NUMERICAL EXPERIMENTS

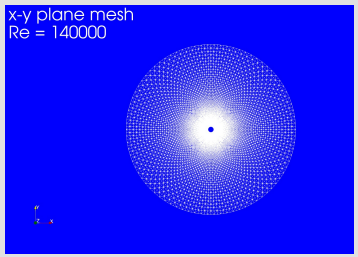
- Circular cylinder at Reynolds number 140,000 $\Rightarrow$ subcritical regime.
- Circular cylinder at Reynolds number 1,000,000 $\Rightarrow$ supercritical regime.
- Circular cylinder at Reynolds number 2,000,000 $\Rightarrow$ supercritical regime.

Sub-critical flow (near critical) : Re=140K

AIRONUM results Cylinder Re= 140K

- **Flow parameters:**
  Reynolds = $140K$
  Mach = 0.1
  reference density = 1.225 kg/m^3
  reference pressure = 101300 N/m^2

  Velocity computed from Mach eqn
  mesh 165x165x33 (θ, radial, span)
  165x165 (θ, radial) coarse mesh



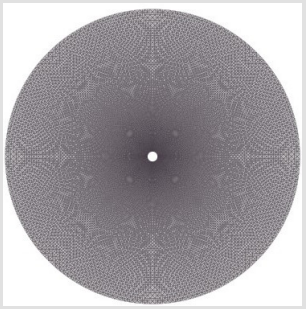
- **Computational grids:**
  0.892MNodes span= 2D

Sub-critical flow (near critical) : Re=140K

AIRONUM results Cylinder Re= 140K

- **Flow parameters:**
  Reynolds $= 140K$
  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn
  mesh 361x325x41 (θ, radial, span)
  span = 2D (41)
  361x325 (θ, radial) fine mesh



- **Computational grids:**
  4.81MNodes span= 2D 41 z-planes
  7.16MNodes span= 3D 61 z-planes

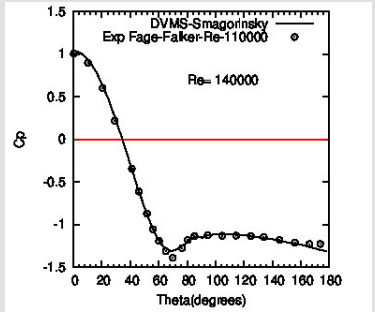
Sub-critical flow (near critical) : Re=140K

AIRONUM results Cylinder Re= 140K

- **Flow parameters:**
  Mach = 0.1
  Reynolds = $140K$
  reference density = 1.225 kg/m^3
  reference pressure = 101300 N/m^2

  Velocity computed from Mach eqn

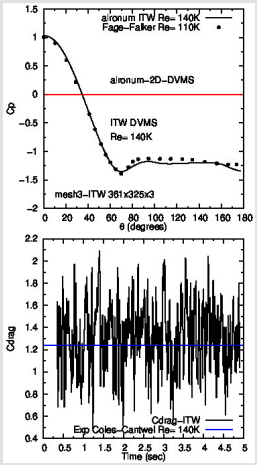
- **Computational grids:**
  0.892MNodes span= 2D
  165x165x21 mesh



Sub-critical flow (near critical) : Re=140K

AIRONUM convergence Cylinder Re= 140K

- **Flow parameters:**
  361x325x3 mesh
  112000 times steps
  cfl= 40
  better ageement with experiments
  that 165x165x3 mesh



Sub-critical flow (near critical) : Re=140K

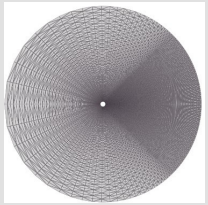
	mesh	$\overline{C}_d$	$\overline{C}_{p_b}$	L_r	S_t
Experiments					
Cantwell-Coles (1983)		1.24	-1.21	0.5	0.179
Son-Hanratty (1969)					$\simeq 0.2$
Zdravkovich (1997)					$\simeq 0.2$
Present simulations					
Experiments					
No model	165x165	0.43	-0.40	0.63	0.142
URANS $k-\varepsilon$	165x165	0.77	-0.87	1.05	0.218
DDES $k-\varepsilon$	165x165	0.97	-1.01	0.96	0.217
DDES/DVMS	165x165	1.04	-1.12	0.91	0.214
DVMS	165x165	1.25	-1.33	0.88	0.217
DVMS	361x325	1.32	-1.17	0.56	0.166

Table 1: Bulk quantities for $Re = 140,000$ flow around a cylinder.

