GNC and AOCS functional chains engineering and verification

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Presentation Outline

- What is Functional Chain Verification?
- Normative framework
- Verification facilities
- Facilities usage in project lifecycle
- Avionics Functional Verification
- Working by increments: importance of continuity and modularity
- AOCS UnitSim
- Distribution logic of AOCS UnitSim

What is Functional Chain Verification?

- Functional Chain Verification is part of the system verification and ensures that the system functions implemented in the OBSW and in HW are verified against the customer's requirements and are fit for their purpose.

VERIFICATION

VALIDATION

- The main questions addressed by Functional Chain Verification are:
  - How can the functions implemented in SW be validated in the HW environment?
  - How can the SW specifications be verified to be "right" for the selected HW and operations?
  - How can the flight product be ensured to be free from workmanship defects and acceptable for flight?

Scope of Functional Chain Verification

- OBSW system-level acceptance and validation
- Verification at unit-level, subsystem-level and system-level of functional chains implemented in OBSW in several functional disciplines:
  - GNC/AOCS
  - Data Handling System
  - Comms
  - Thermal
  - Power
  - Payload
  - ...
- Verification of GNC/AOCS performance & robustness
- Verification of the S/C Database
- Verification of system-level FDIR
- Verification of flight control procedures (nominal and contingency operations)

Normative Framework of GNC/AOCS Functional Chain Verification

- ECSS-E-ST-60-30C covers “the process of verifying the software specification with respect to AOCS functional needs” and “the verification of the whole functionality of the AOCS taking into account the real behaviour of equipment unit issued from equipment unit verification process”.
- Lower level (i.e. unit-level) verification is not covered in ECSS-E-ST-60-30C.
- Satellite integration verification and environmental testing are covered through ECSS-E-ST-10-03.
- ECSS-E-ST-60-30C also covers verification of GNC/AOCS interfaces with the ground flight dynamics system and in-flight verification of the GNC/AOCS functional chain (noting that some parameters can only be verified in flight).
- ECSS-E-TM-10-21A introduces a proposed standard terminology of the simulation facilities and test benches

