Computations of a circular cylinder at Reynolds numbers 1M and 2M using hybrid turbulence models

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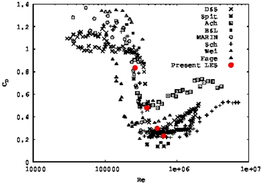


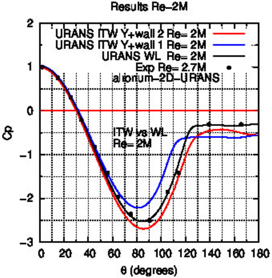
(Drag crisis : Lehmkuhl et al., 2014)

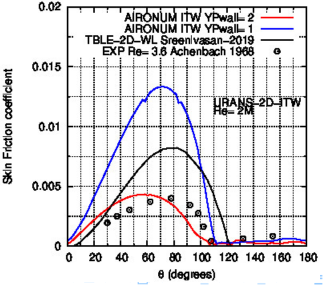
Super-critical flow: Re=2M (2.0E+06)

- **Flow parameters:**
  Reynolds $= 2M(2.0E+06)$
  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

- **Computational grids:**
  2D: 401x225

Re= 2M
- no 3D detailed studies exist.
- several 2D detailed studies exist.
- YPwall= 2 agrees more closely with WL and experimental results.





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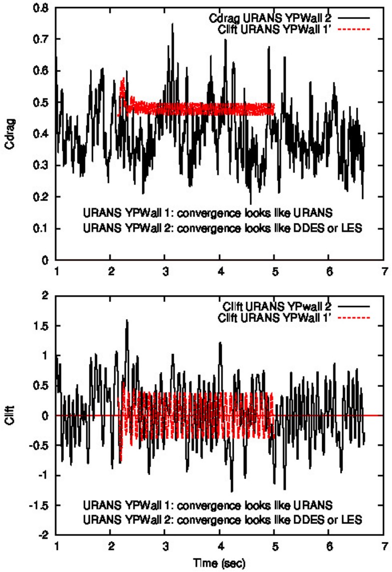
Re= 2M
- YPWall= 1 vs YPWall 2.
- URANS YPWall 1 convergence looks typically URANS.
- URANS YPWall 2 convergence looks like DDES or LES.
- Which convergence behavior is correct?



Re= 2M	model	$\overline{C_d}$	C_l'	-Cp_b	$\overline{\theta}$	St/VTC
AIRONUM-2D	RANS-WL	0.19	-	-0.23	124	-/-
AIRONUM-2D	URANS-WL	0.29	0.12	-0.30	115	0.41
Sreenivasan-2D	TBLE-WL	0.24	0.029	-0.36	104.54	0.36
AIRONUM-ITW-2D						
$Y^+ msh = 1$	URANS-ITW	0.48	0.26	-0.42	127	0.36/24
$Y^+ msh = 2$	URANS-ITW	0.40	0.50	-0.52	106	0.21/36
Exp Schewe al. 2.0M		0.32	0.029	na	na	0.26
Exp Achenbach 1.8M		0.48	na	na	na	
RANS (Steady Reynolds Averaged Navier-Stokes equations)						
URANS (UnSteady Reynolds Averaged Navier-Stokes equations)						

Table 1: Re= 2M: $\bar{C}_d$ is the mean drag, $C_l^{'}$ is the root mean square (r.m.s) of the lift coefficient, $\bar{\theta}$ is the mean flow separation angle. St is the Strouhal number based on the diameter, $\overline{L_r}/D$ the mean flow recirculation length

Standard (Wilcox) k–ω turbulence model [1] [edit]

The eddy viscosity ν_T, as needed in the RANS equations, is given by: $\nu_T = k/\omega$, whi

ω is modelled as:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho u_j k)}{\partial x_j} = \rho P - \beta^* \rho \omega k + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_k \frac{\rho k}{\omega}\right)\frac{\partial k}{\partial x_j}\right], \qquad \text{with } P = \tau_{ij}\frac{\partial u_i}{\partial x_j},$$

$$\frac{\partial(\rho \omega)}{\partial t} + \frac{\partial(\rho u_j \omega)}{\partial x_j} = \frac{\alpha \omega}{k} P - \beta \rho \omega^2 + \frac{\partial}{\partial x_j}\left[\left(\mu + \sigma_\omega \frac{\rho k}{\omega}\right)\frac{\partial \omega}{\partial x_j}\right] + \frac{\rho \sigma_d}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j}.$$

For recommendations for the values of the different parameters, see Wilcox (2008)