



GEA Tianjin / 中国民航大学中欧航空工程师学院

# CS41: Verification and Validation

THALES

 AIRBUS



 eurocopter  
an EADS Company

 SAFRAN

## Verification / Validation – A constant leitmotiv

### ■ VERIFICATION

Confirmation through the provision of objective evidences that the specified requirements have been fulfilled

*Am I building the product right\* ?*

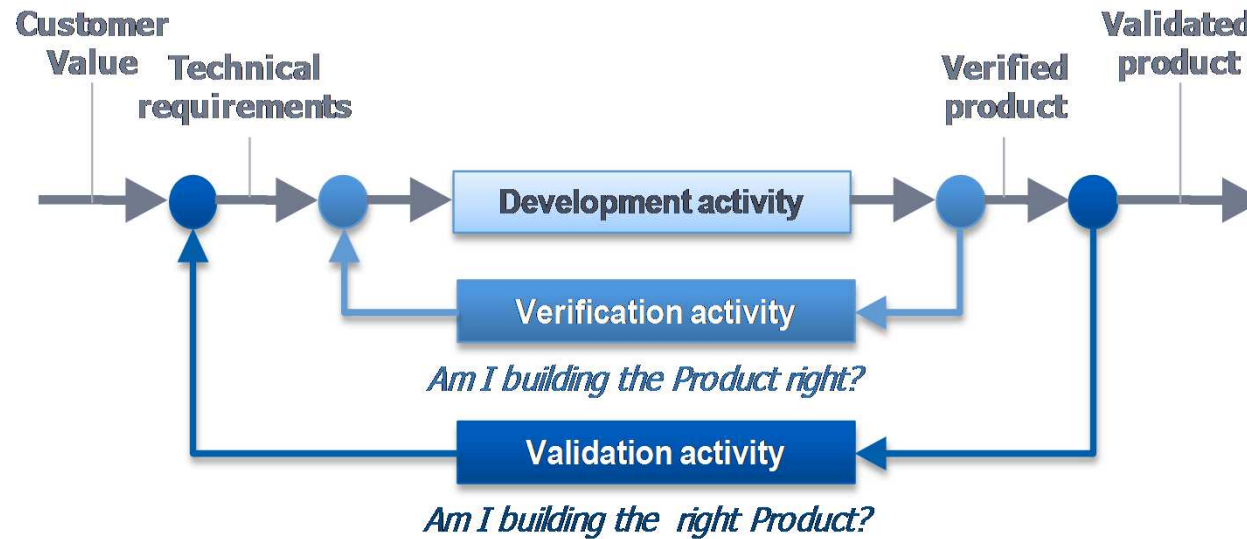
### ■ VALIDATION

Confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

*Am I building the right product\* ?*



## Positioning of V&V



Possible V&V targets:

- Every engineering product
- The system itself

## Design Verification against requirements

- The V&V is based on one or more of the following techniques:
  - Inspection
  - Analysis
  - Demonstration [SEHdbk]
  - Test
- The conditions of **verifications** must be "**representative**"
  - Scenario with respect to the interfaces (test of functional requirements).
  - Analysis based on standards
  - Demonstration on representative system or part of system
- When the representativeness of the conditions of verification is prone to interpretation, it is advised (even necessary) to envisage **procedures of verification as a requirement**
  - For example for environmental conditions (temperature, chocks,...)

## V&V Methods: Inspection/Review

**Inspection**: *an examination of the item against applicable documentation to confirm compliance with requirements.*

→ Used to verify properties best determined by examination and observation (e.g., - paint color, weight, etc.).

- Very practical and efficient method
- demonstrates with a checklist or similar means that the product complies with its requirements
- Can be done on the implemented product (e.g. dimension, wiring) and/or on the design (e.g. architecture review)

# V&V Methods: Inspection/Review

## ➤ Actors:

- ☐ Team members or External colleagues
- ☐ Technical leaders
- ☐ Responsible of Transverse viewpoints (Quality, Safety, Ergonomics,...)
- ☐ Decision makers and managers
- ☐ Audit responsible

## ➤ Means

- ☐ Checklists
- ☐ Indicators
- ☐ Visual inspection
  - Documents reading
  - Code review
  - Product investigation
  - ...

