Standardization training program E-60 discipline: Control

Satellite AOCS requirements

ECSS-E-ST-60-30C

European Space Agency

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E60 discipline: Control

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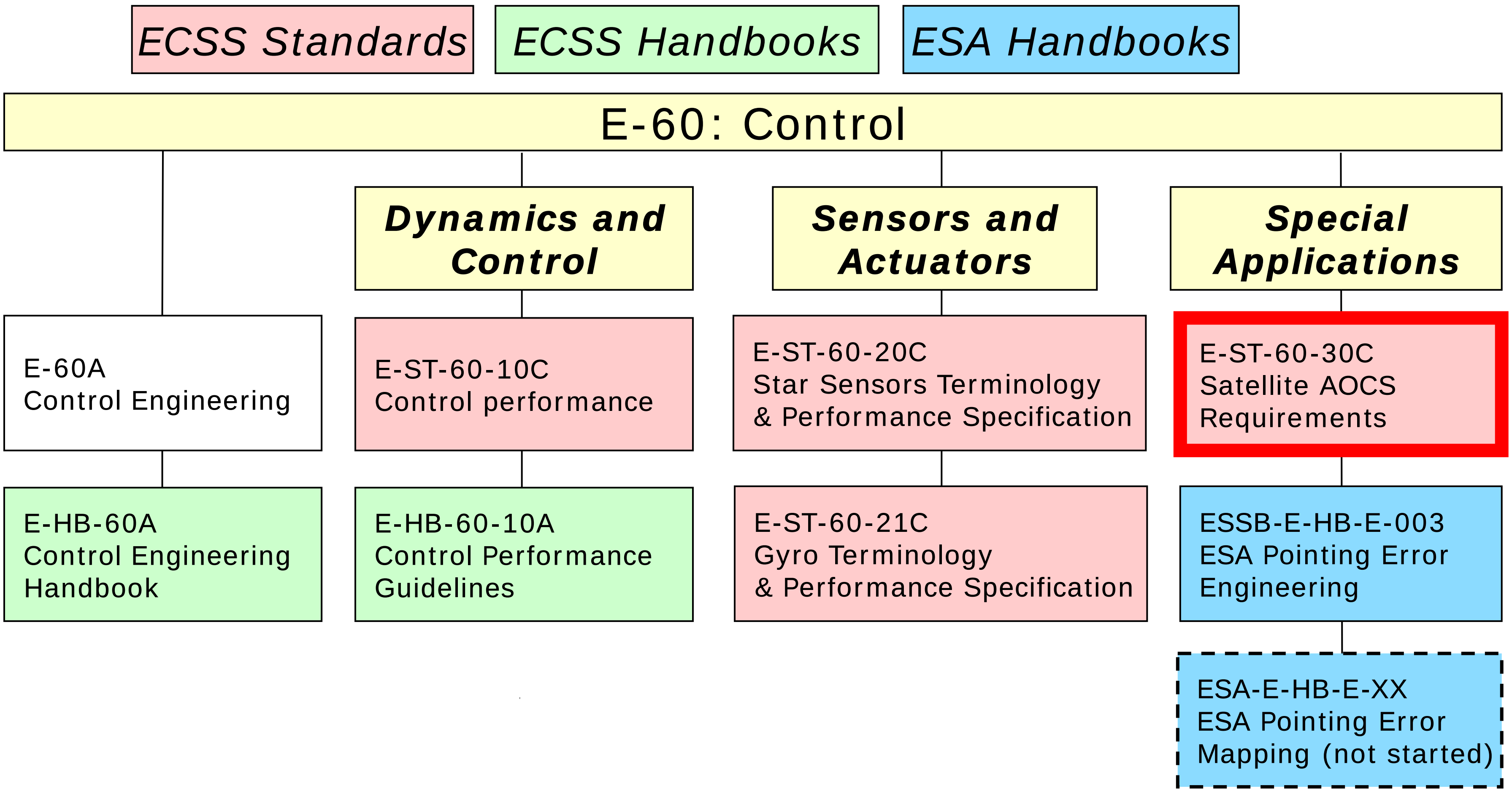

Introduction (1/2)

Standardization training program
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- This document contains a standard set of Attitude and Orbit Control System (AOCS) requirements for the development of satellites
  - It includes all subjects related to AOCS design and verification, namely functions and FDIR, operations, performance, verification and documentation
- Usage
  - A new ESA project will use it (partially) as a standard catalogue for preparing the relevant sections of the project MRD and SRD
  - The ESA project team will also use it (fully) all along the project development to ensure that the mandatory AOCS engineering and verification tasks are correctly specified by the prime and properly executed by the prime and its subcontractors
  - In particular, the normative DRDs in the Annexes will provide a good support for ESA project to obtain proper AOCS documentation
- Variety
  - There is great variation between ESA projects' PRDs, regarding the level of completeness, the level of detail and the expression of similar requirements
  - The distribution of requirements among ESA and industry contractual/technical documentation (e.g. specs and SoW, system and subsystem levels, design and verification, …) also varies a lot between primes and AOCS companies

Introduction (2/2)

Standardization training program
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- Scope
  - covers AOCS attitude estimation, guidance and control; orbit control; and in some cases, on-board orbit estimation
  - excludes full GNC with real-time trajectory guidance and control; relative position estimation and control
  - excludes onboard software
  - is restricted to AOCS-level requirements, e.g. AOCS pointing performance; and AOCS FDIR (excludes system FDIR)

- Tailoring for a specific mission
  - can leave out some requirements if not necessary, depending on the industrial organisation, the type of mission and other factors
  - numerical values to be specified (TBS) considering each mission's specific needs
  - HW and SW will be a key factor for tailoring of the verification requirements: novelty versus heritage
  - tailoring is made easier thanks to the numerous notes embedded in the Standard

