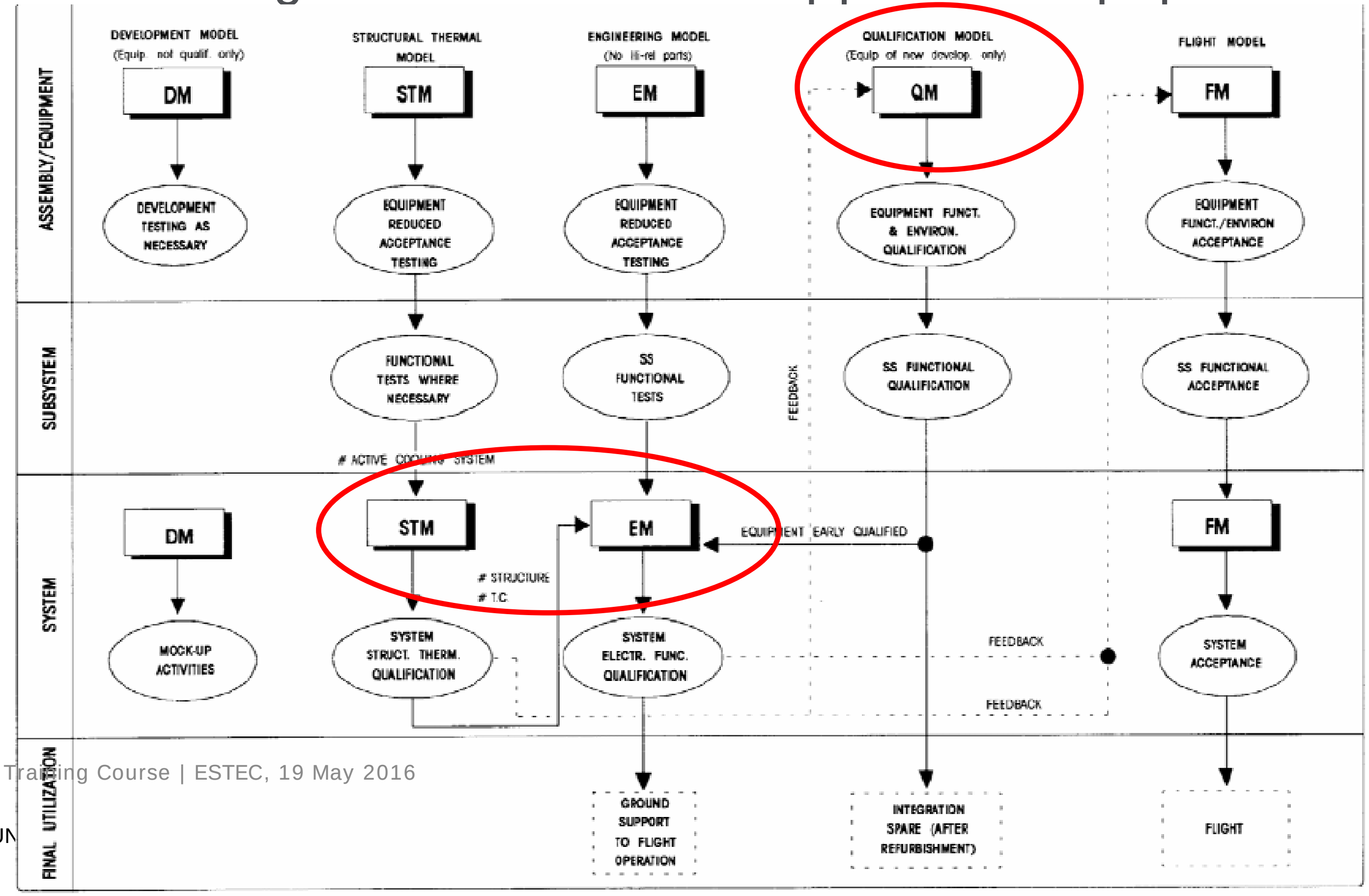
| | | | | |
|---|---|---|---|---|
| Suitcase Model | Simulation of functional & RF performances | • Flight design<br>• Commercial parts<br>• Functional representativity | • Equipment level<br>• System level | Space to ground interface testing |
| Electrical and Functional Model (EFM) | • Functional development<br>• S/W development<br>• Procedure validation<br>• Prepare flight test programme<br>• Closed loop tests | • Functional representativity<br>• Commercial parts<br>• Simulators of missing parts | All levels | • Development or qualification testing<br>• It could be considered something in between a mock-up and an EM<br>• Sometime is called also Integration Model |
| Engineering Model (EM) | Functional qualification failure survival demonstration & parameter drift checking | • Flight representative in form-fit-function<br>• without high reliability parts and usually without redundancy | All levels | Partial functional qualification testing |
| Engineering Qualification Model (EQM) | • Functional qualification of design & I/Fs<br>• EMC | • Full flight design<br>• MIL-Grade parts procured from the same manufacturer of high reliability parts | All levels | Functional qualification testing |
| Qualification Model (QM) | Design qualification | • Full flight design & flight standard | • Equipment level<br>• SS level | Qualification testing |
| Life test Model (LTM) | Qualification of lifetime | • Flight representative with respect to the qualified function | Equipment level | • Model for mechanisms in a protoflight approach with lifetime requirements<br>• Can not be used for flight |

# ECSS-E-ST-10-02C - Models Description - 3

| | | | | |
|---|---|---|---|---|
| Protoflight Model (PFM) | • Flight use<br>• Design qualification | Full flight design & flight standard | All levels | Protoflight qualification testing |
| Flight Model (FM) | Flight use | Full flight design & flight standard | All levels | Acceptance testing |
| Flight Spare (FS) | Spare for flight use | Full flight design & flight standard | Equipment level | Acceptance testing |
| Function oriented model | Qualification against the applicable functional requirements | Flight representative as necessary for the limited qualification objectives | All levels | Qualification testing oriented to a specific function or requirement |
| Training model | Flight training baseline data | Flight representative with modifications to allow for normal gravity operation | All levels | Qualification testing oriented to specific HFE requirements |
| Virtual and hybrid models | Development and verification of specific aspects | Virtual or physical flight representativity as necessary for the applicable verification objectives | All levels | • Composition may change in course of the project life cycle<br>• 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 |

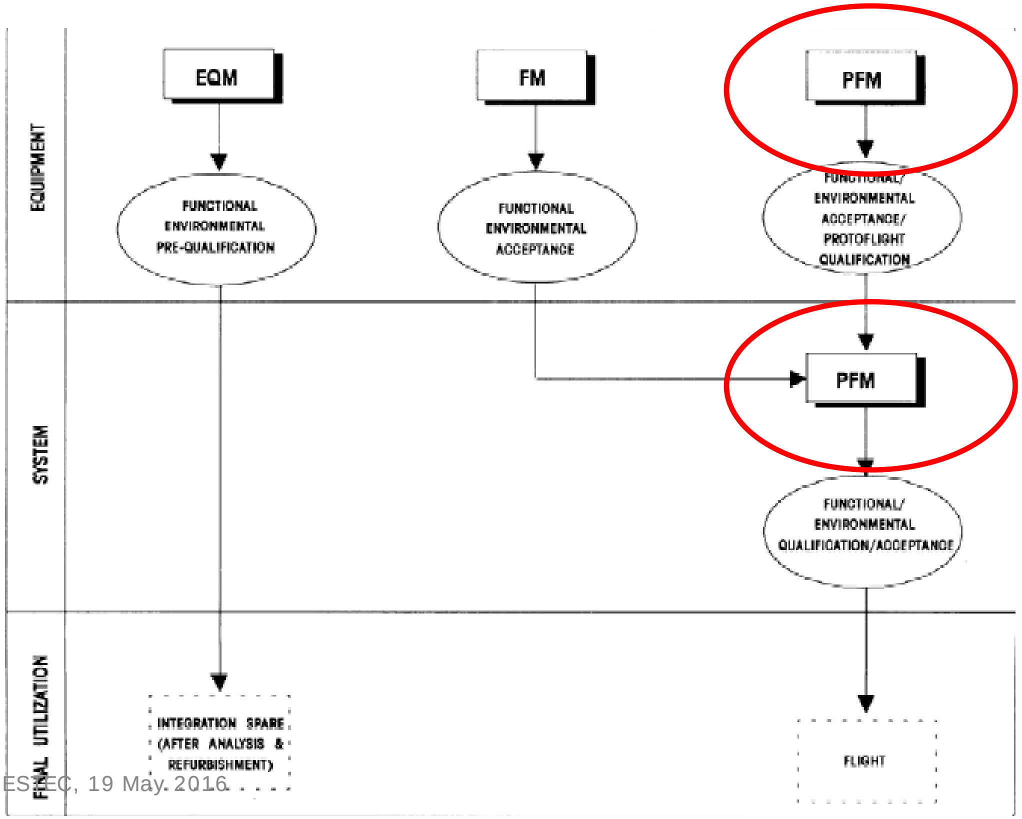
# Prototype and proto-flight verification approaches

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

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.



