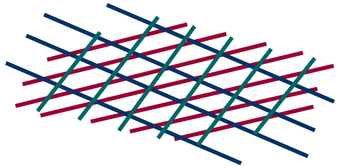
Simulations of the flows over round cylinder at different Reynolds' numbers

NOISEtte

- Scale resolving hybrid RANS-LES **DDES** approach (recent formulation)
  - shear layer adapted Δ_{SLA} [Shur et al., 2015] is used (to provoke RANS-to-LES transition in SL)
  - based on SA turbulence model
  - fully turbulent approach ($\frac{\nu_t}{\nu} \sim 1$) at the inflow
- **Vertex-centered higher accuracy EBR scheme**
  - not higher than 2^{nd} order on arbitrary unstructured meshes (control-volume method)
  - EBR6 CD + EBR5 upwinding
  - **adapting hybrid CD-Upwind-WENO scheme** which depends on local flow characteristics [Guseva et al., 2017], σ_{min}=0.05, σ_{max}=1



- **Time integration**
  - implicit scheme, based on Newton iterations
  - BiCGStab solver
  - ILU0 preconditioner
  - CFL_{max}=500, CFL<1 in the LES region ($d_w > 0.04D$)

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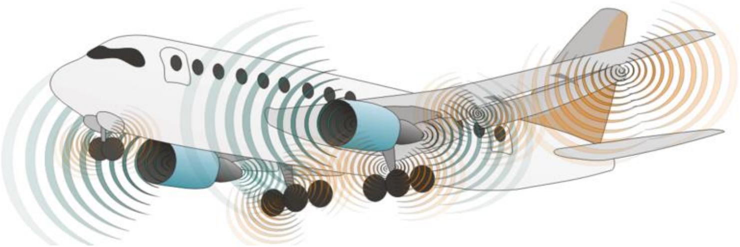
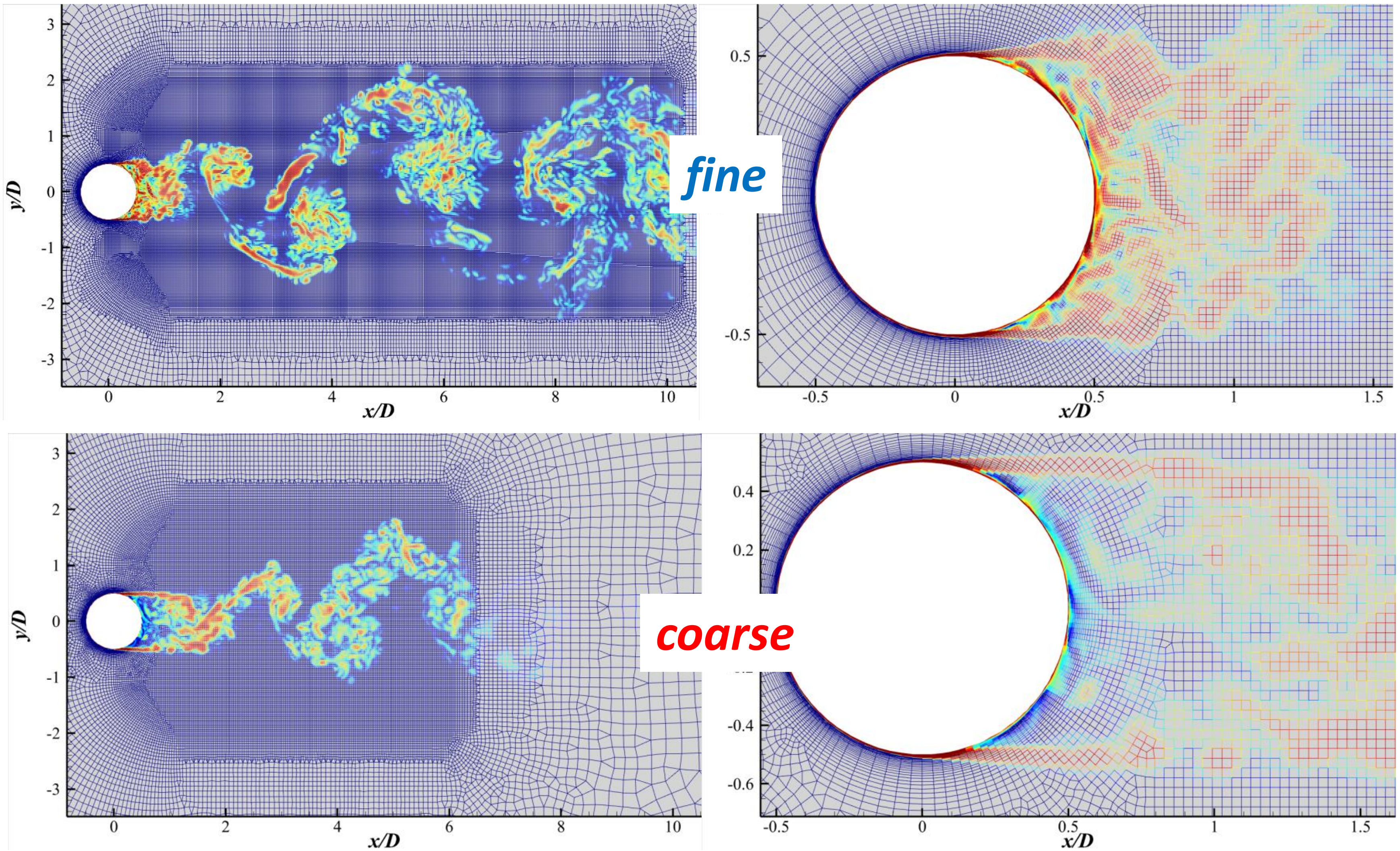