Attitude and Orbit Control System Functions

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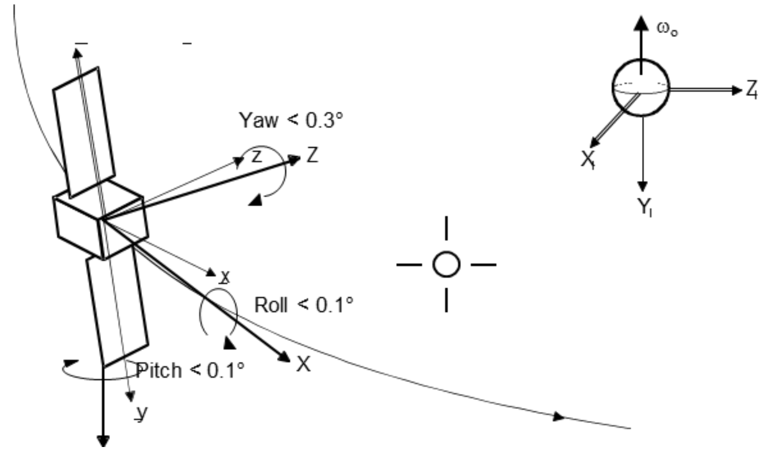
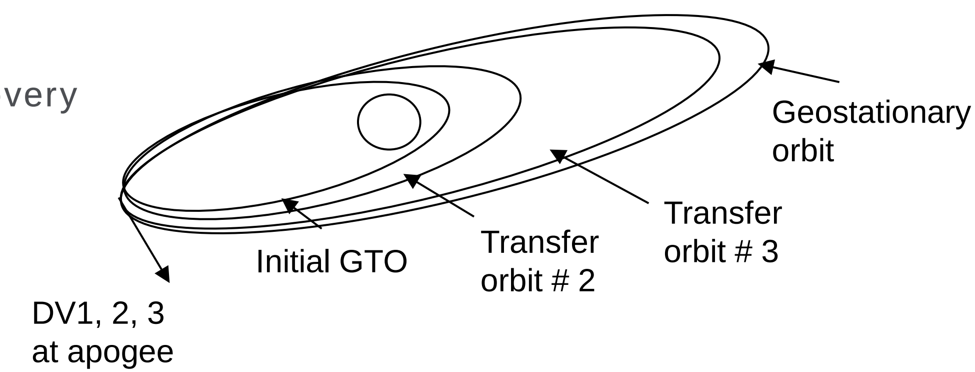
- The AOCS performs the following functions:
  - Attitude (and position) estimation based on sensors measurements and processing
  - Attitude control using actuators (torques)
  - Orbit corrections with actuators (forces)



- With a high level of autonomy:
  - Initialisation without ground intervention
  - Automatic closed loop control: command = feedback (attitude, rate)
  - Autonomous management of modes
  - Failure Detection, Isolation and Recovery

- Throughout the various mission phases:
  - Launch & Early Orbit Phases
  - Operational phase
  - FDIR and Reacquisition



Typical mission timeline and AOCS modes

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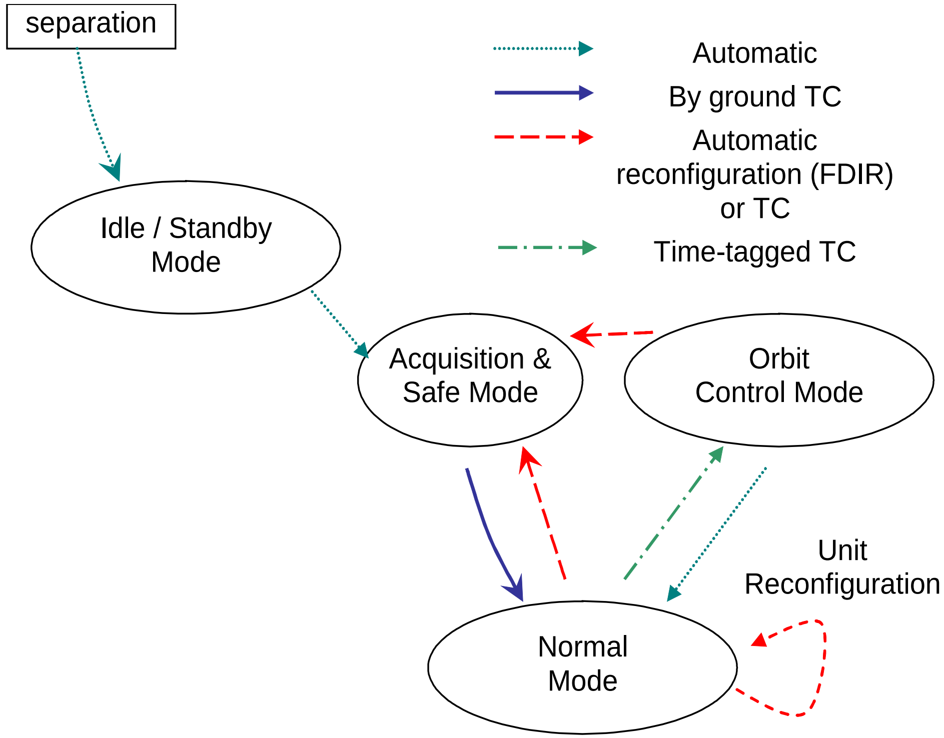
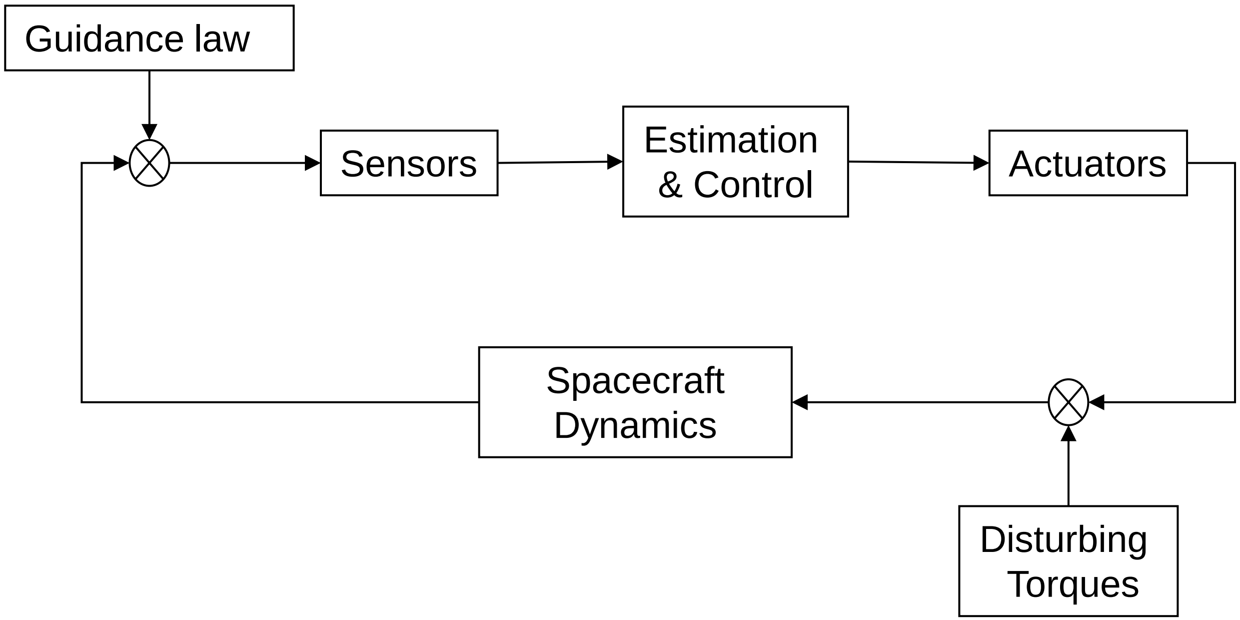
- Launcher separation
  - AOCS units automatic initialisation
- Acquisition Mode
  - Damping of tip-off angular rates
  - Sun acquisition/solar array deployment
- Normal Mode
  - Pointing performance
  - Mission availability
- Orbit Control Mode
  - Delta-V’s to reach final orbit
  - Periodic orbit maintenance
- Safe mode
  - Stable state ensuring satellite safety (power, thermal, communications)
  - Minimisation of orbit degradation



