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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 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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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

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.

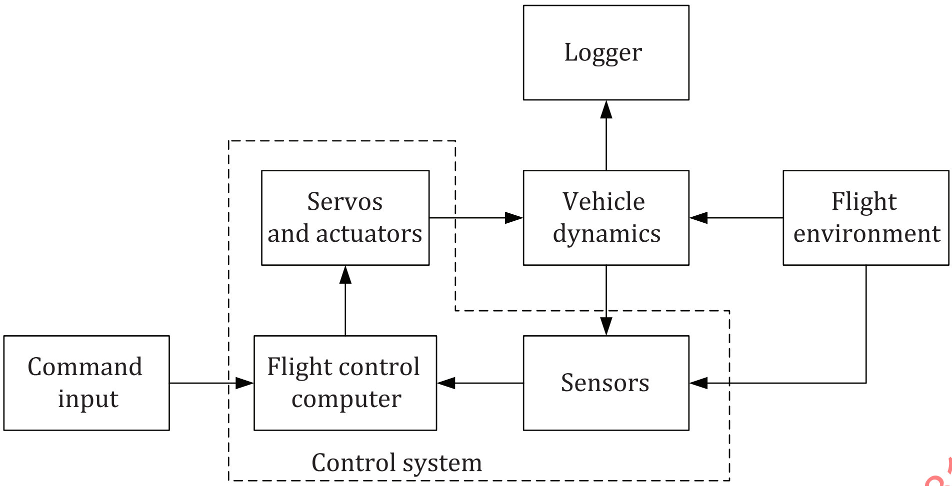

Figure 1 — Simulation system scheme of control system

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

<table>
<tr><th>Parts of control system</th><th>Mathematical simulation</th><th>HITL simulation</th></tr>
<tr><td>Vehicle dynamics</td><td rowspan="5">Mathematical models</td><td>Mathematical model and
motion simulator (turn table, robotic arm, air bearing)</td></tr>
<tr><td>Sensors</td><td>Physical device (either flight hardware or engineering development hardware)
or equivalent mathematical model of sensors</td></tr>
<tr><td>Flight control computer</td><td>Physical device (either flight hardware, engineering hardware, or emulator)</td></tr>
<tr><td>Servos and actuators</td><td>Equivalent servo/actuator mathematical model or
physical device (either flight hardware or engineering development hardware)</td></tr>
<tr><td>Flight environment</td><td>Emulator or mathematical model</td></tr>
</table>

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.

