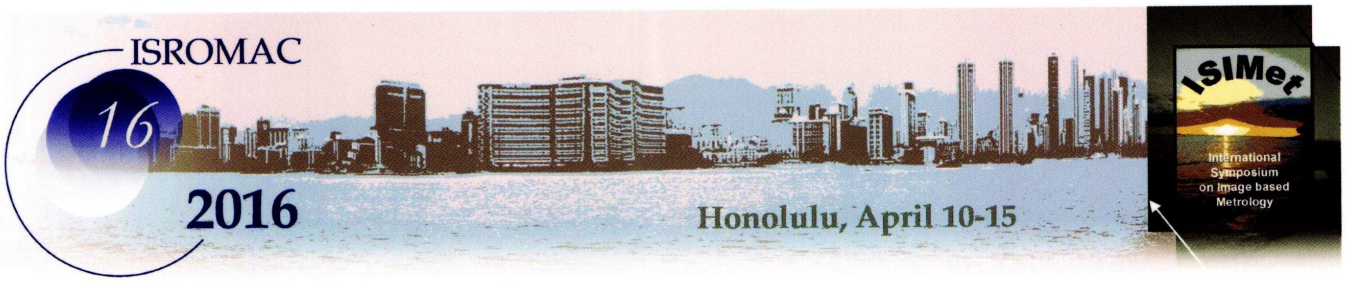

16TH INTERNATIONAL SYMPOSIUM ON TRANSPORT PHENOMENA AND DYNAMICS OF ROTATING MACHINERY

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F4-1	Monday TS 2	Chair: Teemu Turunen-Saaresti		
		2:10p – 2:20p	Installation / session opening	
		2:20p – 3:00p **Keynote speech**	Damian M. Vogt	Numerical and Experimental Study on the Influence of Damping Elements on the Flow and the Vibration Behavior of Industrial Steam Turbine Blades
		3:00p – 3:20p	Bob Kielb, Joshua Waite	Recent Advancements in Turbine Flutter: Understanding and Design Analyses
		3:20p – 3:40p	Romuald Rzadkowski, Vitaly Gnesin, Lubov Kolodyazhnaya, Ryszard Szczepanik	3D Unsteady Forces of the Transonic Flow through a Last Stage of Steam Turbine with Vibrating Blades and Non-Uniform Pressure Distribution behind Rotor Blades

F4-2	Monday TS 3	Chair: Damian M. Vogt		
		4:00p – 4:10p	Installation / session opening	
		4:10p – 4:30p	Ali Afzalifar, Teemu Turunen-Saaresti, Aki Grönman	Comparative Study of Quadrature Method of Moments and Eulerian-Lagrangian to model the Polydispersed Wet-Steam flows
		4:30p – 4:50p	Matthias Kunick, Hans-Joachim Kretzschmar, Francesca di Mare, Uwe Gampe	Fast Calculation of Real Fluid Properties with the New IAPWS Standard on the Spline-Based Table Look-Up Method (SBTL) and its Application in CFD
		4:50p – 5:10p	Tobias W. Zimmermann, Oliver Curkovic, Manfred Wirsum, Andrew Fowler	Influence of adjusting control accuracy on pressure probe measurements in turbo machines
		5:10p – 5:30p	Marco Grosso, Federico Sansoni, Alessandro Sorce, Margherita Monti, Fabio Pascucci, Roberto Razzoli	Influence of Startup Management on the Residual Life of a Large Steam Turbine Shaft

Fast Calculation of Real Fluid Properties with the New IAPWS Standard on the Spline-Based Table Look-Up Method (SBTL) and its Application in CFD

Matthias Kunick and Hans-Joachim Kretzschmar, Department of Technical Thermodynamics, Zittau/Goerlitz University of Applied Sciences, Zittau, Germany
Francesca di Mare, Institute of Propulsion Technology, German Aerospace Center (DLR), Cologne, Germany
Uwe Gampe, Chair of Thermal Power Machinery and Plants, Technical University of Dresden, Dresden, Germany