Meshes

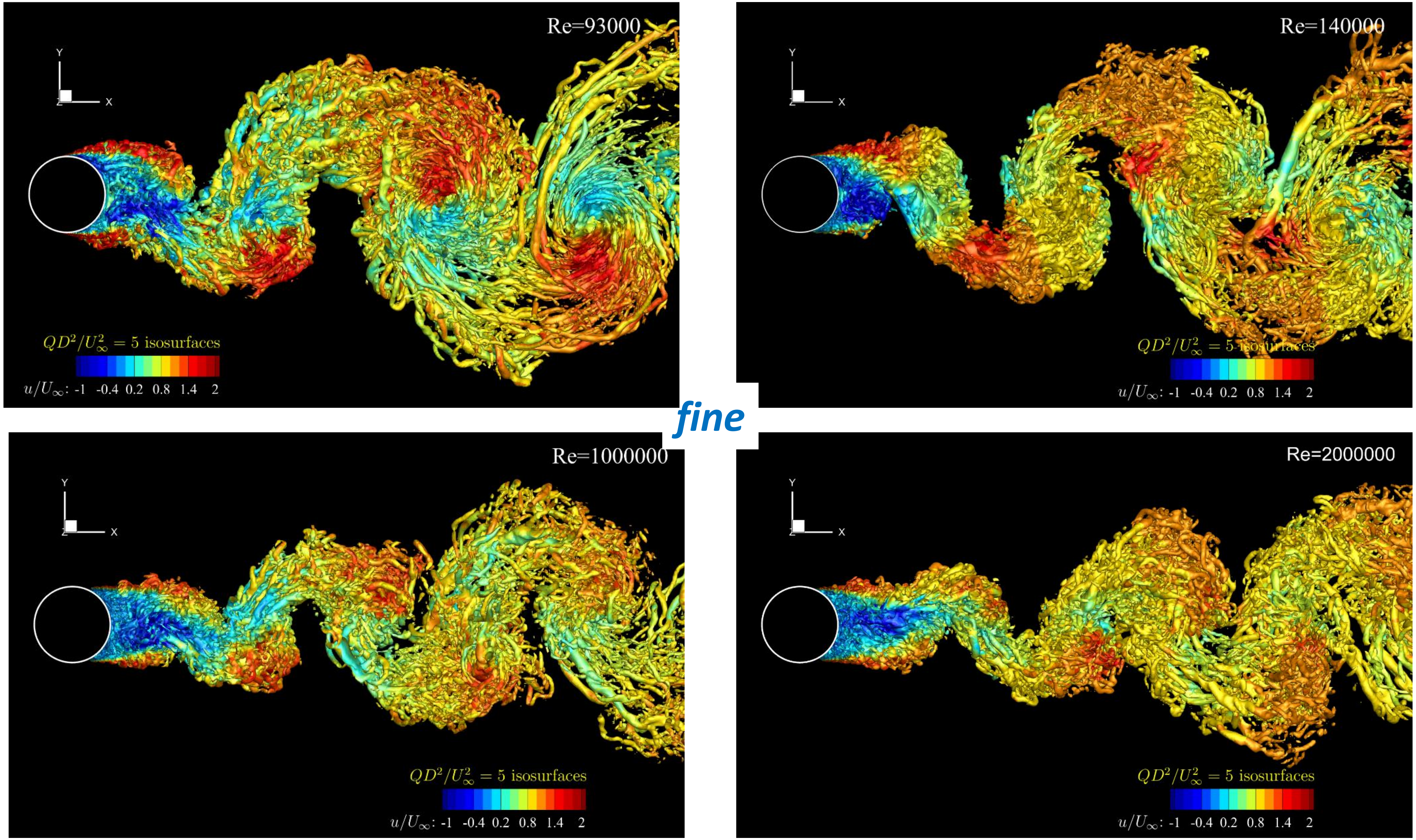
Mesh	N_n	$N_{n,2D}$	N_z	Δ_z/D	Δ_{LES}/D
fine	12.1M	99.6k	121	1/40	1/40
coarse	4.5M	49.3k	91	1/30	1/30

