REALIZAÇÃO | APOIO | PARCEIROS | PATROCÍNIO

DCTA, COMPREP, COM D CIBER, ITA, PPGAO, AeroLogLab ITA, MINISTÉRIO DA DEFESA, CAPES, APG ITA, Spectrum, ROHDE & SCHWARZ, KEYSIGHT TECHNOLOGIES, EDASIM INTEGRATING IDEAS, omnisys, Tektronix, KEITHLEY, invent VISION, MACJEE, Anritsu Advancing beyond, AEL SISTEMAS

Minicurso 04

Introdução à Engenharia de Sistemas Espaciais

Prof. Dr. Márcio Martins da Silva Costa

Prof. Dr. Márcio M. S. Costa

Academics

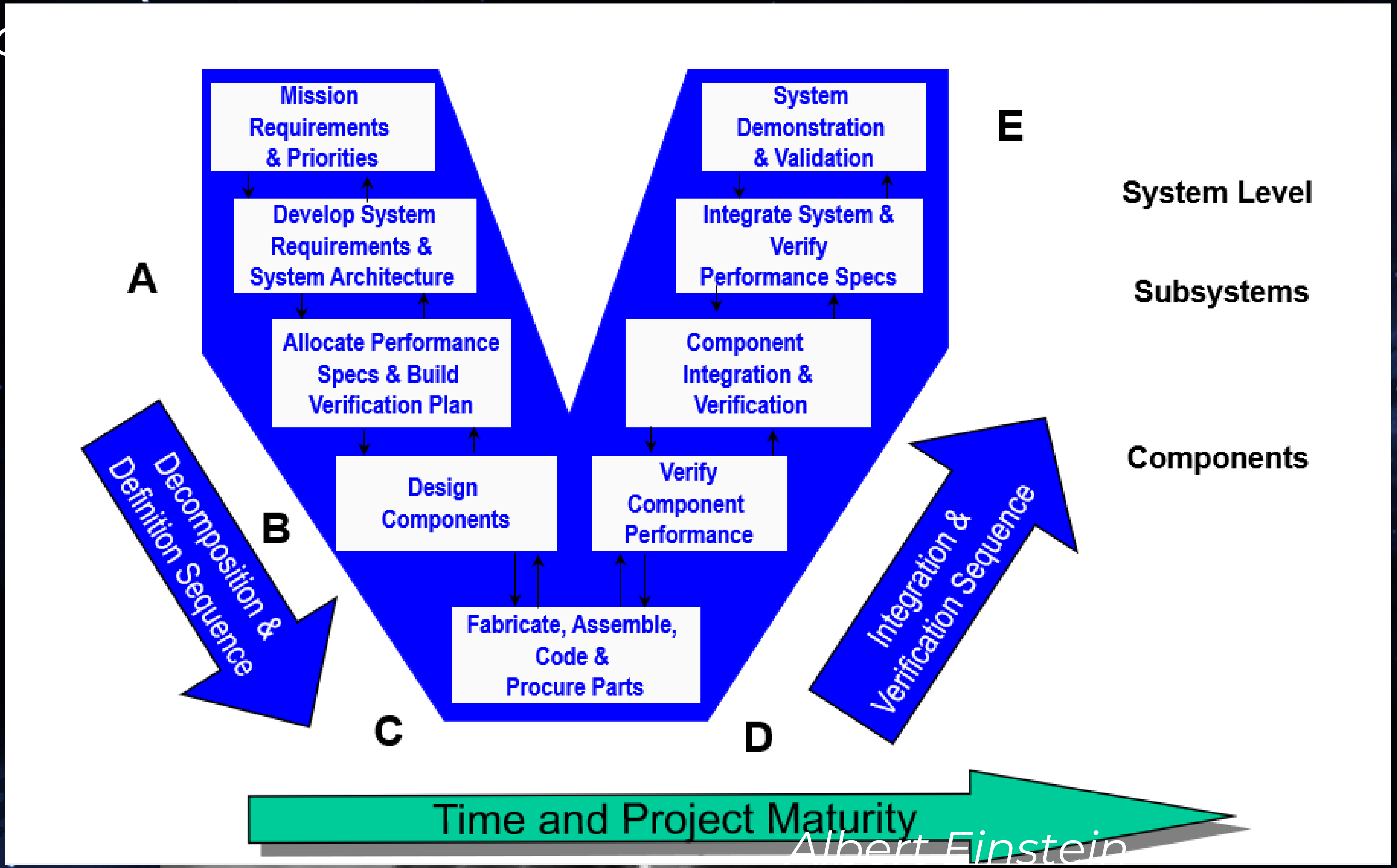
- D. Sc. Science and Space Technologies (ITA)
- M.Sc. Electronic and Computer Engineering (ITA)

Professional

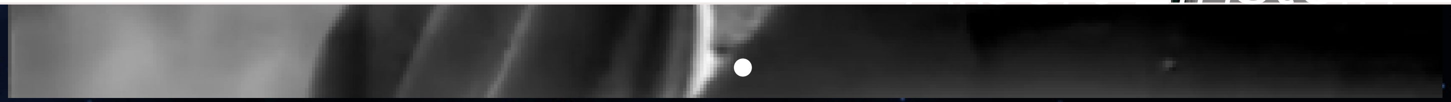
- Head Management Lessonia Projects (SAR Caracrá I/II Constellation)
- SSCS-F1 / CEI-ITA
- LOM Phase 1 / LabGE-ITA
- CubeSAT SAR Project / NST
- Collaborator Professor at ITA/INPE/NST-SJC
- E2MoC - Research Group / CEI-ITA
- PUC-Rio - CCE - Class 18284

“The Need for Systems Thinking”

“Problems c ... *created them.”*



Albert Einstein



https://twitter.com/AlbertEinstein/status/1706444239926603967/photo/1

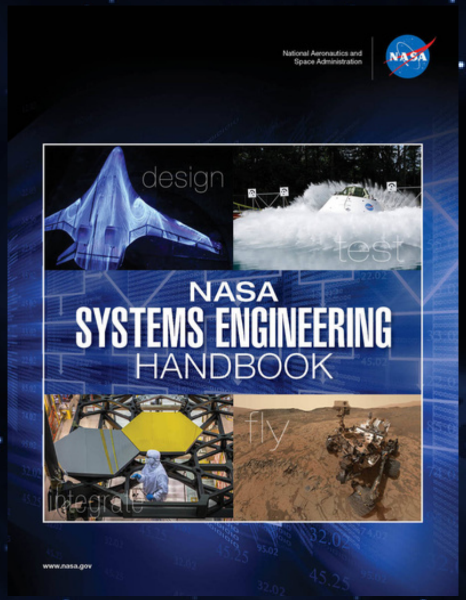
Purpose

Provide general guidance and preliminary information on employing Systems Engineering for the Space Sector

Objectives

Train, raise awareness, and encourage human resources in the use of Systems Engineering for the Space Sector

References


NASA
SYSTEMS ENGINEERING
HANDBOOK
design
fly


EUROPEAN COOPERATION
ECSS
FOR SPACE STANDARDIZATION
Space engineering
Space segment operability
ECSS Secretariat
ESA-ESTEC
Requirements & Standards Division
Noordwijk, The Netherlands


EUROPEAN COOPERATION
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FOR SPACE STANDARDIZATION
Space project management
Project planning and implementation
ECSS Secretariat
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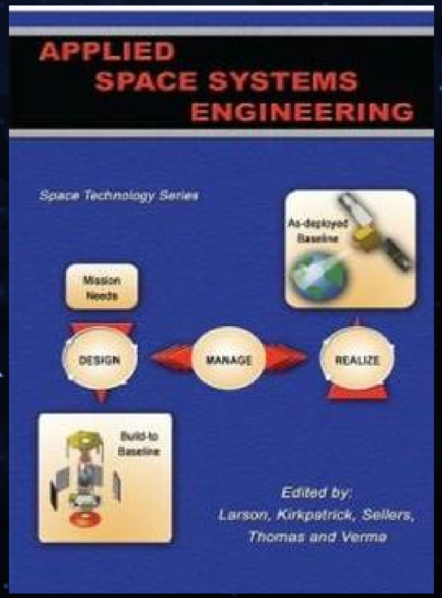
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SPACE SYSTEMS
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Space Technology Series
Mission Needs
As-deployed Baseline
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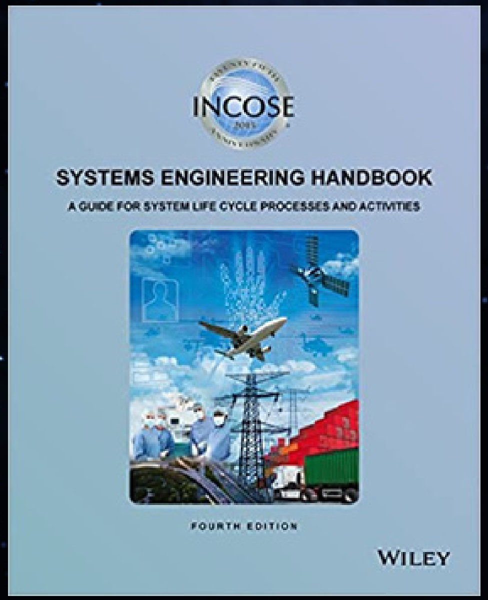
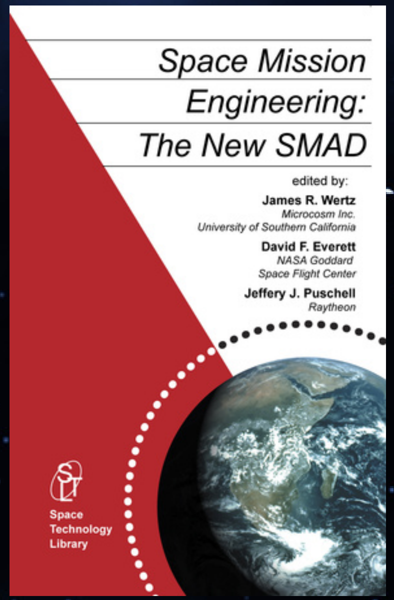
MANAGE
REALIZE
Build-to Baseline
Edited by:
Larson, Kirkpatrick, Sellers,
Thomas and Verma


INCOSE
SYSTEMS ENGINEERING HANDBOOK
A GUIDE FOR SYSTEM LIFE CYCLE PROCESSES AND ACTIVITIES
FOURTH EDITION
WILEY


Space Mission
Engineering:
The New SMAD
edited by:
James R. Wertz
Microcosm Inc.
University of Southern California
David F. Everett
NASA Goddard
Space Flight Center
Jeffery J. Puschell
Raytheon
Space
Technology
Library

Defining “System”

A SYSTEM IS

< set, combination, group, collection, configuration, arrangement, organization>

OF

< parts, components, objects, subsystems, entities>

<combined, integrated, organized, configured, arranged>

IN A WAY THAT

< creats, enable, motivates>

<properties, functions, processes, capabilities, behaviours, dimensions>

NOT

< possessed, exhibited, presented>

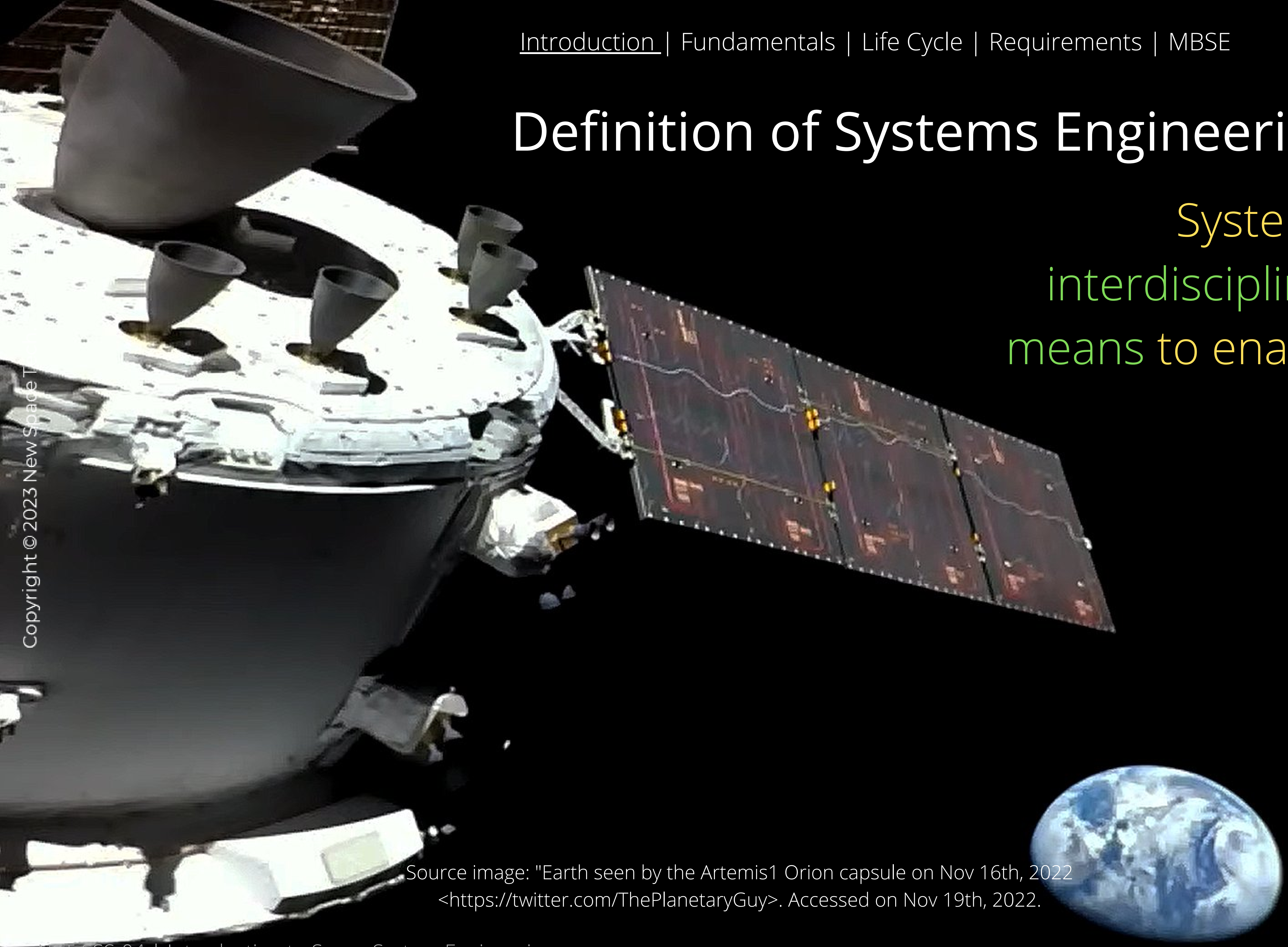
BY THE

< separate, individual, single>

<parts, components, elements, objects, subsystems, entities>

Credits: Prof. Dr. Christopher S Cerqueira, ITA, over "Defining “System”: a Comprehensive Approach. 27th Annual INCOSE International Symposium. 2017"

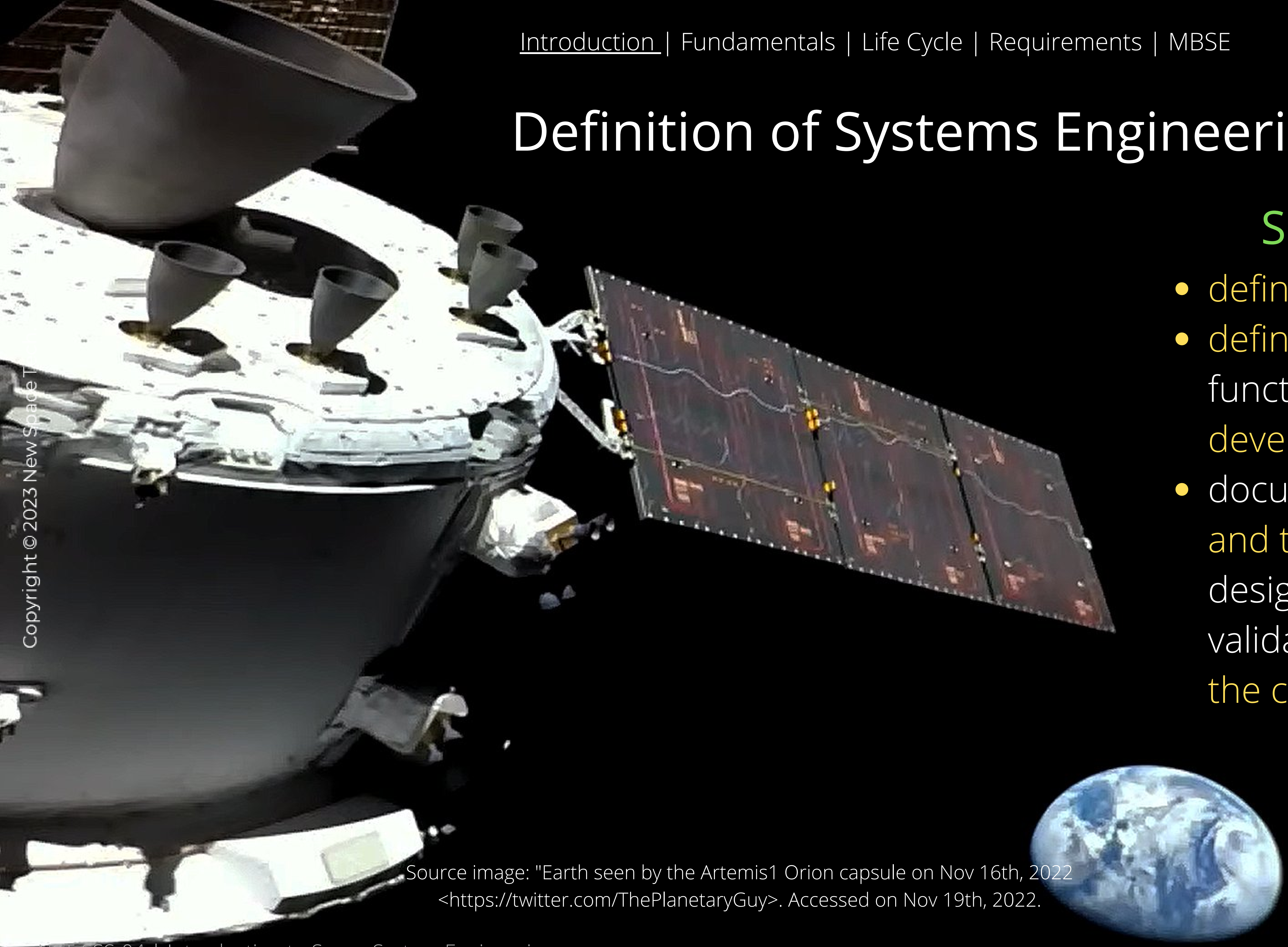
Definition of Systems Engineering



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

Source image: "Earth seen by the Artemis1 Orion capsule on Nov 16th, 2022 <https://twitter.com/ThePlanetaryGuy>. Accessed on Nov 19th, 2022.

Definition of Systems Engineering



Source image: "Earth seen by the Artemis1 Orion capsule on Nov 16th, 2022
<https://twitter.com/ThePlanetaryGuy>. Accessed on Nov 19th, 2022.