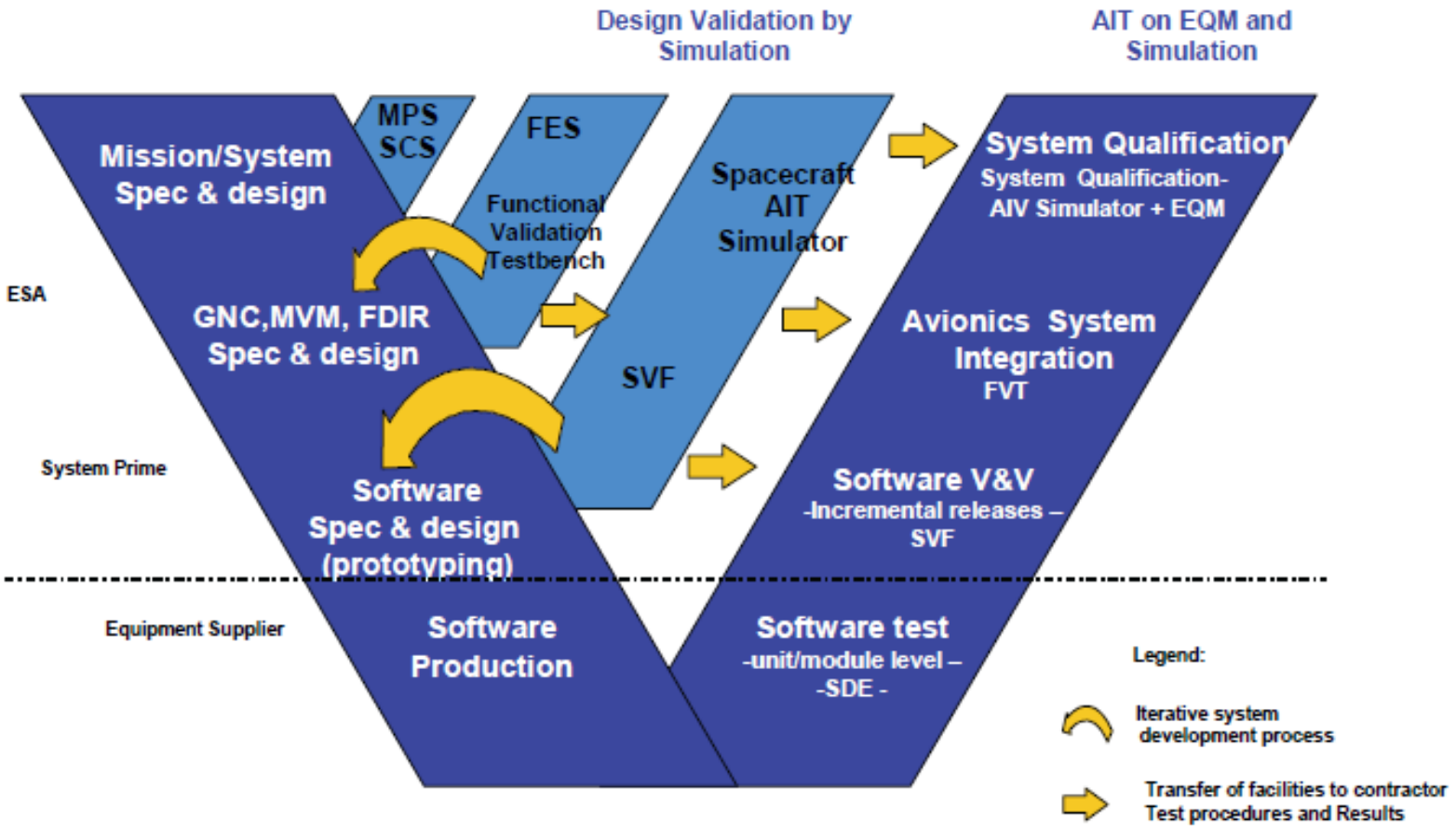
GNC/AOCS Verification Facilities (terminology of ECSS-E-TM-10-21A)

- MATLAB/Simulink simulator that implements non-real time mathematical models of spacecraft dynamics, environment, performance behaviour of units and GNC/AOCS SW algorithms - No uniform terminology yet defined.
- FVT (Functional Validation Testbench) – Used for testing of critical breadboarded or prototype elements. It is mission specific and often not needed if previous heritage is available.
- FES (Functional Engineering Simulator) – High-fidelity simulator that can run the GNC/AOCS source code (either the complete image or individual modules). It is also known as FVB (Functional Validation Bench)
- SVF (Software Verification Facility) – Real-time facility using detailed numerical models of the OBC, detailed functional and performance models of unit, dynamics and environment, representative interfaces with ground.
- AIV Simulator – It is a "FlatSat" setup where unit models are fully or partially replaced by HW. It is also known as ATB (Avionics Test Bench)

