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FAST CALCULATION OF THERMODYNAMIC PROPERTIES OF WATER AND STEAM USING A SPLINE BASED TABLE LOOK-UP METHOD

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For the design and optimization of advanced power cycles and their components extensive process simulations such as Computational Fluid Dynamics (CFD) and the calculation of non-stationary processes are in use. These simulations require very fast and accurate functions for the determination of fluid properties. Furthermore, to meet the demands of numerical solvers, high numerical consistency of forward and backward functions and continuity of these functions and derivatives are required. In order to fulfil these requirements a Spline Based Table Look-up Method (STM) was developed. This paper describes the fundamentals of this method and the generation of a spline based property function for a given range of validity and accuracy.

The generation of a suitable look-up table, the so called grid of nodes, is the crucial step for setting up a spline function. For the desired range of validity and accuracy the amount of data must be minimized whereas the computing speed needs to be maximized. At the same time irregular shaped ranges of validity must be fitted into rectangular grids with equidistant nodes, because this approach simplifies the cell search algorithm in the grid to a straight forward calculation without iterations. The proposed method combines specialized variable transformations and extrapolation techniques to achieve these optimizations. Thereby the shape of the property function is adapted to the shape of the spline-polynomial. Consequently, the number of nodes can be minimized whereas the computational speed is kept as high as possible. The spline based table look-up method also enables the calculation of inverse functions with complete numerical consistency. These inverse functions are the analytic solutions of the spline polynomials solved in terms of one of their independent variables.

In order to demonstrate the applicability of the spline based table look-up method a set of spline functions has been created for superheated steam and wet steam. Accuracies and computing speeds of these functions have been evaluated and compared to IAPWS-IF97. Furthermore, the spline functions have been implemented into TRACE, a CFD software developed at the German Aerospace Agency (DLR). Test calculations show that the proposed approach reduces computing times considerably. Due to the numerical consistency of the spline based property functions the CFD simulations converge with a minimum number of iterations. Consequently, the computing times could be reduced by a factor of ten in comparison with a calculation based on IAPWS-IF97.

For generating spline functions for fluid property calculations, the software FluidSplines has been developed. It makes the spline based table look-up method applicable to all kinds of one- or two-dimensional property functions. Fluid properties can be provided from external databases such as the property libraries of the Zittau/Goerlitz University of Applied Sciences or REFPROP from NIST. The software implements all the features of the spline based table look-up method explained above and assists the user in generating spline functions and inverse spline functions for a given range of validity with the required accuracy.