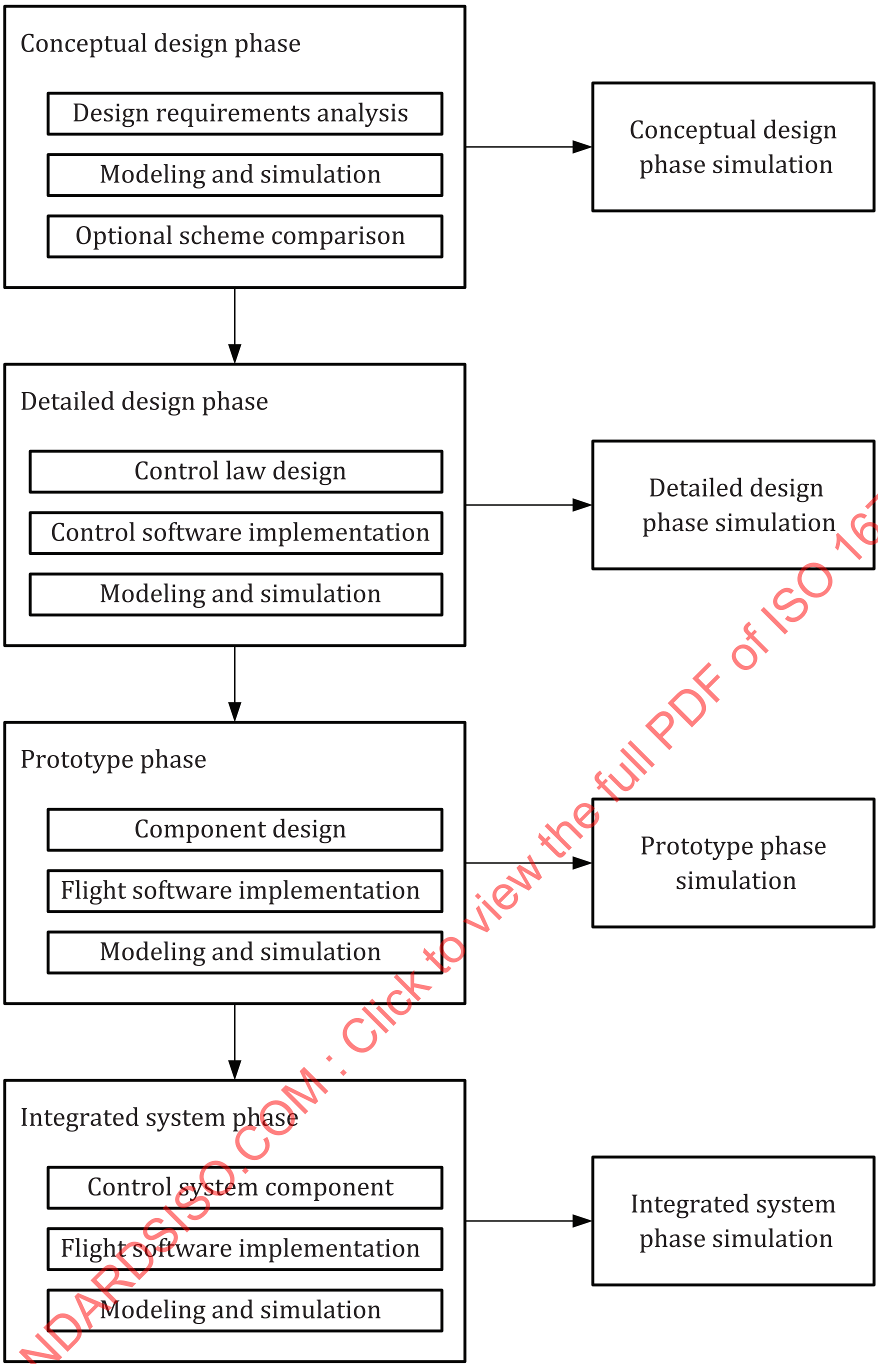

Figure 2 — Relationship between each design phase and simulation

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.

Some formal configuration management/control of models, parameter databases and simulations are required in this simulation environment.

HITL simulation, which combines hardware and software, is often introduced in the prototype phase simulation. The basic components of the control system are realized by prototype. In this phase, the correctness of the control algorithm prototype and flight software and compatibility between various interfaces are validated, in order to reduce the integrated risk of the control system and the entire spacecraft. This simulation environment may allow substitution of control system sensors/actuators models for hardware engineering units as needed. Simple software plant and environment models are used to close the control system loop. Also, some formal configuration management/control of this HITL simulation environment is required.

Testing of the control system flight software nominal functionality as well as failure mode functions is accomplished by HITL simulation in the integrated system phase simulation. The basic components of the control system are realized by real devices, at least including a flight processor hosting the control algorithm as well as other relevant flight software elements. Consistency of all parts of control system is certified to ensure that requirements of space system are satisfied. This M&S environment is often maintained after space system launch to allow:

a) model validation via comparing the operational performance of the actual in-flight control system with pre-launch M&S results;

b) the checkout and verification of control system flight software modifications (e.g. a flight software "patch") prior to implementing the change to the on-board space system;

c) the support of space system anomaly resolution. A very high degree of formal configuration management/control of this simulation environment is needed.

Basic characteristics of the four phases in Figure 2 are listed in Table 3. The four development phases of this document and the phases defined in ISO 14300-1 are compared in Annex A.

