Use of Nektar++ and OpenFOAM for the simulation of bluff-body flows

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Introduction

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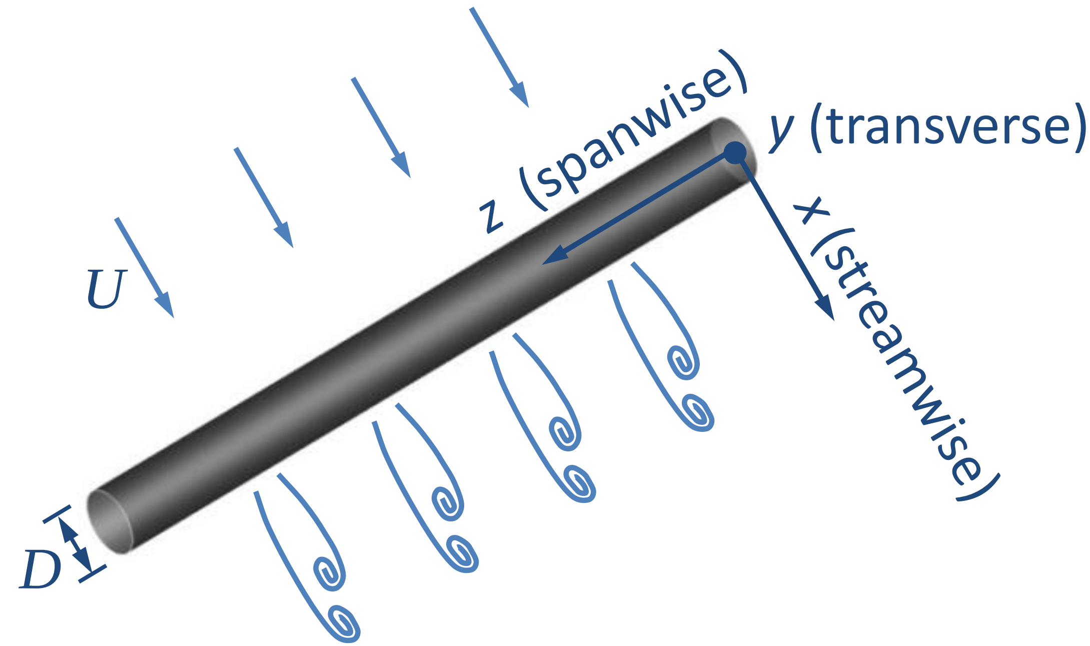

Reynolds number $Re = UD/\nu$

Vorticity $\vec{\omega} = \nabla \times \vec{u} = \left(\frac{\partial u_z}{\partial y} - \frac{\partial u_y}{\partial z}, \frac{\partial u_x}{\partial z} - \frac{\partial u_z}{\partial x}, \frac{\partial u_y}{\partial x} - \frac{\partial u_x}{\partial y} \right)$

(a measure of the rotation of the velocity field)