$$L_x \times L_y \times L_z = 250D \times 220D \times 3D$$

$$\Delta_{y,1}^{+} < 1 \qquad \Delta_{y,1} = 10^{-5}D$$



Instantaneous flow field (*fine* mesh)



Integral characteristics

Re=1.4·10^5

	$\overline{C}_d$	$\overline{C}_{l,\mathrm{rms}}$	$-\overline{C}_{p,\mathrm{b}}$	St	$\theta_{\mathrm{sep}},^\circ$
Experiments					
Cantwell&Coles (1983) [2]	1.24		1.21	0.179	
Zdravkovich (1997) [3]				0.2	
KIAM simulations					
fine	0.458	0.243	1.079	0.265	107.5
fine no model	0.154	0.039	0.22		95.65
coarse	0.309	0.048	0.686	0.225	96.5

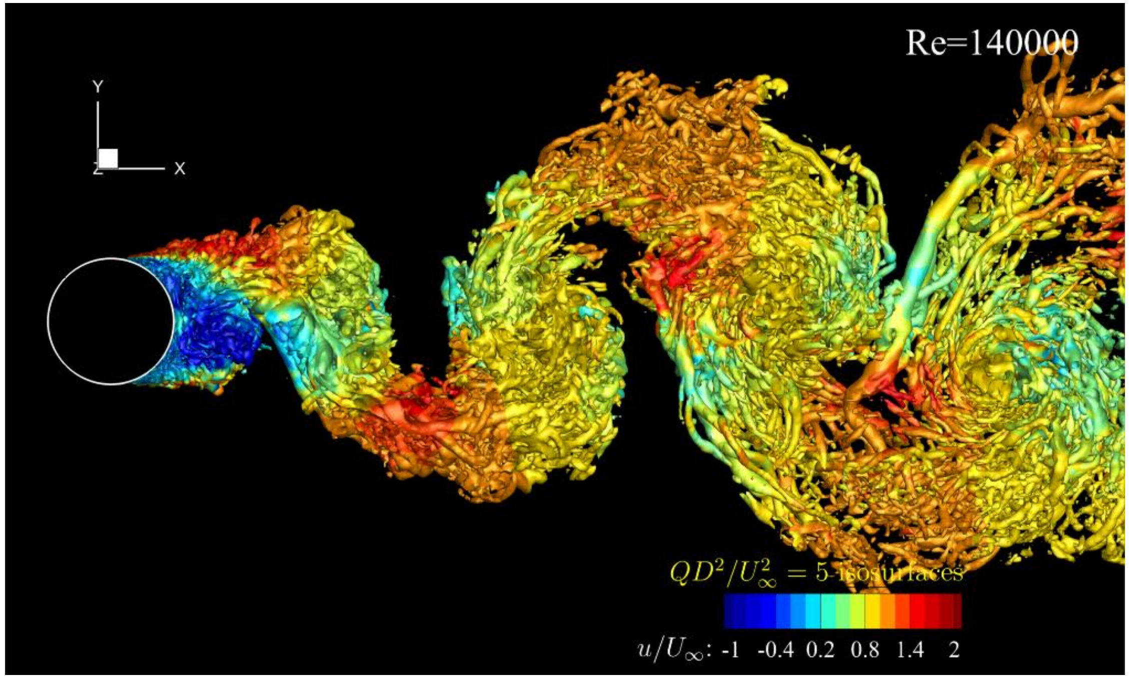
Re=10^6

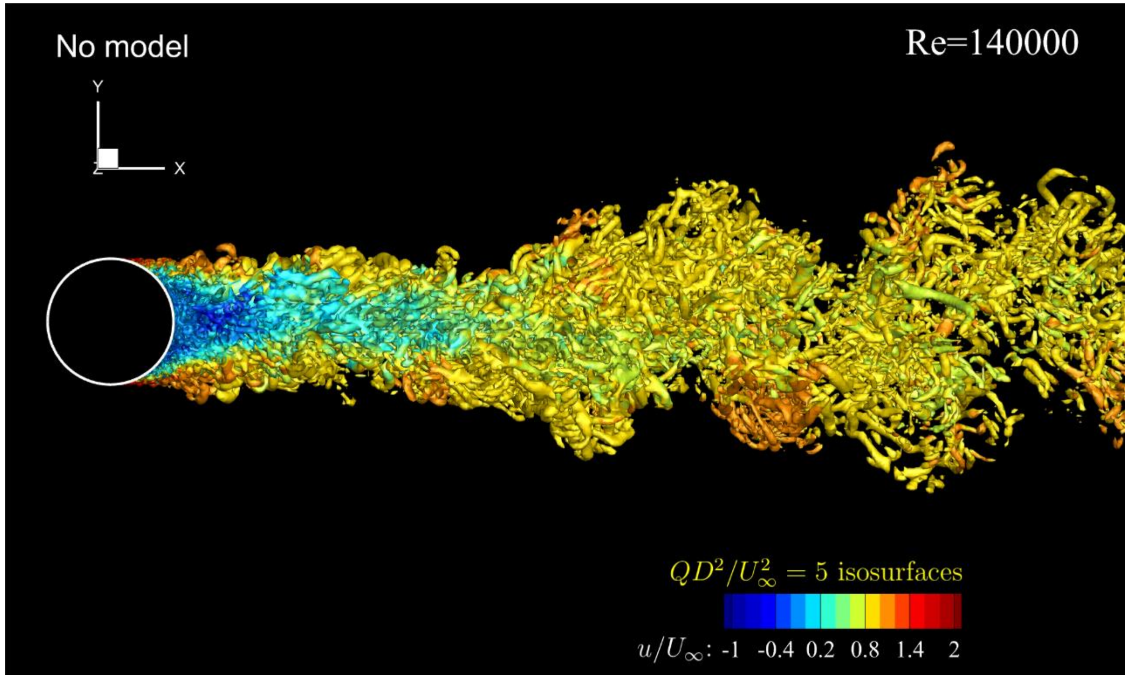
	$\overline{C}_d$	$\overline{C}_{l,\mathrm{rms}}$	$-\overline{C}_{p,\mathrm{b}}$	St	$\theta_{\mathrm{sep}},^\circ$
Experiments					
Szechenyi (1975) [4]	0.25		0.32	0.35	
Goelling (2006) [5]				0.35	
Zdravkovich (1997) [3]	0.2-0.4	0.1-0.15	0.2-0.34	0.5	
KIAM simulations					
fine	0.255	0.065	0.618	0.3	107.5
coarse	0.226	0.027	0.568	0.32	107.1

