Standardization training program
E-60 discipline: Control

Control Engineering Handbook
ECSS-E-HB-60A

The ECSS E60 branch

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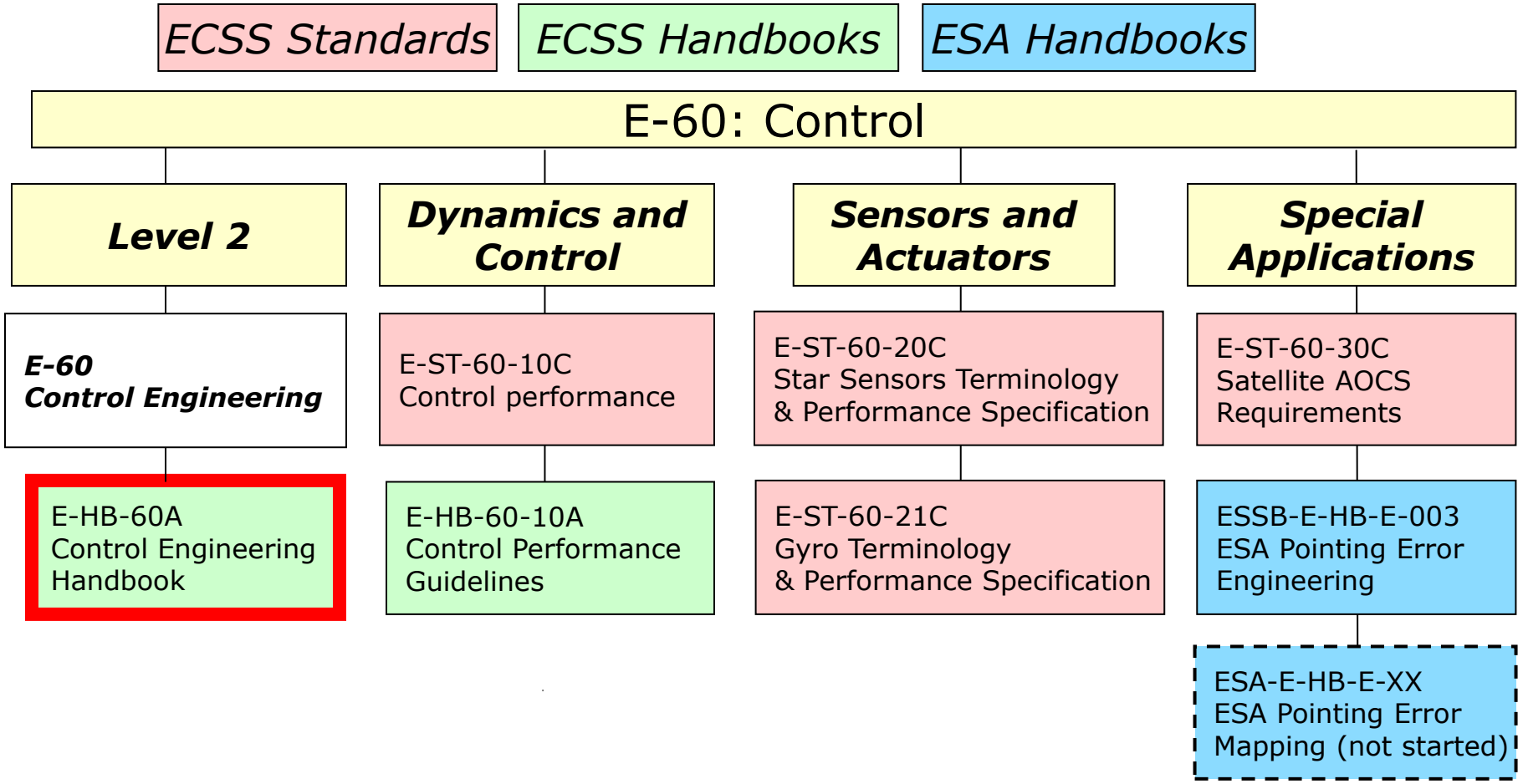