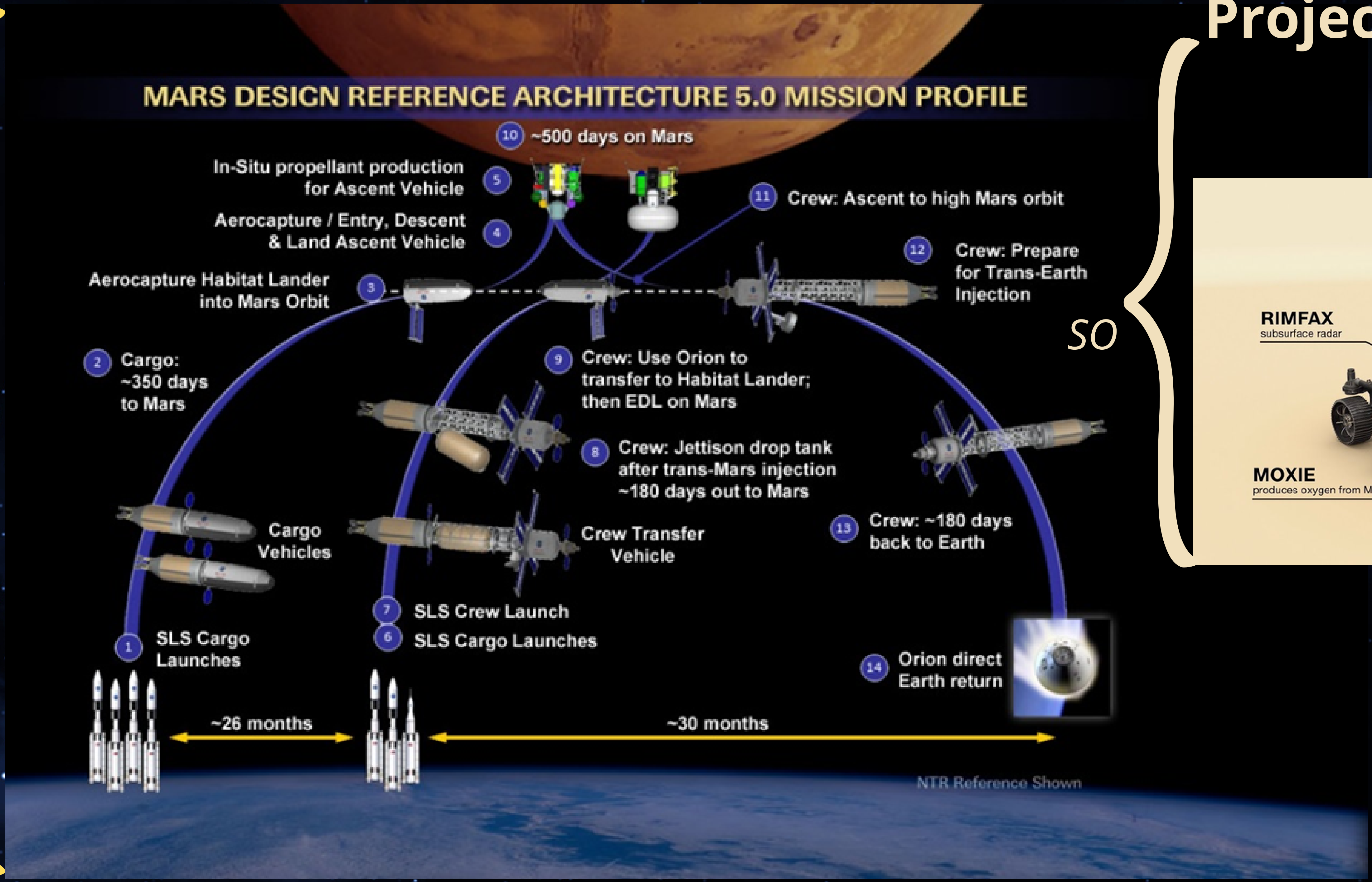
SE Focuses on

- define customer needs;
- define the required functionality early in the development cycle;
- document the requirements and then proceed with design synthesis and system validation while considering the complete problem.

Hierachical Relationships for System of Interest (SO)

Program

SO

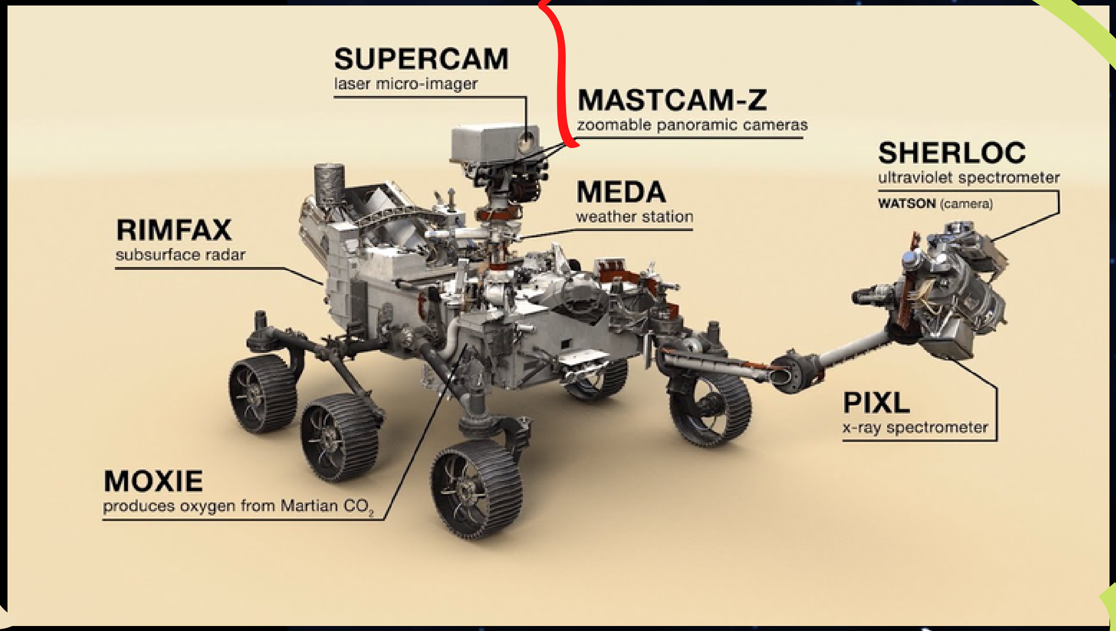


Projects

SO

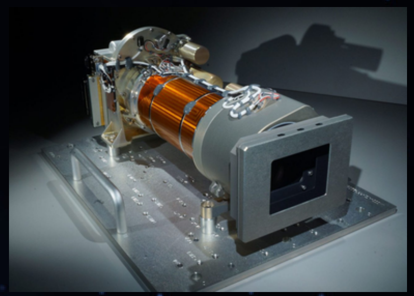
Subsystem

SO



Assembly

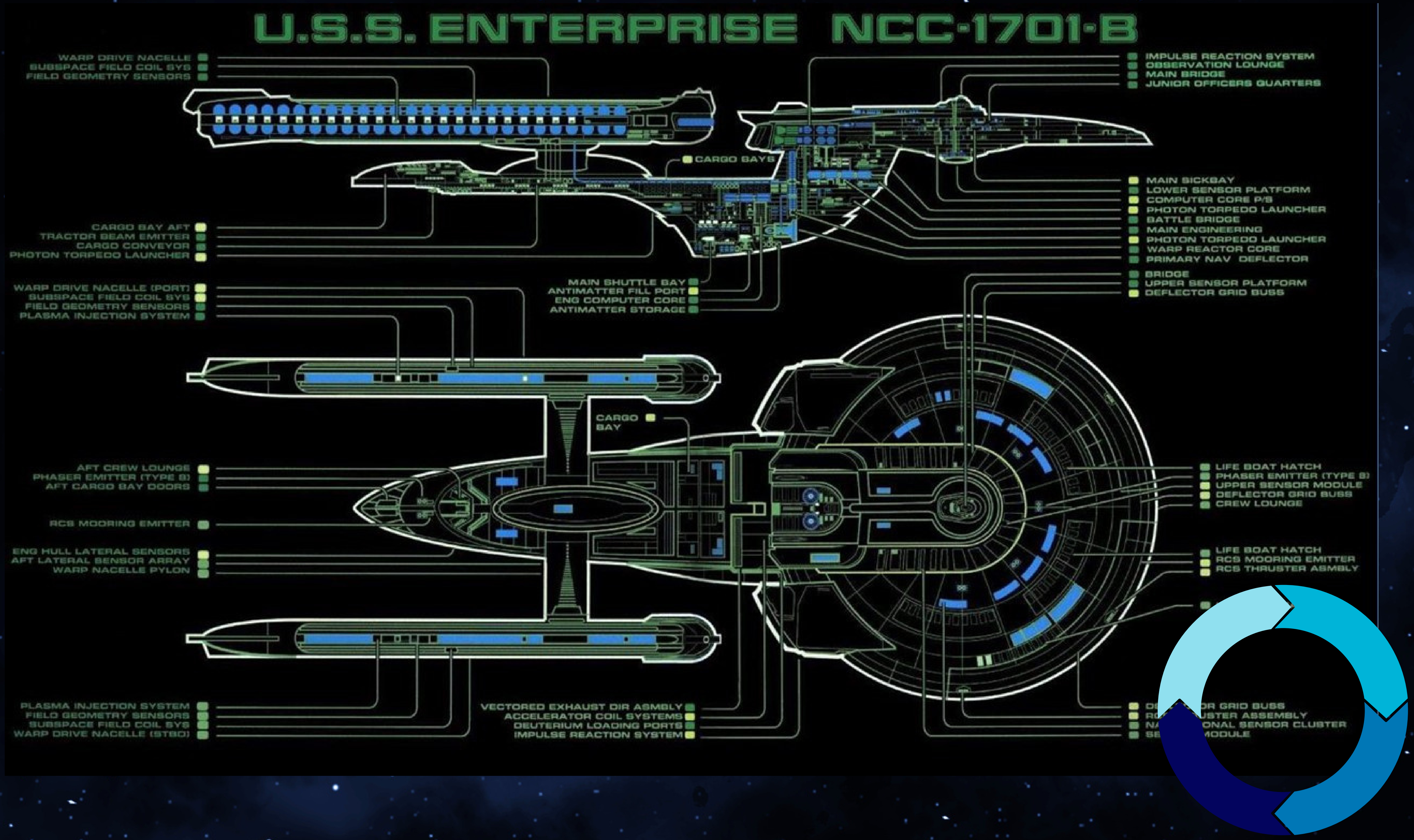
SO



Source: Adapted from by Dr. Paul Graf, Adjunct Professor at the University of Colorado (SE NASA Course) and NASA JPL

NASA's Mars Perseverance rover acquired this image using its onboard Right Navigation Camera (Navcam). The camera is located high on the rover's mast and aids in driving. This image was acquired on Sept. 27, 2023 (Sol 925) at the local mean solar time of 15:21:25.
Credit: NASA/JPL-Caltech/Paul Byrne."

Scope



"SE requires a systematic and disciplined set of processes that are applied *recursively* and *iteratively* for the design, development, operation, maintenance, and closeout of systems throughout the life cycle of the programs and projects.

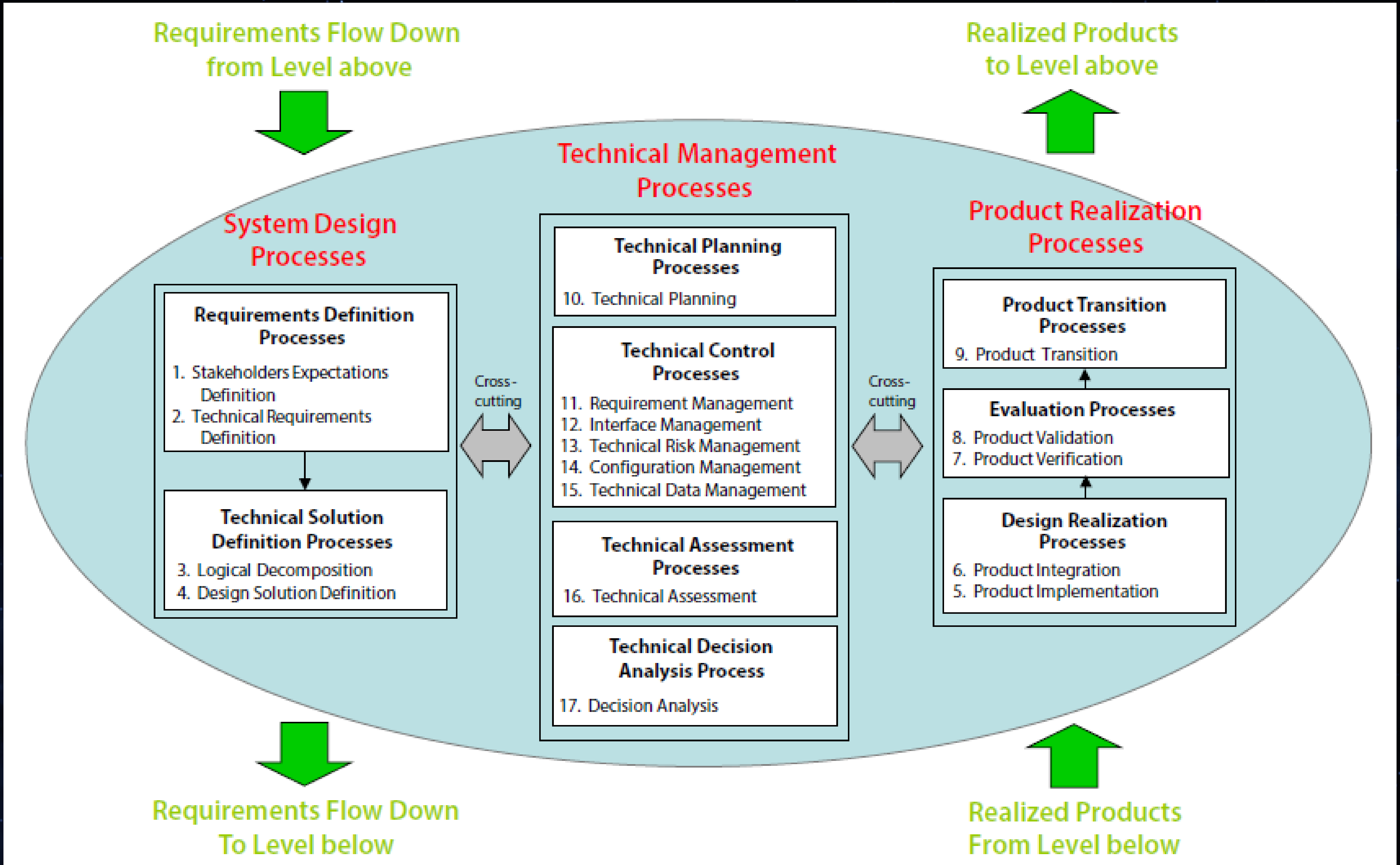
Systems Engineering - Common Technical Processes

There are three sets of common technical processes in a project:

Systems design,

Technical management, and

Product realization



Source: Hirshorn, S. R., Voss, L. D. , and Bromley, L. K.. NASA Systems Engineering Handbook. 2017.

Systems design

A set of recurring processes that result in a validated set of requirements.

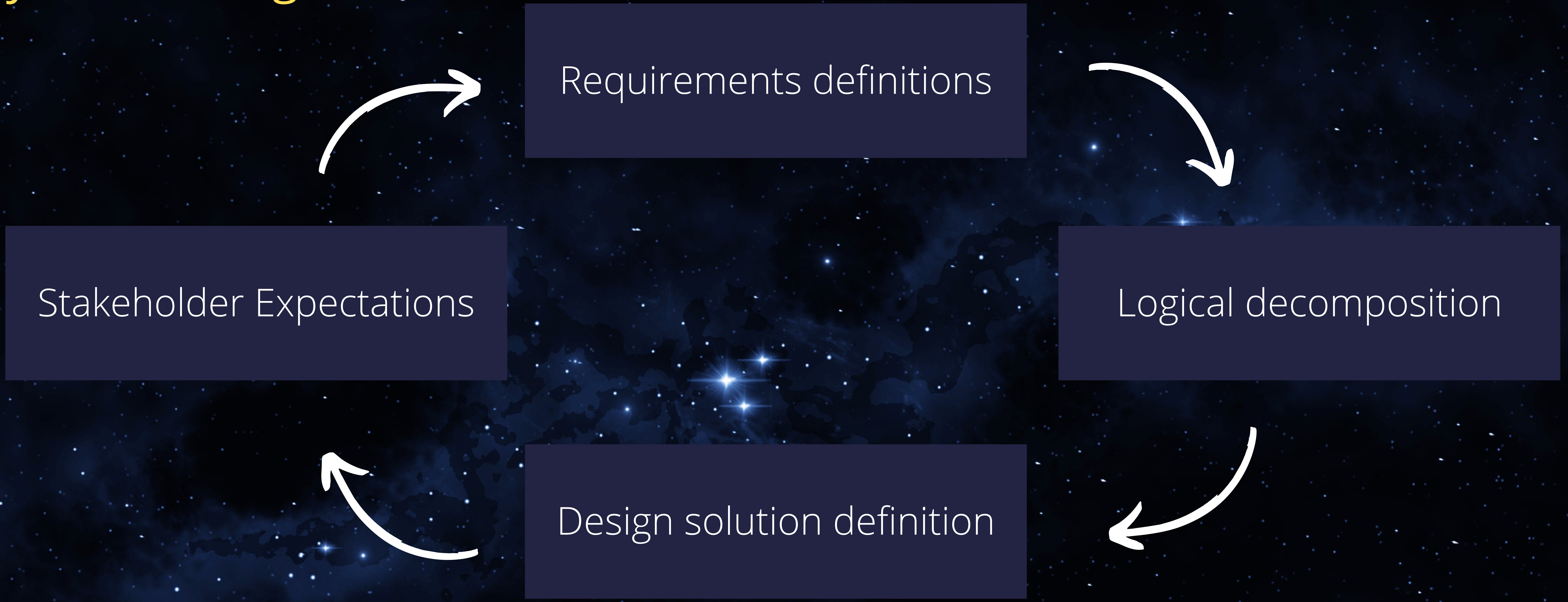
Technical management

Bridges between the project management and the technical team.

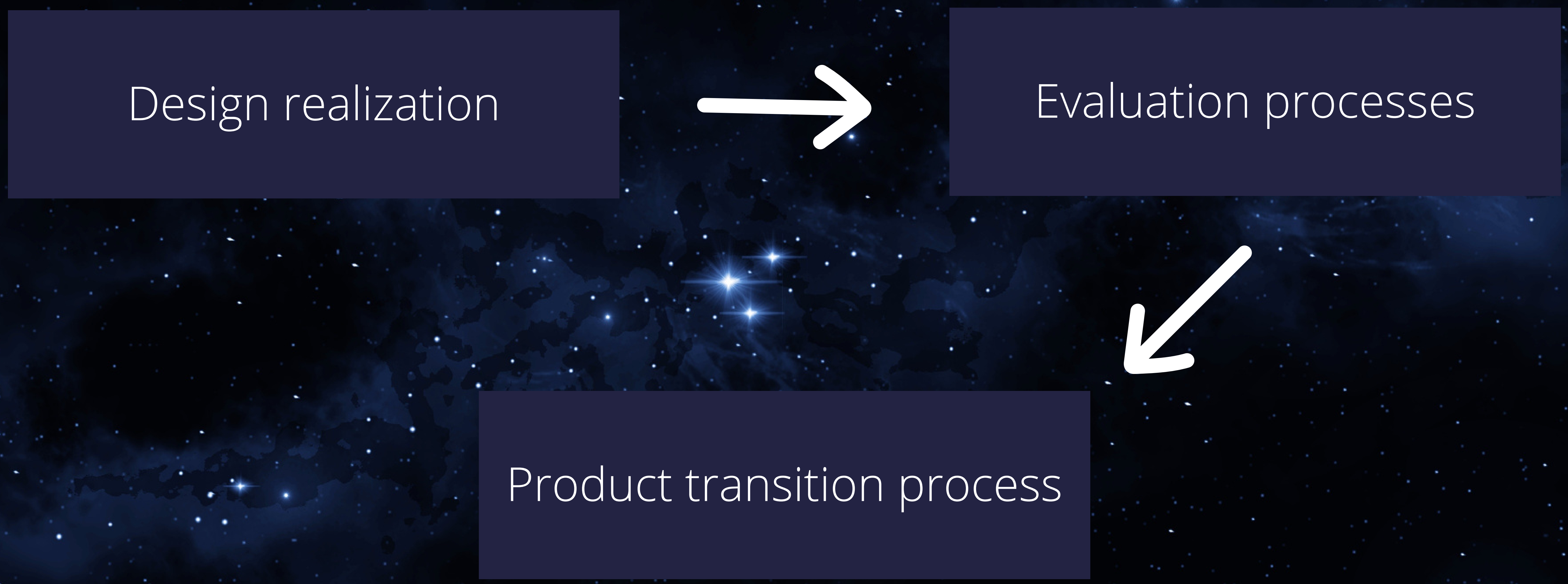
Product realization

Products are produced and validated against stakeholder expectations.