Table 3 — Basic characteristics of the four phases

	Conceptual design phase simulation	Detailed design phase simulation	Prototype phase simulation	Integrated system phase simulation
Simulation environment	pure software, non-real-time	pure software, non-real-time	hybrid hardware/software, prototype or simulators, real-time	hybrid hardware/software, HITL, real-time
Demonstrated Items	mission performance, stability robustness requirements	mission performance, stability robustness requirements	signal/data/timing functional compatibility, interface compatibility, software processing functions	nominal flight software functionality, failure mode functions
Model fidelity	low-order/low-fidelity simple model, linear, e.g. rigid body dynamics	high-order/high-fidelity detailed model, nonlinear, e.g. flexible body dynamics, disturbances	detailed model	detailed model
Control law algorithms coding	not necessarily in modular form	modular form	flight-equivalent code, not necessarily on-board	on-board flight software
Simulation system V&V	mathematic model V&V	mathematic model V&V, simulation software V&V	mathematic model V&V, simulation software V&V, simulation hardware V&V	mathematic model V&V, simulation software V&V, simulation hardware V&V
Configuration management/control	little or no formal	partly formal	partly formal	very high degree formal

4.5 Simulation process

In each control system development phase, the simulation process should include the following.

a) Requirements analysis

Identifying the input of the simulation task, e.g. mathematical model of the control plant, control algorithm, control system criterion, control system specification and corresponding documents.

Identifying the output of the simulation task, e.g. simulation data, simulation result analysis and corresponding documents.

Identifying the simulation functions and all the resources needed (e.g. human resource, staff responsibility, field and equipment).

b) Simulation system design

Designing the simulation system, deciding to realize each part of the control system by software, prototype or real equipment, determining interface in the simulation system, compiling simulation plan and simulation system design report.

c) Simulation software development

Coding and debugging simulation software, implementing mathematical models (e.g. vehicle dynamics, flight environment, and servo) with software.

d) Simulation hardware development

Designing and realizing hardware used in the simulation system.

e) Simulation system verification and validation

Verifying and validating simulation models, evaluating credibility of simulation models.

Ensuring the simulation system function and performance meet requirements.

f) Simulation operation

Carrying out simulation according to the simulation plan.

g) Simulation result analysis

Analysing simulation results, evaluating the control system performance.

h) Document

Documenting relative reports, e.g. simulation results analysis report.

5 General requirements

5.1 General

General requirements to be followed in each control system simulation phase are specified in this clause and the special requirements for simulation of different phases are provided in 5.2 to 5.7. Requirements of control system simulation are divided into: project level requirements, simulation model requirements, simulation facility requirements, simulation operation requirements, simulation analysis requirements and document requirements.

5.2 Project level requirements

Project level requirements cover the simulation process that shall be followed in each control system design phase and shall be defined at the project/system level (see Table 4).

Table 4 — Project level requirements

ID	Requirements
1	Shall identify the inputs and outputs for the simulation mission.
2	Shall define a data policy to ensure that the simulation developers have the timely access to the space system information they need for the model development.
3	Shall clearly declare accuracy, fidelity and reliability of output data.
4	Shall determine the simulation type (mathematical or HITL) according to the particular objective.
5	Shall determine the components of simulation system and their functions.
6	Shall define the models to be integrated (as specified in 5.3).
7	Shall determine the implement mode (software or hardware) of each part according to simulation type.
8	Shall define the data formats and implement modes of interfaces between various components.
9	Shall define the simulation language.
10	Shall determine the execution rate required for each model that is called by the simulation.
11	Shall determine the methods for verification and validation of simulation models.
12	Shall identify verification and validation processes for the simulation models.
13	Shall analyse and identify uncertainty factors of the simulation.
14	Shall formulate a simulation system design report including above items (see 5.7.1).
15	Shall formulate a simulation plan (see 5.7.2).

5.3 Simulation model requirements

Simulation model requirements identify the general requirements that each simulation model shall conform to (see Table 5).

Table 5 — Simulation model requirements

ID	Requirements
1	Shall contain control algorithm, plant model, sensor model, servo model, environment model and database configuration control.
2	Shall identify data sets and any supporting software used in model development and input preparation.
3	Shall guarantee that models of real equipment have interfaces representing the functional input and output.
4	Shall define the basic structure and mathematical formula of the model.
5	Shall define the following requirements for each model: performance, accuracy, fidelity, stability and validity range.
6	Shall define dimension of all input/output variables of the model.
7	Shall define coordinate frames used in the model.
8	Shall provide instructions on proper use of the model.
9	Shall document techniques and domain for verification and validation.
10	Shall document conditions for modelling verification and validation (e.g. the required data and software).
11	Shall document modelling verification and validation results (e.g. whether requirements of simulation are met).
12	Shall clarify and maintain models and associated documentation in a controlled CM system (e.g. updates of document version and models).