Introduction

- This handbook has been adapted from the first document elaborated by the very first Working Group of the E60 branch
  - The initial document was originally published as the Control Engineering Standard ECSS-E-60A in September 2004
  - ECSS Task Force 2 did not recognize it as a standard since it was addressing the control engineering process rather than requirements and decided to replace it with a handbook
- This Control Engineering Handbook was published in Dec 2010
  - This high level document is quite generic since it addresses all systems involving any kind of control (including e.g. thermal control, but not "ground control")
  - It focuses on the specific issues involved in control engineering and is intended to be used as a structured set of systematic engineering provisions
  - Specialised requirements for attitude control and associated equipment will be found in lower level documents such as the Satellite AOCS Requirements Standard or Star Tracker Standard

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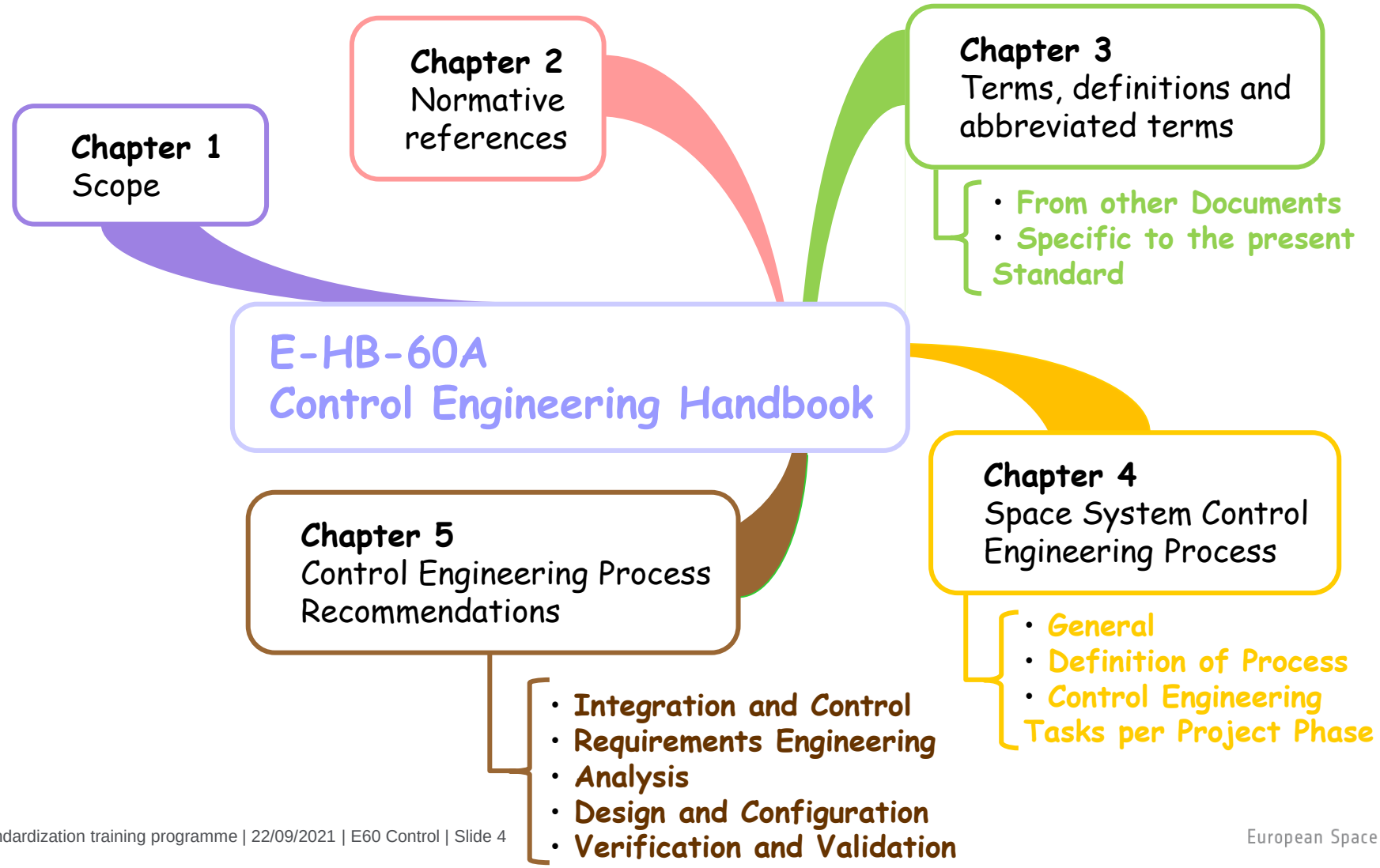