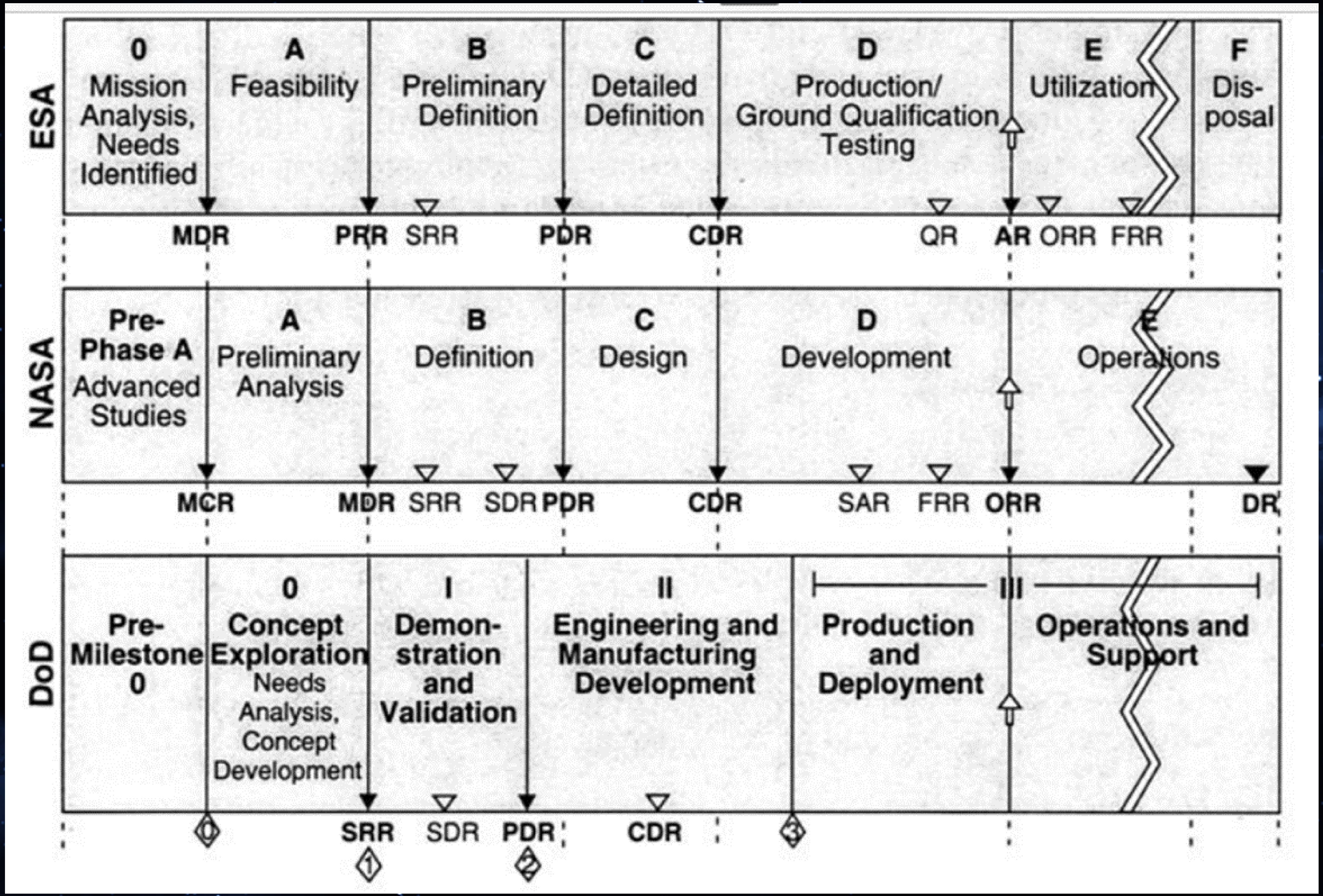
Systems design

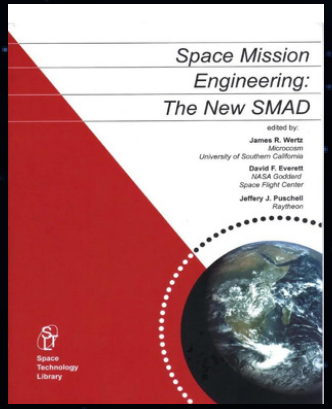


Product realization

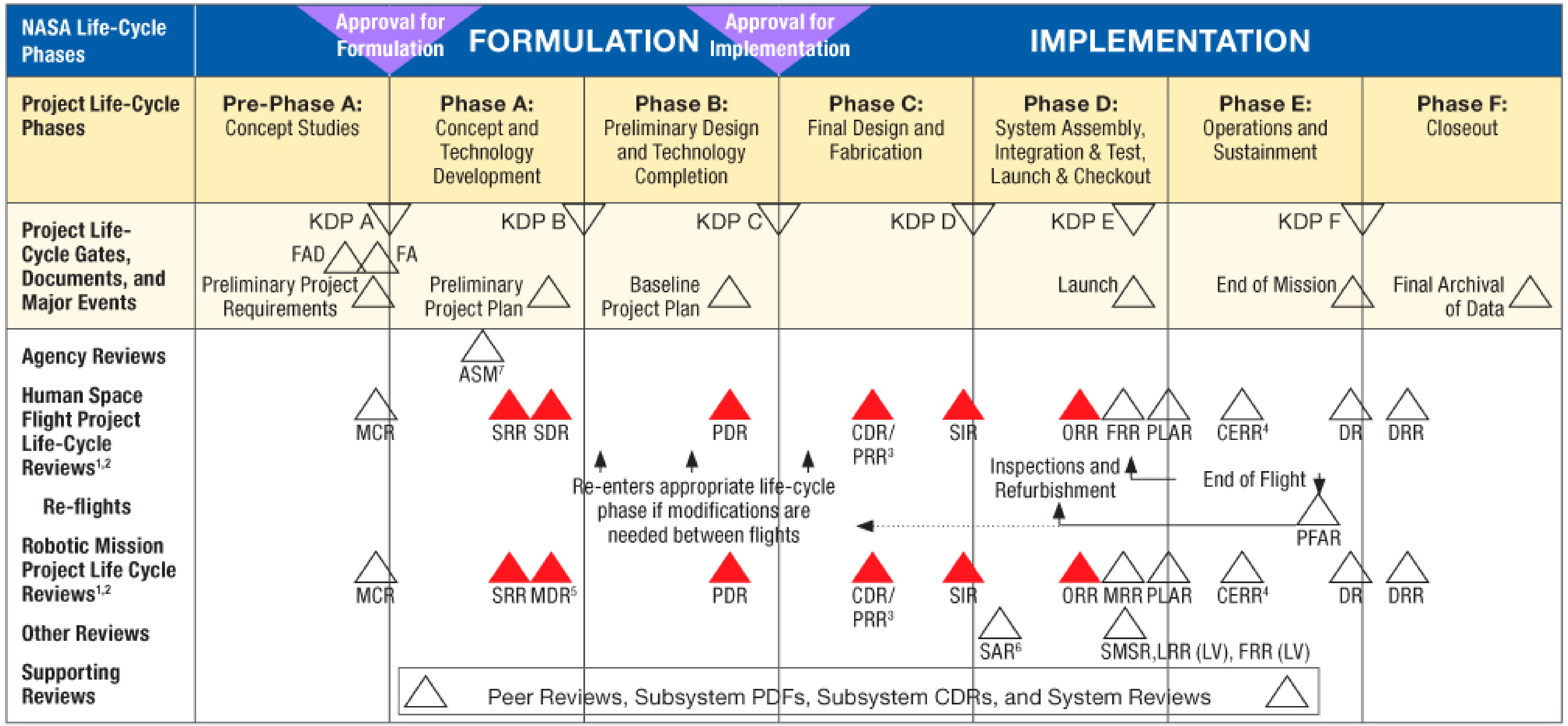


Review - Systems Engineering Phases





Credits image: J. R. Wertz, D. F. Everett, and J. J. Puschell, “Space Mission Engineering – SMAD.”



FOOTNOTES

1. Flexibility is allowed as to the timing, number, and content of reviews as long as the equivalent information is provided at each KDP and the approach is fully documented in the Project Plan.
2. Life-cycle review objectives and expected maturity states for these reviews and the attendant KDPs are contained in Table 2-5 and Appendix D Table D-3 of this handbook
3. PRR is needed only when there are multiple copies of systems. It does not require an SRB. Timing is notional.
4. CERRs are established at the discretion of program .
5. For robotic missions, the SRR and the MDR may be combined.
6. SAR generally applies to human space flight.
7. Timing of the ASM is determined by the MDAA. It may take place at any time during Phase A.

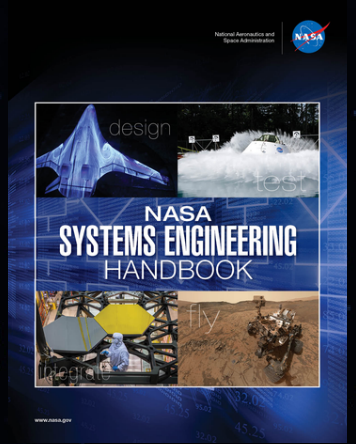
▲ Red triangles represent life-cycle reviews that require SRBs. The Decision Authority, Administrator, MDAA, or Center Director may request the SRB to conduct other reviews.

ACRONYMS

ASM – Acquisition Strategy Meeting
CDR – Critical Design Review
CERR – Critical Events Readiness Review
DR – Decommissioning Review
DRR – Disposal Readiness Review
FA – Formulation Agreement
FAD – Formulation Authorization Document
FRR – Flight Readiness Review
KDP – Key Decision Point
LRR – Launch Readiness Review
LV – Launch Vehicle
MCR – Mission Concept Review
MDR – Mission Definition Review
MRR – Mission Readiness Review
ORR – Operational Readiness Review
PDR – Preliminary Design Review
PFAR – Post-Flight Assessment Review
PLAR – Post-Launch Assessment Review
PRR – Production Readiness Review
SAR – System Acceptance Review
SDR – System Definition Review
SIR – System Integration Review
SMSR – Safety and Mission Success Review
SRB – Standing Review Board
SRR – System Requirements Review

FIGURE 3.0-1 NASA Space Flight Project Life Cycle from NPR 7120.5E

https://www.nasa.gov/seh/3-project-life-cycle



Phase		Purpose	Typical Outcomes
Pre-Formulation	**Pre-Phase A** Concept Studies	To produce a broad spectrum of ideas and alternatives for missions from which new programs/projects can be selected. Determine feasibility of desired system, develop mission concepts, draft system-level requirements, assess performance, cost, and schedule feasibility; identify potential technology needs, and scope.	Feasible system concepts in the form of simulations, analysis, study reports, models, and mock-ups

MCR

PROBLEMS

CONCEPTS

EXPECTATIONS

https://www.nasa.gov/sites/default/files/thumbnails/image/seh_figure_2-2_1_se_phases.png

Committed Costs in Concept Design

"It has been stated that 80% of the eventual costs of a system are determined before the first 20% of the funds have actually been spent."

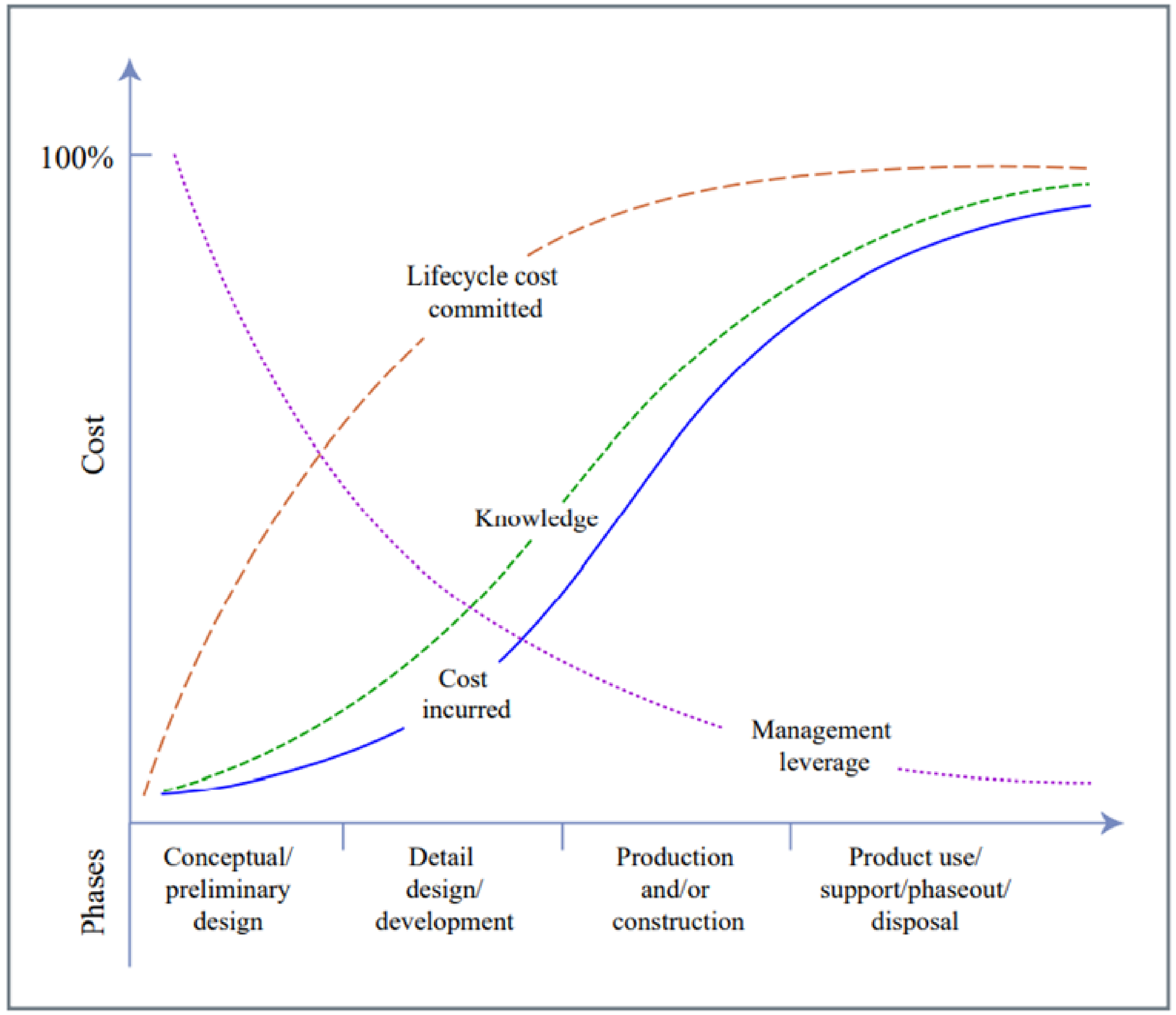
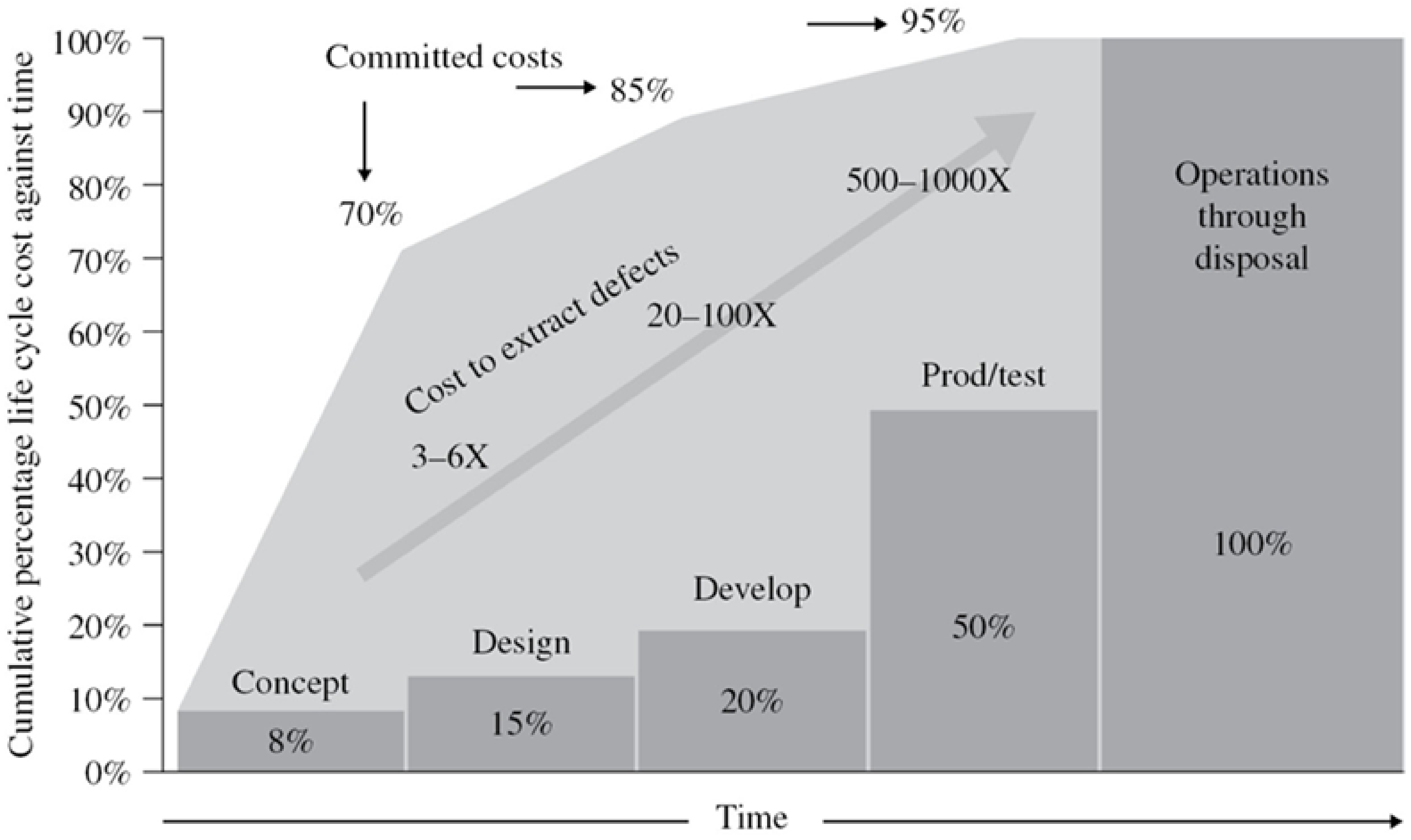


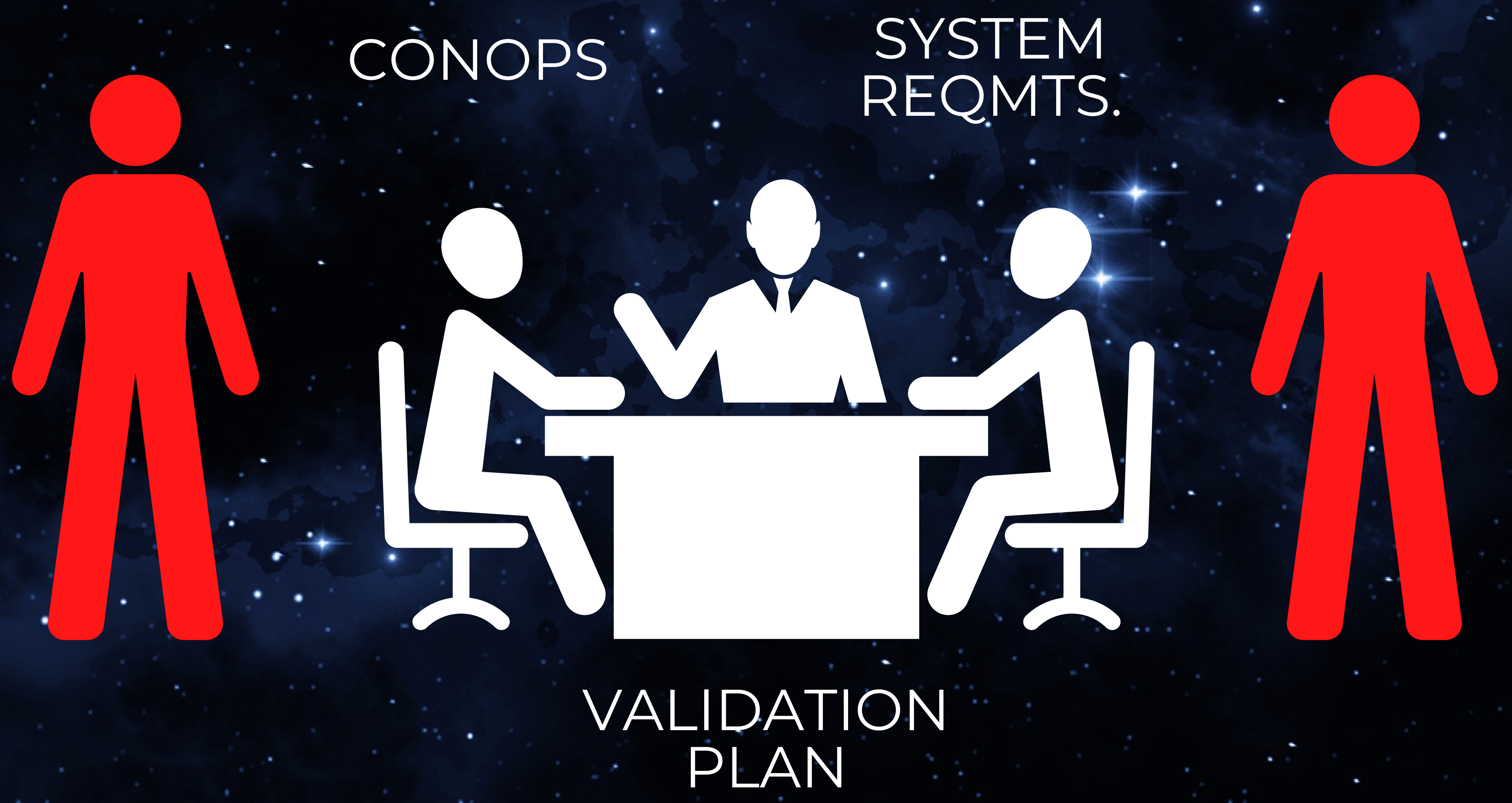
Figure 1. Notional view of costs committed vs. costs incurred over time (Adapted from W. J. Fabrycky, Life Cycle Cost and Economic Analysis, Prentice-Hall, NJ, 1991.)



