Parallel Computation of Unsteady Flow with Nonequilibrium Condensation Through 3-D Multistage Steam Turbine Cascade

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ABSTRACT

The phase change from water vapour to water liquid in steam turbines may be fundamentally governed by homogeneous nucleation and the nonequilibrium process of condensation. The latent heat in water vapour is released to the surrounding non-condensed gas when the phase change occurs, increasing temperature and pressure. It is known that these phenomena certainly affect the performance of steam turbines. The purpose of this study is to develop a computational code for calculating three-dimensional multi-stage stator-rotor cascade channels in steam turbines considering nonequilibrium condensation. The computational code is customized for the supercomputer SX-7 in Tohoku university and for a PC-cluster.

The fundamental equations in this study consist of conservation laws of the density of water vapour, the momentums, the total energy, the density of water liquid, and the number density of water droplets in general curvilinear coordinates coupled with the SST turbulence model[1] as

$$\frac{\partial Q}{\partial t} + \frac{\partial F_i}{\partial \xi_i} + \frac{1}{Re} S = H \quad (i = 1,2,3) \tag{1}$$

$$Q = J\begin{bmatrix} \rho_v \\ \rho u_1 \\ \rho u_2 \\ \rho u_3 \\ e \\ \rho\beta \\ \rho n \\ \rho k \\ \rho\omega \end{bmatrix}, \quad F_i = J\begin{bmatrix} \rho_v U_i \\ \rho u_1 U_i + \partial\xi_i/\partial x_1 p \\ \rho u_2 U_i + \partial\xi_i/\partial x_2 p \\ \rho u_3 U_i + \partial\xi_i/\partial x_3 p \\ (e+p)U_i \\ \rho\beta U_i \\ \rho n U_i \\ \rho k U_i \\ \rho\omega U_i \end{bmatrix}, \quad S = J\frac{\partial\xi_i}{\partial x_j}\frac{\partial}{\partial\xi_i}\begin{bmatrix} 0 \\ \tau_{1j} \\ \tau_{2j} \\ \tau_{3j} \\ \tau_{kj}u_k + (\kappa+\kappa')\partial T/\partial x_j \\ 0 \\ 0 \\ \sigma_{kj} \\ \sigma_{\omega j} \end{bmatrix}, \quad H = J\begin{bmatrix} -\Gamma \\ 0 \\ 0 \\ 0 \\ 0 \\ \Gamma \\ \rho I \\ S_k \\ S_\omega \end{bmatrix}$$

where, Q, F, S, and H are the vector of unknown variables, vector of flux, viscous term, and source terms as follows. The mass generation rate Γ for water droplets is formed as a sum of the mass generation rate of critical-sized nucleus and the growth rate of a water droplet based of the classical condensation theory[2]. The high-order high-resolution finite-difference method based on the fourth-order MUSCL TVD scheme[3] and the Roe's approximate Riemann solver is used for space discretization of convection terms in the fundamental equations Eq.(1). The viscosity term is calculated by the second-order central-difference scheme. The LU-SGS method is used for the time integration.

We first calculated two-dimensional wet-steam flows through two-stage stator-rotor cascade channels developed by Mitsubishi Heavy Industries(MHI). Figures 1 shows the calculated instantaneous condensate mass fraction contours assuming the dry inlet and the 2.44% wetness. The present code could calculate the flow already wetted at the inlet successfully. In dry case, Condensation starts in the first stage rotor cascade channel and the condensed water droplets grow downward. On the other hand, The growing of water droplets may start from the throat of the first stage stator channel of the 2.44% wet case. Figure 2 shows the calculated condensate mass fractions are compared with that predicted by the MHI. The calculated condensate mass fractions are in good agreement.

Three-dimensional flows of wet-steam through a single-stage steam-turbine stator-rotor cascade channels are next calculated. The calculated condensate mass fraction and temperature distribution are shown in Figure 3 and 4. The growth of condensed water may be accelerated near the tip and the base of the three-dimensional rotor cascade channels because of the secondary flows produced near these regions. It is a quite new insight how three-dimensional flows affect condensation in steam turbines. When the phase change occurs the latent heat in water vapor was released to the surrounding non-condensed gas and temperature increased. The present code is further extended to three-dimensional flows of wet-steam in two-stage stator-rotor cascade channels of a steam turbine. Figure 5 shows the calculated instantaneous condensate mass fraction contours. This work is still preliminary and the computation is being executed. Here, only a current solution already obtained is introduced. In addition to them, the computational code is also customized to a PC-cluster. Then, the parallelization of the program and the decreasing of the executing memory are attempted. The obtained performance is also discussed.