5.4 Simulation facility requirements

Simulation facility requirements are defined for the system facilities used in the simulation system (see Table 6).

Table 6 — Simulation facility requirements

ID	Requirements
1	Shall document any unique requirements of computational capability (e.g. support software, main memory, disk capacities, processor and compilation options).
2	Shall provide the capability to monitor and control the operation of simulation.
3	Shall provide the capability to visualize and record input and output data.
4	Shall provide the capability to compare data in compatible format (e.g. to compare the results from two simulation runs or simulated vs. real data).
5	Shall provide the capability to perform online and off-line analyses of simulation output data.
6	Shall provide means to debug the simulation system.
7	Shall provide the capability to input or output an external time source for synchronization.
8	Shall provide the capability to support real-time simulation and non-real-time simulation.
9	Shall provide the capability to support closed-loop simulation.
10	Shall verify and validate all the facility in the simulation system.
11	Shall ensure that operation instructions (including limits) of facilities are available.
12	Shall ensure that the technical indexes of simulation facilities are within permitted range.
13	Shall maintain facilities and associated documentation in a controlled CM system.

5.5 Simulation operation requirements

Simulation operation requirements describe the requirements to perform the simulation (see Table 7).

Table 7 — Simulation operation requirements

ID	Requirements
1	Shall verify and validate all input data, including the correctness, physical meaning and dimension.
2	Shall confirm that the simulation models and facilities have been verified and/or validated.
3	Shall confirm that the simulation facilities have been verified and/or validated available.
4	Shall operate the simulation according to the test cases in the simulation plan.
5	Shall ensure that simulations are conducted within the limits of operation (e.g. altitude range and measurement range) of the models.
6	Shall document the relevant simulation conditions of simulation results.
7	Shall process the simulation results immediately, recognize and capture the need for any changes or improvements in the simulation.
8	Shall analyse the problems (errors and warnings) and corresponding solution during simulation.
9	Shall document and explain any observed warning and error messages resulting from simulation, and convey serious concerns about simulation to project managers (and decision makers, if appropriate) as soon as they are known.

Table 7 *(continued)*

ID	Requirements
10	Shall document the process for conducting simulations and analysis for generating results report.

5.6 Simulation result analysis requirements

Simulation result analysis requirements are defined for the processing of the results from the simulation (see Table 8).

Table 8 — Simulation result analysis requirements

ID	Requirements
1	Shall confirm and document the data and its pedigree used in the analysis.
2	Shall analyse and conclude whether the stability of control system is feasible.
3	Shall analyse and conclude whether the critical technical indexes of control system are feasible.
4	Shall analyse and conclude whether control system adapts to parameter uncertainty of spacecraft.
5	Shall analyse and conclude whether control system is capable of resisting disturbance.
6	Shall analyse and conclude whether control system adapts to fault of control system component.
7	Shall analyse and conclude whether the simulation objective is reached.

5.7 Document requirements

5.7.1 Design report of simulation system

Primary requirements of the simulation system design report are listed in Table 9, to confirm every configuration element to be verified and validated.

Table 9 — Requirements of the simulation system design report

ID	Requirements
1	Shall identify functions and performances of the simulation system.
2	Shall document architecture of simulation system.
3	Shall document facilities involved in simulation and their functions.
4	Shall document software involved in simulation and its functions.
5	Shall identify internal and external interface of simulation system.
6	Shall document design results of facilities/software that are especially designed or modified for the simulation.
7	Shall document the name, number, size, place, status and other important properties of each simulation facility.
8	Shall include documents or handbooks concerned to hardware.
9	Shall include documents or handbooks concerned to software.

5.7.2 Simulation plan

Primary requirements of the simulation plan are listed in Table 10, to show the verification plan, schedule, and the compatibility to the project development, etc.

Table 10 — Simulation plan requirements

ID	Requirements
1	Shall identify objectives of the simulation.
2	Shall document inputs of the simulation.
3	Shall identify outputs of the simulation.
4	Shall identify content, precision, and format of the data to be recorded in the simulation.
5	Shall identify contents of the simulation.
6	Shall document the result of simulation system designed.
7	Shall make a plan of simulation operation steps.
8	Shall document the schedule of simulation.
9	Shall document requirements, plan, and methods of verification and validation for the simulation.
10	Shall identify environment of the simulation (location, electric power, temperature and other environment conditions).
11	Shall document roles and responsibilities of staff.