## Checklist example

Process Assurance Checklist - Supplier Requirement Audit				
ARP4754A Process Objectives	ARP4754A Paragraph	Where to get data?	Yes / No / N/A	Finding / Observation
<b>1- Plans Identification</b>				
<b>11- Requirements Validation</b>				
The version of Requirements used for validation has been properly identified.	5.6	By sampling in RM tool  By sampling, check that validation artifacts references the requirement version on which they apply		
The Requirements at all levels in the requirements flow and their associated rationale have been validated down to the item level.	5.4 5.4.2.1 5.4.7.2 b	Check that validation includes validation of requirements allocated to FAT conventional hardware  Inspect the availability of validation matrix/summary at all levels of the requirements hierarchy (through configuration management tool...)		
Validation methods for each requirement have been identified.	5.4.7.1.a	By sampling  Check cortness of the proposed methods		
Bi-directional traceability has been validated.	5.4.3	By sampling Check for evidences		
For validation by tests/simulation/demonstration, evidences have been produced as per internal standards/guidelines	5.4.6 d	Inspect by sampling validation by tests/simulation/demonstration Check that evidences are identified (reference, version) and are under configuration management Check that the requirements on which evidences apply are identified Check that the used tools are identified,		
For validation by engineering review demonstration, evidences have been produced as per internal standards/guidelines.	5.4.6.f	Inspect by sampling validation by engineering review  Check that evidences are identified (reference, version) and are under configuration management  Check that the requirements on which evidences apply are identified		

## V&V Methods: Analysis

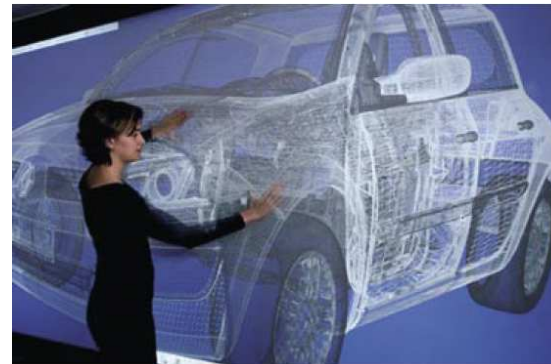
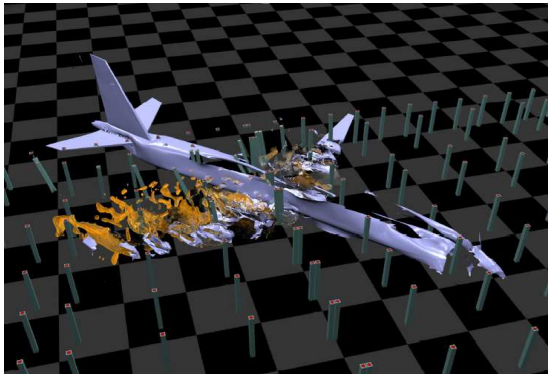
**Analysis**: *use of analytical data or simulations under defined conditions to show theoretical compliance.*

- Used where testing to realistic conditions cannot be achieved or is not cost-effective.
- May be used when such means establish that the appropriate requirement, specification, or derived requirement is met by the proposed solution.



# Analysis

- The tremendous increase in computing power makes simulation a very efficient V&V Method
  - ❑ Digital Mock-up
  - ❑ Multi-domain analysis
    - Combining Fluid Dynamics with acoustics, thermics, ...
  - ❑ Virtual Aircraft



## V&V Methods: Demonstration

**Demonstration:** *a qualitative exhibition of functional performance, usually accomplished with no or minimal instrumentation. A set of test activities with system stimuli selected by the system developer.*

- May be used to show that system or subsystem response to stimuli is suitable.
- May be appropriate when requirements or specifications are given in statistical terms (e.g., mean time to repair, average power consumption, etc.).

### ➤ Approach:

- ☐ By Prototyping: observe a prototype of the final system in operation
- ☐ By Construction: analyze the engineering of the final system
- ☐ By Similarity: compare with other systems having similar properties

## Demonstration: by prototyping

- A prototype is a working version of the final product
  - ❑ Can be tried in close to operational conditions
  - ❑ Most functionalities present, but ...
  - ❑ Usually lacking in scale, robustness, safety, reliability, ...



## Demonstration: by construction

- The expected properties of the system are resulting from
  - ❑ The way it is engineered
  - ❑ Its architecture
  
- Example of demonstration: traceability
  - ❑ All along the engineering process, links are established between the engineering items
    - Requirements, models, V&V means, V&V procedures, Test results, ...
  - ❑ Ensures nothing is forgotten
  - ❑ Facilitates impact analysis in case of changes

## Demonstration: by similarity

- **Service Experience:** Verification credit may be taken from same or other systems on other aircraft that are similar in their relevant attributes. It would be demonstrate that no significant failures remain unresolved in these installations.



