

Supplementing materials

Active and passive in-plane wall fluctuations in turbulent channel flows

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$x_{2,c}^+$	Drag reduction (DR) [%]			
	$u'_{1,a}$ -control		$u'_{3,a}$ -control	
	$Re_\tau \approx 180$	$Re_\tau \approx 1000$	$Re_\tau \approx 180$	$Re_\tau \approx 1000$
1	3.48	4.02	4.78	4.38
2	4.19	—	8.95	—
3	5.23	—	12.20	—
5	6.51	6.65	17.18	—
7	7.84	—	—	—
8	7.97	7.03	—	19.30
9	7.73	—	23.06	—
10	6.87	—	23.85	—
11	—	—	24.15	—
12	—	3.57	24.29	18.16
13	—	—	23.90	—
15	0.63	—	21.91	13.22

Table 1: Drag reduction measured with active streamwise ($u'_{1,a}$) and spanwise ($u'_{3,a}$) controls.

#	Re_τ	A_m	A_d	A_s	DR [%]	Comment
1	≈ 180	4	0.0	0.0625	2.87	
2	≈ 180	4	0.0	0.125	2.25	
3	≈ 180	4	0.0	0.25	3.39	
4	≈ 180	4	0.0	0.50	3.11	
5	≈ 180	4	0.0	1.00	3.68	Lo0Lo, max drag reduction
6	≈ 180	4	0.0	2.00	3.41	
7	≈ 180	4	0.0	4.00	3.33	
8	≈ 180	4	0.0	8.00	2.56	
9	≈ 180	4	0.0	16.00	1.80	
10	≈ 180	4	0.0	32.00	1.28	
11	≈ 180	4	0.0	64.00	0.61	
12	≈ 180	4	0.0	96.59	0.86	Lo0Hi, optimised for max RC$\{\tau'_{1,rms}\}$
13	≈ 180	4	0.0	128.00	0.66	
14	≈ 180	4	0.0	256.00	0.16	
15	≈ 180	4	0.0	512.00	-0.07	
16	≈ 180	4	0.0	1024.00	-0.17	
17	≈ 180	16	0.0	1.00	2.87	
18	≈ 180	64	0.0	1.00	1.77	
19	≈ 180	256	0.0	1.00	0.36	
20	≈ 180	1024	0.0	1.00	0.06	
21	≈ 180	4	1.0	1.00	3.54	
22	≈ 180	4	4.0	1.00	3.19	
23	≈ 180	4	16.0	1.00	2.47	
24	≈ 180	4	64.0	1.00	1.78	
25	≈ 180	4	256.0	1.00	0.66	
26	≈ 180	8	1.0	1.00	3.32	
27	≈ 180	16	1.0	1.00	2.71	
28	≈ 180	32	1.0	1.00	2.21	
29	≈ 180	8	2.0	2.00	3.08	
30	≈ 180	8	4.0	2.00	2.89	
31	≈ 180	8	8.0	2.00	2.87	
32	≈ 180	8	16.0	2.00	2.52	
33	≈ 180	8	32.0	2.00	1.95	LoHiLo
34	≈ 180	8	4.0	0.25	2.66	
35	≈ 180	8	4.0	0.50	2.92	
36	≈ 180	8	4.0	1.00	3.18	
37	≈ 180	8	4.0	2.00	2.89	
38	≈ 180	8	4.0	4.00	2.64	
39	≈ 180	4	0.1	0.10	3.16	
40	≈ 180	4	1.0	0.50	3.61	LoLoLo, same as #44

#	Re_τ	Λ_m	Λ_d	Λ_s	DR [%]	Comment
41	≈ 180	4	1.0	2.00	3.47	
42	≈ 180	4	0.5	1.00	3.45	
43	≈ 180	4	2.0	1.00	3.23	
44	≈ 1000	28	7.0	3.50	1.47	LoHiLo, same as #40
45	≈ 1000	8	1.0	1.00	2.35	LoLoLo, max drag reduction
46	≈ 1000	8	0.0	0.10	-0.64	max drag increase
47	≈ 1000	8	0.0	1.00	2.04	
48	≈ 1000	8	0.0	10.00	1.62	
49	≈ 1000	8	0.0	100.00	2.29	
50	≈ 1000	8	0.0	1000.00	0.18	

Table 2: Drag reduction measured with passive streamwise wall fluctuations ($u'_{1,p}$).