# Proto-flight (PFM)Testing vs Prototype (QM+FM) testing

## Pro's

Prototype:

Lower risk (issues discovered early on different model from flight)

Possibility to refurbish QM as spare

Possibility to use the QM or training, operations, etc.

ProtoFlight:

Lower Cost (single model)

Shorter development schedule

## Cons

Prototype:

Higher Cost (additional model)

Longer schedule

Protoflight:

Higher risk to discover issues too late

More complex spares approach

No further model available for operations, troubleshooting, etc.)

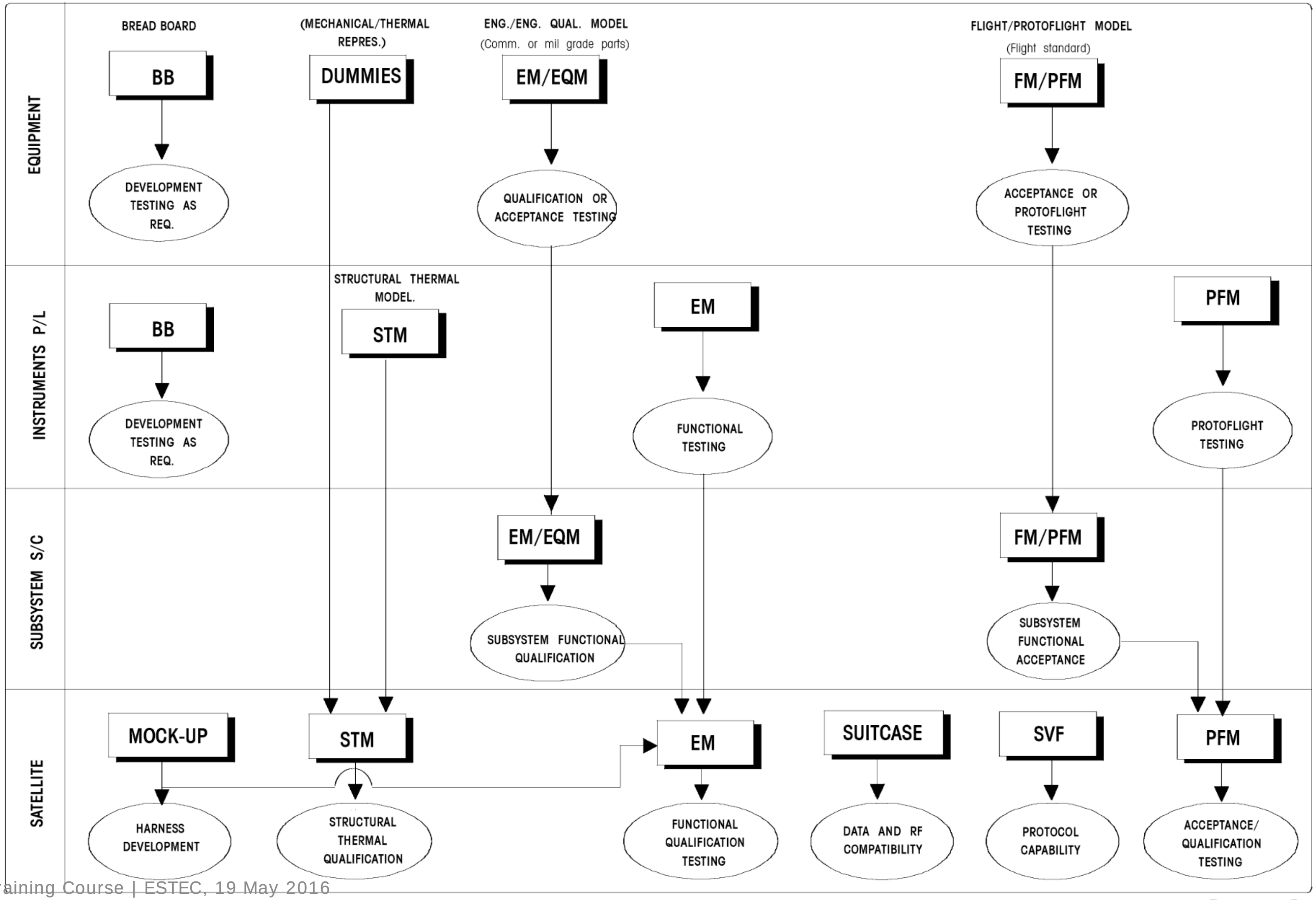
The cost and schedule saving of the Protoflight approach often overrules all other considerations.

Protoflight approach is ideal for "standard" missions with high degree of recurrent equipment

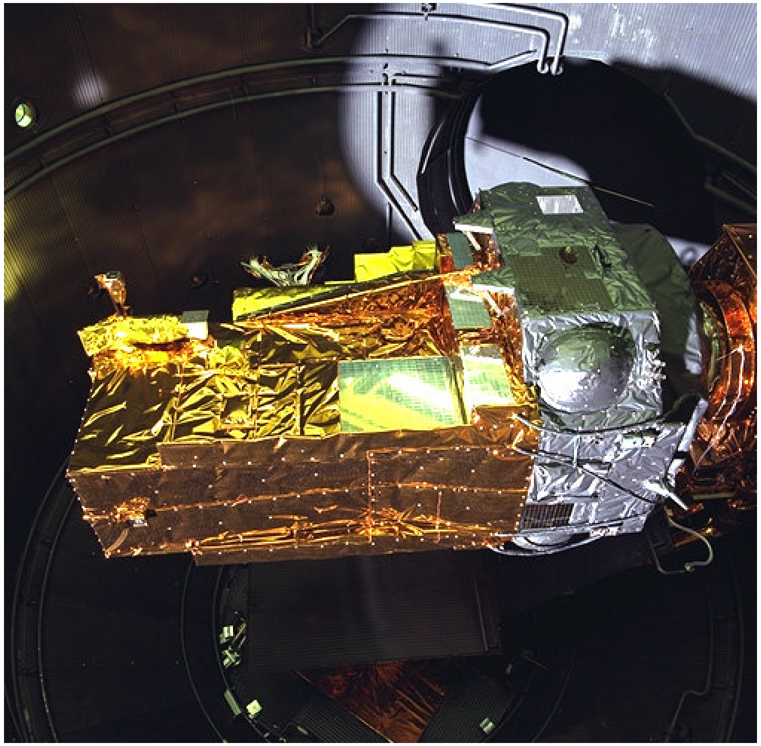
# Proto-flight practical approach

- Generally, risk mitigation for Protoflight Approach consists on:
  - 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)

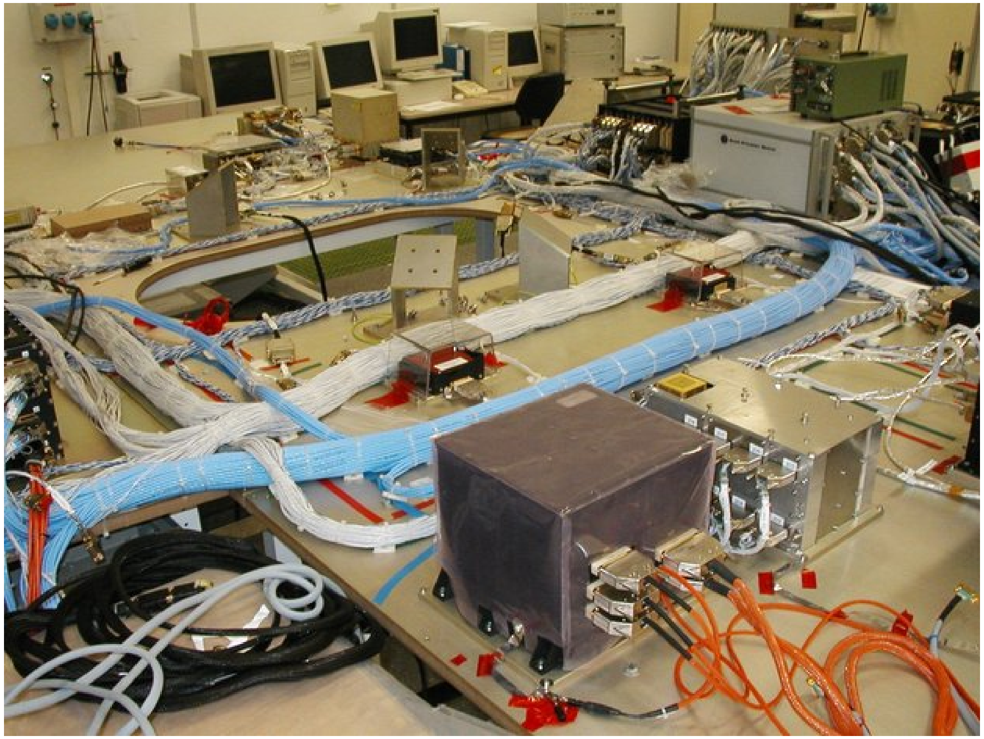
# ECSS-E-ST-10-02C - Overall Model Approach – Hybrid Example



# 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

STM

EM (composed of all the equipment EQMs)

FM (even if it was called at that time PFM)

## Cryosat

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

PFM

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

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

This forms the basis of the procurement activities

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

# Product Matrix - Examples

Assume the Proba-3 mission consisting on 2 small satellites flying in formation in a HEO orbit and launched by PSLV:

1. Reaction wheels from a German small satellite mission in LEO are found suitable in terms of performance:

   Which category are they ? And which models shall be procured ?