AOCS block diagram



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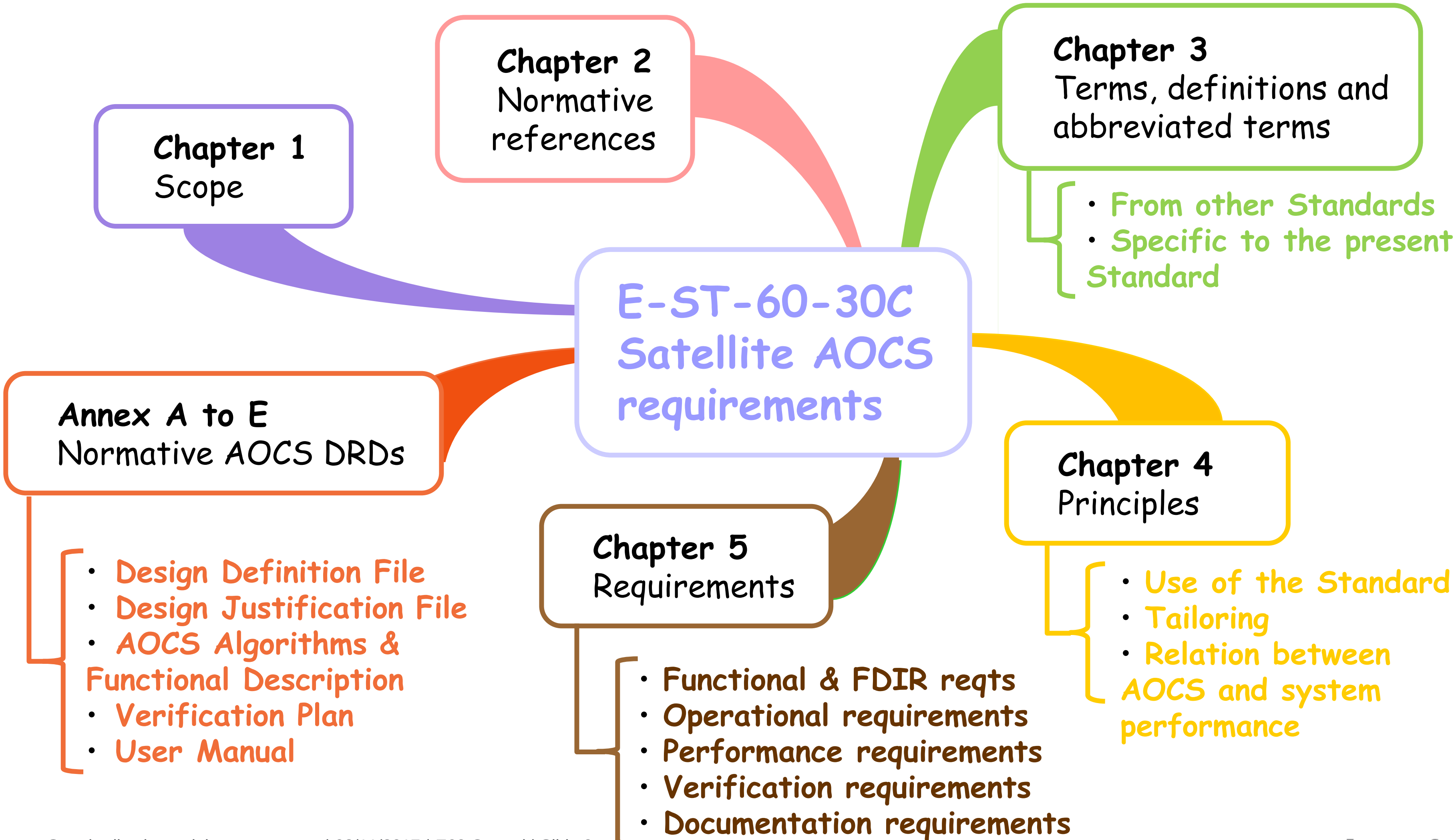

Quick insight

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- Chapter 3 provides the definition of specific terms used in this Standard
  - Other names or definitions may also used during the development of space programmes
- Chapter 4 describes the principles used in this Standard
  - The responsible entity is indicated. The collection of requirements is general and needs tailoring. A distinction is made about the level at which the requirements are applicable.
- Chapter 5 gathers the requirements together into 5 major groups
  - These are functional & FDIR, operational, performance, verification and documentation
  - ESA project can impose a few AOCS design implementation requirements in the SRD, e.g. APS STR
- Annex A-E are 5 normative document requirements definitions (DRDs)
  - These describe design definition, design justification, algorithms and functional description, verification plan and user manual aspects

Relation to other ECSS documents

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Standard	category	title
ECSS-S-ST-00	ECSS System	Description, implementation and general requirements
ECSS-S-ST-00-01	ECSS System	Glossary of terms
ECSS-E-ST-10	Space engineering	System engineering general requirements
ECSS-E-ST-10-02	Space engineering	Verification
ECSS-E-ST-10-03	Space Engineering	Testing
ECSS-E-ST-10-06	Space Engineering	Technical requirements specification
ECSS-E-ST-10-09	Space engineering	Reference coordinate system
ECSS-E-ST-60-10	Space engineering	Control Performance
ECSS-E-ST-70	Space engineering	Ground systems and operations
ECSS-E-ST-70-11	Space engineering	Space segment operability
ECSS-E-70-41	Ground systems and operations	Telemetry and telecommand packet utilization

Chapter 3 overview
Terminology

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- Besides terms defined in ECSS-S-ST-00-01 and ECSS-E-ST-10, **specific terms** include
  - Attitude and Orbit Control System (AOCS)
  - AOCS Mode
  - AOCS Functional Simulator
  - Avionics Test Bench
  - End-to-end Tests
  - Flight Dynamics (FD)
  - Guidance, Navigation and Control Functions (GNC)
  - Sensitivity Analysis
  - Worst Case Analysis

- The following **ECSS terms** are defined in ECSS-E-ST-60-10C
  - Absolute Knowledge Error (AKE)
  - Absolute Performance Error (APE)
  - Relative Knowledge Error (RKE)
  - Relative Performance Error (RPE)
  - Robustness

Chapter 3 examples Terminology

3.2.3 AOCS functional simulator

Fully numerical simulator used to verify the AOCS design, algorithms, parameters and performances

Note: It can be a collection of unitary numerical simulators, provided that full coverage of the verification is ensured.

