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Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 3:
Example of a CFD model

Ingénierie de la sécurité incendie — Évaluation, vérification et validation des méthodes de calcul —

Partie 3: Exemple d'un modèle CFD

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Foreword

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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 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

ISO 16730 consists of the following parts, under the general title *Fire Safety Engineering — Assessment, verification and validation of calculation methods*:

— *Part 3: Example of a CFD model*

— *Part 5: Example of an Egress model* (Technical report)

The following parts are under preparation:

— Part 2: *Example of a fire zone model* (Technical report)

— Part 4: *Example of a structural model* (Technical report)

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For the particular case of the example application of ISO 16730-1 described in this part of ISO 16730, ISO takes no responsibility for the correctness of the code used or the validity of the verification or the validation statements for this example. By publishing the example, ISO does not endorse the use of the software or the model assumptions described therein, and state that there are other calculation methods available.

Fire safety engineering — Assessment, verification and validation of calculation methods —

Part 3:
Example of a CFD model

1 Scope

ISO 16730-1 describes what the contents of a technical documentation and of a user's manual should be for an assessment, if the application of a calculation method as engineering tool to predict real-world scenarios leads to validated results. The purpose of this part of ISO 16730 is to show how ISO 16730-1 is applied to a calculation method, for a specific example. It demonstrates how technical and users' aspects of the method are properly described in order to enable the assessment of the method in view of verification and validation.

The example in this part of ISO 16730 describes the application of procedures given in ISO 16730-1 for a computational fluid dynamics (CFD) model (ISIS).

The main objective of the specific model treated in this part of ISO 16730 is the simulation of a fire in an open environment or confined compartments with natural or forced ventilation system.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16730-1, *Fire safety engineering — Assessment, verification and validation of calculation methods — Part 1: General*

3 General information on the CFD model considered

The name given to the CFD model considered in this part of ISO 16730 is "ISIS". The computer code ISIS, developed by The French Institute for Radiological Protection and Nuclear Safety (IRSN) and defined as a computational fluid dynamic model (also called CFD or field model), is based on a coherent set of models that can be used to simulate a fire in large and mechanically ventilated compartments. This kind of configuration involving complex flows requires an accurate physical modelling and efficient numerical methods. Usually, the spatial and time scales encountered in fires are very disparate and the coupling between phenomena is very strong.

The verification and validation phases of the code are two distinct processes which are constantly updated based on the last code developments. The verification phase employs a wide range of techniques such as the comparison to an analytical solution for model problems, the use of manufactured solution, and the comparison to benchmark result. The validation process is based on the so-called building-block approach including first-unit problems, sub-system cases, and then large-scale realistic fire experiments. This process allows dividing a complex engineering system into several simpler cases. Consequently, the validation guide of this code[1] includes laminar, turbulent, and fire cases and contains a total of 18 test cases.

4 Methodology used in this part of ISO 16730

For the calculation method considered, checks based on ISO 16730-1 and as outlined in this part of ISO 16730 are applied. This part of ISO 16730 lists in Annexes A and B the important issues to be checked in a left-hand column of a two-column table. The issues addressed are then described in detail and it is shown how these were dealt with during the development of the calculation method in the right-hand column of Annexes A and B, where Annex A covers the description of the calculation method and Annex B covers the complete description of the assessment (verification and validation) of the particular calculation method. Annex C describes a worked example, and Annex D adds a user's manual.

Annex A
(informative)

Description of the calculation method

A.1 Purpose

Definition of problem solved or function performed	— The main objective of this calculation method is to simulate a fire in an open environment or confined compartments with natural or forced ventilation system. — The basic modelling relies on a low Mach number formulation of the Navier-Stokes equations combined with a turbulent combustion model adapted for variable density flow.
(Qualitative) description of results of the calculation method	— Output includes — gas temperature in the fire room and neighbouring rooms, — pressure variation during the fire, — inlet and outlet mass flow rates in the admission and extraction branches of the compartment, — heat flux received by a wall, — oxygen depletion in the compartment, and — combustion products in the compartment and target rooms.
Justification statements and feasibility studies	The effect of the fire growth process on the ventilation network is a major concern for Fire Safety Analysis. Consequently, the model has been developed to allow the coupling between a ventilation network and a fire in a mechanically ventilated compartment. Pressure variations in the fire compartment are also connected on the ventilation network and can cause reverse flows in the inlet or exhaust branches. This critical scenario is also of major interest for Fire Safety Analysis.

