Fast Calculation of Thermodynamic and Transport Properties Using Spline Interpolation – Applied in Flow Analyses of Steam Turbines using CFD

Matthias Kunick[a], Hans-Joachim Kretzschmar[a], Francesca di Mare[b], Uwe Gampe[c]

[a] Zittau/Görlitz University of Applied Sciences, Chair of Technical Thermodynamics, Theodor-Körner-Allee 16, 02763 Zittau, Germany

[b] German Aerospace Center (DLR), Institute of Propulsion Technology, Linder Höhe, 51147 Köln, Germany

[c] Technical University of Dresden, Chair of Thermal Power Machinery and Plants, 01062 Dresden, Germany

Email: m.kunick@hszg.de

The simulation of non-stationary processes and the optimization of power cycles and their components with Computational Fluid Dynamics (CFD) as well as online monitoring all require accurate and extremely fast algorithms for computing thermodynamic and transport properties of the working fluids.

The Spline Based Table Look-up Method (STM) has been developed to fulfill these requirements. With this method, spline functions for the independent variables specific internal energy and specific volume (u,v), as well as for pressure and specific enthalpy (p,h) are generated. Using these forward spline functions thermodynamic and transport properties, thermodynamic derivatives, and backward functions of the variables pressure and temperature (p,T), pressure and specific volume (p,v), pressure and specific entropy (p,s), and specific enthalpy and specific entropy (h,s) are calculated in the single-phase regions steam and liquid water, and in the two-phase region wet steam. The backward functions are calculable with complete numerical consistency to the forward spline functions. This feature is advantageous in CFD simulations and the simulation of non-stationary processes.

The entire range of validity of the generated spline functions corresponds to that of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97). The properties calculated from STM are in agreement with those of IAPWS-IF97 within a relative deviation of 10 to 100 ppm depending on the property and the range of state. Consequently, the differences between the results of the process simulation using STM and the results obtained using IAPWS-IF97 are negligible.

The computations of the (u,v) spline functions are more than 200 times faster than the iterative calculations using IAPWS-IF97. Even the (p,h) spline functions are twice as fast as the IAPWS-IF97 backward equations.

In order to demonstrate the applicability of the Spline Based Table Look-up Method the developed algorithms were implemented into the CFD software TRACE of the German Aerospace Agency (DLR). Figure 1 the results of the simulation of condensing steam flow around a fixed blade in a steam turbine, where the colors indicate the vapor fraction in the flow field. These results are in good agreement with available measurements. Using the developed fluid property calculation algorithms, the computing times for flow simulations of steam turbine stages could be reduced by a factor of ten in comparison to the calculation based on IAPWS-IF97. In comparison to CFD-calculations where steam is considered to be an ideal gas, the computing time consumption using STM is increased by a factor of 1,4 only.

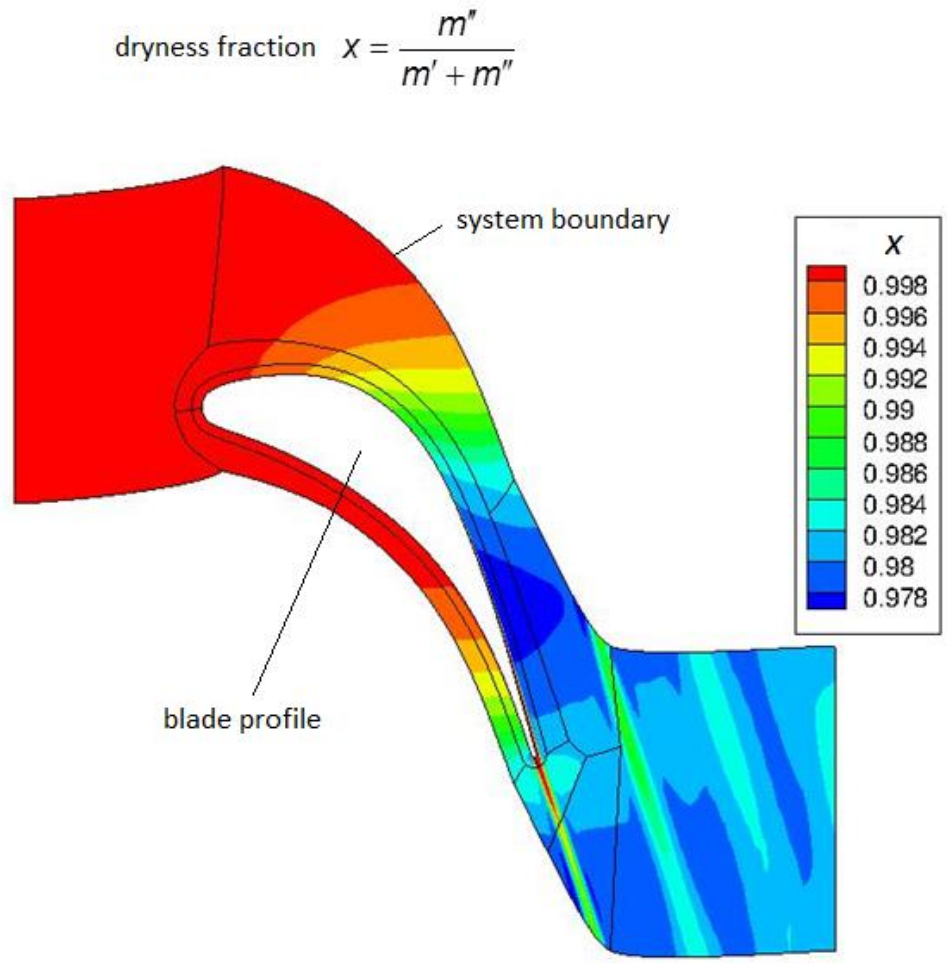

Figure 1: Vapor fraction in the flow field around the blading profile

For generating spline functions for fluid property calculations according to the specific requirements of a process simulation, the software FluidSplines has been developed. This software enables the application of the Spline Based Table Look-up Method to all kinds of property functions and fluids. Spline functions for property calculations based on accurate fundamental equations of state for the required range of validity and accuracy can be generated.

In the presented project the Spline Based Table Look-up Method (STM) for fast and accurate property calculations in extensive process simulations has been developed. Using this method spline functions for thermodynamic and transport properties for water and steam has been prepared. These functions reproduce the results of the industrial standard IAPWS-IF97 within a relative deviation of 10 to 100 ppm and computing times are reduced by factors up to 400. The STM also allows the calculation of backward functions with complete numerical consistency. Therefore the presented method fulfills the requirements of extensive numerical process simulations such as CFD. The generated spline functions for water and steam have been implemented into the software TRACE. Test calculations show, that the real fluid behavior can be considered in CFD using the STM. In comparison to the application of the ideal gas model, the computing time consumption using STM is increased by a factor of 1,4 only. Thus, the applicability of the proposed method in CFD has been proven.

Projects are being planned to apply the STM in advanced CFD simulations for gas turbines. The developed method is subject of the "IAPWS Guideline on the Fast Calculation of Steam and Water Properties in Computational Fluid Dynamics Using the Spline-Based Table Look-Up Method (STM)" which is being evaluated and will be adopted as an international standard at the next IAPWS conference.