3.2.8 Sensitivity Analysis

Identification of the parameters which impact the AOCS performance, and assessment of their individual contribution to this performance

Note 1. Only the dominating contributors are of interest. These contributors can include:

- *Noise, bias, misalignment for the AOCS sensors and actuators*
- *Satellite mass properties*
- *Satellite configuration variation, e.g. solar array position, sensors and actuators configuration*
- *Measurements outages*
- *Environmental conditions*
- *External and internal disturbances*

Note 2. The AOCS performance can be for instance: pointing accuracy, duration of a manoeuvre and fuel consumption.

Note 3. The objective is to have an order of magnitude of the contribution, and this can be achieved by analysis, simulation or test.

Chapter 4
Principles

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- Purpose
  - This Standard gathers together typical AOCS requirements for use in the Project Requirement Documents (PRD) and the AOCS technical specification, for space programmes at all levels of the customer-supplier chain above AOCS.
- Applicability
  - It is applied by the highest level customer (e.g. ESA, CNES, DLR etc.) to the prime contractor, for instance through the MRD or SRD [see figure on slide 5]
  - It is not directly applicable to the AOCS contractor, whose contractual specification document is a PRD derived from this Standard [see figure on slide 6]
- Generality
  - Because of the large variety of space missions, AOCS functions and AOCS performances, the typical AOCS requirements need to be tailored for a dedicated mission. Tailoring needs experience and pragmatism, must read the notes, cannot just cut & paste.
  - The numerical values for performance requirements are expected to be specified (TBS), for each specific project.
- Level
  - It is important to distinguish between AOCS level and system level (i.e. satellite, project, mission or programme).
- The notes
  - These help to decide which requirement to include and how to adapt it for the dedicated mission.
  - EXAMPLE: If a mission requires an onboard navigation function, then requirements dedicated to this function or to an on-board GNSS receiver are applicable.

Chapter 4
Tailoring for ESA MRD / SRD

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- FDIR requirements
  - FDIR requirements are usually defined and specified at satellite level.
  - The ones included in this Standard relate to the contribution from AOCS.
- Performance requirements
  - The pointing performance requirements, expressed at AOCS level in this Standard, originate from mission requirements expressed in terms of the mission objectives (e.g. image processing characteristics, or distances on the Earth surface)
  - The engineering work necessary to translate mission pointing requirements into AOCS level pointing requirements, or to make an apportionment between several contributors is not addressed in this Standard.
  - Expressing the performance requirements at mission level can allow a better optimisation of the system. In this case, the pointing requirements at AOCS level can be drastically simplified or simply cancelled.
  - For a specific mission, the numerical values for performance requirements are expected to be specified (TBS), considering the exact performances required for the mission.
- Verification requirements
  - Verification requirements are in various documents of the ITT package, depending on ESA project.
- Documentation requirements
  - The AOCS documentation is defined in the DRD annexes. A major part of this documentation can be part of the satellite level or avionics level documentation.
- Tailoring depends also on the industrial organisation for a specific mission
  - Whether the Prime is responsible for the AOCS
  - Whether the AOCS contractor is also responsible for other functions such as propulsion and software, for the procurement of AOCS units and computer, and for satellite operations and flight dynamics

Chapter 5
Requirements - Overview

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A Standard providing a comprehensive template for AOCS requirements specification, covering all project phases, gathered into **5 major** groups

5.1 Functional and FDIR requirements

- Modes and functions
- System constraints
- FDIR and redundancy

5.2 Operational requirements

- TM/TC, ground monitoring
- Autonomy
- Calibration operations

5.3 Performance requirements

- Domains definition
- Pointing and knowledge performance
- Agility, outages
- Non nominal modes (safety, orbit control)

5.4 Verification requirements

- Verification facilities (simulators and benches)
- HW/SW verification
- Verification at satellite level and in flight

5.5 Documentation requirements

- Typical documents per phase
- Required documents

Chapter 5.1 contents
Functional and FDIR requirements

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- General functional requirements
  - High level functions
  - Attitude acquisition and keeping
  - Attitude determination
  - Navigation
  - Reference frames
  - Mission pointing
  - Calibration requirements on AOCS

- Fault management requirements
  - Basic FDIR requirements
  - Hardware and software redundancy scheme

- Propulsion related functional requirements
  - Utilization constraints
  - Fuel gauging
  - Fuel sizing
  - Thruster qualification

Chapter 5.1 example 1
Functional requirements

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5.1.1.8 Safe mode

a. *In case of major anomaly, the AOCS shall provide the capability to autonomously reach and control safe pointing attitude and angular rates to ensure the integrity of the spacecraft vital functions, including power, thermal and communications.*

NOTE 1. Depending on satellite design and operational sequences, the Safe pointing attitude can be required to be compatible with several satellite mechanical configurations corresponding to solar arrays and appendages in stowed, partially deployed or fully deployed configurations.

NOTE 2. Major anomalies are defined programme by programme.

Chapter 5.1 example 2
AOCS FDIR requirement evolution

- Earlier ESA projects always expressed strict design implementation requirements for FDIR and Safe Mode, e.g.

> *R-AOCS-0180 The Emergency and Safe Mode [ESM]* ***shall use Actuators and Sensors different*** *from those used in nominal Operational Mode*

- Recent ESA projects tend to be more open
- The Standard “Satellite AOCS requirements” (ECSS-E-ST-60-30C) will not impose a strict upfront architectural design:

> *5.1.2.2 Hardware and software redundancy scheme*
>
> *a. The AOCS shall justify the hardware redundancy implemented against failure tolerance requirements and reliability requirements.*
>
> *b. The AOCS* ***shall justify the design*** *of the safe mode against the risk of common design error and common failure with the modes used for the nominal mission.*

Chapter 5.1 comment
FDIR and ECSS [from ADCSS 2011 workshop]

