Electrical Engineering and Computer Science Dept
College of Engineering

VERIFICATION AND VALIDATION

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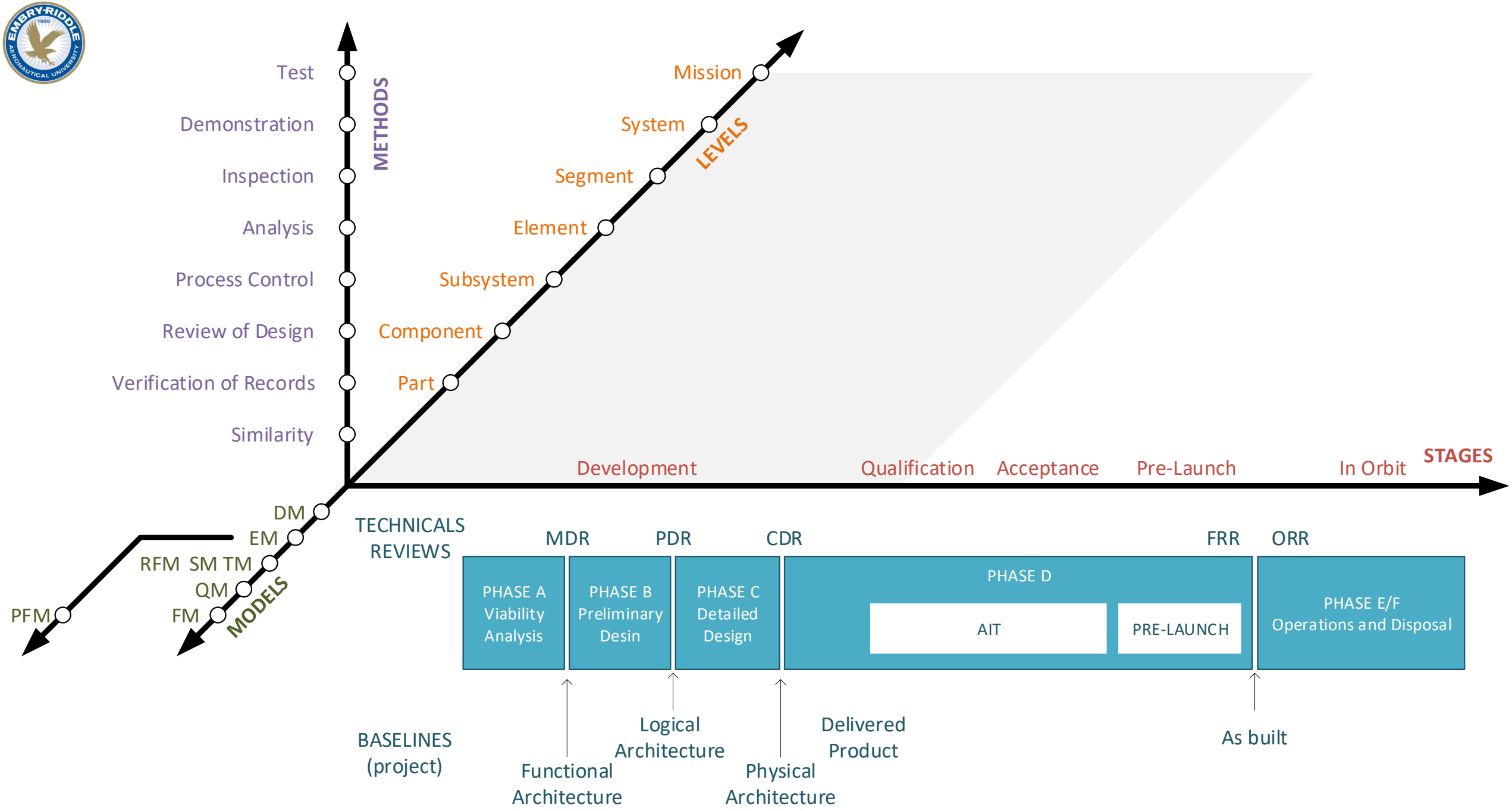
2025

W	Dates	Topic	Ref	Activity
35	26-Aug	Course Introduction Systems Engineering Review Requirement Engineering (Generic Process)	[1][6] [7][9]	Groups & Names
36	2-Sep	Lego exercise 01 - First assessment	[2] [10]	Exercise Report
37	9-Sep	Definition and Structure of Requirements Functional and non-functional Requirements	[8][6] [10]	Exercise List
38	16-Sep	Elicitation Techniques (Interview / Rich Picture / use Cases)		Group Project Delivery
39	23-Sep	Rules for need and requirement statements	[2][3]	Exercise List
40	30-Sep	Attributes of need and requirement statements Boilerplates/patterns	[2]	Exercise List
41	7-Oct	[Carrer Explo]		* Reading activity
42 *	14-Oct	Midterm Session		Self-paced concept questions
		[Fall break]		

W	Dates	Topic	Ref	Activity
43	21-Oct	MBSE Trends	**	Group Project Delivery
44	28-Oct	Traceability - Organization	[5][	Group Project Delivery
45	4-Nov	Metadata: Rationale + Verification and Validation (Success Criteria)	[2][4]	Group Project Delivery
46	11-Nov	[Veterans Day]		* reading activity
47	18-Nov	Lego Exercise 02	[2] [10]	Exercise Report
48	25-Nov	System Requirement Review Presentation (G1-G4)		
		[Thanksgiving]		
48	2-Dec	System Requirement Review Presentation (G5-G8)		
49	9-Dec	Finals		Self-paced concept questions and a small case

W	Dates	Topic	Ref	Activity
43	21-Oct	V&V // DVM // Success Criteria	[4]	Group Project Delivery
44	28-Oct	MBSE	[1] **	Group Project Delivery
45	4-Nov	Model Based Testing		Group Project Delivery
46	11-Nov	[Veterans Day]		* reading activity
47	18-Nov	Lego Exercise 02		Exercise Report
48	25-Nov	System Requirement Review Presentation (G1-G4)		
		[Thanksgiving]		
48	2-Dec	System Requirement Review Presentation (G5-G8)		
49	9-Dec	Finals		Self-paced concept questions and a small

v2


Test
Demonstration
Inspection
Analysis
Process Control
Review of Design
Verification of Records
Similarity
METHODS
Mission
System
Segment
Element
Subsystem
Component
Part
LEVELS
Development
Qualification
Acceptance
Pre-Launch
In Orbit
STAGES
DM
EM
RFM SM TM
QM
FM
PFM
MODELS
TECHNICALS REVIEWS
MDR
PDR
CDR
FRR
ORR
PHASE A Viability Analysis
PHASE B Preliminary Desin
PHASE C Detailed Design
PHASE D
AIT
PRE-LAUNCH
PHASE E/F Operations and Disposal
BASELINES (project)
Functional Architecture
Logical Architecture
Physical Architecture
Delivered Product
As built

Definitions

Verification

- The verification of a product shows **proof of compliance with requirements** – the product can meet each ”shall" claim as proven through the performance of a test, analysis, inspection or demonstration (or combination of these).
- **Verification is a process of confirming that a requirement or system is compliant**.
  - In other words, the system checker asks the question: **Does the system meet your requirements?**
  - The requirements checker asks the question: **Does the system really meet this specific requirement?**

Validation

- VALIDATION refers to the **ConOps document**.
- VALIDATION is conducted **under realistic conditions** (or simulated conditions) on end products for the purpose of determining the effectiveness and suitability of the product for use in mission operations by typical users.
- VALIDATION can be performed at each stage of development using phase products (e.g. models) and not just at delivery using end products.

NOTE: Requirements Validation

- ***Requirements Validation is the process of confirming the completeness and correctness of requirements***.
- ***Requirements Validation answers the question***: *"Are the requirements correctly defined and mean what they should?"*
- ***(think) Validation is the function of ensuring that the design developed for the system will result in a system that meets the customer's operational needs.***
  - This is done before the system is built and then checked.
  - **The project is validated against the requirements and the system is checked against the project.**

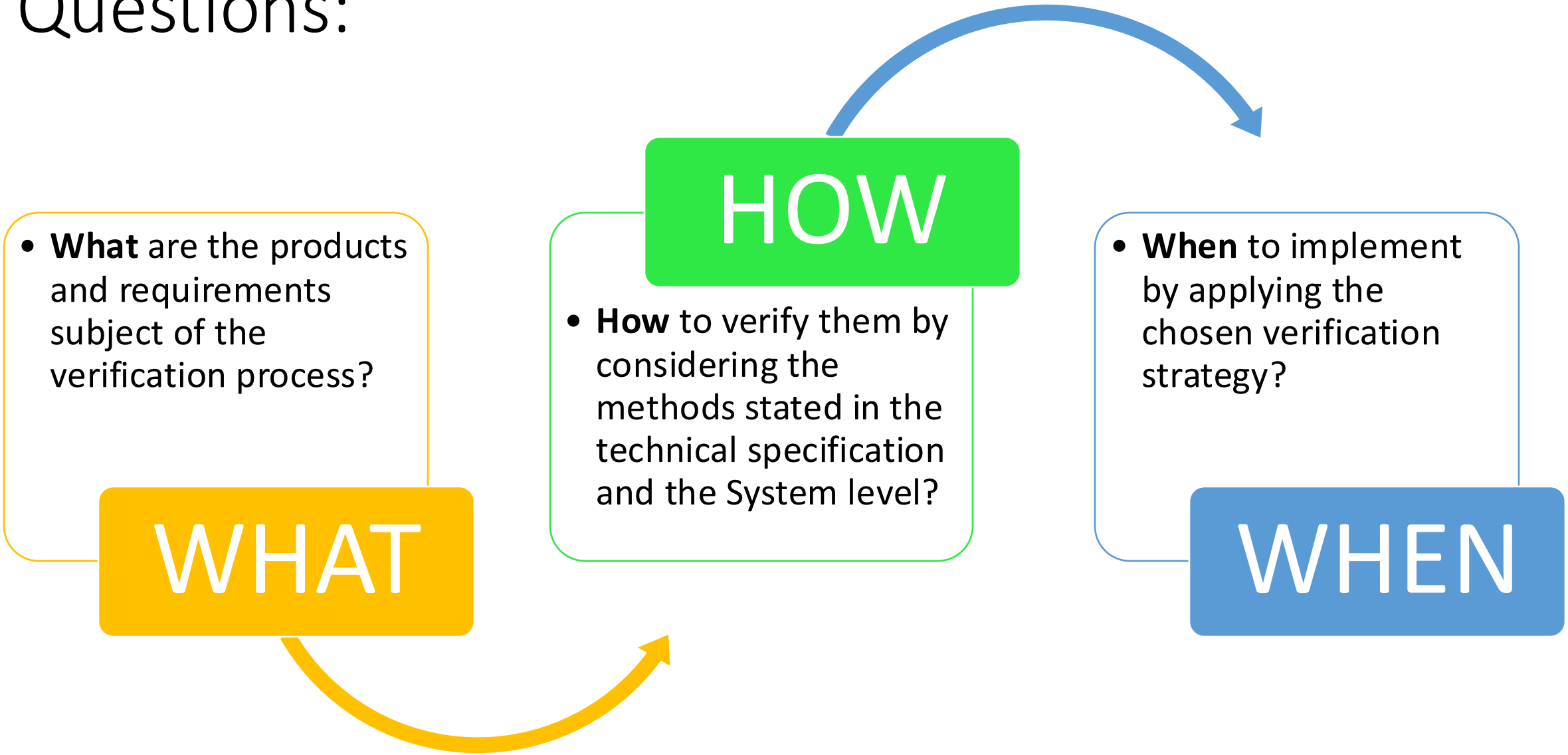
- **When does requirements validation occur?**
  - Before the detailed design, i.e. mainly in Phase B and decreasing (ended) in Phase C
  - Ideally, completed before the System Requirements Review (SRR) but.. *it never happens and hopefully ends on Phase B*
- **What is the importance of getting requirements validation early in the project lifecycle?**
  - So when it comes time to check the system, you're checking the right requirements.
  - Changing requirements at the end of the project - verification occurs in Phase D before launch - has impacts on cost and schedule.

