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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

English Version

Aerospace series - Programme management - Verification and validation of numerical models and simulations

Série aérospatiale - Management de programme -
Vérification et validation des modèles et simulations
numériques

Luft- und Raumfahrt - Programm-Management -
Überprüfung und Validierung von numerischen
Modellen und Simulationen

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee ASD-STAN.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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European foreword

This document (prEN 9247:2025) has been prepared by ASD-STAN.

After enquiries and votes carried out in accordance with the rules of this Association, this document has received the approval of the National Associations and the Official Services of the member countries of ASD-STAN, prior to its presentation to CEN.

This document is currently submitted to the CEN Enquiry.

Introduction

This document has been drawn up in response to an identified need, which is widely shared among aerospace and defence industry, to have a document laying down recommendations and best practices for ensuring the fidelity and robustness of the outputs of physical behaviour simulations.

Through their recommendations, the experts wish to promote to decision-makers the use of calculations and simulations in all stages of the product lifecycle (from the preliminary project stage to the use stage).

1 Scope

This document provides an inventory of best practices, shared by actors from the aerospace and defence sector, concerning the verification and validation (V&V) of numerical simulations and models, in order to ensure the credibility of the outputs obtained in a logic of faster development of decision-making support, of reducing the number of physical tests, of shortening development times, of facilitating numerical qualification and certification, etc. These are all the major challenges concerning simulation.

The approach applies to models based on physical equations.

EXAMPLE Mechanics, acoustics, electrical, electromagnetism, thermal physics for electronics, fluid dynamics, multibody dynamics, multiphysics, optical, signal integrity and power integrity.

The objective is to determine recommendations depending on the challenges of the simulation, in order to adapt the procedures to be applied to ensure the credibility of the simulation. The items being considered are:

- criticality of the product and the simulation;
- complexity of the phenomenon or the product;
- capability, fidelity and maturity of the model;
- product lifecycle;
- skills;
- verification and validation approach, with uncertainties quantification;
- etc.

This document is organized as follows:

- terms and definitions;
- general principles and concepts of simulation V&V:
 - o the document's objectives and added value;
 - o state of the art;
 - o different uses of simulation depending on the maturity (approximation level) of the model and product lifecycle, linked to the expected fidelity of the model and the simulation outputs;
 - o presentation of the different types of models and impacts on criteria and quantities of interest, as well as on requirements;
- recommended V&V process and activities (linked to the degree of maturity);
- an example of a simulation plan template;
- examples for a clearer understanding.

The aim of this document is to complete and reference the information available in the literature. This document takes a generic approach so that it is applicable by most organizations and for different types and domains of simulation.

This document addresses simulation specialists, simulation team managers and other stakeholders involved in the simulation process or decision-making support.

This document provides recommendations for each criticality level, linked also to the level of confidence in the simulation, at each stage of the simulation process.

Modelling and simulation have long been part of product qualification and certification, and the recommendations laid down in this document do not aim to replace the many qualification, certification and analysis processes already proven and established. The practices recommended in this document were specifically developed in response to potential future applications of modelling and simulation which could, in some cases, give it a more prominent role in qualification and certification, thereby reducing programme costs and development times.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

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

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

3.1

sensitivity analysis

estimation of how the intensity of the variation in the output of a model or simulation can be apportioned to variations in an input of the model or of the simulation

Note 1 to entry: This analysis allows to determine what model parameters have a significant impact on the outputs (quantities of interest).

3.2

outputs analysis

any post-processing or interpretation of individual quantities of interest, tables, data files or execution series resulting from a simulation

3.3

model capability

characteristic that enables a model to answer certain questions or fulfil certain functions

3.4

solver

numerical algorithms describing the simulation process

3.5

factor of safety

multiplying factor to be applied to the values (theoretical, calculated, observed, target) to account for uncertainties in the methods, calculations, input data and assumptions

Note 1 to entry: The choice of a factor of safety for a program is directly linked to the rationale retained for designing, dimensioning and testing within the program or it may be required by regulatory authorities.

Note 2 to entry: A factor of safety does not cover analysis or modelling errors, nor poor design or manufacturing practice.

3.6

boundary condition

physical value at the edge of a product or limits of the domain of interest modelled

3.7

product criticality

index of the severity of an effect on a product combined with the probability of expected frequency of its occurrence

Note 1 to entry: Criticality = probability × severity of an effect.