Source: https://webb.nasa.gov/courses/aeronautics-and-astronautics/16-892j-space-system-architecture-and-design-fall-2004/. Accessed on Mar 21th, 2022; and INCOSE-TP-2003-002-03 INCOSE SYSTEMS ENGINEERING HANDBOOK, version 3 June 2006

Formulation

Phase A Concept and Technology Development	To determine the feasibility and desirability of a suggested new system and establish an initial baseline compatibility with NASA's strategic plans. Develop final mission concept, system-level requirements, needed system technology developments, and program/project technical management plans.	System concept definition in the form of simulations, analysis, engineering models and mock-ups, and trade study definition



https://www.nasa.gov/sites/default/files/thumbnails/image/seh_figure_2-2_1_se_phases.png

Formulation

Phase B Preliminary Design and Technology Completion	To define the project in enough detail to establish an initial baseline capable of meeting mission needs. Develop system structure end product (and enabling product) requirements and generate a preliminary design for each system structure end product.	End products in the form of mock-ups, trade study results, specification and interface documents, and prototypes

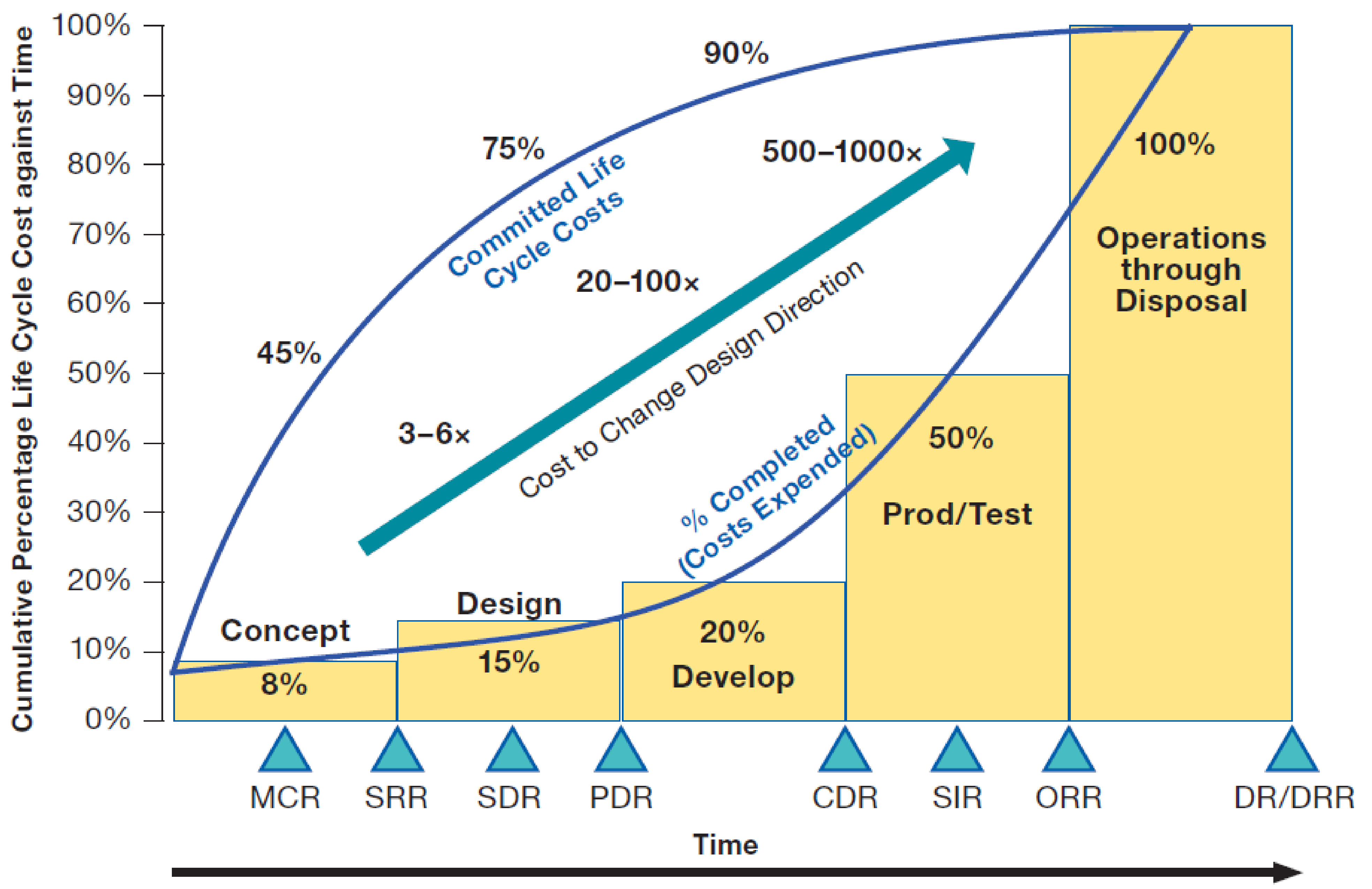
PRELIM. DESIGN

SUBSYSTM REQMTS.

VERIFICATION PLAN

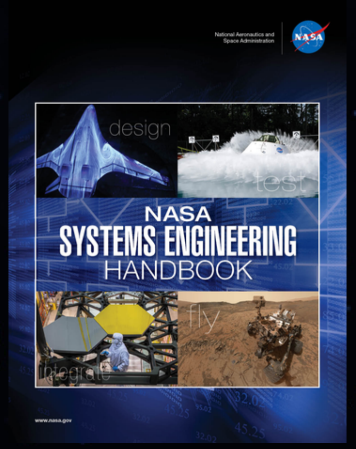
PDR

https://www.nasa.gov/sites/default/files/thumbnails/image/seh_figure_2-2_1_se_phases.png



MCR	Mission Concept Review	CDR	Critical Design Review
SRR	System Requirements Review	SIR	System Integration Review
SDR	System Definition Review	ORR	Operational Readiness Review
PDR	Preliminary Design Review	DR/DRR	Decommissioning/Disposal Readiness Review

Adapted from INCOSE-TP-2003-002-04, 2015



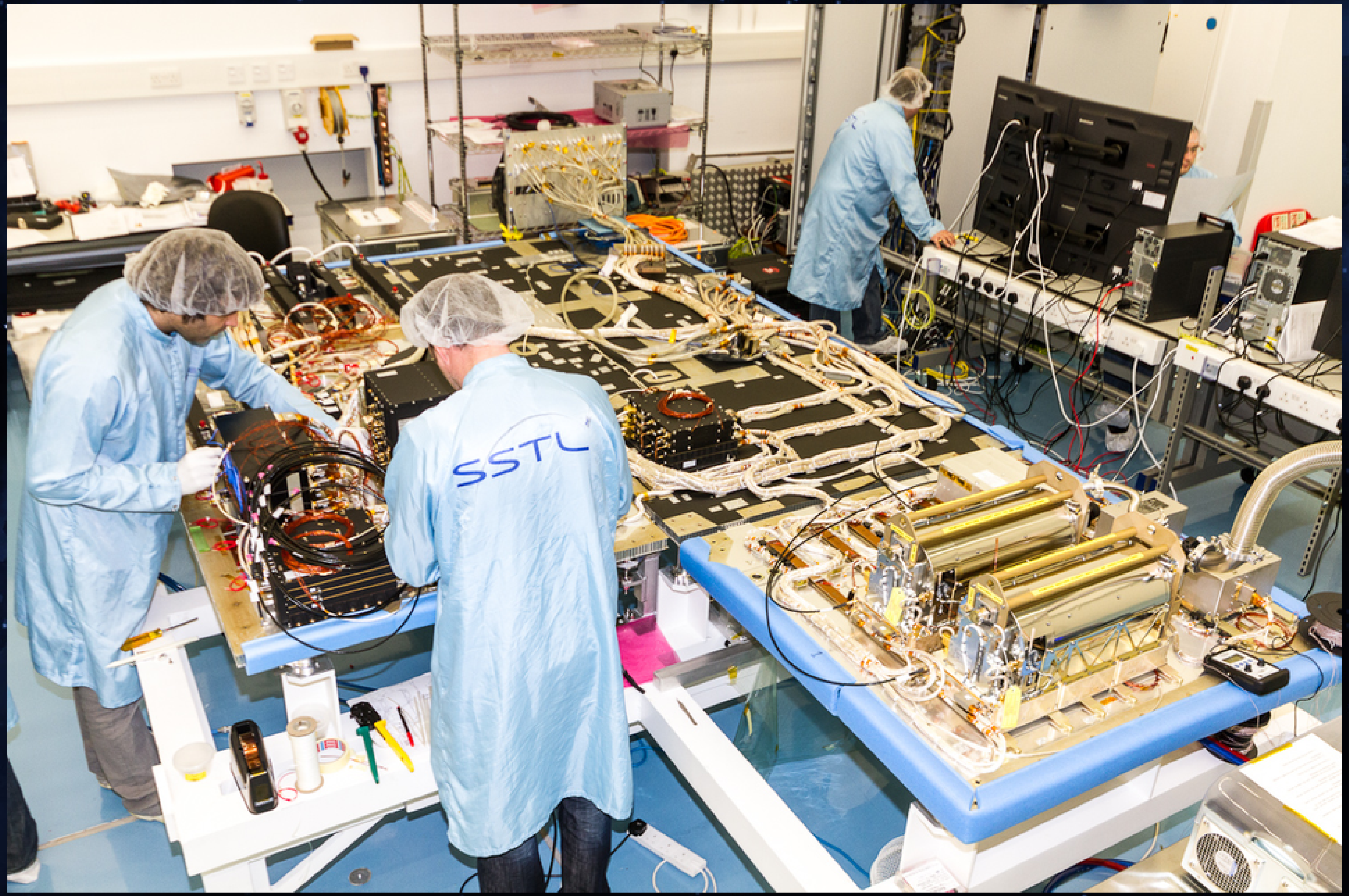
Implementation

Phase C Final Design and Fabrication	To complete the detailed design of the system (and its associated subsystems, including its operations systems), **fabricate hardware, and code software. Generate final** designs for each system structure end product.	End product detailed designs, end product component fabrication, and software development

DESIGN-TO-SPECS

BUILD-TO-SPECS

VERIFICATION PROCEDURES



https://www.sstl.co.uk/media-hub/latest-news/2017/sstl-selected-to-build-third-batch-of-galileo-navigation-payloads

CDR

SIR

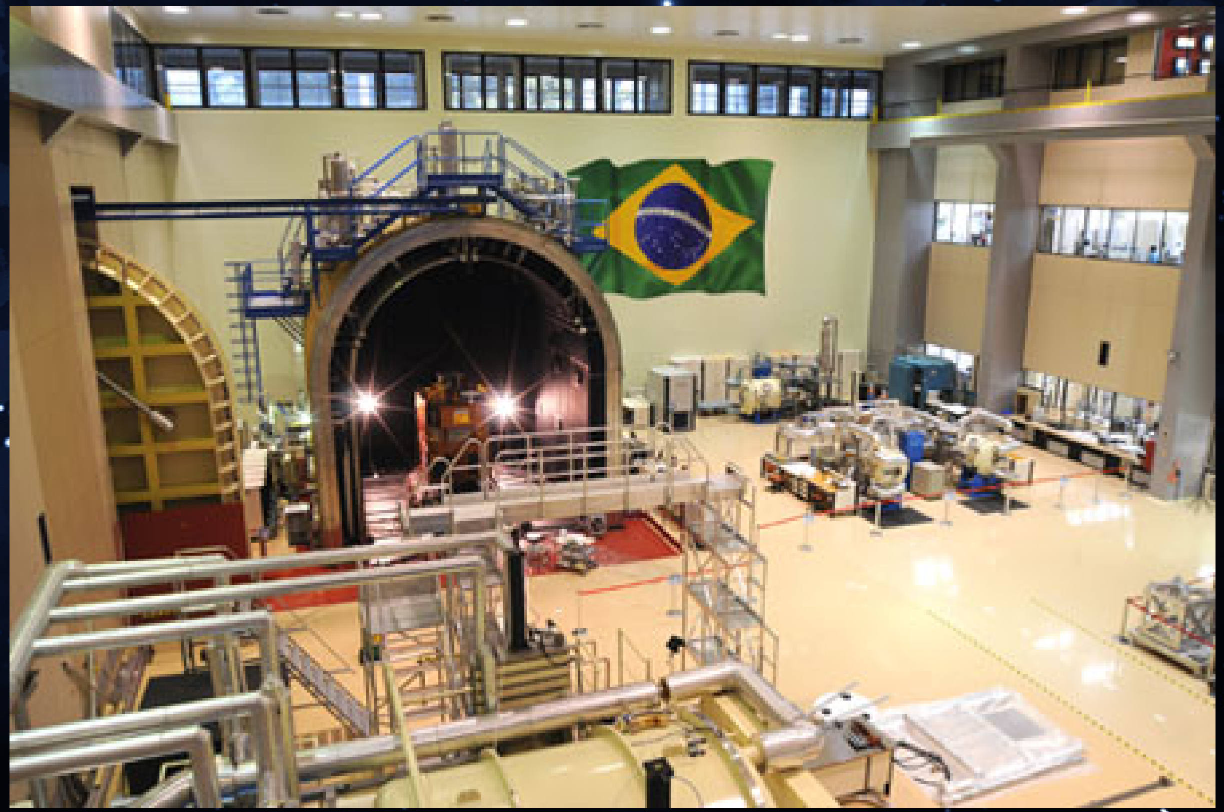
Implementation

Phase D System Assembly, Integration and Test, Launch	To assemble and integrate the system (hardware, software, and humans), meanwhile developing confidence that it is able to meet the system requirements. Launch and prepare for operations. Perform system end product implementation, assembly, integration and test, and transition to use.	Operations-ready system end product with supporting related enabling products

AS-BUILT

AS-VERIFIED

ANOMALIES



http://www.inpe.br/noticias/noticia.php?Cod_Noticia=3162

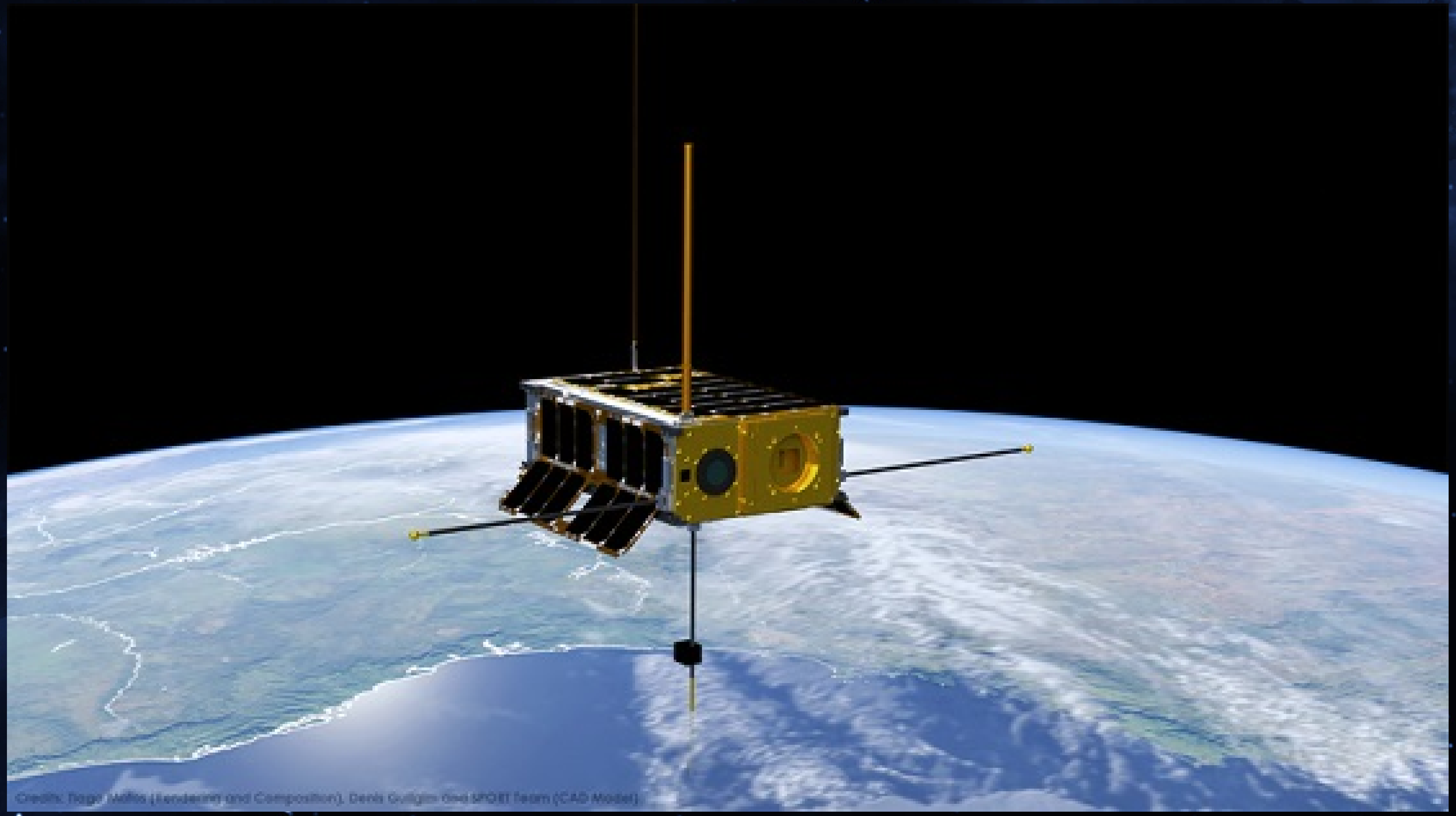
ORR

Implementation

Phase E Operations and Sustainment	To conduct the mission and meet the initially identified need and maintain support for that need. Implement the mission operations plan.	Desired system