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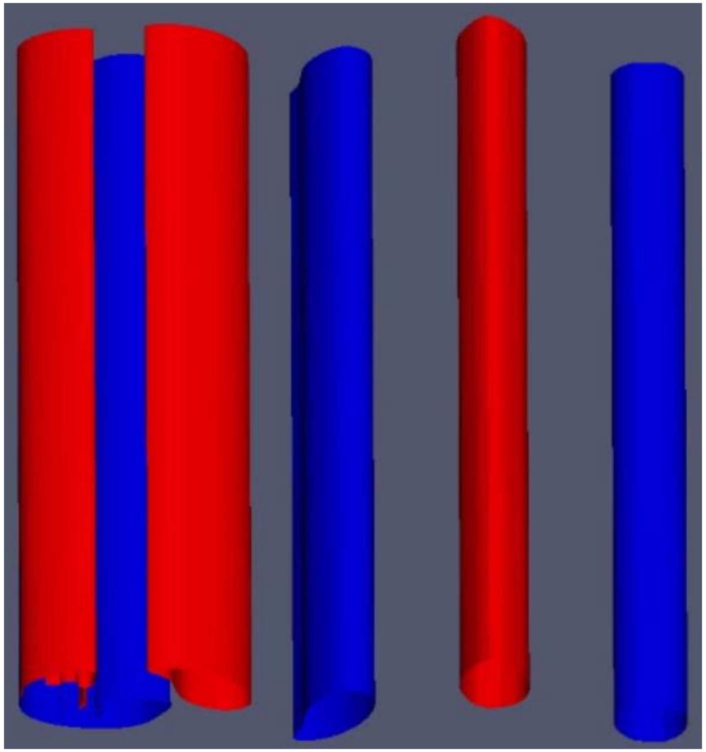
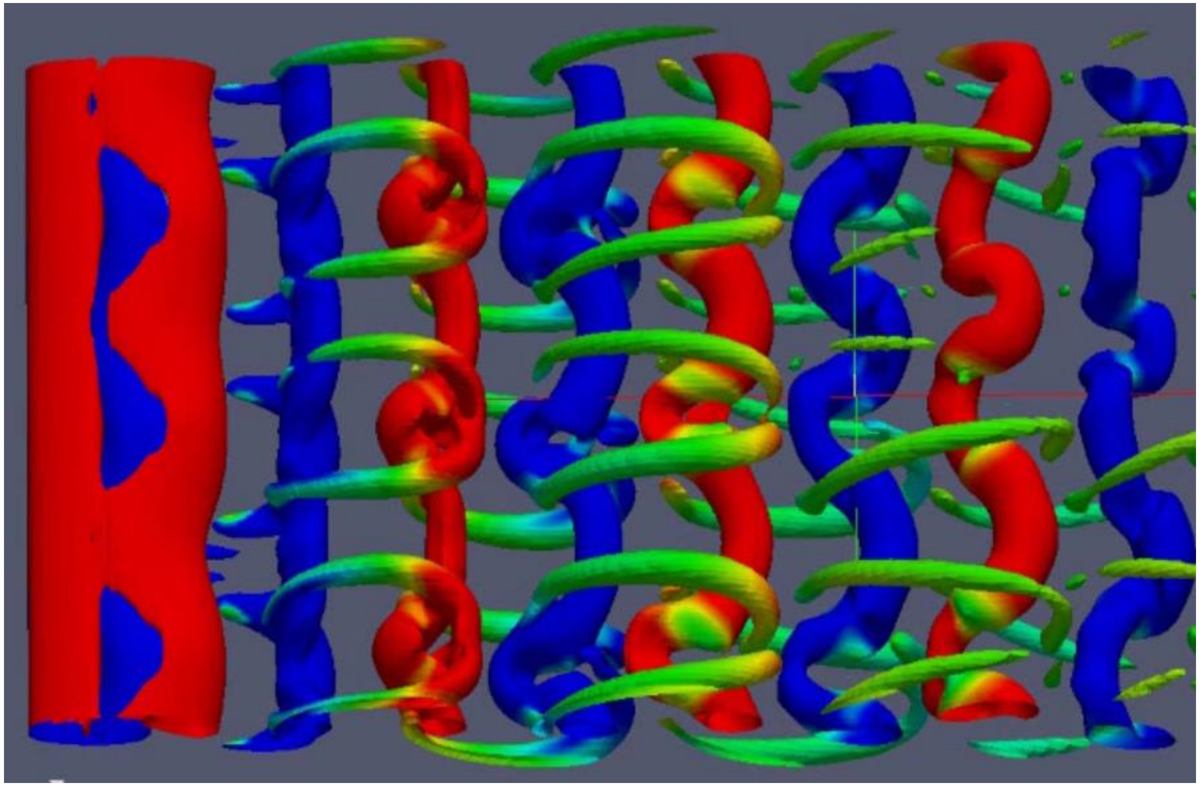
A nominally 2D cylinder → A 3D flow