Global Verification Process

Approach

- The basic verification approach shall be derived through an iteration process, based on **technical / cost / schedule** considerations, which defines the **what, how, where, and when** **of verification** by:
  1. **Identifying** a consistent set of verifiable project requirements which can be subjected to the verification process;
  2. **Selecting methods** of verification;
  3. **Selecting levels** of verification and the associated model philosophy;
  4. **Selecting facilities**;
  5. **Identifying resources required**;
  6. **Identifying the stages** and the events in which the verification is implemented.

Questions:


WHAT
• **What** are the products and requirements subject of the verification process?
HOW
• **How** to verify them by considering the methods stated in the technical specification and the System level?
WHEN
• **When** to implement by applying the chosen verification strategy?

WHAT

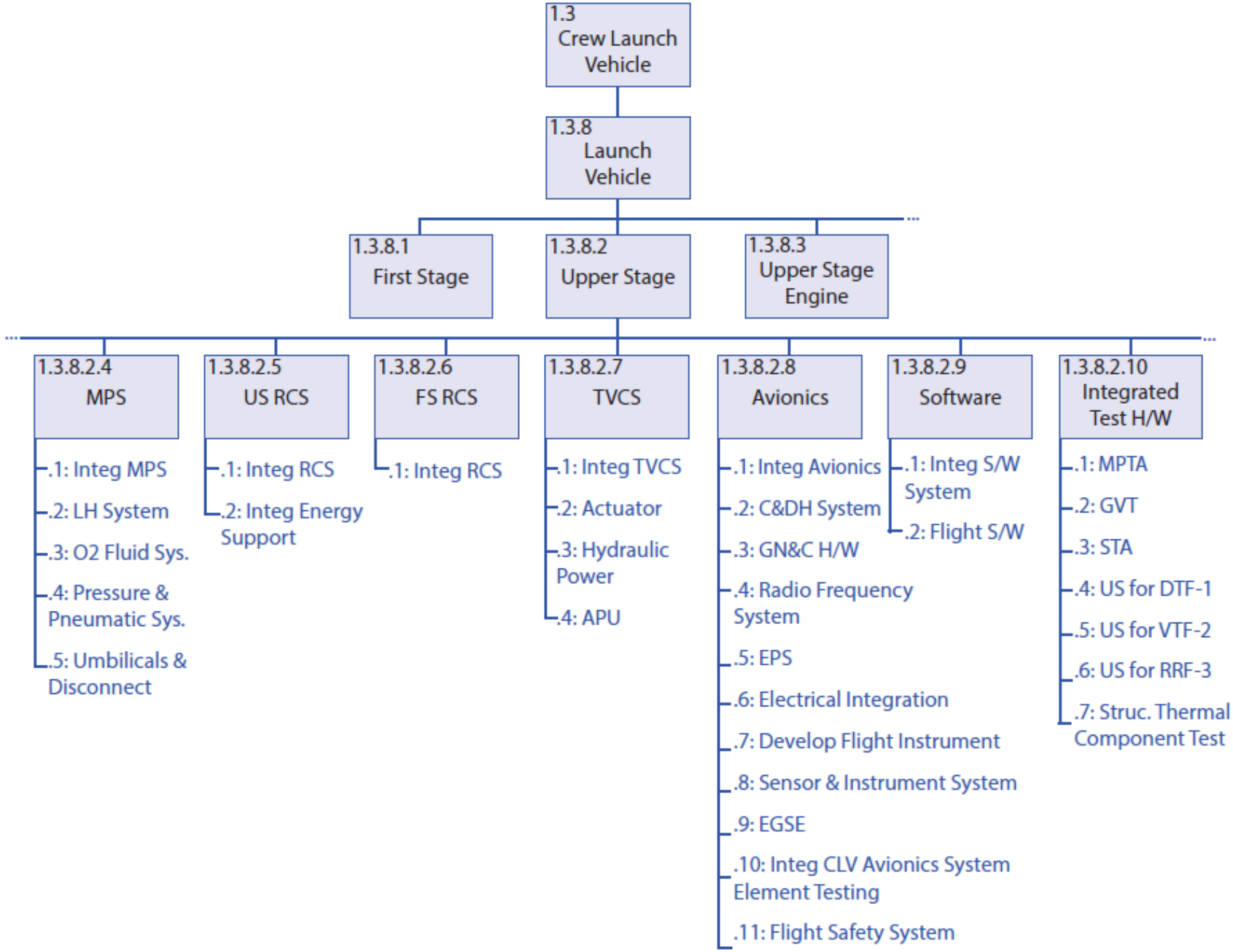
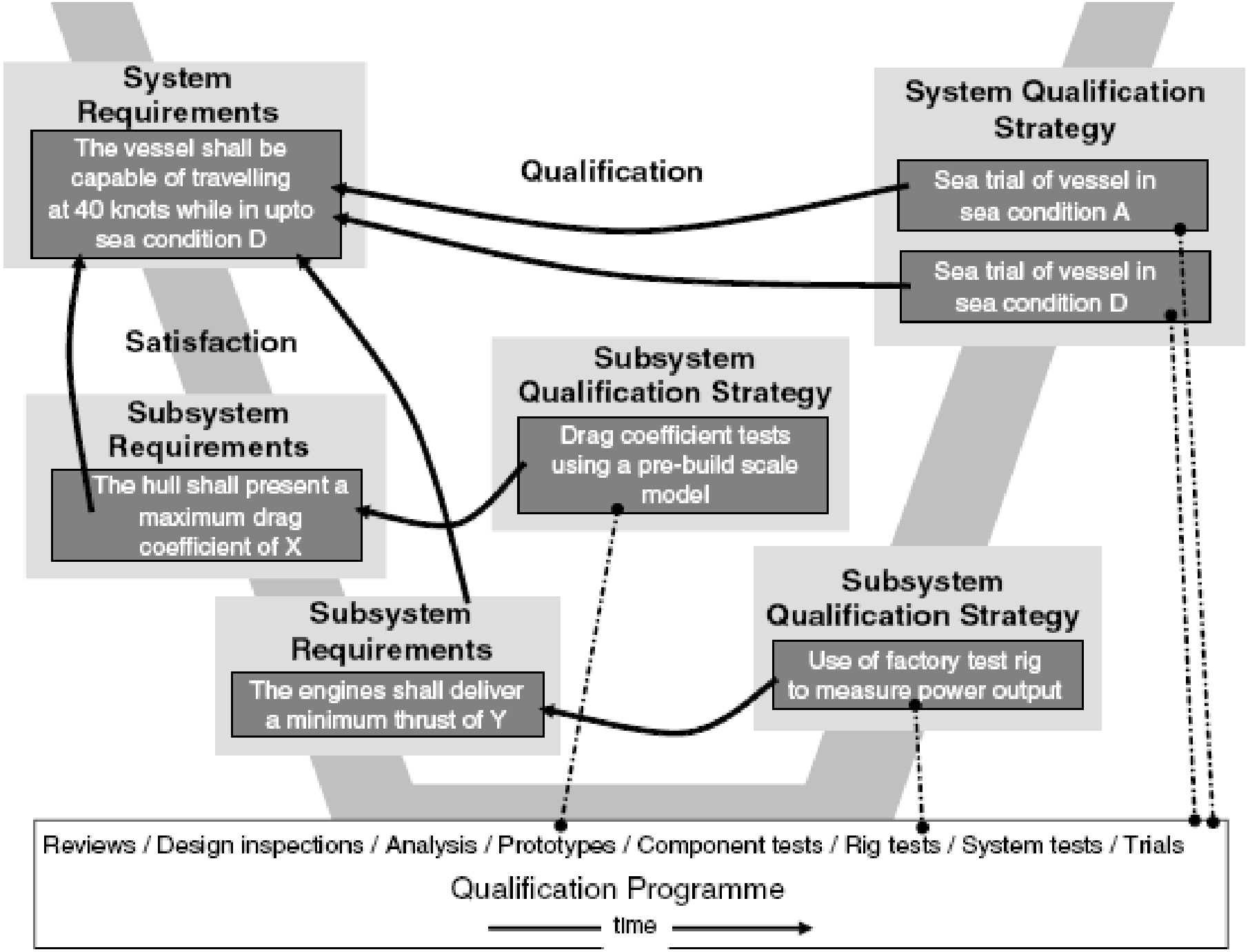
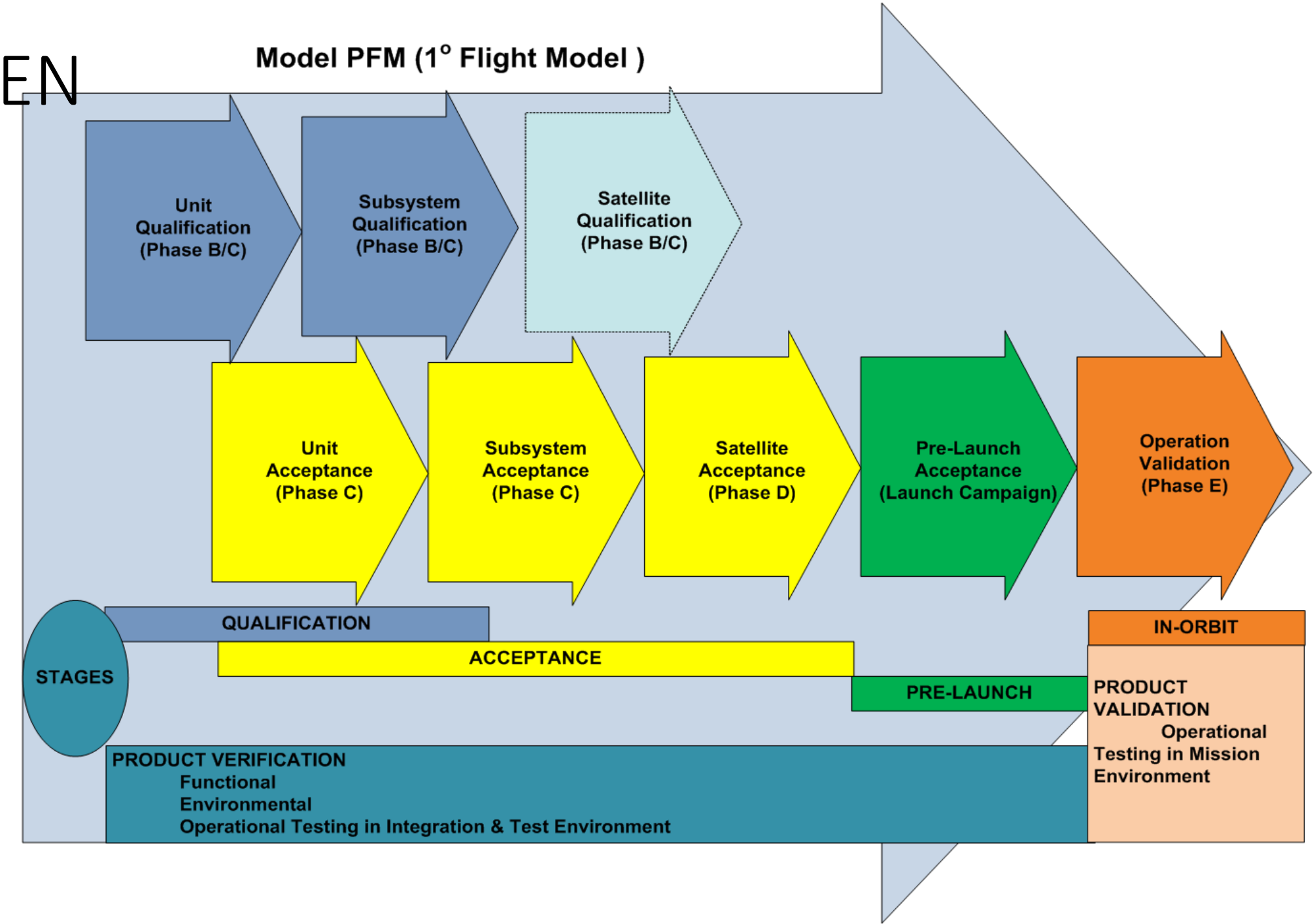


