BS ISO 16781:2013

BSI Standards Publication

Space systems — Simulation requirements for control system

bsi.

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of ISO 16781:2013.

The UK participation in its preparation was entrusted to Technical Committee ACE/68/-/1, Space systems and operations - Design, Engineering and Production.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

ISBN 978 0 580 80471 7

ICS 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 30 November 2013.

Amendments issued since publication

Date	Text affected

BS ISO 16781:2013

INTERNATIONAL STANDARD

ISO 16781

First edition
2013-11-15

Space systems — Simulation requirements for control system

Systèmes spatiaux — Exigences de simulation pour le système de contrôle

Reference number
ISO 16781:2013(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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.

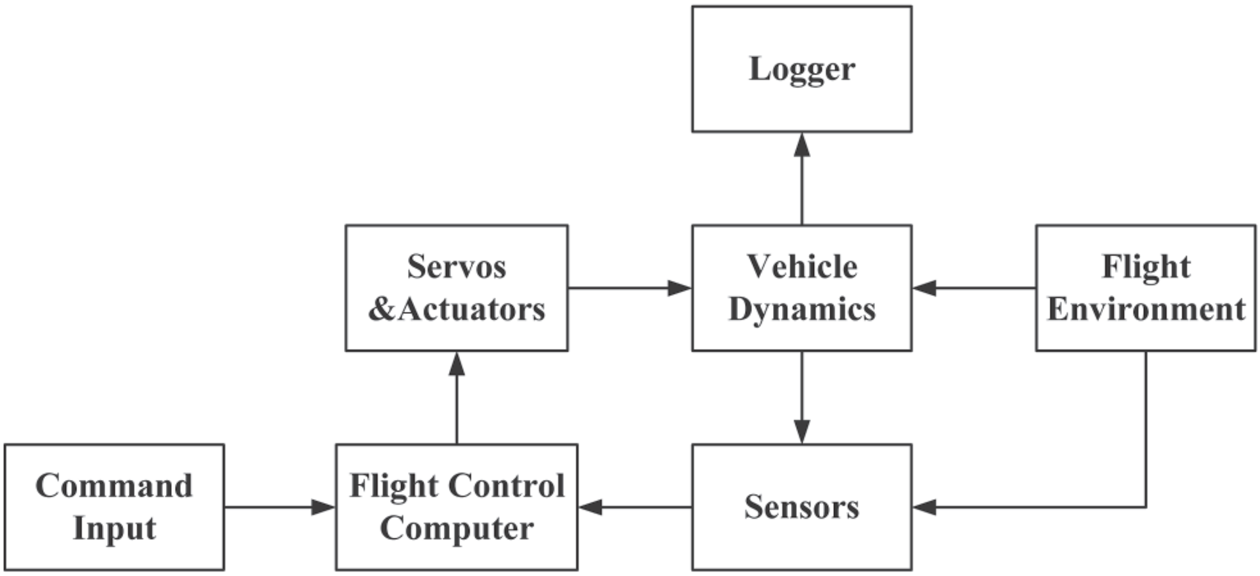

Figure 1 — Control System Architecture

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.