[SOURCE: adapted from ISO 13372:2012 – Note 1 added]

3.8

criticality of the simulation

assessment of the impact of the simulation-based decision making on the product, programme and people

3.9

discretization

replacement of a continuous domain (space) or interval (time) by a finite set of individual and discrete values which are as close to it as possible

3.10

validated application domain

intersection between the intended application domain and the validation domain

3.11

validation domain

all the conditions, parameters and their intervals that enable shared acceptance of the level of confidence in the simulation outputs

Note 1 to entry: Outside this domain, the outputs can no longer be used with the same level of confidence.

3.12

environment

at a given moment in time, set of physical, chemical and biological agents that are either natural (such as temperature and humidity) or induced (such as impact or vibrations) likely to have an effect on the product or the way it operates throughout its lifecycle

EXAMPLE Examples of environments: operating environment, test environment.

[SOURCE: adapted from the NF X 50-144 series]

3.13

credibility assessment

process by which evidence is collected and documented in order to verify and communicate the credibility of the models and simulation outputs

Note 1 to entry: The degree of credibility can be provided by:

- evidence provided by the V&V approach;
- quantification of uncertainties;
- the expertise and experience of the modelling and simulation specialists;
- judgement;
- decision-makers' understanding of and agreement with the simulation assumptions.

3.14

uncertainty

characterization of doubt concerning the output or input data of a measurement or calculation

Note 1 to entry: Uncertainty can take the form of an interval about the output of a measurement or a calculation that encompasses possible values and probably include the actual output attributed to the corresponding quantity of interest.

Note 2 to entry: Characterization can be qualitative or quantitative (see 3.24).

3.15

margin

difference between the value obtained and the target value

Note 1 to entry: If the margin is positive, it represents the product of interest's optimization ability.

3.16

maturity of a simulation

capability to represent the actual physical behaviour of the product of interest

3.17

measurement of simulation fidelity

comparative analysis to estimate how faithfully the model represents its corresponding product of interest

Note 1 to entry: Fidelity measures include: accuracy (representation level), precision, repeatability, resolution (detail level), scope and sensitivity.

3.18

metadata

information describing the characteristics of a model/simulation to help manage it, understand it, and aggregate to other models, etc

EXAMPLE 1 Examples of characteristics: definition, scope, objective, representation, credibility.

EXAMPLE 2 Examples of ways of managing a model/simulation: creation, use, archiving, change.

3.19

model

description or representation of an object (product, phenomenon or process) realized in order to be able to better study it

Note 1 to entry: A model can be constructed from several sub-models (aggregate). Likewise, any data that goes into a model are considered part of the model.

Note 2 to entry: A model can be conceptual, mathematical, analytical or numerical.

[SOURCE: adapted from NASA-STD-7009A]

3.20

modelling

approach by which a model is built

Note 1 to entry: The elaboration of a model is motivated by a set of precise questions and functions that it shall help to answer and fulfil.

3.21

analysis report

document describing the simulation need and the numerical model suited to the simulation process used and the simulation outputs

3.22

simulation plan

document describing the simulation strategy for a given product

Note 1 to entry: It enables forward planning of all the simulations to be realized and identification of the new processes to be developed and qualified.

3.23

accuracy

closeness between the numerically obtained value and the value considered to be the reference value, allowing to determine the quality of a numerical output

Note 1 to entry: The lower the difference, the closer the output of the numerical simulation is to the intended output.

3.24

uncertainty quantification

UQ

approach by which the sources and impact of uncertainty in the model and tests is determined, with an appropriate level of confidence

Note 1 to entry: Uncertainties are quantified in order to determine how variations in numerical and physical parameters affect the simulation outputs.

3.25

calibration

adjustment of modelling parameters (physical or numerical) within their validity domain so that the results converge with experimental or theoretical data

Note 1 to entry: Calibration is not validation.

[SOURCE: adapted from AIAA G-077-1998]

3.26

simulation output

quantity of interest of the simulated model behaviour

EXAMPLE Quantities of interest may be displacements, stresses, the maximum temperature of electronic components, resistance to hail impact, lifetime, velocity field or flow pressure field.

3.27**robustness of the simulation**

stability of the simulation outputs (do not change in a meaningful way) with respect to a set of similar parameters or variables

3.28**simulation**

implementation of a model in order to study the behaviour and performance of a product or a process

Note 1 to entry: A simulation can be analytical or numerical.

