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**Vesoljska tehnika - Priročnik o nadzornem inženiringu**

Space engineering - Control engineering handbook

Raumfahrttechnik - Handbuch zur Regelungstechnik

Ingénierie spatiale - Manuel d'ingénierie du contrôle



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# Space engineering - Control engineering handbook

Ingénierie spatiale - Manuel d'ingénierie du contrôle

Raumfahrttechnik - Handbuch zur Regelungstechnik

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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# European Foreword

This document (FprCEN/TR 17603-60:2021) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-60.

This Technical report (FprCEN/TR 17603-60:2021) originates from ECSS-E-HB-60A.

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This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.



This document has been developed to cover specifically space systems and has therefore precedence over any TR covering the same scope but with a wider domain of applicability (e.g.: aerospace).



**This document is currently submitted to the CEN CONSULTATION.**

# Introduction

Control engineering, particularly as applied to space systems, is a multi-disciplinary field. The analysis, design and implementation of complex (end to end) control systems include aspects of system engineering, electrical and electronic engineering, mechanical engineering, software engineering, communications, ground systems and operations – all of which have dedicated ECSS engineering standards and handbooks. This Handbook is not intended to duplicate them.

This Handbook 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 reasons such as the very rapid progress of control component technologies and associated "de facto" standards, this Handbook does not go to the level of describing equipment or interfaces.

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

# 1 Scope

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

The handbook covers all aspects of space control engineering including requirements definition, analysis, design, production, verification and validation, transfer, operations and maintenance.

It describes the scope of the space control engineering process and its interfaces with management and product assurance, and explains how they apply to the control engineering process.

# 2 References

| EN References | References in text | Title |
|---|---|---|
| EN 16601-00-01 | ECSS-S-ST-00-01 | ECSS System – Glossary of terms |
| EN 16603-10 | ECSS-E-ST-10 | Space engineering – System engineering general requirements |
| EN 16603-10-04 | ECSS-E-ST-10-04 | Space engineering – Space environment |
| EN 16603-70 | ECSS-E-ST-70 | Space engineering – Ground systems and operations |
| EN 16602-20 | ECSS-Q-ST-20 | Space product assurance – Quality assurance |

# 3 Terms, definitions and abbreviated terms

## 3.1 Terms from other documents

For the purpose of this document, the terms and definitions from ECSS-S-ST-00-01 apply.

## 3.2 Terms specific to the present handbook

### 3.2.1 actuator

technical system or device which converts commands from the **controller** into physical effects on the **controlled plant**



### 3.2.2 autonomy



capability of a system to perform its functions in the absence of certain resources

NOTE The **degree of (control) autonomy** of a space system is defined through the allocation of its overall control functions among **controller** hardware, software, human operations, the space and ground segment, and preparation and execution. A low d**egree of autonomy** is characterized by a few functions performed in the software of the space segment. Conversely, a high d**egree of autonomy** assigns even higher level functions to space software, relieving humans and the ground segment from issuing control commands, at least for the routine operations. The **degree of autonomy** can also be considered to be the amount of machine intelligence installed in the system.

### 3.2.3 control

function of the controller to derive **control commands** to match the current or future **estimated state** with the **desired state**

NOTE This term is used as in GNC.

### 3.2.4 control command

output of the **controller** to the **actuators** and the **sensors**

NOTE This definition is applicable in case of **sensors** with command interfaces.

### 3.2.5 control component

element of the **control system** which is used in part or in total to achieve the **control objectives**

### 3.2.6 control feedback

input to the **controller** from the **sensors** and the **actuators**

NOTE This definition is applicable to **actuators** with status feedback.

### 3.2.7 control function

group of related control actions (or activities) contributing to achieving some of the **control objectives**

NOTE A control function describes what the **controller** does, usually by specifying the necessary inputs, boundary conditions, and expected outputs.