2. The mission requires laser-based relative attitude and position sensors of unprecedented accuracy:

   Which category are they ? And which models shall be procured ?

3. Coarse Analogue Sun sensors are used for safe mode

   Which category are they ? And which models shall be procured ?

4. Integrated On-board Computer and PCDU (ADPMS) is a recurrent item from the Proba-V mission

   Which category is it? And which model shall be procured ?

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

1. 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
2. **Verification Control Document (VCD**) (part of Design Justification File): lists the requirements to be verified with the selected methods in the applicable stages at the defined levels. It contains the Verification Matrix
3. 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 of these documents are in Annexes to 10-02C

1. 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.
2. The means to monitor the verification are the VCD and the verification database

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

Guidelines for tailoring are provided in ECSS-E-HB-10-02A (verification guidelines), Annex B.

Requirements that can be tailored and requirements that are recommended NOT to be tailored are indicated:

- Per type of Mission
- Per phase of Project
- Per level within product tree
- Per typical product (HW unit, SW component, Space Element, GSE, Launcher, Ground Segment, Overall System)

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

# Testing

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

1. Provides requirements for testing in general and in particular at space segment element (e.g. spacecraft or instrument) and equipment level
2. Defines the tests to be performed to qualify and accept for flight all equipment sorted per “types” and all elements
3. Defines levels and pass criteria for the above tests
4. Notes:
    a. End-to-end System validation is not included and should be project-specific (when required)
    b. 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)
    c. 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 carried out for development. This is left to the project to define.
- Development Models (sometimes also called breadboards – a terminology not used in ECSS) are built on-purpose for development testing
- 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 tolerance on the most important test parameters are specified:

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

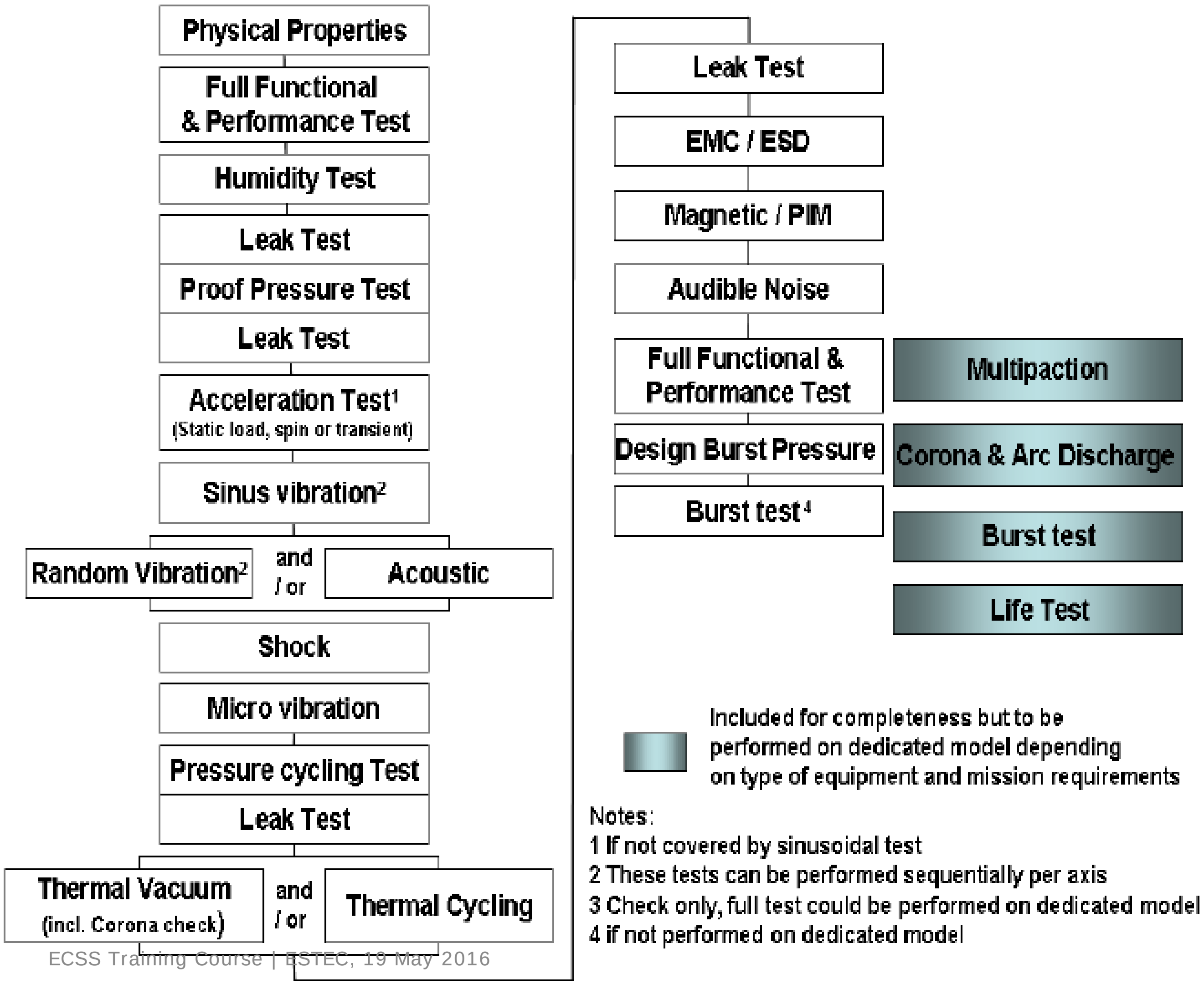
| Test parameters | Tolerances |
|---|---|
| Forces or torque | ±10 % |
| **9. Audible noise (for Crewed Element only)** | |
| Sound-power (1/3 octave band centre frequency) | |
| 32,5 Hz - 160 Hz | ±3 dB |
| 160 Hz – 16 kHz | ±2 dB |
| **9. Shock** | |
| Response spectrum amplitude (1/12 octave centre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

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

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

| Test parameters | Accuracy |
|---|---|
| **1. Mass** | |
| Space segment equipment and space segment element | ± 0,05 % or 1 g whatever is the heavier |
| **2. Centre of gravity (CoG)** | |
| Space segment equipment | Within a 1 mm radius sphere |
| Space segment element | ± 2,5 mm along launch axis<br>± 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<br>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 acceptable) shall follow a pre-defined sequence

This is based on trying 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.

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

| 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 |

- 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)

# ECSS-E-ST-10-03C – Equipment Qualification Tests

The qualification testing shall be conducted on dedicated QM's that are produced from the same drawings, using the same materials, tooling and methods as the flight item.

