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Status and perspectives of CFD

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Abstract

During the last decades, Computational Fluid Dynamics (CFD) has known a very rapid development both in the development and validation of models and in computational capacities. This paper aims at describing this evolution and more especially its impact in the field of nuclear reactor thermal-hydraulics for both design and safety studies applications. The OECD/NEA/WGAMA CFD task group has been very active in this field over the past two decades. Despite these important developments, only a rather limited number of safety demonstrations are currently based on CFD computations. The limitations still hindering a larger use, and perspectives for progress in this field, will be outlined.

1. Introduction

Computational Fluid Dynamics (CFD) corresponds to the numerical solving of the full set of Navier-Stokes equations. In most applications the full spectrum of length and time scales cannot be resolved down to the Kolmogorov scale, and a turbulent model must be introduced (fully resolved turbulence corresponds to Direct Numerical Simulation, DNS, which is still out of reach for most industrial applications). CFD allows for a 3D and potentially transient modelling of the flow in a fluid domain that explicitly considers the details of the geometry (although some hybrid approaches are sometimes used, describing some solid parts of the domain as porous zones). This powerful numerical tool leads to relatively costly computations with respect to other approaches (like system or component codes) but permanent progress in scientific computing allows for huge computations nowadays.

In many industries, e.g. aeronautics, CFD is currently used in the development process of new designs since, according to the quality of its predictions, it can actually partially replace some costly experiments. Nevertheless, it can never fully replace experiments since a large set of open issues concerning turbulence models still limits its validation range. Moreover, validation of CFD against experiments requires a high quality standard of the data, a concept that has been defined as “CFD-grade experiments”, [1]. In nuclear industry, CFD is more and more commonly used for design purposes and begins to appear in a continuously increasing but to this day still limited number of nuclear safety studies.

2. CFD in nuclear safety

Thermal-hydraulic studies in the field of nuclear safety are largely dominated by system codes and so-called component codes.

Still, CFD is an attractive tool for all flow configurations that involve 3D features; these are relatively common in nuclear related TH issues. During the last two decades, the WGAMA has supported the activity of the so-called CFD-TG. Activity of this group has notably concerned the organization of 7 CFD4NRS workshops up to now (CFD4NRS-8 is planned in November 2020). For each workshop, a synthesis report is produced [2]–[7]

and selection of articles are published within special issue [8]–[12]. The group has also produced around a dozen reports including Best Practice Guidelines [13] and has organized several benchmark activities:

1. OECD/NEA-Vattenfall T-Junction Benchmark Exercise (high-cycle thermal fatigue), [14];
2. OECD/NEA-KAERI Rod Bundle CFD Benchmark Exercise (turbulent mixing downstream of a spacer grid), [15];
3. OECD/NEA-PSI CFD Benchmark Exercise (jet erosion of a stratified atmosphere based on PANDA), [16];
4. OECD/NEA-PSI CFD benchmark with Uncertainty Quantification (turbulent mixing based on GEMIX), [17];
5. OECD/NEA-TAMU Cold Leg Mixing Benchmark with Uncertainty Quantification, on-going activity started in 2017.
6. OECD/NEA Fluid Structure Interaction benchmark just started in June 2020, based on an experiment by OKBM).

The development of CFD for its use in nuclear industry covers a wide range of specific fields:

- Coupling with larger scale (like system scale) tools
- Coupling with other physics (thermo-mechanics, neutronics)
- Two-phase flow modelling (most commonly based on the Euler-Euler 6 equations model, but also using the Lagrangian approach for some applications).

Such development activities are performed both for commercial and open-source CFD software and have been often supported by large scale projects (in the U.E. or in the U.S. more particularly).

The use of CFD within a nuclear safety demonstration should allow a better understanding of some TH issues, and potentially allow to go beyond some conservative assumption that were previously used because of a lack of knowledge. But such use of CFD requires the user to follow good practices that can be formalized in Best Practice Guidelines [2]. It also requires the matching of high standards for verification-validation and uncertainty quantification (V&V UQ) [18]. Examples of applications for which CFD has been used in assessed safety studies are the Dry-Cask application in the U.S., [19], or the Heterogeneous Boron Dilution scenario in France, [20].

Recent activity of the WGAMA CFD TG (CAPS “CFD for Nuclear Reactor Safety Phase 5 – Toward an enlarged use” for the 2019-2021 period) is devoted to the analysis of this problematic. A topical opinion paper will be produced to summarize the present situation, and then to identify the present limits hindering a larger use of CFD (all kinds of limits, related to the CFD tools themselves, to methodologies – like with the quantification of uncertainties – or to human factors) and to propose paths to overcome them.

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