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

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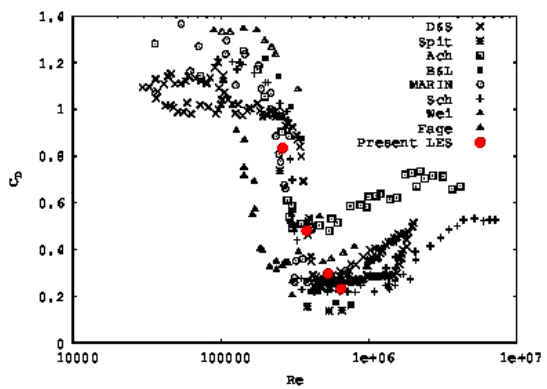


(Drag crisis : Lehmkuhl et al., 2014)

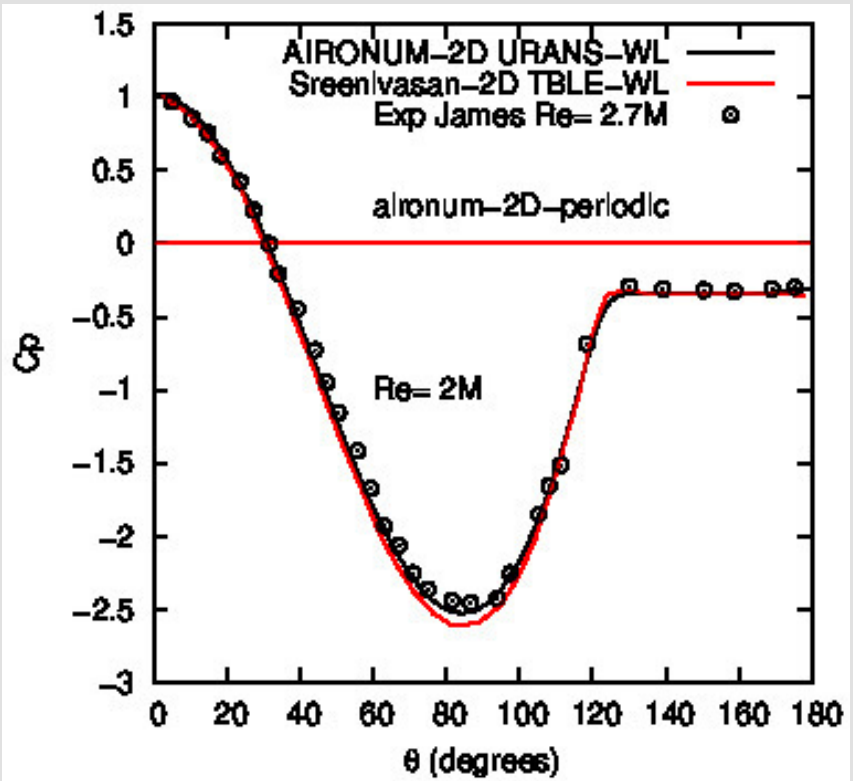
Super-critical flow: Re=2M (2.0E+06)

AIRONUM-WL Re= 2M

- **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: 361x325x3
  3D: 4.8MNodes 361x325x41
  3D: span = 2D and 3D

- AIRONUM correctly predicts the minimum Cp surface pressure.
- At Re= 2M, no 3D detailed studies exist.



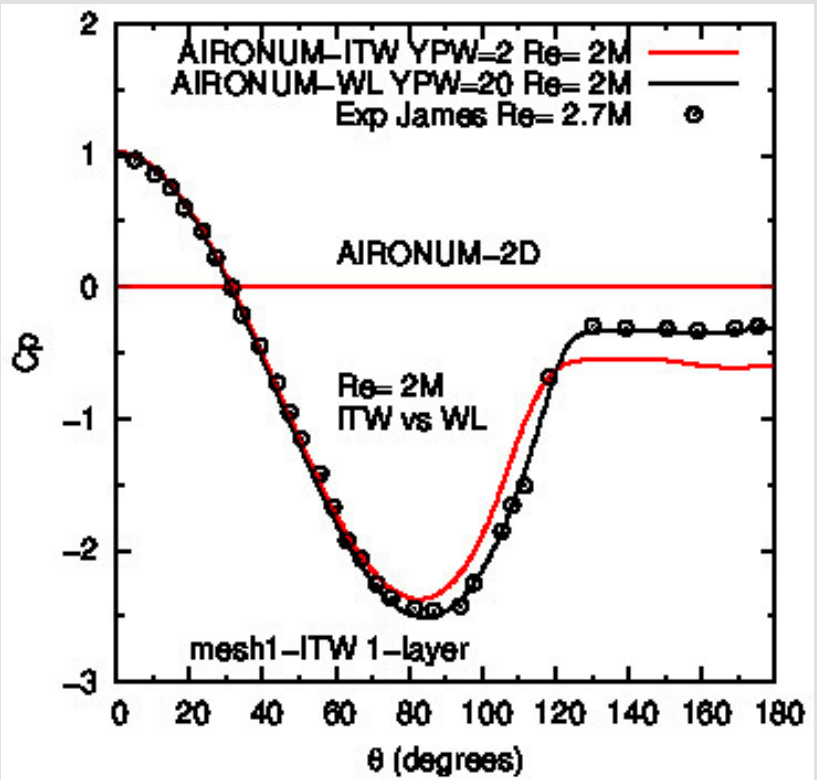
Super-critical flow: Re=2M (2.0E+06)

AIRONUM-ITW Re= 2M

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

- **Computational grids:**
  2D: 361x325x3
  3D: 4.8MNodes 361x325x41
  3D: span = 2D

AIRONUM ITW Re= 2M needs better mesh, transition model.



