UNIVERSITY OF Southampton

Project Lifecycles

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With additional material from the late Dr. Angelo Grubisic of the University of Southampton

Bibliography

Key Text:

Fortescue, P., Stark, J. and Swinerd, G. (Eds) ***Spacecraft Systems Engineering*** (4th Ed). John Wiley & Sons, Chichester, 2011.

Other Recommended Reading:

Ley, W., Wittmann, K. and Hallmann, W. ***Handbook of Space Technology***, John Wiley & Sons, Chichester, UK, 2009.

Larson, W.J. and Wertz, J.R. (Eds) ***Space Mission Analysis and Design*** (3rd Ed), Space Technology Series, Kluwer Academic Publishers, 1999.

https://ecss.nl/standards/ (Accessed 23-11-2020)

Learning Outcomes

1. Describe the main activities from phase 0 to phase F in a project lifecycle.
2. Explain in detail the various reviews which occur throughout a space project and relate this to the customer supply chain.
3. Describe the precise review definition, the phase which it occurs in and the objective of each review.
4. Describe the detailed responsibilities of a systems engineer from phase 0 to phase F in a project lifecycle. Be able to recall with precision the exact function of each phase.
5. Describe the provisions which ECSS sets out to allow the effective development and control of space systems projects.

Review of ECSS

ECSS Types of Documents

	ecss types of documents
standards	for direct use in invitation to tender and business agreements
handbooks	non-normative documents providing guidelines and/or collection of data
technical memoranda	non-normative documents providing useful info or data not yet mature for a standard or handbook

Adapted from: ESA Standards Division – "Introduction into the ECSS standardization system" – May 2016

Review of ECSS

ECSS Standards – https://ecss.nl/standards/

Space Project Management (red); Space Product Assurance (blue); Space Engineering (green).

They express what to do, not how

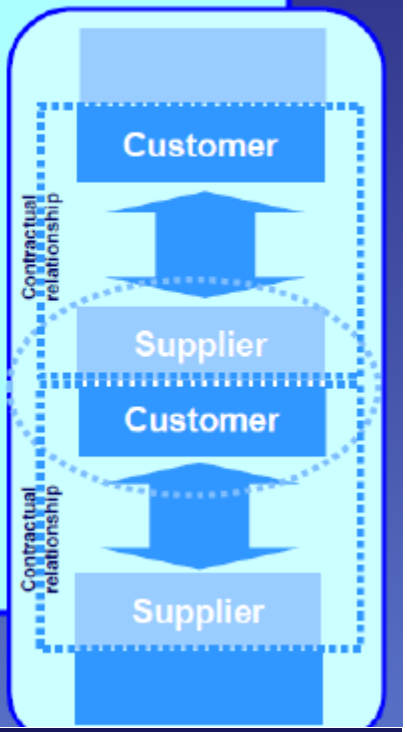
Therefore, the procedural part is not normally covered.
Handbooks are the appropriate documents for it.

They express this in term of regulatory provisions, i.e.

Requirements, recommendations or permissions
NOTE: Explanatory text is only included if necessary to support these provisions

These provisions are focused on a contractual relationship

The contractual model used in ECSS is defined in ECSS-S-00

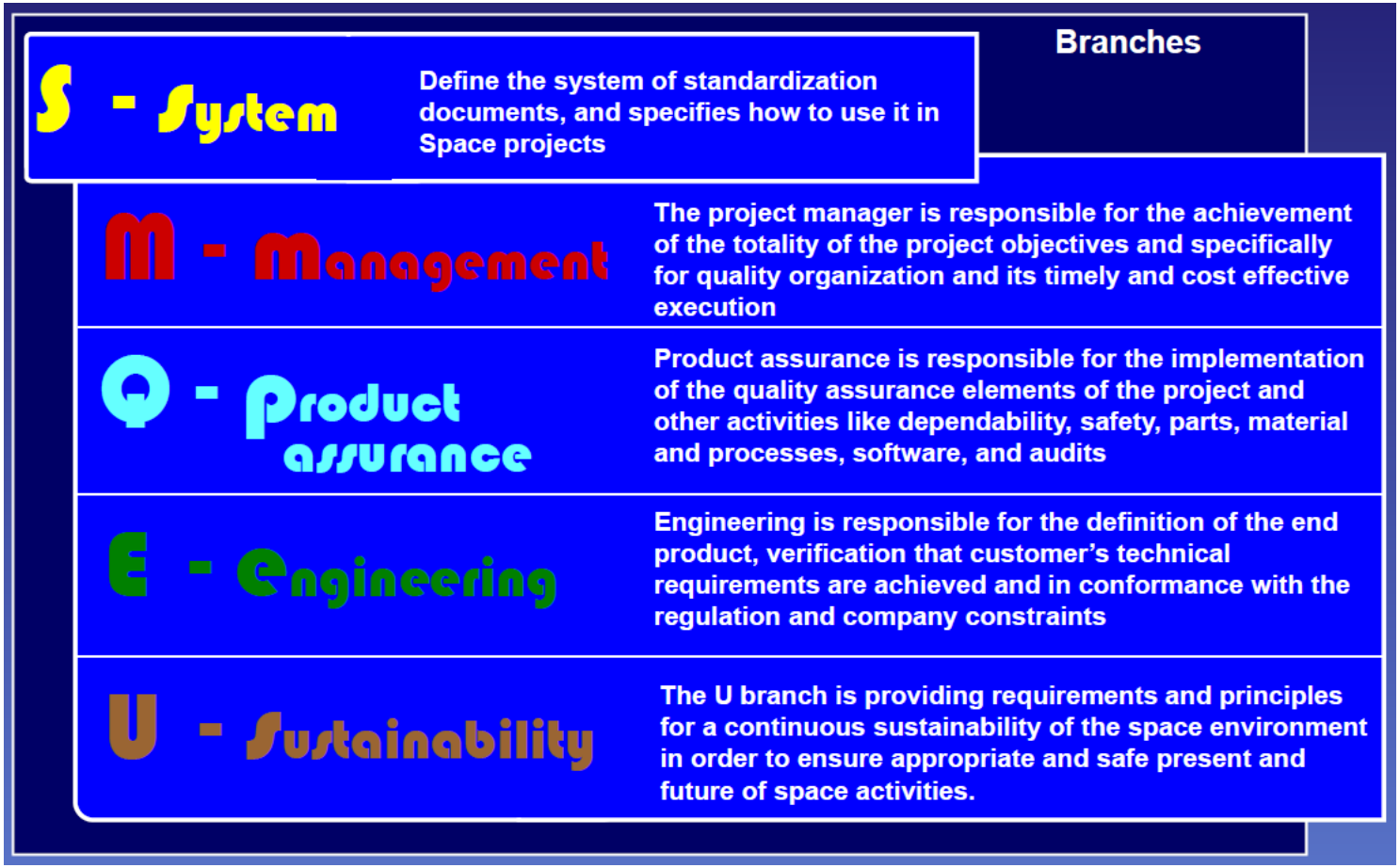


Nov. 2020

Adapted from: ESA Standards Division – "Introduction into the ECSS standardization system" – March 2017