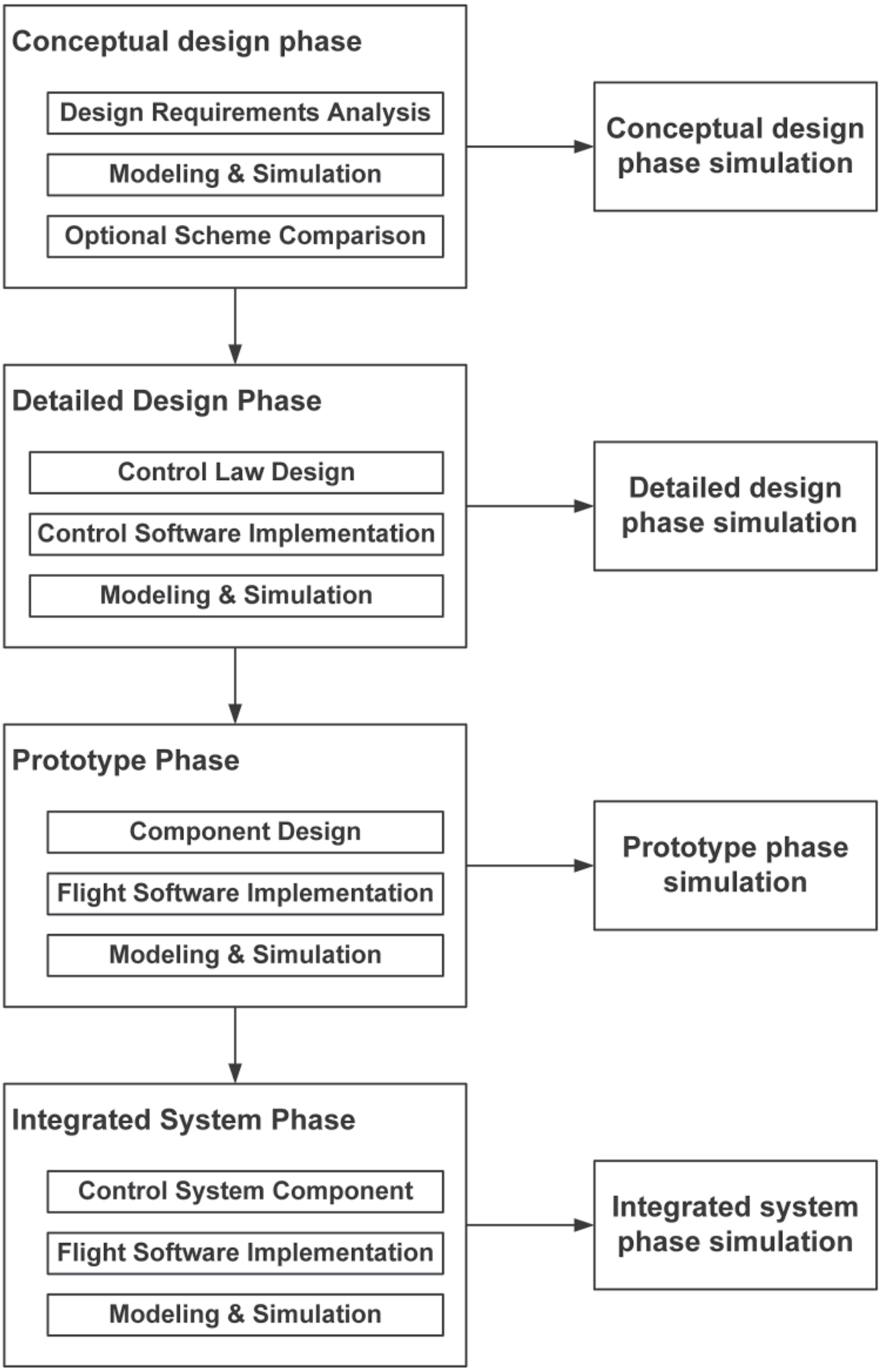

Figure 2 — Relationship between each design phase and simulation

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.

In 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 control system are realized by prototype. In this phase, correctness of control algorithm prototype and flight software and compatibility between various interfaces are validated, in order to reduce the integrated risk of control system and the entire spacecraft. This simulation environment can 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 control system flight software nominal functionality as well as failure mode functions is accomplished by HITL simulation in integrated system phase simulation. The basic components of 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 the following.

a) Model validation via comparing operational performance of 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 on-board space system.

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

Basic characteristic of the four phases in Figure 2 is listed in Table 3.

Table 3 — Basic characteristic 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 robust-ness requirements	mission performance, stability robust-ness requirements	signal/data/timing functional compatibility, inter-face compatibility, soft-ware processing func-tions	nominal flight software function-ality, 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, distur-bances	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 soft-ware V&V, simulation hardware V&V	mathematic model V&V, simulation software V&V, simu-lation 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, simulation process should include the following.

a) Requirements analysis

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

Identifying the output of 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, equipment).

b) Simulation system design

Designing simulation system, deciding to realize each part of 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, 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 simulation system function and performance meet requirements.

f) Simulation operation

Carrying out simulation according to simulation plan.

g) Simulation result analysis

Analysing simulation results, evaluating 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 chapter and the special requirements for simulation of different phases are provided in the following chapters. 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 should be followed in each control system design phase and should be defined at 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 is to comply with (see Table 5).