Re = 100, 2D

Re = 220, Mode A (3D)



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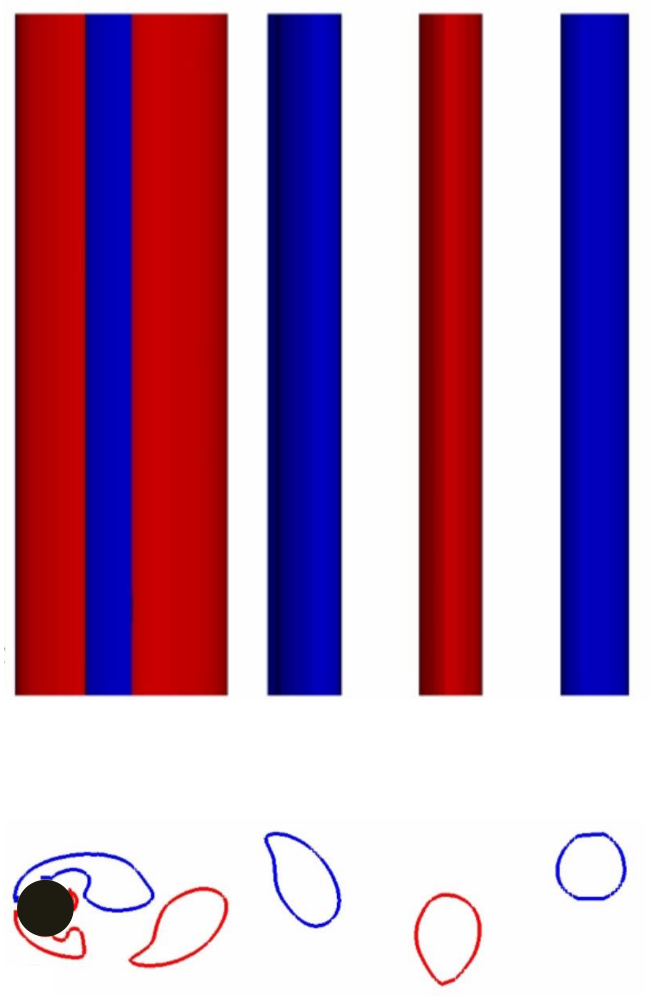
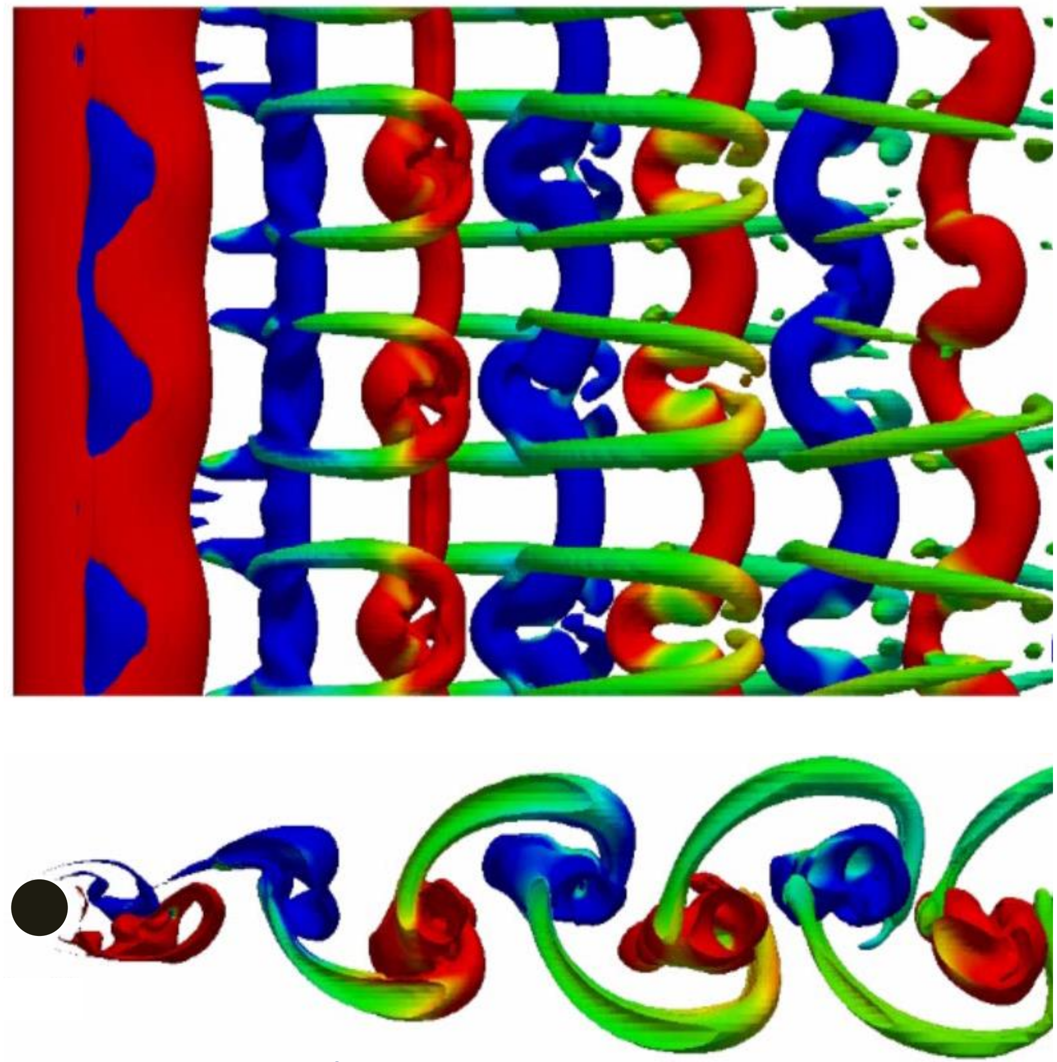


