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AN IMMERSED BOUNDARY METHOD FOR THE RANS EQUATIONS USING ADAPTIVE WALL FUNCTIONS

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ABSTRACT

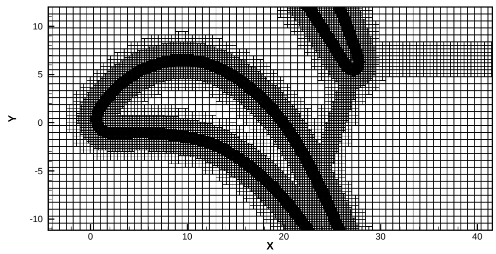
The Immersed Boundary (IB) method simplifies the grid generation process for computing flows with complex and/or moving boundaries, by avoiding the need for a body-fitted mesh. The IB technique, originally developed for incompressible flows [1] using Cartesian grids, has recently been extended to the solution of compressible flows [2, 3] using the preconditioned Navier-Stokes equations, which allow one to provide accurate and efficient solutions for a wide range of the Mach number. Furthermore, a flexible local grid refinement technique is employed, which allows one to increase the mesh resolution only in high flow gradient regions, namely, near solid boundaries and wakes, while coarsening the grid in regions away from the walls, where flow gradients are usually small. In this work, the Reynolds Averaged Navier-Stokes (RANS) equations, written in terms of Favre mass-averaged quantities, are solved in conjunction with the low-Reynolds number k-ω turbulence model. A collocated cell-centred finite volume space discretization is used. The convective terms are discretized using a second-order-accurate upwind flux-difference-splitting scheme. In the presence of shocks, a total variation diminishing approach is employed using the minmod limiter function and either a second- or a third-order accurate upwind scheme. The viscous terms are discretized by second-order-accurate centred differences.

The geometry under consideration, which is described by a closed curve in two dimensions (a closed surface in three dimensions), is overlapped onto a Cartesian (non uniform) grid. Using the ray tracing technique, the computational cells occupied entirely by the flow are tagged as fluid cells; those whose centres lie within the immersed body are tagged as solid cells; the remaining ones are finally tagged as interface cells. Boundary conditions at the immersed surface are applied explicitly at the interface cells, by interpolating the flow variables from the computed values of the surrounding fluid cells and the prescribed wall values. A simple linear interpolation [2, 3] provides accurate results for flows with moderate values of the Reynolds number (Re), but requires a huge number of cells to resolve high-Re wall bounded flows. Local grid-refinement could alleviate such a difficulty, but it is not very effective for the present case of a Cartesian grid method. Therefore, accurate wall functions, as proposed by Kalitzin et al. [4] for body-fitted grids to exploit the universal character of the law-of-the-wall, are employed here: the nondimensional velocity-, k-, and ω-profiles are determined using a very accurate numerical solution of a flow over a flat plate at zero pressure gradient and are used to evaluate the flow

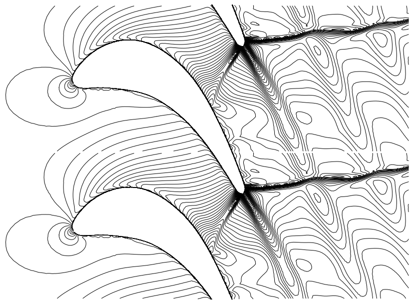
variables at the centres of the interface cells, depending solely on their distance from the wall. The proposed numerical method has been employed to compute the transonic flow through the high-turning VKI LS59 turbine-rotor cascade with: exit Mach number equal to 1.11; Reynolds number, based on the blade chord, c, and exit conditions, equal to 7×10^5; inlet flow angle with respect to the axial direction equal to 30 degrees. The mesh is refined at the immersed boundary and around shocks, see figure 1(a), the maximum distance from the blade profile to the first grid point in the boundary layer being equal to $3 \times 10^{-3}c$ (corresponding to $y^+ = 60$). Figure 1(b) shows the computed Mach number contours: the complex structure of the flow is well predicted and the shocks are captured in the correct position.

Such very promising results suggest to employ more accurate near-wall models recently developed for body-fitted approaches, such as the generalized wall functions of Craft et al. [5] and the zonal two-layer strategy proposed by Balaras et al. [6] for LES, in order to further improve the prediction capability of the present IB-RANS approach.

The final paper will provide the details of the overall methodology and the variuous near-wall models as well as a complete set of results.



(a) Local view of the mesh



(b) Mach number contours ($\Delta M = 0.03$)

Figure 1: VKI LS59 test case.

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