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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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Foreword

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The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *SC14 Space Systems and Operations*.

Introduction

This International Standard provides space system control system engineers, simulation engineers and customers with guidance of use simulation to support their system engineering tasks. This International Standard is intended to help reduce the develop time and cost of space system control system design and also enhance its quality and reliability. This International Standard focuses on requirements and recommendations for what should be done during simulation. It does not prescribe how the requirements are to be met.

Space systems — Simulation requirements for control system

1 Scope

This International Standard provides guidance to control system engineers on what to simulate and how to use simulation to support their system engineering tasks. Ground testing limitations typically preclude a comprehensive "test as you fly" approach to most space system control systems. Likewise, flight tests are prohibitively expensive. Therefore, high-fidelity simulation models of the control system components must be validated. Wherever, possible ground test results should be compared to simulation model outputs. Validated models are then used in various simulation environments to predict flight performance. As an important means of design, analysis and validation, simulation of the control system is widely used in each phase of the control system development, including conceptual design, detailed design, prototype validation, and integrated system verification. This International Standard provides simulation requirements of control system for different phases in the process of designing a control system. Control system engineers can carry out various types of simulation experiments during various phases, according to this International Standard. This International Standard establishes a minimum set of requirements for simulation of control system. The requirements are generic in nature because of their broad applicability to all types of simulations. Implementation details of the requirements should be addressed in project-specific standards, requirements, handbooks, etc.

In general, standards can focus on engineering/technical requirements, processes, procedures, practices, or methods. This International Standard focuses on requirements and recommendations. Hence, this International Standard specifies what must be done; it does not prescribe how the requirements are to be met, nor does it specify who the responsible team is for complying with the requirements. Conflicts between this International Standard and other requirements documents shall be resolved by the responsible technical designer.

2 Terms and definitions

2.1
accuracy
measure of how close a value is to the "true" value

[SOURCE: ISO 14952-1:2003]

2.2
control system
closed-loop configuration of sensors, processors/algorithms, and actuators designed to manage the dynamic behavior of space systems

2.3
emulator
prototype of the flight equipment, which has the identical input/output interfaces as the flight equipment and has similar operating behaviour

2.4
fidelity
degree to which a model or simulation 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

2.5
hardware in the loop simulation
kind of simulation, in which some simulation models of control system are implemented by real equipment

2.6
mathematical simulation
kind of simulation, in which all the simulation models of control system are implemented by software

2.7
real-time simulation
kind of simulation, in which the time scale of dynamic process in simulation model strictly equals to that of the real system

2.8
reliability
ability of an item to perform a required function under given conditions for a given time interval

[SOURCE: ISO 10795:2011]

2.9
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

2.10
simulation of control system
complex progress of building simulation system based on the mathematical model of control system, testing the model, solving the system dynamic equations, imitating dynamic behaviors of control system, and taking qualitative and quantitative analysis and research about scheme, structure, parameters, and performance of control system

2.11
simulation model
equivalent model in the simulation system, which is transformed from mathematical model of control system by means of simulation software or hardware

2.12
simulation plan
document in which the content, operate steps, and implement method of all simulation items are specified

2.13
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

2.14
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 term “validated” is used to designate the corresponding status.

Note 2 to entry: The use conditions for validation can be real or simulated.

Note 3 to entry: Validation can be determined by a combination of test, analysis, demonstration, and inspection.

[SOURCE: ISO 10795:2011]

2.15
verification
confirmation through the provision of objective evidence that specified requirements have been fulfilled

Note 1 to entry: The term “verified” is used to designate the corresponding status.

Note 2 to entry: Confirmation can comprise activities such as

—performing alternative calculations,

—comparing a new design specification with a similar proven design specification,

—undertaking tests and demonstrations, and

—reviewing documents prior to issue.

Note 3 to entry: Verification can be determined by a combination of test, analysis, demonstration, and inspection.

[SOURCE: ISO 10795:2011]

3 Abbreviated terms

Table 1 — Abbreviated terms

A/D	Analog/ Digital Transform
CM	Configuration Management
D/A	Digital/Analog Transform
DI/DO	Digital Input/Digital Output
HITL	Hardware-in-the-Loop
M&S	Modelling and Simulation
V&V	Verification and Validation