Super-critical flow: Re=1M

AIRONUM centerplane mesh

- **Flow parameters:**
  Can be computed with
  two-dimensional codes
  Reynolds $= 1M(1.0E+06)$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$
  ———————————
  Velocity computed from Mach eqn



- **Computational grids:**
  1.210M nodes

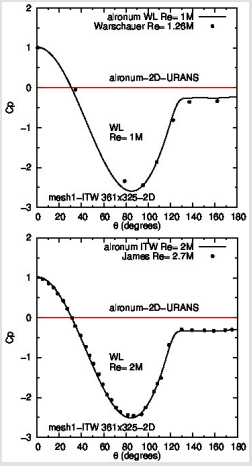
Super-critical flow: Re=1M/2M with WL

AIRONUM URANS-WL

- **Flow parameters:**
  Mesh has fore-aft symmetry
- **Parameters:**
  Reynolds = 1M/2M
- **Eqn of state defined by:**
  Mach = 0.1
  reference density = 1.225 kg/m^3
  reference pressure = 101300 N/m^2

  Velocity computed from Mach eqn
  Reference Velocity (output)
  34.0252 m/s

- **Computational grids:**
  2D mesh 361x325x3 vertices
  θ, radial, span



Super-critical flow: Re= 1M with ITW

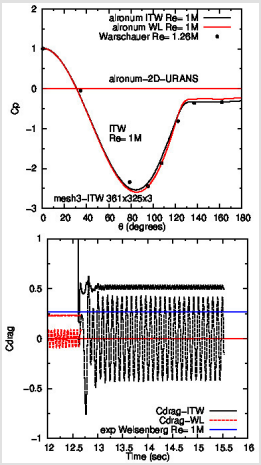
AIRONUM URANS-ITW

- **Flow parameters:**
  Mesh with fore-aft symmetry
  Reynolds $= 1M(2.0E+06)$
- **Eqn of state defined by**

  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn
  convergence available at
  20-04-2021 meeting

- **Computational grids:**
  2D-mesh 361x325x3 vertices
  θ, radial, span



Super-critical flow: Re= 1M with ITW

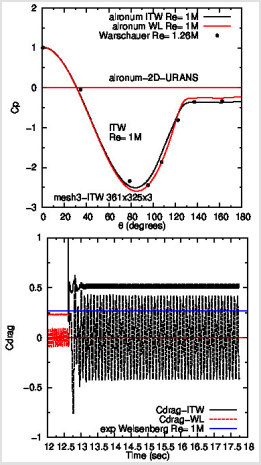
AIRONUM URANS-ITW

- **Flow parameters:**
  Mesh with fore-aft symmetry
  Reynolds $= 1M(2.0E+06)$
- **Eqn of state defined by**

  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn
  fully converged

- **Computational grids:**
  2D-mesh 361x325x3 vertices
  θ, radial, span



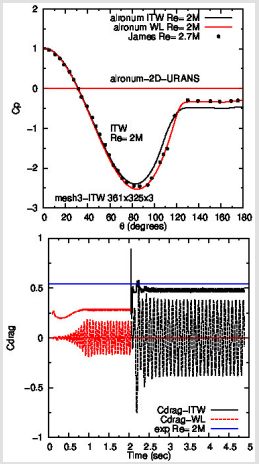
Super-critical flow: Re= 2M with ITW

AIRONUM URANS-ITW

- **Flow parameters:**
  Mesh with fore-aft symmetry
  Reynolds $= 2M(2.0E+06)$
- **Eqn of state defined by**

  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn
- **Computational grids:**
  2D-mesh 361x325x3 vertices
  θ, radial, span



Super-critical flow : Re= 1M

		$\overline{C_d}$	CL'	Cp_{base}	St	θ_{sep}
URANS-WL	Carine (2013)	0.24	0.06	0.25	0.46	129
URANS-WL	2021	0.24	0.08	0.24	0.44	130
URANS-ITW	2021	0.51	0.30	0.27	0.34	110
LES-VMS-WL	Carine (2013)	0.36	0.22	0.22		
H URANS/VMS-WL	Carine (2013)	0.24	0.17	0.28	0.38/0.17	118
H DDES/DVMS-WL	2021	0.23	0.30	0.28	0.47	149
H URANS/DVMS-WL	2021	0.30	0.37	0.30/0.25	0.39	146
Experiments	Shih et al. [?]	0.24		0.33		
Experiments	Schewe [?]	0.22			0.44	
Experiments	Gölling [?]				0.35/0.10	130
Experiments	Zdravkovich [?]	0.2-0.4	0.1-0.15	0.2-0.34	0.50/0.18	

Table 2: Bulk flow parameters prediction for cylinders - 2021

Super-critical flow: Re=1M

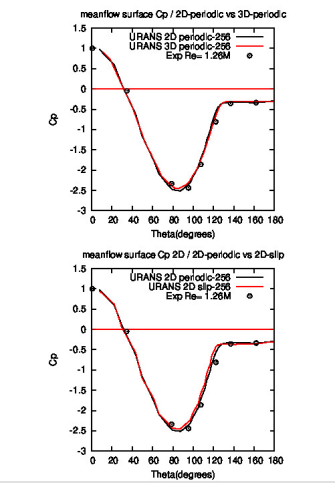
AIRONUM Re= 1M 3D vs 2D-per

- **Flow parameters:**
  Mesh refined for the aft-cylinder
  Reynolds $= 1M(1.0E+06)$
  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn

  2D-per mesh 256x215x3 vertices
  θ, radial, span

- **Computational grids:**
  1.210M nodes



Super-critical flow: Re=1M (1.0E+06)

AIRONUM Re= 1M results near drag crisis

- **Flow parameters:**
  Reynolds $= 1M(1.0E+06)$
  Mach $= 0.1$
  reference density $= 1.225\ kg/m^3$
  reference pressure $= 101300\ N/m^2$

  Velocity computed from Mach eqn

- **Computational grids:**
  1.210M nodes