Review of ECSS

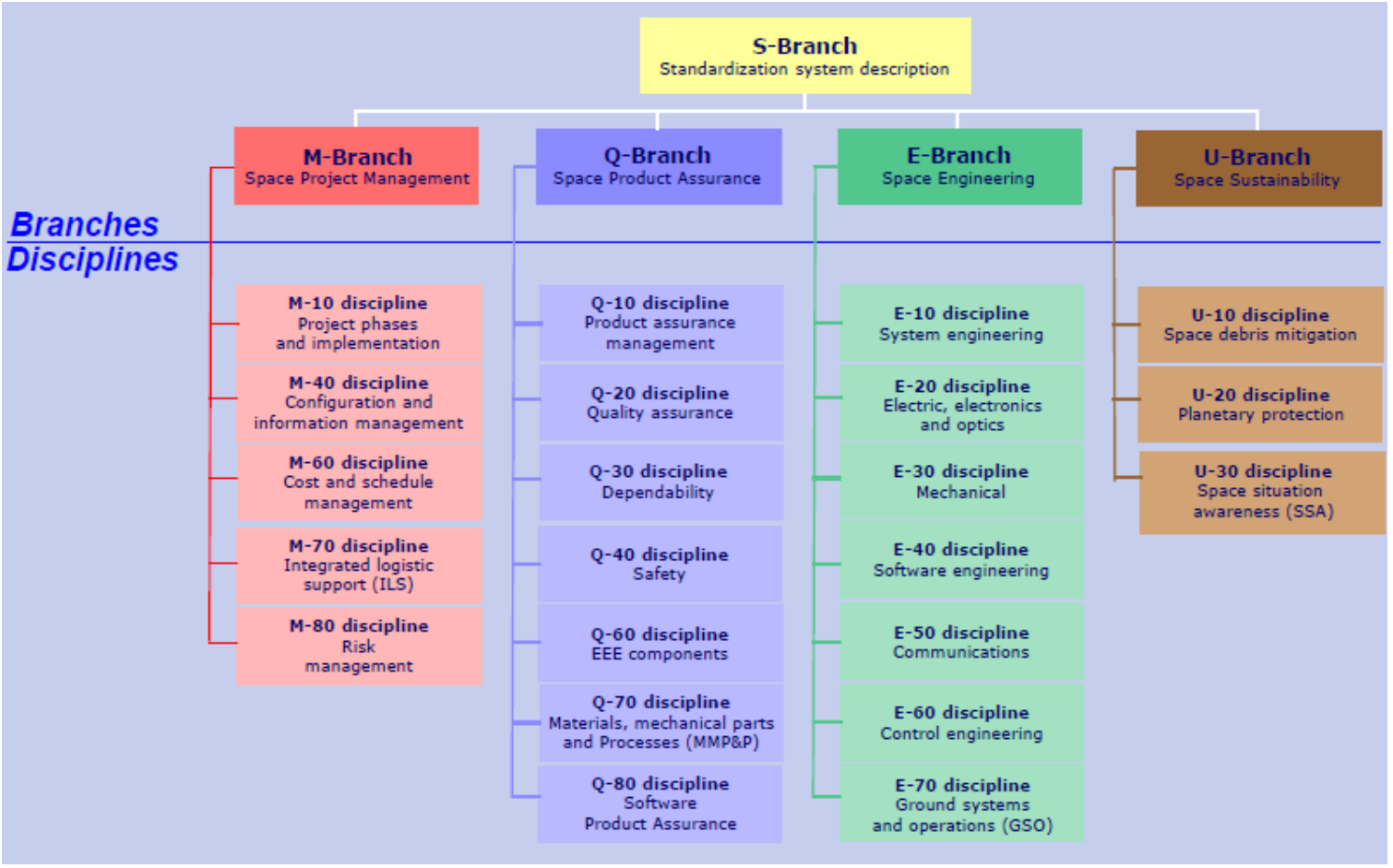
ECSS Documentation Structure



Adapted from: ESA Standards Division – "Introduction into the ECSS standardization system" – May 2016

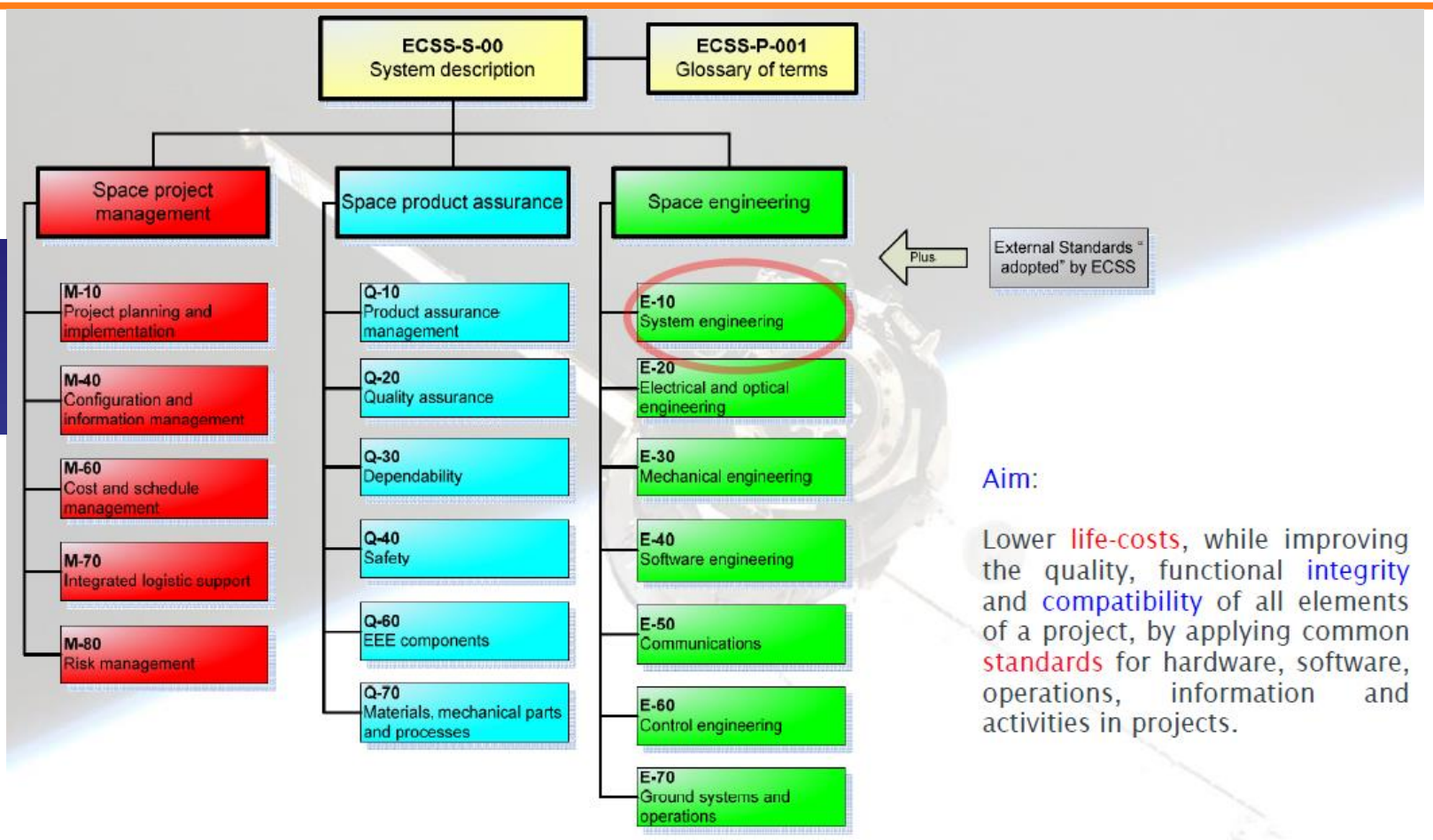
Review of ECSS

European Coordination for Space Standardisation (ECSS) Documentation Structure:



Adapted from: ESA Standards Division – "Introduction into the ECSS standardization system" – May 2016

ECSS and Systems Engineering



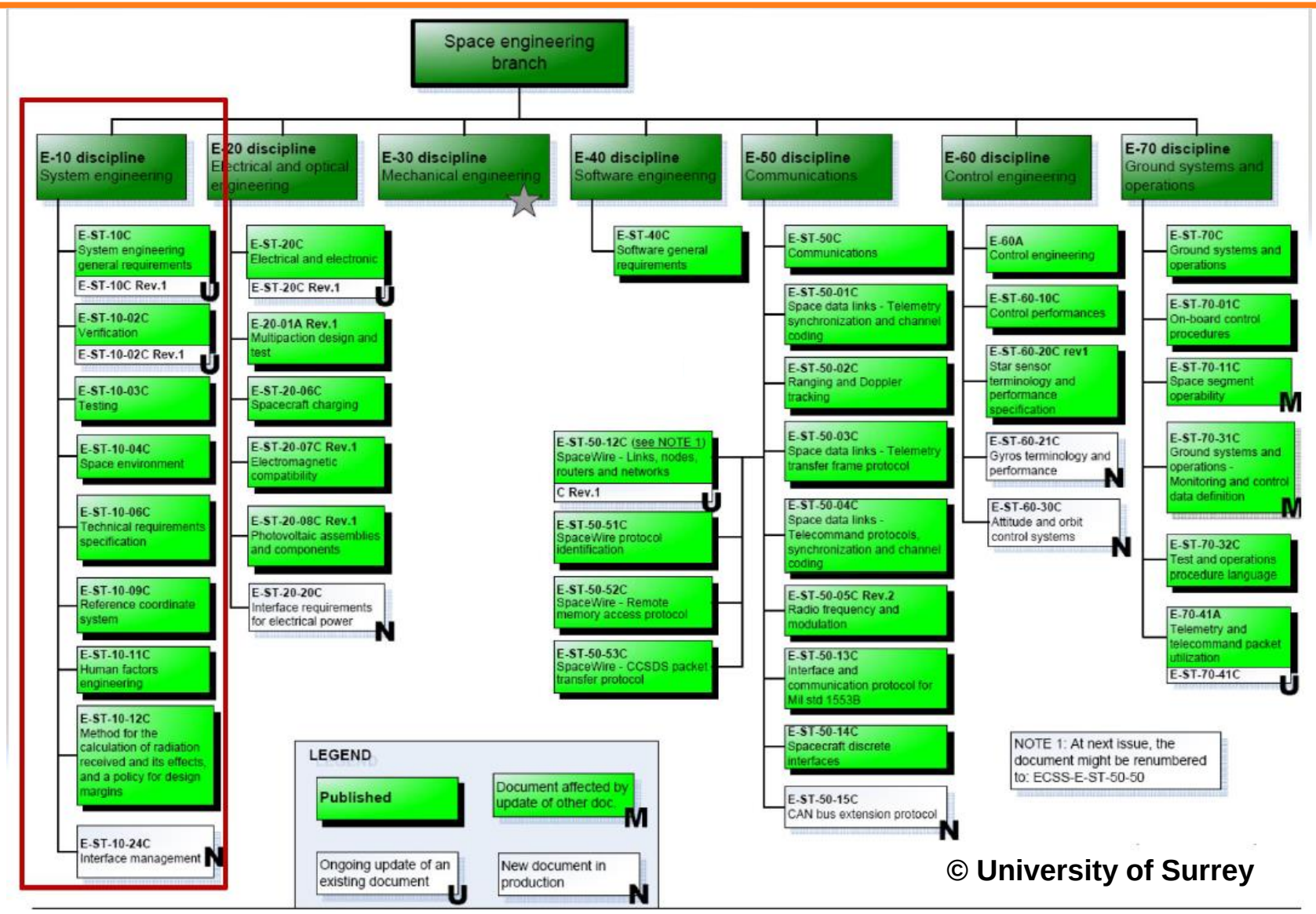
Aim:

Lower life-costs, while improving the quality, functional integrity and compatibility of all elements of a project, by applying common standards for hardware, software, operations, information and activities in projects.

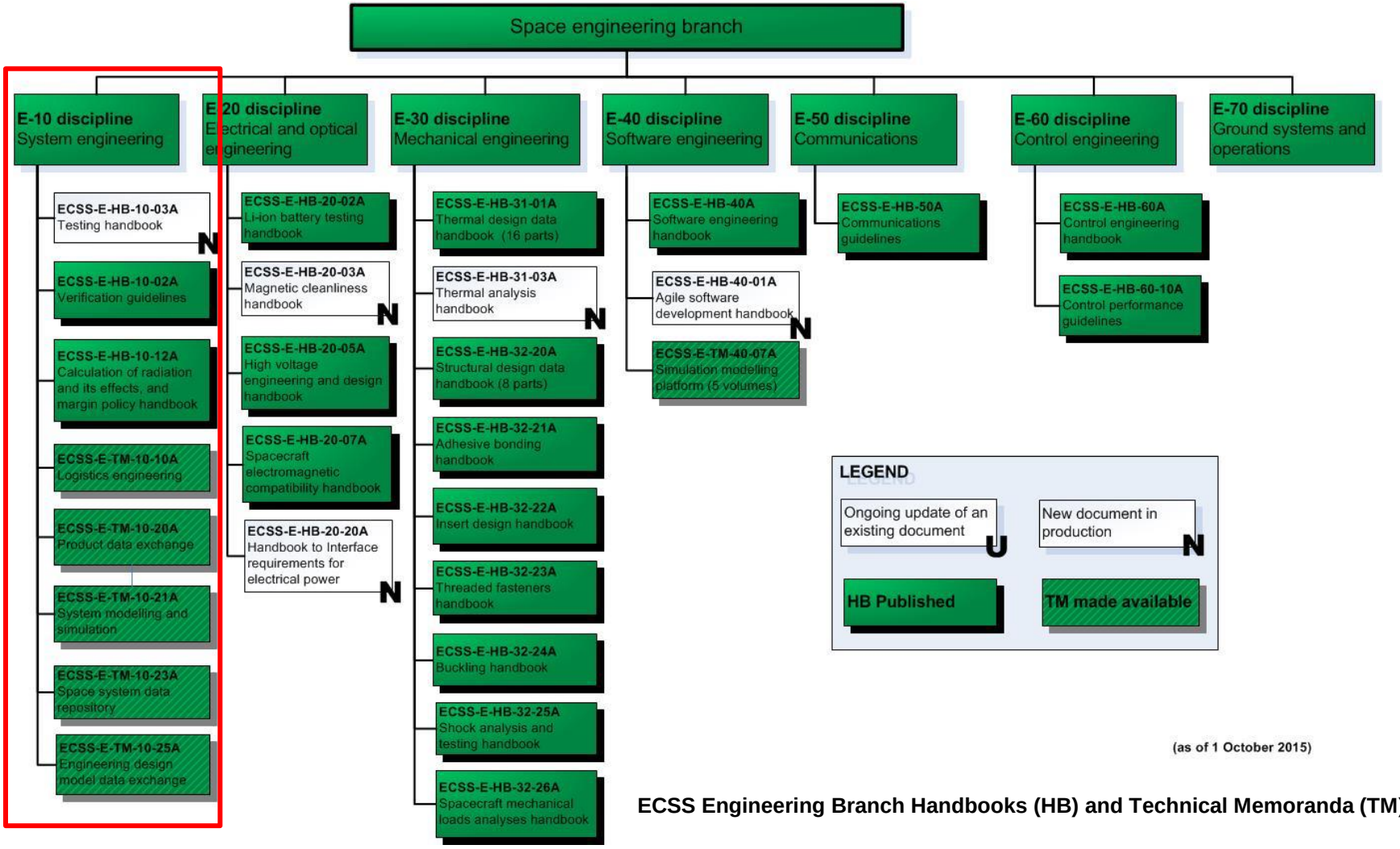
ECSS provides baseline working practices for systems engineering in line with ESA/EU/industry requirements and recommendations

ECSS and Systems Engineering

E-10 Discipline – Systems Engineering



ECSS and Systems Engineering



ECSS Engineering Branch Handbooks (HB) and Technical Memoranda (TM)

Adapted from: ESA Standards Division – "Introduction into the ECSS standardization system" – May 2016