5.7.3 Simulation report

After simulation experiment, simulation operation process and results shall be documented as the simulation report, including the changes or improvements between the plan and the performance. Typical content of the simulation report is listed in Table 11.

Table 11 — Simulation report requirements

ID	Requirements
1	Shall give an overview of simulation performed.
2	Shall document data used as input to the simulation, including original data.
3	Shall illuminate the mathematical model used for simulation.
4	Shall document results of verification and validation for mathematical model.
5	Shall document the technical states of simulation hardware.
6	Shall document not only the method used in hardware device testing, but also results and states.
7	Shall document any aspects of simulation that have not been verified and validated.
8	Shall analyse simulation bias, clarify and document any uncertainty and its influence.
9	Shall analyse the simulation results including documentation of relevant guidelines and statistical processes.
10	Shall document any changes or improvements in the simulation.
11	Shall document the problems (errors and warnings) and corresponding solution during simulation.
12	Shall document the assessment as to the appropriateness of the simulation and analysis.
13	Shall document the simulation result analysed.

6 Requirements of conceptual design phase simulation

6.1 General

In the phase of conceptual design simulation, a simplified system model is generally used for mathematical simulation. Running non-real-time mathematical models supports the specific needs of the engineering disciplines and allows the rapid evaluation of system design concepts. The schematic diagram of the simulation system in the conceptual design phase is illustrated in Figure 3.

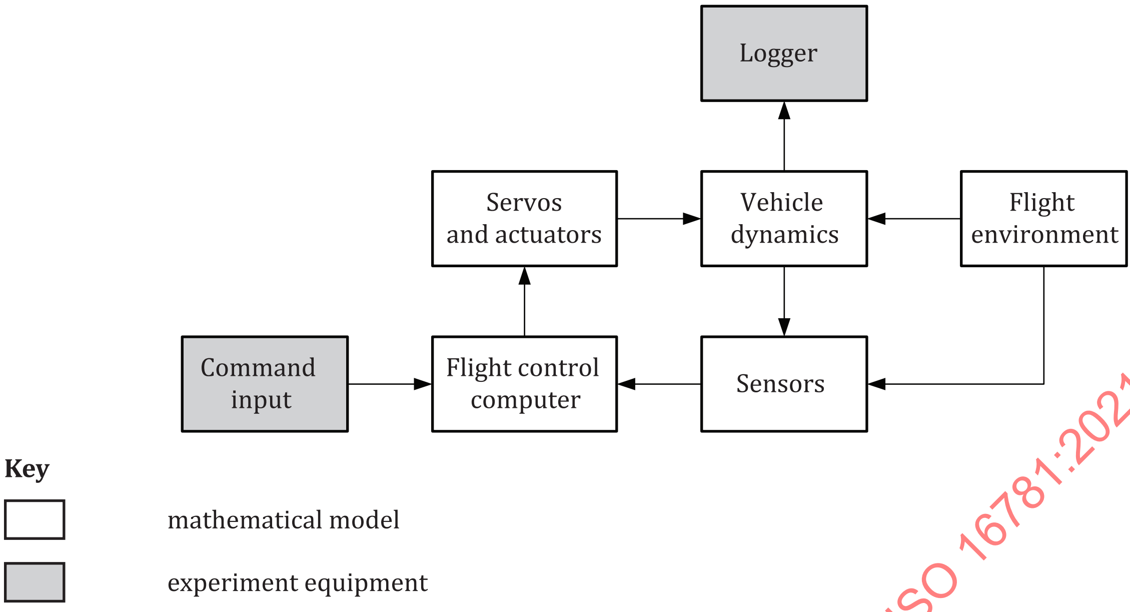

Figure 3 — Simulation system architecture in conceptual design phase

6.2 Objective

a) Demonstrating the rationality for inputs and technical indexes of the control system.

b) Demonstrating the feasibility of the system design for next step.

c) Comparing several optional schemes to select the optimal one.