FIGURE G.1-1 PBS Example

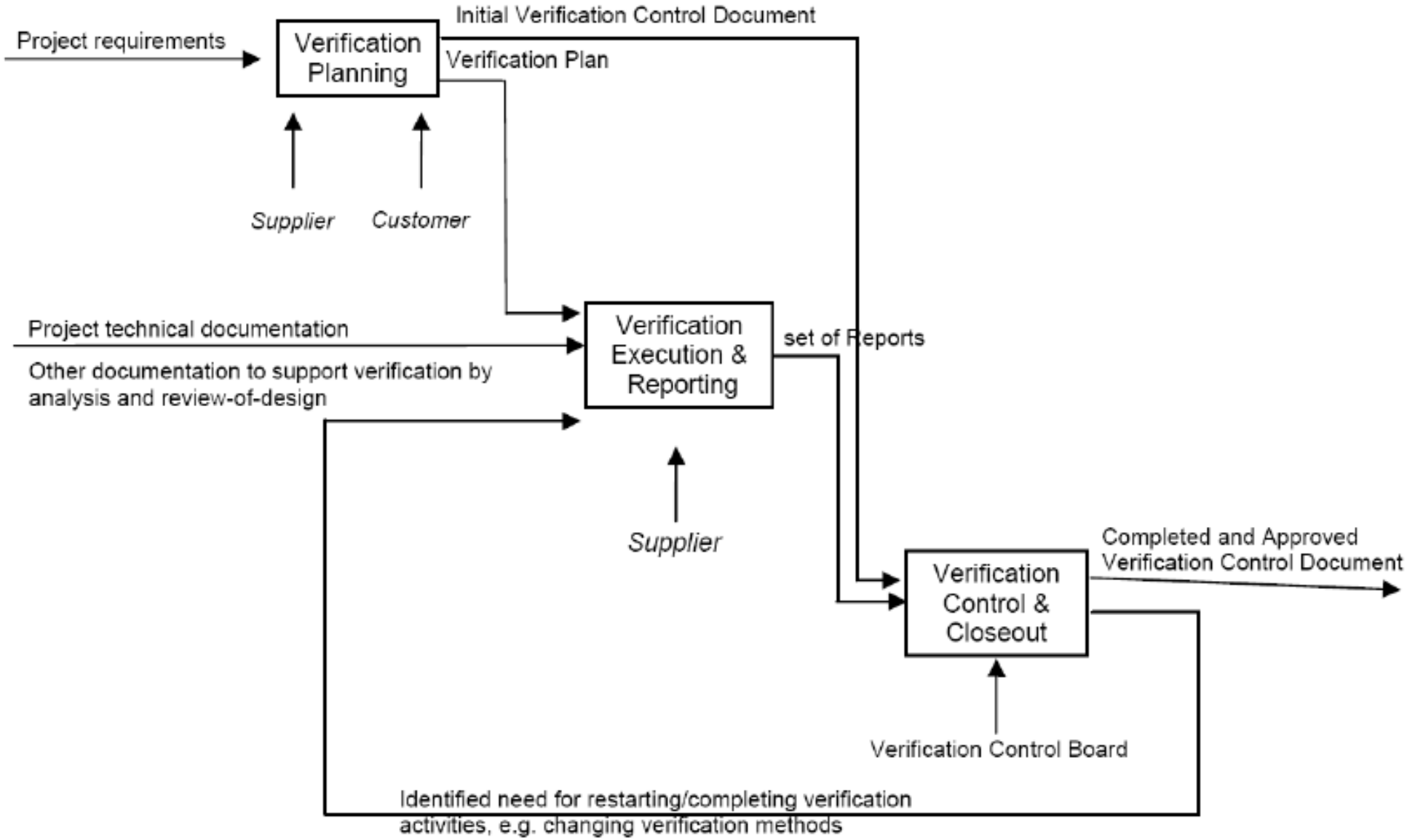
HOW


System Requirements
The vessel shall be capable of travelling at 40 knots while in upto sea condition D
Qualification
System Qualification Strategy
Sea trial of vessel in sea condition A
Sea trial of vessel in sea condition D
Satisfaction
Subsystem Requirements
The hull shall present a maximum drag coefficient of X
Subsystem Qualification Strategy
Drag coefficient tests using a pre-build scale model
Subsystem Requirements
The engines shall deliver a minimum thrust of Y
Subsystem Qualification Strategy
Use of factory test rig to measure power output
Reviews / Design inspections / Analysis / Prototypes / Component tests / Rig tests / System tests / Trials
Qualification Programme
time

WHEN


Model PFM (1° Flight Model)
Unit Qualification (Phase B/C)
Subsystem Qualification (Phase B/C)
Satellite Qualification (Phase B/C)
Unit Acceptance (Phase C)
Subsystem Acceptance (Phase C)
Satellite Acceptance (Phase D)
Pre-Launch Acceptance (Launch Campaign)
Operation Validation (Phase E)
STAGES
QUALIFICATION
ACCEPTANCE
PRE-LAUNCH
IN-ORBIT
PRODUCT VERIFICATION
Functional
Environmental
Operational Testing in Integration & Test Environment
PRODUCT VALIDATION
Operational Testing in Mission Environment

Process flow



Life-cycle and Reviews / Verification Stages

NPR 7123.1

(when)

Life cycle definitions

- A project is divided into distinct life cycle *phases.*
  - Pre-Phase A: Concept studies
  - Phase A: Concept and technology development
  - Phase B: Preliminary design and technology completion
  - Phase C: Final design and fabrication
  - Phase D: System assembly, test and launch
  - Phase E: Operations and sustainment
  - Phase F: Closeout or disposal

Control gates

- These phases are separated by *control gates* - typically associated with a major project review, such as preliminary design review (PDR).
- Each project phase has a distinct purpose and set of products.
- **At the end of each phase a new system baseline —or an agreed-to set of requirements, designs, or documents — is established**.
- A **system baseline is the point of departure** for the development work in each new phase.

Reviews

- A technical review is an evaluation of the project, or element thereof, by a knowledgeable group for the purposes of:
  - a**. Assessing the status of and progress** toward accomplishing the planned activities.
  - b. **Validating the technical tradeoffs** explored and **design solutions** proposed.
  - c. Identifying **technical weaknesses or marginal design and potential problems** (risks) and recommending improvements and corrective actions.
  - d. Making judgments on the **activities' readiness** for the follow-on events, including additional future evaluation milestones to improve the likelihood of a successful outcome.
  - e. Making **assessments and recommendations** to the project team, Center, and Agency management.
  - f. Providing a **historical record** that can be referenced of decisions that were made during these formal reviews.
  - g. Assessing the **technical risk status and current risk profile**.