Re = 100, 2D



Re = 220, Mode A

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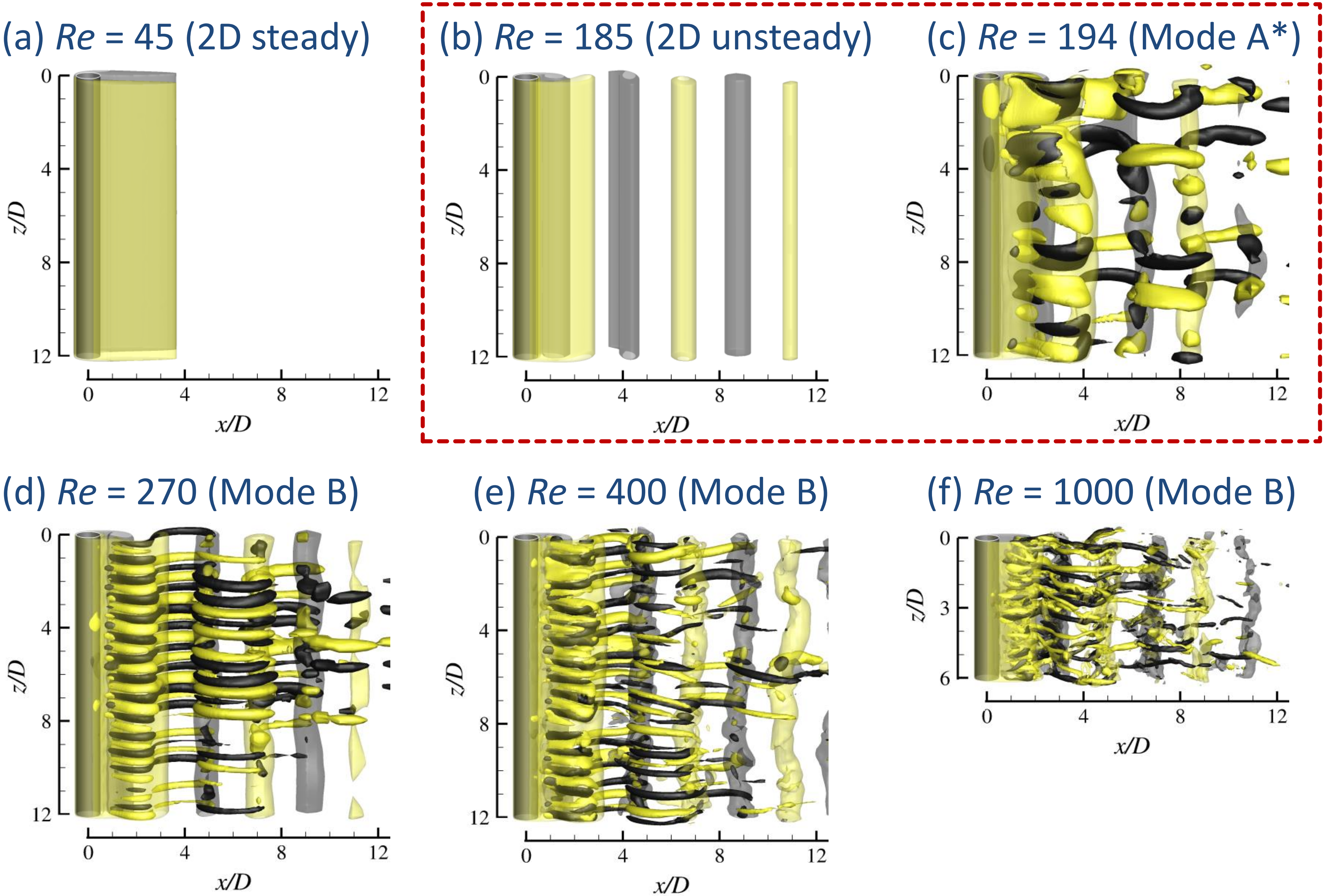
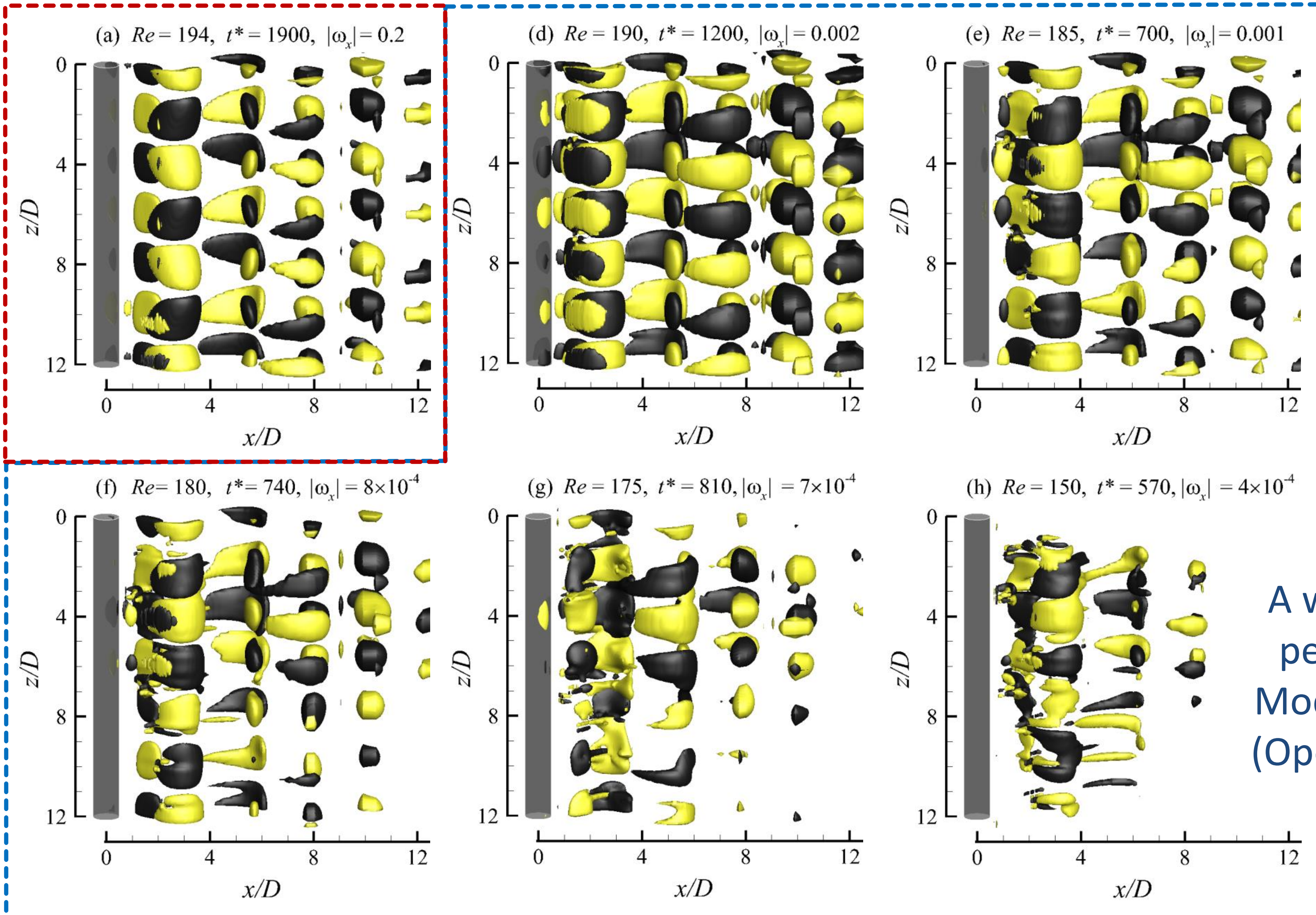


