VERIFICATION AND VALIDATION (V&V)

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OUTLINE

Outline

Generalities

- Verification and Validation - in short *V&V* - in Computational Fluid Dynamics (CFD) and Computational Heat Transfer (CHT).
- The objective of *V&V* is to establish the credibility of a computational/simulation model by assessing the degree of accuracy of the simulation results.
- The consequences of inaccurate CFD results are at best wasted time, money and efforts, and at worst catastrophic failures of components, structures and machines.
- First formal definition of VV due to the US Department of Defense (DoD) in 1994, followed by American Institute of Aeronautics and Astronautics (AIAA 1998), American Society of Mechanical Engineers (ASME 2006; 2009) and US Dept. of Energy (2001).

Verification the process of determining that a computational model represents the underlying mathematical model and its solution (ASME 2006).

Validation the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model (AIAA 1998).

Uncertainty Quantification The process of determining, given uncertainty in inputs and parameters, the uncertainty in the output.

Generalities - cont.

- Although we focus upon CFD and CHT, the same concepts and methodologies apply as well as to all relevant CAE (Computer Aided Engineering) fields, like e.g. Structural analysis (static and dynamic), electromagnetic, acoustics, et.;
- The *V&V* procedures presented can be applied to engineering modelling problems of various degree of complexity (fidelity): from simple lumped element models, to 1D steady flows up to 3D unsteady multiphase flows.
- In *V&V* the goal is *validation*, which is defined as the procedure of determining the degree of accuracy to which a model represent the real world from the perspective of intended use of the model.
- Validation *must* be preceded by *code verification* and *solution verification*:

  Code verification: Establishes that the code accurately solves the mathematical model, i.e. it is free of mistakes.

  Solution verification: Estimates the numerical accuracy of a particular calculation.

Generalities - cont.

Objective of Validation:

- Estimation of the range of the simulation error.
- Comparison of the simulation result (solution) with an *appropriate* experimental result (data) for specified *validation variables* and a specified *set of conditions*.
- Cover a range of conditions within a domain of interest.

There is no validation without experimental data with wich to compare the result of the simulation.

Standards and Guidelines

There are relevant Standards and Guidelines, besides books and manuals, dedicated to *V&V* for CFD, CHT and CSM (Computational Solid Mechanics):

ASME *V&V* 20-2009 ASME (2009). *Standards for verification and validation in computational fluid dynamics and heat transfer*, American Society of Mechanical Engineers, New York, NY.

ASME *V&V* 10-2006 ASME (2006). *Guide for verification and validation in computational solid mechanics*, American Society of Mechanical Engineers, New York, NY.

AIAA-G-077-1998 AIAA (1998). *Guide for the verification and validation of computational fluid dynamics simulations*, American Institute of Aeronautics and Astronautics, Reston, Virginia.

ISOIEC GUIDE 98-3:2008 ISO (2008). *Uncertainty of measurement - Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*, International Organization for Standardization, Geneva.

NISTIR 8298 D.Hun Yeo, *A summary of Industrial Verification, Validation, and Uncertainty Quantification Procedures in Computational Fluid Dynamics*, NIST - National Institute of Standards and Technology, March 2020, available free of charge from: `https://doi.org/10.6028/NIST.IR.8298`.

Standards and Guidelines - cont.

- The *ASME V&V 20-2009* Standard:
  - It is based on on the concepts and definitions of error and uncertainty internationally adopted by the experimental community.
  - It applies to the errors and uncertainties in the experimental result and also to the errors and uncertainties in the result of the simulation.
- *Objective* of the *ASME V&V 20-2009* Standard: specification of a *V&V* approach that quantifies the degree of accuracy inferred from the comparison of solution (simulation) and data (experiment/measurement) for a specified variable at a specified validation point.
- *Scope* of the *ASME V&V 20-2009* Standard: quantification of the degree of accuracy for cases in which the conditions of the actual experiment are simulated.

Error and uncertainty

We should distinguish between *error* and *uncertainty*:

Error: a recognizable deficiency in a CFD model that *is not caused by lack of knowledge.*

Uncertainty: a potential deficiency in a CFD model that *is caused by either randomness or lack of knowledge.*
We should distinguish two types of uncertainties:

- **Aleatory uncertainty:** uncertainty due to inherent randomness.
- **Epistemic uncertainty:** uncertainty due to lack of knowledge.

Error sources

A computational (numerical) model calculated in a computer cannot avoid errors or uncertainties in the results due to a wide range of sources of inaccuracy.
At this stage we make no difference between error and uncertainty and the term *error* is used to identify the sources of inaccuracy of the CFD and CHT results.

The errors in CFD and CHT can be classified into four types:

1. Physical modeling errors.
2. Discretization errors.
3. Convergence and round-off errors.
4. Programming and user errors.

Verification

- Easiest to define
- *Verification:* show that the code solves the equations that it is intended to solve with the expected accuracy:
  1. Code verification (once and for all).
  2. Solution verification (every time for new problems).
- A verified code can produce wrong solutions for different problems if one chose the wrong time-step or inadequate resolution or incorrect boundary conditions.
- Code verification has nothing to do with physical reality: the goal is to simply show that the code correctly solves the equations that it was designed to solve:
  1. Use an exact solution if available.
  2. If not, use the *Method of Manufactured Solutions (MMS)*.