Fully-developed, pressure-driven flow of an incompressible, isothermal fluid through a straight duct with square cross section: data from DNS

A full description of the simulations is available in references [1; 2].

Description of the flow

We are considering the flow of an incompressible and isothermal fluid in a straight duct with square cross-section of half-width h (cf. figure 1). The flow field is assumed to be streamwise periodic over a period of length L_x and a constant flow rate is imposed at each time step.

Flow parameters

The problem is governed by a single parameter, the bulk Reynolds number $Re_b = u_b h/\nu$, where u_b is the bulk velocity and ν the kinematic viscosity. Table 1 shows the simulated Reynolds number values.

Numerical method and resolution

- Incremental-pressure projection method;
- Crank-Nicholson scheme for the viscous terms;
- three-step low-storage Runge-Kutta method for the non-linear terms [3];
- truncated Fourier series in the streamwise direction (2/3 de-aliasing), Chebyshev polynomials in the cross-stream (collocated grid);
- "slip error" was kept below $5 \cdot 10^{-5}$ times the bulk flow velocity.

Numerical parameters

The data included in this repository is characterized by the following features:

- domain size: $10.97h \leq L_x \leq 12.57$.
- time step: $CFL \leq 0.25$;
- streamwise grid spacing: $\Delta x^+ \leq 15$;
- maximum cross-stream grid-spacing: $max(\Delta y^+) \leq 5.7$;
- statistics accumulated over time: $t_{stat} \geq 3500h/u_b$.

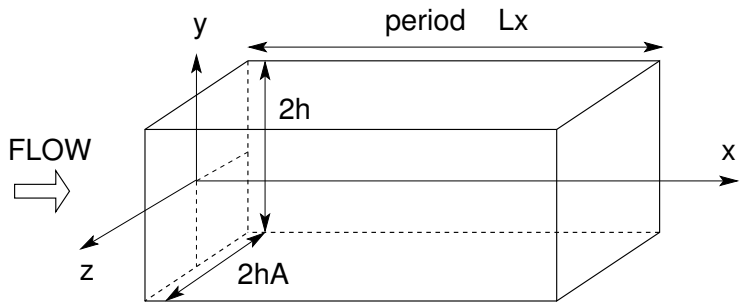

Figure 1: The geometry of the problem and the computational domain.

Re_b	Re_τ	N_y	Δy^+_{min}	Δy^+_{max}	$t_{stat} u_b/h$
1100	78.21	97	0.042	2.56	4685
1150	79.02	97	0.042	2.59	4675
1250	89.23	97	0.048	2.92	4570
1300	92.14	97	0.049	3.01	5012
1350	96.29	97	0.052	3.15	4627
1400	98.75	97	0.053	3.23	5340
1500	104.96	97	0.056	3.43	4579
1600	110.99	97	0.059	3.63	4164
1800	123.20	97	0.066	4.03	3817
2000	136.18	97	0.073	4.46	3991
2205	149.45	97	0.080	4.89	15447
2400	161.54	97	0.086	5.29	4164
2600	174.02	97	0.093	5.69	3904
2900	190.54	129	0.057	4.68	4187
3200	207.86	129	0.063	5.10	3639
3500	225.19	129	0.068	5.53	5591

Table 1: Simulation parameters: bulk Reynolds number Re_b, friction-velocity Reynolds number Re_τ, number of cross-stream Chebyshev polynomials $N_y = N_z$, minimum and maximum cross-stream grid sizes in wall units Δy^+_{min} and Δy^+_{max}, respectively, statistics interval t_{obs} in bulk units.

Available data

The data-set contains the following data items:

- components of the time-averaged velocity vector $\langle \mathbf{u} \rangle (y, z)$;
- components of the Reynolds stress tensor $\langle u_i' u_j' \rangle (y, z)$, where the fluctuation is defined as $\mathbf{u}' = \mathbf{u} - \langle \mathbf{u} \rangle$.

Data format and location

Data is presented in the form of binary files. A script for reading the data and plotting it with Matlab (or GNU/octave) is provided. The data is located below the following URL:

www.ifh.kit.edu/dns_data/duct

Contact

Markus Uhlmann
Institute for Hydromechanics
Karlsruhe Institute of Technology (KIT)
76131 Karlsruhe, Germany
markus.uhlmann@kit.edu

References

[1] A. Pinelli, M. Uhlmann, A. Sekimoto, and G. Kawahara. Reynolds number dependence of mean flow structure in square duct turbulence. *J. Fluid Mech.*, 644:107–122, 2010.

[2] M. Uhlmann, A. Pinelli, G. Kawahara, and A. Sekimoto. Marginally turbulent flow in a square duct. *J. Fluid Mech.*, 588:153–162, 2007.

[3] R. Verzicco and P. Orlandi. A finite-difference scheme for three-dimensional incompressible flows in cylindrical coordinates. *J. Comput. Phys.*, 123:402–414, 1996.