## V&V Methods: Test

**Test:** *an action by which the operability, supportability, or performance capability of an item is verified when subjected to controlled conditions that are real or simulated.*

- often use special test equipment or instrumentation to obtain accurate quantitative data for analysis.

- (ARP4754) Provides repeatable evidence of correctness by exercising a system
- ☐ To demonstrate that the implementation performs its intended functions;
  - ☐ To provide confidence that the implemented system does not perform unintended functions that impact safety.

# Tests

- Most common V&V method
- Pros
  - ☐ Most representative of operation
  - ☐ Necessary
  - ☐ Massive experience (used for more than 40 years in software)
- Cons
  - ☐ Cannot be exhaustive (see Gödel incompleteness theorem)
  - ☐ Is performed on a concrete system, done very late
  - ☐ *“Testing can prove the presence of bugs, but never their absence” (E.W. Dijkstra)*

## Test categories

- **Development Test:** Conducted on new items to demonstrate proof of concept or feasibility.
- **Qualification Test:** Tests are conducted to prove the design on the first article produced, has a predetermined margin above expected operating conditions, for instance by using elevated environmental conditions for hardware.
- **Acceptance Test:** Conducted prior to transition such that the customer can decide that the system is ready to change ownership status from supplier to acquirer.
- **Operational Test:** Conducted to verify that the item meets its specification requirements when subjected to the actual operational environment.





## Verification Methods

- Depending on DAL, some verification methods are recommended

Methods and Data (see paragraphs 8.4 and 8.5)	Development Assurance Level			
	A & B	C	D	E
SSA (paragraph 6.3)	R	R	N	N
Inspection, Review, Analysis, or Test (note 1)	Test and one or more of others	One or more	A	N (note 2)
Test, unintended function	R	A	A	N
Service Experience	A	A	A	A

R - Recommended.

A - As negotiated.

N - Not required for certification.

Note 1: These activities provide similar degrees of verification. The selection of which activities will be most useful may depend on the specific system architecture or the specific function(s) implemented.

Note 2: Installation and environmental compatibility should be shown.



## 4 steps for V&V



- Requirements Verification & Validation
  - ❑ Activities to ensure that **requirements** are sufficiently correct and complete.
  
- Design Verification
  - ❑ Evaluation of proposed **design** to determine that it meets its requirements.
  
- Product Verification and Integration
  - ❑ Evaluation of **implementation** to determine that it meets its requirements.
  
- Product Validation
  - ❑ Evaluation of **final product** against the user needs.

