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Space systems — Simulation requirements for control system

Systèmes spatiaux — Exigences de simulation pour le système de contrôle

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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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*.

This second edition cancels and replaces the first edition (ISO 16781:2013), which has been technically revised.

The main changes compared to the previous edition are as follows:

- the Introduction and the Scope have been revised; the scope is re-stated to concentrate on the simulation requirements of the flight control system of space system;
- the definition of “control system” in 3.1.2 has been revised;
- the title of 4.1 and Figure 1 have been revised as “simulation system scheme of control system”;
- some statements have been added in 8.1 to explain the usage requirements of actual hardware devices for prototype phase simulation;
- the previous Annex B has been deleted;
- the Bibliography has been added.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Simulation is an important means to design, analyse and validate the space control system, and it is widely used in each phase of control system development. The objective of simulation is to demonstrate that the proposed or designed system will function as desired; and the simulation allows engineers and technical decision makers to evaluate the feasibility, validity and rationality of the design scheme more accurately.

This document provides space control system engineers, simulation engineers and customers with guidance for using simulation to support their system engineering tasks. This document is intended to help reduce the development time and cost of space control system design and also enhance its quality and reliability. This document focuses on the requirements and recommendations during simulation. It does not prescribe how the requirements are to be met, nor does it specify who the responsible team is for conforming to the requirements.

Space systems — Simulation requirements for control system

1 Scope

This document establishes the requirements for simulation of the space control system, including the objective, architecture and procedure, etc. This document is applicable to four phases of control system development, including conceptual design, detailed design, prototype and integrated system.

The control system referred to in this document is the flight control system for guidance, navigation and control (GNC) of space systems which include launch vehicle, satellite and spaceship, etc. This document establishes a minimum set of requirements for simulation of the flight control system, and provides guidance to engineers on what to simulate in each phase of control system development. The requirements are generic in nature because of their broad applicability to all types of simulations. Implementation details of the requirements are addressed in project-specific standards, requirements, and handbooks, etc.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1.1
accuracy
measure of how close a value is to the “true” value

[SOURCE: ISO 14952-1:2003, 2.1]

3.1.2
control system
system designed to give the controlled plant the specified control objectives, and including relevant functions of controller, sensor and actuator

Note 1 to entry: In this document, the word “controller” is used to designate the flight control computer which manages the flight dynamic behaviour of space system.

3.1.3
emulator
prototype of the flight equipment, which has the identical input/output interfaces as the flight equipment and has similar operating behaviour

3.1.4
fidelity

degree to which a model or *simulation* (3.1.9) reproduces the state and behaviour of a real-world object or the perception of a real-world object, feature, condition, or chosen standard in a measurable or perceivable manner

3.1.5
hardware-in-the-loop simulation
HITL simulation

kind of *simulation* (3.1.9), in which some *simulation models* (3.1.11) of the *control system* (3.1.2) are implemented by real equipment

3.1.6
mathematical simulation

kind of *simulation* (3.1.9), in which all the *simulation models* (3.1.11) of the *control system* (3.1.2) are implemented by software

3.1.7
real-time simulation

kind of *simulation* (3.1.9), in which the time scale of dynamic process in the *simulation model* (3.1.11) strictly equals to that of the real system

3.1.8
reliability

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

Note 1 to entry: It is generally assumed that the item is in a state to perform this required function at the beginning of the time interval.

Note 2 to entry: Generally, reliability performance is quantified using appropriate measures. In some applications these measures include an expression of reliability performance as a probability, which is also called reliability.

[SOURCE: ISO 10795:2019, 3.198]

3.1.9
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

3.1.10
control system simulation

complex progress of building *simulation* (3.1.9) system based on the mathematical model of the *control system* (3.1.2), testing the model, solving the system dynamic equations, imitating dynamic behaviours of the control system, and taking qualitative and quantitative analysis and research about the scheme, structure, parameters, and performance of the control system

3.1.11
simulation model

equivalent model in the *simulation* (3.1.9) system, which is transformed from the mathematical model of the *control system* (3.1.2) by means of simulation software or hardware

3.1.12
simulation plan

document in which the content, operate steps and implement method of all *simulation* (3.1.9) items are specified

3.1.13
stability

ability of a system submitted to bound external disturbances to remain indefinitely in a bounded domain around an equilibrium position or around an equilibrium trajectory

3.1.14
validation
confirmation, through the provision of objective evidence, that the requirements for a specific intended use or application have been fulfilled

Note 1 to entry: The objective evidence needed for a validation is the result of a test or other form of determination such as performing alternative calculations or reviewing documents.

Note 2 to entry: The word “validated” is used to designate the corresponding status.

Note 3 to entry: The use conditions for validation can be real or simulated.

