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Space systems — General requirements for control engineering

Systèmes spatiaux — Exigences générales relatives aux techniques de régulation

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Foreword

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

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Introduction

The development of control systems applied to space systems requires cooperation among multi-disciplinary technology fields. A control system is often comprised of a large system integration of these technology fields. The development also requires cooperation with higher-level systems and the systems engineering method.

The purpose of this document is to provide general requirements for the entire life cycle in control systems development including the systems engineering method required for developing control systems applicable to space systems. Control engineering refers to systematic activities using systems engineering methods to realize the control system. The concepts, methods and models of system engineering are also applicable to control engineering. This document focuses on the special requirements of control engineering.

The development of a control system involves important aspects of system engineering, electrical and electronic engineering, mechanical engineering, software engineering, communications, ground systems and operations – all of which have their own dedicated standards. This document does not intend to duplicate them.

This document focuses on the specific issues involved in control engineering and is intended to be used as a structured set of systematic engineering provisions, referring to the specific standards and handbooks of the discipline where appropriate. For this and given the very rapid progress of control component technologies and associated “de facto” standards, this document does not go to the level of describing equipment or interfaces. Specific project or program standards are prepared for these purposes.

This document is not intended to replace textbook material on control systems theory or technology; and such material is intentionally avoided. The users of this document are assumed to possess general knowledge of control systems engineering and its applications to space missions.

Space systems — General requirements for control engineering

1 Scope

This document deals with control systems developed as part of a space project. It is applicable to all the elements of a space control system, including the space segment, the ground segment and the launch service segment.

This document establishes general principles for all technical activities of space control engineering, including control engineering management, requirements definition, analysis, design, production, verification and validation, operation, maintenance, and disposal. It also provides requirements to progressively refine and manage control system realizations in space systems including multiple control systems.

The requirements of this document can be tailored for each specific space program application.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14300-1, *Space systems — Programme management — Part 1: Structuring of a project*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
activity
set of cohesive *tasks* (3.26) of a *process* (3.21)

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.3]

3.2
actuator
component that performs the moving function of a mechanism

Note 1 to entry: An actuator can be either an electric motor, or any other mechanical (e.g. spring) or electric component or part providing the torque or force for the motion of the mechanism.

[SOURCE: ISO 26871:2020, 3.1.1]

3.3
control
purposeful action on or in a *process* (3.21) to meet specified objectives

Note 1 to entry: Control includes function of the *controller* (3.14) to derive *control commands* (3.4) to match the current or future estimated state with the desired state.

[SOURCE: IEC 60050-351:2013, 351-42-19, modified — The original notes to entry has been replaced by a new note 1 to entry.]

3.4
control command
output of the *controller* (3.14) to the *actuators* (3.2) and the *sensors* (3.24)

Note 1 to entry: This definition is applicable in case of sensors with command interfaces.

3.5
control component
element of the *control system* (3.12) which is used in part or in total to achieve the *control objectives* (3.9)

3.6
control engineering
systematic *activities* (3.1) using systems engineering methods to realize the *control system* (3.12)

3.7
control function
group of related *control* (3.3) actions (or *activities* (3.1)) contributing to achieving some of the *control objectives* (3.9)

Note 1 to entry: A control function describes what the *controller* (3.14) does, usually by specifying the necessary inputs, boundary conditions and expected outputs.

3.8
control mode
temporary operational configuration of *control systems* (3.12) implemented through a unique set of *sensors* (3.24), *actuators* (3.2) and *controller* (3.14) algorithms acting upon a given *controlled plant* (3.11) configuration

3.9
control objective
goal that the *controlled system* (3.13) is supposed to achieve

Note 1 to entry: Control objectives are issued as requests to the *controller* (3.14), to give the *controlled plant* (3.11) a specified *control performance* (3.10) despite the disturbing influences of the environment. Depending on the complexity of the control problem, control objectives can range from very low-level commands to high-level mission goals.

3.10
control performance
quantified capabilities of a *controlled system* (3.13)

Note 1 to entry: The control performance is usually the quantified output of the *controlled plant* (3.11).

Note 2 to entry: The control performance is shaped by the *controller* (3.14) through *sensors* (3.24) and *actuators* (3.2).

3.11
controlled plant
plant
physical system, or one of its parts, which is the target of the control problem

Note 1 to entry: The control problem is to modify and shape the intrinsic behaviour of the controlled plant such that it yields the *control performance* (3.10) despite its (uncontrolled other) interactions with its environment.

3.12
control system
part of a *controlled system* (3.13) which is designed to give the *controlled plant* (3.11) the specified *control objectives* (3.9)

Note 1 to entry: This includes all relevant functions of *controllers* (3.14), *sensors* (3.24) and *actuators* (3.2).

3.13
controlled system
control (3.3) relevant part of a system to achieve the specified *control objectives* (3.9)

Note 1 to entry: This includes the *control system* (3.12) and the *controlled plant* (3.11).