Table 5 — Simulation model requirements

ID	Requirements
1	Shall contain control algorithm, plant model, sensor models, servo models, environment models, 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 open-loop simulation and 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.
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 Other document requirements

5.7.1 Design report of simulation system

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

Table 9 — Requirements of 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 simulation plan are listed in Table 10, to show 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 simulation report, including the changes or improvements between planed and performed. Typical content of 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, 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 simulation system in conceptual design phase is illustrated in Figure 3.

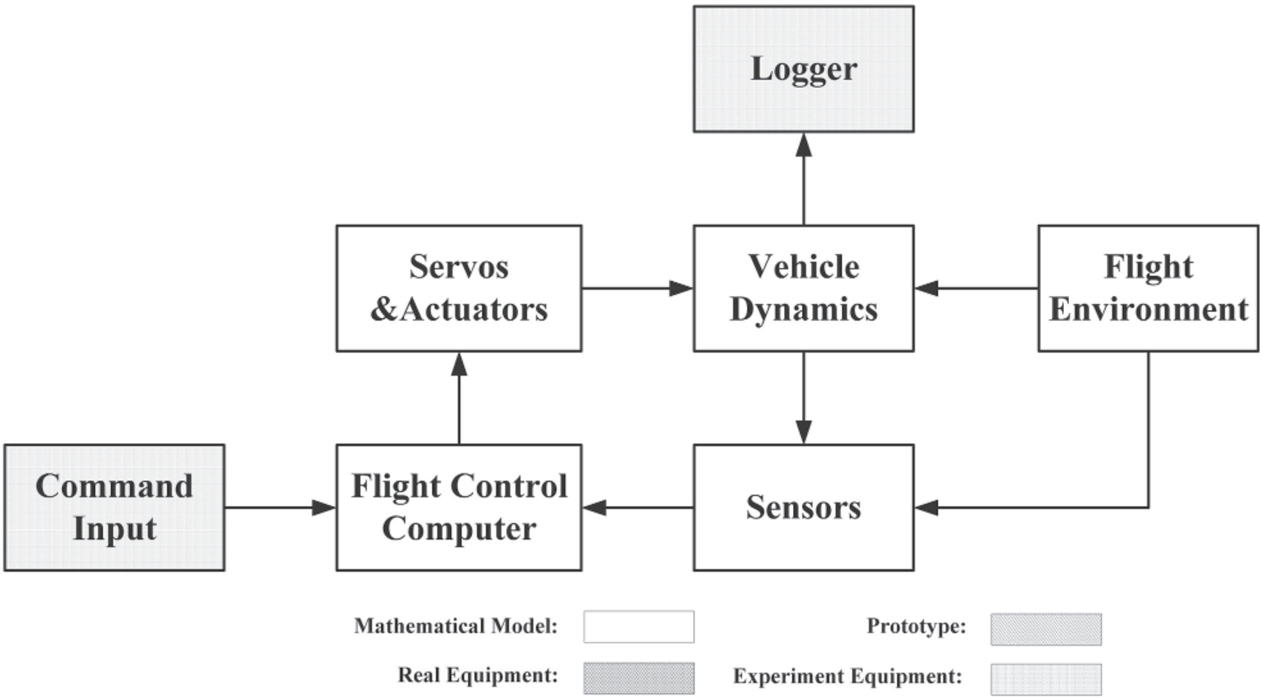

Figure 3 — Simulation system architecture in conceptual design phase

6.2 Objective

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

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

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

6.5 Simulation model requirements

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

Low fidelity plant model and environment model shall be adopted properly.

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

6.6 Simulation facility requirements

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

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

Simulation software shall provide the capability to support not only rapid establishment of simulation system, but also convenient modification for studying optional control schemes. Integration step of simulation shall be able to be adjusted according to 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 can 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 simulation system in detailed design phase is illustrated in Figure 4.