NASA Procedural Requirements

NPR 7123.1D
Effective Date: July 05, 2023
Expiration Date: July 05, 2028

COMPLIANCE IS MANDATORY FOR NASA EMPLOYEES

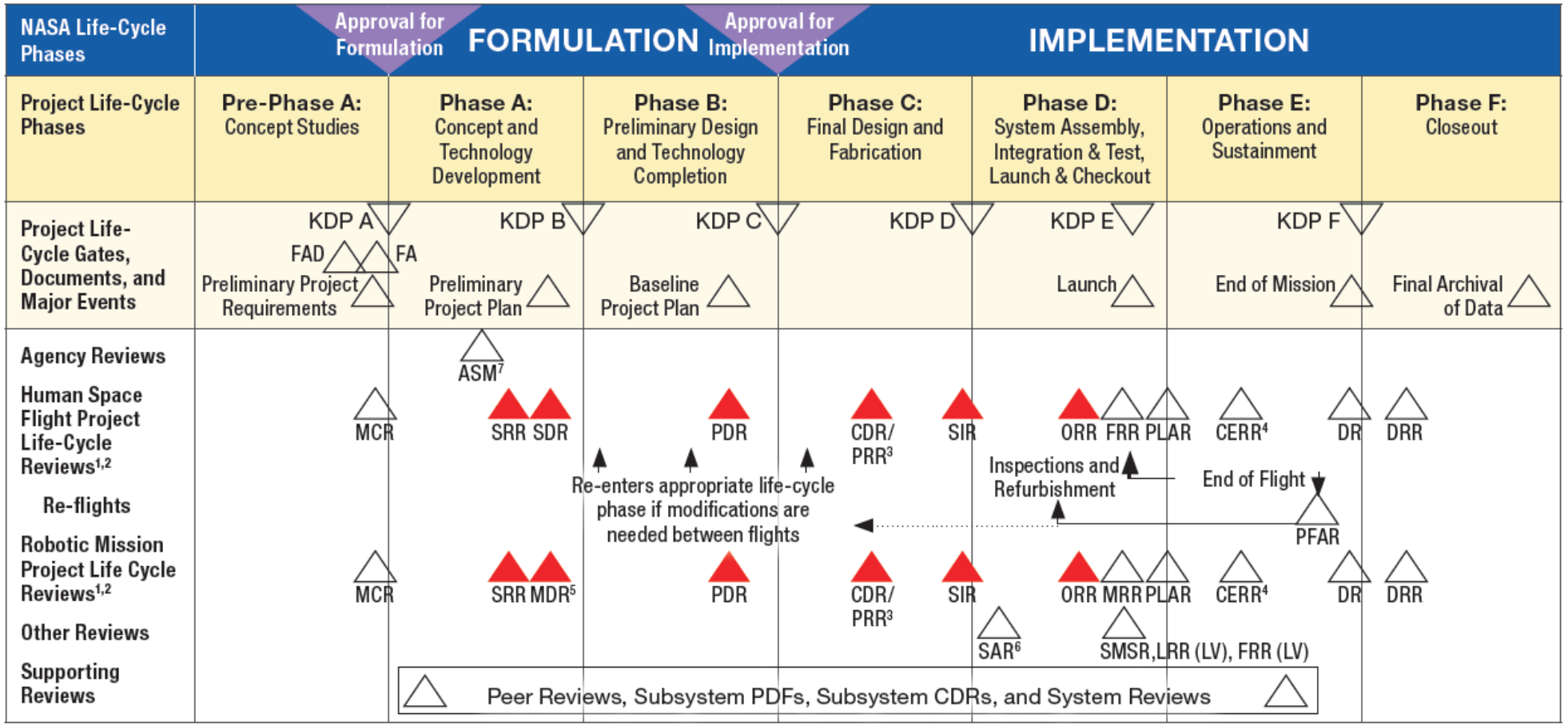
Subject: NASA Systems Engineering Processes and Requirements Updated w/Change 2

Responsible Office: Office of the Chief Engineer

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Change Log



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

TABLE 3.0-1 SE Product Maturity from NPR 7123.1

Products		Formulation				Implementation					
	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				
Verification and validation results							**Initial	**Preliminary	**Baseline		
Transportation criteria and instructions						Initial	Final	Update			
Operations plans					Baseline	Update	Update	**Update			
Operational procedures						Preliminary	Baseline	**Update	Update		
Certification (flight/use)								Preliminary	**Final		
Decommissioning plans					Preliminary	Preliminary	Preliminary	**Baseline	Update	**Update	
Disposal plans					Preliminary	Preliminary	Preliminary	**Baseline	Update	Update	**Update

Verification Stages/Phases

- The verification process shall be implemented in subsequent **verification stages all along the program life cycle**.
- The stages depend upon project characteristics and identify a type of verification.
- The classical verification stages/phases are:
  - I. **Development**
  - II. **Qualification**
  - III. **Acceptance**
  - IV. **Pre-launch**
  - V. **In-orbit**
  - VI. **Post-landing**

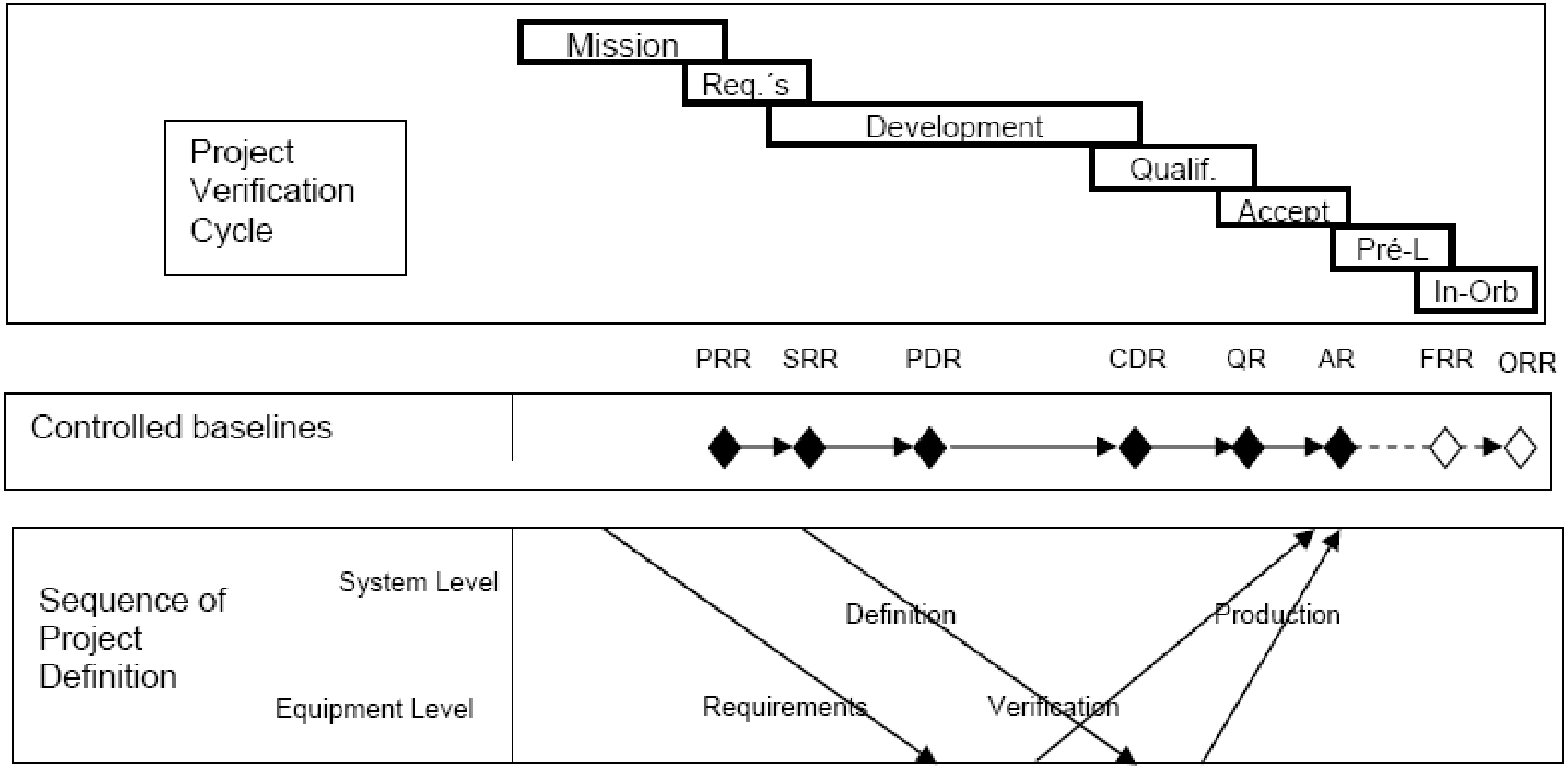
Stages

- **I.DEVELOPMENT -** In this stage the verification objective shall be to demonstrate that the design meets all applicable requirements.
- **II.QUALIFICATION -** In this stage the verification objective shall be to demonstrate that the design meets all applicable requirements and includes proper margins.
- **III.ACCEPTANCE -** In this stage the verification objective shall be to demonstrate that the item is free of workmanship defects and integration errors and is ready for subsequent operational use.

Stages

- **IV.PRE-LAUNCH -** The verification objective of the pre-launch stage shall be to verify that the article is properly configured for launch and early operations and, to the extent practicable, it is capable to function as planned for launch.
- **V.IN-ORBIT -** This stage is valid for projects whose characteristics (e.g. mission or in-orbit operations) require in-orbit verification.

Verification – Execution X Stages X Baselines



Verification & Validation Methods

“HOW”

V&V Requirements Development

- V&V information should be developed concurrently with system requirements
- Systems Engineer (SE) works with Requirement Owners to help establish methodology to verify the requirements



- On small projects, SE may try at method, phase, level, then have discipline experts' review.

- Larger projects, may use V&V Working Group or a series of sessions with Stakeholders.



SE should ensure all requirements are **verifiable as written**

Analysis

- The use of mathematical modeling and analytical techniques to **predict the suitability** of a design to stakeholder expectations based on calculated data or data derived from lower system structure end product verifications.
- Analysis is generally used when a prototype; engineering model; or fabricated, assembled, and integrated product is not available. Analysis includes the use of modeling and simulation as analytical tools. A model is a mathematical representation of reality. A simulation is the manipulation of a model. Analysis can include verification by similarity of a heritage product.

Demonstration

- Showing that the use of an end product **achieves the individual specified requirement**.
- Showing that the use of an end product achieves the **stakeholder expectations as defined in the NGOs and the ConOps**.
- It is generally a basic confirmation of performance capability, differentiated from testing by the lack of detailed data gathering. Demonstrations can involve the use of physical models or mock-ups; for example, a requirement that all controls shall be reachable by the pilot could be verified by having a pilot perform flight-related tasks in a cockpit mock-up or simulator. A demonstration could also be the actual operation of the end product by highly qualified personnel, such as test pilots, who perform a one-time event that demonstrates a capability to operate at extreme limits of system performance, an operation not normally expected from a representative operational pilot.

Inspection

- The visual examination of a realized end product.
- Inspection is generally used to **verify physical design features or specific manufacturer identification**.
- For example, if there is a requirement that the safety arming pin has a red flag with the words “Remove Before Flight” stenciled on the flag in black letters, a visual inspection of the arming pin flag can be used to determine if this requirement was met. Inspection can include inspection of drawings, documents, or other records.

Test

- The use of an end product to obtain detailed data needed to **verify performance** or provide sufficient information to verify performance through further analysis.
- The use of an end product to obtain detailed data needed to determine a behavior or provide sufficient information to **determine a behavior t**hrough further analysis.
- Testing can be conducted on final end products, breadboards, brassboards, or prototypes. Testing produces data at discrete points for each specified requirement under controlled conditions and is the most resource-intensive verification technique. As the saying goes, “Test as you fly, and fly as you test.”

Other types

- Review of Design
  - When verification is achieved:
    - by validation of records or
    - by evidence of validated design documents or
  - when approved design reports, technical descriptions, engineering drawings unambiguously show the requirement is met, the method shall be referred as “Review-of-design”.