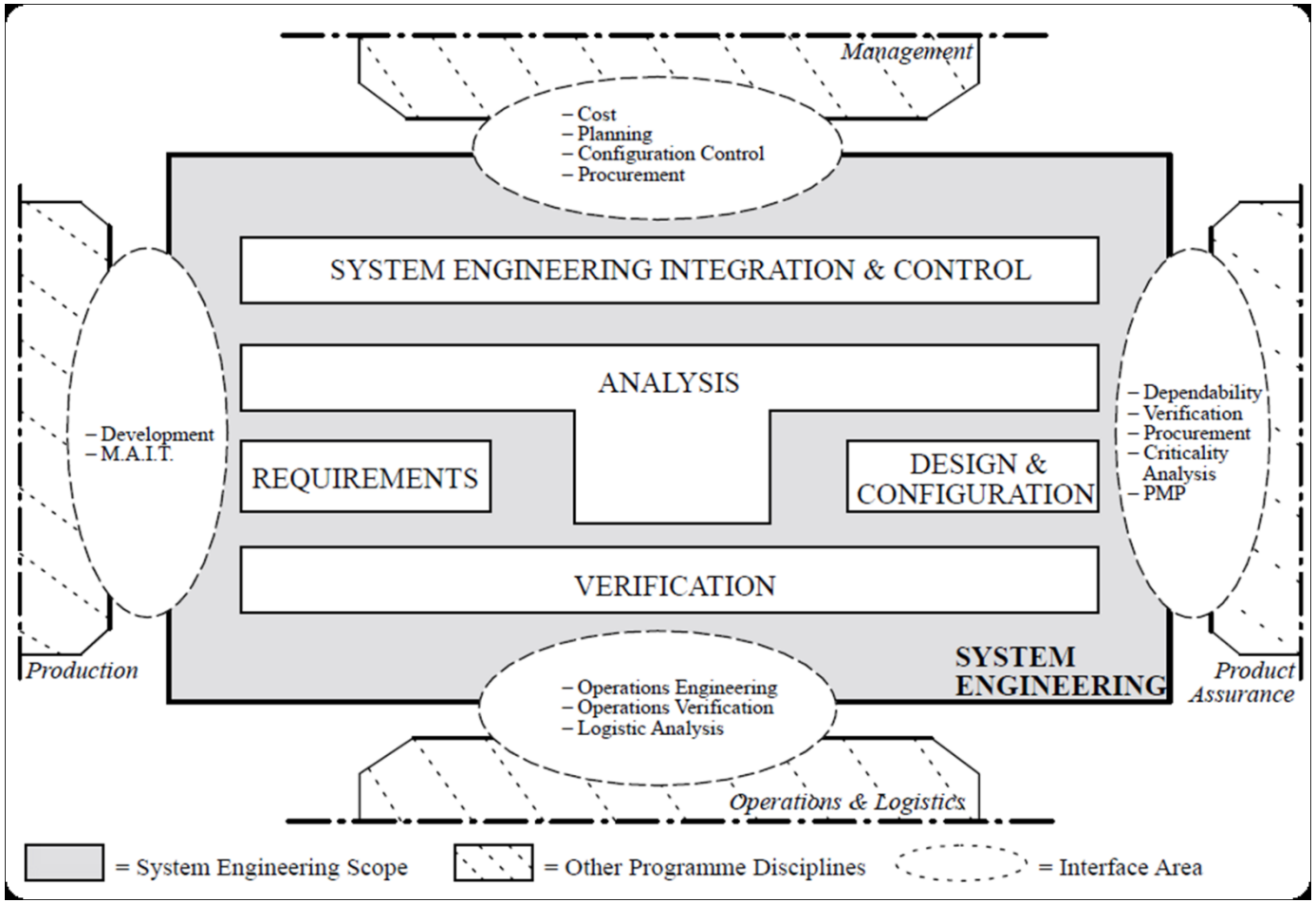
Systems Engineering for ESA Projects

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

ISO = International Standards Organisation
ESSB = ESA Standardization Steering Board
TRL = Technology Readiness Level
SOW = Statement of Work
ICD = Interface Control Document

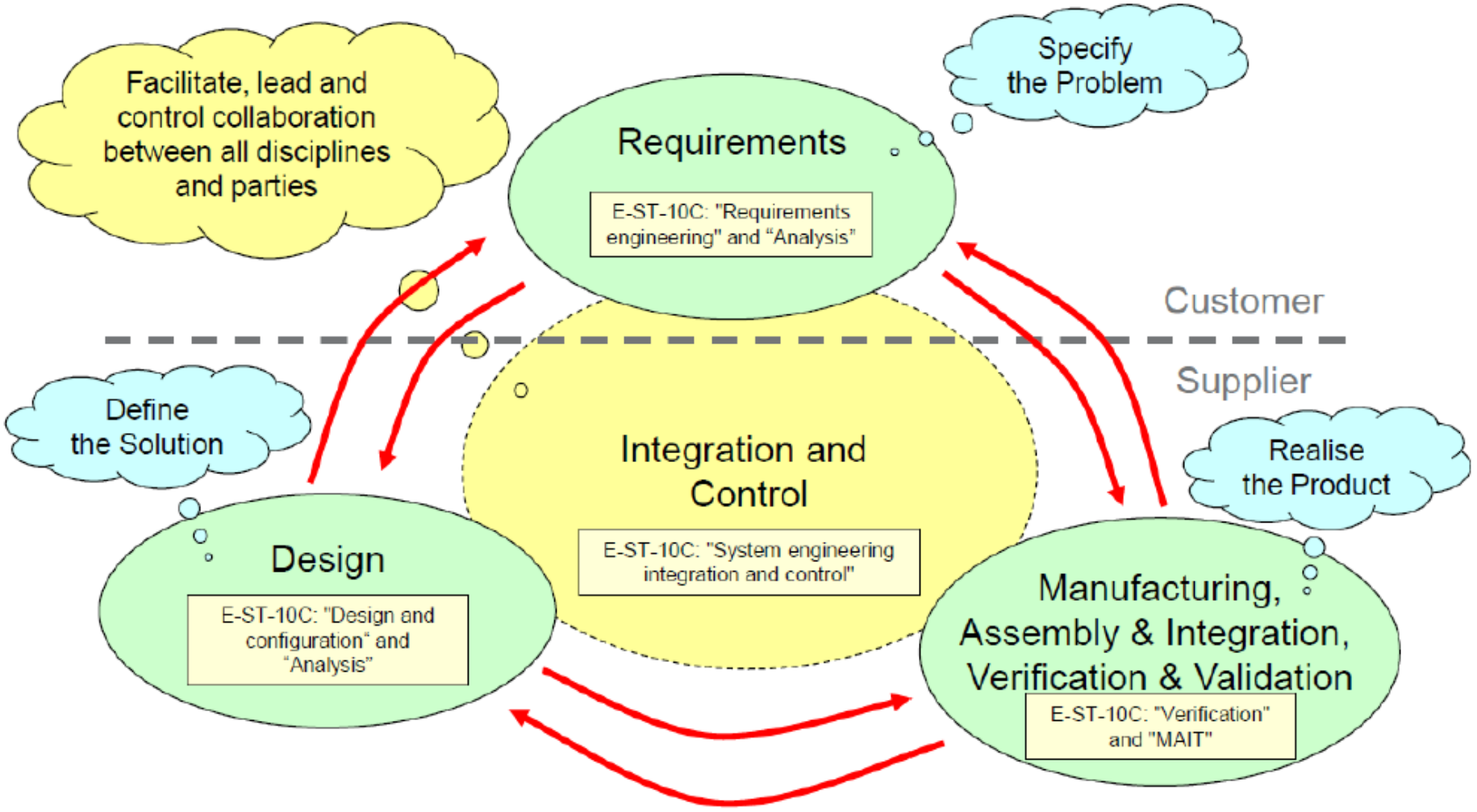
ECSS-E-ST-10C – SE General Requirements

Systems Engineering (SE) Functions



MAIT = Manufacturing, Assembly, Integration and Test
PMP= Parts, materials, Processes

ECSS-E-ST-10C – SE General Requirements



Nov. 2020

Three Main Areas of Concern
One Central Task: "Integration and Control"

Project Lifecycles

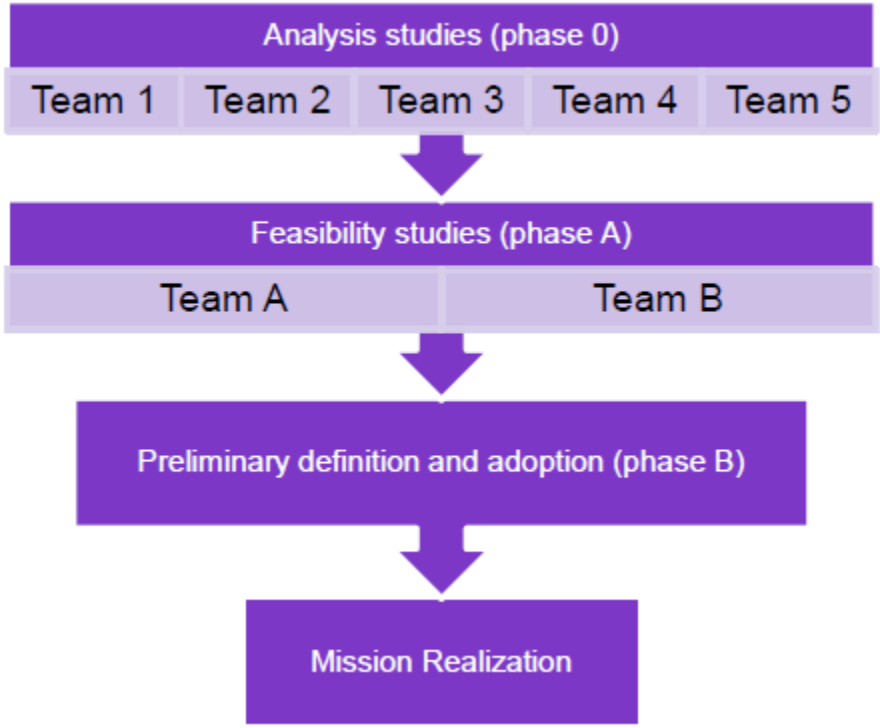
The European Space Agency (ESA)

- ESA does not build satellites – satellites are built by industry.
- ESA is a contractor agency that arranges the work.
- ESA communicates and works with industry and academia.
- **Invitations to tender** (ITT) for the work are issued through ESA's **EMITS** Invitation to Tender System.
- Industry/academia responds to the ITT with their various bids.
- On the basis of these bids, ESA will then select one or more to progress.
- ESA makes the rules, arranges the competition and builds the European space infrastructure.
- All work, processes and documentation must be ECSS compliant.

Project Lifecycles

The European Space Agency (ESA)

- ESA applies a competition based approach for both mission ideas and implementation ideas.
- ESA releases **Announcement of Opportunities** to seek new ideas, to which industry and academia respond with bids.
- The winning team(s) may be single entities or may involve consortia with internal sub-contracts.
- Ideas are refined through analysis studies and feasibility studies.

