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TRANSITIONAL FLOW SIMULATION IN TURBOMACHINERY WITH AN HIGH-ORDER ACCURATE METHOD

M. Lorini[1], A. Ghidoni[1], F. Bassi[2], A. Colombo[2] and S. Rebay[1]

[1] Department of Mechanical and Industrial Engineering, University of Brescia,
via Branze 38, 25123 Brescia, Italy
marco.lorini@ing.unibs.it, antonio.ghidoni@ing.unibs.it, stefano.rebay@ing.unibs.it
[2] Department of Industrial Engineering, University of Bergamo,
viale Marconi 5, 24044 Dalmine, Italy
francesco.bassi@unibg.it, alessandro.colombo@unibg.it

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Nowadays numerical simulations have become an important tool in almost all sectors of fluids engineering. Computational fluid dynamics (CFD) has been widely accepted as one of the main methods to evaluate the performances of the new turbomachinery designs. Industrial CFD applications range from classical single- and multi-blade row simulations in steady and unsteady mode, to cavity flows, heat transfer and combustion chamber simulations.
In spite of the recent advances in scale-resolving CFD simulations, the most commonly considered equations to simulate turbulent flows in industrial applications are the Reynolds-Averaged Navier-Stokes (RANS) equations. Due to their lower computational cost, RANS equations, supplemented by a suitable partial differential turbulence model, can represent a reasonable compromise between accuracy and expense.
These turbulence models are very well suited for high Reynolds number flows, whereas for low Reynolds numbers flows (as in low pressure gas-turbines), where a large part of the boundary layer is laminar or transitional, they can provide wrong results. In fact the boundary layer development, the losses, the efficiency and the heat transfer are greatly affected by the location and the extent of the laminar-to-turbulent transition. Therefore, the ability to accurately predict the transition is crucial for the design of efficient and reliable machines.
Due to the increasing required level of resolution and to analyze ever more complex geometries and flows, there is a growing concern that state-of-the-art FV technology requires, and will continue to require, too expensive computational resources. The demand for high resolution naturally leads to consider methods with a higher order of accuracy, such as discontinuous Galerkin (DG) methods [2]. The DG method is one of the most promising

techniques in this respect because of its robustness, accuracy and flexibility. DG methods are in fact finite element methods which account for the physics of wave propagation by means of Riemann solvers as in upwind FV methods but, unlike the latter, can achieve higher-order accuracy on general unstructured grids using high degree polynomials as in the classical (continuous) finite element method.

The MIGALE code, based on the DG spatial discretization, has been already used to study the transitional flow through the T106A turbine cascade [3], with the low-Reynolds version of the k-ω turbulence model. In this work we extended the prediction capabilities of the code coupling the turbulence model with an integral and non-local transition model developed in the context of the finite volume (FV) methods [5] and based on the empirical correlation proposed by Abu-Ghannam and Shaw [1].

Different transition modes may occur, depending on flow parameters such as the free stream turbulence intensity, the pressure gradient and the roughness of the blade. All the relevant modes of transition were taken into account by this model, *i.e.* the natural/bypass mode and the separation induced mode. Each transition mode yielded an intermittency value, γ, and the maximum value was applied to the source terms of the turbulence model. In particular, an intermittency value $\gamma = 0$ corresponded to a laminar boundary layer, while $\gamma = 1$ to a fully turbulent boundary layer. The intermittency in the free-stream region was set to one.

We assessed and validated the transition model in the computation of two test cases: the compressible turbulent flow over a flate plate (test T3A of the ERCOFTAC SIG 10) and through the T106A turbine cascade for different Reynolds numbers [4].

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