Long Abstract

Introduction

The simulation of non-stationary processes with CFD is acquiring growing importance for the development and optimization of turbomachinery. In these computationally intensive simulations, precise and extremely fast fluid property calculation algorithms are required. For this purpose, table look-up methods are frequently applied. Discrete values of the required properties are calculated from accurate equations of state and are stored in look-up tables. During the CFD simulation, properties are determined from these look-up tables with simple interpolation algorithms. With local algorithms, such as bi-linear or local bi-cubic interpolation, properties within a cell of the look-up table are calculated from adjacent values only, as opposed to global methods, where all tabulated values are used. Although local algorithms are easily implemented, they do have their deficiencies. Bi-linear interpolation requires comparatively large look-up tables to represent the fluid properties with acceptable accuracy and does not provide continuous first derivatives. Local bi-cubic interpolation overcomes these problems, but the calculation of the required inverse functions is computationally intensive as it requires the evaluation of transcendental functions. Moreover, to achieve the desired accuracy over the entire range of state, the look-up tables are frequently prepared with variable distances between the nodes. This requires extensive cell search algorithms during the property calculation and decreases the computing speed. In order to provide fast and accurate property calculation algorithms for CPU-intensive complex simulations, the Spline-Based Table Look-up Method (SBTL) was developed in this project. Through the use of this method, existing equations of state, such as the industrial formulation IAPWS-IF97 for water and steam, can be reproduced with high accuracy and minimal computing-time consumption.

The IAPWS Standard on the Spline-Based Table Look-up Method (SBTL)

The SBTL method combines global bi-quadratic spline interpolation with specialized coordinate transformations and simplified search algorithms. In this way, existing fluid property formulations (equations of state) can be reproduced with high accuracy and high computing speed, whereas the size of the look-up tables is minimized.

In a project of the International Association for the Properties of Water and Steam (IAPWS) the SBTL method has been applied to the industrial formulation IAPWS-IF97 [1] and the scientific formulation IAPWS-95 [2]. SBTL property functions for water and steam have been generated [3] for the independent variables specific volume and internal energy (v,u) for the entire range of validity, including the metastable states, of the respective formulation. With these functions thermodynamic and transport properties, thermodynamic derivatives, and backward functions are calculable in the single-phase, two-phase and

metastable regions. Backward functions of the variables pressure and specific volume (p,v), and internal energy and entropy (u,s) are calculated with complete numerical consistency to the spline functions of (v,u). The properties calculated from the SBTL property functions are in agreement with those of the underlying IAPWS standard within a maximum relative deviation of 10 to 100 ppm depending on the property and the range of state. Consequently, the differences between the results of process simulations using the SBTL method and those obtained through the use of the corresponding IAPWS formulation are negligible. Computations from the (v,u) spline functions are more than 200 times faster than calculations with IAPWS-IF97 and are more than 400 times faster than calculations with IAPWS-95.

The International Association for the Properties of Water and Steam (IAPWS) has issued the "Guideline on the Fast Calculation of Steam and Water Properties with the Spline-Based Table Look-Up Method (SBTL)" [4] as an international standard. In addition to the spline and inverse spline functions of (v,u), (p,v), and (u,s), the IAPWS Guideline also contains SBTL property functions of pressure and enthalpy (p,h) along with the corresponding inverse functions of pressure and temperature (p,T), pressure and entropy (p,s), as well as enthalpy and entropy (h,s).

Application of the SBTL Method in CFD

In order to demonstrate the applicability of the SBTL method, the developed algorithms have been implemented into the CFD software TRACE of the German Aerospace Center (DLR). As a result, the computing times for flow simulations of steam turbine stages considering real fluid behavior are reduced by a factor of 6 to 10 in comparison to the calculations based on IAPWS-IF97. In comparison to CFD-calculations where steam is considered to be an ideal gas, the computing times are increased by a factor of 1.4 only through the use of the SBTL method. Consequently, the newly developed SBTL method enables the accurate consideration of real fluid behavior in complex CFD simulations.

For generating SBTL property functions, the software FluidSplines has been developed. This software enables the application of the SBTL method to any property function and fluids other than water and steam. Projects are being planned to apply the SBTL method to carbon dioxide, dry air, humid air and combustion gas mixtures. The resulting property functions can be used in advanced CFD simulations for compressors and gas turbines.

The SBTL method, its application in CFD, and software for generating SBTL functions are presented.

References

[1] IAPWS, Revised Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (2007), available at *http://www.iapws.org*.

[2] IAPWS, Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use (2009), available at *http://www.iapws.org*.

[3] Kunick, M., Kretzschmar, H.-J., Property libraries with the Spline-Based Table Look-Up Method (SBTL) applied to IAPWS-IF97 and IAPWS-95 for CFD and other computationally intensive process simulations, available at *http://www.thermodynamics-zittau.de*.

[4] IAPWS, Guideline on the Fast Calculation of Steam and Water Properties with the Spline-Based Table Look-Up Method (SBTL), available at *http://www.iapws.org.*