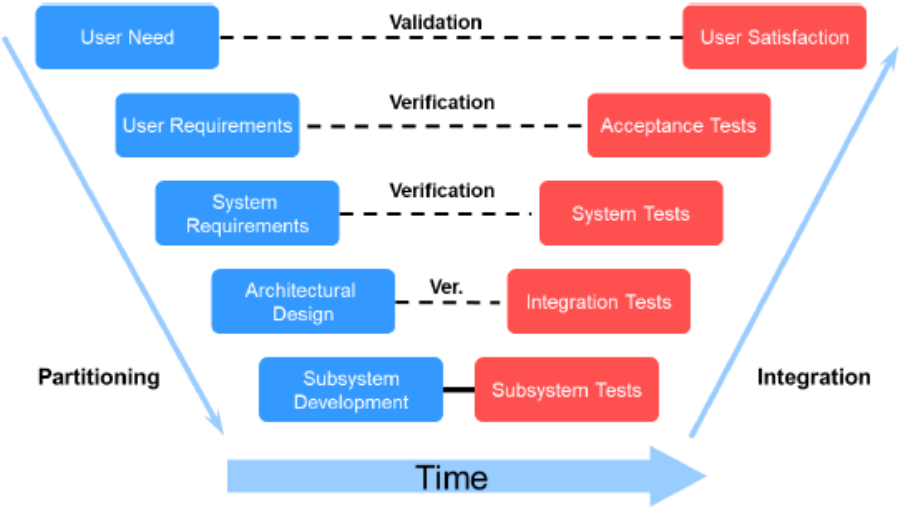


Project Lifecycles

Team Structure and Activities

- **Management**
  - Project manager
  - Team managers
- **Quality Assurance**
  - Quality Chief
  - Quality engineers
- **Science**
  - Principal Investigators
  - Scientist
- **Engineering**
  - Systems Engineer
  - Engineers

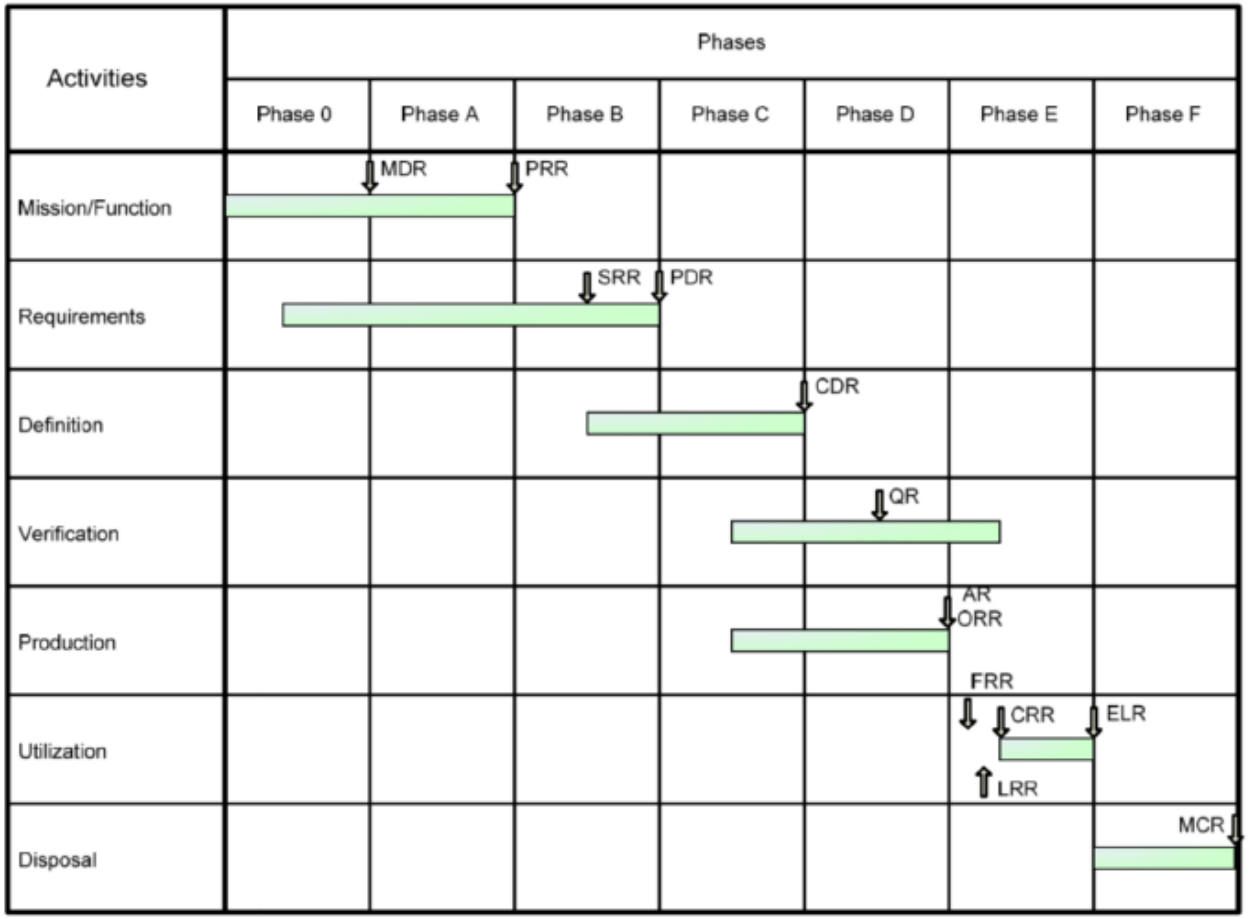
- Mission / Function
- Requirements
- Definition
- Verification
- Production
- Utilisation
- Disposal



"V"- Chart

Project Lifecycles

ESA Projects go through defined phases: 0, A, B, C, D, E and F



MDR – Mission Definition Review

PRR – Preliminary Requirements Review

SRR – System Requirements Review

PDR – Preliminary Design review

CDR – Critical Design Review

QR – Qualification Review

ORR – Operational Readiness Review

LRR – Launch Readiness Review

FRR – Flight Readiness review

AR – Acceptance Review

CRR – Commissioning Result Review

ELR – End of Life Review

MCR – Mission Close-Out Review

Project Lifecycles

ESA Projects go through defined phases: **0**, **A**, B, C, D, E and F

- **Phases 0 and A**, are focused mainly on the elaboration of system functional and technical requirements and identification of system concepts to comply with the mission statement, taking into account the technical and programmatic constraints identified by the project initiator and top level customer.
  - Phase 0: Mission Analysis / Needs Identification
  - Phase A: Feasibility
    - Identification, characterisation & feasibility of mission
    - System trade-off / mission baseline selection
    - Assessment of launcher, orbit & operational constraints
    - Evaluation / definition of system concepts, payload, instruments & platform
    - Programmatic assessment (schedule / cost / risks)
    - Identification of critical development activities
    - Preliminary functional specifications / development plans
  - Typical Contract: 1-3 FTE, 0.6-1.2 MEuro, 6-12 months duration

FTE = Full-Time Equivalent (staff)

Adapted from “Proving the Concept”, Talk by Justin Byrne, Head of Future Programs EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

Project Lifecycles

ESA Projects go through defined phases: 0, A, **B**, C, D, E and F

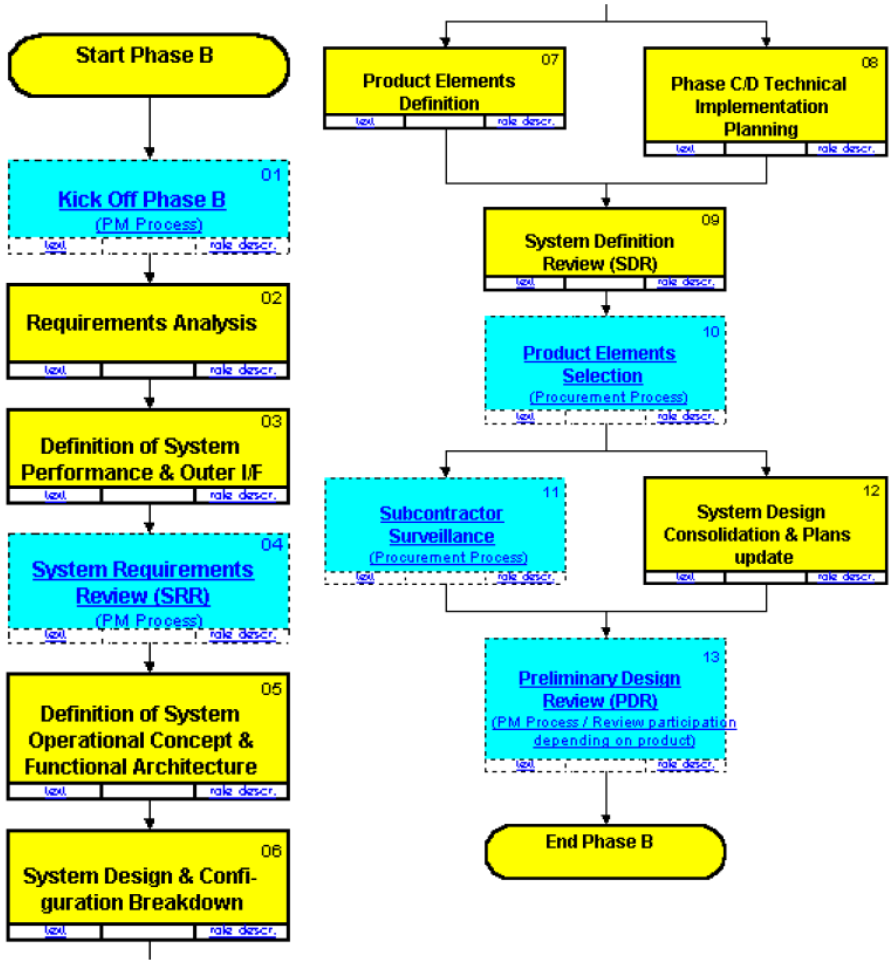
- **Phase B** includes further assessments of technical and programmatic risk, initiation of pre-development activities, the identification of all activities and resources to be used to develop the space and ground segments of the project. Key to this is understanding the Technology Readiness Level (TRL) of the components of the mission.