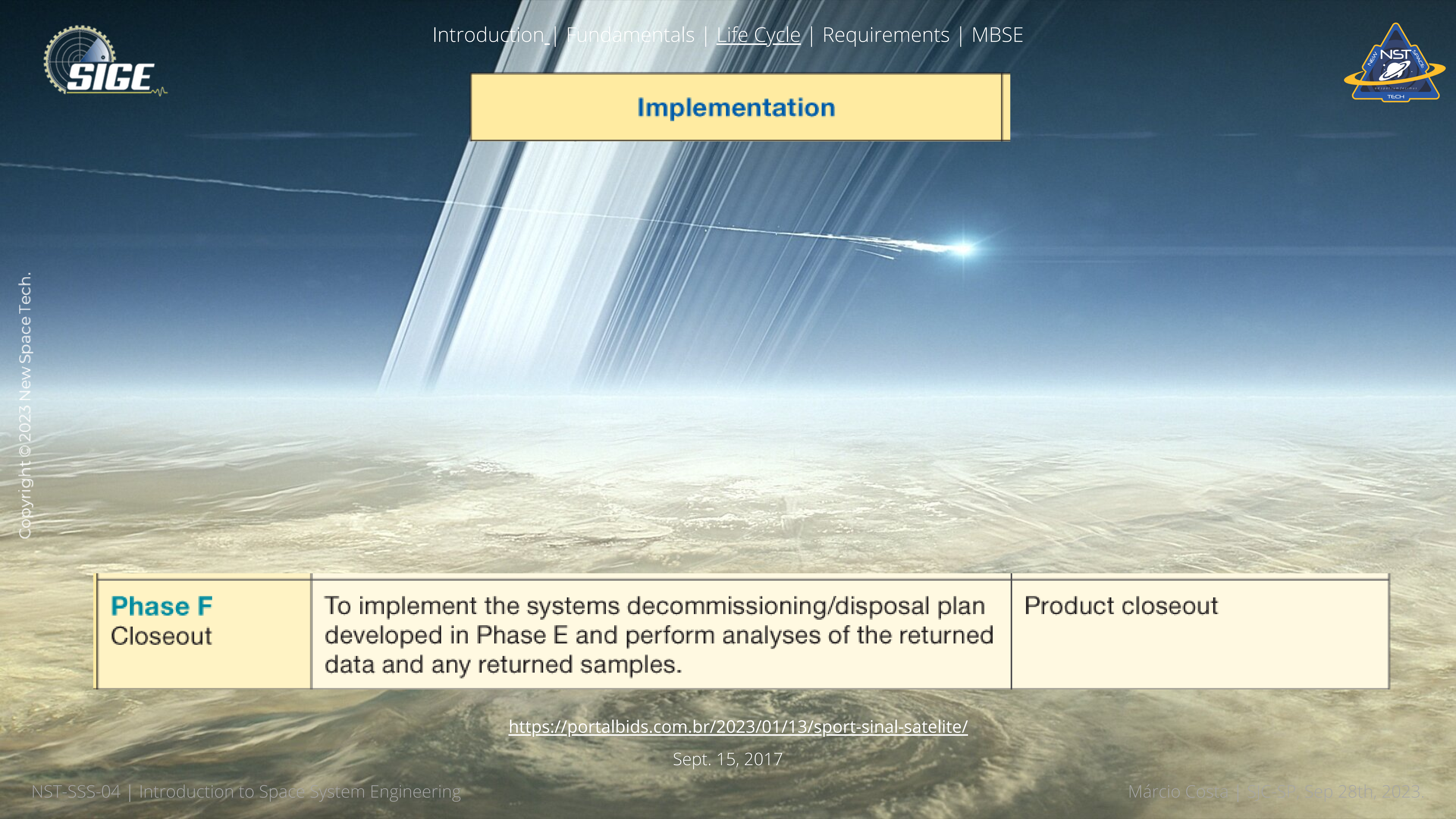
AS-DEPLOYED

AS-OPERATED



https://portalbids.com.br/2023/01/13/sport-sinal-satelite/

Implementation

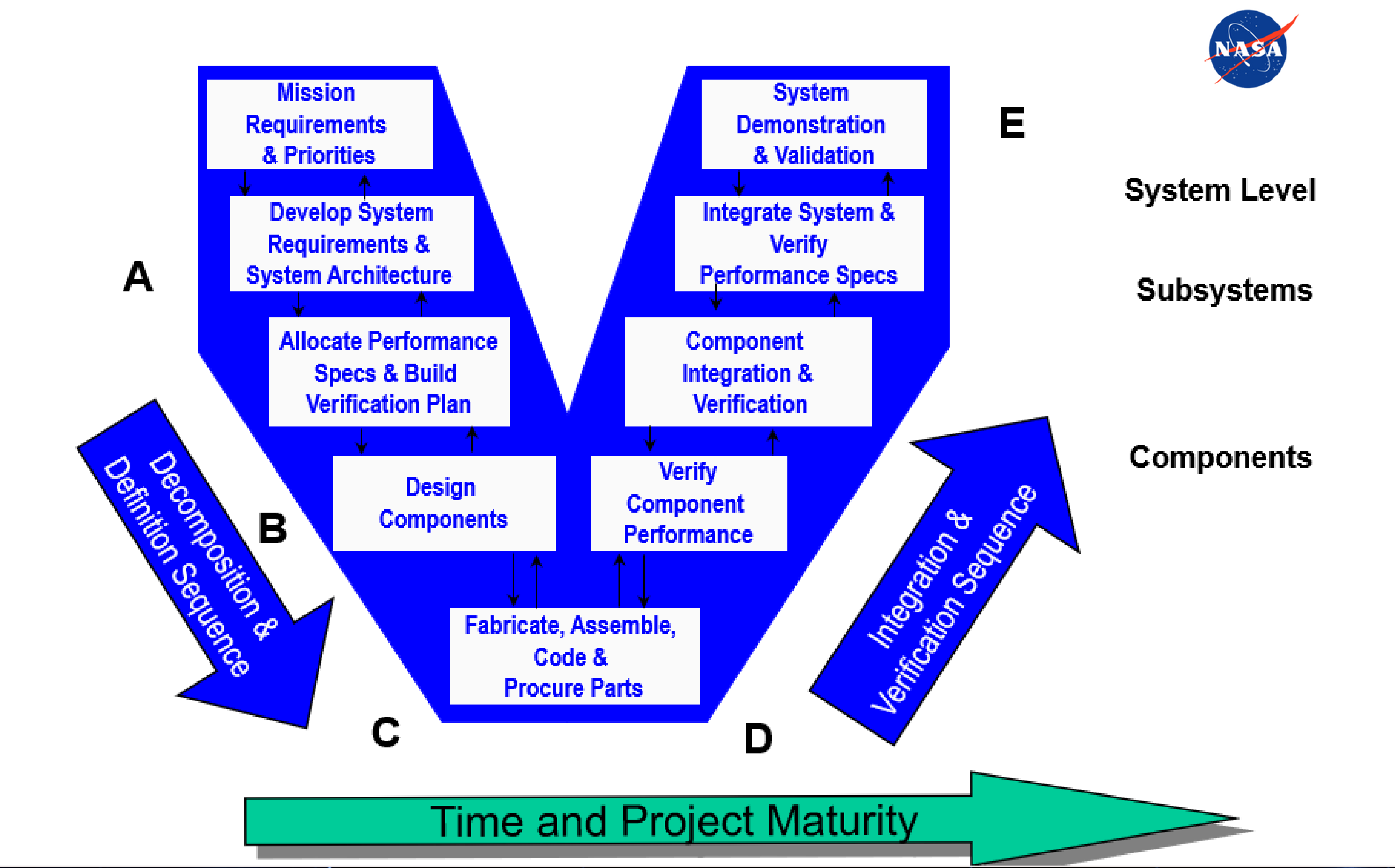


Phase F Closeout	To implement the systems decommissioning/disposal plan developed in Phase E and perform analyses of the returned data and any returned samples.	Product closeout

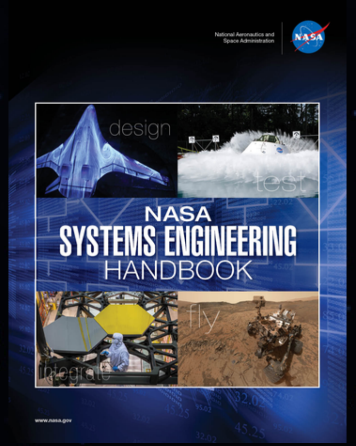
https://portalbids.com.br/2023/01/13/sport-sinal-satelite/

Sept. 15, 2017

	Phase
Pre-Formulation	**Pre-Phase A** Concept Studies
Formulation	**Phase A** Concept and Technology Development
Formulation	**Phase B** Preliminary Design and Technology Completion
Implementation	**Phase C** Final Design and Fabrication
Implementation	**Phase D** System Assembly, Integration and Test, Launch
Implementation	**Phase E** Operations and Sustainment
Implementation	**Phase F** Closeout



Credits image: NASA SE Course



Verification and Validation

Product Verification and Product Validation processes may be similar in nature, but the objectives are fundamentally different:

Verification of a product shows proof of compliance with requirements—that the product can meet each "shall" statement as proven though performance of a test, analysis, inspection, or demonstration.

Baseline: Specifications, drawings, parts lists, and other setup documentation.

- Related to the set of approved requirements;
- Performed at different stages of the product lifecycle;
- It avoids high costs and performance issues if later modifications are required.

Validation of a product shows that the product fulfills its intended purpose in the intended environment;

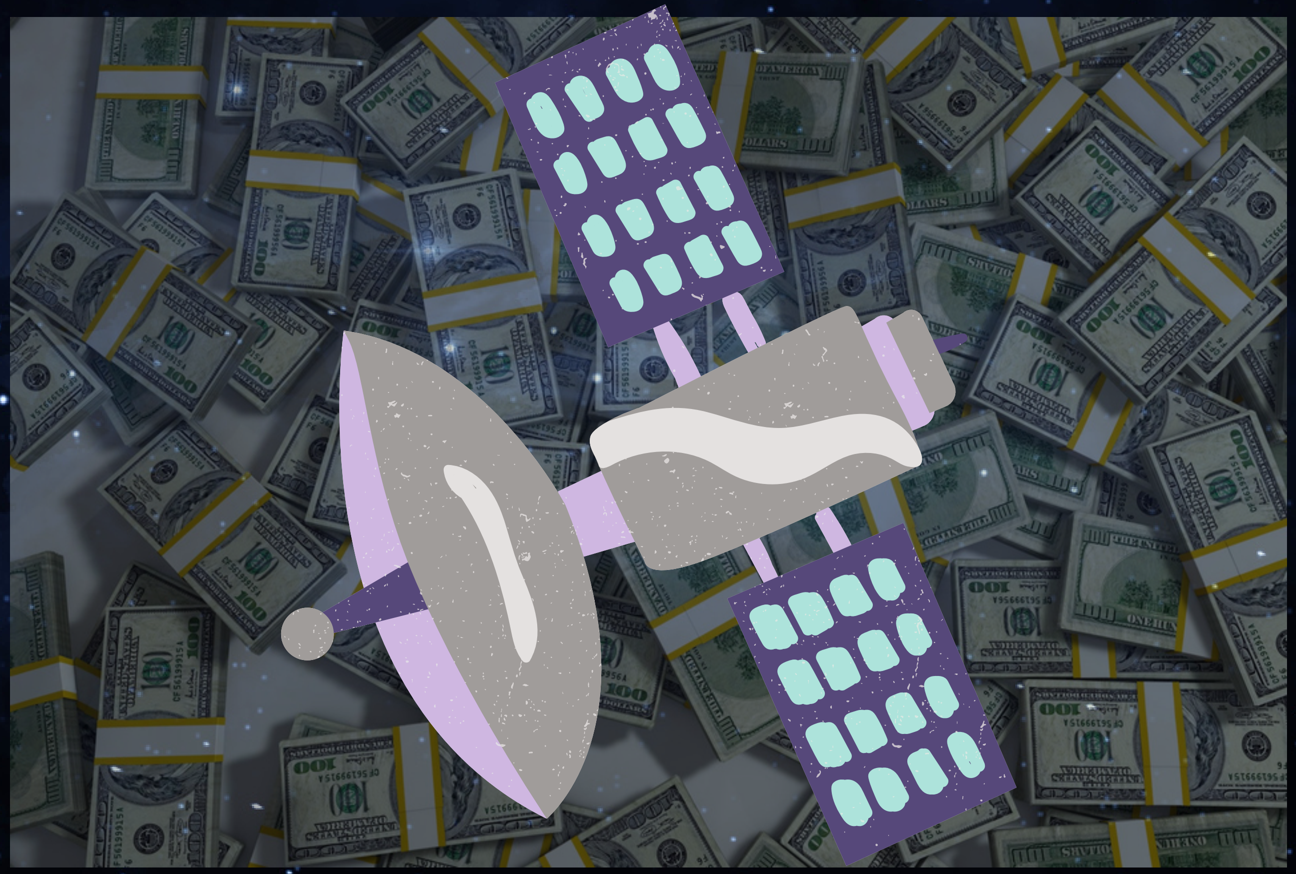
- Determine the effectiveness and suitability of the product for use;
- Demonstration by conducting a test, analysis, inspection or demonstration;
- Performed under realistic or simulated conditions;
- Validation is related to the ConOps document;
- It can be performed at each stage of development using stage products.

Cost-effective

The objective of systems engineering is to ensure that the system is designed, built, and operated as economically as possible, considering performance, cost, schedule, and risk.

Objective: try to find designs that provide the best combination of cost and effectiveness.

Indefinition: there are usually many projects that meet the cost-benefit condition.



At each cost-effective solution:

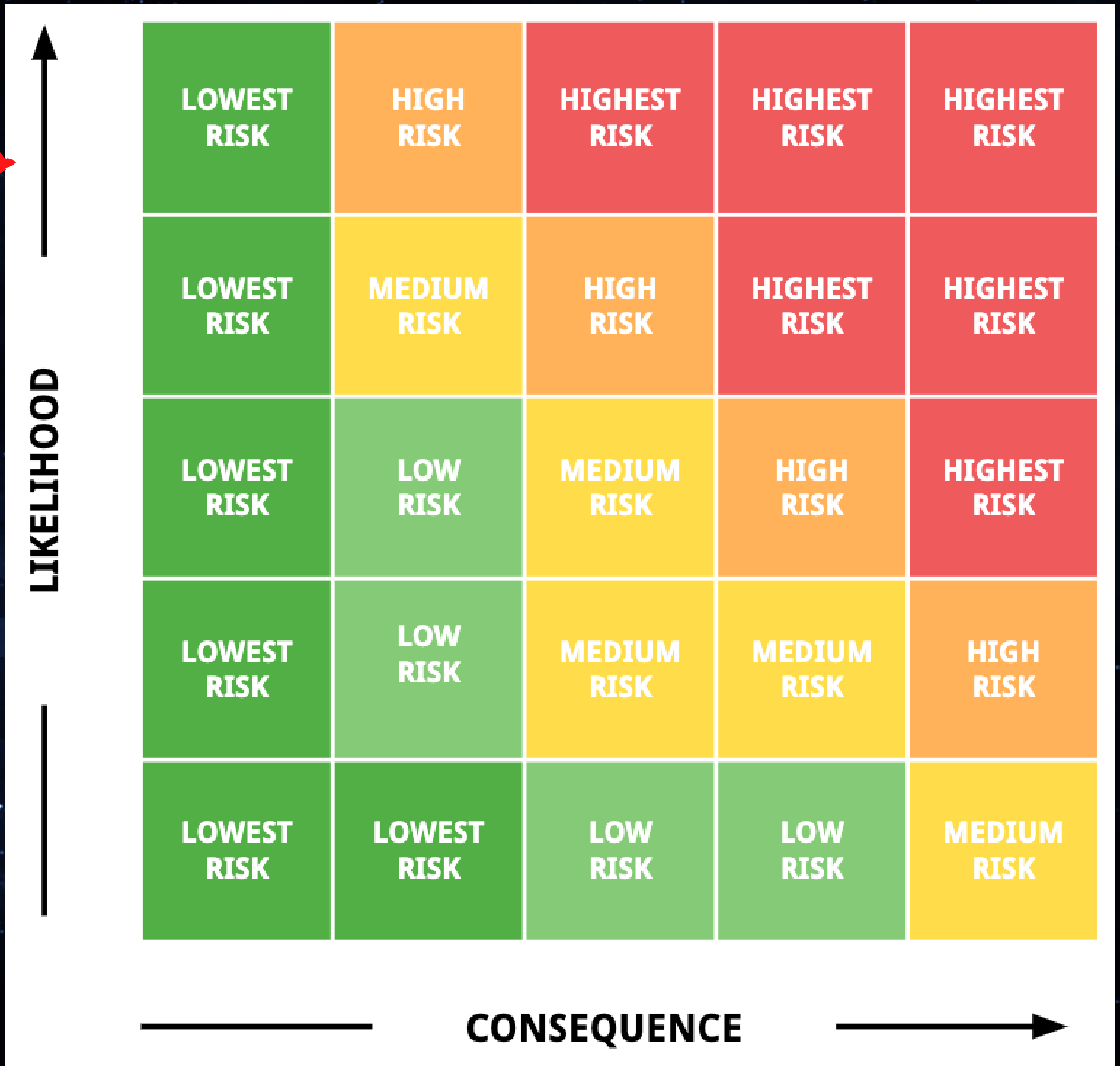
- **To reduce cost at constant risk**, performance must be reduced.
- **To reduce risk at constant cost**, performance must be reduced.
- **To reduce cost at constant performance**, higher risks must be accepted.
- **To reduce risk at constant performance**, higher costs must be accepted.

Pre-Phase A: Concept Studies

a broad spectrum of ideas and alternatives for missions

- Identify risk classification
- Identify initial technical risks

- Identify the roles and responsibilities in performing mission objectives (*i.e., technical team, flight, and ground crew*) *including training*



Source image: Available at <https://nesslabs.com/nasa-risk-matrix>. Accessed on Nov 19th, 2022.

Pre-Phase A: Concept Studies

a broad spectrum of ideas and alternatives for missions

- Develop plans
  - Develop preliminary SEMP
  - Develop and baseline Technology Development Plan
  - Define preliminary verification and validation approach

TABLE E-1 Validation Requirements Matrix

Validation Product #	Activity	Objective	Validation Method	Facility or Lab	Phase	Performing Organization	Results
Unique identifier for validation product	*Describe evaluation by the customer/ sponsor that will be performed*	*What is to be accomplished by the customer/ sponsor evaluation*	*Validation method for the requirement (analysis, inspection, demonstra-tion, or test)*	*Facility or laboratory used to perform the validation*	*Phase in which the verification/ validation will be performed[a]*	*Organization responsible for coordinating the validation activity*	*Indicate the objective evidence that validation activity occurred*
1	Customer/ sponsor will evaluate the candidate displays	1. Ensure legibility is acceptable 2. Ensure overall appearance is acceptable	Test	xxx	Phase A	xxx	TPS 123456

a. Example: (1) during product selection process, (2) prior to final product selection (if COTS) or prior to PDR, (3) prior to CDR, (4) during box-level functional, (5) during system-level functional, (6) during end-to-end functional, (7) during integrated vehicle functional, (8) during on-orbit functional.

Source image: Available at <https://www.nasa.gov/seh/appendix-e_creating-the-validation-plan>. Accessed on Nov 19th, 2022.

Outline

TABLE 3.0-1 SE Product Maturity from NPR 7123.1

		Formulation			Implementation						
Products	Uncoupled/ Loosely Coupled	KDP 0		KDP I	Periodic KDPs						
	Tightly Coupled Programs	KDP 0			KDP I	KDP II		KDP III		Periodic KDPs	
	Projects and Single Project Programs	Pre-Phase A	Phase A		Phase B	Phase C		Phase D		Phase E	Phase F
		KDP A	KDP B		KDP C	KDP D		KDP E		KDP F	
		MCR	SRR	MDR/SDR	PDR	CDR	SIR	ORR	FRR	DR	DRR
Stakeholder identification and		**Baseline	Update	Update	Update						
Concept definition		**Baseline	Update	Update	Update	Update					
Measure of effectiveness definition		**Approve									
Cost and schedule for technical		Initial	Update	Update		Update	Update	Update	Update	Update	Update
SEMP[1]		Preliminary	**Baseline	**Baseline	Update	Update	Update				
Requirements		Preliminary	**Baseline	Update	Update	Update					
Technical Performance Measures definition				**Approve							
Architecture definition				**Baseline							
Allocation of requirements to next lower level				**Baseline							
Required leading indicator trends				**Initial	Update	Update	Update				
Design solution definition				Preliminary	**Preliminary	**Baseline	Update	Update			
Interface definition(s)				Preliminary	Baseline	Update	Update				
Implementation plans (Make/code, buy, reuse)				Preliminary	Baseline	Update					
Integration plans				Preliminary	Baseline	Update	**Update				
Verification and validation plans		Approach		Preliminary	Baseline	Update	Update				

Source: Available at <https://www.nasa.gov/seh/3-project-life-cycle>. Accessed on Nov 19th, 2022.

Systems Engineering Management Plan (SEMP)

SEMP is the foundation document for the technical and engineering activities conducted during the project.

The SEMP conveys information to all of the personnel on the technical integration methodologies and activities for the project within the scope of the project plan.

Source: Available at <https://www.nasa.gov/seh/appendix-jsemp-content-outline>. Accessed on Nov 19th, 2022.

Source image: Available at <https://www.nasa.gov/press-release/nasa-s-webb-reaches-alignment-milestone-optics-working-successfully>. Accessed on Nov 19th, 2022.

Systems Engineering Management Plan (SEMP)

The SEMP includes the following three general sections:

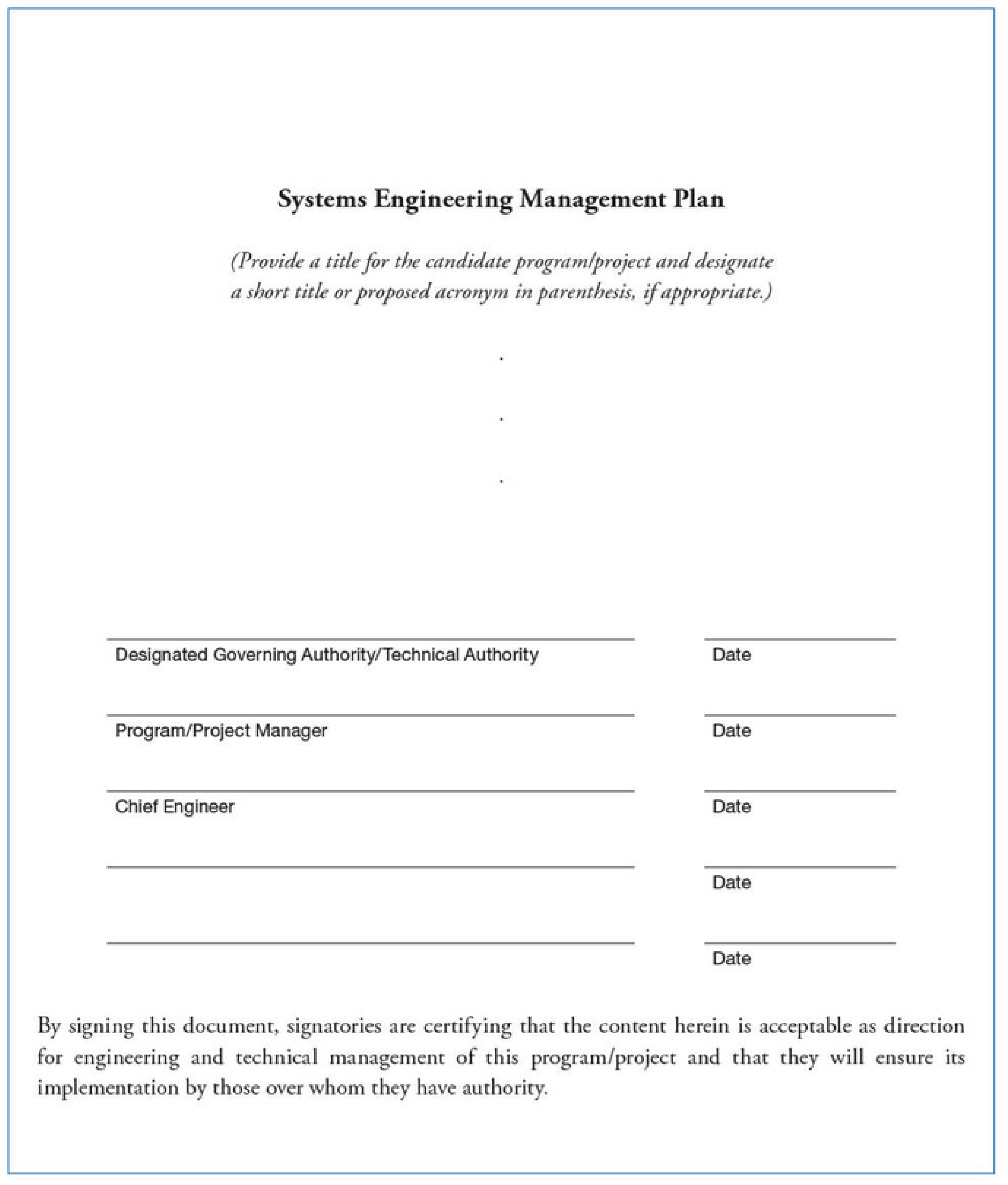
- **Technical program planning and control**, which describe the processes for planning and control of the engineering efforts for the design, development, test, and evaluation of the system.
- **Systems engineering processes**, which include specific tailoring of the systems engineering process as described in the NPR, implementation procedures, trade study methodologies, tools, and models to be used.
- **Engineering specialty integration** describes the integration of the technical disciplines' efforts into the systems engineering process and summarizes each technical discipline effort and cross references each of the specific and relevant plans.