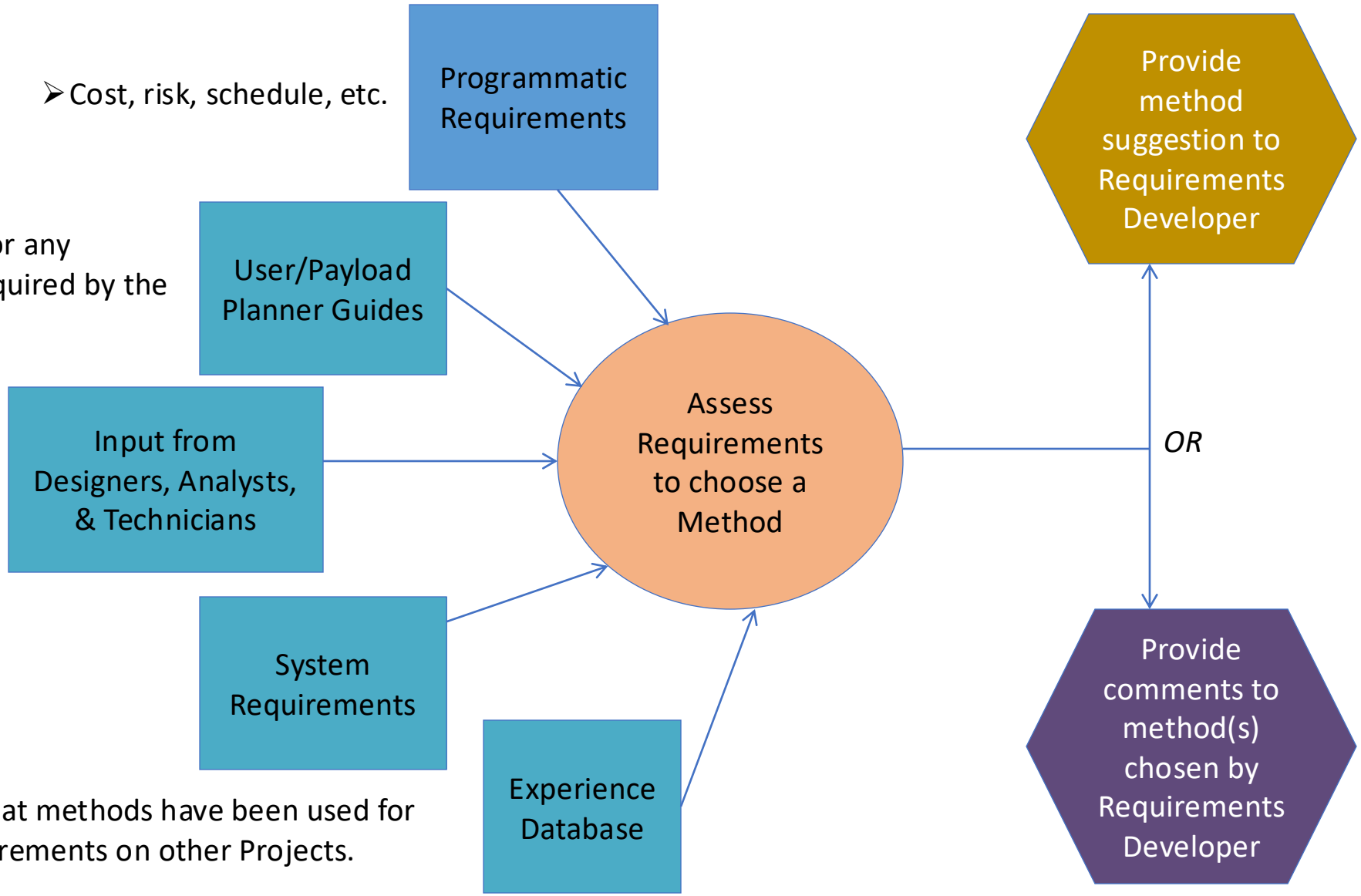
- Process Control:
  - Process control values are accepted as evidence of requirements compliance.
  - Process factors are known, measured, and held to predetermined targets.
  - It is used to show dependability and consistency of process results. Process Control cannot be used to show that a system/component design complies with requirements.

Choosing a V&V Method

- Cost, risk, schedule, etc.

- Review these to look for any verification method required by the launch vehicle/carrier

- Research what methods have been used for similar requirements on other Projects.



Choosing a V&V Method

Test used when:

*Analytical techniques do not produce adequate results

*Failure modes exist which compromise safety, space systems or mission objectives

*Components associated with critical system interfaces

Demonstration used when:

*Verification of designed functions can be performed through observation

*Results tend to be “pass/fail”, “yes/no”

*Requirements are more subjective in nature such as human factors or maintainability

*Uses actual or representative flight systems

Inspection is used when:

*Drawings, documents or data can be visually checked to verify that the physical characteristics have been designed into the product

*Typically used for design features, construction methods, workmanship, dimensions and records

Analysis is used when:

*Accurate analytical techniques are possible

*Test is not a cost effective option

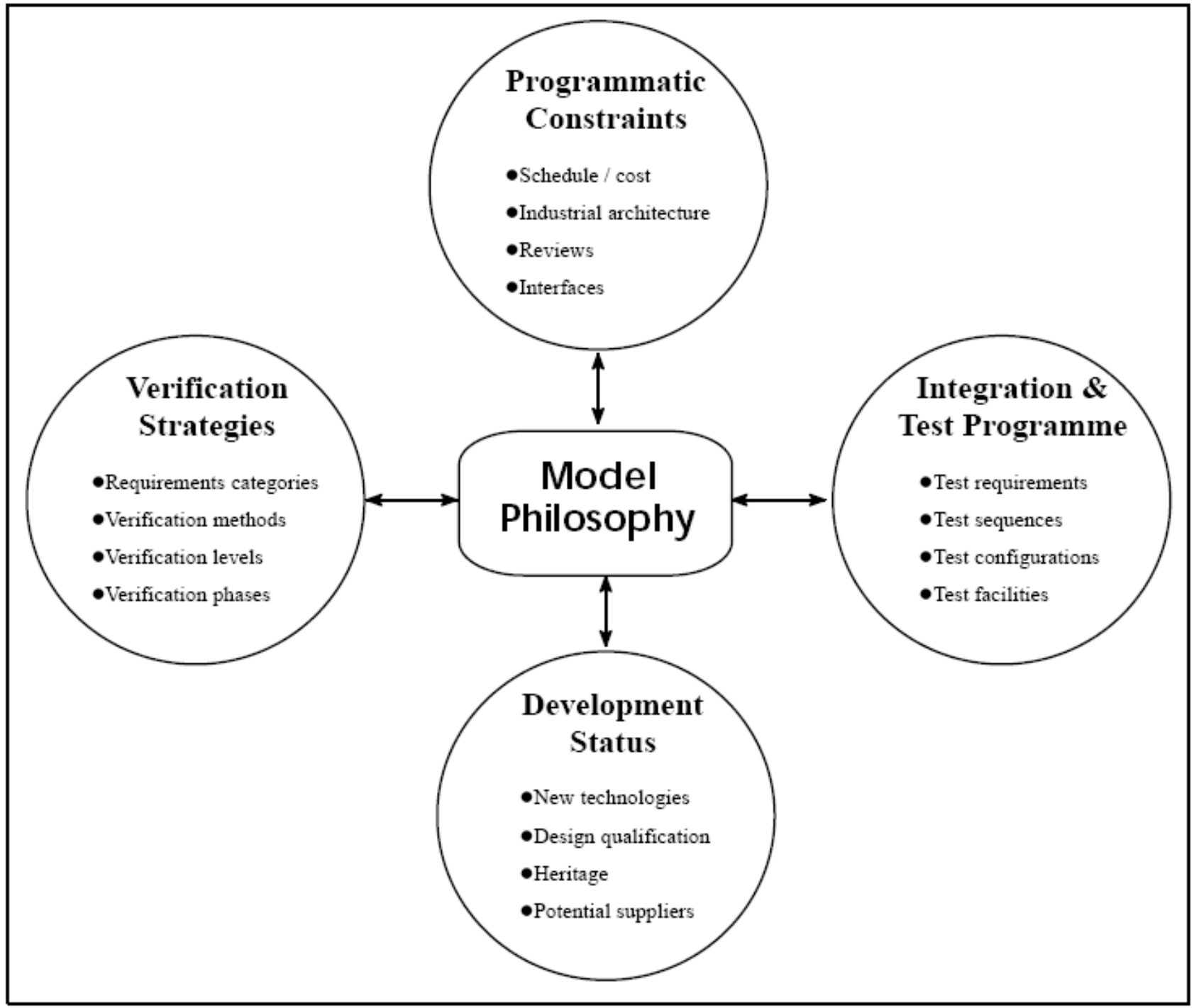
*Verification by inspection is not adequate

*Analytical techniques and models have been validated

Model Philosophy

Model Philosophy Definition

- Model philosophy shall be defined by means of an iterative process which combines:
  - **programmatic constraints,**
  - **verification strategies and the**
  - **integration and test programme**, considering the development status of the candidate design solution.
- Model philosophy shall be defined **early in the project** and frozen as soon as possible due to its impact on the project implementation.


Programmatic Constraints
●Schedule / cost
●Industrial architecture
●Reviews
●Interfaces
Verification Strategies
●Requirements categories
●Verification methods
●Verification levels
●Verification phases
Model Philosophy
Integration & Test Programme
●Test requirements
●Test sequences
●Test configurations
●Test facilities
Development Status
●New technologies
●Design qualification
●Heritage
●Potential suppliers

Selection of Models

- Models **shall be selected** defining the **optimum number** and type of **physical models** required to achieve a **high confidence** in the product verification with the **shortest schedule** and a suitable weigh of **costs and risks** .
- The are various types of models and model philosophies. Their applicability depends on the **specific project requirements** .
- Model philosophy shall be defined **early in the project** and frozen as soon as possible due to its impact on the project implementation

Typical Model Philosophies

- Typical model philosophies are **prototype**, **protoflight** or a mix of the two called ”**hybrid philosophy**”.
  1. **Prototype Model Philosophy**
     - This approach is generally used in projects for which all affordable measures are taken to achieve minimum risk.
  2. **Protoflight Model Philosophy**
     - Model philosophy based on a single model (Protoflight Model) to be flown after it has been subjected to a protoflight qualification and acceptance test campaign.
     - Typical philosophy for projects with no technology critical design and compromise permitted to reduce cost accepting a medium risk.
  3. **Hybrid Model Philosophy**
     - Model philosophy representing a compromise between prototype and protoflight approaches. It is based on a protoflight model on which a partial protoflight qualification test campaign is carried out.

- Specific qualification test in the critical areas are carried out on dedicated models.

Prototype Philosophy

- This approach is generally used in projects for which all affordable measures are taken to achieve **minimum risk**.
- The typical characteristics of these projects are:
  - new and/or complex design;
  - impossibility to be recovered or repaired after launch;
  - special mission requirements.
- The advantages of this approach are:
  - low risks;
  - possibility to perform parallel activities on different models;
  - completion of qualification activities prior to acceptance;
  - possibility to use QM or EQM as an integration spare during high level activities.
- The disadvantage is high costs.