### 3.2.8 control mode

temporary operational configuration of the **control system** implemented through a unique set of **sensors**, **actuators** and **controller** algorithms acting upon a given **plant** configuration

### 3.2.9 control mode transition

passage or change from one **control mode** to another

### 3.2.10 control objective



goal that the **controlled system** is supposed to achieve

NOTE Control objectives are issued as requests to the **controller**, to give the **controlled plant** a specified **control performance** 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.



### 3.2.11 control performance

quantified capabilities of a **controlled system**

NOTE 1 The **control performance** is usually the quantified output of the controlled plant.

NOTE 2 The control performance is shaped by the controller through sensors and actuators.

### 3.2.12 control system

part of a **controlled system** which is designed to give the **controlled plant** the specified **control objectives**

NOTE This includes all relevant functions of **controllers, sensors and actuators**.

### 3.2.13 controllability

property of a given **plant** to be steered from a given **state** to any other given **state**

NOTE This mainly refers to linear systems, even if it applies also to nonlinear ones.

### 3.2.14 controlled plant

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

NOTE 1 The control problem is to modify and shape the intrinsic behaviour of the **plant** such that it yields the **control performance** despite its (uncontrolled other) interactions with its **environment**. For space systems, the **controlled plant** can be a launcher rocket, a satellite, a cluster of satellites, a payload pointing system, a robot arm, a rover, a laboratory facility, or any other technical system.

NOTE 2 The **controlled plant** is also referred as the **plant**.

### 3.2.15 controlled system

control relevant part of a system to achieve the specified **control objectives**

NOTE This includes the **control system** and the controlled **plant**.

### 3.2.16 controller

control component designed to give the **controlled plant** a specified **control performance**

NOTE The **controller** interacts with the **controlled plant** through **sensors** and **actuators**. 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.



### 3.2.17 desired state

set of variables or parameters describing the **controller** internal reference for derivation of the **control commands**



NOTE 1 The desired state is typically determined from the **reference state,** e.g. by generation of a profile.

NOTE 2 The difference between desired state and estimated state is typically used for the derivation of the **control commands** (see 0).

### 3.2.18 disturbance

physical effect affecting the **control performance** that can act onto all components of the **controlled system**

NOTE The source of the disturbance can be internal (if generated inside the **controlled system**) or external (if coming from the **environment**).

### 3.2.19 environment

set of external physical effects that interact with the **controlled system**

NOTE The environment can act as disturbance on the plant but also on sensors, actuators and the controller.

### 3.2.20 estimated state

set of variables or parameters describing the **controller** internal knowledge of the **controlled system** and **environment**

### 3.2.21 estimator

algorithm to determine the current or future **state** (**estimated state**) of a dynamic system from the **measured state**

### 3.2.22 guidance

function of the **controller** to define the current or future **desired state**

NOTE The term is used as in GNC.

### 3.2.23 implementation

actual realization of a specific function in terms of algorithms, hardware, software, or human operations

### 3.2.24 mathematical model

mathematical description of the behaviour of the **plant**, a **control system** component or the **environment**

NOTE This consists of algorithms, formulas and parameters.

### 3.2.25 measured state

set of variables or parameters derived from physical measurements

NOTE This is based on the control feedback of sensors and actuators



### 3.2.26 navigation

function of the **controller** to determine the current or future **estimated state** from the **measured state**

NOTE The term is used as in GNC.



### 3.2.27 observability

property of a given **controlled system** that enables the complete **state** to be determined describing its dynamics

NOTE The observability is normally affected by number and location of sensors.

### 3.2.28 quantization

process by which **control system** variables are converted into discrete finite units

NOTE This usually applies to **sensor** readings and **control commands** towards **actuators**, and in general, when an analogue-digital conversion is used.

### 3.2.29 reference state

set of variables or parameters describing the **control objectives** for a **controlled system**

### 3.2.30 robustness

property of a **controlled system** to achieve the **control objectives** in spite of uncertainties

NOTE 1 The uncertainty can be divided into:

- signal uncertainty, when **disturbances** acting on the **controlled system** are not fully known in advance;