Preface

Why collect test-cases for interface tracking methods?

Several years ago, Hewitt *et al.* (1986) suggested that refined modelling of two-phase flow was a major key in meeting some complex industrial challenges associated with nuclear energy production. In particular, they reported that the understanding of the intricate heat transfer and fluid mechanics phenomena that control the critical heat flux or the pressurized thermal shock could not be easily reached within the frame of area-averaged or time-averaged models. In addition, the understanding of the interaction of probes with two-phase flows or the local conditions controlling wall boiling could benefit from a refined analysis of two-phase flows describing both the motion of each phase and that of the interfaces.

Beyond the energy field, the oil industry is also facing new challenges related to two-phase production of oil and gas. Sizing pipelines, separators and predicting the hydrate formation requires a flow description at a scale which is not covered by the existing 1D area-averaged models. From these examples arising from nuclear engineering and the oil industry, there is clearly a *definite need* to refine the models scale of analysis of two-phase flow with or without phase change.

Modeling requires characterizing flow and heat transfer at a scale consistent with the scales described by the models. When refining the scales of observation, instrumentation may become unacceptably intrusive or mere observation may become impossible without hampering the flow features by modifying the boundary conditions. An example of this situation is forced convective boiling. Details of the high pressure water flows close to the walls are probably beyond the reach of existing experimental techniques for several years and refined modeling was identified as a possible breakthrough to progress towards an in-depth physical understanding (Delhaye & Garnier, 1999).

Another objective favouring the development and the use of local models of two-phase flows is the tremendous difficulty in providing appropriate models (closure relations) to local-time-averaged models. Solving at a refined scale and analyzing the results by averaging them at the scale relevant to the time-averaged model is a possible way to identify appropriate closure relations to these averaged models.

However, *local modeling* of two-phase flow must not be confused with *simulation* as it is for example understood when solving the Navier-Stokes equations for single-phase flow. Indeed, wetting phenomena, coalescence physics or heat transfer along a moving contact line cannot be described and must be modeled. As a consequence and as usual when modeling is involved, validation is necessary to gain confidence in the model predictions.

A historical view

In 1994, CEA started studying new methods to describe local two-phase flows and heat transfer with phase change. At that time, several two-phase CFD modeling methods or computational multiphase flow dynamics models (CMFD) were developed, but the inclusion of phase change into them was still a real challenge. Among all tracks which were identified, two main paths were explored to account for phase change phenomena: improving front tracking algorithms to account for the normal velocity discontinuity at the interface, and modifying the thermodynamic description of the interface within a single fluid approach. It was readily demonstrated that various physical and numerical problems were to be solved and that the evaluation of the potential solutions required reference situations where both the physics and the numerical techniques were precisely controlled. This was the basic idea of the test-cases.

In France and in Europe, several groups were also interested in these problems and during two meetings on January and June 2000 in Grenoble, France, it was realized that the need for test-cases was merely universal in this community and that exchanging, or better sharing, a common set of well tried and tested benchmarks could benefit to the progress of CMFD development. A first set of nearly 20 test-cases were then decided. Originally written in French, it was thought useful to invite European colleagues to contribute and to select English as a common language. Next, collecting these test-cases into a book was the sound and logical follow-up of the basic idea to provide worldwide developers with this previously scattered information.

Multiphase Science and Technology traditionally fosters this type of activity. Hewitt *et al.* (1986) edited a selection of reference data sets for validating 1D area-averaged two-phase flow and later, Hewitt *et al.* (1991) provided a forum to discuss the merits of various systems codes based on their ability to describe the physical situations relative to the collected data. The editors of this book thank Multiphase Science and Technology for its constant help in suggesting contributors and organizing the internal review of the proposed test-cases.

Organization of the test-cases collection

Test-cases were initially collected rather randomly and as they became more and more numerous, it was deemed important to provide the reader with the primary interest of the test-case and the targeted part of the CMFD model. This is indicated by capital letters directly following the title of the test-case. Two main categories are proposed:

- **N**: Purely numerical test-case to check for example some discretization methods,
- **P**: Physical test-case to verify a selected physical model or phenomenon controlled by the balance of selected effects.

In this latter category, further subdivision was considered:

- **PN**: Physical test-case compared to a reference numerical method regarded as more accurate
- **PA**: Physical test-case compared to an analytical solution possibly evaluated numerically
- **PE**: Physical test-case compared to an experiment
- **PC**: Test of coherence

A tentative sorting may be proposed according to the type or number of competing physical mechanisms involved in the test-case.

- Test with only one effect:
  - Pure transport (numerical scheme only: rotation, translation, stretching, etc.)
  - Interface deformation in a prescribed velocity fields
  - Shock jump conditions
- Two or three terms of the momentum balance equation:
  - Surface tension truncation errors against viscosity (spurious currents)
  - Buoyancy against surface forces (Rayleigh-Taylor)
  - Inertia against surface tension forces (oscillation of an inclusion)
  - Inertia against viscous forces (capillary standing waves, solitary capillary wave)
  - Buoyancy against drag forces (rise of an inclusion)
  - Viscosity contrast (two-phase Poiseuille flow)
  - Compressibility contrast (shock-bubble interaction)
- Phase-change:
  - Heat conduction and mass balance (1D Stefan problem, plane or spherical symmetry,)
  - Bubble growth in a superheated liquid
- Solid surface effects:
  - Contact angle (pinning)
  - Capillary rise upon gravity reduction
  - Droplet impact and bouncing on a hot wall

- Local mechanisms with more complex situations :
  - Drop impact on a liquid film
  - Gas bubble bursting at a free surface
  - Collision of two droplets (hydrodynamics)
  - Shape of long bubbles in a tube
- Complex mechanisms or situations:
  - Mould filling by a viscous jet (inertia, viscosity and gravity)
  - Phase inversion in a closed box (mass balance, with viscosity and surface tension)
  - 2D sloshing
  - Lock-exchange flow
  - Unsteady cavitation in a Venturi

Each test-case is self-supporting and focused. The interest and emphasis are developed in a first section. Next, the theory necessary to understand the physical situation and the reference model is shortly explained with a discussion of its validity domain. Necessary references are provided. Next, the details of the test-case are provided *i.e.* the definition of the computation domain, the boundary conditions and the physical properties. Finally some results in a form that allows an easy handling (analytical formula, arrays of figures) are proposed with a common method for evaluating the errors between the calculated results and the reference.

Finally to ensure each data set is complete, a referee has been selected within the group of contributors to play the role of a potential user of the test-case. When the input of this internal referee was deemed significant by the authors they usually included him as the last author of their test-case.

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References

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