| Test | Reference clause | Ref. to Level & Duration | Applicability versus types of space segment equipment | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | a | b | c | d | e | f | g | h | i | j | k | l |
| **General** | | | | | | | | | | | | | | |
| Functional and performance (FFT/RFT) | 5.5.1.1 | | R | R | R | R | R | R | R | R | R | R | R | R |
| Humidity | 5.5.1.2 | | X | X | X | X | X | X | X | X | X | X | - | X |
| Life | 5.5.1.3 | See Table 5-2 No 1 | X | X | R | R | X | X | R | X | X | R | - | - |
| Burn-in | 5.5.1.4 | | X | - | - | X | - | - | X | - | - | - | - | - |
| **Mechanical** | | | | | | | | | | | | | | |
| Physical properties | 5.5.2.1 | | R | R | R | R | R | R | R | R | R | R | R | R |
| Static load | 5.5.2.2 | See Table 5-2 No 2 | X | X | X | X | X | X | X | X | X | X | X | - |
| Spin | 5.5.2.2 | See Table 5-2 No 3 | X | X | X | X | X | X | X | X | X | X | X | - |
| Transient | 5.5.2.2 | See Table 5-2 No 4 | X | X | X | X | X | X | X | X | X | X | X | - |
| Random vibration | 5.5.2.3 | See Table 5-2 No 5 | R | X | R | R | R | R | R | R | X | X | X | - |
| Acoustic | 5.5.2.4 | See Table 5-2 No 6 | - | X | - | - | - | - | - | - | X | X | R | - |
| Sinusoidal vibration | 5.5.2.5 | See Table 5-2 No 7 | R | R | R | R | R | R | R | R | R | R | R | - |
| Shock | 5.5.2.6 | See Table 5-2 No 8 | R | X | R | R | R | X | R | X | R | R | - | - |
| Micro-vibration generated environment | 5.5.2.7 | | X | X | - | X | X | - | X | - | - | X | - | - |
| Micro-vibration susceptibility | 5.5.2.8 | See Table 5-2 No 9 | X | - | - | - | - | - | - | - | X | X | - | - |
| **Structural integrity** | | | | | | | | | | | | | | |
| Leak | 5.5.3.1 | See Table 5-2 No 10 | X | - | R | R | R | R | X | X | - | - | - | - |
| Proof pressure | 5.5.3.2 | See Table 5-2 No 11 | X | - | - | R | R | R | R | - | - | - | - | - |
| Pressure cycling | 5.5.3.3 | See Table 5-2 No 12 | X | - | - | R | R | R | R | - | - | - | - | - |
| Design burst pressure | 5.5.3.4 | See Table 5-2 No 13 | X | - | - | R | R | R | R | - | - | - | - | - |
| Burst | 5.5.3.5 | See Table 5-2 No 14 | X | - | - | R | R | R | R | - | - | - | - | - |
| **Thermal** | | | | | | | | | | | | | | |
| Thermal vacuum | 5.5.4.1 & 5.5.4.2 | See Table 5-2 No 15 | R | X | R | R | R | X | R | R | R | R | - | R |
| Thermal ambient | 5.5.4.1 & 5.5.4.3 | See Table 5-2 No 16 | R | X | R | R | R | X | R | R | R | R | - | - |
| **Electrical / RF** | | | | | | | | | | | | | | |
| EMC | 5.5.5.1 | See Table 5-2 No 17 | R | X | X | X | X | X | X | X | X | X | X | X |
| Magnetic | 5.5.5.2 | | X | X | X | X | X | X | X | X | X | X | X | X |
| ESD | 5.5.5.3 | See Table 5-2 No 19 | R | X | X | X | X | X | X | X | X | X | X | X |
| PIM | 5.5.5.4 | See Table 5-2 No 19 | X | X | - | - | - | - | - | - | - | - | - | - |
| Multipaction | 5.5.5.5 | | X | X | - | - | - | - | - | - | - | - | - | - |
| Corona and arc discharge | 5.5.5.6 | See Table 5-2 No 20 | R | R | R | - | - | - | - | - | - | - | - | - |
| **Mission specific** | | | | | | | | | | | | | | |
| Audible noise | 5.5.6.1 | | R | - | - | R | R | - | R | - | - | R | - | - |

**Key**

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

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

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

Examples of qualification factors:

For mechanical loads: KQ = 1.25 (recommended) over the limit loads or
+3dB for shock, random and acoustic expected spectra

For thermal: ±10 $^{0}$C on design max and min temperatures (operational and non-operational)

Some launchers require higher qualification factors. E.g. Soyuz asks for KQ = 1.3 on limit loads. In this case, the KQ from launcher is taken as reference.

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

The acceptance testing shall be conducted on all the flight products (incl. spares)

| Test | Reference clause | Ref. to Level & Duration | Applicability versus types of space segment equipment | | | | | | | | | | | | Application notes |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | a | b | c | d | e | f | g | h | i | j | k | l | |
| **General** | | | | | | | | | | | | | | | |
| Functional and performance (FFT/RFT) | 5.5.1.1 | | R | R | R | R | R | R | R | R | R | R | R | R | For k (solar array), the deployment test is mandatory before and after the environmental tests (manual deployment before the environmental tests). |
| Humidity | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| Life | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| Burn-in | 5.5.1.4 | | X | - | - | X | - | - | X | - | - | - | - | - | To be performed, if the total duration of the acceptance test sequence is insufficient to detect material and workmanship defect occurring in the space segment equipment lifetime. |
| **Mechanical** | | | | | | | | | | | | | | | |
| Physical properties | 5.5.2.1 | | R | R | R | R | R | R | R | R | R | R | R | R | Upon agreement with customer the CoG and MoI is not measured by test but calculated. |
| Static load | | | - | - | - | - | - | X | - | - | - | - | - | - | |
| Spin | | | - | - | - | - | - | - | - | - | - | - | - | - | General structural proof test is performed on pressure vessel if no covered by higher level test (e.g. sinusoidal with full tanks). |
| 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 random vibration test should be added to acoustic test for fixed solar array mounted directly to the spacecraft side wall (without offset bracket). |
| Acoustic | 5.5.2.4 | See Table 5-4 No 2 | - | X | - | - | - | - | - | - | X | X | R | - | For b (antennas), i (optical), j (mechanism), random vibration or acoustic test is selected depending on the type, size and location of the space segment equipment. For k (solar array), acoustic acceptance testing of recurrent FMs (from the second FM) can be omitted on condition that they are subjected to acceptance testing at space segment element level. |
| Sinusoidal vibration | 5.5.2.5 | See Table 5-4 No 3 | - | - | - | - | - | - | - | - | - | - | R | - | For k (solar array), sinusoidal vibration acceptance testing of recurrent FMs (from the second FM) can be omitted on condition that they are subjected to acceptance testing at space segment element level, or in case of significant flight heritage on design, processes and manufacturers. |
| 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 only if need is identified by analysis. |
| **Structural integrity** | | | | | | | | | | | | | | | |
| Leak | 5.5.3.1 | See Table 5-4 No 5 | X | - | R | R | R | R | X | - | - | - | - | - | For a (electronic, electrical and RF equipment) required only on sealed or pressurized space segment equipment. |
| Proof pressure | 5.5.3.2 | See Table 5-4 No 6 | - | - | - | R | R | R | X | - | - | - | - | - | For c (battery) proof pressure, is performed at cell level (i.e. component level). |
| Pressure cycling | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| Design burst pressure | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| Burst | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| **Thermal** | | | | | | | | | | | | | | | |
| Thermal vacuum | 5.5.4.1 & 5.5.4.2 | See Table 5-4 No 7 | R | X | R | R | R | X | R | R | R | R | - | R | |
| Thermal ambient | 5.5.4.1 & 5.5.4.3 | See Table 5-4 No 8 | R | X | R | R | R | X | R | R | R | R | - | - | Can be combined in thermal vacuum test. Tests not required for batteries that cannot be recharged after testing. |
| **Electrical / RF** | | | | | | | | | | | | | | | |
| EMC | 5.5.5.1 | See Table 5-4 No 9 | R | X | X | X | X | X | X | X | X | X | X | X | For equipment without electronic test are limited to bonding test. |
| Magnetic | 5.5.5.2 | | X | X | X | X | X | X | X | X | X | X | - | X | Magnetic test to be performed if justified by mission needs, in accordance with the EMCCP. |
| ESD | | | - | - | - | - | - | - | - | - | - | - | - | - | |
| PIM | 5.5.5.4 | See Table 5-4 No 10 | X | X | - | - | - | - | X | - | X | - | - | - | |
| Multipaction | 5.5.5.5 | | X | X | - | - | - | - | - | - | - | - | - | - | |
| Corona and arc discharge | 5.5.5.6 | See Table 5-4 No 11 | R | R | R | - | - | - | - | - | - | - | - | - | For condition of applicability of test, refer to 5.5.5.6. |
| **Mission specific** | | | | | | | | | | | | | | | |
| Audible noise | 5.5.6.1 | | R | R | - | R | R | - | R | - | - | R | - | - | Required for space segment equipment for crewed space segment element. |

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

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

Examples of acceptance factors:

For mechanical loads: KA = 1. (recommended) over the limit loads or +0dB for shock, random and acoustic expected spectra

For thermal: ±5 $^{0}$C on design max and min temperatures (operational and non-operational)

# ECSS-E-ST-10-03C – Equipment Protoflight Tests, Test Levels and durations

- Protoflight tests are the same as for qualification except for static loads (not required) and destructive tests (burst – obviously not for the PFM)
- The Protoflight test levels and durations shall be as follows:
  1. Proto-flight test levels: as qualification levels.
  2. Proto-flight test durations: as acceptance durations (e.g. 4 cycles for thermal).