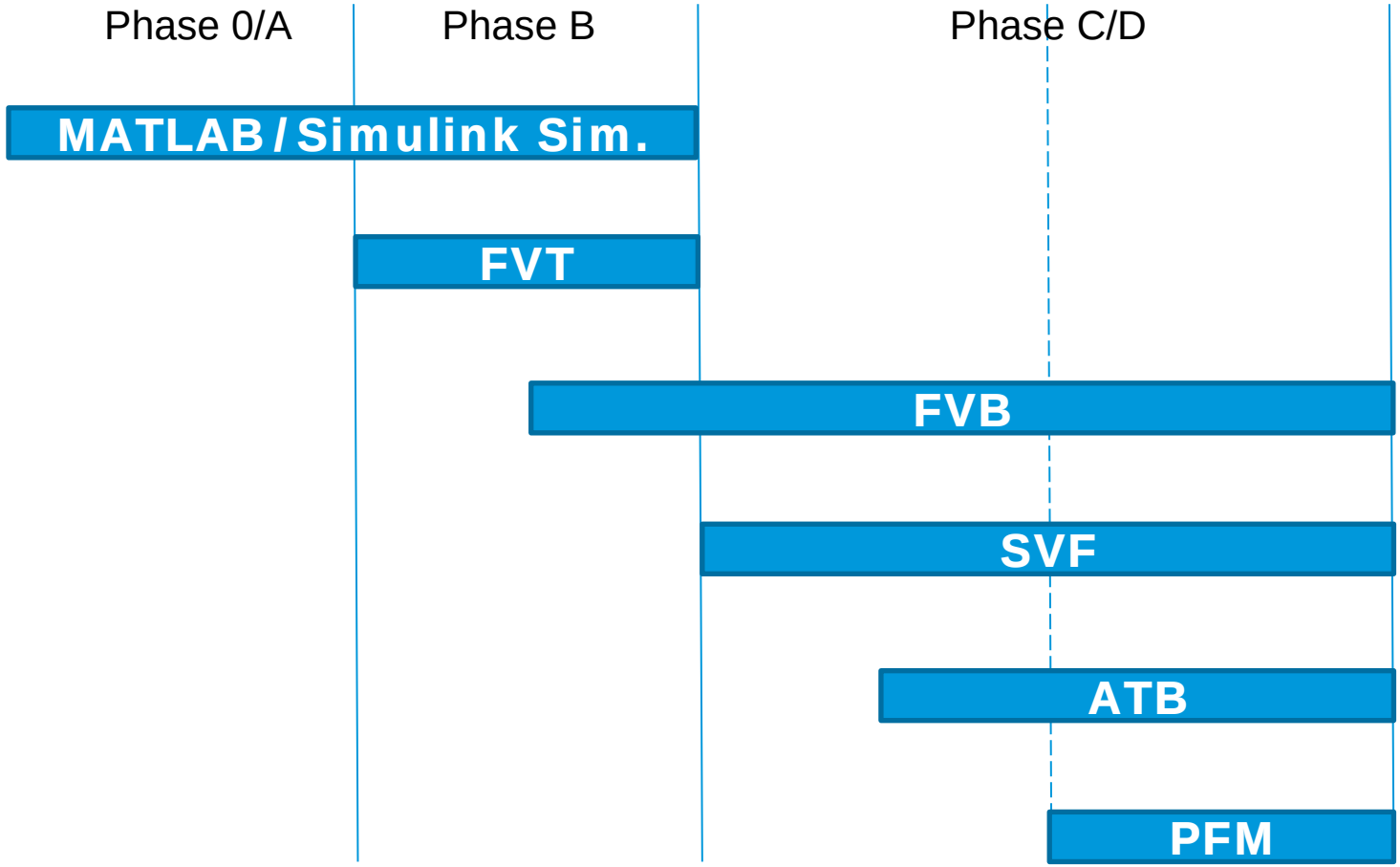
ECSS-E-ST-60-30C: Verification facilities

- Requirements are defined for FVB (referred to as “AOCS functional simulator”) and ATB.
- Representativeness of AOCS modes, of algorithms in OBSW, of AOCS units behaviour, of dynamics and kinematics, of environmental models used on FVB.
- Simulation models used on FVB and ATB must be validated (w.r.t real hardware), must be populated with parameters provided by the unit suppliers, and their use must be justified
- Representativeness of HW model (w.r.t. FM) of the OBC used on ATB
- Need to embed the real OBSW on ATB
- Representativeness of real HW interfaces and of real-time behaviour on ATB

Facilities Usage in System Engineering Lifecycle (from ECSS-E-TM-10-21A)



Facilities Usage per Project Phase



Avionics Functional Verification

- Due to the tight interconnection between GNC and AOCS subsystems and OBSW, a joint verification process is needed (at avionics level)
- Avionics verification includes:
  - GNC/AOCS Performance Verification campaign, to validate the GNC/AOCS requirements, to check the tuning the GNC/AOCS parameters, and verify closed-loop performance on the FVB
  - OBSW Verification campaign, which entails SW module-level testing, HW/SW models verification and calibration, and finally OBSW integration and final verification on the SVF
  - Functional Chain Verification campaign, which includes real HW and has system-level oriented objectives. It is performed on the SVF, on the ATB, and on PFM
  - AIT campaign, which includes verification of system interfaces and is performed on PFM

