14TH EUROPEAN TURBULENCE CONFERENCE, 1–4 SEPTEMBER 2013, LYON, FRANCE

NUMERICAL STUDY OF A QUASI-TWO-DIMENSIONAL CONFINED TURBULENT JET

Rustam Mullyadzhanov[1,2], Boris Ilyushin[1,2], Muhamed Hadžiabdić[3] & Kemal Hanjalić[2,4]
[1]*Institute of Thermophysics, Novosibirsk, Russia*
[2]*Novosibirsk State University, Novosibirsk, Russia*
[3]*International University of Sarajevo, Sarajevo, Bosnia and Herzegovina*
[4]*Delft University of Technology, Delft, Netherlands*

Abstract Large-eddy simulations of a wall-bounded turbulent slot-jet have been performed to analyze the dynamics of quasi-two-dimensional large-scale meandering vortical structures and their interaction with small-scale stochastic turbulence. Despite a wide scale separation, LES indicate that there is an energy exchange between the two spectral ranges in both directions. The phenomenon is of relevance to fluid/pollutant discharge into shallow rivers or water basins.

INTRODUCTION

We report on a study of a turbulent jet discharged through a slot into a large medium of the same ambient fluid bounded by two narrowly spaced parallel walls. Thus, the characteristic horizontal (streamwise and spanwise) dimensions are significantly larger than the fluid layer thickness. This flow configuration is encountered in water cooling of equipment in various industries and it is also relevant to pollutants discharged from rivers or open channels into lakes and ocean. However, because of the closely spaced bounding walls that suppress the growth of vortical structures and turbulent eddies in the lateral direction and large dimension in the spanwise direction, it is also of interest for studying some aspects of turbulence physics, primarily the interaction of large-scale quasi-two-dimensional recirculating motion and the small-scale stochastic turbulence.

A striking feature of this flow is the "meandering" pattern of the large-scale structures due to eddies growing in the checkerboard order on both spanwise sides of the jet flow [1]. The development of these eddies is the result of the linear instability of a shallow-water jet, as discussed in [2].

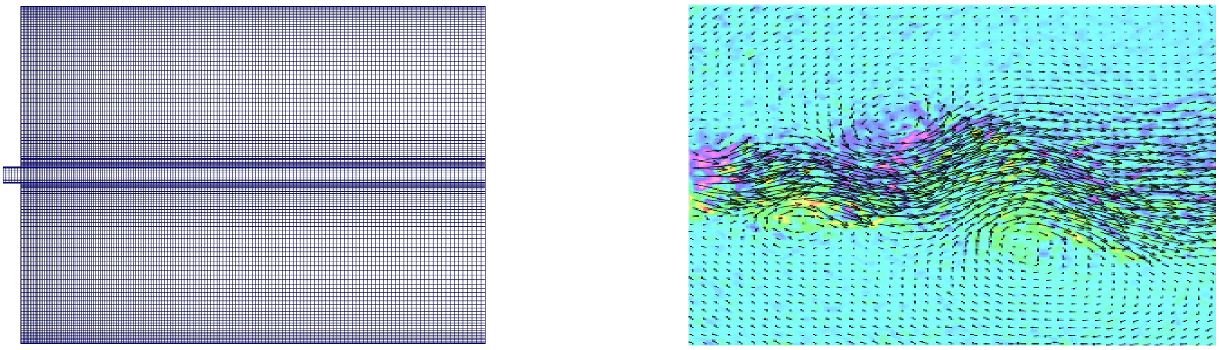
In the literature the theoretical treatment is usually limited to integral models and time-averaged solutions which cannot give any information about time-space correlations of the flow. On the other hand, experimental works on plane ("slot") turbulent jets are usually focused on quasi-infinite configuration with the spanwise direction exceeding by order of magnitude the jet width. Early studies in [3, 4] investigated the influence of the secondary flows due to walls on mean flow characteristics. Later in [1, 5] it was shown that secondary flows were only significant in the near-field region. Results in [6, 7, 8] suggest that in the far-field of the jet different types of structures may co-exist despite being quasi-two-dimensional, while the near-field flow is three-dimensional. In works [1, 9, 10] a detailed measurement of the jet is provided addressing its different parts.