3.14
controller
control component (3.5) designed to give the *controlled plant* (3.11) a specified *control performance* (3.10)

Note 1 to entry: The controller interacts with the controlled plant through *sensors* (3.24) and *actuators* (3.2). In its most general form, a controller can include hardware, software, and human operations. Its implementation can be distributed over the space segment and the ground segment.

3.15
dependability
<of an item> ability to perform as and when required

Note 1 to entry: Its main components are *reliability* (3.22), availability and *maintainability* (3.17).

Note 2 to entry: The extent to which the fulfilment of a required function can be justifiably trusted.

Note 3 to entry: Dependability shall be considered in conjunction with *safety* (3.23).

Note 4 to entry: Dependability is used as a collective term for the time-related quality characteristics of an item.

[SOURCE: ISO 10795:2019, 3.80]

3.16
guidance
function of the *controller* (3.14) to define the current or future desired state

Note 1 to entry: This term is used as in guidance and *navigation* (3.18) *control system* (3.12) (GNC).

Note 2 to entry: GNC and attitude and orbit control systems (AOCS) or are often decomposed as two separate subsystems.

3.17
maintainability
<of an item> ability to be retained in, or restored to a state in which it can perform as required, under given conditions of use and maintenance

Note 1 to entry: Given conditions of use may include storage.

Note 2 to entry: Given conditions of maintenance include the procedures and resources for use.

Note 3 to entry: Maintainability may be quantified using such measures as mean time to restoration, or the probability of restoration within a specified period of time.

[SOURCE: ISO 10795:2019, 3.144]

3.18
navigation
function of the *controller* (3.14) to determine the current or future estimated state from the measured state

Note 1 to entry: This term is used as in *guidance* (3.16) and navigation *control system* (3.12) (GNC).

3.19
operability
feature of the spacecraft itself that enables a specified ground segment to operate the space segment during the complete mission lifetime of the spacecraft

[SOURCE: ISO 14950:2004, 3.1.7, modified — Note 1 to entry has been removed.]

3.20
pointing control
function of determining the direction of the *controlled plant* (3.11), turning toward a target, and remaining fixed on that target

3.21
process
set of interrelated or interacting *activities* (3.1) that use inputs to deliver an intended result

[SOURCE: ISO 9000:2015, 3.4.1, modified — Notes to entry have been removed.]

3.22
reliability
ability of an item to perform a required function under given conditions for a given time interval

[SOURCE: ISO 10795:2019, 3.198, modified — Notes to entry have been removed.]

3.23
safety
state where an acceptable level of risk is not exceeded

Note 1 to entry: Risk relates to:

— fatality,

— injury or occupational illness,

— damage to launcher hardware or launch site facilities,

— damage to an element of an interfacing crewed flight system,

— the main functions of a flight system itself,

— pollution of the environment, atmosphere or outer space, and

— damage to public or private property.

[SOURCE: ISO 10795:2019, 3.210, modified — "manned" has been changed to "crewed".]

3.24
sensor
device that measures states of the *controlled plant* (3.11) and provides them as feedback inputs to the *controller* (3.14)

3.25
simulation
use of a similar or equivalent system to imitate a real system, so that it behaves like or appears to be the real system

[SOURCE: ISO 16781:2021, 3.1.9]

3.26
task
required, recommended, or permissible action, intended to contribute to the achievement of one or more outcomes of a *process* (3.21)

[SOURCE: ISO/IEC/IEEE 15288:2015, 4.1.50]

4 Abbreviated terms

CE	control engineering
EGSE	electrical ground support equipment
FDIR	fault detection, isolation and recovery
H/W	hardware
ICD	interface control document
SE	system engineering
S/W	software
V&V	verification and validation
TM/TC	telemetry-telecommand
TRL	technology readiness levels
TT&C	telemetry, tracking and control

5 Control engineering

5.1 The general control structure

To illustrate and delineate the scope of CE, Figure 1 shows a general control structure.