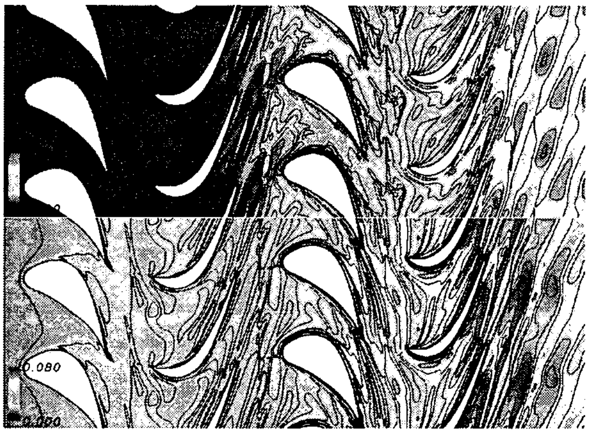

Figure 1. Instantaneous condensate mass fraction contours (Upper: β_{in} = 0.00%, Lower: β_{in} = 2.44%)

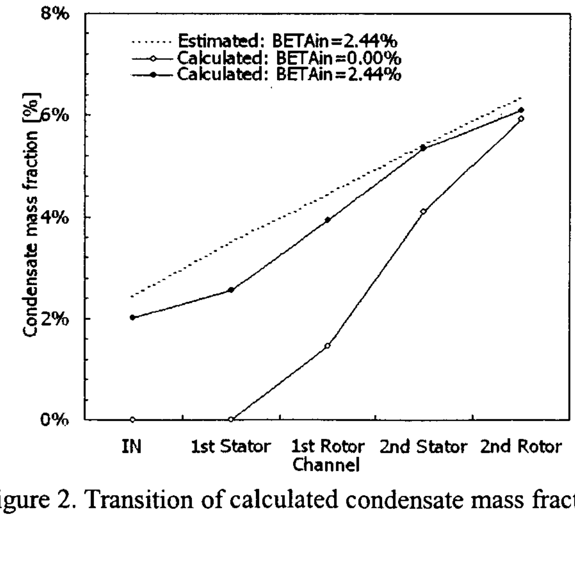

Figure 2. Transition of calculated condensate mass fraction.

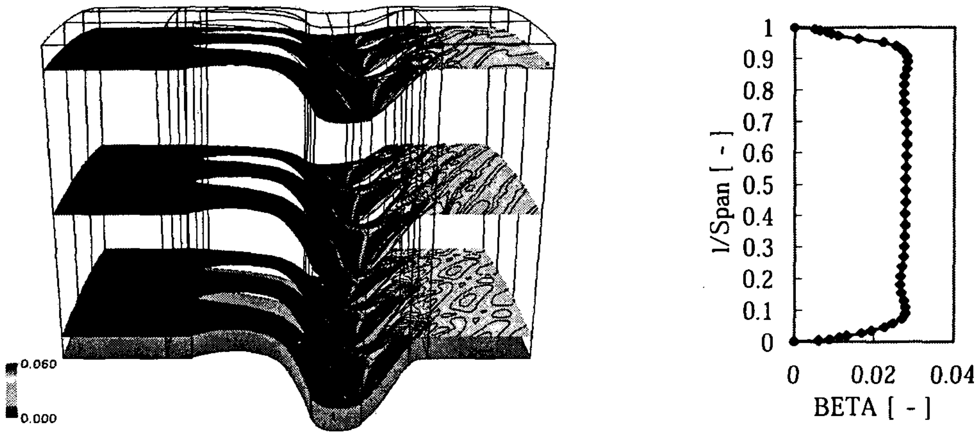

Figure 3. Instantaneous condensate mass fraction contours and span wise distribusion.

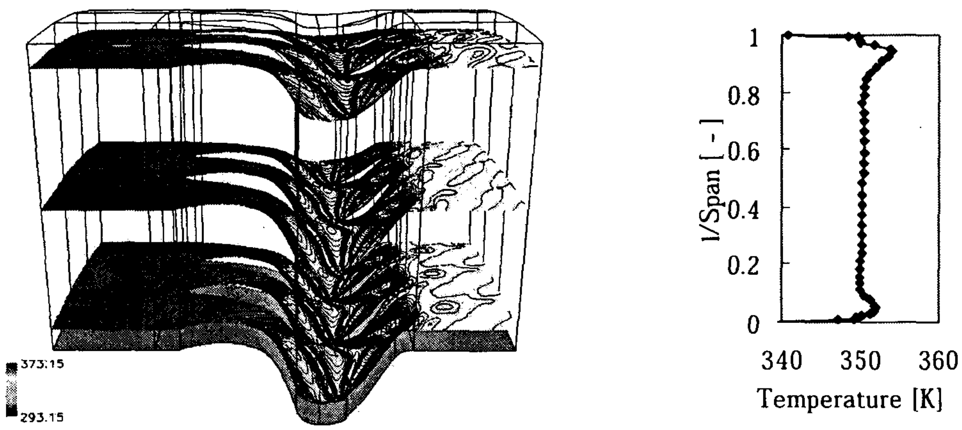

Figure 4. Instantaneous teperature distribution contours and span wise distribusion.

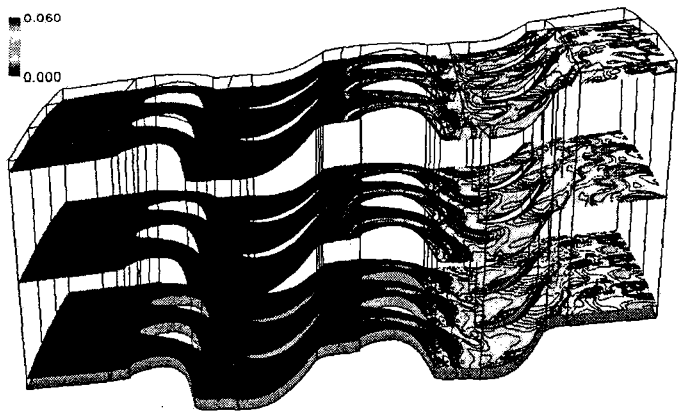

Figure 5. Instantaneous condensate mass fraction contours.

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