6.3 Input

a) Mission requirements of the control system.

b) Mathematical models of plant, sensors, and actuators.

c) Critical technical indexes and critical parameters of the control system.

d) Control algorithm.

6.4 Output

a) Simulation results corresponding to various parameters and technical conditions.

b) Analysis and conclusion of simulation results.

c) Report of scheme argumentation for the control system.

6.5 Simulation model requirements

Simulation models shall include the control algorithm, plant model, sensor model, servo and actuators model, flight environment model and so on, which make up of a whole system for concept scheme validation.

The low-fidelity plant model and environment model shall be adopted properly.

Control algorithm, sensor model, and servo model may allow substitution for comparing and argumentation of optional control schemes.

6.6 Simulation facility requirements

For the conceptual design phase, the simulation facilities include the simulation computer and simulation software.

The simulation computer shall meet the requirements of calculation speed, memory capacity and calculation precision.

The simulation software shall provide the capability to support not only rapid establishment of the simulation system, but also convenient modification for studying optional control schemes. The integration step of simulation shall be able to be adjusted according to the requirements. Simulation results shall be analysed and compared easily.

6.7 Simulation operation requirements

In this phase, simulation is generally accomplished by control system engineers. Therefore, there may be little or no formal requirements for simulation operation.

7 Requirements of detailed design phase simulation

7.1 General

The high-fidelity control system mathematical simulation is first developed and then used extensively in this design phase to verify that the baseline control system meets mission stability and performance requirements. The schematic diagram of the simulation system in the detailed design phase is illustrated in Figure 4.

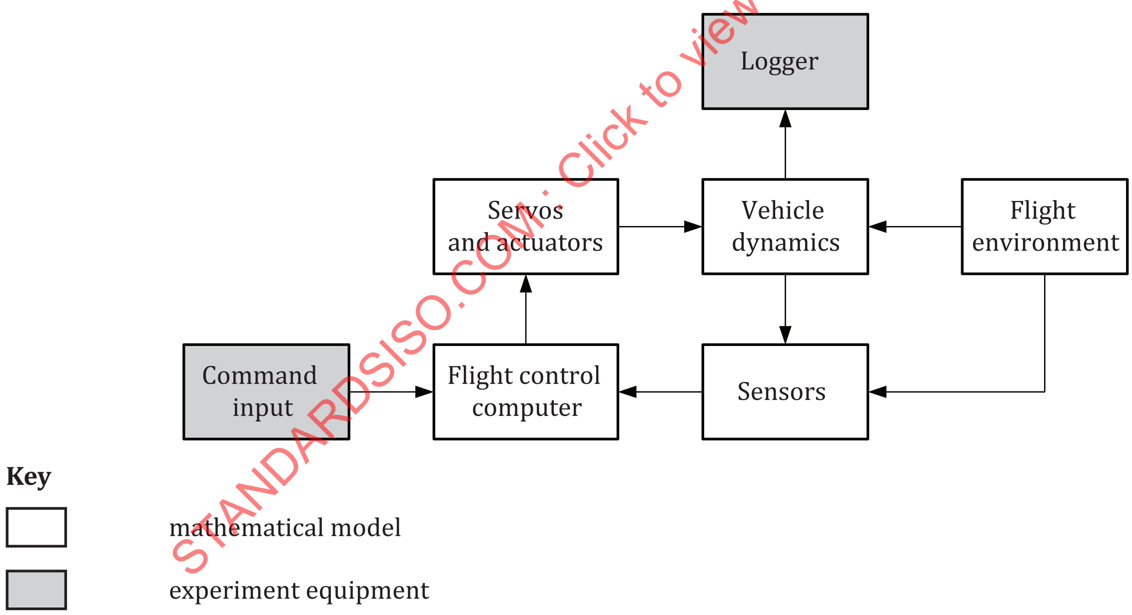

Figure 4 — Simulation system architecture in detailed design phase

Detailed design phase simulation is founded on the conceptual design phase simulation, providing the basis for prototype phase simulation and integrated system phase simulation. In this phase, the simulation system contains all the functional models needed for the algorithms validation used for argumentation and determination of critical technical parameters in the control system.