ECSS-E-ST-60-30C: AOCS Design and Performance Verification

- Possible means of verification (theoretical analyses and numerical simulations) are defined and the need to justify their choice is expressed
- Scope of verification (all AOCS modes, functions and mode transitions) is defined
- The need to cover robustness analysis over a range of non-nominal values for a number of parameters is expressed
- The need to analyse the numerical accuracy of the OBC in the frame of AOCS design and performance verification is also expressed

ECSS-E-ST-60-30C: AOCS Hardware/Software Verification

- Scope of verification (all AOCS modes and mode transitions) is defined
- Needs are expressed in terms of configuration and representativeness of hardware, hardware/software interfaces, real-time performances, and mission conditions
- The use of reference cases is required
- Stimulation capabilities are defined

ECSS-E-ST-60-30C: Other Levels of Verification

Satellite-level

- Reference is made to ECSS-E-ST-10-03 for execution of end-to-end tests and polarity tests

AOCS-ground interface

- Generic need to test this interface is expressed

In-flight verification

- The need to verify the AOCS functional chain during commissioning is expressed
- Also, a health-check of units (including redundant branch, if possible) is required during commissioning
- The need is expressed of imposing time-limits to in-flight verification

Avionics Functional Verification

- Items of GNC/AOCS functional verification can be mapped on the available facilities, for instance in tabular form

Item to be verified	Unit level	Analysis	FVB	SVF	ATB		PFM
					Open loop	Closed loop	
GNC/AOCS performances							
GNC/AOCS unit direct commanding							
GNC/AOCS function commanding via OBSW							
Modes transitions							
Real-time aspects							
FDIR surveillances							
FDIR recovery actions							
Interfaces with other subsystems							
Polarity check							

- The table should be populated on the basis of the design approach, and in particular on the basis of the OBSW releases approach

Working by Increments

- OBSW is typically developed in incremental way, with several releases that incorporate more and more functions/modes
- This is driven by the uneven level of maturity of different subsystems/functions and also by the need to correct bugs of previous releases
- In addition, the verification facilities also undergo a series of updates, for instance when HW units become available and can replace the simulation models
- The need to handle the incremental nature of the GNC/AOCS functional verification chain calls for emphasis on ensuring continuity