[SOURCE: ISO 10795:2019, 3.243]

3.1.15
verification
confirmation, through the provision of objective evidence, that specified requirements have been fulfilled

Note 1 to entry: The objective evidence needed for a verification can be the result of an inspection or of other forms of determination such as performing alternative calculations or reviewing documents.

Note 2 to entry: The activities carried out for verification are sometimes called a qualification process.

Note 3 to entry: The word “verified” is used to designate the corresponding status.

[SOURCE: ISO 10795:2019, 3.244]

3.2 Abbreviated terms

For the purposes of this document, the abbreviated terms given in Table 1 apply.

Table 1 — Abbreviated terms

CM	configuration management
HITL	hardware-in-the-loop
M&S	modelling and simulation
V&V	verification and validation

4 Control system simulation

4.1 Simulation system scheme of control system

The control system is one of the most important systems of launch vehicle, satellite, spaceship, etc.

Generally, the simulation system scheme of the control system is illustrated in Figure 1.

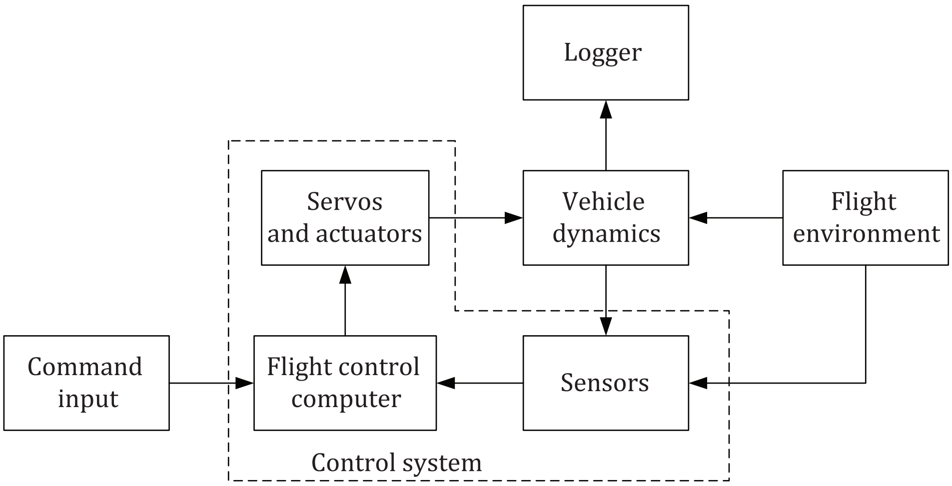

Figure 1 — Simulation system scheme of control system

a) The flight environment includes atmosphere or space environment in which the spacecraft exists. In terms of different kinds of spacecraft, the control system shall consider mechanical, thermodynamic, optical and electromagnetic environment, etc.

b) Sensors are fixed on the spacecraft to measure the states, which are provided to the flight control computer for control algorithm calculation.

c) The flight control computer receives and deals with the measured information from sensors, and then control signals are gained by the control algorithm and sent to servos as commands.

d) Servos receive commands from the flight control computer and drive actuators, which produce forces and moments and affect the flight states of spacecraft, so that a closed loop is formed and the objective of control is achieved.

e) The command input indicates the control command and binding parameter.

f) Vehicle dynamics indicates the dynamic behaviour of a plant.

g) The logger records the telemetry data and flight status.

4.2 Objectives of control system simulation

Control system design is an iterative process from design, test and validation to modification, retest, and revalidation. Analytical method is not enough for research and design of the control system, so simulation experiment is demanded.

The primary objectives of control system simulation are as follows:

a) verify and optimize the control system scheme;

b) verify and optimize the control system parameters;

c) analyse the stability and robustness of the control system;

d) emulate control system faults that can occur in flight;

e) predict the performance of the control system;

f) comprehensively verify functions of control system components;

g) minimize scheme design iteration;

h) shorten the development time;

i) minimize the development budget.

4.3 Mathematical simulation and HITL simulation

Compared to mathematical simulation, the structure of an HITL simulation system is more complex. It can reflect the hardware/software characteristics of the control system, and verify the functions/performances of the control system (e.g. interface matching properties). Generally, HITL simulation should be done after mathematical simulation.

The corresponding relationship between simulation types and the practical control system is listed in Table 2.

Table 2 — Relationship between simulation types and the practical control system

Parts of control system	Mathematical simulation	HITL simulation
Vehicle dynamics	Mathematical models	Mathematical model and motion simulator (turn table, robotic arm, air bearing)
Sensors		Physical device (either flight hardware or engineering development hardware) or equivalent mathematical model of sensors
Flight control computer		Physical device (either flight hardware, engineering hardware, or emulator)
Servos and actuators		Equivalent servo/actuator mathematical model or physical device (either flight hardware or engineering development hardware)
Flight environment		Emulator or mathematical model

4.4 Simulation in different phases

Design of a control system is not a simple iterative process. It can be divided into the conceptual design phase, detailed design phase, prototype phase and integrated system phase. Simulation is demanded in each phase in order to realize flight equivalent examples for the control system validation or equipment verification. The relationship between each design phase and simulation is described in Figure 2.