3.29**numerical simulation**

mathematical and computational method for calculating a quantity of interest with respect to a product requirement using a given numerical approach

3.30**solution**

synonym of output

Note 1 to entry: There are three types of reference solution that are used for verification and validation of the simulation:

- the reference analytical solution, the outputs of which come from the analytical resolution of equations;
- the reference numerical solution, the outputs of which come from the numerical resolution of equations;
- the reference experimental solution, the outputs of which come from experimental tests.

Note 2 to entry: Each of these three reference solutions can be used to check non-regression of the simulation software.

3.31**enabling system**

system that supports a product of interest during its lifecycle stages

Note 1 to entry: Enabling systems do not necessarily contribute directly to the product of interest's functions during operation.

[SOURCE: adapted from ISO/IEC/IEEE 15288 – addition of note 1]

3.32**phenomena identification and ranking table – *PIRT***

list of physical phenomena influencing the responses of the product of interest

Note 1 to entry: This list is accompanied by a ranking showing the importance of each phenomenon.

[SOURCE: ASME V&V 10:2019]

3.33**validation**

approach of determining the degree to which a numerical model is an accurate representation of the physical product from the perspective of the intended uses of the model

Note 1 to entry: Validation aims to make sure the right equations are solved.

[SOURCE: adapted from ASME V&V 40:2018]

3.34

verification

approach of determining that a numerical model accurately represents the underlying mathematical model and its reference solutions from the perspective of the intended uses of the model

Note 1 to entry: Verification aims to determine that the equations are rightly solved in terms of accuracy, stability and performance, from a numerical and computational perspective.

Note 2 to entry: In the case of multiphysics coupling, verification aims to determine that the links and interfaces between the simulation tools are correctly designed and implemented.

[SOURCE: adapted from ASME V&V 40:2018]

4 List of acronyms

0D	zero-dimensional space
1D	one-dimensional space
2D	two-dimensional space
3D	three-dimensional space
ASME	American society of mechanical engineers
ASN	French nuclear safety authority [<i>autorité de sûreté nucléaire</i>]
CAD	computer-aided design
CAS	credibility assessment scale
CDR	critical design review
CFD	computational fluid dynamics
DNS	direct numerical simulation
EAS	electronic archival system
EASA	European union aviation safety agency
EHSA	electro-hydro-static actuator
EMA	electro-mechanical actuator
ESQMS	engineering simulation quality management guidelines
FDA	food and drug administration
GAP	gap analysis process
IADT	inspection, analysis, demonstration, test
ISS	in-service support
IVVQ	integration, verification, validation and qualification
IVVQP	integration, verification, validation and qualification plan
LES	large eddy simulation
LOTAR	long-term archiving and retrieval
MIL-STD	military standard
NAFEMS	national agency for finite element methods and standards
NASA	national aeronautics and space administration
OAIS	open archival information system
PCMM	predictive capability maturity model
PIRT	phenomena identification ranking table
PLM	product lifecycle management
PSD	power spectral density
RETEX	lessons learned [<i>retour d'expérience</i>]
SOM	strength of materials
SPDM	simulation process and data management
SPH	smoothed particle hydrodynamics
VCRM	verification cross-reference matrix
V&V	verification and validation
V&V&UQ	verification, validation and uncertainty quantification

5 Principles/concepts

5.1 Document objectives and added value

The objective of this document is to provide, in a shared (essential for collaborative work) and recognized manner, a V&V approach for numerical simulation, based on experience sharing and the use of best practices (such as modelling, V&V or drafting of the analysis report).

Thus, by following a mature and shared process, the outputs of simulations, whose robustness and relevance can be better accepted, may be used as reliable justification elements for qualifying or even certifying a physical product.

What is important is to highlight best practices to be shared along with the rules, in order to shorten development stages and, consequently, reduce product development costs and risks (while providing justification for the cost of setting up the simulation). These benefits can be achieved by improving the credibility of the simulation.

5.2 Simulation-related organization

The model V&V approach covers elements such as:

- selection and validation of the software used;
- development of “in-house” tools for verification of the model (such as meshing) and the quality of the outputs;
- checklist of verifications performed;
- model design guides;
- staff training and supervision policy;
- validation and authorization workflow for technical reports; or
- archiving policy for models and related technical reports;

If the project involves cooperation between several stakeholders, it is preferable for them all to refer to the same document, one that is accepted by everyone, recommending a set of best practices. That means everyone is using the same baseline, and it reinforces mutual confidence in the quality of the simulations.