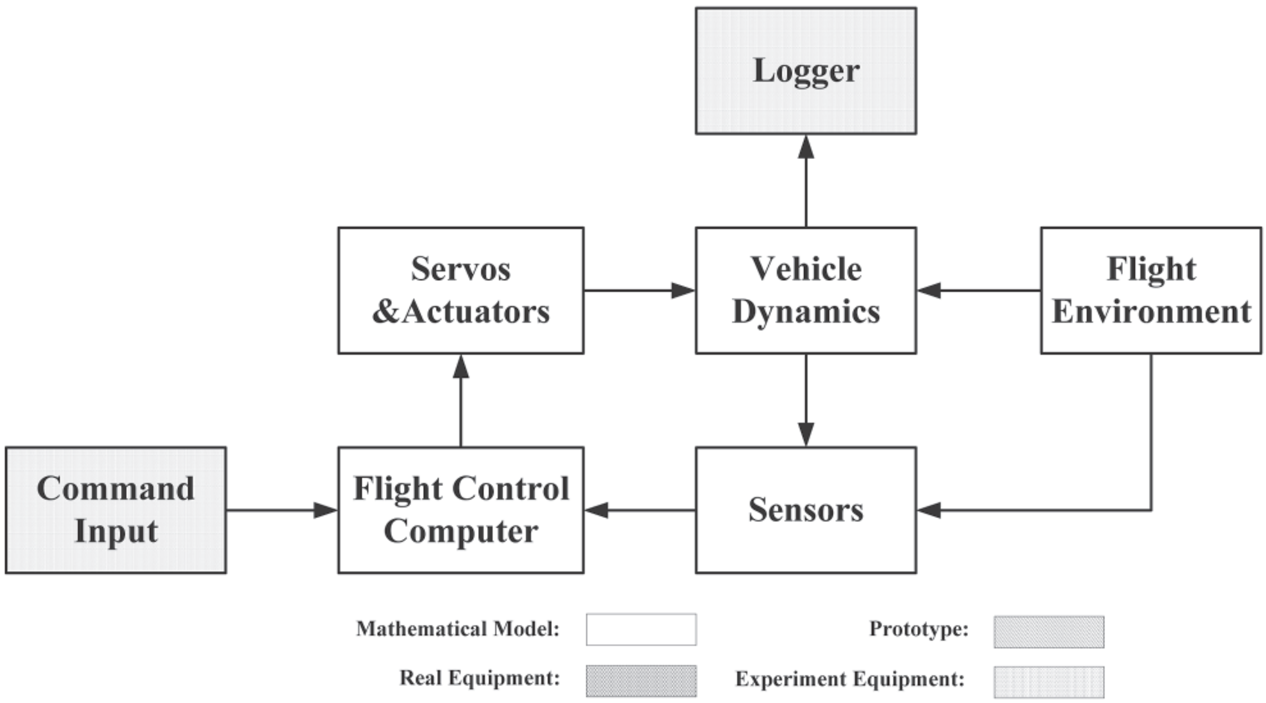

Figure 4 — Simulation system architecture in detailed design phase

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, simulation system contains all the functional models needed for the algorithms validation used for argumentation and determination of critical technical parameters in control system.

7.2 Objective

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

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

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

c) Mathematical model of 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 control system (e.g. compliance to requirements of dynamic performance for control system).

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

e) Simulation report.

7.5 Simulation model requirements

Simulation models shall include 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 computer shall meet requirements of calculation speed, memory capacity, and calculation precision.

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, correctness of control algorithm prototype and flight software and compatibility between various interfaces are validated in order to reduce the integrated risk of control system and the entire spacecraft.

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

The schematic diagram of simulation system in prototype phase is illustrated in Figure 5.