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

Taken as an example for Space Segment Element Testing

Note that tests are different from the equipment ones

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

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

R Mandatory

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

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

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

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

Documents:

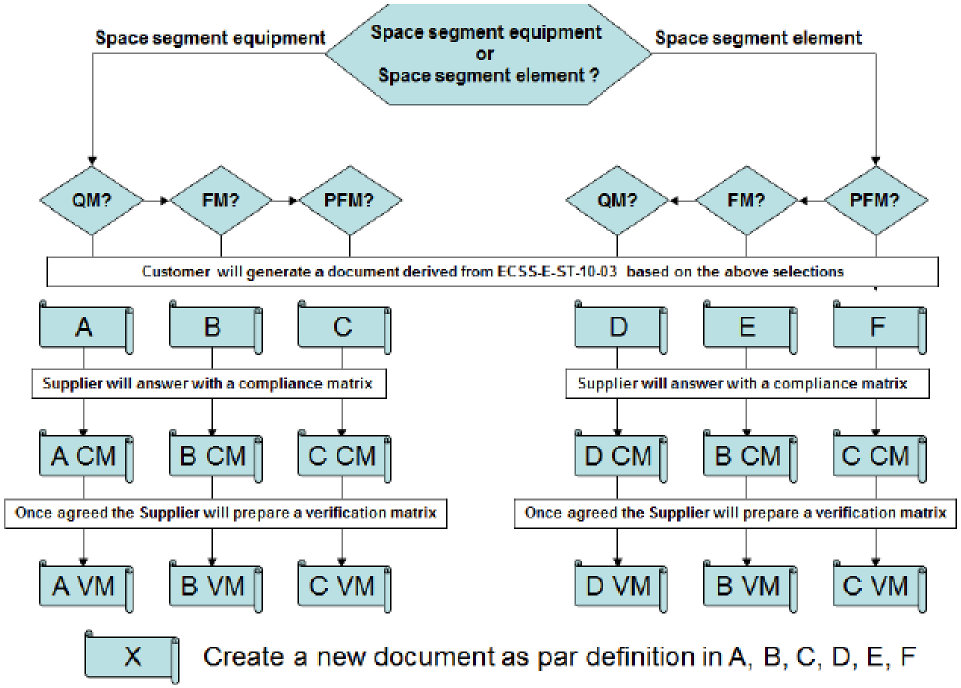
1. AIT Plan – describes the AIT process and, with the Verification Plan, gives the process for requirements verification. It drives the project and cost schedule
2. Test specification - defines the purpose of the test, the test approach, the item under test and the set-up, the required GSE, test tools, test instrumentation and measurement accuracy, test conditions, test sequence, test facility, pass/fail criteria, required documentation, participants and test schedule
3. Test Procedure - detailed step-by-step instructions for conducting test activities

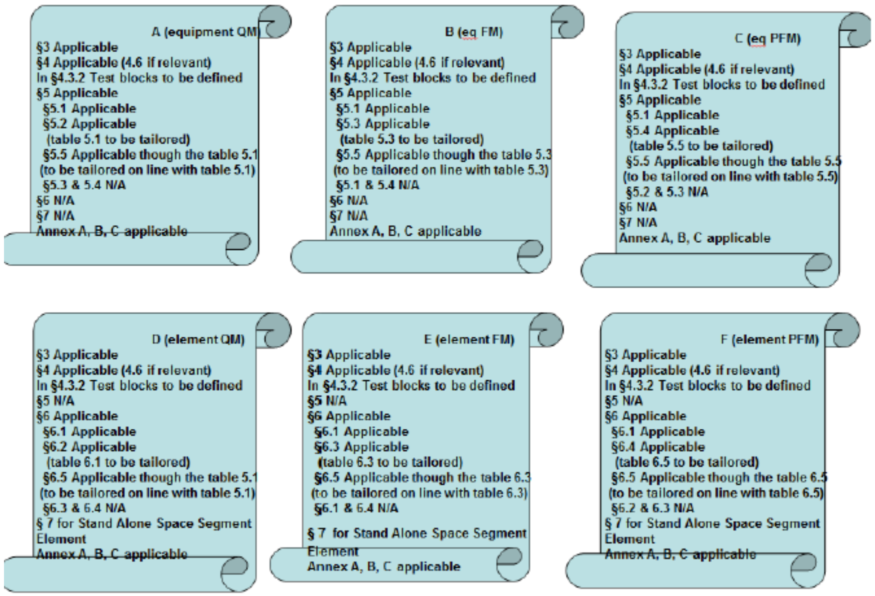
Programme:

- 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

1. 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:
   a. (Earth) gravity: EIGEN-GLO4C model is specified complemented by IERS models and JPL Planet and Lunar Ephemerides for perturbations
   b. (Earth) Magnetic field (internal and external)
   c. Electromagnetic radiation (e.g. thermal)
   d. (Earth) atmosphere - NRLMSISE-00 model for altitudes < 120 km, JB-2006 model above 120 km (Annex G mentions also Planetary atmospheres)
   e. (Earth) plasma (e.g. charged particles) and energetic particles radiation (Annex I gives some planetary environment data)
   f. Space debris and meteoroids
   g. Contamination

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

1. The Standard only provide requirements for the preparation of a Radiation Environment Specification and not for an overall Mission Environment Specification
2. 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

1. Generally for Earth-bound missions, all natural and main induced environments are well covered and within each section the standard provides tailoring guidelines

2. For interplanetary missions, especially if including a surface mission (e.g. ExoMars, Lunar Lander, etc.), project own environment description and requirements are needed

3. 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

4. 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

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

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

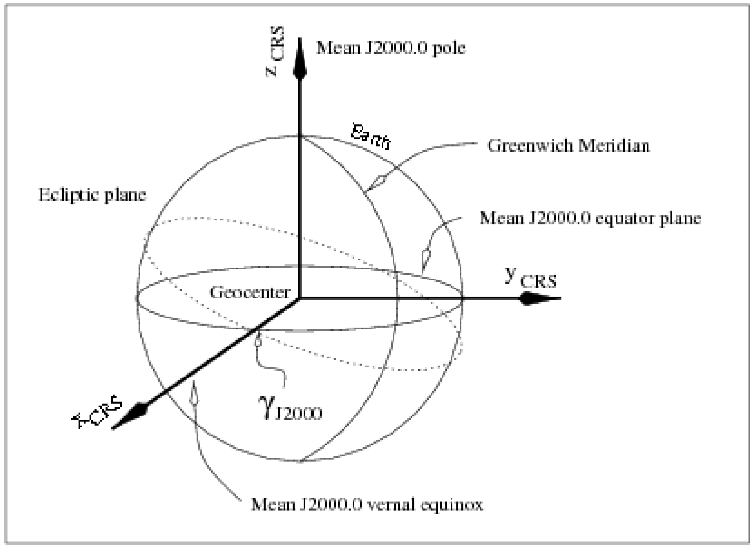
The Standard does not provide " recommended" Coordinate Systems definition but leave it to each individual project to define and to choose from International Standards (those are however not of much practical use).

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 RCS

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



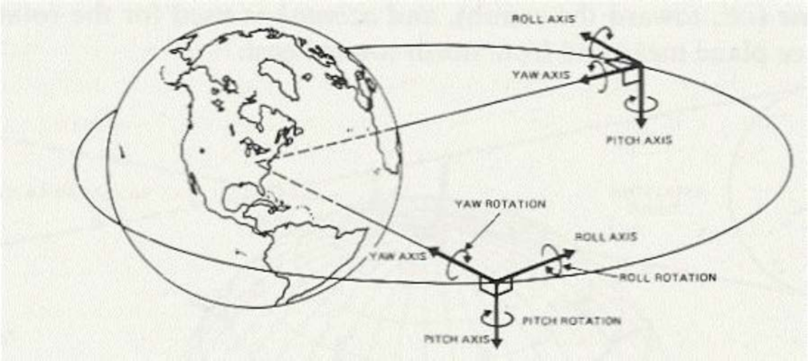

Earth Centred Inertial (ECI) used for satellite motion

**O**rigin: 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

**O**rigin: 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

# ECSS-E-ST-10-09C - Examples of commonly used RCS - 2

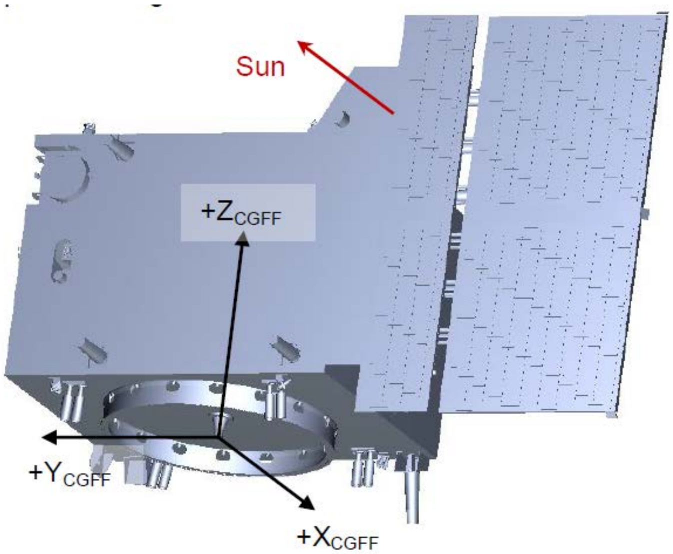
Mechanically-fixed Satellite Coordinate System used to identify attitude and locations onboard the satellite