Quick insight

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- Chapter 2 contains the normative references
  - High level ECSS documents: Glossary of Terms, Space Engineering Requirements and Process, Space Project Management
- Chapter 3 provides definitions of control-related terms
  - e.g. actuator, autonomy, control, controllability, estimated state, estimator, guidance, robustness, sensor, simulation model, stability, state, etc.
- Chapter 4 describes the space system control engineering process
  - main engineering activities defined and characterized by the following:
  - inputs, tasks to be performed, outputs (including documents), milestones and relationship to the project phases
- Chapter 5 contains recommendations for the engineering activities
  - a checklist of recommendations for tasks to be performed and the associated expected outputs

Introduction
General Control Structure

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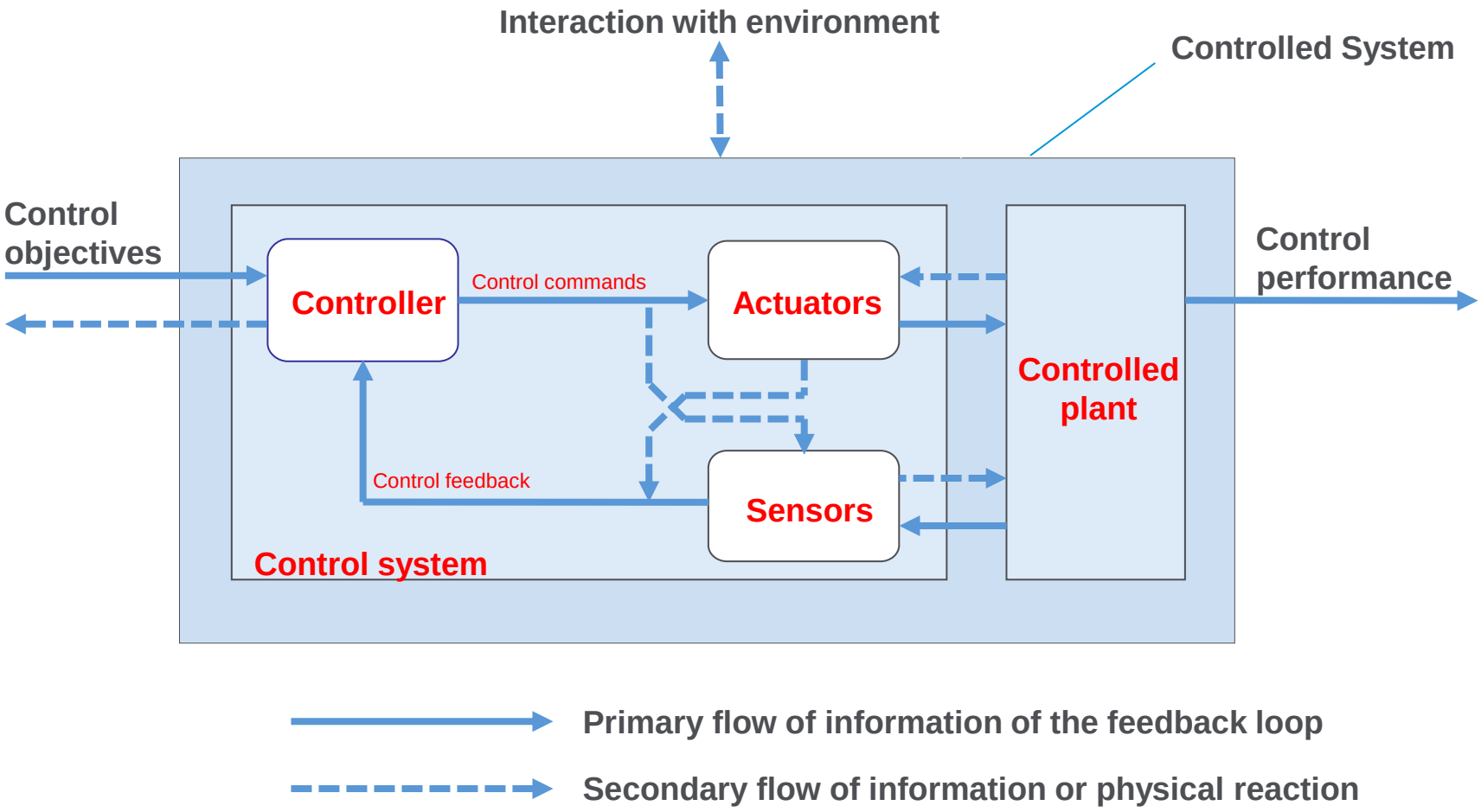