Protoflight Philosophy

- The pure protoflight approach is based on a **single model (Protoflight Model)** to be flown after it has been **subjected to a protoflight qualification and acceptance test campaign**.
- This approach is applied to projects whose characteristics are:
  - no critical technology is employed in the design;
  - qualified hardware is extensively used;
  - compromise is permitted to reduce cost, accepting a moderate level of risk.
- The advantage of this approach is its low cost.
- The disadvantages are:
  - increased risks;
  - serial activity flow on the same model;
  - contextual qualification and acceptance Activities;
  - no integration spares

Hybrid Philosophy

- This philosophy is a **compromise** between prototype and protoflight approaches.
- The hybrid model philosophy is used in projects where advanced qualification activities shall be performed in areas of new design or in areas having a critical impact on the verification programme.
- The hybrid approach always assumes a protoflight model be flown after a proto-flight test campaign whose **scope is reduced** with respect to that of the pure proto-flight approach.
- **Specific qualification tests in the critical areas** are carried out on dedicated models. In these areas only acceptance testing is performed on the PFM.
- The advantages and disadvantages of this approach are intermediate between those of the prototype and the protoflight approaches in terms of risks, costs and schedule.

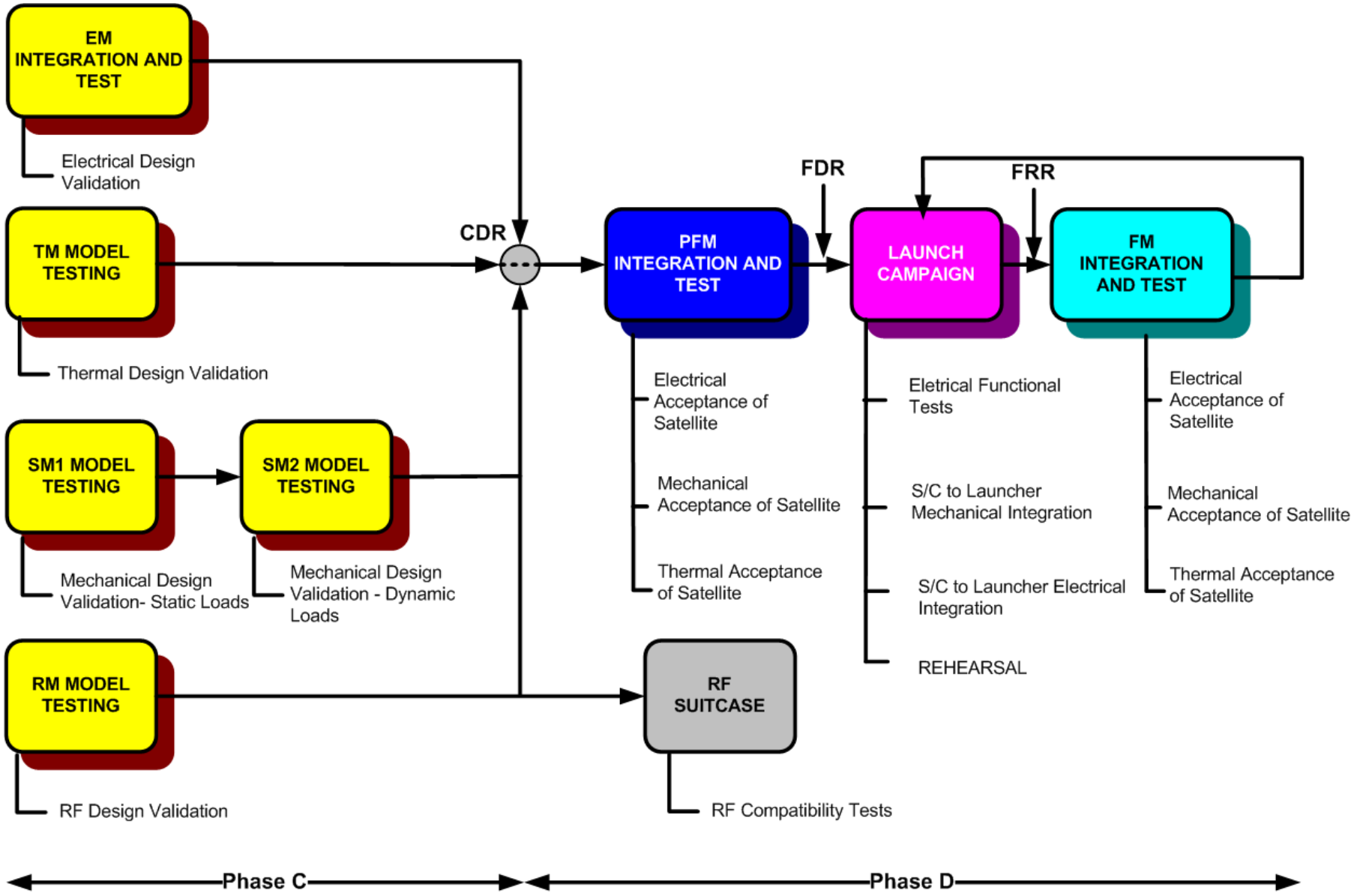
Models Definition -Applicability

Model	Objectives	Representativeness	Applicability	Remarks
Mock-Up (MU)	• I/F layout optimization/ assessment • Integration procedure validation • Accommodation checks	• Geometrical configuration • Layouts • Interfaces	• System/element levels	• According to their representativeness MUs are classified as: - Low fidelity - High fidelity (to be maintained under configuration control)
Development Model (DM)	• Confirmation of design feasibility	• Total conformity with functional electrical & S/W req. in agreement with verif. objectives (size, shape & I/Fs could not be representative)	• All levels	• Development testing • Sometime it is also called breadboard
Integration Model (IM)	• Functional development • S/W development • Procedure validation	• Functional representativeness • Commercial parts • Simulators of missing parts	• All levels	• Development testing • It could be considered something in between a mock-up and an EM • Sometime is called also Electrical Model
Suitcase	• Simulation of functional & RF performances	• Flight design • Commercial parts • Functional representativeness	• Equipment level • System level	• Qualification testing

Structural Model (SM)	• Qualification structural design • Validation of structural mathematical model	• Flight standard with respect to structural parameters • Equipment structural dummies	• SS level (structure) • Sometime it could be considered system level if involves other SS or is merged with the system test flow	• Qualification testing
Thermal Model (TM)	• Qualification of thermal design • Validation of thermal mathematical model	• Flight standard with respect to thermal parameters • Equipment thermal dummies	• SS level (thermal control) • Sometime it could be considered system level if involves other SS or is merged with the system test flow	• Qualification testing
Structural-Thermal Model (STM)	• SM & TM objectives	• SM & TM representativeness • Equipment thermo structural dummies	• System level	• Qualification testing
Engineering Model (EM)	• Functional qualification failure survival demonstration & parameter drift checking	• Flight representative in form-fit-function • Flight design without redundancies and hi-rel parts	• All levels	• Partial functional qualification testing
Engineering Qualification Model (EQM)	• Functional qualification of design & I/Fs • EMC	• Full flight design • MIL-Grade parts procured from the same manufacturer of hi-rel parts	• All levels	• Functional qualification testing
Qualification Model (QM)	• Design qualification	• Full flight design & flight standard	• Equipment level • SS level	• Qualification testing
Flight Model (FM)	• Flight use	• Full flight design & flight standard	• All levels	• Acceptance testing
Protoflight Model (PFM)	• Flight use design qualification	• Full flight design & flight standard	• All levels	• Protoflight qualification testing

Flight Spare (FS)	• Spare for flight use	• Full flight design & flight standard	• Equipment level	• Acceptance testing
Function Oriented Models	• 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
Simulators	• Validation of operations concepts	• Flight representative as necessary for the applicable qualification objectives	• All levels	• Qualification testing oriented to specific HFE requirements
Other Man Oriented 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

Model execution sequence



Facilities

Pupose of an AIT facility

- The AIT building is an environmentally controlled laboratory constructed to **accommodate the testing requirements of both ground-based instruments and fully qualified space-flight hardware**.

- It is specifically designed to **permit the assembly, integration and test** or verification of spacecraft components, equipment, instruments, satellite modules and systems.

Common test facilities

- These are required to fulfill the subsystem/system testing requirement and may include some or all of the following facilities :
  - Satellite integration clean room;
  - Vibration Tests facility – dynamic tests;
  - Vibration Test facility – static load tests;
  - Acoustic Test facility;
  - Mass Properties, Dynamic Bal & Spin tests facility;
  - Thermal Vacuum Test facility;
  - EMC Tests facility;
  - Antenna Gain & Pattern Diagrams facility;
  - Solar Array Test facility;
  - Magnetic Tests facility;
  - Global leakage test facility;
  - Space Qualified welding facility;

- The test facility also must be equipped with:
  - a) cranes,
  - b) vacuum systems,
  - c) compressed air systems,
  - d) Fire detection and protection and environmental monitoring
  - e) system which monitor the clean room temperature, air pressure as well as humidity.
- These are considered as necessities for the operation of a satellite test facility.
- Besides the above-mentioned areas, the AIT building also housed office space for engineers, technicians and administration staffs, meeting rooms, and utilities such as
  - a) bathroom, security and control room,
  - b) communication room as well as network room.
- These areas are kept in normal environment condition.

I’ve worked for a period at this AIT Facility at INPE





https://www.gov.br/inpe/pt-br/area-conhecimento/montagem-integracao-e-testes.



Tests using models

Model Definition x Testing

S/C MODEL	TEST OBJECTIVE	TEST TO BE PERFORMED
FM	Subsystem to Subsystem Compatibility Interface completeness and redundancies Integration of on board software Full implementation of Procedures : Electrical/Mechanical Satellite Alignment Electrical Acceptance of Satellite Mechanical Acceptance of Satellite Thermal Acceptance of Satellite Validation of S/C to Ground Segment/Launcher data compatibility	• Electrical Integration tests • Functional Performance tests • EMI/EMC check • Magnetic Balance • Alignment • Mass Properties • Vibration Test • Acoustic • Leakage • Thermal Vacuum Test + Thermal Balance Test • Ground Segment/Launcher data Compatibility

Model Definition x Testing

S/C MODEL	TEST OBJECTIVE	TEST TO BE PERFORMED
PFM	Subsystem to Subsystem Compatibility Interface completeness and redundancies Integration of on board software Full implementation of Procedures : Electrical/Mechanical Satellite Alignment Electrical Acceptance of Satellite Mechanical Acceptance of Satellite Thermal Acceptance of Satellite Validation of S/C to Ground Segment/Launcher data compatibility	• Electrical Integration tests • Functional Performance tests • RF Compatibility check • Magnetic Balance • Alignment • Mass Properties • Vibration Test • Acoustic • Leakage • Thermal Vacuum Test • Ground Segment/Launcher data Compatibility
GSE	GSE Validation Test Software commissioning AIT personnel training	• Satellite / EGSE Interfaces validation • MGSE loads • SCOEs/SCOEs/OCOE interfaces verifications

