Verification & Validation

Computational Fluid Dynamics Methodology

- Physics
  - Problem Statement
  - Governing Equations
  - Physical Models
  - Assumptions & Simplifications
- Grid
  - Geometry
  - Structure
  - Special Requirements
    - Wall functions
- Discretization/Numerics
  - Discretization Method
  - Accuracy
  - Implicit v. Explicit
- Solution
  - Algorithm Development
    - Traditional Methods:
      - Finite Difference Method (FDM)
      - Finite Element Method (FEM)
      - Finite Volume Method (FVM)
    - Discrete Simulation or Particle methods
      - lattice gas automata (LGA)
      - lattice Boltzmann equation (LBE)
      - discrete velocity methods (DVM)
      - dissipative particle dynamics (DPD)
      - smoothed-particle hydrodynamics (SPH)
      - direct simulation Monte Carlo (DSMC)
      - stochastic rotation dynamics (SRD)
      - molecular dynamics (MD)
      - hybrid methods
  - Steady v. Transient
  - Simulation Execution
    - HPC capability computing (maximum compute power to solve a single large problem in the shortest amount of time)
    - HPC capacity computing (most efficient configuration to solve multiple complex problems simultaneously)
  - Convergence
- Analysis
  - Verification & Validation
  - Postprocessing & Visualization
  - Interpretation of Results

Concepts of Model V&V

> "Model verification and validation are the primary processes for quantifying and building credibility in numerical models. *Verification* is the process of determining that a model implementation accurately represents the developer's conceptual description of the model and its solution. *Validation* is 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. Both verification and validation are processes that accumulate evidence of a model's correctness or accuracy for a specific scenario; thus, V&V cannot prove that a model is correct and accurate for all possible scenarios, but, rather, it can provide evidence that the model is sufficiently accurate for its intended use.
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> "**Model V&V is fundamentally different from software V&V.** Code developers developing computer programs perform software V&V to ensure code correctness, reliability, and robustness. In model V&V, the end product is a predictive model based on fundamental physics of the problem being solved.
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> "**The expected outcome of the model V&V process is the quantified level of agreement between experimental data and model prediction, as well as the predictive accuracy of the model.** Model V&V is undertaken to quantify confidence and build credibility in a numerical model for the purpose of making a prediction."[LA-14167-MS]
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> "Verification assessment examines 1) if the computational models are the correct implementation of the conceptual models, and 2) if the resulting code can be properly used for an analysis. The strategy is to identify and quantify the errors in the model implementation and the solution. The two aspects of verification are the verification of a code and the verification of a calculation. The objective of verifying a code is error evaluation, that is, finding and removing errors in the code. The objective of verifying a calculation is error estimation, that is determining the accuracy of a calculation."[NASA CFD]
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> "One can only validate the code for a specific range of applications for which there is experimental data. Thus one validates a model or simulation. Applying the code to flows beyond the region of validity is termed prediction.
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> "Validation examines if the conceptual models, computational models as implemented into the CFD code, and computational simulation agree with real world observations."[NASA CFD]

Considerations include:

- Selectivity/specificity
- Accuracy and precision
- Repeatability
- Reproducibility
- System suitability

Validation Assessment Process

The process for validation assessment of a CFD simulation can be summarized as follows:

1. *Examine Iterative Convergence.*
   “Validation assessment requires that a simulation demonstrates iterative convergence.

2. *Examine Consistency.*
   “One should check for consistency in the CFD solution. For example, the flow in a duct should maintain mass conservation through the duct. Further total pressure recovery in an inlet should stay constant or decrease through the duct.

3. *Examine Spatial (Grid) Convergence.*
   “The CFD simulation results should demonstrate spatial convergence.

4. *Examine Temporal Convergence.*
   “The CFD simulation results should demonstrate temporal convergence.

5. *Compare CFD Results to Experimental Data.*
   “Experimental data is the observation of the ‘real world’ in some controlled manner. By comparing the CFD results to experimental data, one hopes that there is a good agreement, which increases confidence that the physical models and the code represent the ‘real world’ for this class of simulations. However, the experimental data contain some level of error. This is usually related to the complexity of the experiment. Validation assessment calls for a ‘building block’ approach of experiments which sets a hierarchy of experiment complexity.

6. *Examine Model Uncertainties.*
   “The physical models in the CFD code contain uncertainties due to a lack of complete understanding or knowledge of the physical processes. One of the models with the most uncertainty is the turbulence models. The uncertainty can be examined by running a number of simulations with the various turbulence models and examining the effect on the results.”[NASA CFD]