## Requirement verification

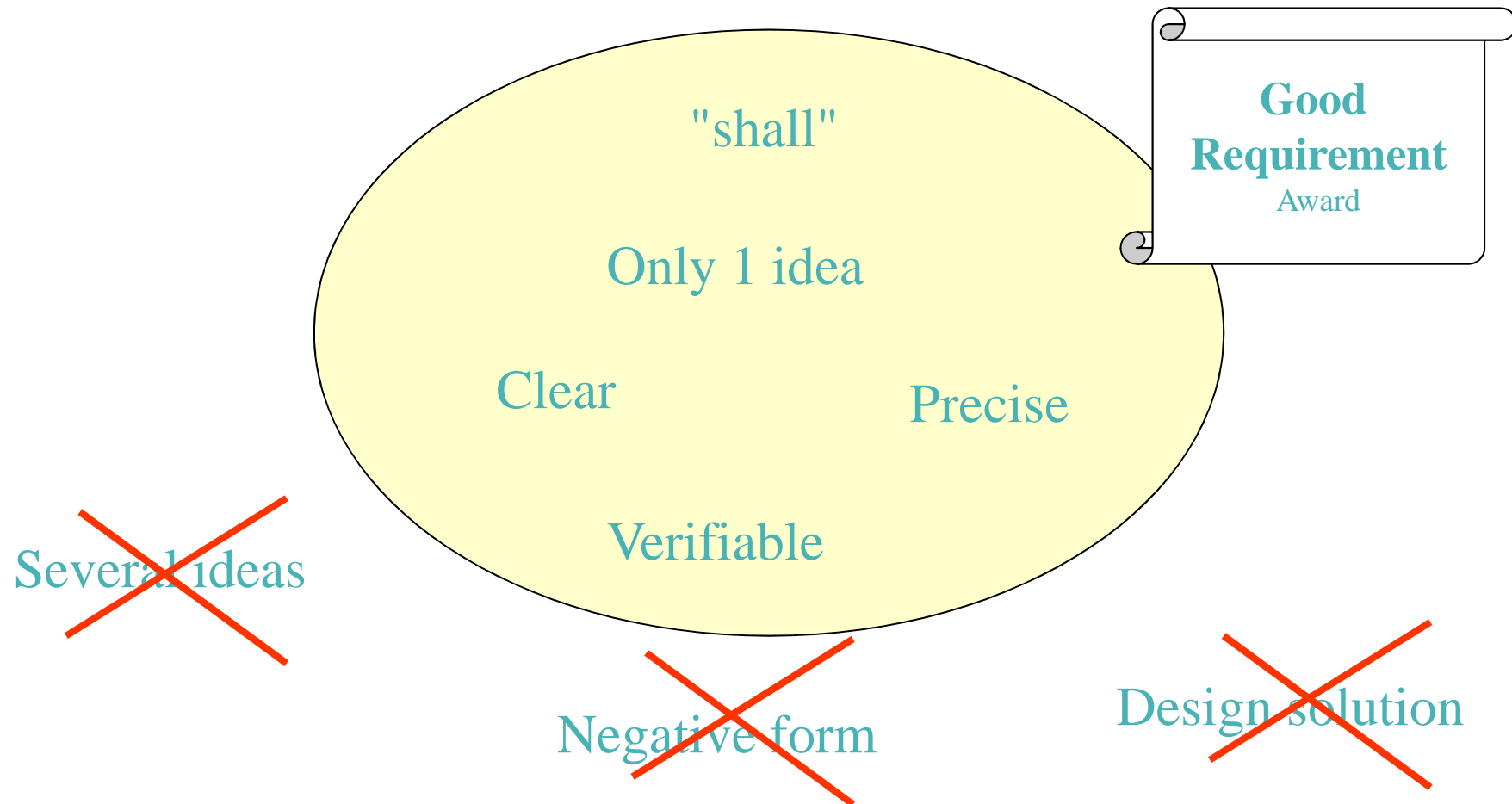
- Feasible One or several technical solutions are foreseen
- Needed The requirement has a technical value
- Verifiable A verification mean and an objective can be identified
- Concise The sentence is short and easy to understand
- Complete The requirement contains all necessary information for understanding
- Single idea The requirement expresses only one idea
- No design solution A requirement expresses the “What” not the “How”
- Not-ambiguous There is only one possible meaning
- Simple The words used are common or in a glossary
- Correctly written The requirement complies with grammatical rules and imposed formalisms.

→ V&V Mean: **Inspection**

☐ Proof reading



## Visual reminder



## Verification of the set of requirements

- Exhaustiveness: all the sources of requirements (stakeholders, applicable documents, ...) have been taken into account
- Consistency : No conflict between two requirements of a given set
- Uniqueness: A requirement exist only once in a set of requirements

→ V&V Mean: **Inspection**

Proof reading



## Validation of requirements

- Relevance Do the requirements allow to define a solution to the problem ?
- Justification = Why do these requirements exist?

V&V Mean: **Inspection, Analysis, Demonstration**

- ☐ Document reading, Peer review
- ☐ Modeling, prototyping



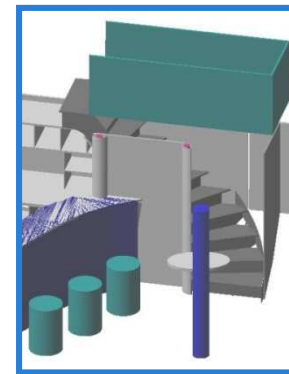
# Design verification

- Is the design feasible ?
  - ❑ Is it possible to implement a solution from it ?
- Is the design exhaustive ?
  - ❑ Does it take into account all requirements?
- Is the design optimized ?
  - ❑ Are all architecture elements necessary?