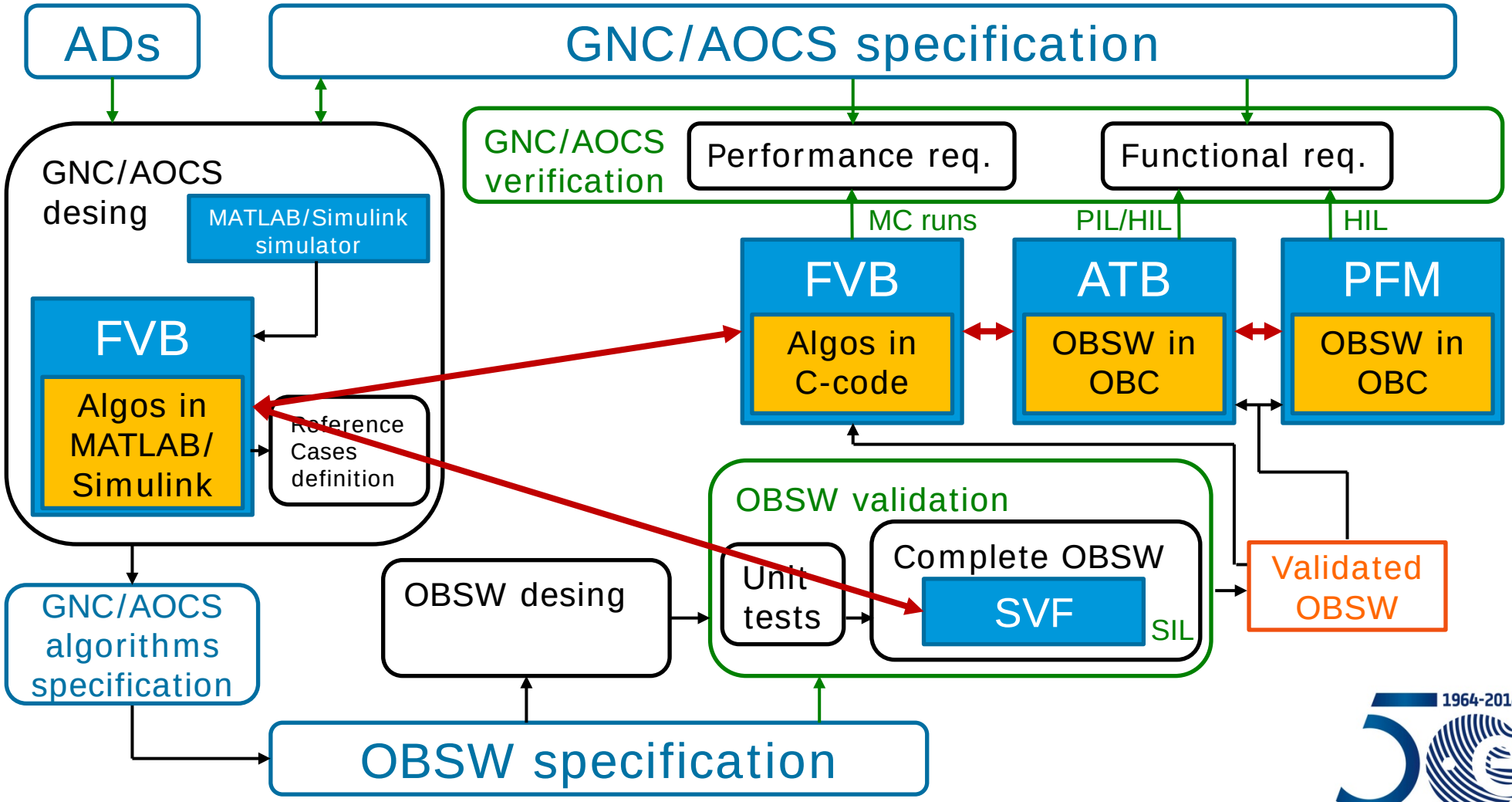
Continuity

- Continuity between verification facilities
  - Simulation models should have a common core and must be developed with specific layers (or “wrappers”) that ensure the compatibility with the interfaces of the other elements of the verification facility
- Continuity between verification steps
  - The same reference cases are run on several benches to compare the results and identify the effects of the new elements introduced on the verification facility
  - Reference cases are also helpful to compare the behaviour of real HW with respect to simulation models and thus to validate the models
  - As a rule, reference cases must cover all GNC/AOCS modes, all functions, all mode transitions and all FDIR surveillances and each type of recovery action
  - The global behaviour of the GNC/AOCS must be similar (but not necessarily identical) across test benches: order of magnitude of performances, transients durations, time of main events, duration of phases must be comparable. New phenomena (such as spikes, transients, etc.) not previously seen on other benches should be investigated and explained