5.3 Maturity of a model

5.3.1 Maturity levels

The maturity of a simulation model is the status of a simulation model in its development stage, enabling identification of its context of use. The maturity of the model is directly linked to knowledge of:

- the product (maturity) and its environment;
- the data (source and quality);
- the physical behaviours to be taken into consideration and their simulation methodologies [lessons learned (RETEX) from the physics modelled].

There are two aspects to be noted when assessing the maturity of a model:

- the question of interest;

- the development cycle of the product of interest.

Answers to the question of interest differ depending on whether the model is used upstream of the product development with the aim of performing V&V as early as possible, or later in the product development process, with fewer uncertainties.

5.3.2 Maturity assessment methods

5.3.2.1 General

Maturity assessment can be addressed from two perspectives:

- from the perspective of the simulation specialist; or
- from the perspective of the person who needs to have confidence in the model or simulation outputs, which constitute a decision-making support.

Two model maturity assessment methods are presented, one from the perspective of a simulation specialist (see 5.3.2.2 and 5.3.2.3) and one method based on the second perspective (see 5.3.2.4).

An approach for creating a maturity assessment method is also described (see 5.3.2.5).

Model maturity is expressed as an overall level for the first method (see 5.3.2.2) and according to maturity criteria for the other methods.

5.3.2.2 Overall maturity assessment

Table 1 gives an example of an assessment of the overall maturity level of a simulation model.

Table 1 — Example of an assessment of the overall maturity level of a simulation model

Maturity levels of the simulation model	Maturity criteria
1	Geometrical representation, loads and boundary conditions adapted to analytical calculations.
2	Mesh based on simplified geometries. Uncertain loads. Approximate boundary conditions. Simplified constitutive laws.
3	Mesh based on detailed geometries. Formally and completely defined loads. Formally and completely defined boundary conditions. Simplified constitutive laws.
4	Mesh based on detailed geometries. Formally and completely defined loads. Formally and completely defined boundary conditions. Constitutive laws adapted to the physical phenomena to be analysed.

5.3.2.3 PCMM method

Another example of model maturity assessment method is the PCMM (predictive capability maturity model) method. This method assesses the maturity level corresponding to the impact of the simulation on the product development (from concept engineering through to qualification or certification).

These four maturity levels take into account:

- the impact of the simulation with respect to other contributing evidence in addressing the question of interest; and
- the consequence of the decision, i.e. the significance of an adverse outcome resulting from an incorrect decision concerning the question of interest.

Six types of evidence of maturity related to model fidelity (both geometric and physics), verification (code and solution), validation and analysis of uncertainties, are assessed.

5.3.2.4 CAS method

Another method for assessing the credibility of the simulation outputs is the CAS (credibility assessment scale) method put forward by NASA (NASA-STD-7009A, Appendix E, 2016). This method is based on eight independent criteria grouped into three categories (model and simulation development, model and simulation use, supporting evidence).

Each criterion is assessed against a set of five maturity levels related to data, practices and processes control (in terms of formalization, documentation, traceability, source, uncertainties, sensitivities) and experience.

5.3.2.5 Approach for creating a specific method

A maturity assessment method for a simulation model can be established as follows:

- a) choose and classify the maturity evidence so as to assess the different aspects of the modelling and simulation;
- b) establish maturity criteria corresponding to the maturity evidence to be provided;
- c) specify, for each maturity criterion, the activities that make it possible to progressively increase their maturity level;
- d) define, for each maturity criterion, the target maturity level to be reached, in accordance with the related risk;
- e) describe, for each maturity criterion, how to achieve the proposed maturity objective.

The target maturity level increases in relation to the risk level associated with use of the model. The maturity level of each criterion contributes to the overall maturity level of the model.

It is recommended that the maturity requirements be adjusted with respect to:

- the model purpose and scope; and
- the consequences of an incorrect decision.

The applicability of the maturity criteria with respect to the model's purpose and scope shall be described.

The higher the maturity requirements for a simulation output, the higher the amount of effort and rigor level applied to V&V, adapted to the risk.

The level of confidence in a simulation output is assessed by maturity criteria and not globally.