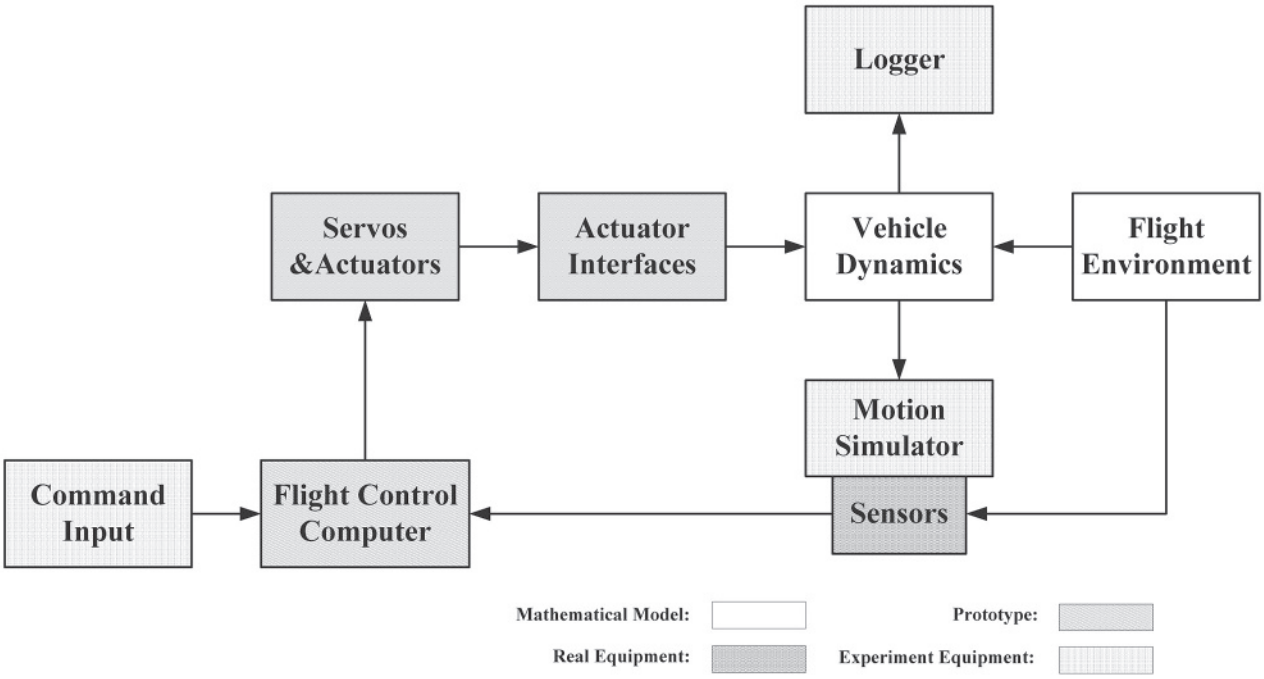

Figure 5 — Simulation system architecture in prototype phase

8.2 Objective

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

b) Performance analysis and validation of critical elements/components (such as 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 control system meets mission requirements.

f) Validating the performance of 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 simulation task.

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

c) Mathematical model of critical elements/components.

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

e) Mathematical model of 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 control algorithm, plant model, sensor model, servo model, and environment model.

Control algorithm can be implemented by either mathematical model or flight software on 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 could be used to represent the sensors and servos/actuators.

8.6 Simulation facility requirements

8.6.1 Requirement of simulation devices

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

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

Special simulation devices include 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 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) could also be proposed according to simulation demands. Also, requirements for motion stimulator 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 requirements of 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 open-loop hardware system to meet requirements of open-loop gain and delay;
- Simulation of open-loop system;
- Simulation of close-loop system.

9 Requirements of integrated system phase simulation

9.1 General

In this phase, HITL simulation is used to validate not only correctness of control algorithm, real equipment of 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 simulation system in integrated system phase is illustrated in Figure 6.