Modularity

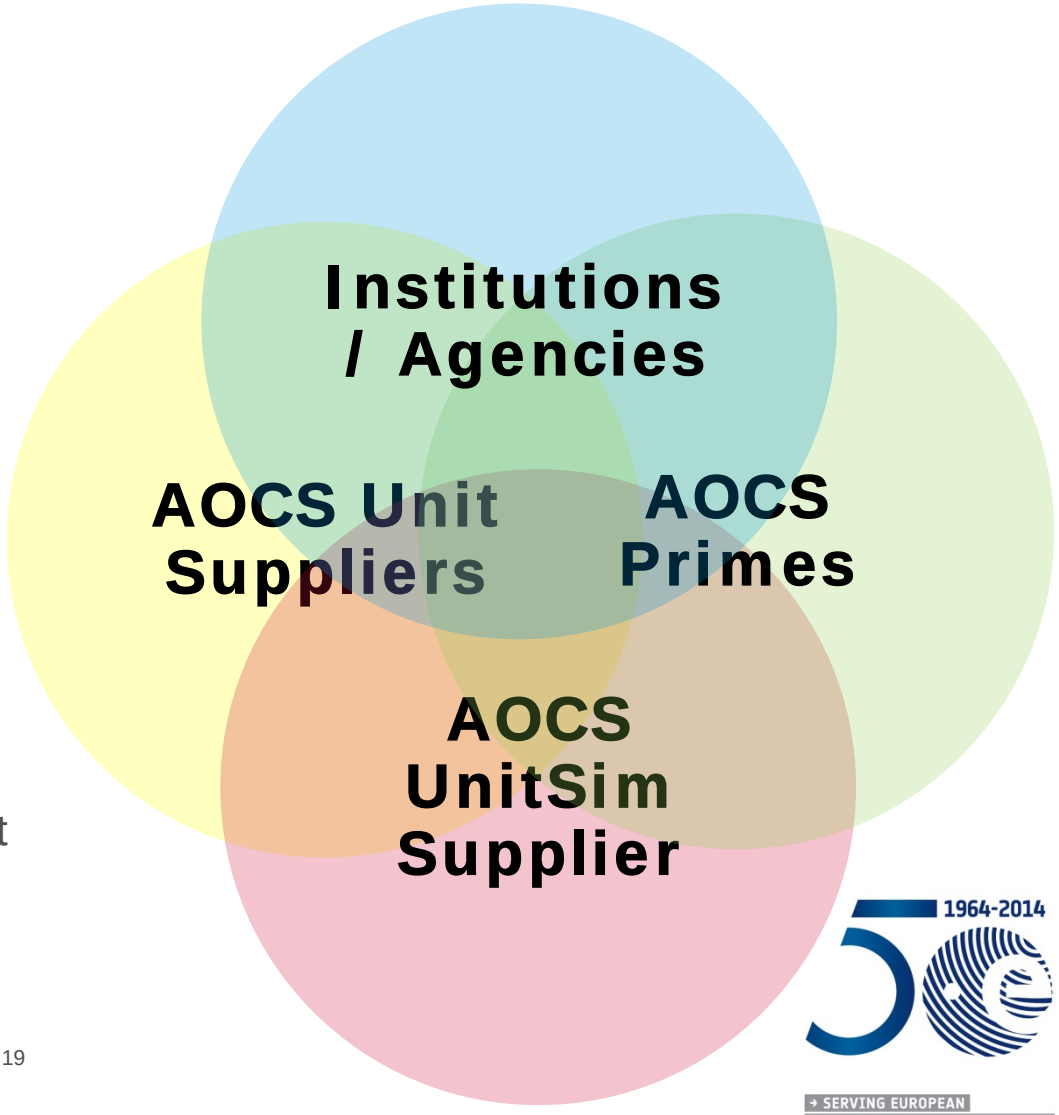
- Efficiency of the verification effort can be improved by using a modular approach
- Test cases and test procedure can be developed for basic OBSW, unit or system function
- These test cases and procedures can be used as building blocks, grouped together, and used to generate higher-level test cases
- Scripting can be used to further improve efficiency

Summary of GNC/AOCS Functional Chain Verification Logic



AOCS UnitSim: a building block for AOCS verification

- **GENERIC functional core**
  AOCS HW simulation models (gyro, star tracker, reaction wheel)
- **Building Blocks** shared by all stakeholders of the AOCS V&V
- **ONE tool** for any unit mathematical model (performance/functional)
- Simulation Datafile checked against **real HW behaviour**