Re=2·10^6

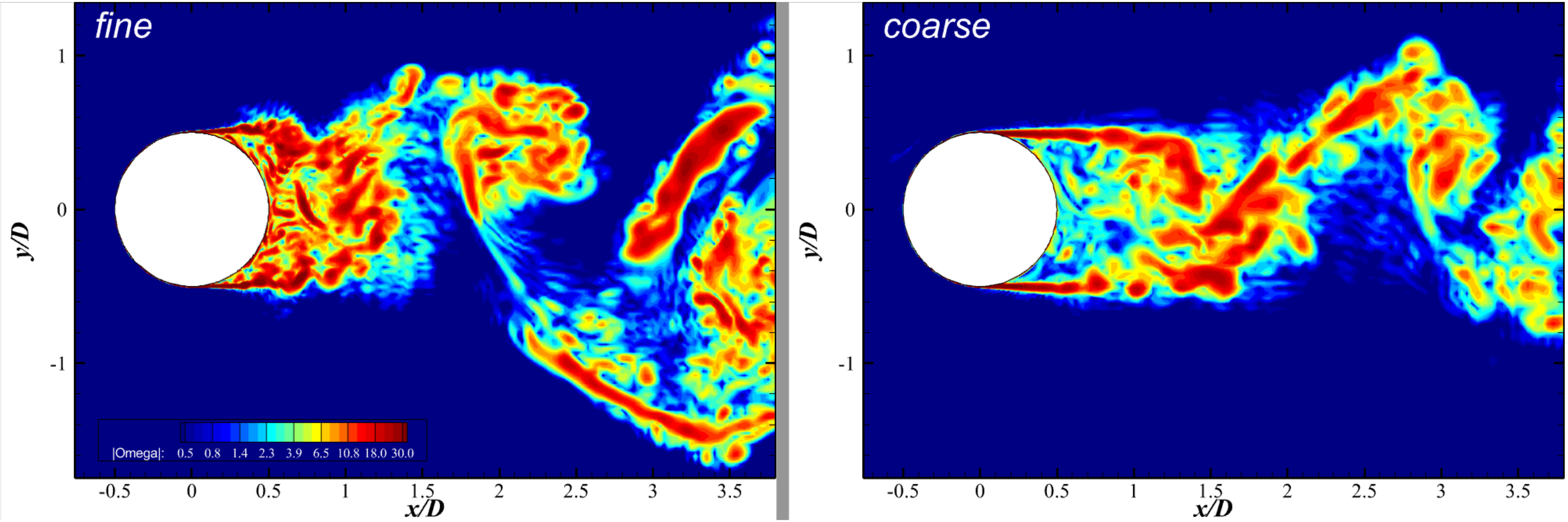
	$\overline{C}_d$	$\overline{C}_{l,\mathrm{rms}}$	$-\overline{C}_{p,\mathrm{b}}$	St	$\theta_{\mathrm{sep}},^\circ$
Experiments					
Shih et al.	0.24		0.33		
Schewe	0.24	0.02	0.48		
Szechenyi	0.25		0.32	0.35	
Golling				0.35	130
Zdravkovich	0.17-0.4	0.1-0.15	0.2-0.34	0.5-0.18	
KIAM simulations					
fine	0.234	0.051	0.583	0.315	109.5
coarse	0.215	0.027	0.548	0.34	109.4

