A Hybrid Method for CAA

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Introduction

For the simulation of aeroacoustical phenomena in complex structures, e.g. high lift wing configurations the generation of a structured grid is very complicated and consequently, the application of unstructured grids is advantageous. However, in the far field which very often covers the larger part of the computational domain the generation of structured grids is really straightforward, so one can benefit from their advantages in terms of memory demand, grid handling effort and visualization. This leads to the idea of coupling schemes that work on those different types of grids. Former work has been done in this field by Utzmann [2], who worked on the coupling of different solver types, equations, orders, grid types and grid spacing, delivering an expert-system-like solver framework. This project is based on this work and aims at the development of a user friendly framework for industrial application. Hence, the bandwidth of included solvers has been reduced drastically and more aspects of the preprocessing and initialization have been automated.

The Used Codes

PIANO

PIANO has been developed by the Institute of Aerodynamics and Flow Technology (IAS) at the German Aerospace Center (DLR) in Braunschweig. It is a finite difference solver for linearized acoustic equations on block structured, boundary-fitted grids. The time integration is done with Runge-Kutta schemes of 4th or 6th order. PIANO is parallelized using the Message Passing Interface (MPI). For more information refer to [3].

NoisSol

NoisSol has been developed by the Institute of Aerodynamics and Gasdynamics at Universität Stuttgart. It uses an ADER-DG scheme of high order to solve the linearized acoustic equations on unstructured grids. It applies global or local timestepping. For details of the scheme refer to [4]. NoisSol is parallelized with MPI as well.

Grid Coupling

The decomposition of the computational domain is done such that both programs work on non overlapping grids with straight coupling interfaces. The information of the coupling partner are included using ghost cells (NoisSol) or ghost points (PIANO). These are generated by mirroring the last cells / nodes inside the computational domain at the interface. Due to the size of PIANO's finite difference stencil three rows of ghost points are needed. NoisSol only needs ghost cells for those elements, which share a surface with the coupling interface.
Former work on the coupling between FD and DG showed that continuity of the primitive variables rather than continuity of the fluxes is very suitable to prevent artificial reflections at the interface. Thus, this method is used for the coupling here.

Setting of the Ghost Points

PIANO applies different multi-step Runge-Kutta-schemes for the time integration. To update the ghost points after each Runge-Kutta step the state and its time derivatives at the initial Runge-Kutta level of each time step are necessary. To determine these one can benefit from the Cauchy-Kovalevskaja (CK) procedure, which is the key feature of the ADER-DG scheme. This operation calculates the time derivatives of the state at the beginning of the current time step by using the known state at this time and the governing equation.
Using Taylor series' one can calculate the state and its derivateves for any time level within the DG time step. Only one data exchange per timestep is necessary, which reduces the communication effort significantly.

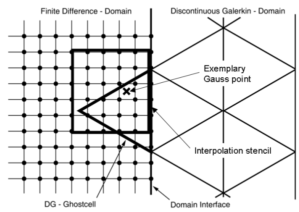

Abbildung 1: DG-Ghostcells

Setting of the Ghost Cells

To transform the data in the ghost cells to NoisSol's modal data basis, the state has to be known at the Gauss points. To determine these values in the PIANO domain a polynomial interpolation with an odd maximum order is used. This allows the use of a symmetric stencil around the cell, in which the point is located. Where required the stencil is shifted away from the interface (figure 1). To allow a fast calculation of the interpolated values at each exchange time level it is convenient to calculate coefficients for each grid point in the stencil using a Lagrange interpolation scheme. This reduces the interpolation process during the simulation to a simple multiplication.
The whole initialization and interpolation process has been developed and implemented for 2D and 3D.

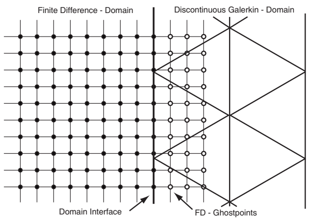

Abbildung 2: FD-Ghostpoints

Process Management

In the coupling framework both included codes are conserved as stand-alone programs. This allows the transfer of new features from the single codes to the coupled version, which thereby benefits from the ongoing improvement work done at the codes. To enable the information transfer between the two solvers, a common communication infrastructure is necessary. Hence, the two solvers are linked together after compilation in one executable. Running both of them separately, linked by the MPI process management, would be the better choice in principal but was resigned due to the poor implementation of these features in some MPI distribution.

Convergence Test

To proof that the coupling is able to maintain the order of accuracy over the whole domain a convergence test was performed. For this test a simple square shaped domain is chosen in which a small square with an unstructured grid is surrounded by 4 structured blocks which leads to 4 coupling interfaces (Figure 3). The domain is confined by periodic boundaries. PIANO and NoisSol were adjusted to 4th order.

The initial condition is a planar sinusoidal wave, shaped proportional to one of the eigenvectors of the linearized Euler equations. Hence, the initial state represents an acoustical wave which will be transported with the speed of sound. This allows the simple calculation of the local error due to the known analytical solution: $(\rho \;\; u \;\; v \;\; p)^T \;=\; \mathbf{b} \;\; sin\,(2\pi\,x + 2\pi\,y - \omega t)$ where $\mathbf{b} = 0.5\;\left(\rho_0/c_0 \;\; -1/\sqrt{2} \;\; -1/\sqrt{2} \;\; \rho_0 c_0\right)^T$ is one of the eigenvectors of the linearized Euler equations with the corresponding eigenvalue $u_0 - c_0$ and $\omega = -2\pi\,\sqrt{2}\,c_0$ is the wave speed in normal direction. The used meanflow values lead to $c_o = 1$ and $u_0 = 0$. These settings result in a wave travelling diagonally through the computational domain in negative x- and y-direction (Figure 4). In the simulated time of $t = 5$ the waves do about half a cycle through the domain.

The convergence rates, calculated with the norms of the local error of the acoustic pressure p', were 3.87 to 3.97 (PIANO) and 3.85 to 3.95 (NoisSol), which captures the theoretical value of 4.0 very well. Figure 5 shows that there is no local error caused by the coupling.

An analogue convergence test in 3D showed achieved an order of accurance of 3.8 to 4.4.

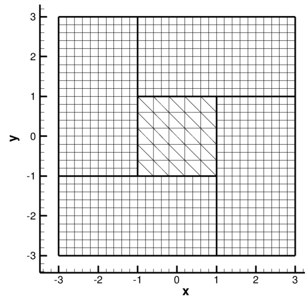

Abbildung 3: Mesh setup

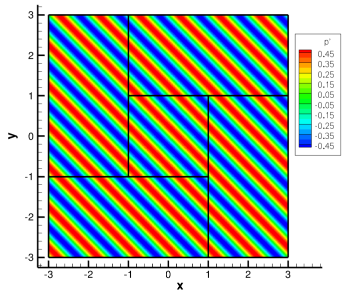

Abbildung 4: Initial condition, pressure

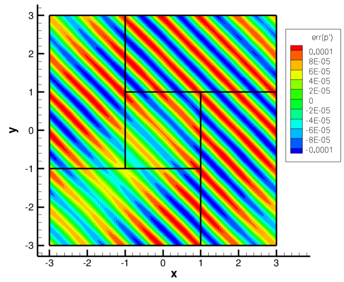

Abbildung 5: Local pressure error, t=5

Literatur

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