Source: Available at <https://www.nasa.gov/seh/appendix-jsemp-content-outline>. Accessed on Nov 19th, 2022.

Systems Engineering Management Plan (SEMP)

Some additional important points on the SEMP:

- **The SEMP is a living document.**
- The initial SEMP is used to establish the technical content of the engineering work early in the Formulation Phase for each project and updated as needed throughout the project life cycle.



Systems Engineering Management Plan

(Provide a title for the candidate program/project and designate a short title or proposed acronym in parenthesis, if appropriate.)

Designated Governing Authority/Technical Authority	Date
Program/Project Manager	Date
Chief Engineer	Date
	Date
	Date

By signing this document, signatories are certifying that the content herein is acceptable as direction for engineering and technical management of this program/project and that they will ensure its implementation by those over whom they have authority.

Source: Available at <https://www.nasa.gov/seh/appendix-jsemp-content-outline>. Accessed on Nov 19th, 2022.

Systems Engineering Management Plan (SEMP)

TABLE J-1 Guidance on SEMP Content per Life-Cycle Phase

SEMP Section	SEMP Subsection	Pre-Phase A KDP A	Phase A KDP B		Phase B KDP C	Phase C KDP D		Phase D KDP E		Phase E KDP F	Phase F
		MCR	SRR	SDR/MDR	PDR	CDR	SIR	ORR	MRR/FRR	DR	DRR
Purpose and Scope		Final	Final	Final	Final	Final	Final	Final	Final	Final	Final
Applicable Documents		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
Technical Summary		Final	Final	Final	Final	Final	Final	Final	Final	Final	Final
System Description		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
System Structure	Product Integration	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR	Define thru SIR	Define thru SIR	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program
	Planning Context	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR	Define thru SIR	Define thru SIR	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program	Define sustaining thru end of program
	Boundary of Technical Effort	Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
	Cross References	Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
Technical Effort Integration	Responsibility and Authority	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SDR timeframe	Define thru SIR timeframe	Define thru SIR timeframe	Define thru SIR timeframe	Define sustaining Roles and Responsibilities through end of program	Define sustaining Roles and Responsibilities through end of program	Define sustaining Roles and Responsibilities through end of program	
	Contractor Integration	Define acquisitions needed		Define insight/ oversight through SIR timeframe				Define sustaining insight/ oversight through end of program			
	Support Integration	Define acquisitions needed		Define insight/ oversight through SIR timeframe				Define sustaining insight/ oversight through end of program			

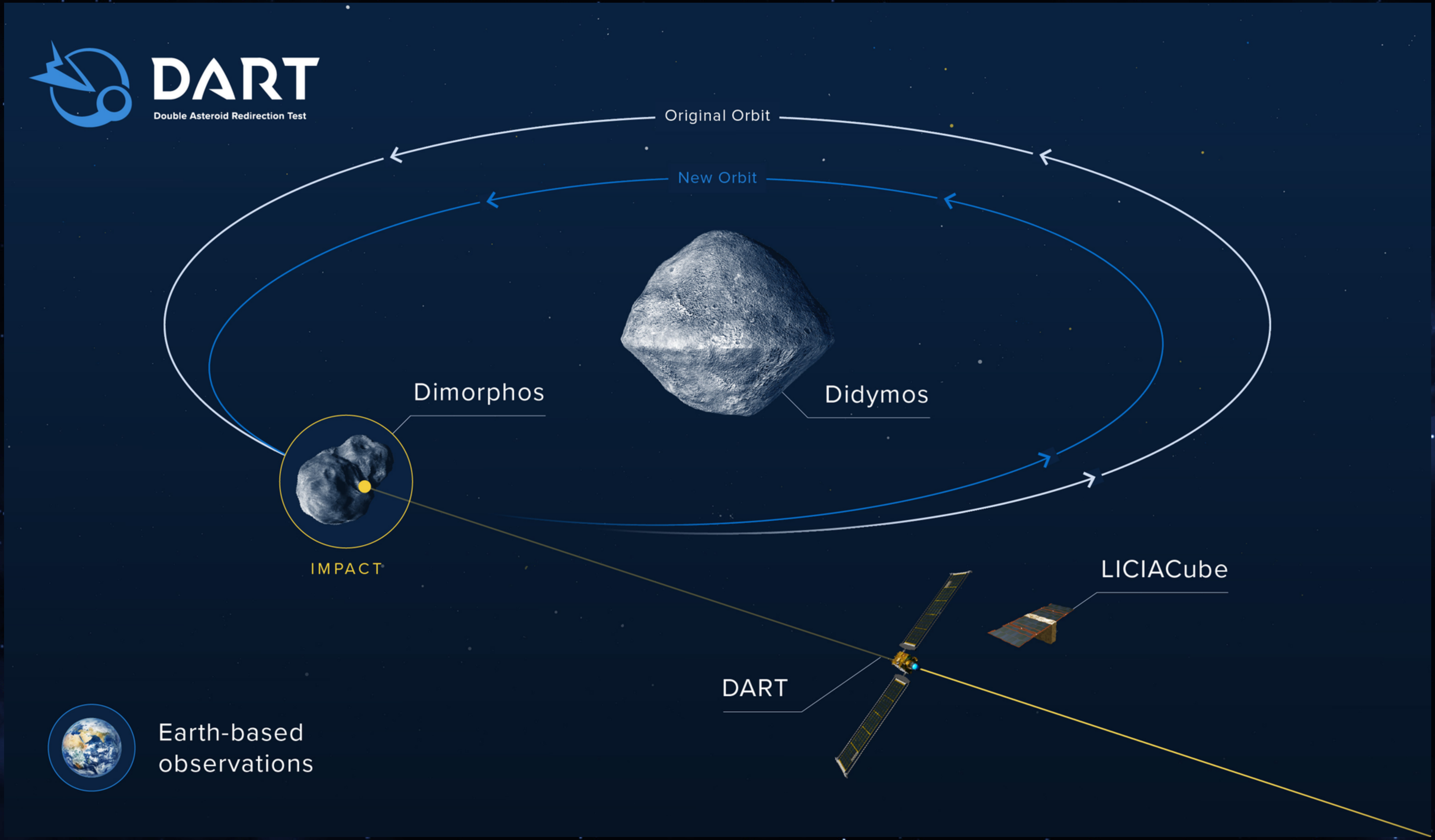
Source: Available at <https://www.nasa.gov/seh/appendix-jsemp-content-outline>. Accessed on Nov 19th, 2022.

Systems Engineering Management Plan (SEMP)

SEMP Section	SEMP Subsection	Pre-Phase A KDP A	Phase A KDP B		Phase B KDP C	Phase C KDP D		Phase D KDP E		Phase E KDP F	Phase F
		MCR	SRR	SDR/MDR	PDR	CDR	SIR	ORR	MRR/FRR	DR	DRR
Common Technical Processes Implementation		Processes defined for Concept Development and Formulation		Processes defined for the Design Phase		Processes added for the integration and Operations Phase		Update Operations processes. Define close out processes and sustaining engineering processes			
Technology Insertion		Define technologies to be developed		Define decision process for on ramps and off ramps of technology efforts				Define technology sustaining effort through end of program.			
Additional SE Functions and Activities	System Safety	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
	Engineering Methods and tools	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
	Specialty Engineering	Define process through CDR						Define sustaining Roles and Responsibilities through end of program			
Integration with the Project Plan and Technical Resource Allocation		Define through SDR timeframe			Define through SIR	Define through SIR	Define through SIR	Define sustaining through end of program	Define sustaining through end of program	Define sustaining through end of program	Define sustaining through end of program
Compliance Matrix (Appendix H.2 of SE NPR)		Initial	Initial	Initial	Final	Final	Final	Final	Final	Final	Final
Appendices		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required
Templates		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required
References		As required	As required	As required	As required	As required	As required	As required	As required	As required	As required

Source: Available at <https://www.nasa.gov/seh/appendix-jsemp-content-outline>. Accessed on Nov 19th, 2022.

Concept of Operations (ConOps)

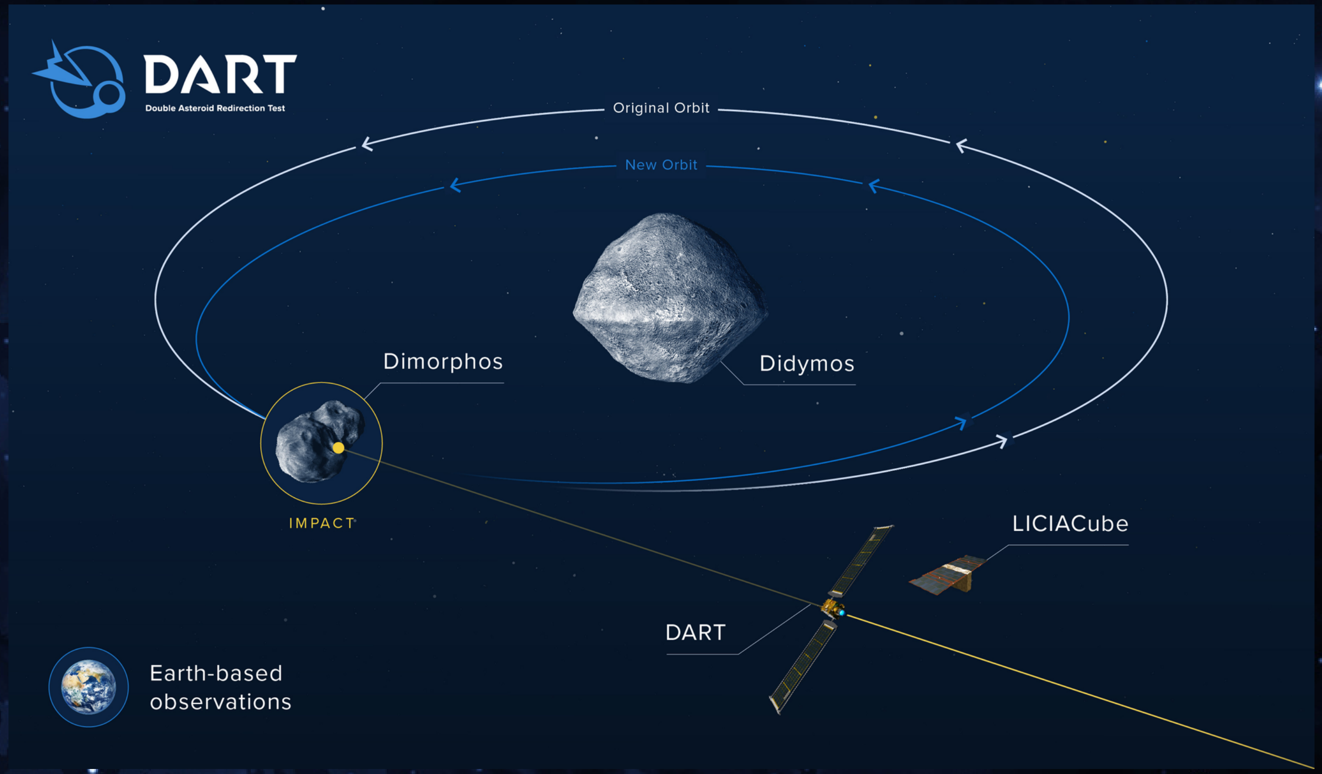


Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.

Concept of Operations (ConOps)

1º Executive summary

- mission
- organizations' roles and responsibilities
- key capabilities and performance characteristics the stakeholders want.



2º Mission description

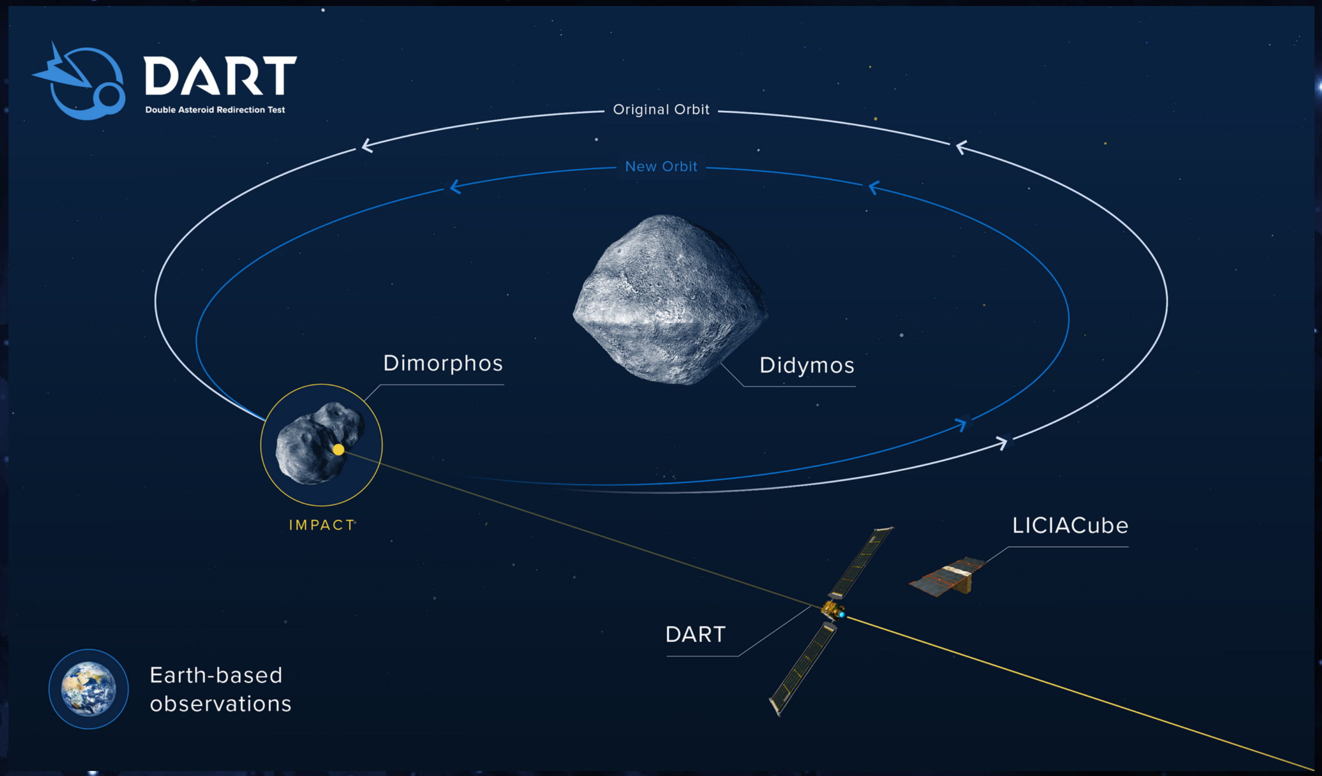
- Describe the mission,
- its goals and objectives, and
- the underlying mission
- business rationale.
- Identify relevant stakeholders and their main expectations.

Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.

Concept of Operations (ConOps)

3º System operational context and reference operational architecture

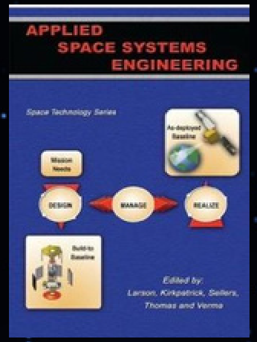
- system's boundary
- initial reference architecture based on what similar systems have used.
- Describe the 'as-is" and "to-be" contexts to help clarify the conceived system's value.



4º System drivers and constraints

- Describe performance drivers and constraints;
- constraints resulting from the existing systems and infrastructure;
- doctrine (policy, procedures, and processes);
- organizational roles

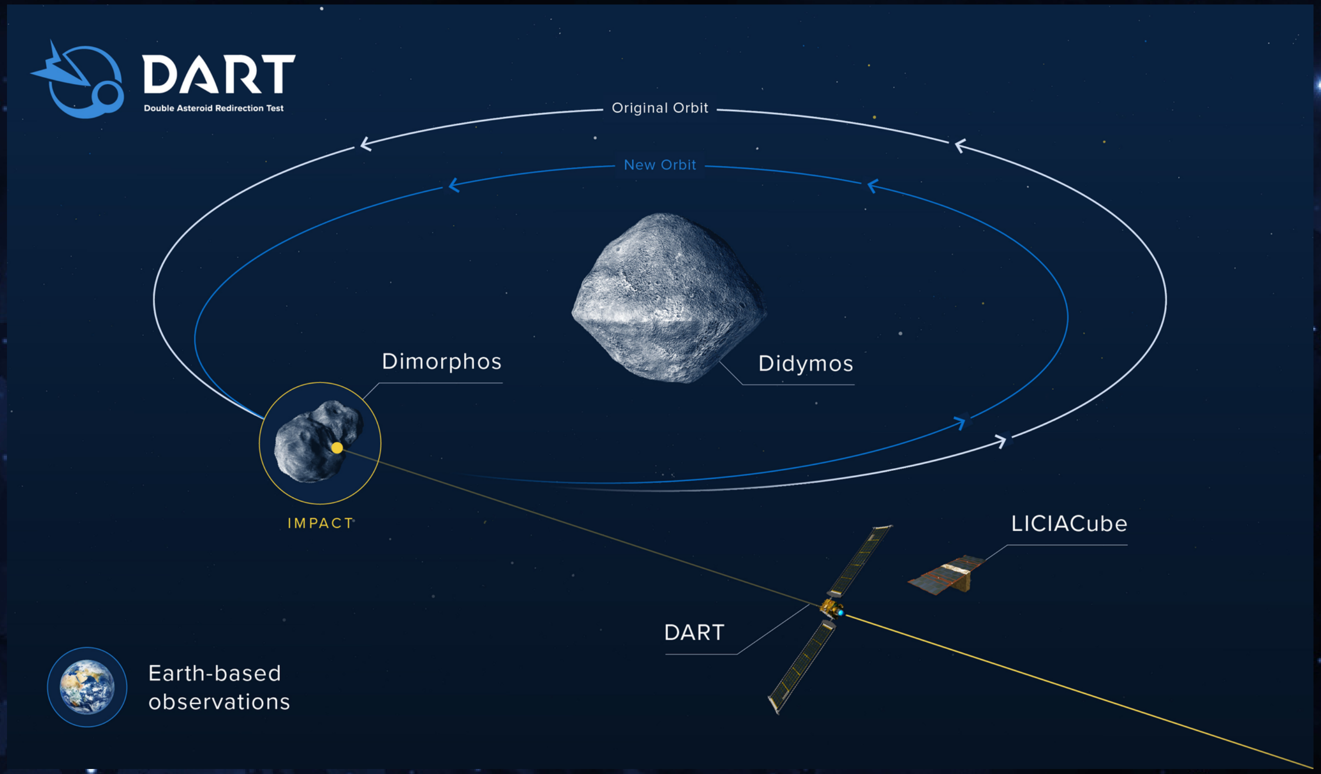
Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.



Concept of Operations (ConOps)

5º Operational scenarios

- Create the main operational scenarios to support capabilities the stakeholders expect,
- Use language and graphics to ensure that systems engineers understand the stakeholders' expectations.
- Develop timelines for each operational scenario to gain insights into other concepts for partitioning and implementation.



Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.