Advantage 1



A weak but persistent Mode A flow (OpenFOAM)

Advantage 1

Experimental evidence:

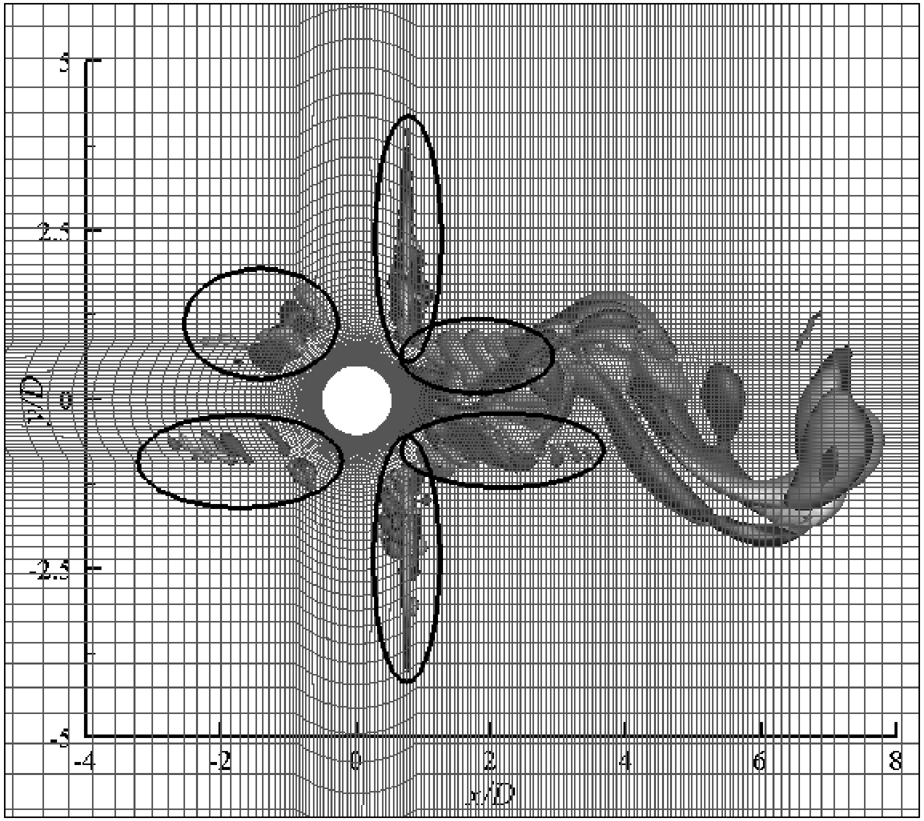
There does remain the likely possibility that there exists a very small range of *Re* for which the flow is unstable to small scales of mode A, but whose amplitude is too weak to trigger intermittent vortex dislocations. This would be consistent with the result of