→V&V means: **Inspection, Analysis, Demonstration**



Cockpit mock up



Cabin mock up



# Implementation Verification

Ensure that the implementation meets its specified requirements

## ➤ Verification Process Objectives:

- ☐ Confirms that the intended functions have been correctly implemented
- ☐ The requirements have been satisfied
- ☐ Ensures that the safety analysis remains valid for the system as implemented

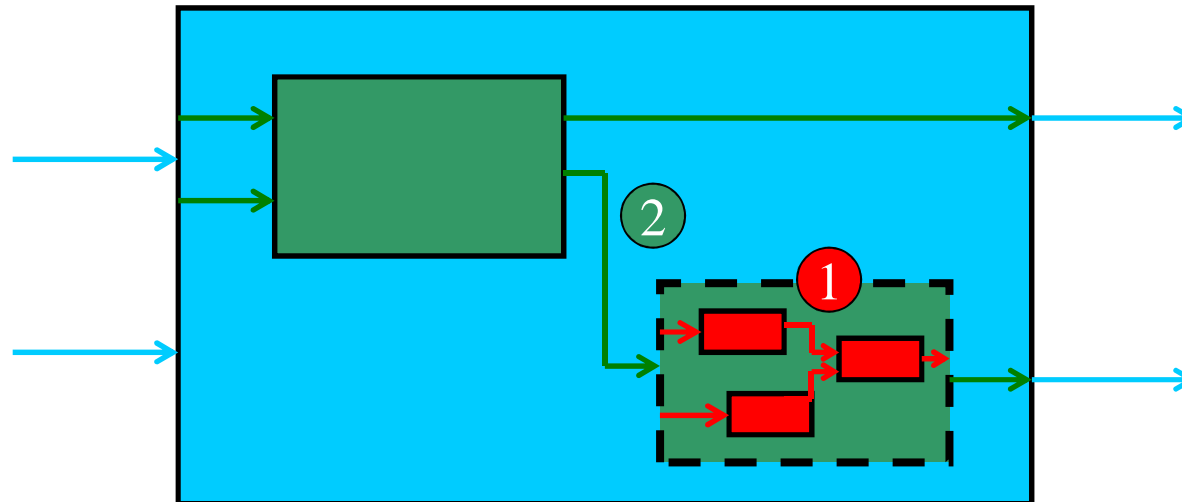
## ➤ V&V means: **Analysis, Test**




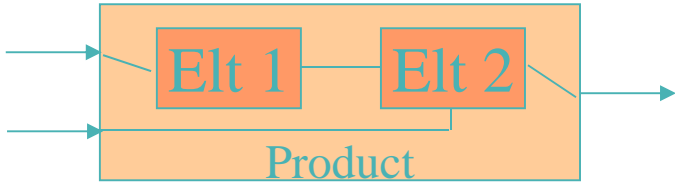


# Product Verification – Integration objectives

- ◀◀ Ensure that the internal interfaces are correct ①
- ◀◀ Ensure that the external interfaces are correct ②
- ◀◀ Ensure that the internal behaviours are correct
- ◀◀ Ensure that the chronological aspects are executed as defined in the design
- ◀◀ Ensure that the degraded cases, the borderline cases and the safety aspects are taken into account