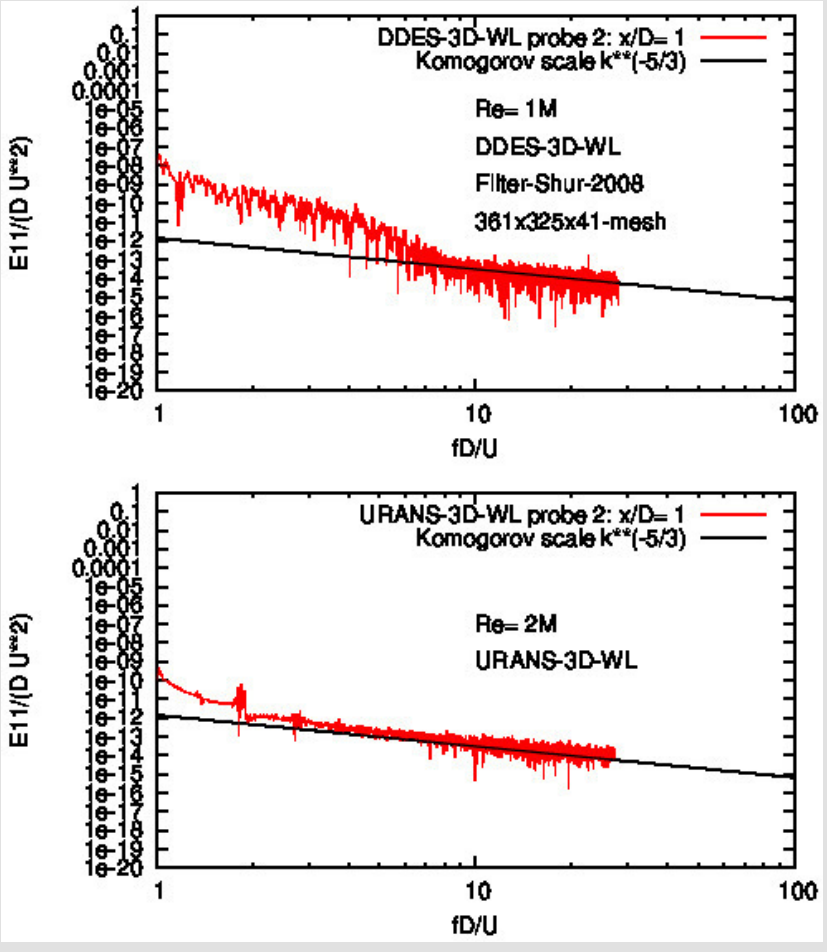
Super-critical flow: Re=2M (2.0E+06)

AIRONUM Re= 2M probe spectrum

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

  AIRONUM probe u-spectrum agrees with the Komogorov scale

- **Computational grid:**
  3D: 4.8MNodes 361x325x41
  3D: span = 2D



Supercritical flow : Re=2M

- **AIRONUM 2D and 3D Results at Re= 2M:**
  The focus in the following table is on the prediction of CL'.

Re= 2M	model/Δ SGS filter	$\overline{C_d}$	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
ITW-2D						
AIRONUM-2D	URANS-ITW	0.61	0.51	-0.85	111	0.31/31
Hybrid-3D						
AIRONUM-3D	DDES-WL/$\Delta_{shur2008}$	0.28	0.038	-0.27	132	0.42/108
AIRONUM-3D	URANS-DVMS-WL	0.26	0.048	-0.31	128	0.44
Exp Shih et al. 1.5M		0.26	0.033	-0.40	105.2	0.46
Exp Schewe al. 2.0M		0.32	na	na	na	0.26
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

Resume of AIRONUM-2D and AIRONUM-3D WL results

- Observations at Re= 2M : LES, DDES and other Hybrid methods using a WL :
  - The focus here is on the prediction of CL'.
  - AIRONUM-2D over-predicts the experimental CL' values at Re= 2M.
  - TBLE-2D (Sreenivasan-2019) correctly predicts the experimental CL' values at Re= 2M. ✓
  - AIRONUM-3D correctly predicts the experimental CL' values at Re= 2M. ✓
  - No published 3D CFD detailed studies exist with which to compare.

Resume of AIRONUM-2D and AIRONUM-3D WL results

- Observations at Re= 1M :
  - TBLE-2D and AIRONUM-2D both correctly predict the experimental CL' value at Re= 1M. ✓
  - Moussaed(2013,2014) correctly predicted the exp CL' value at Re= 1M. ✓
  - Kim and Mohan(2005) correctly predicted the exp CL' value at Re= 1M. ✓
  - AIRONUM-3D under-predicts the experimental CL' value at Re= 1M.
  - With the exception of Moussaed (2013), Moussaed et al.(2014) and, Kim and Mohan(2005), no published 3D CFD results exist that correctly predict the experimental CL' values at Re= 1M.

Hybrid turbulence models : future works for improvement

- Some tracks to explore :
  - AIRONUM, add a transition prediction model in order to more accurately compute transitional boundary layers (ITW, supercritical regime).
  - $k - R$ transition model (Zhang-Rahman-Chen, 2019) combined with DDES, URANS/DVMS and DDES/DVMS.
  - Validate the Δ_{SLA} (shear-layer-adaptive) filter in the AIRONUM sortware.
  - SST $k - \omega$ model combined with DDES, RANS/DVMS and DDES/DVMS.
  - Further improve the blending function in the URANS/DVMS approach.
  - A seamless DDES/DVMS strategy based on a blending function allowing for an automatic switch from DDES to DVMS and vice versa.
  - A DDES variant (limitation of the production term, Reddy-Ryon-Durbin, 2014) which avoids the log-layer mismatch issue.