Re=1.4·10^5: DDES vs no model ("DNS")

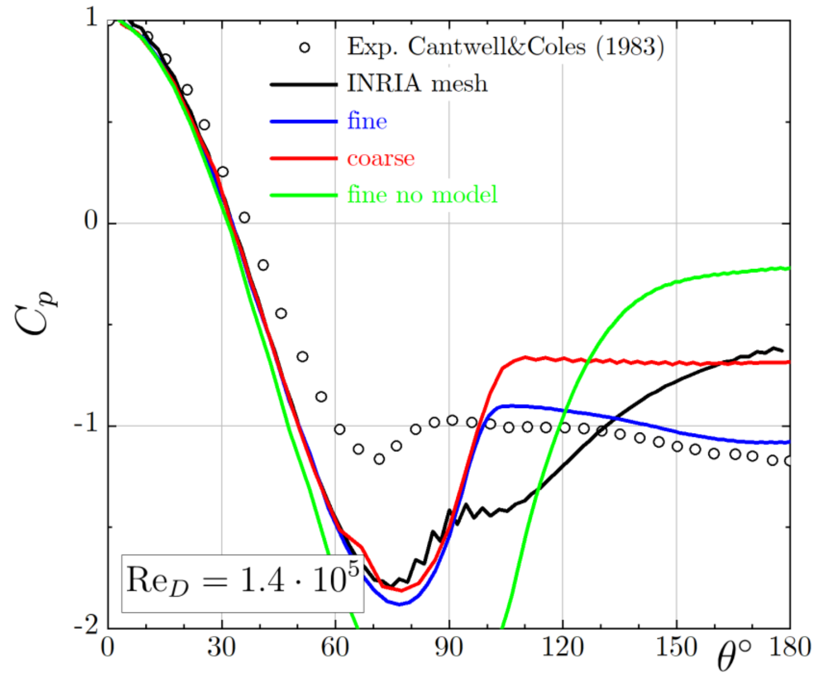


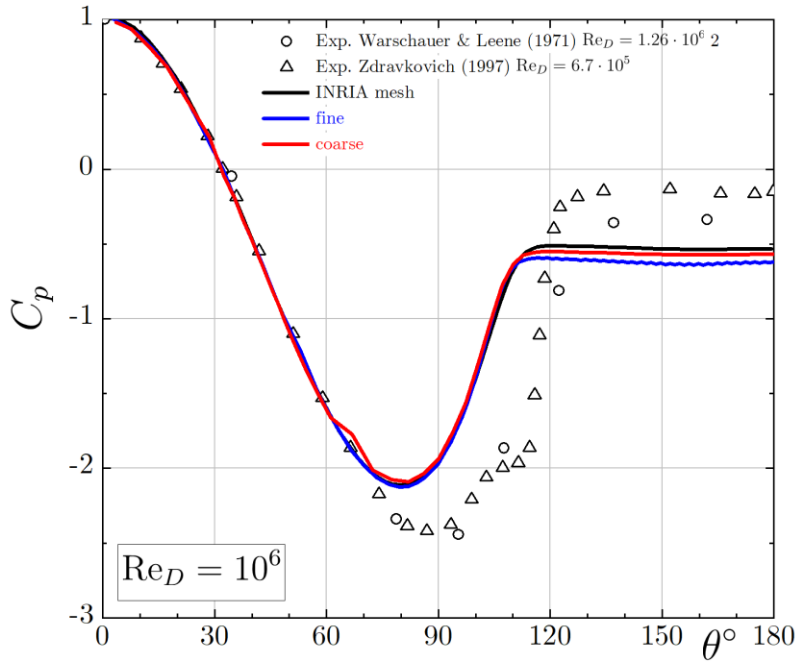


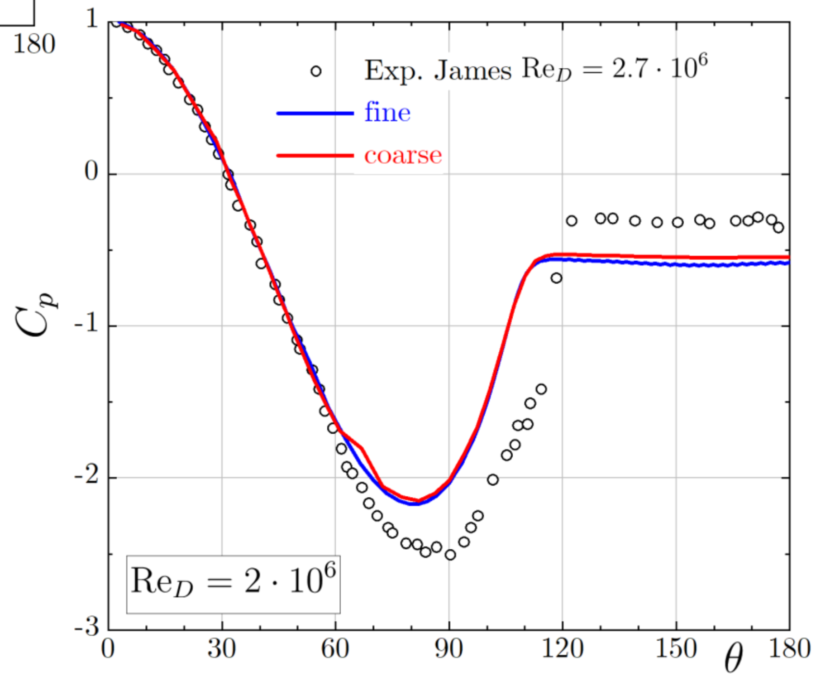
Re=1.4·10⁵: fine vs coarse



C_p distributions





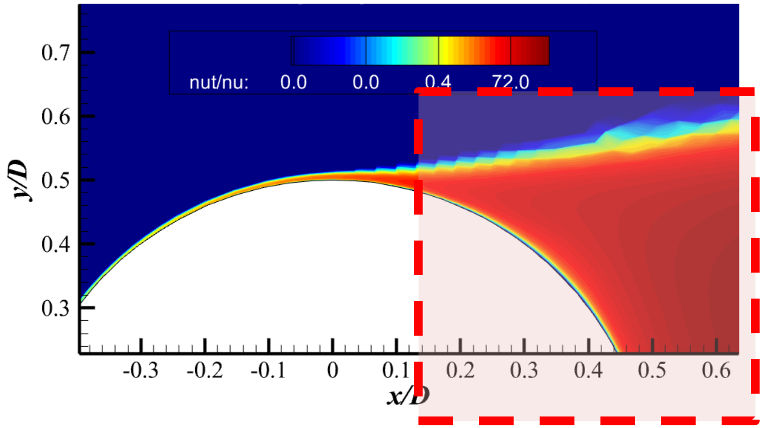


INRIA mesh: wall functions

fine and *coarse*: No-slip BC

Conclusions

- Correspondence with the experiment is improving while Re is growing (or reducing) far from critical Re number (~10^5)
- Reducing $\frac{\nu_t}{\nu}$ ratio at the inflow does not lead to variation of the results
  - the separation remains turbulent (BL upstream is turbulent)
  - laminar separation (laminar BL and turbulization in shear layer) is challenging
- Re=$1.4 \cdot 10^5$ case is the most challenging: flow aerodynamics is very sensitive to the simulation parameters
  - boundary layer (BL) upstream separation is crucial: laminar/turbulent, transition point if BL is turbulent
  - shear layer development: KH instability, turbulization
- Mesh resolution is important
  - BL upstream separation: RANS region (while simulation using DDES) depends on the wall-tangent mesh resolution
  - shear layer region



$\frac{\nu_t}{\nu} > 0$ at the initialization