# Product Verification – Type of Test

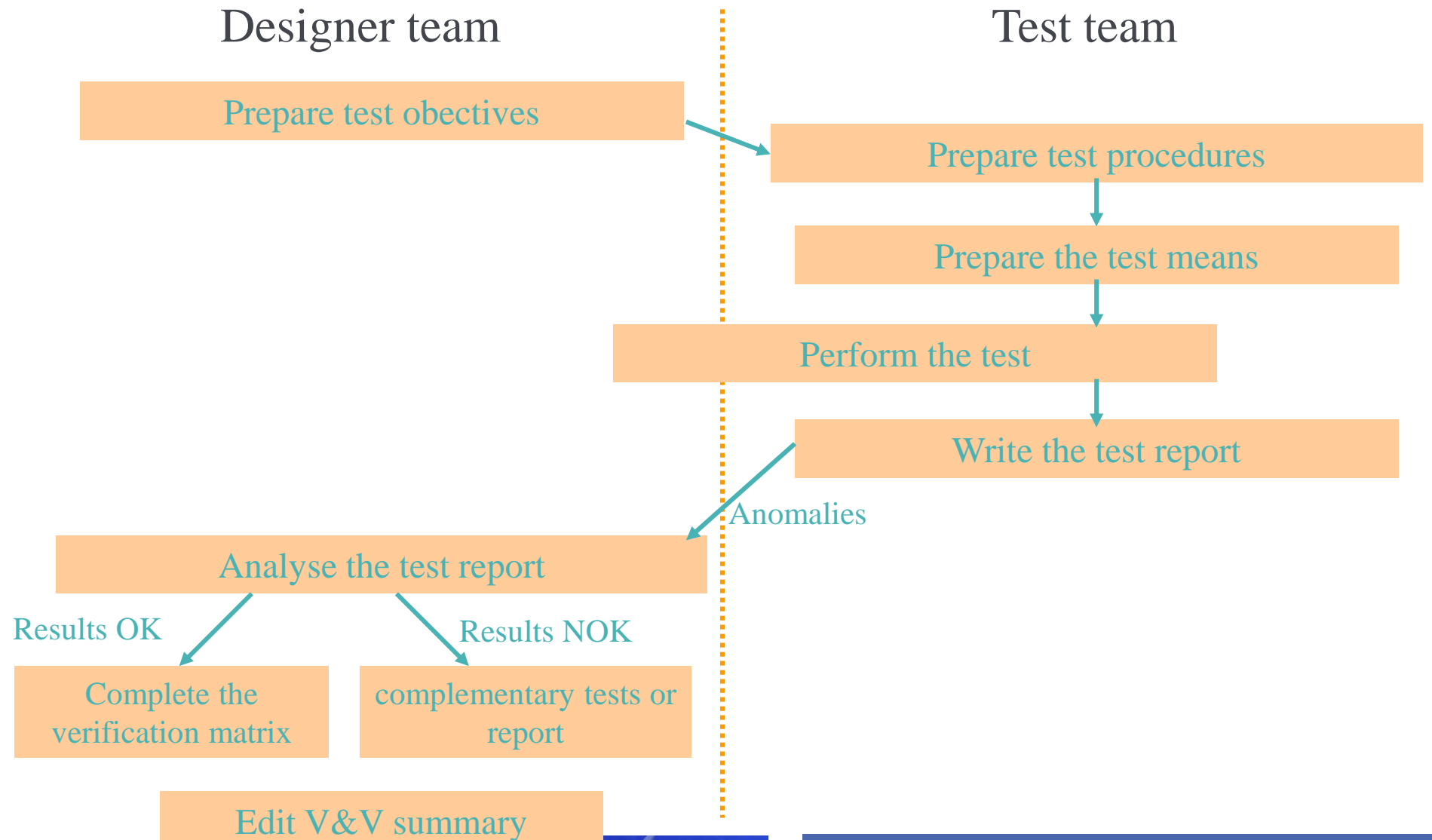
<u>2 types of test</u>		<u>Objectives</u>
Conformity tests		Requirements compliance
Functional & Environmental robustness		Maturity Compliance to robustness requirements

To test = To ensure that the behaviours are as expected. Absence of unintended behaviours.

## Product Verification – Test Means (aeronautical example)



# Product Verification – Test Process



# Product validation

Objective: Demonstrate that the product meets the needs of the customer ...

... including the implicit and non stated needs

i.e. the product can perform the required operational functions over the complete range of operational scenarios.

➤ V&V means: test

- ☐ Typical operational trials, ergonomics procedure...
- ☐ Validation tests in operational environment.

➤ Virtual prototypes help to validate the functions operational behaviour.



## Example of product validation: Early Long Flight



Objective: anticipate potential system and cabin issues

- Early in the program
- Long Flights (6 to 12h) in realistic operational conditions with full load of passengers



## Example of Product Validation - Route Proving

Demonstration of maturity and compliance to requirements of CFTP (Certification Flight Tests Program)

- Representative passengers and cargo loads
- Customers Airlines active participation (crews, maintenance...)
- EASA participation