  - Phase B: Preliminary Definition (Project and Product)
    - Define a complete and coherent mission architecture & system design
    - Finalise the System Requirements (SRR), flow-down, define the product tree and product specifications.
    - Detailed definition of programmatics (cost, schedule & risk), industrial structure and development / verification planning.
    - Supplier / Long Lead Items selection & Kick Off (KO) (Best Practice)
    - Geo-return management (ESA's policy to share work amongst its contributing nations by % contribution)
    - Preliminary Design Review (PDR) to proved coherent system – product design / achieve performance requirements / programmatics
  - Typical contract: 10-20 FTE, 12-24 MEuro, 12-18 months duration.

Adapted from "Proving the Concept", Talk by Justin Byrne, Head of Future Programs
EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

Project Lifecycles

ESA Projects go through defined phases: 0, A, **B**, C, D, E and F



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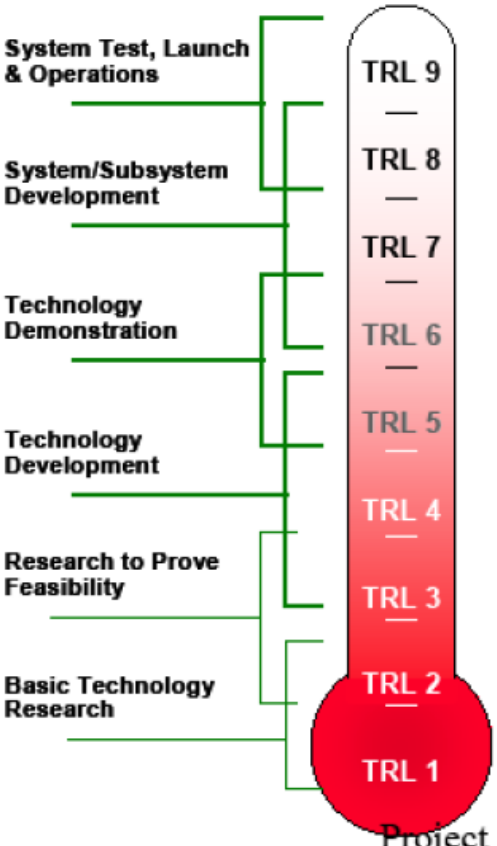
Project Lifecycles

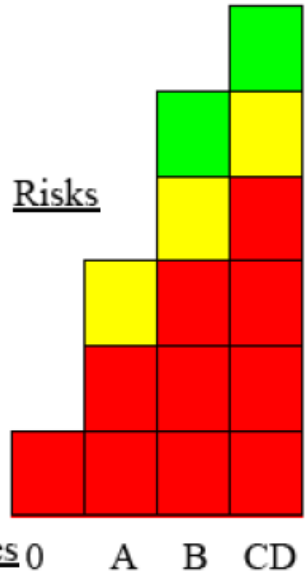
ESA Technology Readiness Level (TRL) Definitions



Technology is with access to space one of the enabling activities of ESA

The requirements on technology are increasing, performance, reliability, etc so as to make impact on science and provide services

Failure to have technology at the right readiness level at each project phase is a major sources of risks for schedule delays and cost overruns



Technology development shall be sufficiently and timely supported

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

Project Lifecycles

ESA Projects go through defined phases: 0, A, B, **C**, **D**, E and F

- **Phases C and D** comprise all activities to be performed in order to develop and qualify the space and ground segments and their products.
  - Phase CD: Detailed definition, production and verification
    - Finalise the detailed definition of the products and their interfaces
    - Define the detailed qualification and verification activities
    - Complete all of the equipment / S/W design reviews and confirm manufacturability of the products
    - Integration, test, qualification / verification of equipment and S/W through to S/C AIT
  - Typical contract: 30-40 FTE, 120-300 MEuro, 24-36 months duration

Typical project (Phase 0 through to FAR): ~5 years, ~150-300 Meuro

Complex projects (e.g. B*epiColombo*, *ExoMars*, etc.) may take considerably longer!

BepiColombo – Approved 2000, launched 2018 – cost US $2 billion

ExoMars – Begun 2001 – due to be launched 2022? – cost US $2 billion?

c.f. SmallSat project (12-18 months – cost US $1.5-30 million)

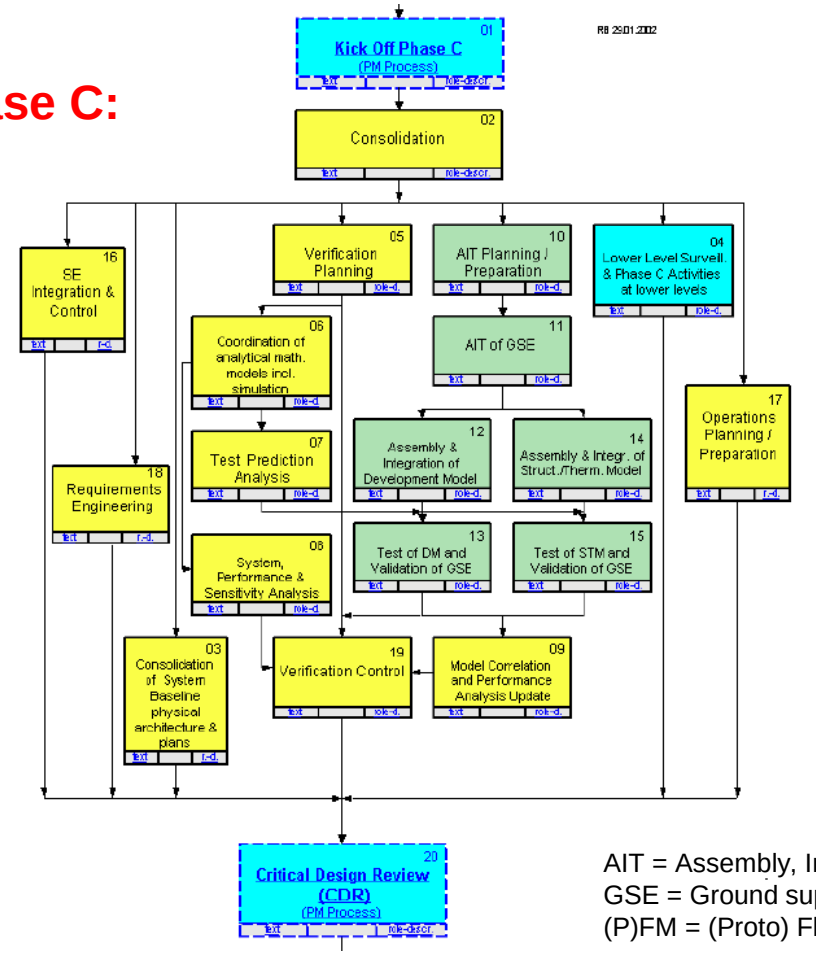
S/W = Software
S/C = Spacecraft
AIT = Assembly, Integration & Test
FAR = Flight Acceptance Review

Adapted from “Proving the Concept”, Talk by Justin Byrne, Head of Future Programs
EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