**O**rigin: 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

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

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

1. Provides extensive description of the recommended analysis processes for definition of the expected radiation environment and effects on a space mission
2. It is complemented by the guidelines HB (not normative) which give explanations, formulas and examples for the calculations.
3. Includes:
   a. Summary of radiation effects (highly recommended reading !)
   b. Calculation methods and margins
   c. Shielding approach
   d. 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)

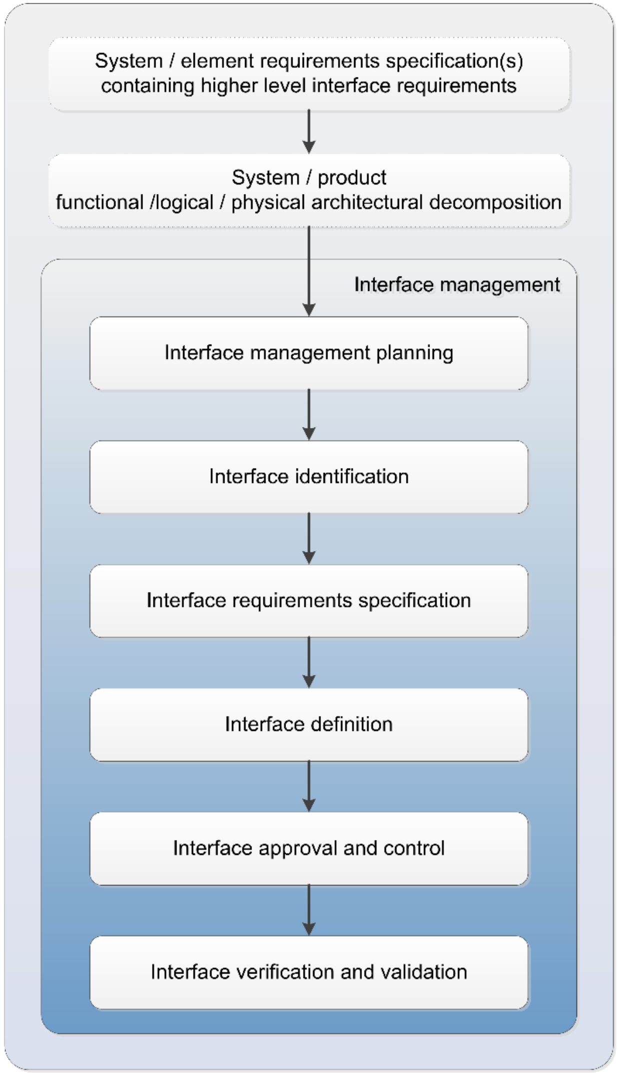
# ECSS-E-ST-10-12C - Methods for Calculation of Radiation - Application

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

| Sub-system or component | Technology | Effect |
|---|---|---|
| Integrated circuits | Power MOS | TID<br>SEGR<br>SEB |
| | CMOS | TID<br>SEE (generally) |
| | Bipolar | TNID<br>SEU<br>SET<br>TID |
| | BiCMOS | TID<br>TNID<br>SEE (generally) |
| | SOI | TID<br>SEE (generally exc. SEL) |
| Optoelectronics and sensors (1) | MEMS [a] | TID |
| | CCD | TNID<br>TID<br>Enhanced background (SEE) |
| | CMOS APS | TNID<br>TID<br>SEE (generally)<br>Enhanced background |
| | Photodiodes | TNID<br>TID<br>SET |
| | LEDs | TNID<br>TID |
| | laser LEDs | TNID<br>TID |
| | Opto-couplers | TNID<br>TID<br>SET |

| Sub-system or component | Technology | Effect |
|---|---|---|
| Optoelectronics and sensors (2) | $\gamma$-ray or X-ray scintillator | TNID (alkali halides)<br>Enhanced background |
| | $\gamma$-ray semiconductor [b] | TNID<br>Enhanced background |
| | charged particle detectors | TNID (scintillator [c] & semiconductor)<br>Enhanced background<br>TID (scintillator [c] & semiconductors) |
| | microchannel plates | Enhanced background |
| | photomultiplier tubes | Enhanced background |
| | Other imaging sensors<br>(*e.g.* InSb, InGaAs, HgCdTe, GaAs and GaAlAs) | TNID<br>Enhanced background |
| | Gravity wave sensors | Enhanced background |
| Solar cells | Cover glass & bonding materials | TID |
| | Cell | TNID |
| Non-optical materials | Crystal oscillators | TID |
| | polymers | TID (radiolysis) |
| Optical materials | silica glasses | TID |
| | alkali halides | TID<br>TNID |
| Radiobiological effects | | Early effects |
| | | Stochastic effects |
| | | Deterministic late effects |

# ECSS-E-ST-10-24C "Interface Management" (Published 1 June 2015)



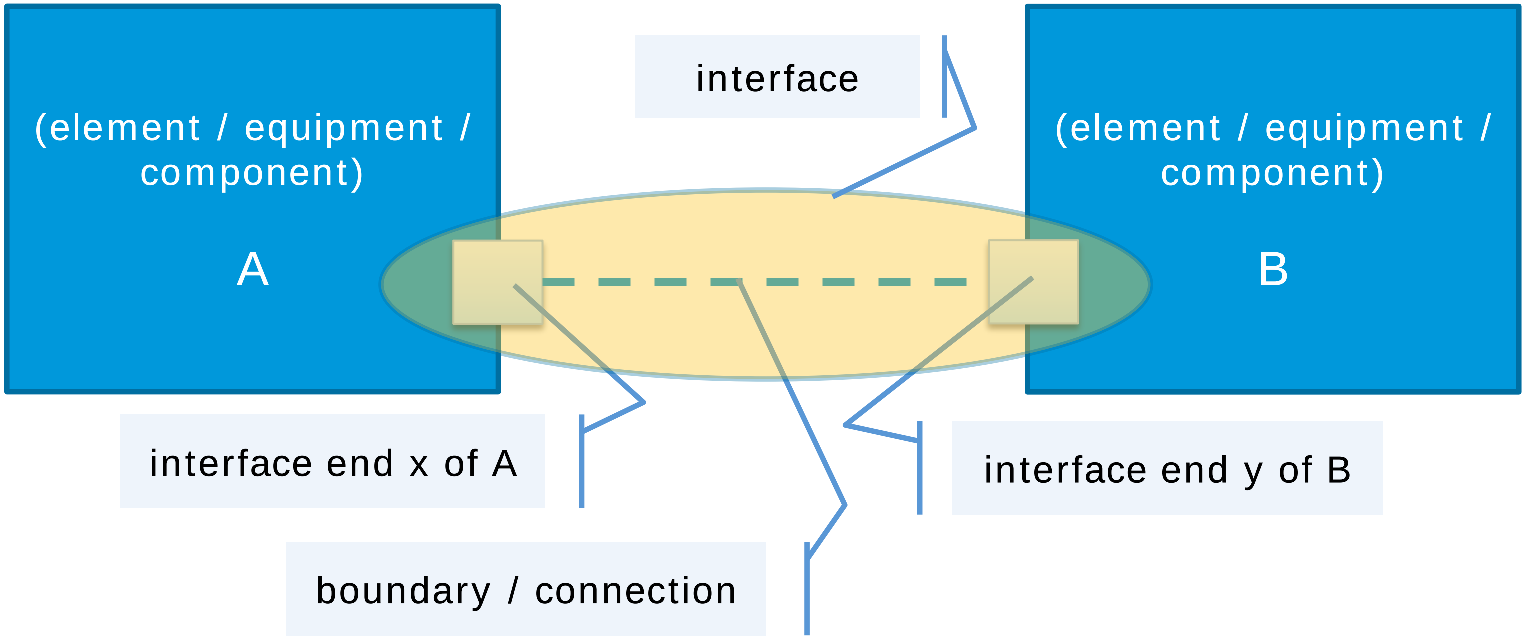

Describes the process for interface management and control, which is a critical system activity

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

It includes:

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

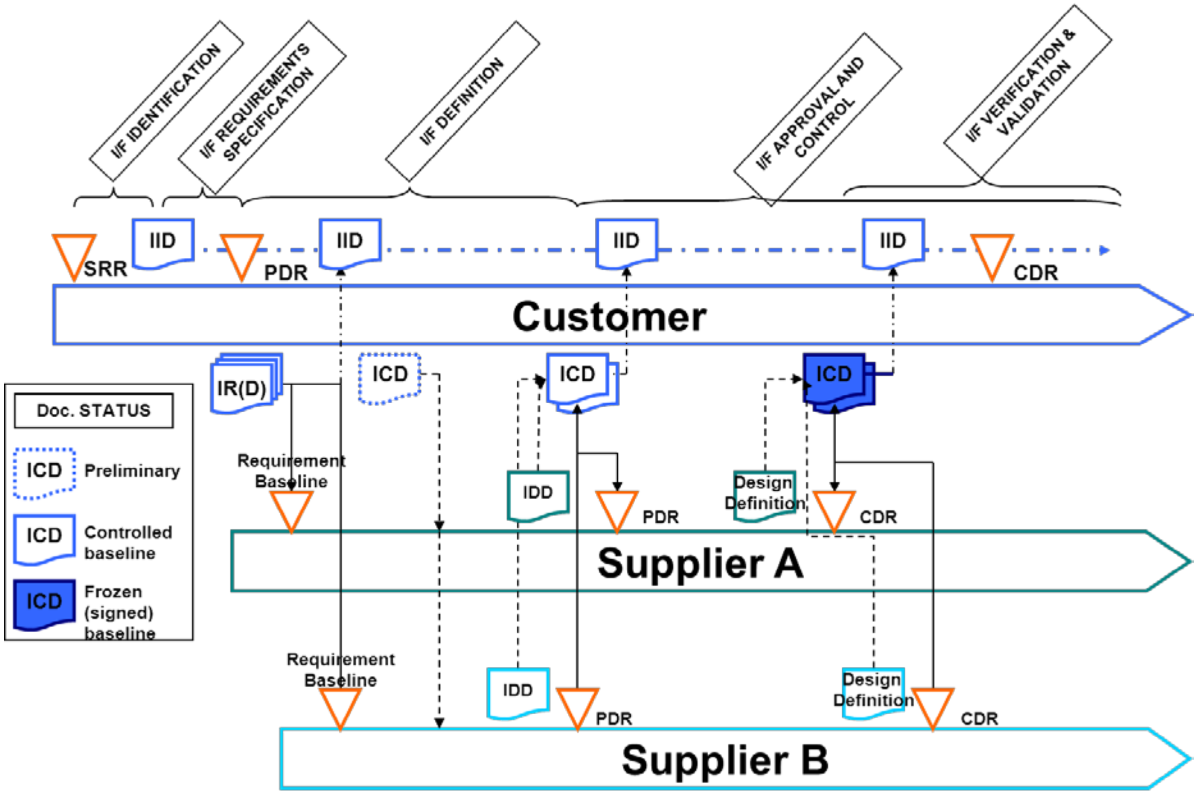
# ECSS-E-ST-10-24C “Interface Management” Definitions



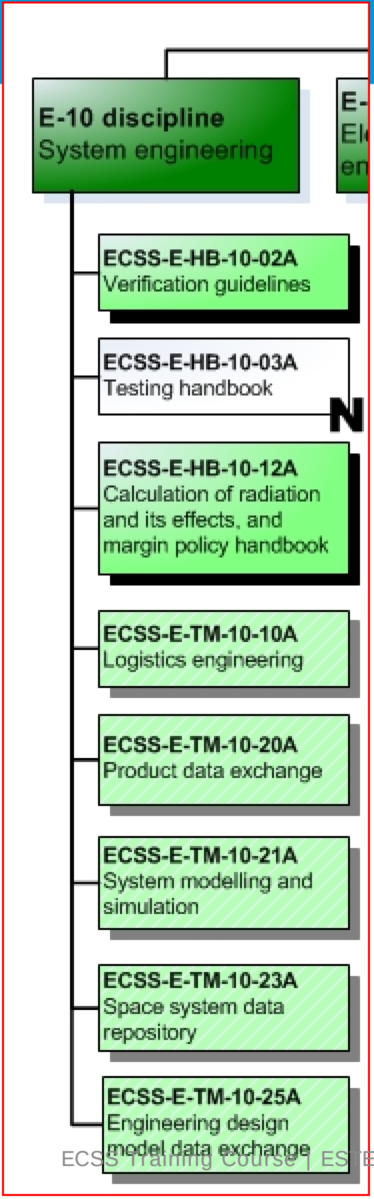

- **interface** – boundary where two or more products meet and interact
- **interface end** – one side of an interface
- **external interface** – interface between items under different programme responsibilities
- **internal interface** – interface between items within the same programme responsibility

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

## Generic interface management life cycle



# 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.*

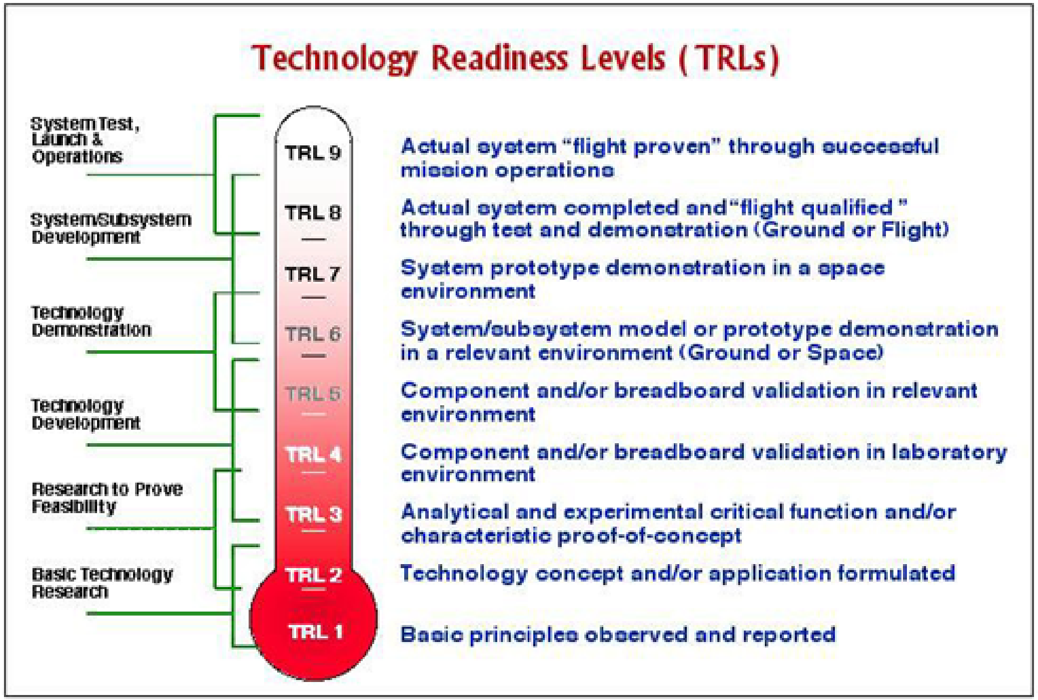
*ECSS-S-ST-00C, c5.2.3:*
*Technical memoranda are non-normative documents providing useful information to the space community on a specific subject.*

1. ECSS-E-HB-10-02A Verification guidelines
2. ECSS-E-HB-10-12A Calculation of radiation and its effects and margin policy handbook
3. ECSS-E-TM-10-10A Logistics engineering
4. ECSS-E-TM-10-20A Product data exchange
5. ECSS-E-TM-10-21A System modeling and simulation
6. ECSS-E-TM-10-23A Space system data repository
7. ECSS-E-TM-10-25A Engineering design model data exchange (CDF)

# ISO 24113 "Space debris mitigation requirements" adopted through ECSS-U-AS-11C

1. Not part of E-10 series but large impact on system design
2. ECSS has adopted the international standard:
   ISO 24113: Space systems - Space debris mitigation requirements.
3. Only small modifications have been introduced via the Standard:
   ECSS-U-AS-10C
4. Policy in summary:
   a. All ESA Space Vehicle including Satellites, Launchers and Inhabited Vehicles shall be disposed of
   b. 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
   c. Either moved to non-protected regions or re-entered into Earth atmosphere for break-up and burning
   d. Uncontrolled re-entry not allowed if casualty risk > 10-4 (the case of ATV and possibly Envisat)
   e. 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 by ECSS through Adoption Notice 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