7.2 Objective

a) Validating the correctness of the design scheme by a detailed simulation model with high-fidelity.

b) Verifying the system performance through a set of analysis.

c) Optimizing control parameters to meet the requirements of dynamic performance for the control system.

d) Simulating potential disturbance and fault of the control system, and researching how to cope with them.

7.3 Input

a) Simulation task.

b) Critical technical indexes and critical parameters of the control system.

c) Mathematical model of the plant.

d) Control configuration and algorithm.

7.4 Output

a) Simulation results corresponding to various parameters and technical conditions.

b) Analysis and conclusion of simulation results.

c) Performance evaluation of the control system (e.g. compliance to requirements of dynamic performance for control system).

d) Validation of the simulation system design with respect to the requirements of the control system.

e) Simulation report.

7.5 Simulation model requirements

Simulation models shall include the control algorithm, plant model, sensor model, servo model, environment model and so on, which make up of a whole system for detailed design phase simulation.

Detailed plant model, environment model, sensor model, and servo model shall be adopted properly.

Control algorithm, sensor model and servo model shall be frozen with some parameters adjustable according to simulation results.

7.6 Simulation facility requirements

Simulation computers shall meet the requirements of running speed, memory capacity and calculation precision.

The simulation software shall have the following functions:

— data handling functions;

— scenario definition functions;

— post-process functions;

— independence among modules.

7.7 Simulation operation requirements

In this phase, simulation shall be performed according to the process described in 5.5.

8 Requirements of prototype phase simulation

8.1 General

HITL simulation, which combines hardware and software, is often introduced in the prototype phase simulation. In this phase, the correctness of the control algorithm prototype and flight software and compatibility between various interfaces are validated, in order to reduce the integrated risk of the control system and the entire spacecraft.

This simulation is only a preliminary testing for function and performance of the control system, and is not intended for detailed performance prediction.

The schematic diagram of the simulation system in the prototype phase is illustrated in Figure 5. In order to validate the compatibility between various interfaces, it is suggested that all actual hardware devices be used in the simulation, such as the flight control computer, actuators and sensors. However, if the recommendation of using all actual hardware devices is not met, some devices can be replaced by mathematical models except for the flight control computer.