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- The area of "system FDIR" is supported by many ECSS Standards
  - ECSS-Q-ST-30C Dependability (FMECA/FMEA/FTA)
  - ECSS-Q-ST-30-02C FMEA/FMECA
  - ECSS-Q-ST-40C Safety
  - ECSS-Q-ST-40-09C Availability
  - ECSS-Q-ST-40-09C Hazard Analysis
  - ECSS-Q-ST-40-12C FTA
  - ECSS-E-ST-70-11C Space Segment Operability
  - ECSS-Q-ST-80C SW Product Assurance (SW Criticality)
- But at system level
  - there is currently no specific ECSS for verification and validation of "system FDIR"
    - at which level should some FDIR aspect be included for verification purposes ?
  - "System FDIR" engineering lifecycle is unclear, so is its relation to the project lifecycle
    - what is reviewed FDIR-wise at project milestones ?
    - what are measurable criteria for FDIR maturity? etc. etc.
  - FDIR definitions need to be revised for completeness and consistency

- However, now ECSS-E-ST-60-30C **does** provide AOCS-related FDIR requirements for inclusion in a system-level SRD

Chapter 5.2 contents
Operational requirements

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- Requirements for ground TC
  - Requirements for parameters update
  - Orbit control manoeuvres
  - Orbit determination
  - Attitude guidance
- Requirements for TM
  - AOCS needs ground monitoring
  - Housekeeping TM
  - Diagnostic and event TM
- Requirements for autonomous operations
  - AOCS autonomy
  - Safe mode
- Requirement for calibration operations

Chapter 5.2 example
Operational requirements

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5.2.1.4 Attitude guidance

a. *The AOCS shall identify constraints for the generation of the attitude profiles by the ground.*

> *NOTE: These constraints include maximum angular velocity, maximum angular acceleration and continuity between profiles.*

b. *The AOCS shall implement the set of attitude guidance profiles to be commanded by ground TC.*

> *NOTE: Attitude profiles include bias with respect to the reference attitude and varying attitude profiles, defined through a polynomial law versus time or a harmonic law.*

Chapter 5.3 contents
Performance requirements

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- Flight domain
- Normal mode
  - Overview
  - Absolute attitude pointing (APE class)
  - On-board absolute attitude knowledge (AKE class)
  - A posteriori absolute attitude knowledge (AKE class)
  - Attitude pointing stability (APE class)
  - Relative attitude pointing (RPE class)
  - A posteriori relative pointing knowledge (RKE class)
- Orbit knowledge and orbit control
  - Orbit knowledge (AKE class)
  - Orbit control
- Attitude agility
- Performances outages
- Acquisition and safe mode
- Performance budgets

5.3.3.2 Orbit Control

a. *The AOCS shall perform the Delta-V commanded by the ground for the orbit control with an accuracy better than:*

1. *TBS % of the Delta-V magnitude along the commanded direction,*
2. *TBS % of the Delta-V magnitude on the perpendicular directions (parasitic impulses).*

NOTE 1. This requirement is valid when the delta-V magnitude is commanded from ground and executed onboard with a closed loop control of the magnitude.

NOTE 2. This requirement can not be used in the following cases:

- *Case of an autonomous orbit control, where performances are described with respect to the reference orbit.*
- *Case of Delta-V computed onboard by a position guidance function.*
- *Case of a thrust activation profile commanded from ground, with the Delta-V managed on ground.*

NOTE 3. The requirement can be complemented by an absolute threshold (in metres per second) for low Delta-Vs.

NOTE 4. A confidence level can be associated to these requirements.

Chapter 5.3 lesson learnt
ESA project issue at FAR

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- ISSUE
  - Missing requirement 5.3.3.2a.2 on parasitic Delta-V
- STATUS
  - Late discovery by ESOC reviewers: missing parasitic Delta-V specification detrimental to operations, for nominal manoeuvre planning and also for safe mode
  - Correction would incur additional delays and costs
    - The question was how to demonstrate compliance. Monte Carlo would need a large number of simulations (>>100), unless a worst case justification could be accepted together with a limited number of test runs
- WORK AROUND SOLUTIONS
  - ESOC to urgently consolidate acceptable requirements on parasitic Delta-V
  - ESA and Contractor to formally agree on this
  - Contractor to demonstrate full AOCS compliance to parasitic Delta-V requirements by analysis complemented by a simulation campaign
  - Contractor to produce a TN on parasitic Delta-V, incorporated in the requirements baseline, properly verified and included in all AOCS documentation

Chapter 5.4 contents
Verification requirements

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Chapter 5.4 scope Verification

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inside scope	outside scope
AOCS verification at functional chain level. The verification steps used in programmes NB As there are too many situations, a standard process is not described in order to allow flexibility. Requirements are specified to be included in a company's own V&V process.	A complete list of testing facilities (see E-TM-10-21 for some)
Verification process of the software specification w.r.t. AOCS functional needs (see Clauses 5.4.3b & 5.4.5)	Verification process of software conformance w.r.t. its specifications (see E-ST-40C)
Verification process of the AOCS functional chain, taking into account real behaviour of equipment issued from the equipment verification process (see Clause 5.4.5)	Verification process of the conformance of equipment (AOCS units) w.r.t. their specifications (see E-ST-10-03C; E-ST-20C; E-ST-50-12C; and the ECSS-Q series)
Polarity testing (see Clause 5.4.6b)	Satellite integration verification (see E-ST-10-03C)
	Environmental testing (see E-ST-10-03C)

Chapter 5.4 example
Verification requirements

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5.4.3 Verification facilities

a. The AOCS functional simulator shall be representative of:

1. all the AOCS functions and states;
2. the algorithms specified for the on-board software, or directly implemented in hardware;
3. the AOCS equipment behaviour and performances;
4. the satellite dynamics and kinematics;
5. the space environment related to the dynamic evolution of the attitude and possibly the position, depending on the mission.

Note 1. This representativity includes an adequate modelling of the delays, jitters, and sampling rates of the AOCS loop.

Note 2. It is recommended to include in the simulator the representativity of the failure detection algorithms or function.

Note 3. A good way to ensure the representativity of the algorithms is to reuse the source code of the flight AOCS application software.

Note 4. The representativity of the position evolution (6 degree of freedom simulator) is useful for instance for Drag Free missions.

b. The simulation models of the AOCS sensors and actuators implemented respectively in the AOCS functional simulator and in the Avionics test bench shall be validated with respect to the real hardware behaviour.

Note A good way is to perform a correlation between sensors and actuators simulation models and hardware test results.

c. The simulation models used in the AOCS functional simulator or the avionics test bench for dynamics effects shall be justified.

Note Dynamic effects can arise from thermal snap, liquid sloshing and flexible modes of appendages.

d. The avionics test bench shall include a hardware model of the on-board computer functionally representative of the flight model.

Note Consequently, the numerical precision of the onboard computer is represented and is compared to analysis or simulations performed during the AOCS development process.

e. The avionics test bench shall embed the real flight software.

f. It shall be possible to introduce a simulation of the forces and torques generated by the AOCS actuators in the dynamics model of the avionics test bench.

g. The avionics test bench shall be representative of real hardware interfaces.

h. The avionics test bench shall be representative of the real time behaviour.

