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Opinion

Including Computational Validation as Part of a Model Validation Process: Using Legacy Type Models

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Opinion

The advances made in computational algorithms, computing power and visualization tools are motivating researchers to develop new numerical models or enhance the predictive abilities of existing numerical models. These advances include a combination of enhanced flow equations, improved discretization techniques that reduce the flow equations to algebraic equations, grid methodology, a better understanding of the flow phenomena, high-performance computers, optimization tools, interfaces to enter and process the data input, post-processor visualization and analysis tools. These next-generation computational models are facilitating in capturing the flow physics at various spatial and temporal scales that were not possible until two decades back, primarily due to limitations in computing power. As this limitation eases, numerical modeling will continue to be at the forefront for advancing the frontiers of knowledge across all modeling disciplines.

The reliability of these enhanced models is measured by validating their results with standard benchmark tests. Experiments play an important role, and their data vastly improves the understanding of physical flow. Using the measured physical data as a benchmark for testing various numerical models has been a standard practice across all disciplines. To this end, the physical experiments and the associated measurements need to be done in sufficient detail for a range of flow scenarios to arrive at an acceptable dataset for calibrating, verifying and validating the models. Model validation with experimental benchmark data, although highly recommended, is not feasible for all flow cases due to the costs, time, and limitations in the equipment to measure chosen flow variables in the flow domain. Because the numerical model can simulate complex flow phenomena across different scales, it might not be feasible to obtain the corresponding experimental data. In its absence, using the output from other numerical models as the benchmark data is the second approach to validate the models of interest.

Legacy numerical models are those that were primarily developed before the 1990s and were primarily written in Fortran 77. Characteristic features of these legacy models include (a) they are based on strong mathematical foundational, (b) they have been rigorously tested by users who have spent millions of hours in using them for their applications, and (c) their applications at that time were constrained by available computational resources. While some of the legacy models have evolved with time, others are still available for free in public domains, and their popularity among the modeling community varies from discipline to discipline. Their solution is reliable and can be used with confidence as benchmark data to measure the performance details of current-day models.

In the field of computational hydraulics, one of the legacy models is the Diffusion Hydrodynamic Model (DHM), which was developed for the United States Geological Survey (USGS) in the 1980s (https://pubs.er.usgs.gov/publication/wri874137). DHM solves the two-dimensional overland flow coupled with one-dimensional open channel flow equations and includes interfaces between these two flow regimes using source and sink term approximations. For simulating flows where inertial forces dominate over frictional forces, as in many types of floods, the solution of the two-dimensional diffusion wave equation will suffice. The model source code is written in Fortran 77 and can approximate various hydraulic effects as backwater, drawdown, channel overflow, storage and ponding. The model has been extensively tested for different flow scenarios, as detailed in the above document. Its solution has been compared with experimental, theoretical and numerical data. The model's companion website www.diffusionhydrodynamicmodel.com has the source code and documentation along with various applications for which the model was applied.

The next-generation models that are now more popular for modeling free surface flows include HEC-RAS 2D, TUFLOW, MIKE 21, FLOW-3D, Open-FOAM, WSPG, and XP SWMM. Other models are also being developed and are gaining momentum. The theoretical pinning's of these models and their applications have been well documented in the literature.

When one utilizes a computational model to develop opinions related to a problem in engineering and science, it is appropriate to also provide a validation of the computational results. Such validation includes an examination of the developed computational model with a variety of plausible modeling parameters leading to a general sensitivity evaluation as to modeling performance versus choice of model parameters (and also boundary conditions). Another type of evaluation is to evaluate the choice of computational model used. That is, there is a space of computational model outcomes that depend upon selection choices of problem boundary conditions and modeling parameter values. But there is also a space of computational outcomes that depend upon the selection of modeling genre and the choice of computational model features. For example, the comparison of meshless models versus meshed or gridded, or celled models can deliver a significant difference in computational outcomes. An approach presented in this note is to model the target problem using a computational modeling approach developed during the initial model evolution stage (typically, in the 1970's and 1980's-time frame) but generally prior to about 1990. Such a computational model suitable for use in computational validation is the USGS Diffusion Hydrodynamic Model, which is useful in the computational validation assessment of the more modern computational models. The DHM is recommended to be called a "Legacy" type model where its computer code, FORTRAN 77, remains available from the web and in hard-copy report format. The use of DHM to test the computational outcome from a more modern computational model provides a second opinion as to the veracity of the modeling effort and related outcomes.