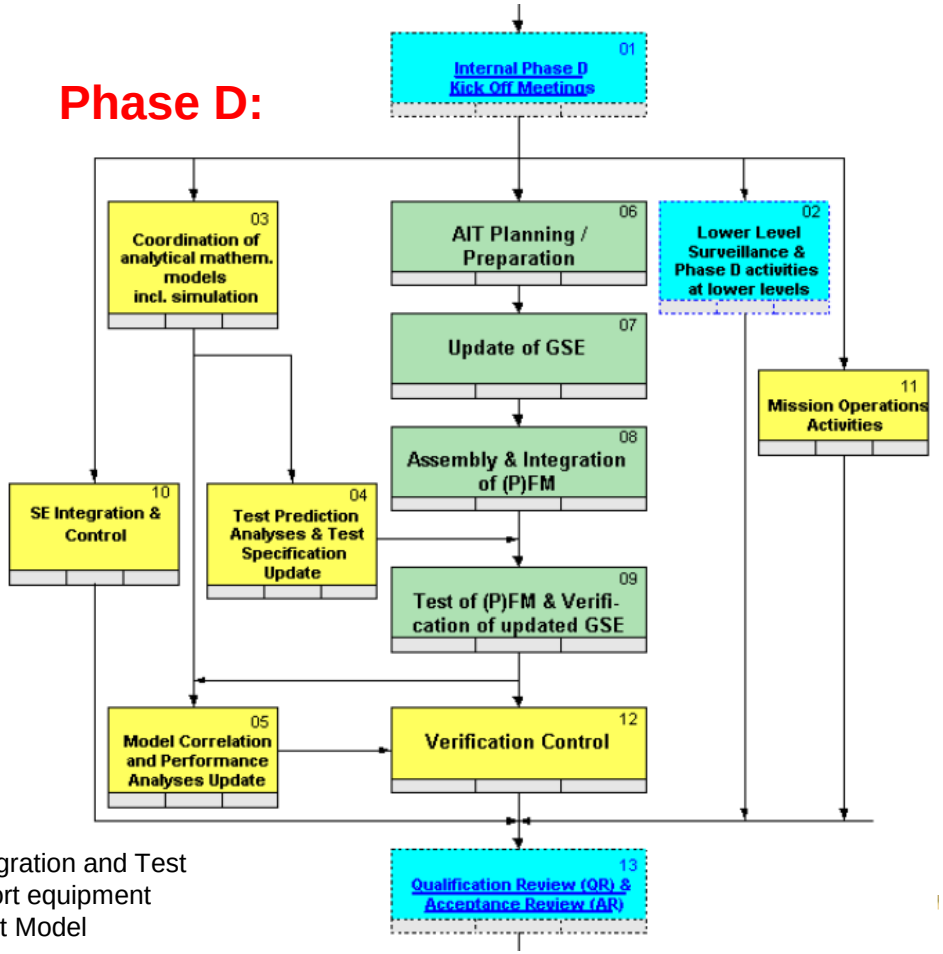
Project Lifecycles

ESA Projects go through defined phases: 0, A, B, **C**, **D**, E and F

Phase C:



Phase D:

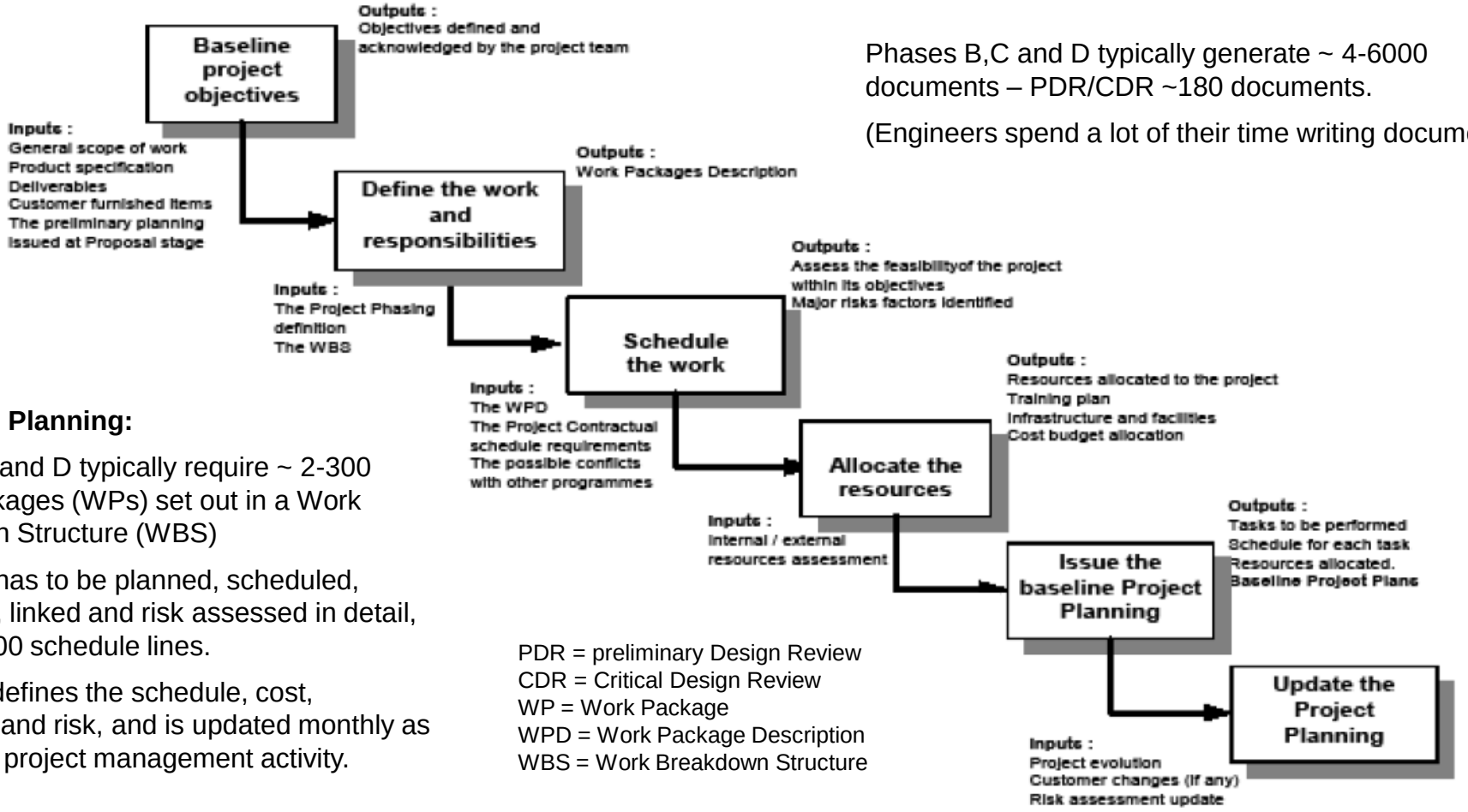


AIT = Assembly, Integration and Test
GSE = Ground support equipment
(P)FM = (Proto) Flight Model

Adapted from "Proving the Concept", Talk by Justin Byrne, Head of Future Programs
EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

Project Lifecycles

ESA Projects go through defined phases: 0, A, B, **C**, **D**, E and F



Phases B,C and D typically generate ~ 4-6000 documents – PDR/CDR ~180 documents.

(Engineers spend a lot of their time writing documents!)

Phase CD Planning:

Phases C and D typically require ~ 2-300 Work Packages (WPs) set out in a Work Breakdown Structure (WBS)

Each WP has to be planned, scheduled, resourced, linked and risk assessed in detail, with ~ 4-600 schedule lines.

The Plan defines the schedule, cost, resources and risk, and is updated monthly as part of the project management activity.

PDR = preliminary Design Review
CDR = Critical Design Review
WP = Work Package
WPD = Work Package Description
WBS = Work Breakdown Structure

Adapted from “Proving the Concept”, Talk by Justin Byrne, Head of Future Programs EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

Project Lifecycles

ESA Projects go through defined phases: 0, A, B, C, D, **E** and **F**

- **Phase E** comprises all activities to be performed in order to launch, commission, utilize, and maintain the orbital elements of the space segment and utilize and maintain the associated ground segment.
- **Phase F** comprises all activities to be performed in order to safely dispose all products launched into space as well as (ultimately) the ground segment.

  - Phase E/F: Utilisation and Disposal
    - Confirm spacecraft ready for launch, ground segment ready for operations
    - Launch campaign, Flight Readiness Review (FRR), launch & LEOP
    - Operations
    - In-orbit performance assessment
    - Disposal / grave-yarding

LEOP = Launch & Early Operations Phase
GEO = Geostationary Earth Orbit
LEO = Low Earth Orbit

Active operational life: ~ 5-20 years (15 years typical for GEO; ~ 5-10 for LEO)

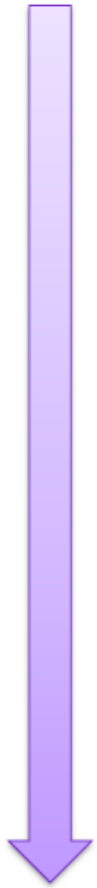
For LEO, disposal must occur within 25 years of active mission end.