NOTE: The requirements on the avionics test bench define the features necessary on this bench when it is used for the hardware/software verification. Other solutions are however possible as mentioned in the clause 5.4.5.

Chapter 5.5 overview
AOCS Documentation

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- Typical AOCS documentation versus development phase
- Formalised normative DRDs (document requirements definition) provided in annexes

Subject	Availability				Comments
	Phase A (end)	PDR	CDR	QR	
AOCS Technical Specification	✓	✓			Can be part of Platform level specification DRD in ECSS-E-ST-10-06 Annex A
Design Definition File for AOCS	Preliminary	✓	✓	✓	DRD in Annex A
AOCS Algorithms and Functional Description		✓(part)	✓		DRD in Annex C
AOCS Hardware Units Specifications		✓			DRD in ECSS-E-ST-10-06 Annex A
Design Justification File for AOCS		Preliminary	✓	✓	DRD in Annex B
Verification Plan for AOCS		Preliminary	✓		DRD in Annex D
AOCS Simulation Plans			✓		
AOCS Test Plans			✓		DRD in ECSS-E-ST-10-03 Annex A for satellite tests
AOCS Simulation Results Reports			✓	✓	
AOCS Test Reports			✓ (part)	✓	DRD in ECSS-E-ST-10-02 Annex C
AOCS Budgets	Preliminary	✓	✓	✓	Refer to ECSS-E-ST-60-10 for performance budgets
AOCS Software Parameters			✓	✓	
User Manual (AOCS part)			Preliminary	✓	DRD in Annex E

Annexes A-E normative DRDs

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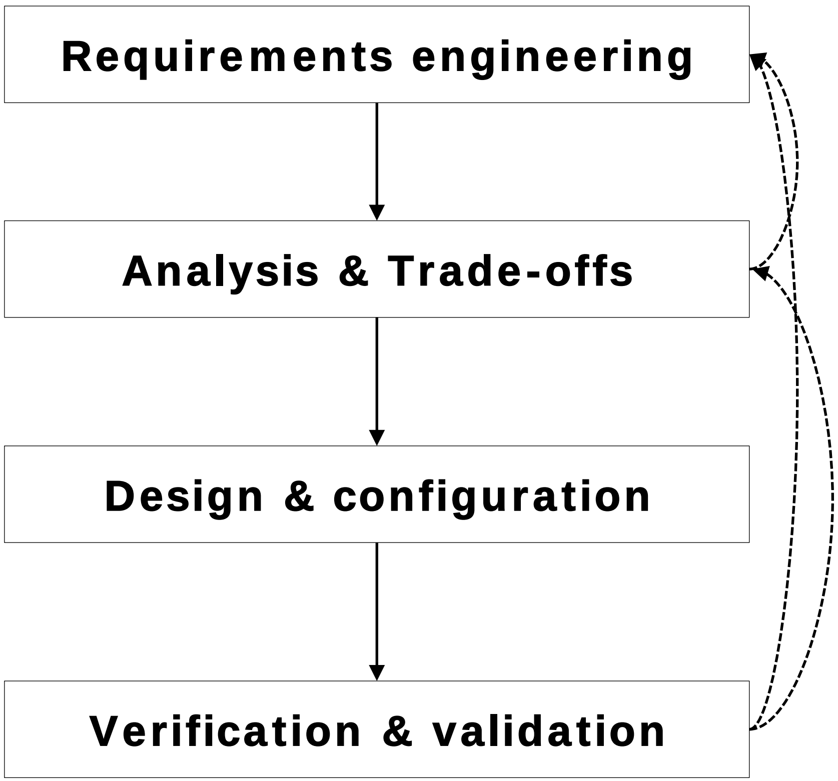
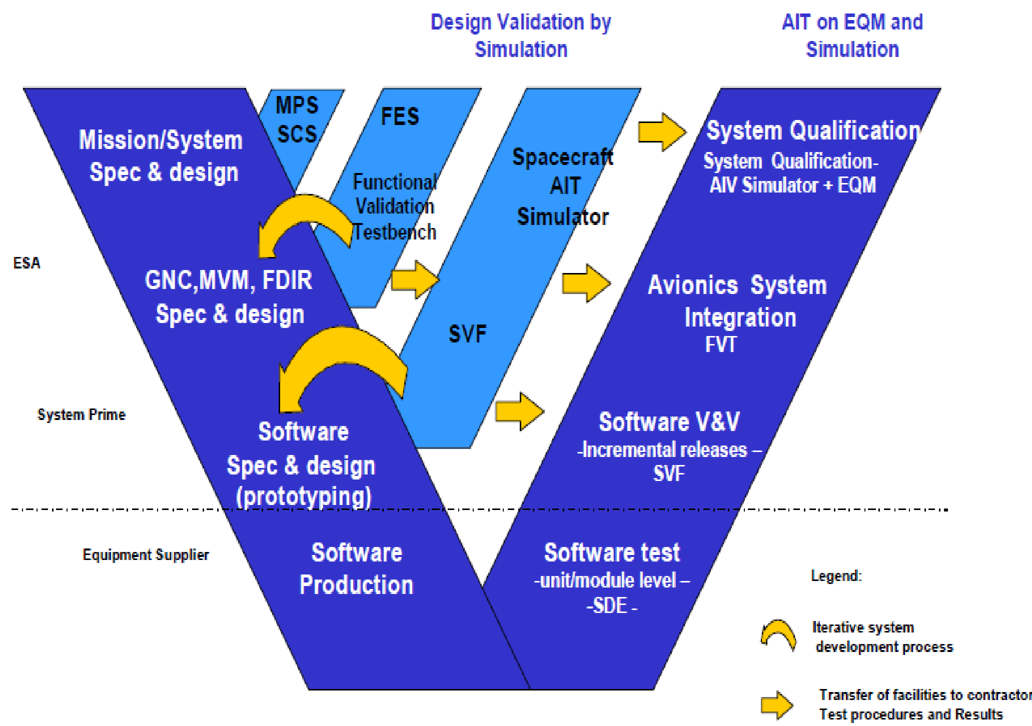
annex		DRD
A	normative	Design Definition File (DDF) for AOCS
B	normative	Design Justification File (DJF) for AOCS
C	normative	AOCS Algorithms and Functional Description
D	normative	Verification Plan (VP) for AOCS
E	normative	User Manual (UM) for AOCS

Process for AOCS design



Example of System Engineering Lifecycle



Typical AOCS documentation

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Subject	Availability			
	Phase A (end)	PDR	CDR	QR
AOCS Technical Specification	✓	✓		
Design Definition File for AOCS	Preliminary	✓	✓	✓
AOCS Algorithms and Software Functional Description		✓	✓	
AOCS Hardware Units Specifications		✓		
Design Justification File for AOCS		Preliminary	✓	✓
Verification Plan for AOCS		Preliminary	✓	
AOCS Simulation Plan			✓	
AOCS Test Plans (ATB & satellite)			✓	
AOCS Simulation Results			✓	✓
AOCS Test Reports			✓ (part)	✓
AOCS Budgets	Preliminary	✓	✓	✓
AOCS Software Parameters			✓	✓
User Manual (AOCS part)			Preliminary	✓

- Formalised normative DRDs (document requirements definition)
- The concerned documents can be issued either at AOCS level, or at satellite level.