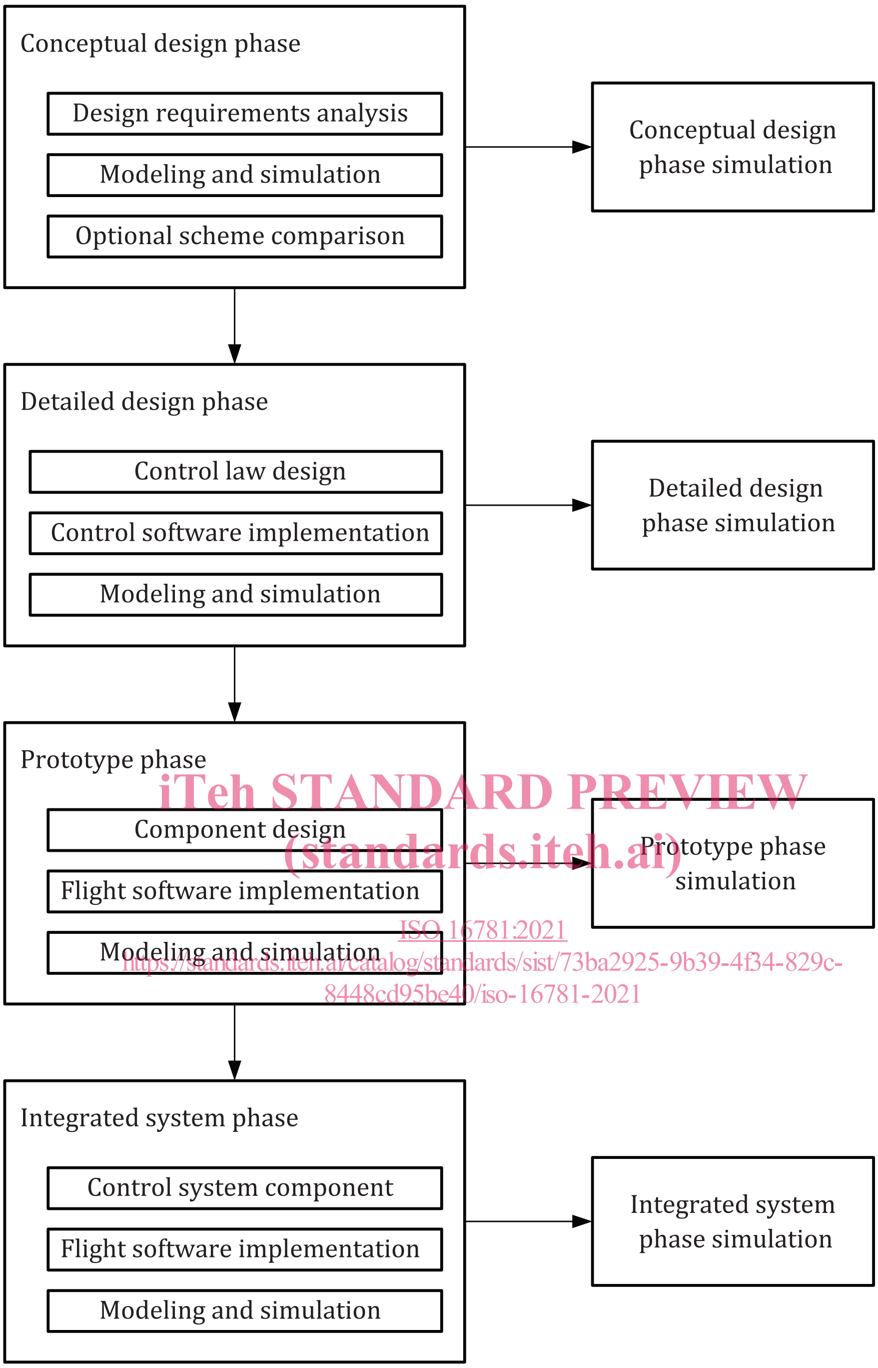

Figure 2 — Relationship between each design phase and simulation

In the conceptual design phase simulation, mathematical simulation is used for control system architecture and conceptual design studies. This pure software simulation environment supports the identification of optional control system architectures/top level designs that meet both mission performance requirements and stability robustness requirements. Low-order/low-fidelity models and simple operational environment models are adopted for mathematical simulation. Multiple co-existing models and simulation tools are managed by individual engineers.

In the detailed design phase simulation, mathematical simulation is used for system optimizations, parameter sensitivity assessments, performance evaluations, stability robustness assessments, etc. This simulation environment supports the identification of the final control system design that matches mission performance and stability robustness requirements. High-order/high-fidelity, possibly nonlinear models and detailed flight-equivalent operational environment models are adopted.