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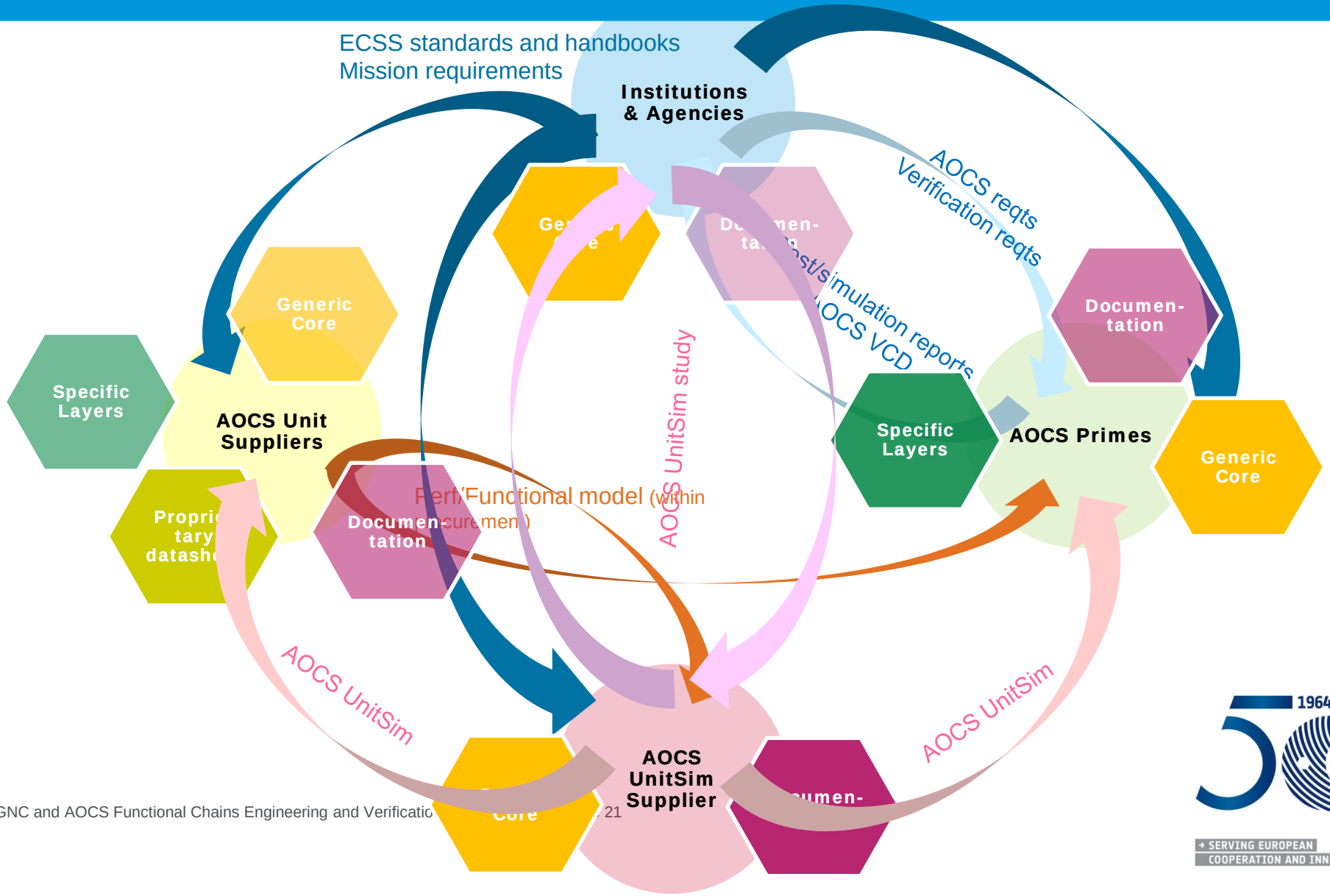
AOCS UnitSim Distribution logic: which community of users for which products

- Simulation model (except data): IPR belongs to ESA
- Currently Point-to-Point ESA License
  - Protection of ESA IPR
  - … But limitation in redistribution and sharing
- Towards an ESA Community License scheme
  - Proprietary level
  - Common core level

AOCS UnitSim Distribution logic: which community roles?



Thank you for your attention