COUPLED FLUID-STRUCTURE INTERACTION SIMULATIONS FOR AERO-ELASTIC BENCHMARK CASES

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SUMMARY

The aerospace industry was one of the first branches to use numerical simulation to improve the performance of wings and airplanes in general. Finite Element Methods and especially Computational Fluid Dynamics have been used for many different aerospace applications during the last decades and are quite established in the research and development procedures.

The investigation of the aeroelastic behaviour of wings is one of the most important issues in this context. To get a clear picture of the interaction occurring between the deformable wing and the air flowing around the wing a coupled fluid-structure interaction simulation is necessary. Although FSI simulations have been used for a long time there are still a lot of problems and challenges to encounter when using coupled FSI simulations for real-life applications.

The most important aspect is perhaps the verification of the results of the coupled simulations. Several benchmark and test cases have been set up in wind tunnels to obtain experimentally measured values. Two of these test cases will be used to compare the results of coupled FSI simulations with the values measured in different experimental settings: the “High Reynolds Number Aero structural Dynamics” (HIRENASD) example and one of the AGARD test cases.

Several scenarios for the two test cases will be presented. Dynamic behaviour – e.g. a buffeting or flutter analysis of the wing – and steady state phenomena are investigated. To get meaningful comparisons of the experimental and the numerical data the different data sets have to be analysed carefully.

Results of non-linear fluid-structure interaction simulations will be presented and compared to the experimental findings. Nastran and Fluent are used for the FEA and CFD simulations. The coupling is realized with the code-independent tool MpCCI.

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1: Introduction

Without a detailed verification of the used procedures the results of numerical simulation cannot be used to get meaningful statements. The comparison with experimental measurements is especially important in the context of coupled simulations since the different simulation codes and the additional coupling process can introduce errors that cannot be recognized in stand-alone CFD or FEA simulations.

Two different benchmark cases for aeroelastic applications have been selected. Several results will be presented and compared to values obtained by experimental measurements.

The Hirenasd benchmark is described in section 2, the Agard benchmark in section 3. Section 4 contains a short summary.

2: Hirenasd Benchmark

The Hirenasd (High Reynolds Number Aero-Structural Dynamics) benchmark consists of a series of measurements that were taken in the European Transonic Wind tunnel in Aachen. High Reynolds numbers up to 80 million and transonic Mach numbers were investigated. These boundary conditions can be compared to the flight conditions of a big passenger aircraft.

Steady state and transient measurements are available for many different Mach and Reynolds number values. The wing in the wind tunnel is equipped with 250 miniature pressure sensors, 11 velocity sensors and 22 strain sensors to provide the necessary experimental measurements to which the results of the coupled FSI simulation can be compared.

The CFD model of the wing is built in Fluent 15.0. The mesh consists of 15 million tetrahedral and prismatic cells and the wing and the fuselage are covered by 14 boundary layers.

The air is modelled as an ideal gas. The other boundary and material conditions – e.g. the viscosity of the air, the inlet and outlet pressure or the temperature – are dependent on the investigated Mach and Reynolds number. Transient simulations are initialized with a steady state solution and a second order implicit and density-based solver is used.

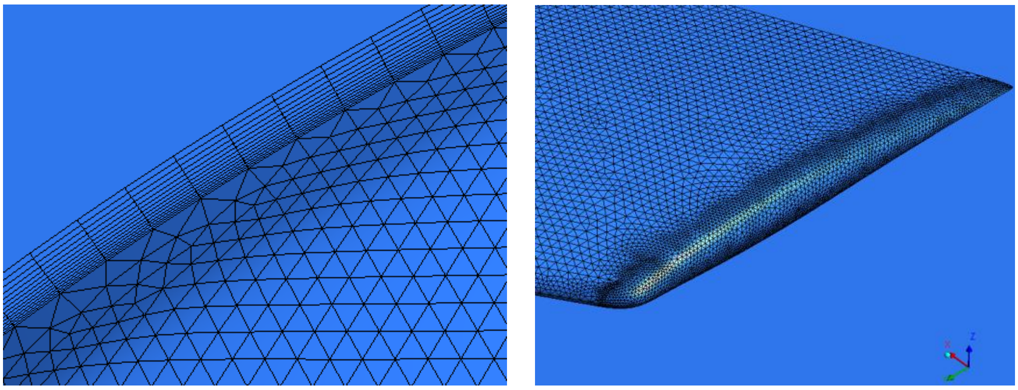

Figure 1: CFD mesh for the Hirenasd benchmark: wing tip on the right and boundary layer on the left.

Nastran is used to model the structural response of the wing. The mesh consists of 200.000 second order tetrahedral elements. The Young's modulus of the used material is 2.1e11 Pa and the density is 7,860 kg/m^3. The poisson ration and the thermal expansion coefficient are temperature dependent. The mounting and excitation mechanism which is located outside of the wind tunnel is also part of the Nastran model.

The interaction of the structural and the fluid dynamics code is realised with the code independent coupling interface MpCCI. MpCCI manages the necessary data exchanges: the position of the wing surface is sent from Nastran to Fluent and the wall force on the wing surface is sent from Fluent to Nastran. MpCCI offers different coupling algorithms and possibilities to manipulate the coupled data.

Figure 2: Hirenasd wind tunnel assembly on the left, and FEA model of the wing and excitation model on the right.

For the presented benchmark simulations steady state and transient simulations in Nastran and Fluent were coupled with MpCCI. Results of the coupled simulations are compared to the experimental measurements and will be presented in this talk. The presented results were calculated for Mach 0.8 and a Reynolds number of 7 million.

3: Agard Benchmark

The Agard (Advisory Group for Aerospace Research and Development) benchmarks were conducted in the Langley transonic wind tunnel in Virginia in the 1960s and are still widely used to verify results of numerical simulations. The wing profile NACA 65A004 is selected from the wide range of Agard test cases.

The same simulation codes as for the Hirenasd benchmarks have been used: Fluent for the CFD simulation, Nastran for the FEA simulation and MpCCI for the coupling of the two codes.

The CFD model consists of 3.6 million polyhedral and hexahedral cells and uses a first order implicit PISO solver with a steady state initial solution. A constant density of 1.225 k/m^3 is used. The rest of the boundary conditions is dependent on the Mach number – for the presentation of the results Mach 0.678 is used. This leads to an inlet velocity of 172.669 m/s.

The wing structure is modelled in Nastran with 5,500 hexahedral elements. The density of the wing material is 380 kg/m^3 with an anisotropic shear modulus.

4: Summary

Results of the coupled fluid-structure interactions for both benchmark cases will be presented in the talk. The results of the coupled simulations agree with the experimental findings.

However, the solution of non-linear FSI simulations with a coupled simulation is a complicated system. It is often hard to locate the source of errors, problems or instabilities. This is why it is quite important to verify coupled FSI simulations with experimentally measured values – particularly when new coupling methods or algorithms are used.

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