Advanced Three-Dimensional CFD Applications Using Spline Functions for the Computation of Thermodynamic Properties of Real Fluids

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New technological constraints imposed by new energy production processes require more detailed understanding of the thermodynamic and fluid-dynamic phenomena occurring in power plants. The use of experimental investigations is necessarily limited due to the extremely high costs involved. Computational fluid dynamics has therefore become an indispensable tool for the design and optimization of components for the energy industry, in particular steam and gas turbines. While for the numerical simulation of the flow in the latter it is acceptable to approximate by assuming ideal gas behavior of the working fluid, this is not the case for steam turbines, where phase changes and large deviation of the thermodynamic properties from the ideal state must be accounted for.

Fully-compressible, density-based flow solvers are perfectly suited to solve the system of Euler/Navier-Stokes equations governing the flow in turbo-machines, however introducing real fluid property algorithms such as IAPWS-IF97 into existing CFD codes dramatically increases computational efforts. Real fluids generally possess highly non-linear caloric and thermal state relationships, hence extensive use of iterative solution methods is to be made to obtain accurate updates of the primitive state variables, which normally renders use of numerical simulation in realistic industrial configuration unfeasible.

In this paper an innovative approach is described for the calculation of the thermodynamic properties of steam for density-based, fully compressible CFD applications.

Continuous spline functions are used to describe the fundamental caloric and thermal relationships and the relevant thermodynamic differentials also across the saturation boundaries. The spline method has been embedded in a fully-implicit, Roe-based turbo-machinery code and the new generalized formulation thus obtained has been applied to the simulation of the flow in a model turbine stage.

The proposed approach has proved to allow a drastic reduction of the computational time while at the same time achieving very high accuracy.