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

Description of the flow

We are considering the flow of an incompressible and isothermal fluid in a straight open duct with rectangular cross-section of duct full-height 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 two parameters, namely: the bulk Reynolds number $Re_b = u_b h/\nu$, where u_b is the bulk velocity and ν the kinematic viscosity; and aspect ratio $A = L_z/(2h)$. Note the factor of 2 difference between the above aspect ratio definition and more conventional width-to-height ratio. The current definition is used to maintain the consistency between the open and the closed duct with the identifical hydraulic diameter ($D_H = 4\mathcal{A}/P$, where $\mathcal{A}$ is duct cross-sectional area and P is wetted perimeter) having the same aspect ratio. Table 1 shows the simulated Reynolds numbers as well as aspect ratios.

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 [1];
- Truncated Fourier series in the streamwise direction (2/3 de-aliasing),
- Chebyshev polynomials in the cross-stream (collocated grid);

Numerical parameters

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

- Domain size: $L_x = 8\pi h$

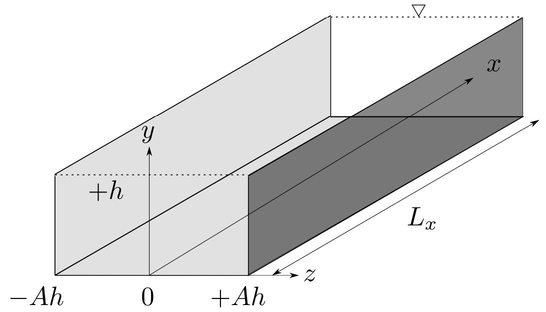

Figure 1: Coordinate system and geometry of open duct simulations. Shaded planar boundaries represent no-slip walls, whereas the transparent plane enclosed by dotted lines represents free-slip boundary.

- Time step: $CFL \leq 0.3$
- Streamwise grid spacing: $\Delta x^+ \leq 15.2$
- Maximum cross-stream grid-spacing: $\max(\Delta y^+, \Delta z^+) \leq 4.0$
- Statistics accumulated over time: $t_{\text{stat}} \geq 6009$

Available data

The data-set contains the following data items:

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

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:

http://www.ifh.kit.edu/dns_data/duct/OPEN_duct/

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References

[1] R Verzicco and P Orlandi. A finite-difference scheme for three-dimensional incompressible flows in cylindrical coordinates. *J. Comput. Phys.*, 123(2):402–414, 1996.

A	Re_b	Re_τ	$N_x \times N_y \times N_z$	Δx^+	$\max\{\Delta y^+, \Delta z^+\}$	$t_{\mathrm{stat}} u_b / h$
0.5	1900	124	$256 \times 97 \times 97$	12.2	2.0	31083
0.5	2000	142	$256 \times 97 \times 97$	13.9	2.3	20323
0.5	2205	154	$256 \times 97 \times 97$	15.2	2.5	6456
0.5	3000	203	$384 \times 97 \times 97$	13.3	3.3	8301
0.5	5000	325	$512 \times 129 \times 129$	16	4.0	12021
1	1450	102	$256 \times 97 \times 193$	10.2	1.69	9183
1	1480	103	$256 \times 97 \times 193$	10.1	1.68	5248
1	1500	104	$256 \times 97 \times 193$	10.2	1.69	11807
1	1550	107	$256 \times 97 \times 193$	10.4	1.74	9180
1	1800	125	$256 \times 97 \times 193$	12.3	2.05	11449
1	2205	150	$256 \times 97 \times 193$	14.8	2.46	12940
1	3000	197	$384 \times 97 \times 193$	12.9	3.23	9082
1	3500	226	$384 \times 97 \times 193$	14.8	3.70	14826
1	4000	254	$512 \times 129 \times 257$	12.5	3.12	9016
1	4500	282	$512 \times 129 \times 257$	13.8	3.45	10304
1	5000	309	$512 \times 129 \times 257$	15.2	3.80	8005
1	5500	336	$768 \times 193 \times 385$	11.0	2.75	7156
1	6000	363	$768 \times 193 \times 385$	11.9	3.00	9686
1	6500	388	$768 \times 193 \times 385$	12.7	3.20	6009
1	7000	415	$768 \times 193 \times 385$	13.6	3.40	6310
1.5	2205	147	$256 \times 97 \times 289$	14.4	2.4	18166
2	1080	74	$256 \times 97 \times 385$	7.3	1.2	8587
2	1100	75	$256 \times 97 \times 385$	7.4	1.2	11449
2	1150	77	$256 \times 97 \times 385$	7.6	1.3	11449
2	1200	81	$256 \times 97 \times 385$	7.9	1.3	12403
2	1250	84	$256 \times 97 \times 385$	8.3	1.4	12403
2	1300	89	$256 \times 97 \times 385$	8.7	1.4	12403
2	1350	92	$256 \times 97 \times 385$	9.0	1.5	8587
2	1400	95	$256 \times 97 \times 385$	9.4	1.6	10494
2	1450	99	$256 \times 97 \times 385$	9.7	1.6	8587
2	1500	102	$256 \times 97 \times 385$	10.0	1.7	13357
2	1600	108	$256 \times 97 \times 385$	10.6	1.8	8587
2	1800	121	$256 \times 97 \times 385$	11.9	2.0	8587
2	2205	145	$256 \times 97 \times 385$	14.2	2.4	23778
2	3000	191	$384 \times 97 \times 385$	12.5	3.1	9817
2	5000	297	$512 \times 129 \times 513$	14.6	3.7	6144
4	2205	143	$256 \times 97 \times 769$	14.0	2.3	11270
8	1800	120	$256 \times 97 \times 1153$	11.8	2.6	8953
8	2205	143	$256 \times 97 \times 1153$	14.1	3.1	8140

Table 1: Simulation parameters.