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Code Verification of a Partitioned FSI Environment for Wind Engineering Applications using the Method of Manufactured Solutions

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In this work, the solution quality of a partitioned Fluid-Structure Interaction (FSI) simulation environment for lightweight structures (cf. Fig. 1 right) and hence the prerequisite for predictive capability are assessed. These lightweight structures are highly sensitive to dynamic loading and excitation, induced for instance by wind.

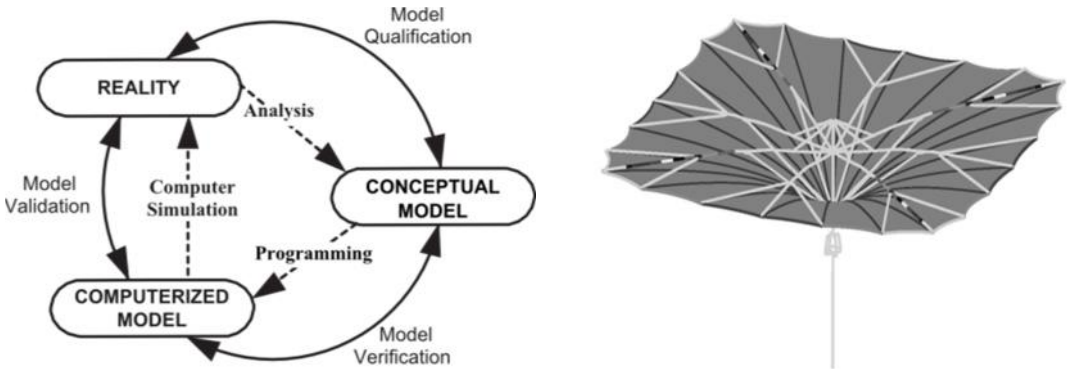

Figure 1: Phases of Modeling & Simulation and the role of V&V (left) [1,9]; A lightweight umbrella structure of a prototype structure (right).

Oberkampf and Roy name a list of influence factors for the predictive capability of simulations [1]. Among them are Verification and Validation (V&V). V&V provide evidence for the correctness of the code and its results and contain a concept of quantitative accuracy assessment (cf. Fig. 1 left). One part of Verification is called Code Verification. It "ensures that the underlying mathematical model, e.g. a Partial Differential Equation (PDE) is correctly implemented in the computer code and identifies software errors" [1]. Therefore exact solutions for comparison are necessary. Here, the Method of Manufactured Solutions (MMS) enters the stage [1, 4-8]. The principal idea is to choose own, manufactured analytical solutions. Since the chosen solution does in general not fulfil the physical equilibrium, the principal idea is to enrich the PDE by source terms resp. loads. With these additional source terms the software should compute the analytical solution. The observed error reduction with systematic refinement in space and time (i.e. the observed order of accuracy) must be in the range of the formal order of accuracy, which can be derived by Taylor series expansion [1, 3, 4]. If these two orders match in the asymptotic range, the implemented numerical algorithms are working as intended. All parts of the simulation, including implemented boundary conditions and discretization schemes, can be assessed with a set of manufactured test cases. Arranging these tests in a hierarchical manner, an obstacle course is built.

The first part of this work is an overview of the MMS derivation, its application and the therein created benchmark suites of parts of the FSI environment which already have been successfully conducted. In detail, on the one hand MMS has been applied for the incompressible and turbulent version of the Finite-Volume based CFD software OpenFOAM® [7]. On the other hand MMS has been applied for geometrically nonlinear membranes with the Finite-Element based structural mechanics software Carat++ [8].

The second part of this work is the Code Verification of the complete partitioned FSI environment, which in addition to the software introduced above consists of the interface coupling software Empire.
It is obvious that besides the observed errors of the single field solution of the fluid and the structure, the total FSI process introduces additional errors which potentially influence the solution and its quality. Particularly the influence of time progression and spatial mapping schemes on the solution error is discussed. In the context of FSI, spatial mapping schemes have the task to transform or to map field information from one mesh to another. Due to the fact that two meshes in general are not coincident or not even based on the same spatial discretization method, this task is not trivial. Different mapping procedures are presented and their method-specific errors are analyzed and assessed with the MMS.

At the end selected elaborate benchmark examples of the complete framework are shown in order to demonstrate the overall capability of the presented procedure.

In conclusion, the elaborated systematic procedure on the basis of MMS to verify different software packages, first on their own but also all together in combination, proves to be an effective and qualified method for Code Verification.

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