THE STRUCTURE OF THE NEAR WALL SUBLAYER IN ROTOR/STATOR NON-ISOTHERMAL FLOWS

Kamil Kiełczewski[1], Ewa Tuliszka-Sznitko[1]
[1]*Institute of Thermal Engineering, Poznań University of Technology*
Poznań, Poland

Abstract The article summarizes the authors numerical results (DNS/SVV) obtained during investigations of the structures in rotating 3D turbulent flows with heat transfer. Attention is focused on the near wall area that is crucial for modelling purposes. The obtained results are compared with the experimental and numerical data published in literature as well as with the theoretical solutions. Computations are performed on grids with about 40 million collocation points..

INTODUCTION

The problem of laminar-turbulent transition and turbulence in the near wall sublayer is far from solved, both in terms of understanding of physics and in terms of obtaining engineering accuracy for different devices in which turbulent flows play an important role (fluid flow machines, aircraft and automobile industries). The near wall sublayer is presently modeled mostly based on the existing knowledge about simple 2D models (zero pressure gradient boundary layers and plane channel flow). It is believed that the understanding of the structure of coherent eddies in transitional and turbulent areas in simple model flows helps to understand more complex wall flows. This knowledge can contribute to wall turbulence controlling and to the development of scaling ideas. Additionally, the knowledge about turbulent flow structures, their origins, role in creating stress and transporting energy can help to understand the nature of the turbulence.

RESULTS AND DISCUSSION

In paper the authors have attempted to study numerically the structure of the near wall sublayer by means of the strongly 3D non-isothermal rotor/stator and rotor/rotor model flows (with and without axial annular jets). These simple model flows contain Reynolds stresses which transport mean momentum and they also produce and dissipate turbulent kinetic energy. Rotor/rotor and rotor/stator flows are the simplest possible wall flows which exhibit most of the phenomena that are needed to understand strongly 3D transitional and turbulent flows in more general flow cases (the model is particularly suitable for gas turbines and axial compressors). The authors deliver the detailed characteristics of the boundary layers: distributions of structural parameters, turbulence scales (Kolmogorow, Taylor), skewness $S=\overline{(\partial u_i/\partial x_j)^3}/\left[\overline{(\partial u_i/\partial x_j)^2}\right]^{3/2}$ and flatness $F=\overline{(\partial u_i/\partial x_j)^4}/\left[\overline{(\partial u_i/\partial x_j)^2}\right]^{2}$ factors, dimensionless dissipation rate $\varepsilon^+=\varepsilon\nu/u_\tau^4$ of the turbulent kinetic energy, dissipation rate tensor $\varepsilon_{ij}=\nu\overline{(\partial u_i'/\partial x_k)(\partial u_j'/\partial x_k)}$, normalized eddy viscosity $\nu_t^+=\nu_t/\nu$, turbulent stress-generation tensor $-(\overline{u_i'u_k'}\,d\bar{u}_j/dx_k+\overline{u_j'u_k'}\,d\bar{u}_i/dx_k)$, heat flux generation rates due to a temperature gradient, Reynolds stress tensor components $\overline{u_i'u_j'}/u_\tau^2$, turbulent heat transfer tensor components and many others in function of wall coordinate z^+. The authors expect that the obtained detailed characteristics have universal character (computations are performed for up to 40 million collocation points that should guarantee high precision of computations). Figure 1 presents the exemplary budget for transport equation of turbulent temperature fluctuation obtained for aspect ratios L=25, curvature parameter Rm=1.8 and Reynolds numbers Re=400000. The authors compare their results (also visualization of structures, Figure 2a) with the existing experimental and numerical data obtained for similar configurations ([1], [2], [3], [4]) and discuss result in the light of 2D well known models published in literature. Results are obtained for different geometrical parameters: aspect ratio L=25-45 and curvature Rm=1.8-3.0, for wide range of Reynolds numbers (up to $8\cdot10^5$) and the thermal Rossby number, $B=\beta(T_2-T_1)=0.1$. The authors also present Nusselt number distributions along disks. The Nusselt number distributions are also presented for the laminar flow cases with axial annular jet impinging on a heated rotor and are correlated with the resulting flow structure (Figure 2b). These results can be particularly interesting for engineering dealing with cooling system in gas turbines. The flow is described by the Navier-Stokes, continuity and energy equations, written in a cylindrical coordinate system (r, φ, z) with respect to the rotating frame of reference. The numerical solution is based on a pseudo-spectral Chebyshev-Fourier-Galerkin collocation approximation. In the time approximation the authors use a second-order semi-implicit scheme, which combines an implicit treatment of the diffusive terms and an explicit Adams-Bashforth extrapolation for the non-linear convective terms. In non-homogeneous radial and axial directions the Chebyshev polynomials with the Gauss-Lobatto distributions to ensure high accuracy of the solution inside the very narrow boundary layers at the disks are used; Fourier series is used in azimuthal direction ([5], [6], [7]). Code is parallelized with OpenMP technology. The visualization is prepared using ParaView (the Q criterion is used). In order to further increase in the precision of computations the authors are going to implement the multi-domain technology.