# 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. |

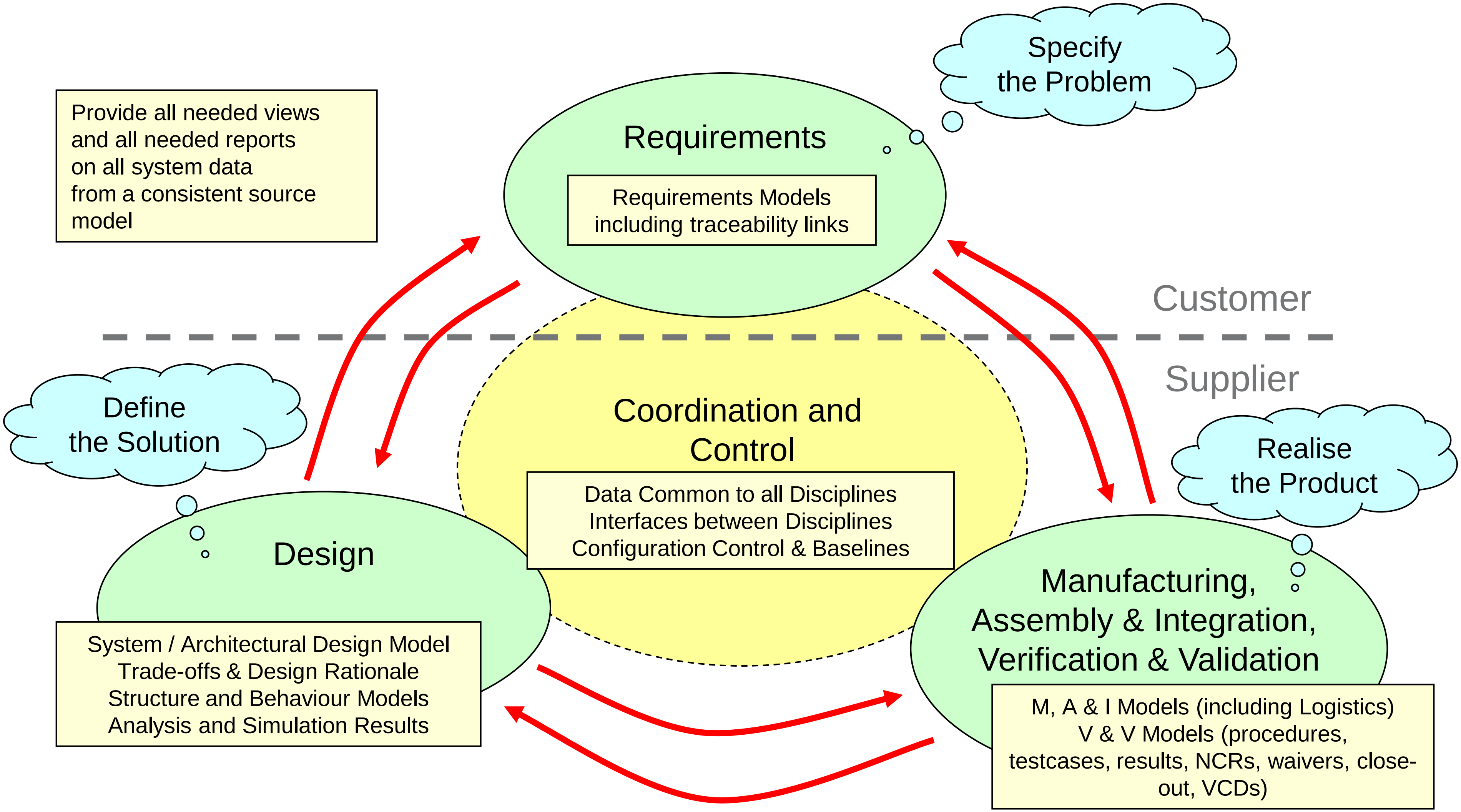
# TRL Scale as Adopted through E-AS-11C "Work achievement"

| 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.<br>Breadboard definition for the functional performance verification. Breadboard test reports. |
| TRL 5 | Preliminary definition of performance requirements and of the relevant environment.<br>Identification and analysis of the element critical functions.<br>Preliminary design of the element, supported by appropriate models for the critical functions verification.<br>Critical function test plan. Analysis of scaling effects.<br>Breadboard definition for the critical function verification. Breadboard test reports. |
| TRL 6 | Definition of performance requirements and of the relevant environment.<br>Identification and analysis of the element critical functions.<br>Design of the element, supported by appropriate models for the critical functions verification.<br>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.<br>Model definition and realisation. Model test plan. Model test results. |
| TRL 8 | Flight model is built and integrated into the final system. Flight acceptance of the final system. |
| TRL 9 | Commissioning in early operation phase. In-orbit operation report. |

# Outlook: Gradually Increased use of Model-Based System Engineering (MBSE)

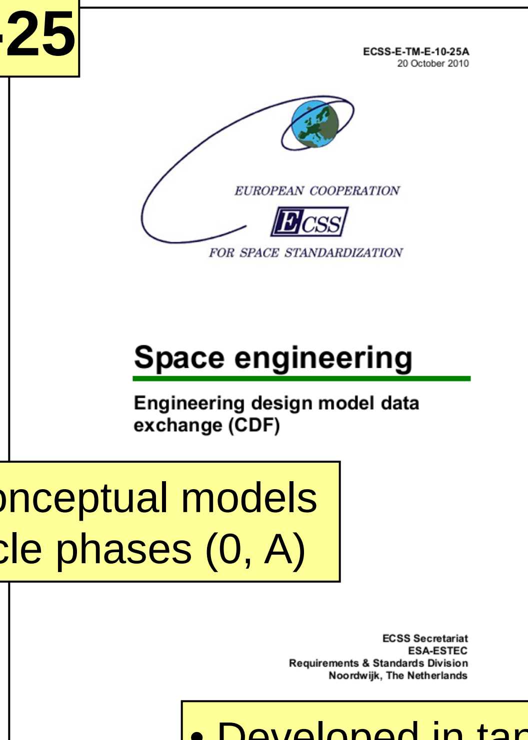
1. Since about 2006 there has been a growing trend to move to MBSE
2. INCOSE MBSE Initiative started early 21st century
3. OMG System Modelling Language (SysML) released 2010
4. MBSE tool implementations (COTS and open source) maturing and being put into industrial practice
5. Main goal: more efficient 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)
6. Main expected benefits:
   a. Single source definition of information
   b. Any number of (inherently consistent) views on the same information
   c. Manageable version, configuration and traceability control

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



# ECSS-E-TM-10-23 and E-TM-10-25 Towards a Semantic "Space System Data Repository"

## E-TM-10-25


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

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

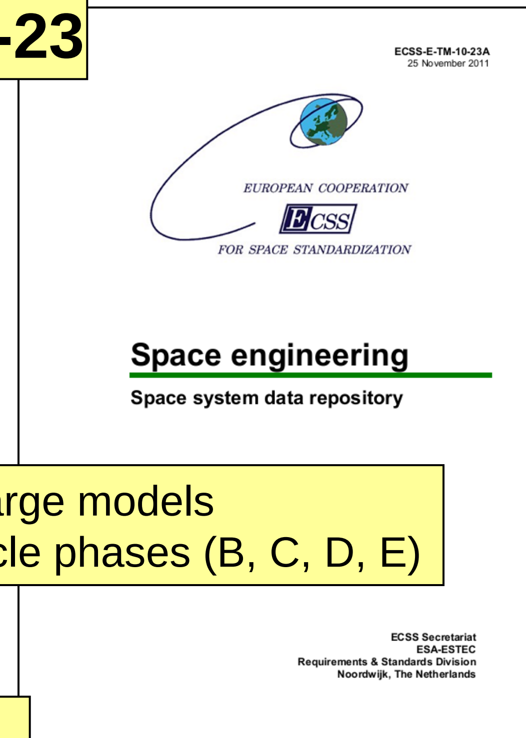
**Space engineering**

**Engineering design model data exchange (CDF)**

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

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

## E-TM-10-23


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

EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION

**Space engineering**

**Space system data repository**

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

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

- Developed in tandem
- Where possible use common approach
- Where possible align with SysML
- Future merge to single real standard
- E-TM-10-25A made available Oct 2010
- E-TM-10-23A made available Nov 2011

# ECSS Implementations and further development

1. Proof-of-concept tool for E-TM-10-23 validation available at Virtual Spacecraft Design site: http://www.vsd-project.org
2. Evolution of VSD used in EGS-CC (European Ground System Common Core) project
3. E-TM-10-25 implemented in Open Concurrent Design Tool (OCDT) under ESA Community Open Source License, see https://ocdt.esa.int
4. OCDT used in daily practice in ESTEC CDF
5. 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
6. Harmonisation activity “Space System Data Repository” was run in 2015, defining a roadmap for coming years to develop a genuine standard / best practice for MBSE for the European Space sector

# Useful references


1. ISO/IEC 15288, Systems and software engineering — System life cycle processes, http://en.wikipedia.org/wiki/ISO/IEC_15288
2. NASA/SP-2007-6105 Rev1, NASA Systems Engineering Handbook, http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20080008301.pdf
3. International Council on Systems Engineering (INCOSE), see http://www.incose.org
4. INCOSE MBSE Initiative, see http://www.omgwiki.org/MBSE/doku.php