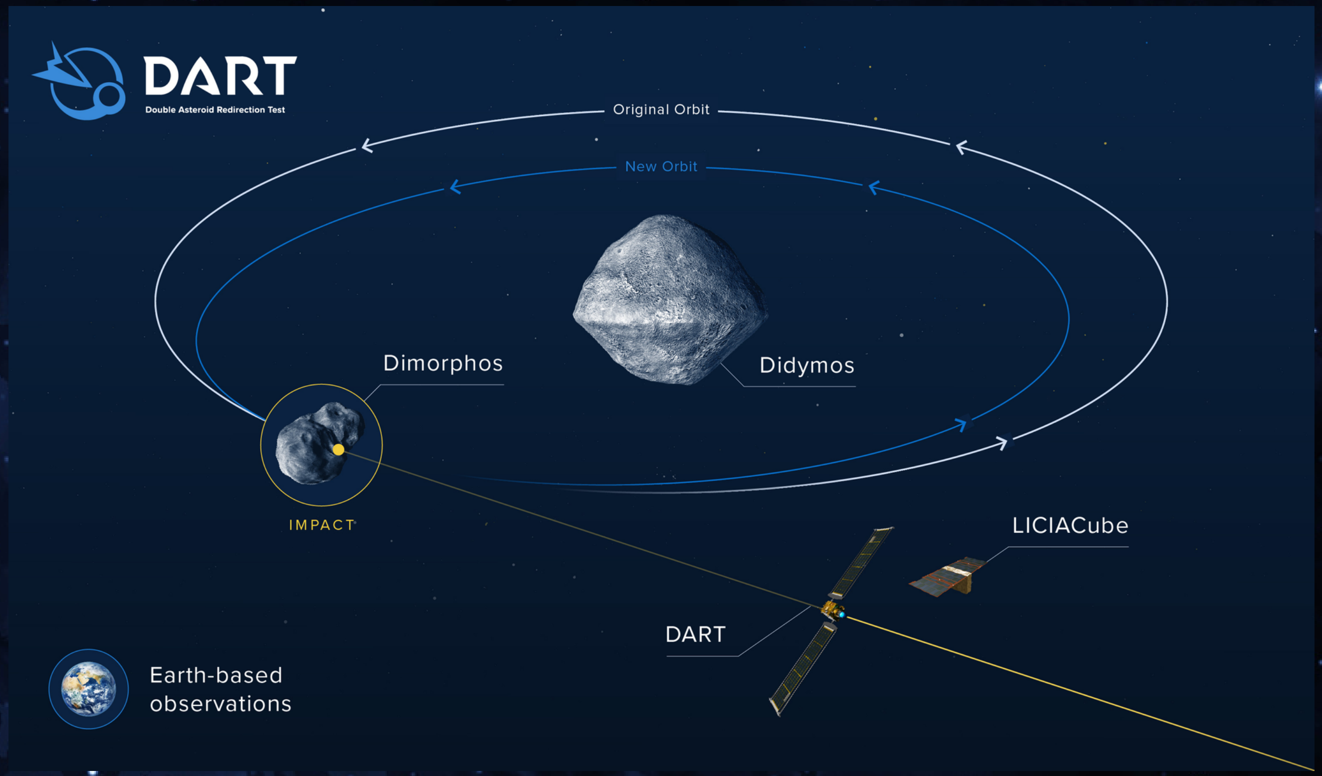
6º Proposed system operational architecture

- Document changes to partitioning of the system, its elements and sub-elements, in a proposed system operational architecture.

Concept of Operations (ConOps)

7º Organizational and business impact

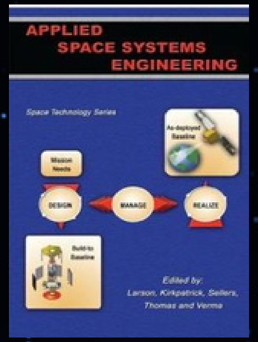
- Analyze and present the effects of a changed operational architecture on legacy doctrine to ensure appropriate decision making.



8º Risks and technology readiness

- Include technology readiness levels for the principal implementing concepts.
- Also assess schedule and funding risks resulting from the proposed approach.

Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.



Concept of Operations (ConOps)

86 CHAPTER 3—CONCEPT OF OPERATIONS AND SYSTEM OPERATIONAL ARCHITECTURE

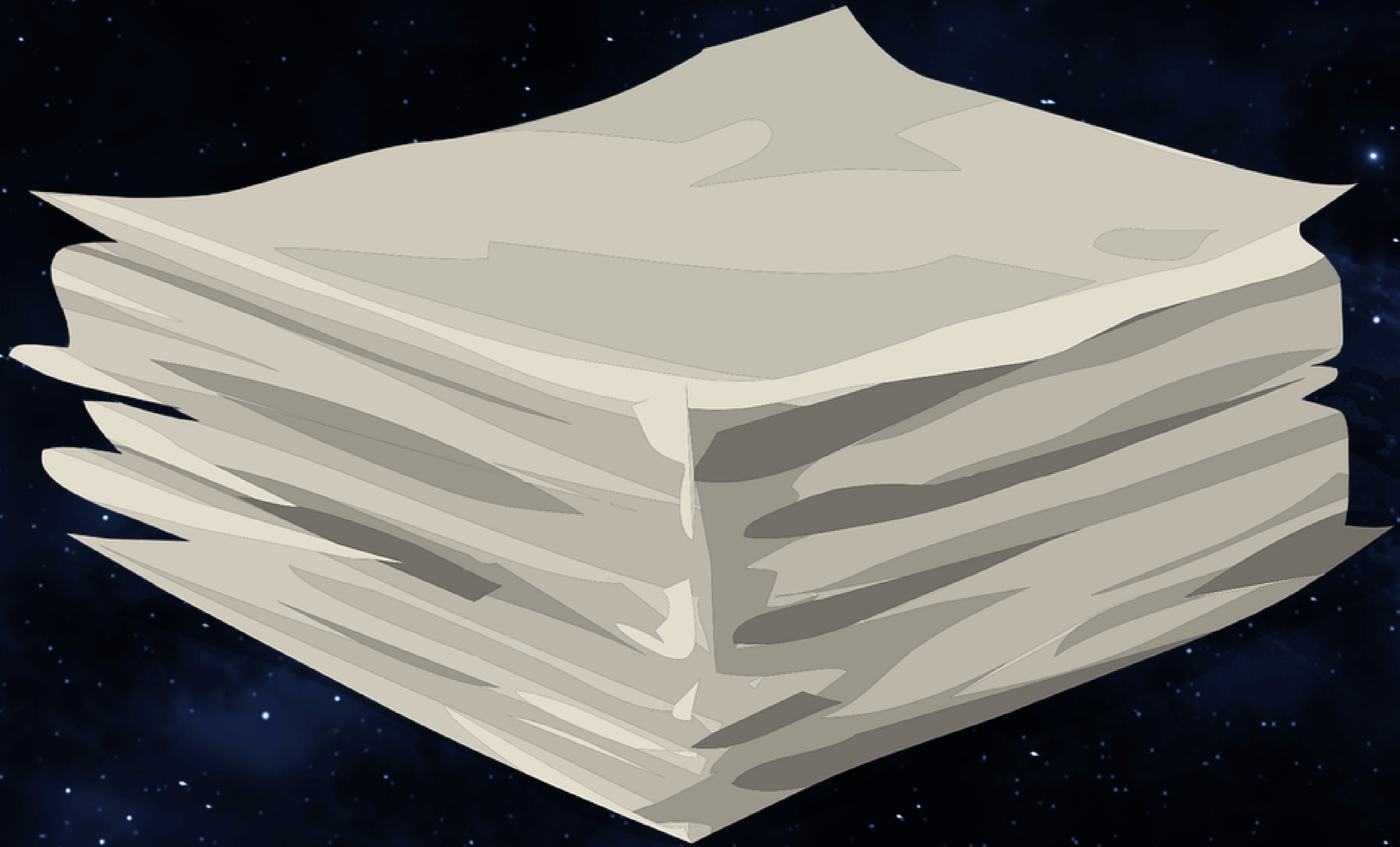
TABLE 3-8. Suggested Outline for a System Concept of Operations. This table consolidates the major aspects of a concept of operations.

Section #	Section Name	Remarks
1	Executive summary	Briefly summarize the mission, organizations' roles and responsibilities, and key capabilities and performance characteristics the stakeholders want. Outline main findings and significant departures from legacy systems; include a brief rationale in each case.
2	Mission description	Describe the mission, its goals and objectives, and the underlying mission and business rationale. Identify relevant stakeholders and their main expectations.
3	System operational context and reference operational architecture	These elements clarify the system's boundary and establish the initial reference architecture based on what similar systems have used. Reference active stakeholders in the context diagram, together with the reference system's elements and sub-elements. Describe the 'as-is" and "to-be" contexts to help clarify the conceived system's value.
4	System drivers and constraints	Describe performance drivers and constraints; constraints resulting from the existing systems and infrastructure; doctrine (policy, procedures, and processes); organizational roles and responsibilities; and regulatory requirements. Explicitly defining drivers helps us assess different concepts for the system, its elements, and its sub-elements.
5	Operational scenarios	Create the main operational scenarios to support capabilities the stakeholders expect, considering the system context and reference operational architecture, as well as the proposed operational architecture. Use language and graphics to ensure that systems engineers understand the stakeholders' expectations. Develop timelines for each operational scenario to understand latency thresholds and gain insights into other concepts for partitioning and implementation.
6	Implementation concepts selected and rationale	Synthesize different ways to partition and carry out stakeholders' intentions in system elements and sub-elements. Document why we selected the preferred application, addressing especially the important drivers and constraints, including funding and schedule.
7	Proposed system operational architecture	Document changes to partitioning of the system, its elements and sub-elements, in a proposed system operational architecture.
8	Organizational and business impact	Analyze and present the effects of a changed operational architecture on legacy doctrine to ensure appropriate decision making. Doctrine includes policy, procedures, and processes; organizational roles and responsibilities; necessary skills and competencies; and workload changes.
9	Risks and technology readiness assessment	Document risks for the proposed operational architecture. Include technology readiness levels for the principal implementing concepts. Also assess schedule and funding risks resulting from the proposed approach.

Source: Available at <https://dart.jhuapl.edu/Mission/index.php>. Accessed on Nov 19th, 2022.

Writing a good requirement

A good requirement must have:



- Clarity
- Completeness
- Compliance
- Consistency
- Traceability
- Correctness
- Maintainability
- Reliability
- Functionality
- Testability

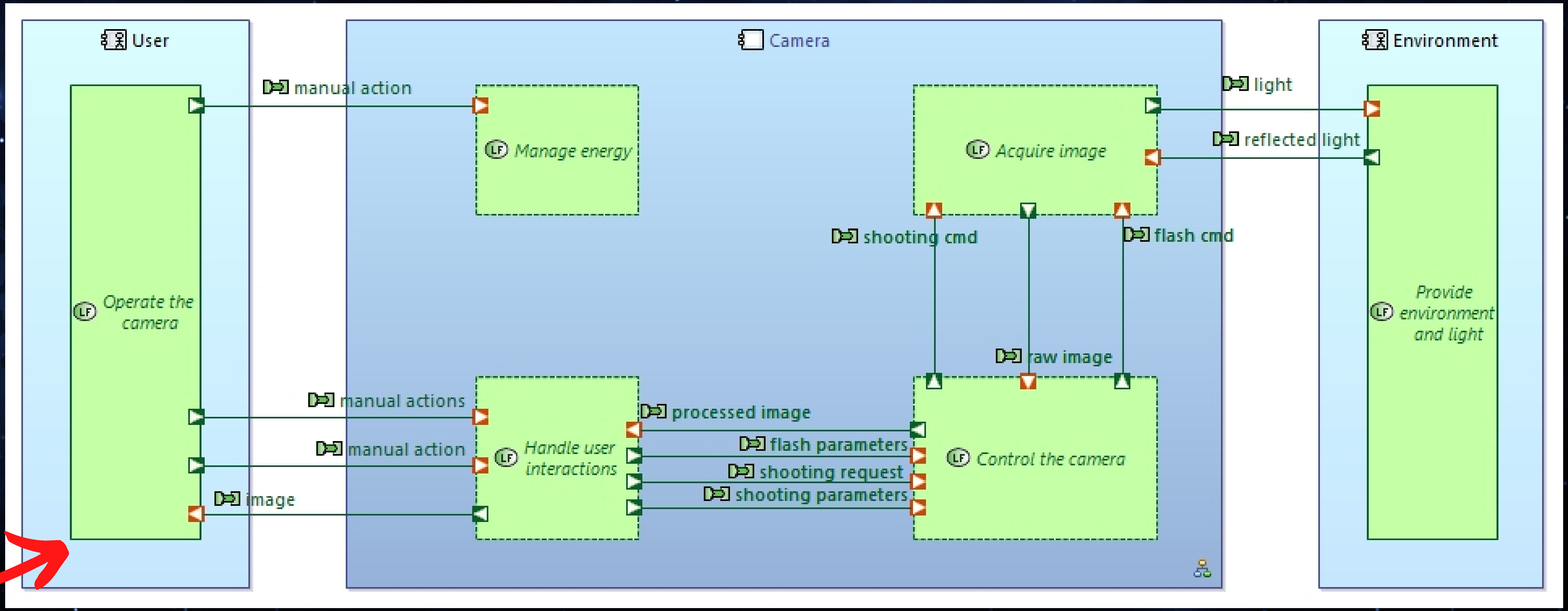
Requirements verification matrix

Requirement No.	Document	Paragraph	Shall Statement	Verification Success Criteria	Verification Method	Facility or Lab	Phase[a]	Acceptance Requirement?	Preflight Acceptance?	Performing Organization	Results
Unique identifier or each requirement	*Document number the requirement is contained within*	*Paragraph number of the requirement*	*Text (within reason) of the requirement, i.e., the "shall"*	*Success criteria for the requirement*	*Verification method for the requirement (analysis, inspection, demonstration, test)*	*Facility or laboratory used to perform the verification and validation.*	*Phase in which the verification and validation will be performed.*	*Indicate whether this requirement is also verified during initial acceptance testing of each unit.*	*Indicate whether this requirement is also verified during any pre-flight or recurring acceptance testing of each unit*	*Organization responsible for performing the verification*	*Indicate documents that contain the objective evidence that requirement was satisfied*
P-1	xxx	3.2.1.1 Capability: Support Uplinked Data (LDR)	System X shall provide a max. ground-to-station uplink of…	1. System X locks to forward link at the min and max data rate tolerances 2. System X locks to the forward link at the min and max operating frequency tolerances	Test	xxx	5	Yes	No	xxx	TPS xxxx
P-i	xxx	Other paragraphs	Other "shalls" in PTRS	Other criteria	xxx	xxx	xxx	Yes/No	Yes/No	xxx	Memo xxx
S-i or other unique designator	xxxxx (other specs, ICDs, etc.)	Other paragraphs	Other "shalls" in specs, ICDs, etc.	Other criteria	xxx	xxx	xxx	Yes/No	Yes/No	xxx	Report xxx

Source: Hirshorn, S. R., Voss, L. D. , and Bromley, L. K.. NASA Systems Engineering Handbook. 2017.

Model-based systems engineering (MBSE)

"MBSE is a systems engineering methodology that focuses on creating and exploiting domain models as the primary means of information exchange between engineers, rather than on document-based information exchange."



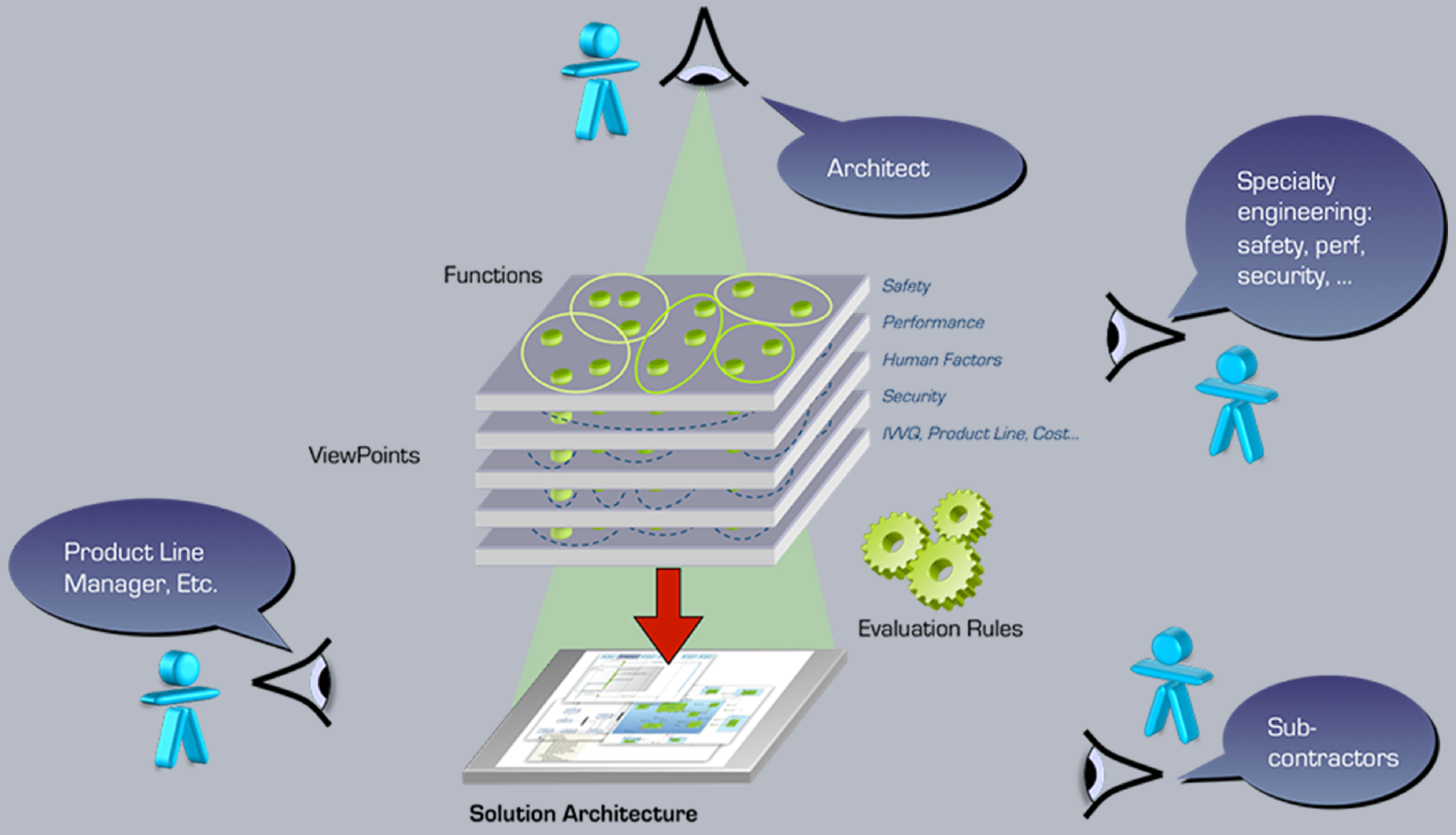
Source: Available at <https://www.omgwiki.org/MBSE/doku.php>. Accessed on Nov 19th, 2022.

Source: Available at <https://www.eclipse.org/capella/features.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

Arcadia Method

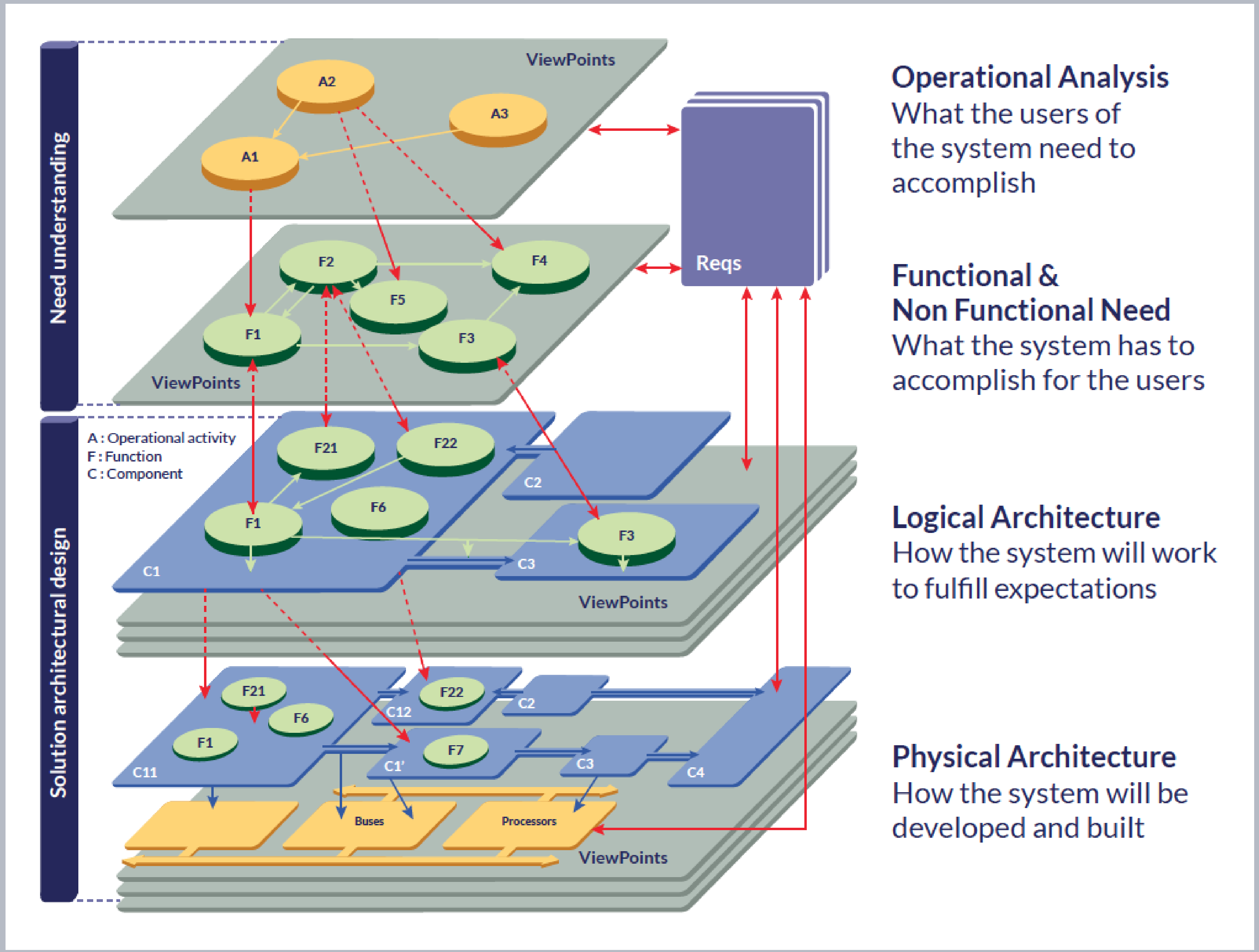
Arcadia is a system engineering method based on the use of models, with a focus on the collaborative definition, evaluation and exploitation of its architecture.