The interaction of the two-dimensional large-scale vortices with small-scale three-dimensional turbulence implies a more complicated dynamics, spectral structure and spectral transfer of turbulent eddy structures. Such a dynamics can be observed in the atmospheric boundary layers as well as in coastal ocean currents near river mouths. Namely, we expect that for the range of wave numbers corresponding to linear sizes larger than the size of the slot, the flux of the spectral turbulent energy is directed upward, while the energy transfer from the small-scale turbulence is directed downward. In this case, turbulent energy sink should occur in two areas of the spectrum: viscous dissipation of 3D turbulence in small-scale region and wall friction losses by large-scale vortices. The aim of this work is to study the structure and the spectral energy flux in fluid flows of specific slender geometry and its sink mechanisms due to viscous effects both on the wall and in the core of the flow. To this aim we perform large-eddy simulations of the above described flow in order to get an insight into the dynamics, statistics, and structure of large-scale eddies as well as to analyze the mechanisms of energy transfer from small scales to large ones and vice versa.

NUMERICAL METHOD AND RESULTS PREVIEW

The numerical simulations are conducted using the finite-volume computational code *T-FlowS*, with the cell-centered collocation grid structure [11, 12]. The filtered Navier-Stokes equations for incompressible fluid are closed by the dynamic Smagorinsky subgrid-scale model. The diffusion and convection terms in the momentum equations are discretised by the second-order central-differencing scheme, whereas the time-marching is performed using a fully implicit three-level time scheme. The iterative pressure correction algorithm SIMPLE is used for coupling velocity and pressure fields.

The geometry under consideration is shown in Fig. 1a. The distance between the narrowly spaced parallel walls is h, the width of the computational domain is $200h$ and its length is $270h$. The fluid is discharged into the volume through a slot of the width $10h$ and length $30h$. The Reynolds number is 10000 based on h and the bulk velocity of the slot



(a) (b)

Figure 1. (a) Geometry of the problem and the coarse mesh used for preliminary computations. (b) Instanteneous velocity field from experiment [10].

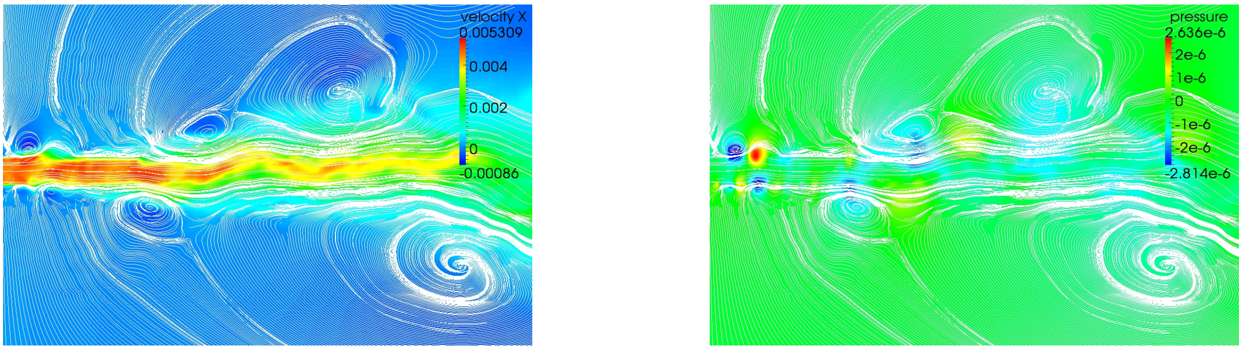


Figure 2. Streamlines and instanteneous field of axial velocity and pressure. Only a part of described geometry is shown.

flow. The geometry and flow intensity are selected to match the unpublished experimental data available to the authors. No-slip boundary condition is used for all walls, while convective outflow condition is applied at the end of the domain. A uniform velocity profile is applied at the inflow.

At the moment preliminary results from coarse LES are available. Fig. 2 shows instanteneous streamlines together with axial velocity and pressure fields. The result shows qualitative agreement with experimental visualization of [10] shown in Fig. 1b. It displays an unsteady and meandering character of the core of the flow. The large-scale vortices are due to ambient fluid entrained by the jet in the near-field region.

The full paper will present the comparison of numerical simulations (on a fine mesh of about 20 million cells) and experimental data from the literature. In particular, we will compare mean velocity profiles with existing self-similar solutions, calculate high-order statistics and analyze temporal and spatial spectra of the flow.

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