(See ISO standards: 16164:2015 and ISO 24113 and 1995 NASA Safety Standard 1740.14, *Guidelines and Assessment Procedures for Limiting Orbital Debris*)

Adapted from “Proving the Concept”, Talk by Justin Byrne, Head of Future Programs EADS Astrium Ltd. 2008 – costs adjusted by European Inflation to 2020

Project Lifecycles

Each of the project phases includes end milestones in the form of project review(s), the outcome of which determines readiness of the project to move forward to the next phase.



Idea

Satellite

Launch

Operation

Disposal

MDR mission definition review
PRR preliminary requirements review

SRR system requirements review
PDR preliminary design review

CDR critical design review

QR qualification review
AR acceptance review

ORR operational readiness review
FRR flight readiness review
LRR launch readiness review
CRR commissioning result review
ELR end-of-life review

MCR mission close-out review

Stage payments are often set to coincide with the successful passing of critical (mandatory) review milestones.

Project Lifecycles

- 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 (RID = Review Item Discrepancy)
- 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

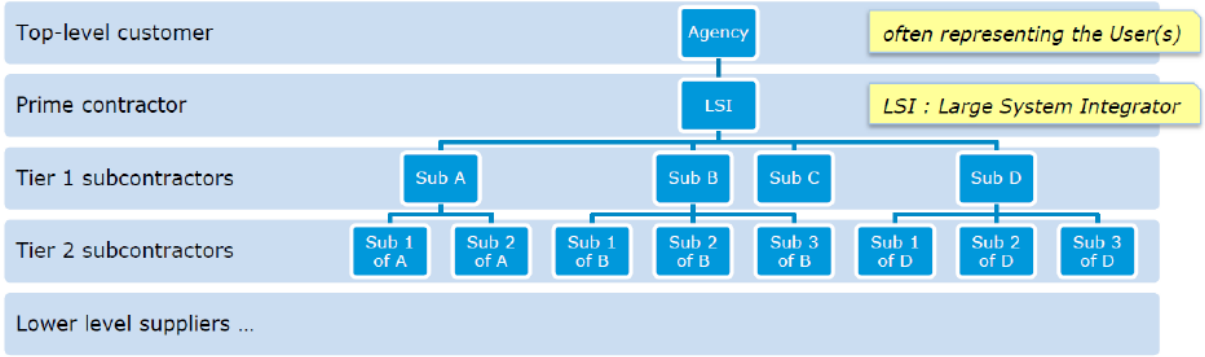
SRR = System Requirements Review
PDR = Preliminary Design Review
CDR = Critical Design Review
FAR = Flight Acceptance Review

Project Lifecycles

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

Project Lifecycles

Customer – Supplier Model



Customer

Organization
Resonsibilities

Communication:
Standards
Deliverables
Reviews

Supplier

Organization
Responsibilities

Who is talking to whom?
Who is responsible? How to communicate?

Activity in ESA Science missions	Approximate Duration
ESA Internal Assessment Phase 0	1.25 yrs
Industrial Assessment Phase A	2.25 yrs
Definition Phase B1	0.5 yrs
Preparation of Implementation Phase	1 yr
Implementation Phase B2/C/D	5 – 7 yrs

ECSS sets the framework

Rôle of Systems Engineering

Mission Phases and the Rôle of Systems Engineering (SE)

Phase	Role
0 – Mission Analysis	Support the customer in identifying their needs; propose possible system concepts
A – Feasibility	Finalise the expression of needs; propose solutions to meet the perceived needs
B – Preliminary Definition	Establish system preliminary definition for selected option; demonstrate the solution meets the technical requirements to schedule, cost and organisation requirements
C – Detailed Definition	Establish the system detailed definition; demonstrate capability to meet the technical requirements
D – Qualification and Production	Finalise the development of the system by qualification and acceptance; finalise the preparation for operations and utilisation
E – Operations / Utilisation	Support the launch campaign; support entities in charge of operation and exploitation; support anomaly investigation
F – Disposal	Support the entity in charge of disposal

Rôle of Systems Engineering

Sarafin TP, Larson WJ (eds) (1995) Spacecraft structures and mechanisms—from concept to launch. Microcosm Press and Kluwer Academic Publishers, Torrance, CA

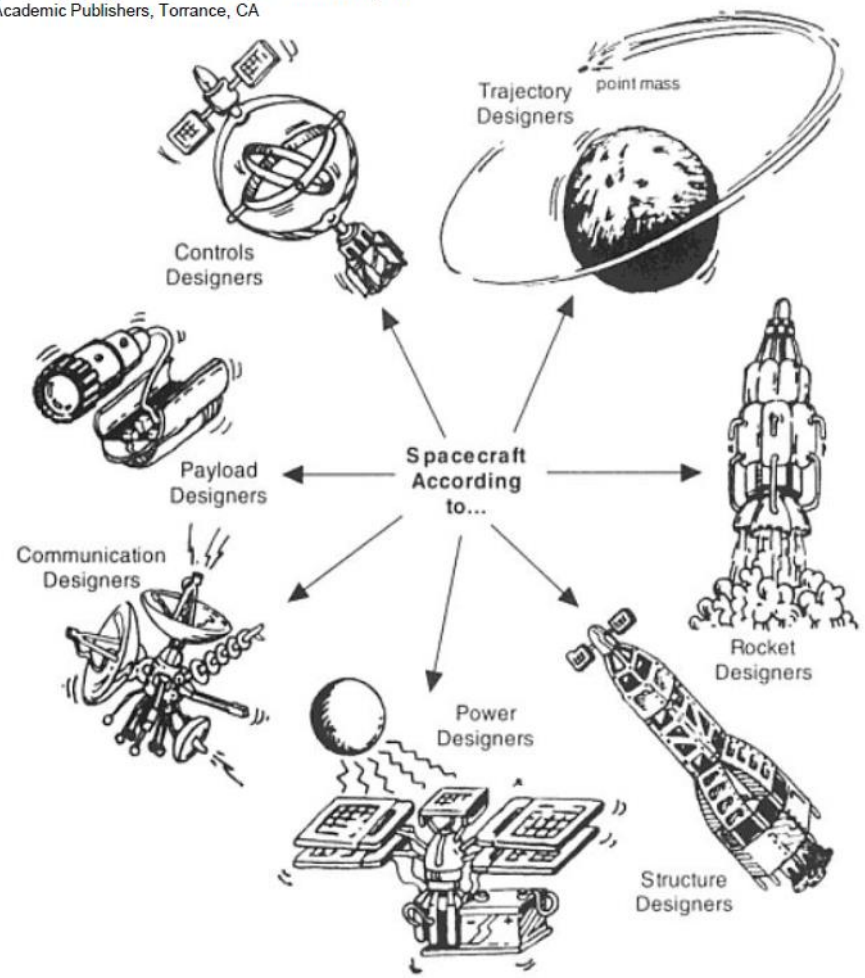


Fig. 1.5. **How a Spacecraft Might Look if Designed by a Single Engineering Discipline.** Teamwork keeps people from focusing on narrow objectives. (Adapted from *Understanding Space—An Introduction to Astronautics*, J. Sellers, 1994.)

Systems Thinking and Clear Communication Between all Parties is the Key to Project Success!

Rôle of Systems Engineering

System Engineering Functions – ECSS E-ST-10C

- The table below describes the precise responsibilities of a systems engineer and the tasks expected of the systems engineer within given functions. The since you are studying Spacecraft Systems Engineering you should know these well.

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

Rôle of Systems Engineering

Main Systems Engineering Deliverables and Organisation

- The table below describes the main deliverables expected of systems engineers throughout the project lifecycle.
- Note – DDF and DJF are extensive repositories of multiple files delivered at reviews

TS = Technical Specification

AIT = Assembly, Integration & Test

QM = Qualification Model

FM = Flight Model

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"

Rôle of Systems Engineering

- The following slides give some idea of the quantity of documentation delivered by systems engineers over the project lifecycle. You are expected to appreciate, but now know every one of these.

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 H		+	+	+									
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		+	+	+	+	+							

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			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		+	+	+	+	+							

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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 and the Customer Supply Chain

- What you should know/understand:
  - The main activities from phase 0 to phase F in a project lifecycle.
  - The detail of the various reviews which occur throughout a space project and be able to relate this to the customer supply chain
  - The precise definition of each review, the phase which it occurs in and the objective of each review
  - The detailed responsibilities of a systems engineer from phase 0 to phase F in a project lifecycle and be able to recall with precision the exact function of each phase.
  - The provisions which ECSS sets out to allow the effective development and control of space systems projects.