Requirements engineering

Standardization training program E60 discipline: Control

Subject	Availability			
	Phase A (end)	PDR	CDR	QR
AOCS Technical Specification	✓	✓		
Design Definition File for AOCS	Preliminary	✓	✓	✓
AOCS Algorithms and Software Functional Description		✓	✓	
AOCS Hardware Units Specifications		✓		
Design Justification File for AOCS		Preliminary	✓	✓
Verification Plan for AOCS		Preliminary	✓	
AOCS Simulation Plan			✓	
AOCS Test Plans (ATB & satellite)			✓	
AOCS Simulation Results			✓	✓
AOCS Test Reports			✓ (part)	✓
AOCS Budgets	Preliminary	✓	✓	✓
AOCS Software Parameters			✓	✓
User Manual (AOCS part)			Preliminary	✓

- Requirements engineering
- Design & configuration
- Analysis & Trade-offs
- Verification & Validation

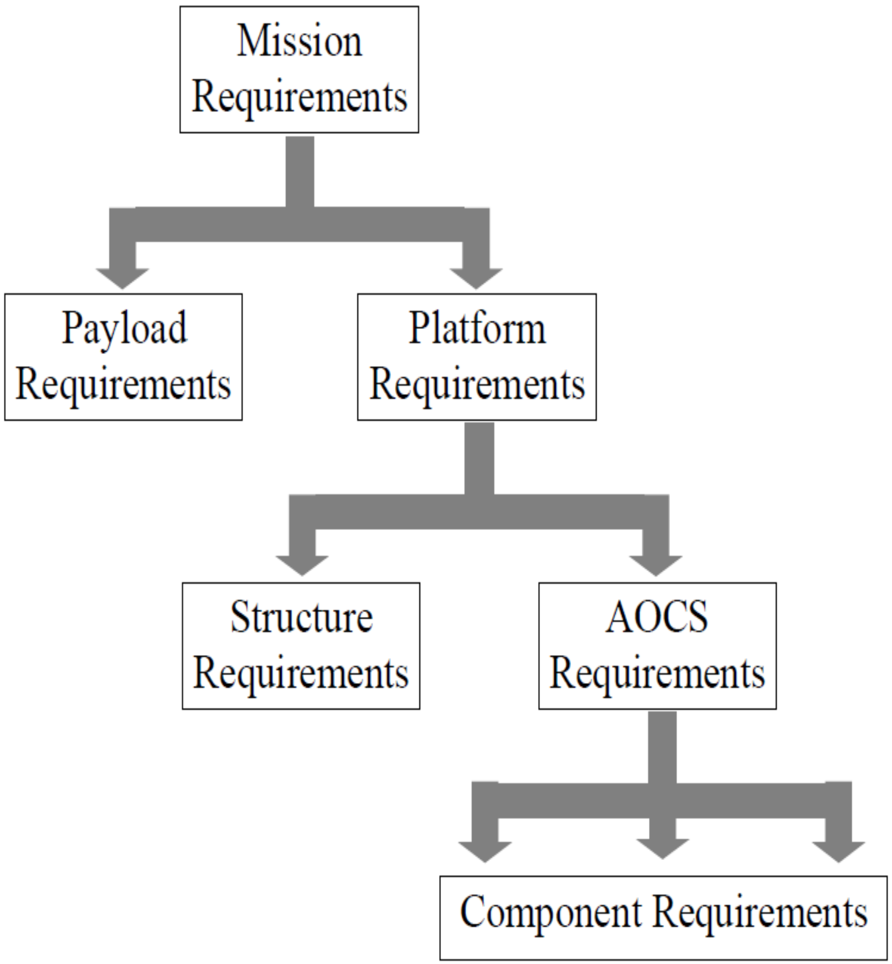
AOCS Technical Specification

The objective of the AOCS Technical Specification is to establish the design, performance, interface and verification requirements of the AOCS subsystem.

Expected content:

- Functional and FDIR requirements
  - high level functionality
  - system level constraints related to the mission and payload
- Operational requirements
- Performance requirements
- Verification requirements

Requirements capture & dissemination



- **Requirements capture**: preliminary then detailed formulation of system requirements to be met by the payload in order to perform the mission successfully.
- **Requirements engineering**: translate mission and system objectives into preliminary control performance needs.
- **Requirements breakdown:** breakdown of performance requirements to subassemblies and equipment (sensors, actuators, and controller HW)

Design & configuration

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Subject	Availability			
	Phase A (end)	PDR	CDR	QR
AOCS Technical Specification	✓	✓		
Design Definition File for AOCS	Preliminary	✓	✓	✓
AOCS Algorithms and Software Functional Description		✓	✓	
AOCS Hardware Units Specifications		✓		
Design Justification File for AOCS		Preliminary	✓	✓
Verification Plan for AOCS		Preliminary	✓	
AOCS Simulation Plan			✓	
AOCS Test Plans (ATB & satellite)			✓	
AOCS Simulation Results			✓	✓
AOCS Test Reports			✓ (part)	✓
AOCS Budgets	Preliminary	✓	✓	✓
AOCS Software Parameters			✓	✓
User Manual (AOCS part)			Preliminary	✓

- Requirements engineering
- Design & configuration
- Analysis & Trade-offs
- Verification & Validation

Design Definition File

The objective of the design definition file (DDF) for AOCS is to establish the technical definition of the AOCS (in terms of description of algorithms and hardware) that complies with its technical requirements specification.