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# V&V MANAGEMENT

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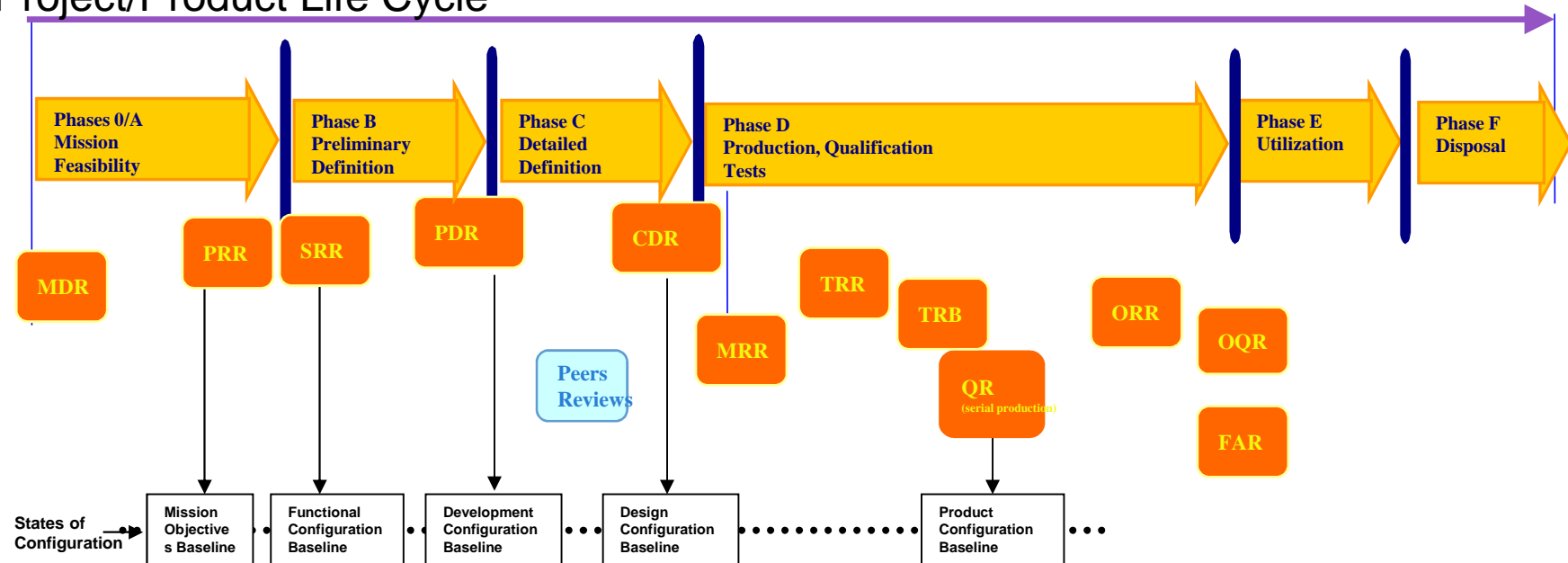
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# Milestones and reviews

## Project/Product Life Cycle



# Main reviews

## ➤ 12 reviews for the management of engineering activities:

- Mission Definition Review (MDR)
- Preliminary Requirements Review (PRR)
- System Requirements Review (SRR)
- Preliminary Design Review (PDR)
- Critical Design Review (CDR)
- Manufacturing Readiness Review (MRR)
- Test Readiness Review (TRR)
- Test Review Board (TRB)
- Qualification Review (QR)
- Operation Readiness Review (ORR)
- Operation Qualification Review (ORQ)
- Final Acceptance Review (FAR)

# System Requirements Review (SRR)

## 4 Purpose

- á Confirms technical requirements feasibility as established during proposal, and Identify key & critical requirements.

## 4 Objectives

- á The objectives of the review are to:
  - Ensure that ambiguities on customer requirements have been clarified.
  - Confirm technical requirements feasibility as established during proposal, and the understanding of the technical feasibility factors;
  - Validate that the requirements are mature enough to go further in development.
  - Verify the requirements quality analysis report.
  - Verify the traceability between technical requirements and the customer requirements;
  - Identify the “Make or Buy, Team” alternatives;
  - Verify that the operational and logistics concepts necessary for fulfilling the mission and quantified the Life Cycle Cost, are correctly analyzed;
  - Verify that the Justification of the System/Product Requirements, are included in the Design Justification File (DJF);
  - Validate the definition of the validation criteria and validation method for each customer requirements.



# Tests Readiness Review (TRR)

## 4 Purpose

- á TRR is not a single review but a number of reviews that includes the system structure conducted on specific Configuration Items (CIs). The TRR ensures that the test facility, ground support personnel, and test procedures are ready for testing. A TRR should be applied before each major sequence of tests (e.g. Integration, Verification, Validation, Qualification, Acceptance) or dedicated sequences (thermal vacuum, vibration...).

## 4 Objectives

- á The objectives of the review are to validate or confirm that the:
  - In-place test plans meet validation & verification requirements and specifications;
  - Sufficient resources are allocated to the test effort;
  - Detailed test procedures for completeness and safety during test are correctly defined;
  - Critical test personnel are test and safety-certified;
  - Test support (facility) is adequate, pertinent, and verified.
  - Nonconformance related to production are processed
  - Test bench configuration (both hardware and software) for the test, are validated
  - Test organization and dispositions, are validated.



# Tests Review Board (TRB)

## 4 Purpose

- á TRB is not a single review but a number of reviews that includes the system structure conducted on specific Configuration Items (CIs). The TRB ensures that the test results are successful. A TRB should be applied after each tests sequence starting by a TRR.

