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A HYBRID MESH LINEAR HARMONIC SOLVER FOR THE AEROELASTIC ANALYSIS OF TURBOMACHINERY

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This paper describes the implementation of a solver for the linearised three-dimensional, Reynolds-averaged Navier-Stokes equation in the frequency domain on structured and unstructured meshes. Linear harmonic methods are particularly attractive to simulate blade flutter in turbomachinery. In order to apply linear techniques to complex configurations, e.g., computational domains with cavities as shown in Fig. 1, the authors extend an existing solver which, on the one hand, provides a structured linearised solver module [3], [1], and, on the other hand, a non-linear solver for *hybrid* meshes, i.e., meshes which decompose into structured and unstructured blocks [4].

The spatial discretisation, for both structured and unstructured meshes, is based on a second-order finite volume approach using flux functions after Roe which are applied to second order reconstructed left and right states at each cell face. On a moving mesh, the spatially discretised URANS equations thus take the form

$$\frac{\partial}{\partial t}(V_i q_i) + V_i R_i, \quad R_i = V_i^{-1} \sum_j F'_j - S_i. \tag{1}$$

Here q, V, R, F, S denote conservative flow variables, cell volumes, residuals, fluxes, and source terms, respectively. i denotes a cell index. j runs over the cell faces of the i-th cell. F' denotes the modified numerical flux for moving meshes. The linear harmonic (sometimes called *time-linearised*) approach [2] is to linearise Eqn. (1) and to transform the system into the frequency domain, which results in a complex linear equation for each angular frequency ω of the form

$$\left(\mathbf{i}\omega + \frac{\partial R}{\partial q}\right)\hat{q}_\omega = -\left[\frac{\partial R}{\partial x}\hat{x}_\omega + \frac{\partial R}{\partial \dot{x}}\mathbf{i}\omega\hat{x}_\omega + \mathbf{i}\omega\frac{\hat{q}_0}{\hat{V}_0}\hat{V}_\omega\right]. \tag{2}$$

The first part of this work describes the setup of the sparse block matrix which corresponds to the left-hand side of Eqn. (2). We show how to determine the sparsity patterns and how to compute the flux Jacobians involved.

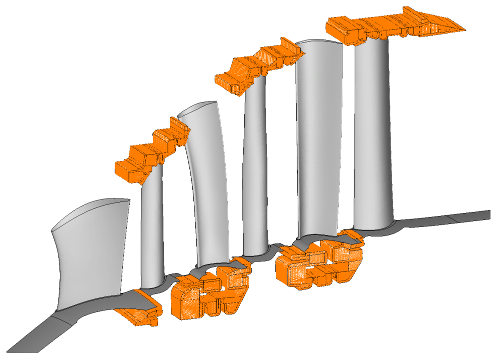

Figure 1: Turbine configuration with cavities.

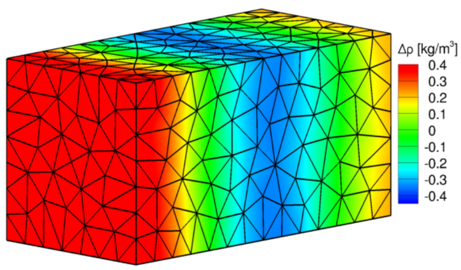

Figure 2: Cuboid with constant mean flow and a precribed, harmonic entropy disturbance.

The second part outlines how the matrices, together with an implementation of various boundary conditions are integrated into a parallel GMRES solver. First results demonstrate the performance and the accuracy of the methods implemented, see Fig. 2.

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