Model Definition x Testing

S/C MODEL	TEST OBJECTIVE	TEST TO BE PERFORMED
SM	Mechanical Design Validation	• Vibration: low level/sinus/random • Launcher Compability Tests • SAG Deployment Test • Mass Properties: Mass/COG/MOI
STM	Thermal Deisign Validation	• Thermal Balance Test
RFM	RF Design Validation	• Far Field Antennas Measurements
EM	Electrical Design Validation Subsystem to Subsystem Compatibility Interface completeness and redundancies Integration of on board software Implementation of Procedures : Electrical/Mechanical	• Electrical Integration Tests • Functional Performance Tests • EMI/EMC RE/RES/CE/CS

Associations

- Associate
  - The **products** with their relative **models**
  - The **models** with the **tests** that will be performed
  - The **models** with the **facilities**

Product x Models

No.	Subsystem/ Instrument	Abbr.	Qual. Status	DM	STM	EM	FM	SP	Remarks
1	Structure	STR	D		1		1	*	* STM Spare
2	Thermal control	TCS	D		1	*	1	1	* STM Spare
3	AOCS								
	• Coarse Sun Sensor	CSS	A		2*	1	2		* Dummy
	• Star Tracker	ST	A		3*	1	3		* Dummy
	• Star Tracker Electr.	STE	A		3*	1	3		* Dummy
	• Gyro package	GYR	A		1*	1	1		* Dummy
	• Gyro Electronic	GYE	A		4*	1	3		* Dummy
	• Reaction wheel	RW	A		1*	1	4		* Dummy
	• Wheel drive electronic	WDE	A		1*	1	1		* Dummy
	• Actuator gyro electronic	ADE	A		1*	1	1		* Dummy
	• Flap assembly	FL	D	1	2*	1	2**		* Dummy ** PFM
	• Attitude control electronic	ACE	D	1	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	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

Product Matrix - Example

Equipment	CAT	EM	QM	FM	PFM	Provider	Remarks
PCU	A	1	1	1		INPE	
PDU	B			1		CNES	FPL Heritage
Solar Array	A	1*		1		INPE	* Test Coupon
Battery	A				1	INPE	
RW	D			4		CNES	
Torque Rods	D			3		CNES	
Magnetometer	D			1		CNES	
Star Sensor	D			2		CNES	
Coarse Sun Sensor	D			3		CNES	
OBC	C			1		CNES	
Transponder	D			2		CNES	
Antenna	C			4		CNES	
Structure	A		1	1		INPE	
Thermal Control	A		1*	1		INPE	* STM concept
Harness	A	1*			1	INPE/ CNES	* For test and integration of Payload Engineeging models with OBDH simulator.
Payload Equipment	E				1*	INPE/ CNES	One for each Payload equipment.

Test x Models

System Tests	Satellite models							
	SM1	SM2	TM	RM	EM	SIM	FM3	FM4
Electrical tests					X		X	X
EMI/EMC tests					X			
Launcher compatibility test		X						
Control Segment compatibility test						X		
Application Segment Compatibility test						X		
Magnetic balance							X	X
Radio coverage test				X				
Mass properties measurement		X					X	X
Alignments							X	X
S/C to Launcher separation test		X						
SAG deployment test (s/s level)		X					X	X
Leakage test							X	X
Static load test	X							
Sinusoidal Vibration Test		X					X	X
Acoustic Noise Test		X					X	X
Thermal Balance Test (TBT)			X				X	
Thermal Vacuum Test (TVT)							X	X

Test facilities x Satellite Models

Test Facilities	Satellite Models				
	RM	SM	TM	EM	FM
Satellite integration clean room;		X	X		X
Vibration Tests facility – dynamic tests;		X			X
Vibration Test facility – static load tests;		X			
Acoustic Test facility;					X
Mass Properties, Dynamic Bal & Spin tests facility;					X
Thermal Vacuum Test facility;			X		X
EMC Tests facility;				X	X
Antenna Gain & Pattern Diagrams facility;	X				
Solar Array Test facility;					X
Magnetic Tests facility;					X
Global leakage test facility;					X
Space Qualified welding facility;					X

Success Criteria

https://ndiastorage.blob.core.usgovcloudapi.net/ndia/2011/test/11570MondayScukanec.pdf

Success Criteria

- The Product Verification/Product Validation success criteria provide **the detailed and specific criteria that determine the successful completion of the verification/validation planning activities**.

- Product Verification/Product Validation **success criteria are submitted as part of the PDR data package (ideally) and established (prepared) at least 90 days prior to the start of the verification/validation activity** to provide sufficient time to develop and publish the procedures.

Verification Requirements
- Inspection
- Analysis
- Modeling and Simulation
- Demonstration
- Test

Must answer 5 Questions

☑Objective

What is the purpose of this verification?

☑Method

What method do you need performed? What are the verification circumstances (e.g., laboratory, desk-top analysis, flight test)?

☑Environment

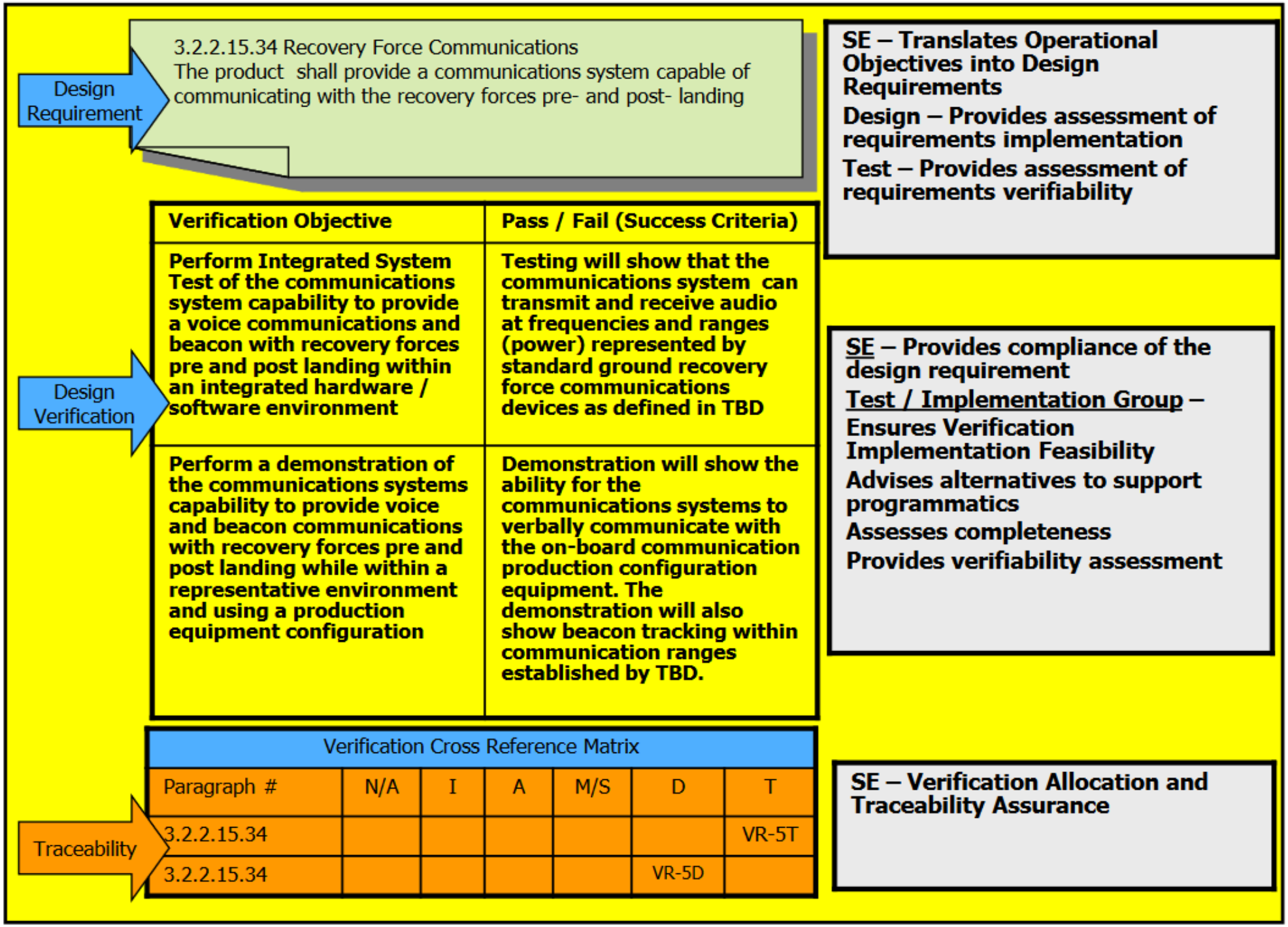
What are the environmental conditions under which the item will be verified?

☑Special Conditions (if necessary)

Are there any unique conditions (e.g., item configurations) necessary for the execution of the verification?

☑Success Criteria

What results are to expected?


Design Requirement
3.2.2.15.34 Recovery Force Communications
The product shall provide a communications system capable of communicating with the recovery forces pre- and post- landing
SE – Translates Operational Objectives into Design Requirements
Design – Provides assessment of requirements implementation
Test – Provides assessment of requirements verifiability
Design Verification
Verification Objective
Pass / Fail (Success Criteria)
Perform Integrated System Test of the communications system capability to provide a voice communications and beacon with recovery forces pre and post landing within an integrated hardware / software environment
Testing will show that the communications system can transmit and receive audio at frequencies and ranges (power) represented by standard ground recovery force communications devices as defined in TBD
Perform a demonstration of the communications systems capability to provide voice and beacon communications with recovery forces pre and post landing while within a representative environment and using a production equipment configuration
Demonstration will show the ability for the communications systems to verbally communicate with the on-board communication production configuration equipment. The demonstration will also show beacon tracking within communication ranges established by TBD.
SE – Provides compliance of the design requirement
Test / Implementation Group – Ensures Verification Implementation Feasibility
Advises alternatives to support programmatics
Assesses completeness
Provides verifiability assessment
Traceability
Verification Cross Reference Matrix
Paragraph # | N/A | I | A | M/S | D | T
3.2.2.15.34 | | | | | | VR-5T
3.2.2.15.34 | | | | | VR-5D |
SE – Verification Allocation and Traceability Assurance

- **VR-5T: Prove that the product's communications system is capable of communicating with the ground command team by performing an integrated system test within an integrated hardware/software environment. Testing will show that the product can transmit and receive to standard ground recovery forces audio at frequencies represented by communications devices defined in (TBD).**

Verification Objective

Verification Method

Environment

Note – there are no Special Conditions

Success Criteria

DVM – Design Verification Matrix

DVM

- The verification strategy should be reflected in a verification matrix that indicates, for all requirements:
  - The verification methods selected for (hows / where)
  - The different levels of verification (what)
  - verification phases applicable. (when)

TABLE D-1 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

[a] Phases defined as: (1) Pre-Declared Development, (2) Formal Box-Level Functional, (3) Formal Box-Level Environmental, (4) Formal System-Level Environmental, (5) Formal System-Level Functional, (6) Formal End-to-End Functional, (7) Integrated Vehicle Functional, (8) On-Orbit Functional.

