CFD-ANALYSIS OF 3D FLOW STRUCTURE AND ENDWALL HEAT TRANSFER IN A TRANSONIC TURBINE BLADE CASCADE: EFFECTS OF GRID REFINEMENT

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Development of three-dimensional structures in turbine blade rows are controlled mostly by flow physics in the layer adjacent to the endwall. The main factors are the deceleration of the endwall boundary layer, when approaching the blade leading edge (LE), and the flow turn in the blade passage. The first factor action is typical also for a wing-body junction, so the experience on modeling of 3D flow structure and heat transfer in blade rows can be useful for external aerodynamics applications as well.

CFD-analysis is a powerful tool to obtain data on 3D turbulent flow structure and local heat transfer that are necessary to design a turbine stage. However, a systematic work aimed at CFD model validation and grid dependence evaluation has to be performed comparing computational results with benchmark-quality experimental data. It should be emphasized here, that among other data of practical interest the local heat transfer data are the most sensitive to peculiarities of secondary flows, and, consequently, to details of physical and computational modelling.

The NASA Glenn Research Center (GRC) linear transonic blade cascade of a large-scale (Giel *et al*, 1996-2001) is a test case specially designed to provide a detailed high Mach number rotor blade flow and heat transfer data set to CFD code developers and users.

Previous CFD studies dealing with the NASA GRC transonic blade cascade test cases were performed using Navier-Stokes codes of second-order accuracy with block-structured computational grids consisting of about 350,000 to 550,000 cells (for one half of the blade passage height, in compliance with the flow symmetry). Analysis of the computational data reported allows a conclusion that computations with grids of such a size produce grid-independent data on wall pressure distribution and shock position, but the grid sensitivity of local heat transfer and pressure losses remains questionable.

The present contribution covers CFD results obtained with the code SINF being under long-time development at the Department of Aerodynamics of the St.-Petersburg State Polytechnic University. For the NASA GRC experimental case of the inlet Reynolds number of 1.0×10^6 and the isentropic exit Mach number of 1.3, computational data were obtained with several low-Re turbulence models (k-w model by Wilcox, Menter SST model, v^2-f model by Durbin) and several computational meshes. The meshes are comprised of about 360,000 to 1,200,000 cells. Finer grids were generated by clustering grid nodes in the blade leading edge region. With the grid refinement, average cell size

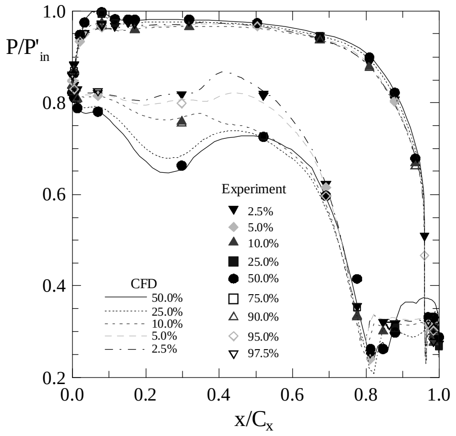

Figure 1. Blade surface pressure distributions.

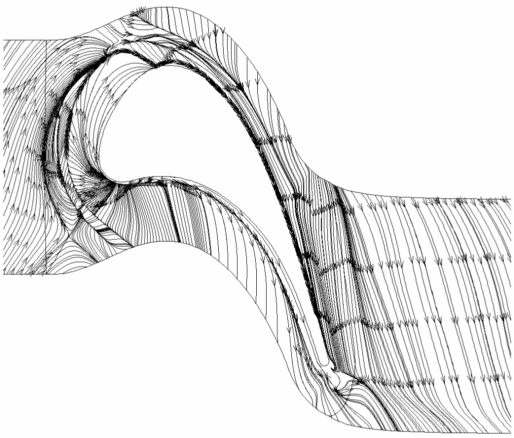

Figure 2. Endwall flow visualization.

in the middle between the saddle (separation) point and the LE was gradually decreased from about 3% of the blade axial chord to 1%.

Figure 1 shows blade pressure loading distributions at 50%, 25%, 10%, 5% and 2.5% span. For all the grids and turbulence models used, the distributions computed are in a good agreement with experimental data.

A pattern of limiting streamlines on the endwall is shown in Figure 2. These results were obtained with the (finest) grid of 1,200,000 cells. With the MSST model, the most complicated vortex structure (with the main horseshoe vortex, the counter rotating secondary vortex located near the endwall and the tertiary vortex) was obtained.

Local heat transfer prediction results in terms of the Stanton number are illustrated in Figure 3. One can conclude that both the form of isolines and maximum values of the Stanton number depend strongly on the grid refinement, especially it is sensitive to grid clustering near the blade LE.

As a whole, on the base of the present CFD-analysis one can conclude that rather fine computational grids are needed to get grid-independent data on the endwall local heat transfer controlled by complex 3D structure of secondary flows. With CFD codes of second-order accuracy, one should use grids comprised of more than 2 millions cells (for each full blade passage) to get a definite conclusion on preference of one or another turbulence model for predictions of phenomena under consideration.

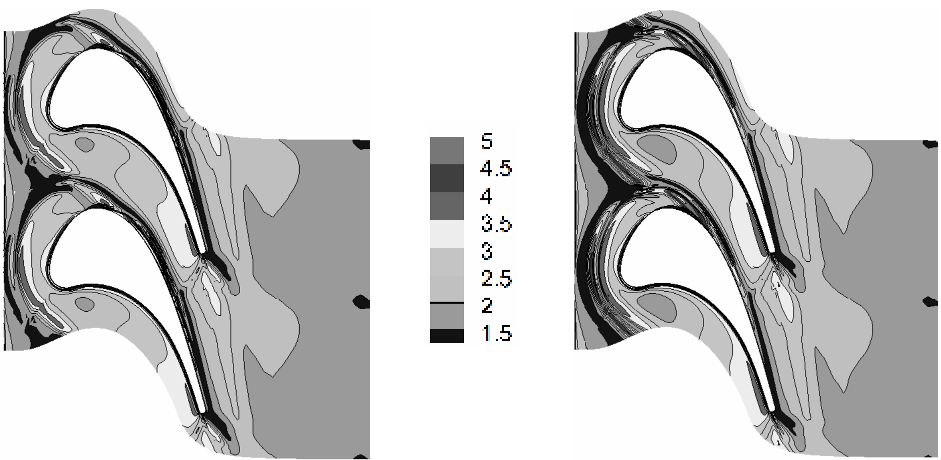

Figure 3. Stanton number (x10^3) distributions over the endwall obtained with (left) a grid of 750,000 cells, and (right) a grid of 1,200,000 cells.