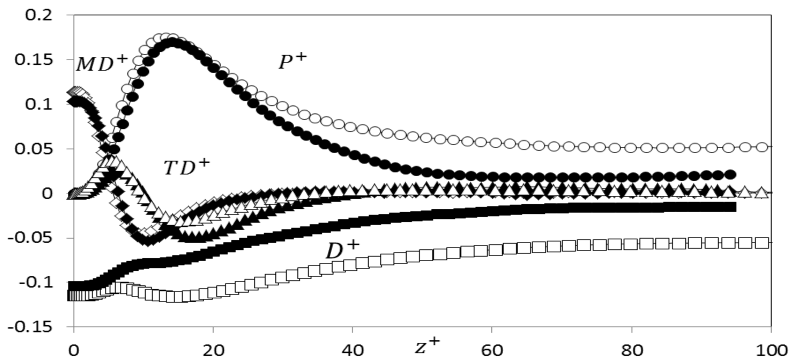
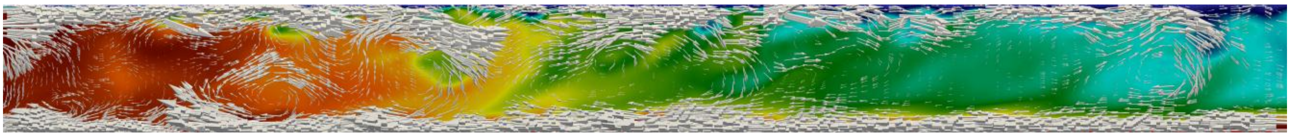
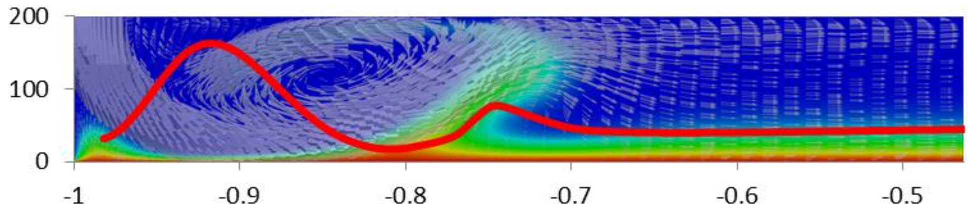


Figure 1. Budget for transport equation of turbulent temperature fluctuation obtained for Re=400000, L=5, Re=1.5, B=0.1. Comparison with the numerical results [1], [2], [3]. Kasagi results are depicted by white dots and the present results by black dots.



a)



b)

Figure 2. a) The temperature and velocity fields. The fragment of the meridian section of the rotor/stator cavity. Re=4000000, B=0.1, Pr=0.7, L=25, Rm=1.8. b) Preliminary results with the axial annular jet and distribution of the Nusselt number, Re=80000, L = 15, Rm=1.8, $(r_a - r_{R_0}) = 0{,}02432$.

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