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Abstract

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Capturing rapid nonlinear phenomena using coupled thermal Fluid-Solid Interaction numerical analysis

The concept of Fluid - Solid Interaction has already appeared in the literature in the 1970s. Taking additionally into account the current state of advancement of Computational Solid Dynamics as well as Computational Fluid Dynamics methods, the Thermal Fluid-Solid Interaction (Thermal FSI) methodology seems remarkably undeveloped. Given the contemporary industrial challenges in the fields of power engineering, aviation and rocket transportation, as well as the current state of knowledge of Thermal FSI methodology in the literature, two objectives have been identified for this dissertation. The first is to determine whether contemporary commercial numerical tools are suitable for simulating fast, non-linear thermal phenomena with Thermal FSI methodology for industrial purposes. The second is to compare and demonstrate the advantages and disadvantages of the Thermal-FSI method in comparison with the Thermal Structural and Conjugated Heat Transfer methods. In addition, a condition was also imposed to reproduce the nonlinear behaviour of the structures.

For this purpose, an open thin-walled container was selected for testing after an initial selection. The container was characterised by repeatable buckling of the bottom on contact with hot water. A test rig was then prepared for the selected object, in which hot water was dispensed into the bottom of the tank in a controlled manner. Here, the displacement of the tank bottom, its temperature as well as the inlet water temperature were measured at selected points. The experiment was then reproduced numerically, using the two-way Thermal FSI method with the ANSYS Workbench package. The fluid domain, using the Volume of Fluid method in Fluent was coupled using the System Coupling module to the solid domain in the Mechanical module. Uncoupled Conjugated Heat Transfer and Thermal Structural analyses were also carried out for comparison. Finally, the results from the three analyses were collated, determining their deviations from experiment. The Thermal FSI methodology not only provided the smallest deviation, but was also the only one able to capture the non-linear buckling behaviour of the structure.

For a clear discussion of the above issues, in the first instance Chapter 2: "Literature review" presents the literature items since the emergence of the term FSI. Applications, developmental issues and tools are discussed here, splitting the chapter into the more popular Momentum FSI type of analysis and the target Thermal FSI.

Then, Chapter 3: "Model theory" firstly presents the ideal FSI numerical model, and then discusses the models actually used in the Computational Fluid Dynamics and Computational Solid Dynamics solvers, for the target numerical analysis. Lastly, the coupling of the two solvers is discussed.

Chapter 4: "Experimental stand - a steel thin-walled container" provides a detailed presentation of the structure chosen for analysis as well as the experimental stand. It then presents the results of the measurements, in the form of temperature and displacement curves at selected points, supplemented by photographs of the water flow.

In Chapter 5: "Coupled Thermal-FSI numerical analysis", the heart of this dissertation, the focus is on the target analysis of Thermal FSI, as well as the comparative Thermal Structural and Conjugated Heat Transfer. First, a simple mesh density analysis was performed for the fluid domain. This was followed

by a description of boundary conditions, material data as well as CFD and CSD solver settings. Finally, a range of results for the three types of analysis is presented, comparing them to experimental results. Differences in the results of stress calculations are also considered here.

Finally, Chapter 6: “Conclusions” briefly summarises each of the previous chapters. Furthermore, the results of the numerical analyses are discussed here and a comparison of deviations from the experimental results is presented. A number of observations on the Thermal FSI methodology are also detailed.