## 4 Objectives

- á The objectives of the review are to validate or confirm that the:
  - Test results are compliance with their procedures and tests specifications; and they are within required limits,
  - Discrepancies are documented and dispositioned
  - Anomalies are under control and the Non-Conformance processed accordingly to the Nonconformance process;
  - Inspection of the hardware integrity, are done.



# Qualification Review (QR)

## 4 Purpose

- á The Qualification Review (QR) ensures that the qualification verifications demonstrated design compliance with functional and performance requirements. Qualification tests generally are designed to subject the hardware to worst caseloads and environmental stresses. Some of the verifications performed to ensure hardware compliance to worst case loads and environments are vibration/acoustic, pressure limits, leak rates, thermal vacuum, thermal cycling, electromagnetic interference and electromagnetic compatibility (EMI/EMC), high and low voltage limits.

## 4 Objectives

- á The objectives of the review are to validate or confirm that the:
  - Functional and performance requirements, and that test plans and procedures were executed correctly in the specified environments
  - Traceability between test article and production article is correct, including name, identification number, and current listing of all waivers
  - Incremental tests required or conducted due to design or requirements changes made since test initiation, and resolve issues regarding their results.
  - Anomalies are under control and the Non-Conformance processed accordingly to the NCR process;



# The V&V plan: Objectives

The V&V plan describes the technical context of V&V,  
in order to have visibility on V&V activities to be performed

➤ It shall define

- ☐ The validation, integration and verification strategy
- ☐ The organisation and responsibilities
- ☐ The tests methods and means
- ☐ The V&V deliverables
- ☐ The V&V schedule

## V&V Strategy

➤ The V&V strategy is based on the identification of the following elements:

- ☐ Risk and Novelties
- ☐ Main Integration Platforms and Equipments needed
- ☐ Expectations to Supplier V&V strategy and activities
- ☐ Identification of the different standards deliveries
- ☐ Availability of the various equipments to integrate
- ☐ Definition of requirements / design cascade
- ☐ Coverage / traceability policy





# Verification Planning

- The purpose of this phase is to define the processes and criteria to be applied to the verification of each requirement to achieve the verification objectives.
- ❑ Identification of the system or item configuration
- ❑ Collation of all requirements appropriate including derived requirements and their traceability.
- ❑ Definition of the specific verification methods to show compliance with each requirement.
- ❑ Definition of the criteria to assess the evidence resulting.
- ❑ Identification of system verification credit taken for hardware or software verification activities.



## Verification Data

- The purpose of verification data is to provide evidence that the verification process was conducted as planned.
- ❑ Verification plan:

The verification plan establishes the strategies to show how the implementation satisfies its requirements.
- ❑ Verification Procedures and Results:

Data describing the verification procedures together with the results achieved
- ❑ Verification Matrix

A verification matrix or an equivalent tracking document should be produced to track the status of the verification process.
- ❑ Verification Summary
  - ❑ The verification summary provides visibility for the evidence used to show that the system or item implementation satisfies its requirements

## V&V Tools

- Word and Excel are very widely used
- More powerful tools are needed when :
  - ☐ Working multi-located, large teams
  - ☐ Managing properly changes and configuration
  - ☐ Handling hundred of thousands of engineering items (requirements, V&V data, ...)
  - ☐ Combining models in the V&V data
  - ☐ Integrating with other tools
- Example of such tools
  - ☐ System Engineering tools: IBM Doors, Vitech CORE
  - ☐ Product Life-cycle Management tools: Siemens TeamCenter, 3DS Enovia, PTC Windchill
  - ☐ Software development environment are often integrated with requirements and test functionalities





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**ANNEX**

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## Reminder – various elements

One of the handyman's explicit needs is to hang his tools to a front panel.

### Stakeholder Requirement:

handy-042: The system (front panel) shall allow tools hanging.

### System Requirement:

#### *Functional requirement*

Panel-005: The front panel shall be equipped with nails to hang the tools.

### Equipment requirement

plank-118: The front plank dimensions shall be: 2000 x 800 x 10 mm

plank-218: The plank shall be riddled with holes at the following places...



## Reminder – Answers

### Equipment verification:

The plank supplier verifies the dimensions and the holes locations.

### System integration:

The system integrator hammers the nails into the plank.

### Product integration:

The system integrator assembles the nailed plank into the workbench.

### Product verification:

The tester hangs a tool on each front panel nail.

### Product validation:

The handyman uses the workbench.