4 Control system simulation

4.1 Structure of control system

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

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

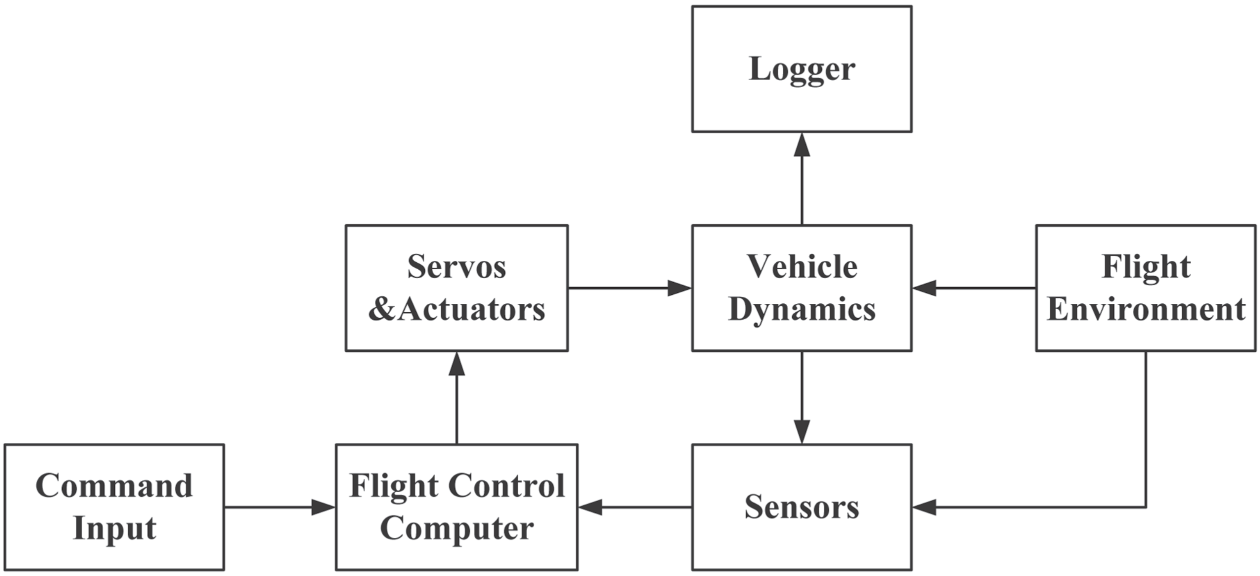

Figure 1 — Control System Architecture

a) Flight environment includes atmosphere or space environment in which the spacecraft exists. In terms of different kinds of spacecraft, 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 flight control computer for control algorithm calculation.

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

d) Servos receive commands from 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) Command input indicates control command and binding parameter.

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

g) Logger records 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 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 control system;

f) comprehensively verify functions of control system components;

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

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

Table 2 — Relationship between simulation types and 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 control system is not a simple iterative process. It can be divided into 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. Relationship between each design phase and simulation can be described in Figure 2.

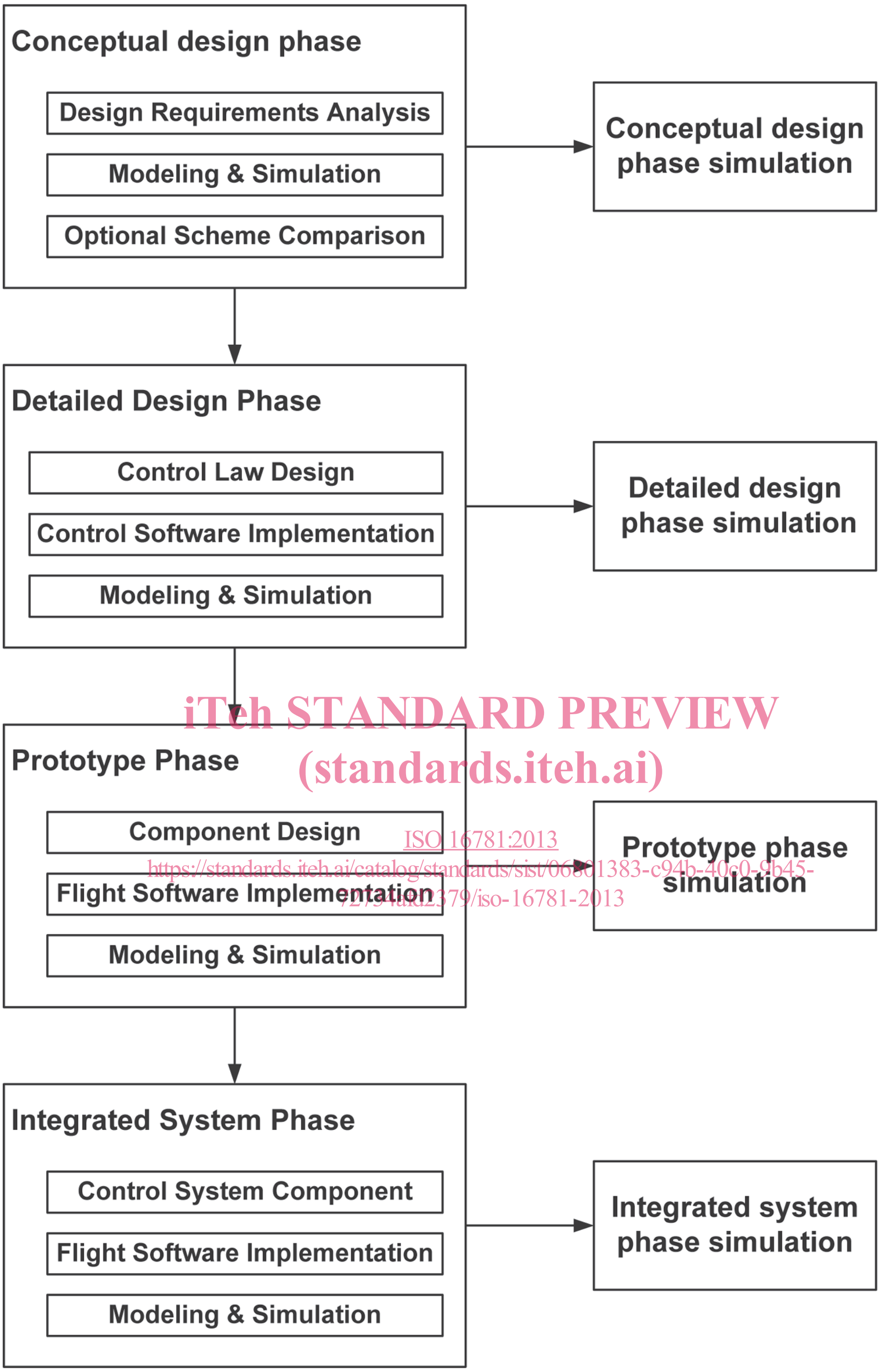

Figure 2 — Relationship between each design phase and simulation

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 architecture/top level design that meets 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.