5.3.2.6 Aggregation of one or more models in a higher-level model

Models and simulations can be developed from the elementary level (material, component) of a product-to-product level (subassembly, system). Models can be aggregated in the following ways:

- between one hierarchical level of the product and a higher level, for example in order to understand the interactions between elements represented at different levels (multiscale simulation);
- at the same hierarchical level of the product, for example in order to understand interactions between physical phenomena (multiphysics simulation);
- by combining the first two approaches (multiphysics and multiscale simulation).

The computation time, levels of detail and accuracy (resolution) and fidelity are the main differences between these models. Elementary-level models and simulations usually have greater resolution and are more accurate than their higher-level counterparts.

If the simulation purpose requires more accurate solutions, but the implementation of a model is compromised by the complexity of the problem, it is possible to fulfil this purpose in various stages.

EXAMPLE The structural zoom method makes it possible to refine a small concerned section of the part within a complex assembly with the geometry of simplified parts.

When one or more models are aggregated in a higher-level model (model hierarchy), in another context or in the case of coupling between models, the level of each maturity criterion of the lower-level model(s) ought to be known and traced, to facilitate the assessment of the maturity levels of the higher-level model. This also raises the question of the propagation of uncertainties.

Each organization should define and share (at least internally) its maturity levels as well as its criteria for progressing to the next maturity level.

5.3.3 Maturity based on the product lifecycle stages

5.3.3.1 Design and development

In the preliminary project stage, the necessary input data (geometries, loads, etc.) to realize the simulations are often inaccurate and can change considerably. During this design stage, simulation plays a risk-elimination role and guides the major design choices. Models are often basic and offer the possibility of testing several configurations quickly. Model maturity levels are often fairly low overall.

NOTE Representation of the physical model is sufficient when it comes to making a choice, but not for qualifying the product of interest.

In the development stage, input data becomes more accurate, models are more complex and incorporate more and more details.

5.3.3.2 Manufacturing

In the manufacturing stage, simulation can be used to assess the consequences of any factory anomalies on the performance of the product of interest. The models' degree of detail and the complexity of the simulations may vary considerably according to expertise to be carried out.

5.3.3.3 Test preparation

Simulation can be used in the test preparation stage, for example to:

- suggest the best way of positioning an instrument;

- ensure the success of a test;
- quantify the deviations between a test and “real life” behaviour (e.g. wind tunnel vs flight).

It is sometimes necessary to represent the product of interest with its enabling system (e.g. test equipment for this stage in the lifecycle of the product of interest).

During the analysis stage, simulation will provide a way of interpreting the measurement outputs. On-site and laboratory tests are one way of increasing a model's maturity level.

5.3.3.4 Qualification/certification

The qualification and/or certification stages often require tests that can be very expensive or sometimes impossible to realize. During this stage, simulation purpose to represent the real world, meaning they can help reduce the number of tests necessary for qualification and/or certification of the products of interest (shift to virtual tests). Models often have a very high maturity level in this stage.

5.3.3.5 In-service support (ISS)

During its operating stage, the product of interest may be subject to different types of damage, the consequences of which can be analysed using numerical simulation. As for the manufacturing stage, a model's degree of detail may depend heavily on the needs of the expertise.

Appropriate models and simulations are set up for each of the stages related to the lifecycle of the product of interest and based on its development maturity.

During the lifecycle stages of the product of interest, the models shall be reassessed, especially if the assumptions or expertise needs change (data calculated or observed, etc.).

6 Modelling and simulation

6.1 Assessment of the simulation need

Before performing a simulation (considered as model instancing), its contribution in terms of knowledge and/or its added value for the programme or for the organization should be identified.

For example, simulations can be used to understand, explain, describe, predict, explore and support decision-making. These are some examples of the types of use for different stages of the product lifecycle:

- design and development:
 - o contribute to the product specification (severity of the requirements and their breakdown);
 - o guide the product design (choice of architecture);
 - o analyse the product behaviour to understand the product and its behaviour;

NOTE In some cases, simulation is the only way of study [rare, incomplete, inaccurate or unreliable data, real target product of interest or elements interacting with the target product of interest are unavailable, costs lower or development times shorter than those of physical tests (as in the nuclear industry, for example)].

- o study dependencies or the influence of deterministic or random variables [stability, sensitivity, reliability (e.g. Monte-Carlo method) and robustness analyses] to make it easier to explain a phenomenon and enable the prediction of what might happen;
- o establish critical points by exploring different situations in order to find a robust and optimum solution;