A.2 Theory

Underlying conceptual model (governing phenomena)	Physical modelling in this calculation method is based on classical local conservations laws for physical quantities such as mass, momentum (in a low-speed flow formulation), energy, and species concentrations. Governing formulae in the case of a fire simulation describe a turbulent reactive flow with radiative transfers.
Theoretical basis of the phenomena and physical laws on which the calculation method is based	This field model is a Reynolds-Averaged Navier-Stokes (RANS) model with a two-formula closure for turbulent flow. The scalars fluxes are modelled by the gradient diffusion assumption and buoyancy effects are considered in turbulence production terms. The combustion model is based on the conserved scalar approach and assumes a fast chemistry. It relies on a modified eddy break up model for non-premixed combustion.

A.3 Implementation of theory

Governing formulae	The set of governing formulae are described in detail in References [2] and [5]. To simulate a fire in a confined compartment, the following governing formulae are solved: — RANS equations; — two-formula turbulence closure (k-ε); — mixture fraction (combustion process); — fuel mass fraction; — enthalpy; — radiation transfers; — Bernoulli equations for inlet and exhaust branches. The density of the reactive mixture is defined using the ideal gas law (equation of state of perfect gas) and the mean molecular weight of individual species of the mixture.

Mathematical techniques, procedures, and computational algorithms employed, with references to them	The balance formulae for scalars (species, enthalpy, etc.) are discretized in time and in space using a finite volume method to obtain schemes that achieve a good compromise between the calculation time and accuracy and ensure that unknowns stay within their physical boundaries; second-order up winding techniques are used to accurately take into account fast spatial variations in unknowns, without stability loss. The Navier-Stokes equations are discretized in space using a finite element technique that satisfies the compatibility properties between velocity and pressure necessary for stability. Unlike finite volume schemes with staggered meshes, this technique also makes it easy to use meshes that are locally unstructured due to the geometry involved or refinement. To ensure coherence with the finite volume discretization, the approximation selected is low-order and conforming.[10] The temporal discretization is performed with a fractional step scheme such that in Reference [11]. This semi-implicit scheme allows large time-step while each formula is solved in sequence. The model is based on the scientific computing development platform PELICANS, which is available as open-source software (https://gforge.irsn.fr/gf/project/pelicans). PELICANS offers a library of software components, consisting of "building blocks" for implementing numerical methods. The model is entirely parallelized via this platform, for both the assembly and solution of discrete systems.
Identification of each assumption embedded in the logic; limitations on the input parameters that are caused by the range of applicability of the calculation method	— structured mesh; — hydrodynamic model: low Mach number assumption; — molecular diffusion: each species of the mixture have the same mass diffusion coefficient; — heat capacity: only constant heat capacity is used; — turbulence model: RANS formulation, Boussinesq approximation for the eddy viscosity, simple gradient diffusion hypothesis, constant turbulent Prandtl, or Schmidt number; — combustion model: non-premixed combustion, unity Lewis approximation; — heat transfer model: 1D heat conduction in walls; — radiation model: gray media assumption, no diffusion in the Radiative Transfer Equation.
Discussion of precision of the results obtained by important algorithms, and, in the case of computer models, any dependence on particular computer capabilities	In general, the results given by the model for the simulation of a fire in a confined compartment are in good agreement with the measurements. An error of the order of 10 % to 20 % is observed for temperature, species mass fraction, wall heat flux, pressure, and ventilation flow rate variations.
Description of results of the sensitivity analyses	Work described in Reference [12].

A.4 Input

Required input	— geometry; — mesh; — time-step; — thermophysical properties (for fuel, walls, insulation); — initial conditions; — boundary conditions; — resistance of the inlet and exhaust branches.
Source of the data required	— Data for geometry, time, and space discretization are user's input. — Material properties should be taken from test or literature.
For computer models: any auxiliary programs or external data files required	LINUX distribution with — gcc 4 (or newer version), — GNU make 3.77 (or newer version), — PERL 5.6 (or newer version), and — Java 1.5.0 (or newer version). Postprocessing tools are — Meshtv, — OpenDX, — GMV, — PARAVIEW, or — FIELDVIEW. Mesh generation with ISIS or — Emc2, — Mefisto, — Gambit, or — GMSH.
Provide information on the source, contents, and use of data libraries for computer models	Data libraries concerning fuel properties or walls or insulation materials can be found in SFPE Handbook of Fire Protection Engineering.