Expected content:

- Reference frames and conventions
- Interfaces (between AOCS and ground system, payload…)
- Hardware architecture (sensors and actuators)
- Mode logic (purpose of the mode, HW used in the mode…)
- Summary of AOCS Budgets
- Summary of operational constraints (e.g. calibration needs, timing constraints…)

Analysis & Trade-offs

Standardization training program E60 discipline: Control

Subject	Availability			
	Phase A (end)	PDR	CDR	QR
AOCS Technical Specification	✓	✓		
Design Definition File for AOCS	Preliminary	✓	✓	✓
AOCS Algorithms and Software Functional Description		✓	✓	
AOCS Hardware Units Specifications		✓		
Design Justification File for AOCS		Preliminary	✓	✓
Verification Plan for AOCS		Preliminary	✓	
AOCS Simulation Plan			✓	
AOCS Test Plans (ATB & satellite)			✓	
AOCS Simulation Results			✓	✓
AOCS Test Reports			✓ (part)	✓
AOCS Budgets	Preliminary	✓	✓	✓
AOCS Software Parameters			✓	✓
User Manual (AOCS part)			Preliminary	✓

- Requirements engineering
- Design & configuration
- **Analysis & Trade-offs**
- Verification & Validation

Design Justification File

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The objective of the DJF is to present the rationale for the selection of the design solution, and to demonstrate that the design meets the baseline requirements.

Expected content:

- Summary of trade-off and main design choices
- Justification of the selected AOCS hardware, processing and algorithms
- AOCS performance justification, including failure modes

Verification & Validation

Standardization training program E60 discipline: Control

Subject	Availability			
	Phase A (end)	PDR	CDR	QR
AOCS Technical Specification	✓	✓		
Design Definition File for AOCS	Preliminary	✓	✓	✓
AOCS Algorithms and Software Functional Description		✓	✓	
AOCS Hardware Units Specifications		✓		
Design Justification File for AOCS		Preliminary	✓	✓
Verification Plan for AOCS		Preliminary	✓	
AOCS Simulation Plan			✓	
AOCS Test Plans (ATB & satellite)			✓	
AOCS Simulation Results			✓	✓
AOCS Test Reports			✓ (part)	✓
AOCS Budgets	Preliminary	✓	✓	✓
AOCS Software Parameters			✓	✓
User Manual (AOCS part)			Preliminary	✓

- Requirements engineering
- Design & configuration
- Analysis & Trade-offs
- **Verification & Validation**

Verification Plan

Standardization training program E60 discipline: Control

The purpose of this document for the AOCS is to describe the overall strategy of the AOCS verification process in order to prove that the implemented AOCS meets all its objectives and its related requirements.

Expected content:

- Description of the verification philosophy
- Description of each verification step, including:
  - coverage provided by each step with regards to AOCS verification objectives
  - Type of verification methods (e.g. analysis, time-domain simulation, tests with hardware)
- Description of verification tools (such as S/W facilities, special tools, simulators, analytical tools)

AOCS Verification and Validation logic

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The AOCS cannot be fully verified in real conditions before flight. The main reason is that the hardware on ground cannot be submitted to the real flight conditions and environment.

During the AOCS verification process, a complete and careful step by step verification logic from numerical models to real hardware is carried out in order to validate the behavior of the AOCS.

Main steps of AOCS verification at different levels:

- Design and performance verification
- Hardware/software verification
- Verification at satellite level
- AOCS-ground interface verification
- In-flight verification

Verification

check/ensure that
the system has been built according to the design:
"check that we built the system right"

Validation

check/ensure that
the system is compliant with the requirements
"check that we built the right system"

AOCS Verification and Validation logic

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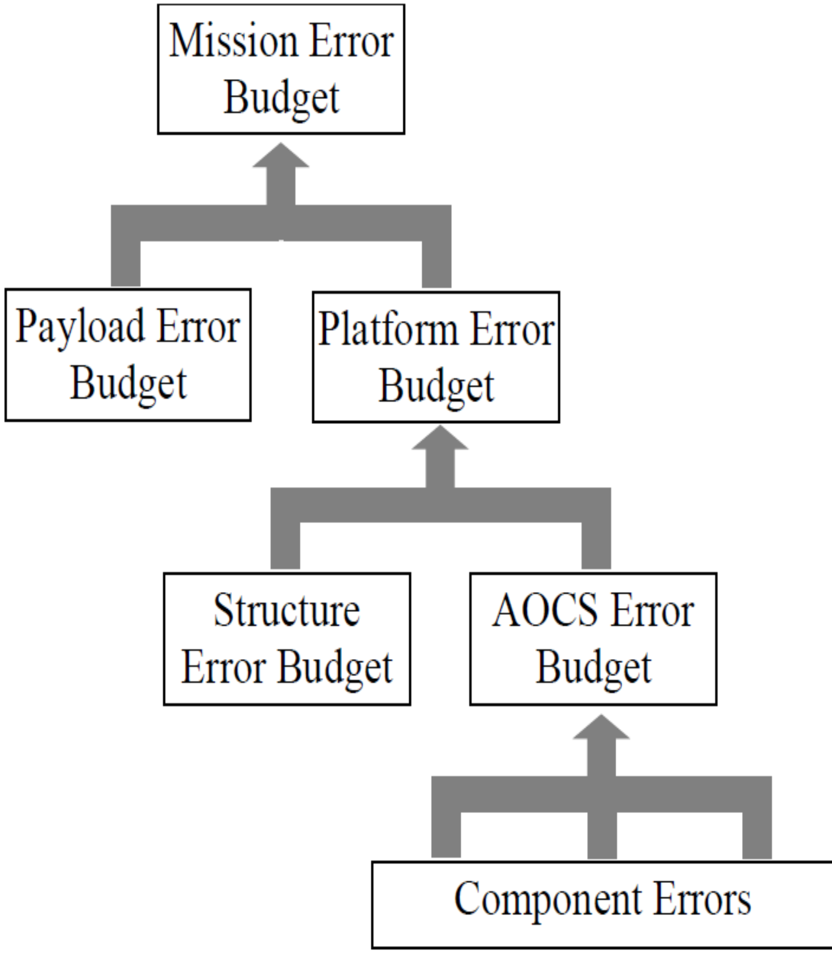

Design and performance verification

- The AOCS design and performance verification shall be performed through theoretical analyses and numerical simulations on the AOCS functional simulator.
- The design and performance verification shall cover all the AOCS modes, functions and mode transitions.
- The selected approach for the analyses and simulations shall be defined and justified (e.g. Monte Carlo method, worst case analysis or sensitivity analysis).

Conclusions

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- The E60-30 standard published in 2013 contains a consistent set of Attitude and Orbit Control System (AOCS) requirements for the development of satellites
  - It includes all subjects related to AOCS design and verification, namely: functions and FDIR, operations, performance, verification and documentation
- In the ITT preparation phase, it provides a robust set of high level AOCS requirements which can be directly implemented with limited tailoring in the ESA MRD/SRD, limiting the risk of ambiguous or missing or design-oriented requirements
- In the implementation phase, it helps ESA project team to ensure that AOCS engineering and verification tasks are
  - correctly specified by the prime with proper flow down to potential subcontractors,
  - and properly executed by the prime and its AOCS subcontractor.
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