4.1.2 Control Engineering Activities

- From the general control structure introduced previously, control engineering includes, as a minimum:
  - analysis of the mission objectives in order to define the control objectives;
  - requirements analysis and specification
  - analysis and modelling of the controlled plant and its interaction with the environment;
  - analysis, modelling and specification of sensors and actuators (configuration and characteristics) w.r.t. the control requirements;
  - design and configuration of the controller;
  - verification of the control performance;
  - control system related ground operations.

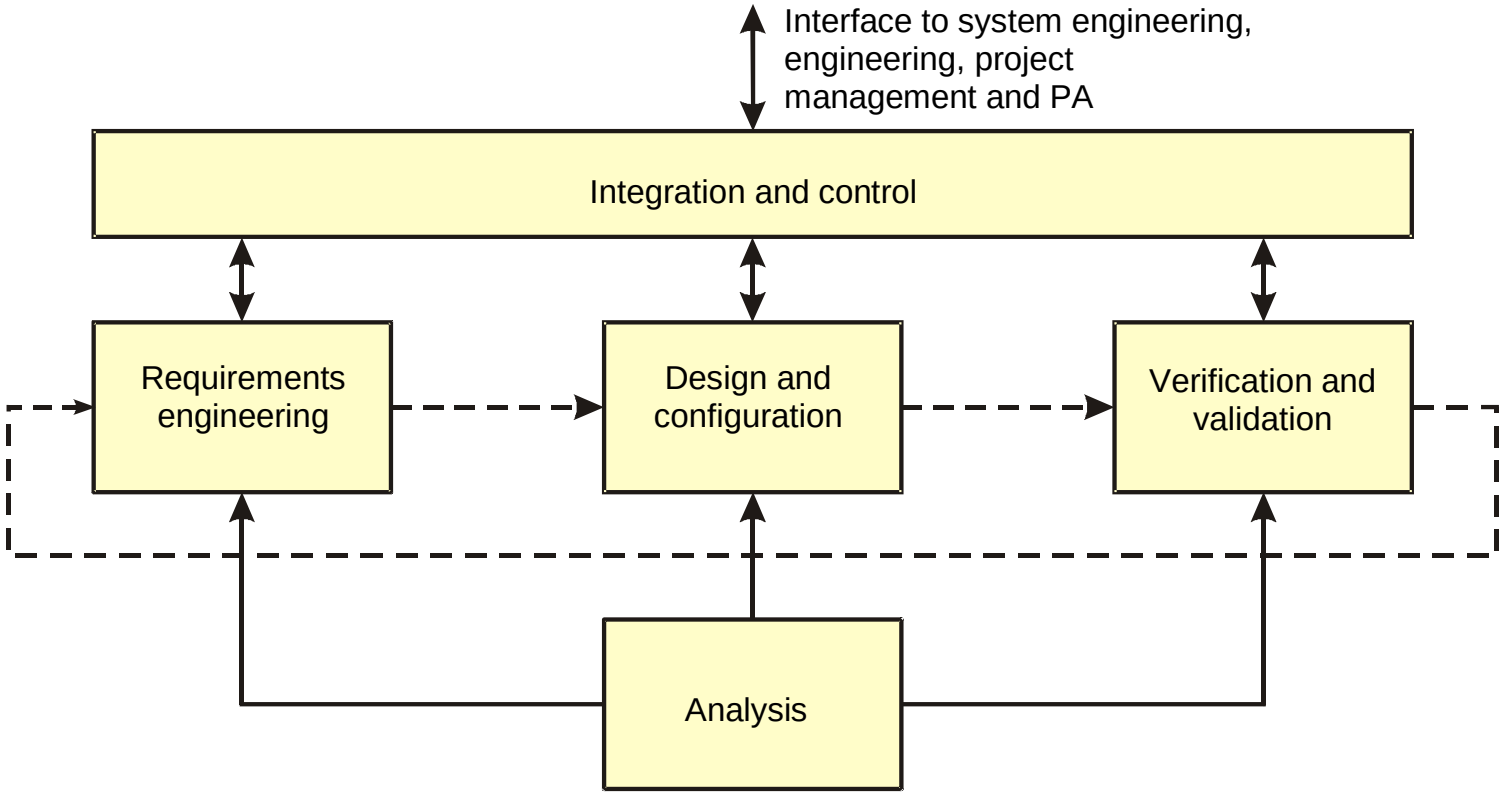
- Consequently control engineering
  - is multidisciplinary
    - cannot be performed without significant insight into at least mechanics, dynamics, the space environment and its effects, digital and analogue electronics, control theory, computer systems and networks, software engineering, and operations;
  - has a strong system aspect
    - significant level of interaction with the system engineering process specified in ECSS-E-ST-10.

4.2 Definition of the Control Engineering Process

- As part of the system engineering process defined in ECSS-E-ST-10, it can similarly be decomposed into the same engineering activities:
  - Integration and (project) Control
    - integration of the various control related disciplines throughout all project phases towards the total definition and realization of the controlled system (management, planning, database, interface control, risk control, change and non-conformance control,…)
  - Requirements Engineering
    - proper interpretation of the mission and system requirements, coherent and appropriate derivation of control requirements, definition of lower component or equipment level requirements and continuous supervision of their status and traceability
  - Design and Configuration
    - derivation of a physical control architecture and the controller design capable of meeting the control requirements (supported by proper analyses and trade-offs)
    - derivation of all the control budgets with appropriate budget methodology and margin policy
  - Analysis
    - performed at all levels and in all domains for the purpose of resolving control related functional and performance requirements, evaluating control design alternatives, consolidating and verifying control performances and complementing tests
  - Verification and Validation
    - demonstrates, through a dedicated process, that the controlled system meets its control objectives and requirements

4.2 Interaction between Control Engineering activities

- At various phases of the system development, the control engineering activities are conducted in parallel to support one another in the proper development of the control system and of its components.



- Iterative between system engineering and lower assembly or equipment level engineering
- Progressive from preliminary design to verification and inflight validation.