#	Re_τ	Λ_m	Λ_d	Λ_s	DR [%]	Comment
51	≈ 180	4	1.0	1.00	-58.77	max drag increase
52	≈ 180	8	1.0	1.00	-55.12	
53	≈ 180	16	1.0	1.00	-49.00	LoLoLo
54	≈ 180	32	1.0	1.00	-40.52	
55	≈ 180	16	1.0	2.00	-48.52	
56	≈ 180	16	1.0	4.00	-47.88	
57	≈ 180	16	1.0	8.00	-46.76	
58	≈ 180	16	1.0	16.00	-43.63	
59	≈ 180	16	64.0	16.00	-17.65	
60	≈ 180	16	64.0	64.00	-13.37	
61	≈ 180	16	64.0	128.00	-10.26	
62	≈ 180	16	128.0	128.00	-7.18	
63	≈ 180	4	0.0	646.93	-3.67	Lo0Hi, optimised for max RC$\{\tau'_{3,rms}\}$
64	≈ 180	4	0.0	1024.00	-1.77	min drag increase

Table 3: Drag reduction measured with passive spanwise wall fluctuations ($u'_{3,p}$).

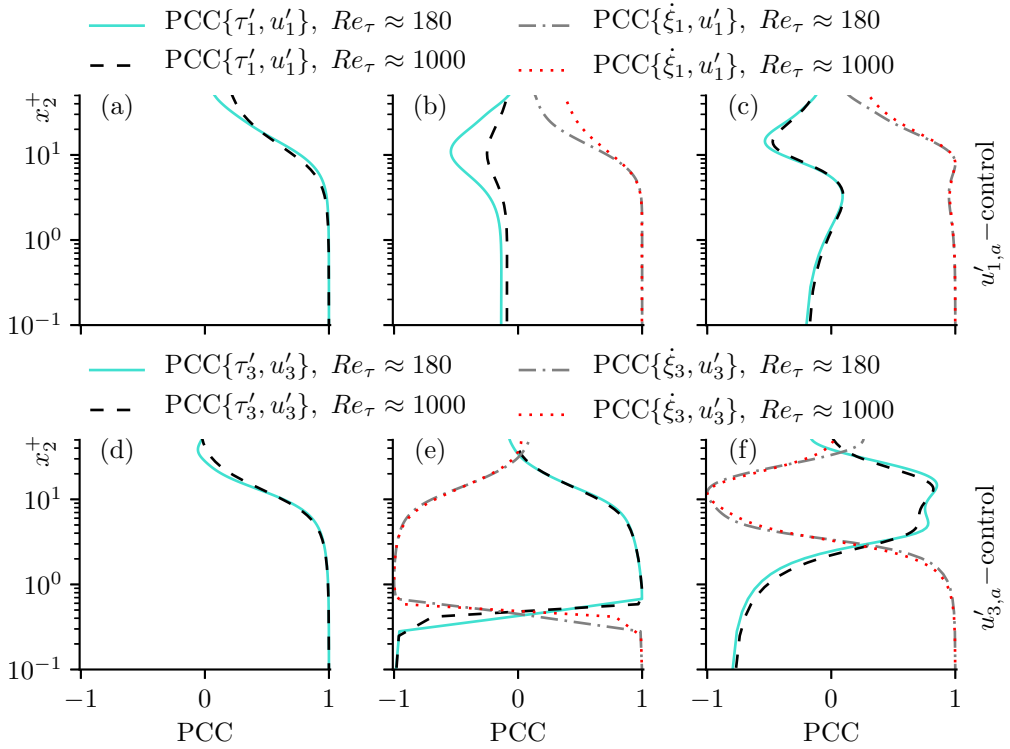


Figure 1: Pearson Correlation Coefficients of the wall shear stress fluctuations and the corresponding fluid velocities ($\text{PCC}\{\tau'_1, u'_1\}$ and $\text{PCC}\{\tau'_3, u'_3\}$), and the wall velocities and the corresponding fluid velocities ($\text{PCC}\{\xi'_1, u'_1\}$ and $\text{PCC}\{\xi'_3, u'_3\}$): baseline, streamwise direction (a); $u'_{1,a}$ -control with $x_{2,c}^+ = 1$ (b); $u'_{1,a}$ -control with $x_{2,c}^+ = 8$ (c); baseline, spanwise direction (d); $u'_{3,a}$ -control with $x_{2,c}^+ = 1$ (e); and $u'_{3,a}$ -control with $x_{2,c}^+ = 8$ (f).

The Pearson Correlation Coefficient (PCC) between two variables with zero mean value (q_1 and q_2) based on spatial averaging is

$$\text{PCC}\{q_1, q_2\} = \frac{\langle q_1 q_2 \rangle_s}{\sqrt{\langle q_1^2 \rangle_s \langle q_2^2 \rangle_s}}. \quad (0.1)$$