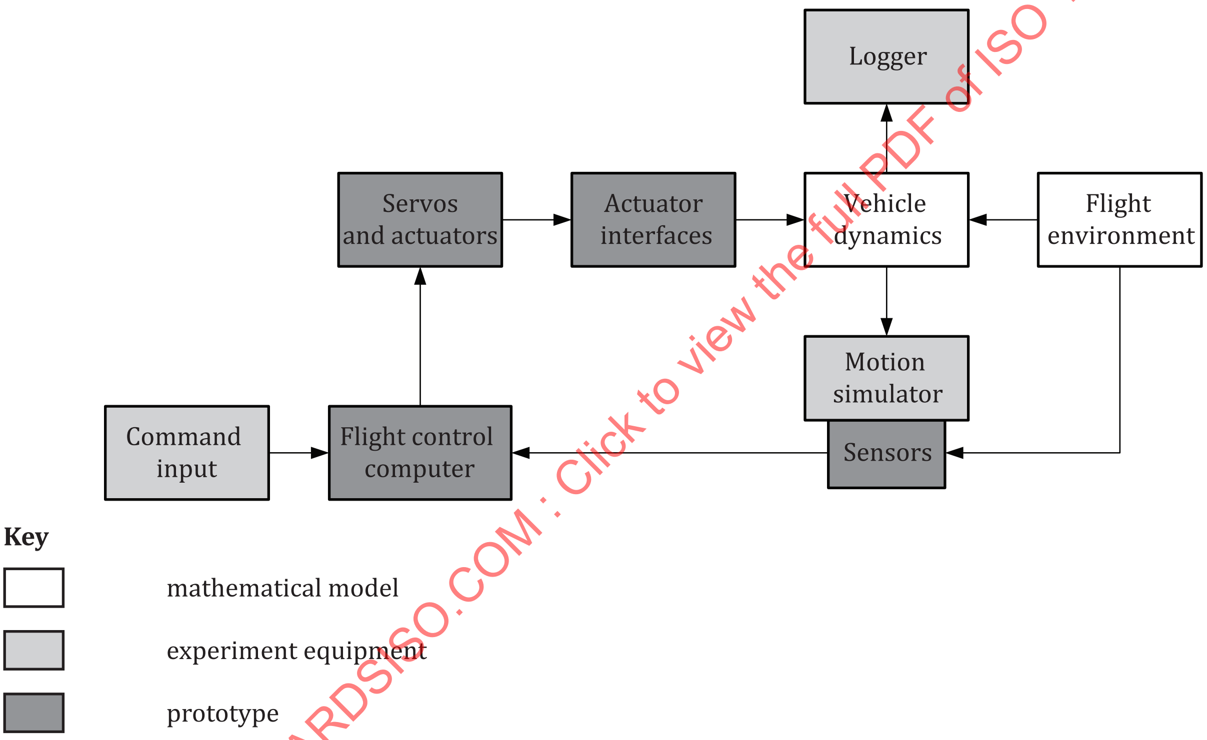

Figure 5 — Simulation system architecture in prototype phase

8.2 Objective

a) Preliminary tests of control system flight software processing functions.

b) Performance analysis and validation of critical elements/components (such as the flight control computer, sensors, servos).

c) Demonstration of signal/data/timing functional compatibility between sensors, servos and a flight processor emulator hosting the flight software.

d) Validating the consistency between software and hardware.

e) Validating whether the function of the control system meets mission requirements.

f) Validating the performance of the control system (e.g. dynamic quality, stability, adaptability and robustness).

g) Simulating potential disturbance and fault of the control system, and validating how to cope with them.

8.3 Input

a) Requirements of the simulation task.

b) Critical technical indexes and critical parameters of the control system.

c) Mathematical models of critical elements/components.

d) Prototype, instruction and interface documents of critical elements/components.

e) Mathematical model of the plant, including equations, constants, parameters, physical significance and dimension of variables.

f) Flight control software.

8.4 Output

a) Technical state documents of all devices and software.

b) Simulation results corresponding to various parameters and technical conditions.

c) Checkout results and conclusions of critical elements/components.

d) Checkout results and conclusions of flight control software.

e) Checkout results and conclusions of critical indexes.

f) Simulation report.

8.5 Simulation model requirements

Simulation models shall include the control algorithm, plant model, sensor model, servo model, and environment model.

The control algorithm can be implemented by either a mathematical model or flight software on the flight control computer.

The high-fidelity mathematical models for both the plant and flight environment are typically used in this phase of HITL testing.

Either mathematical models or prototypes can be used to represent the sensors and servo/actuators.

8.6 Simulation facility requirements

8.6.1 Requirements of simulation devices

There are three types of simulation devices: critical elements/components, special simulation devices and universal simulation devices.

Critical elements/components include the on-board computer, sensors, servos/actuators and so on.

Special simulation devices include the simulation console, cable net, simulation computer, monitor computer, data acquisition and process system, equivalent devices of control system product, devices of fault injecting, environmental physical effect simulators and so on.

Universal simulation devices include the alternating-current power, direct-current power, signal generator, signal measuring equipment (such as multimeter, oscilloscope, frequency response analyser, frequency spectrum analyser), data record equipment and so on.

These requirements only refer to special simulation devices. Requirements to control system product (such as on-board computer, sensors, servos /actuators) can also be proposed according to simulation demands. Also, requirements for motion simulator shall be included.

8.6.2 Requirements of simulation environment

The requirements of temperature, humidity, power, electromagnetism, and other environmental factors shall be proposed according to the requirements of the simulation task and simulation devices. For special devices, relative requirements shall be proposed.

8.7 Simulation Operation Requirements

Besides the requirements described in 5.5, the following contents shall be involved:

— checkout of simulation hardware devices to meet the performance requirements;

— checkout of the open-loop hardware system to meet requirements of open-loop gain and delay;

— simulation of the closed-loop system.

9 Requirements of integrated system phase simulation

9.1 General

In this phase, HITL simulation is used to validate not only the correctness of the control algorithm, real equipment of the control system, and flight software, but also compatibility between various interfaces. In this phase, simulation is generally accomplished by hardware design engineers, software design engineers and control system engineers together.

Software, hardware and models used in the simulation shall be strictly configured and managed.

The schematic diagram of the simulation system in the integrated system phase is illustrated in Figure 6.