4.3 Control Engineering Tasks
Integration and Control

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Integration and (project) control	Main deliverables

- Organization and planning of control engineering activities
- Assessment of control technology (development needs?) and cost
- Risk management
- Control engineering capability assessment and resource management
- Engineering support to control components procurement
- Management of interfaces (data exchanges), with other
  ○ disciplines, e.g. mechanical engineering and software engineering
  ○ activities, e.g. procurement and quality assurance
- Contribution to system engineering database and user/operations manual
- Contribution to human factors engineering when humans in the loop
- Definition of budget and margin philosophy for control
- Support to change management involving non-conformance control
	Phase 0/A: inputs to
	- System Engineering Plan
	- cost and schedule estimates
	- Technology Plan
	
	Phase B: inputs to
	- System Engineering Plan
	- cost and schedule estimates
	
	Phase C/D: inputs to
	- system database
	- operations handbook
	- cost estimates for Phase E/F
	
	Phase E/F: updates to
	- disposal plan

4.3 Control Engineering Tasks
Requirements Engineering

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Requirements engineering	Main deliverables
- Generation of (system) control requirements from system and mission requirements - Contribution to system requirements to meet control requirements (bottom up) - Allocation of control requirements to subassemblies or equipment (flow-down) ○ sensors, actuators and controller H/W - Definition of control S/W requirements - Definition of control interface requirements between control components - Definition of control operations requirements - Definition of control verification requirements	**Phase 0/A**: inputs to - Project Requirements Documentation **Phase B**: inputs to - System and S/S technical specifications - lower level technical specifications - Interface Control Documents **Phase C/D**: updated inputs to - System and S/S technical specifications - lower level technical specifications - Interface Control Documents **Phase E/F**: inputs to - new control related operational requirements

4.3 Control Engineering Tasks
Design and Configuration

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Design and configuration	Main deliverables

- Definition of functional control architecture
  ○ including functional interfaces
- Definition of operational control architecture
  ○ including modes
- Definition of physical control architecture
  ○ including H/W, S/W and human operation
- Control design trade-offs
- Contribution to selection and procurement of control components
- Design of control concepts and algorithms
- Generation of control budgets
- Contribution to system configuration management
	Phase 0/A:
	- Preliminary control system design and analysis report
	Phase B:
	- Control system design report (incl. design justification) (DDF, DJF)
	- Preliminary control algorithms specification
	- Preliminary control system budgets
	Phase C/D:
	- Final control system design report (DDF, DJF)
	- Final control algorithms specification
	- Final control system budgets
	Phase E/F:
	- Controller design updates

4.3 Control Engineering Tasks
Analysis

Analysis	Main deliverables

- Selection of adequate analysis tools and methodologies
- Requirements evaluation and budgets breakdown
- Disturbances evaluation
- Numerical trade studies
  ○ to support the definition of the control architecture with respect to requirements
  ○ considering programme imposed constraints such as cost, schedule and risk
- Numerical analysis to support the control design
- Performance verification analysis
  ○ including simulation
- Numerical analysis to support inflight evaluation
	Phase 0/A:
	- Control system analysis
	
	Phase B:
	- Controlled system analysis report (including simulation models description)
	
	Phase C/D:
	- Controlled system analysis report
	- Strategies for the inflight calibration and performance analysis
	
	Phase E/F:
	- Inputs to controlled system operational performance report
	- Inputs to payload data evaluation

4.3 Control Engineering Tasks
Verification and validation

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Verification and validation	Main deliverables

- Definition of control verification and validation strategy
  ○ including specification of requirements for test environments
- Preliminary verification of performance
  ○ by analysis or prototyping
- Final functional and performance verification
  ○ by analysis
- Final verification and validation of controlled system
  ○ H/W, S/W and human operation
  ○ by hardware in the loop tests
- Inflight validation of controlled system behaviour
	Phase 0/A: inputs to
	- development and verification planning

	Phase B: - Controlled system verification plan - Preliminary controlled system verification report
	Phase C/D: - Controlled system verification report - Inputs to inflight verification plan
	Phase E/F: inputs to - inflight acceptance report - periodic mission reports