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, demonstration, 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.

DVM ("Design Verification Matrix" NASA)

. Specification Requirements, Compliance, and Verifications (By Spec #)

Space Flight Systems

6149-EP0001-01 Requirement				Method:		Verification			Last Modified	
Paragraph	Title	Requirement	Verification Methodology	Qual	Acc	#	Name	Type	Date	By
3.1.1.1	Physical Interfaces	The ExPCA shall provide interfaces for its installation on and its removal from the EXPRESS Pallet via the CFE ExPA through extravehicular activity (EVA) and extravehicular robotics (EVR).	Inspection of data from Boeing pertaining to the CFE ExPA will verify EVA and EVR attachment requirements as specified in SSP 52055.	I	I	190	BFG Inspection: Check to ID drawing	I		
3.1.1.2	Electrical Interfaces	All electrical interfaces shall be through SSQ 22680 type connectors located on the ExPCA.	Inspection of connectors will verify SSQ22680 type, unless otherwise specified and approved.	I	I	190	BFG Inspection: Check to ID drawing	I	2000-07-27	Mark Hyman
3.1.1.2.1 [1]	Power Inputs	The ExPCA shall [1] have two (2) power inputs (MAIN and AUXILIARY) of 120 vdc, 25 amperes (A) each from the Umbilical Mechanism Assembly (UMA) on the International Space Station Payload Attach System (PAS).	Review of schematics, inspection to the BFG ID drawings and the WCA will provide visual verification of two 120V, 25 A inputs so present. The QTP and ATP will provide test verification of these inputs	I, A,T	I,T	190 191	BFG Inspection: Check to ID drawing Analysis via WCA test via STE	I A	2000-07-27	Mark Hyman
3.1.1.2.1 [2]	Power Inputs	The ExPCA shall [2] have a third power input (STAY ALIVE) of 28 vdc, 5 A (TBR) while the ExPCA is in the Orbiter cargo bay.	Inspection of schematics, AU and ExPCA ID drawings will provide verification of 28V Orbiter input. The WCA provides the analytical compliance. Formal QTP and ATP will provide the test compliance	I, A,T	I,T	190 191	BFG Inspection: Check to ID drawing Analysis via WCA test via STE	I A	2000-07-27 2000-07-27	Mark Hyman Mark Hyman

Table 3-3 – Example of DT VRTM

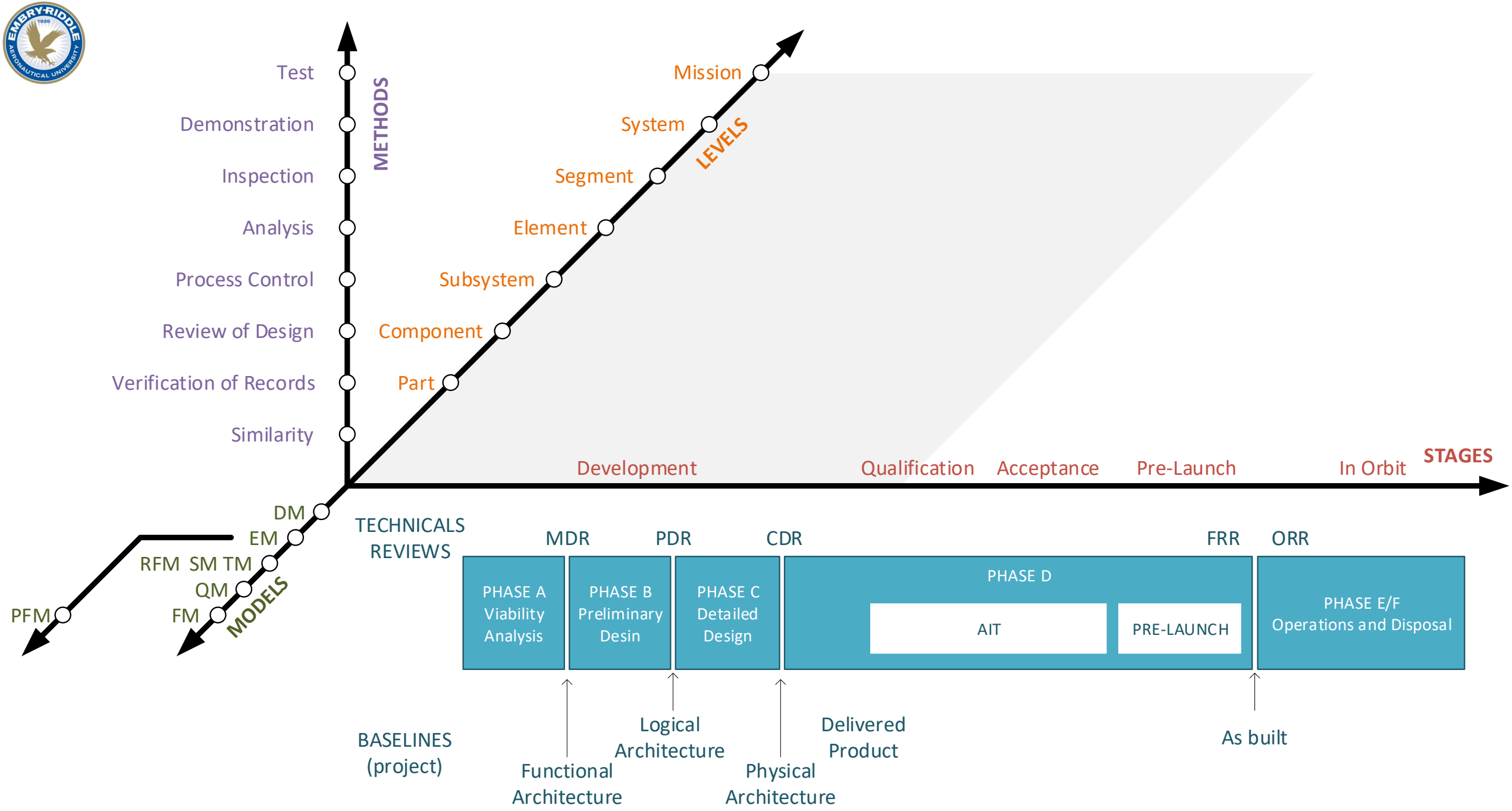
DT VRTM FOR [*PROGRAM*] – modified *[Date]*

SSS ID	REQ TEXT	REQ/PARENT TRACE	PRD TRACE	CPR (N/A OR #)	ACTIVITY ID	TEST CASE ID	VERIF METHOD	RUN DATE	TEST RESULT
SSS-11	3.1 The SYSTEM must enable all SYSTEM Services identified in Table 3-1 …	SSD-111	PRD-379	7	FAT	4.5.6	T	01/19/2018	Pass
				7	I & I	4.5.7	T	03/20/2018	Pass
				7	SAT	4.5.8	D, A	05/20/2018	Pass
SSS-12	3.2 The SYSTEM must disable individual SYSTEM Services …	SSD-112	PRD-380	N/A	FAT	2.2.1	D	01/22/2018	Fail
SSS-34	4.1 The system shall provide a subset of the SYSB services to …	SSD-7	PRD-997	2	*	*	*	*	Partial
SSS-841	4.2.1 The AI Service Engine shall provide access to web services only to consumers on-ramped to SYSTEM2.	SSD-7/ SSS-34	PRD-997	2	FAT	3.4.1	T, A	01/20/2018	Fail
				2	SAT	3.4.2	D	05/20/2018	Pass

* Indicates a Parent where verification occurs at the Child level

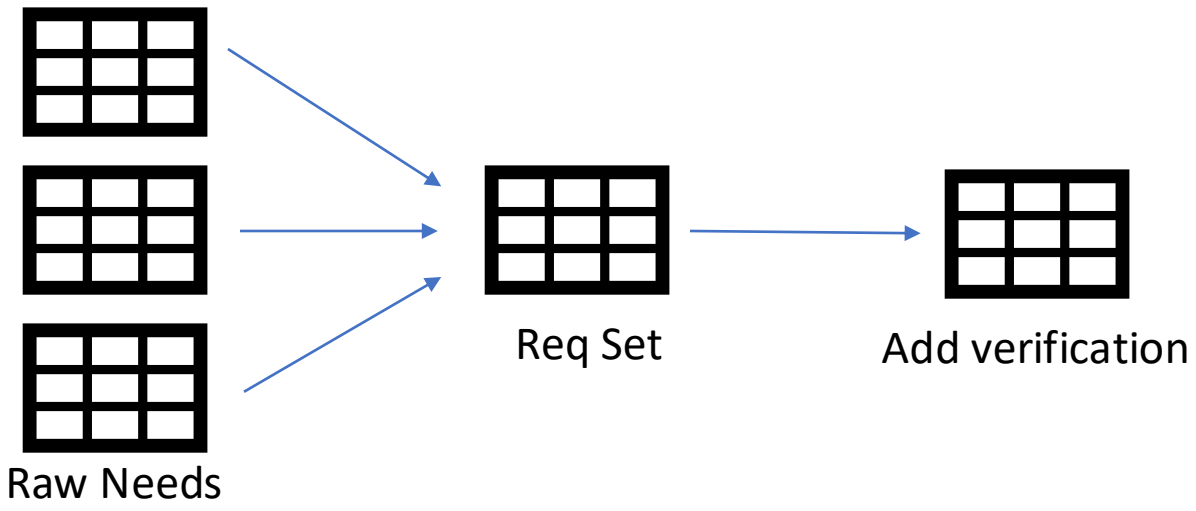
https://www.faa.gov/sites/faa.gov/files/2022-02/VVSPT-E5-GDE-017_VRTM_V3.0.pdf

Final Remarks


Test
Demonstration
Inspection
Analysis
Process Control
Review of Design
Verification of Records
Similarity
METHODS
Mission
System
Segment
Element
Subsystem
Component
Part
LEVELS
Development
Qualification
Acceptance
Pre-Launch
In Orbit
STAGES
DM
EM
RFM SM TM
QM
FM
PFM
MODELS
TECHNICALS REVIEWS
MDR
PDR
CDR
FRR
ORR
PHASE A Viability Analysis
PHASE B Preliminary Desin
PHASE C Detailed Design
PHASE D
AIT
PRE-LAUNCH
PHASE E/F Operations and Disposal
BASELINES (project)
Functional Architecture
Logical Architecture
Physical Architecture
Delivered Product
As built

Assignment

- Review your project and from the use case, write: (4-10) (min 2 functional) **system level** requirements. (we will decompose one into the next classes and make a requirement verification plan using test)
- Add the **Verication Method** & **Verification Success Criteria**
- Review / Reorganize in one DVM *(id/ title/ statement/ rationale/ trace(s)/ method(s) / successcriteria(s) / verificationcase(s) /facility(ies) /phase(s))*



Grading Criteria:

1. EARS / INCOSE Rules checked
2. Attributes checked
3. Coherent Method x Success
4. Reorganization
5. Functions identified.