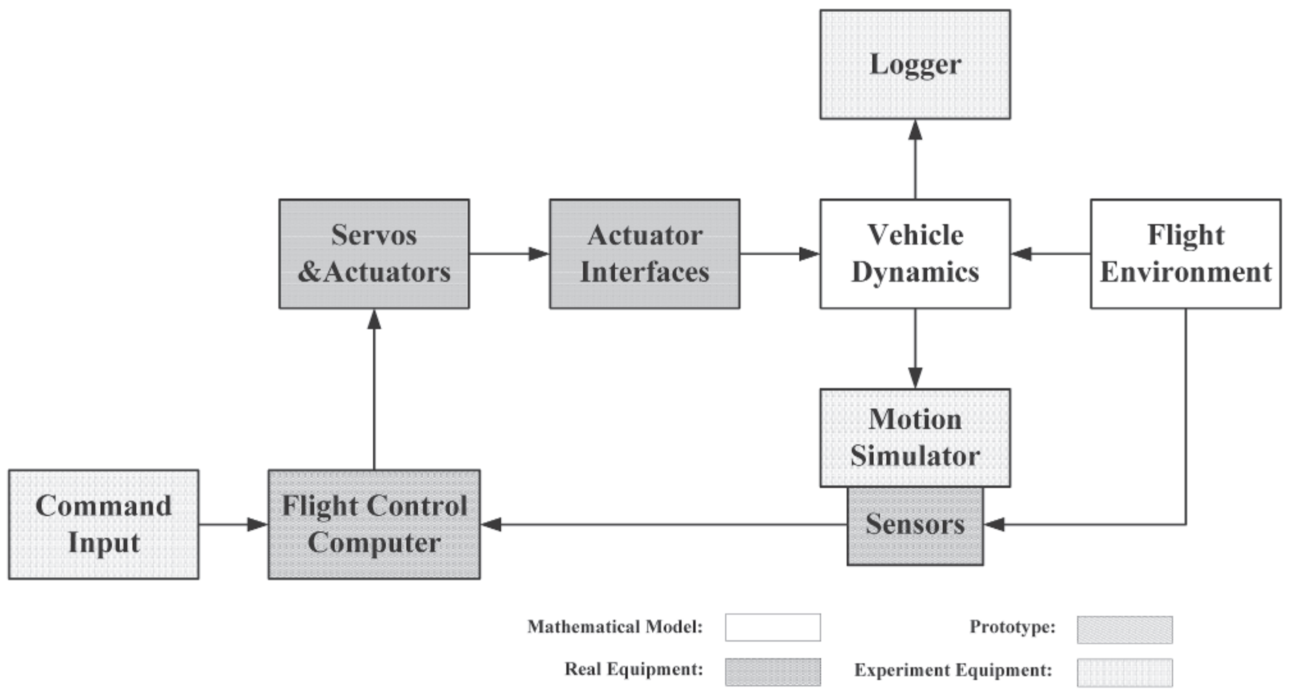

Figure 6 — Simulation system architecture in integrated system phase

9.2 Objective

a) Validating control system flight software functions.

b) Validating signal connection compatibility among sensors, servos and flight control computer.

c) Validating performance of critical elements/components.

d) Validating the consistency between software and hardware.

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

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

g) Verifying design assumptions about control system noise characteristics.

h) Evaluating the effects of nonlinear dynamics not completely known.

i) Simulating potential disturbance and fault of the control system, and validating whether control system could operate under such conditions.

9.3 Input

a) Critical technical indexes and critical parameters of control system.

b) Critical elements/components (including flight control computer at least), and their instruction and interface documents.

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

d) Flight control software.

e) Development and debugging environment of flight control software.

9.4 Output

a) Technical state documents of all devices and software.

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

c) Check-out results and conclusions of critical elements/components.

d) Check-out results and conclusions of flight control software.

e) Check-out results and conclusions of critical indexes.

f) Simulation report.

9.5 Simulation model requirements

Simulation model requirements are same as simulation model requirements of prototype phase (see 8.5).

9.6 Simulation facility requirements

Flight control computer shall use real equipment. The description of any other requirements is same as simulation operation requirements of prototype phase (see 8.6).

9.7 Simulation operation requirements

Besides the requirements described in simulation operation requirements of prototype phase (see 8.7), the following requirements shall be included especially:

— Open-loop testing of flight software;

— Closed-loop testing of flight software.

Annex A
(normative)

Phase comparison between ISO 14300 and ISO 16781

Table — A 1 — Phase comparison between ISO 14300 and ISO 16781

ISO 14300-1	ISO-16781
Phase 0: Mission analysis phase	Conceptual design phase simulation
Phase A: Feasibility phase	
Phase B: Definition phase	
Phase C: Development phase	Detailed design phase simulation
	Prototype phase simulation
Phase D: Production phase	Integrated system phase simulation
Phase E: Utilization phase	—
Phase F: Disposal phase	—

Annex B
(normative)

Relationship between simulation phases and tables

Table — B 1 — Relationship between simulation phases and tables

	Conceptual design phase	**Detailed design phase**	**Prototype phase**	**Integrated system phase**
Chapter 5 (Table 4 to Table 11)	√	√	√	√
Chapter 6	√	—	—	—
Chapter 7	—	√	—	—
Chapter 8	—	—	√	—
Chapter 9	—	—	—	√

ICS 49.140

Price based on 24 pages

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™