Source: Available at <https://www.eclipse.org/capella/arcadia.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

Capella™



Source: Available at <https://www.eclipse.org/capella/arcadia.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

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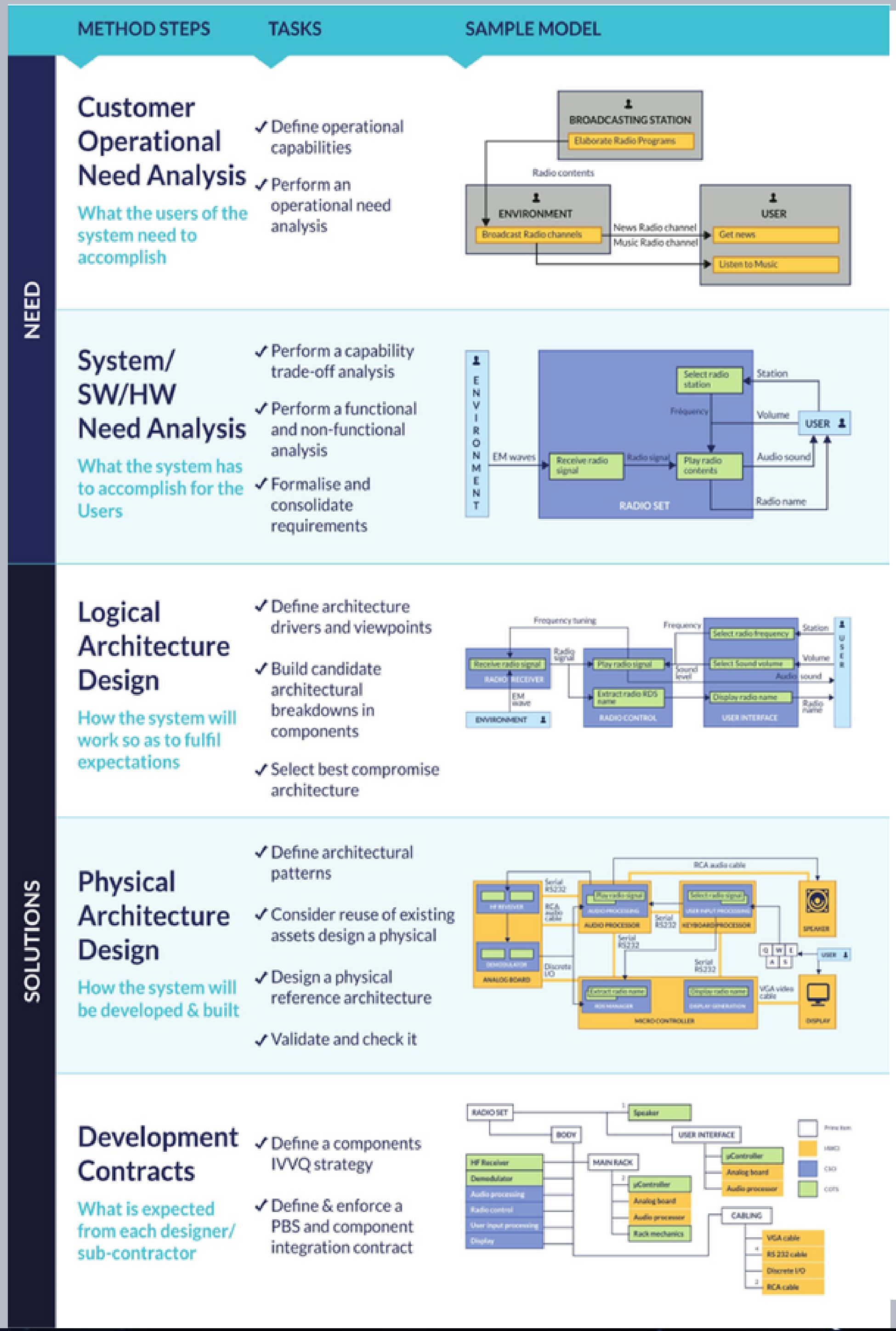

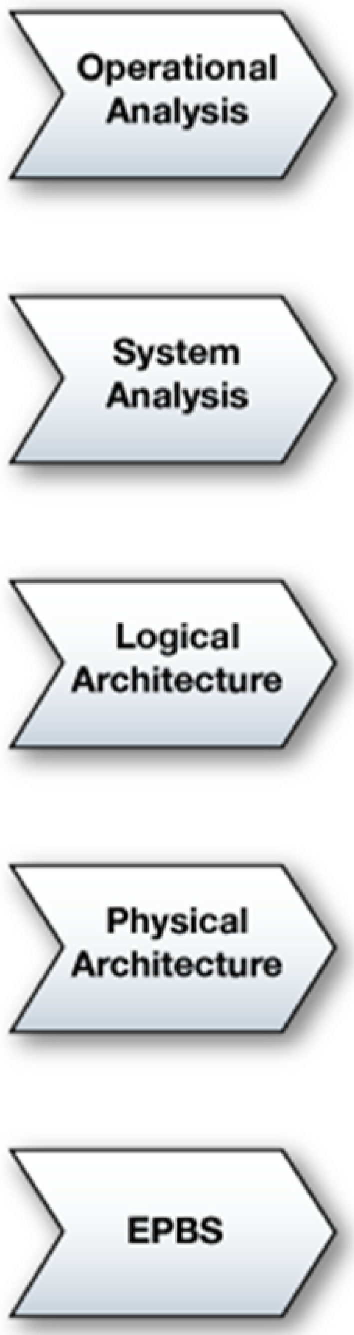

Define Stakeholder Needs and Environment

Capture and consolidate operational needs from stakeholders
Define what the users of the system have to accomplish
Identify entities, actors, roles, activities, concepts

Formalize System Requirements

Identify the boundary of the system, consolidate requirements
Define what the system has to accomplish for the users
Model functional dataflows and dynamic behaviour

Develop System Logical Architecture

See the system as a white box
Define how the system will work so as to fulfill expectations
Perform a first trade-off analysis

Develop System Physical Architecture

How the system will be developed and built
Software vs. hardware allocation, specification of interfaces, deployment configurations, trade-off analysis

Formalize Component Requirements

Manage industrial criteria and integration strategy: what is expected from each designer/sub-contractor
Specify requirements and interfaces of all configuration items

Source: Available at <https://www.eclipse.org/capella/arcadia.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

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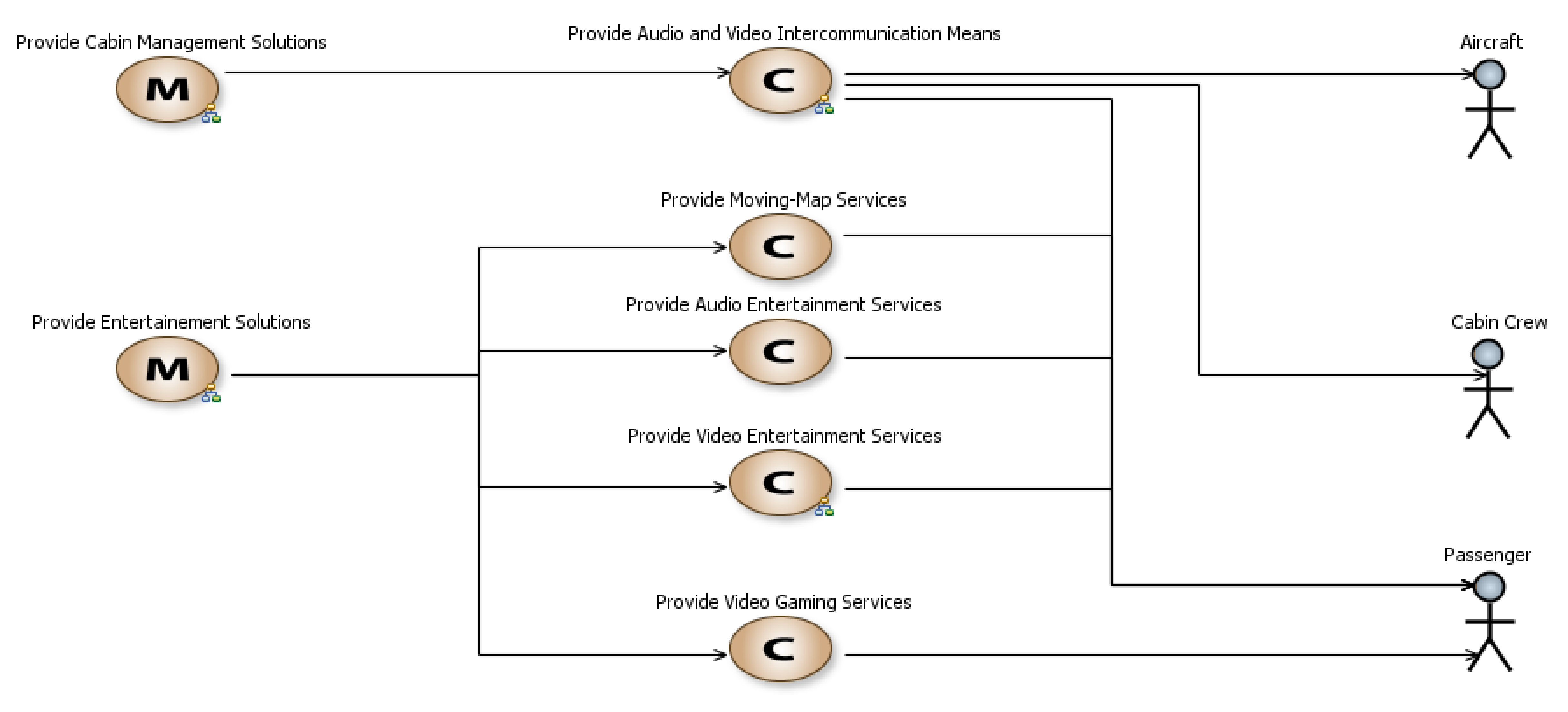
Capabilities



Source: Available at <https://www.eclipse.org/capella/features.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

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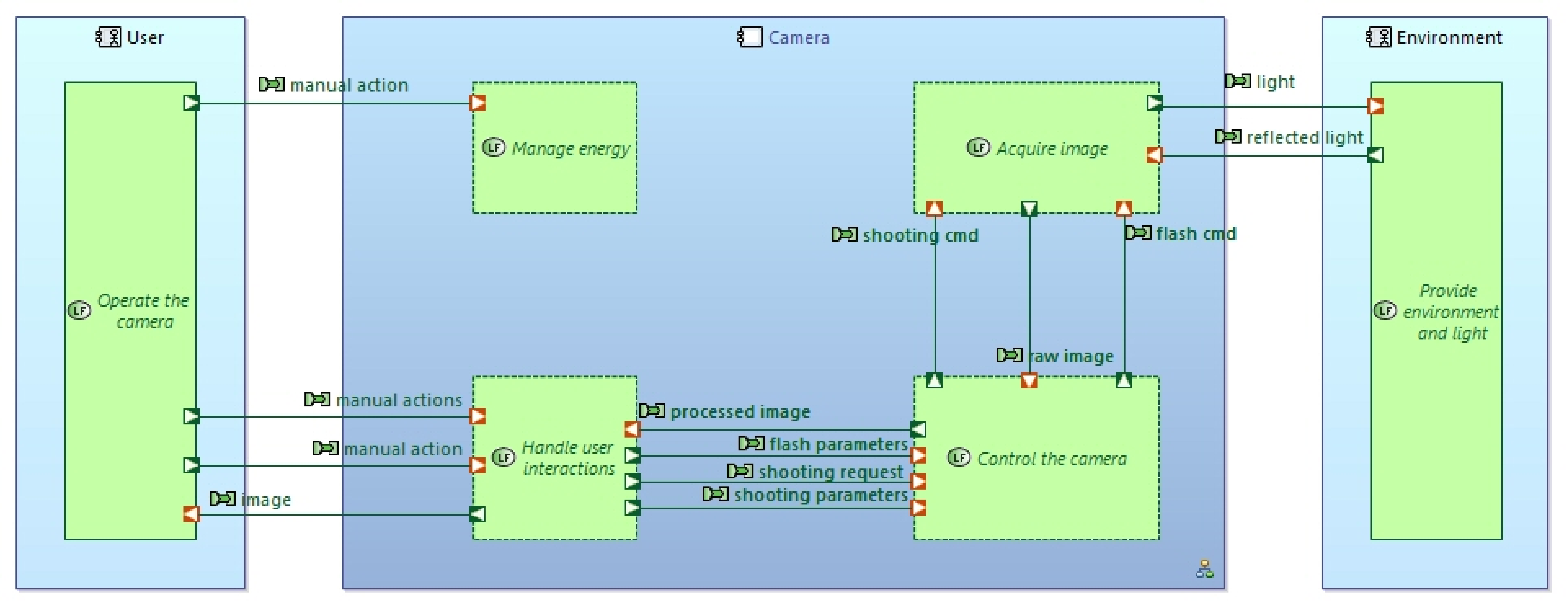
Architecture



Source: Available at <https://www.eclipse.org/capella/features.html>. Accessed on Nov 19th, 2022.

Model-based systems engineering (MBSE)

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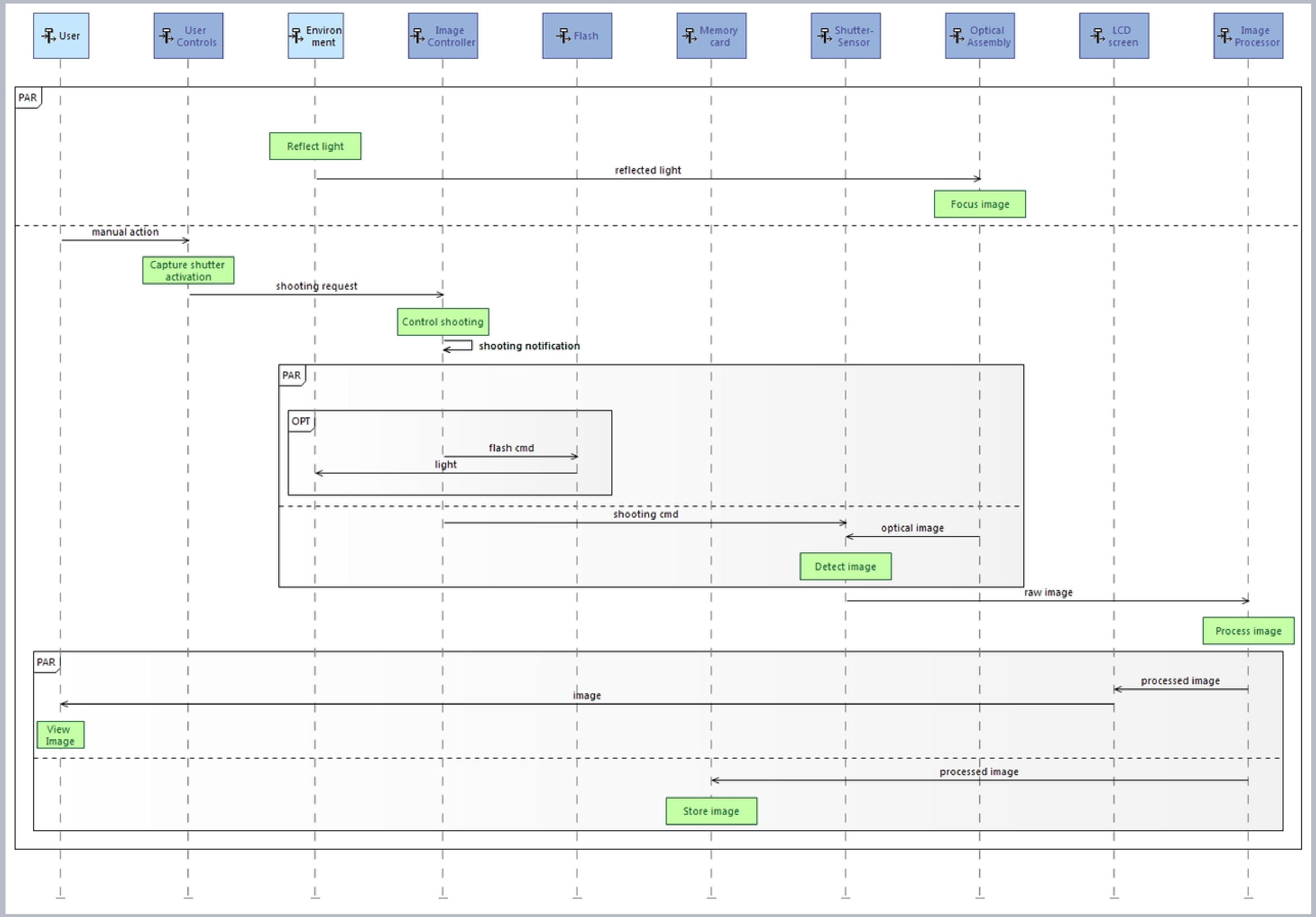
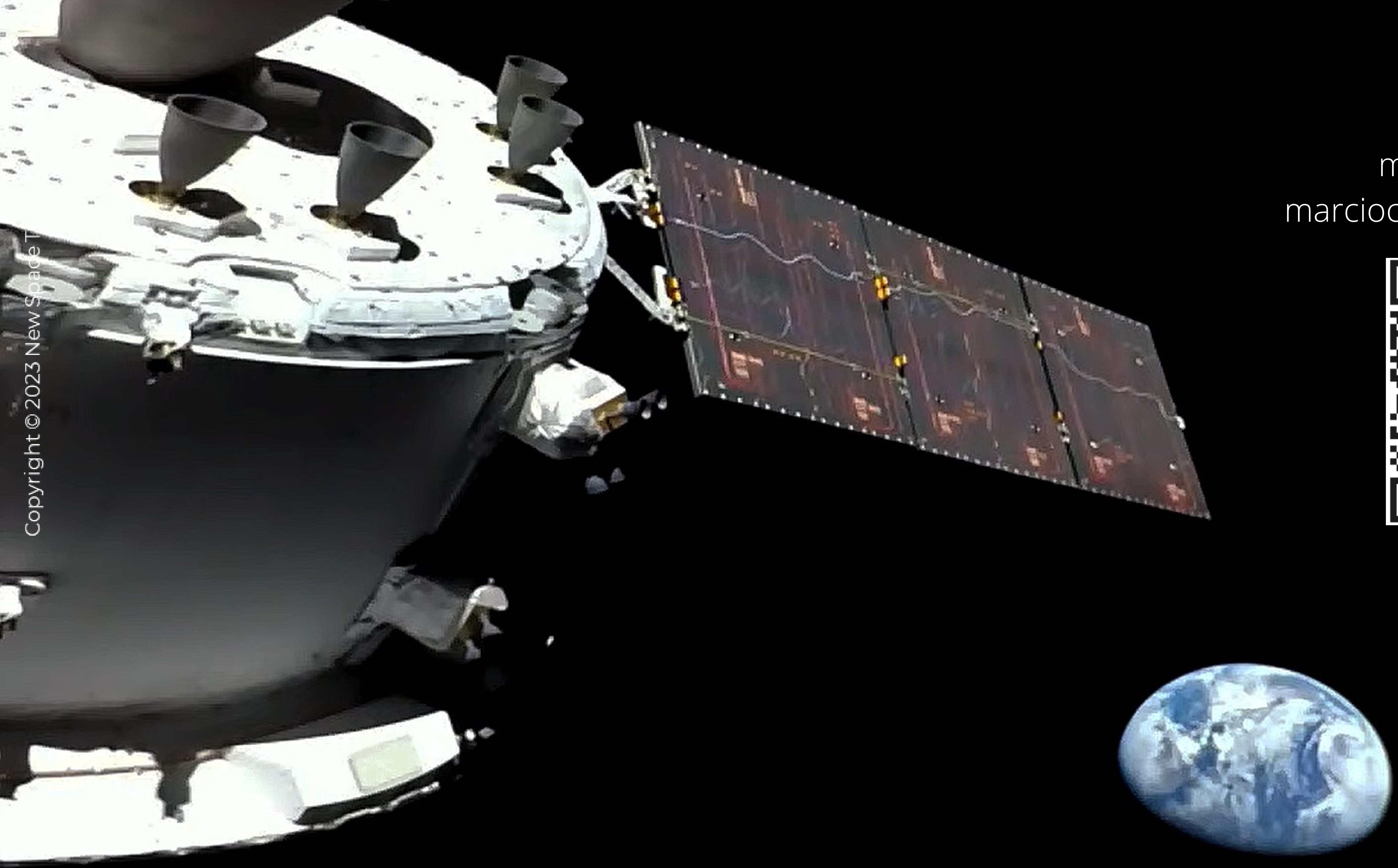
Sequence Diagrams



Source: Available at <https://www.eclipse.org/capella/features.html>. Accessed on Nov 19th, 2022.

Thanks for coming!



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