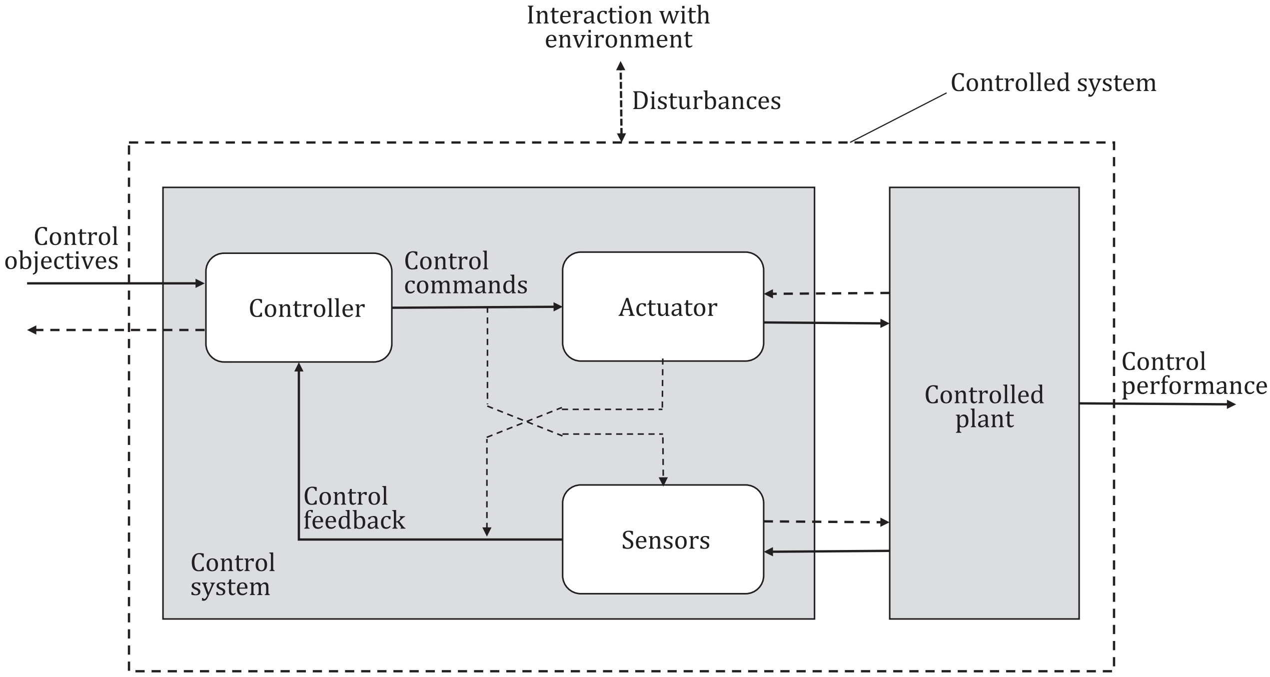

Figure 1 — General control structure

CE, as applied to control system development, in which performance and functional requirements and trade-offs are allocated aspects of top-level systems design, performs in close cooperation with systems engineering as specified in ISO 18676. CE aims at hands-on guidelines for developing the control system, while SE is common for any technical field.

The controlled system can be realized as multiple instantiations of the general control structure. Control engineering activities specified in this document are implemented for developing a control system controlling each controlled target, and those activities are integrated within the controlled system development.

Control system always includes some kind of feedback loop. The intrinsic behaviour and output of the controlled plant do not meet the expectations without being modified and shaped. For space applications, the controlled plant can be:

a) satellite (its attitude, orbit) or a cluster of satellites;

b) spacecraft during re-entry, landing, rendezvous or docking;

c) pointing control system;

d) robot arm system;

e) rover;

f) automation of payload and experiment facility;

g) launch vehicle;

h) any other technical system involving feedback control.

5.2 Project phases

As defined in ISO 14300-1, to minimize the technical, scheduling and economical risk of the project, and to make the progress of the project being controlled, the product life cycle shall be divided into distinct phases which are interlinked.

The phases of a project are listed in Table 1.

Table 1 — Phases of a project

Index	Name
Phase 0 or pre-phase A	Mission analysis phase
Phase A	Feasibility phase
Phase B	Definition phase
Phase C	Development phase
Phase D	Production phase
Phase E	Utilization phase
Phase F	Disposal phase

During phase 0, CE makes an initial definition about the mission of control system development and makes a preliminary assessment of the concepts needed for consideration in the next phase (phase A).

During phase A, CE explores various possible control system schemes, so as to meet the requirements requested by the spacecraft system for the control system, including performance, cost and schedule.

During phase B, CE selects one proposal for development among those proposed at the end of the previous phase (phase A) and specifies the necessary requirements.

During phase C, CE conducts a detailed study of the proposal of the previous phase (phase B), so as to obtain a qualified solution of control system for mass production of deliverable products for operation.

During phase D, CE accomplishes procurements, manufacture and delivery to the user the control system. For scheduling reasons, some procurement may be started prior to phase D.

Phase C and phase D may be merged into one unique C/D phase if the project leads to the manufacturing of a single-flight unit or of a very small quantity of product.

During phase E, the control system is properly operated and maintained, thus it is put into service, used and supported.

During phase F, CE prepares and completes the discontinuance of control system operation, in accordance with other systems of the spacecraft.

The number of phases and their objectives should be defined at the start of the project. They should also be tailored to minimize risks from cost, scheduling and technical problems that can compromise the success of the project.

5.3 Control engineering process

The CE process itself employs many of the same elements as the SE process to achieve precision performance, dynamic responsiveness, default isolation, control ability, and functional and non-functional goals. As such, it can also be broken down into some engineering activities:

a) control engineering management, which integrates the various control related disciplines throughout all project phases to define and realize the controlled system;

b) requirements definition, which includes proper interpretation of the mission, control requirements, and definition of lower-level requirements;

c) analysis, performed at all levels and in all domains for resolving control related functional and performance requirements, evaluating control design alternatives; consolidating and verifying control performances and complementing tests;

d) design, which includes interface design, algorithm design, software design and integrated design;