(Williamson, 1996. Three-dimensional wake transition. *J. Fluid Mech.* 328, 345–407.)

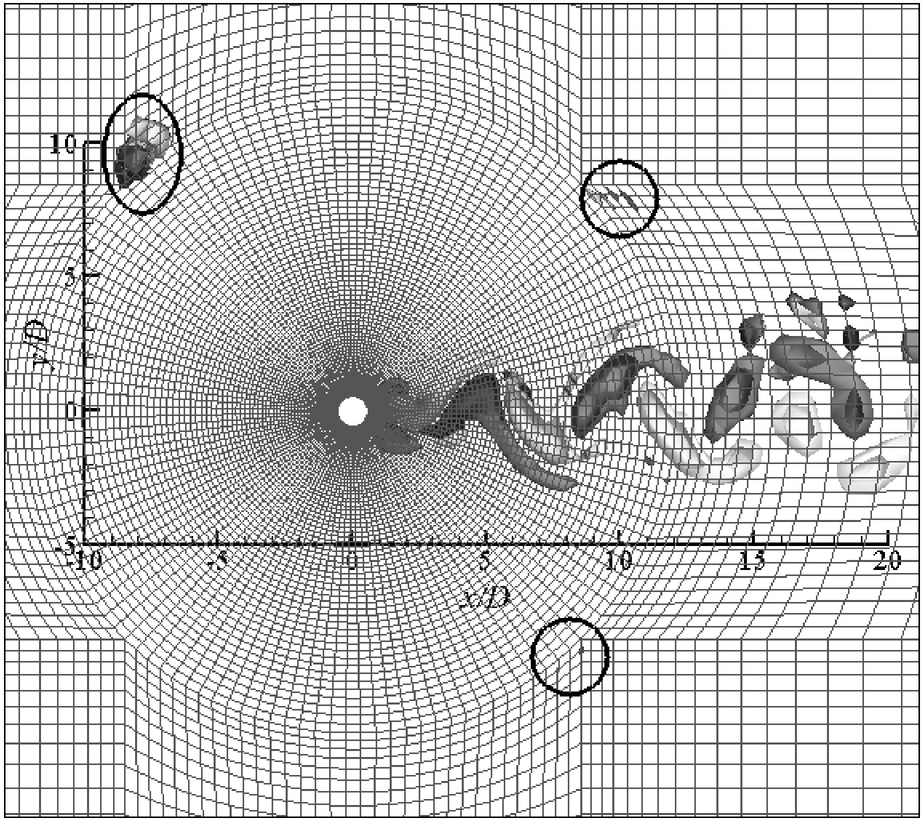
End of story?

Advantage 1

(a) *Re* = 100, $u_z = \pm 2\times10^{-5}$

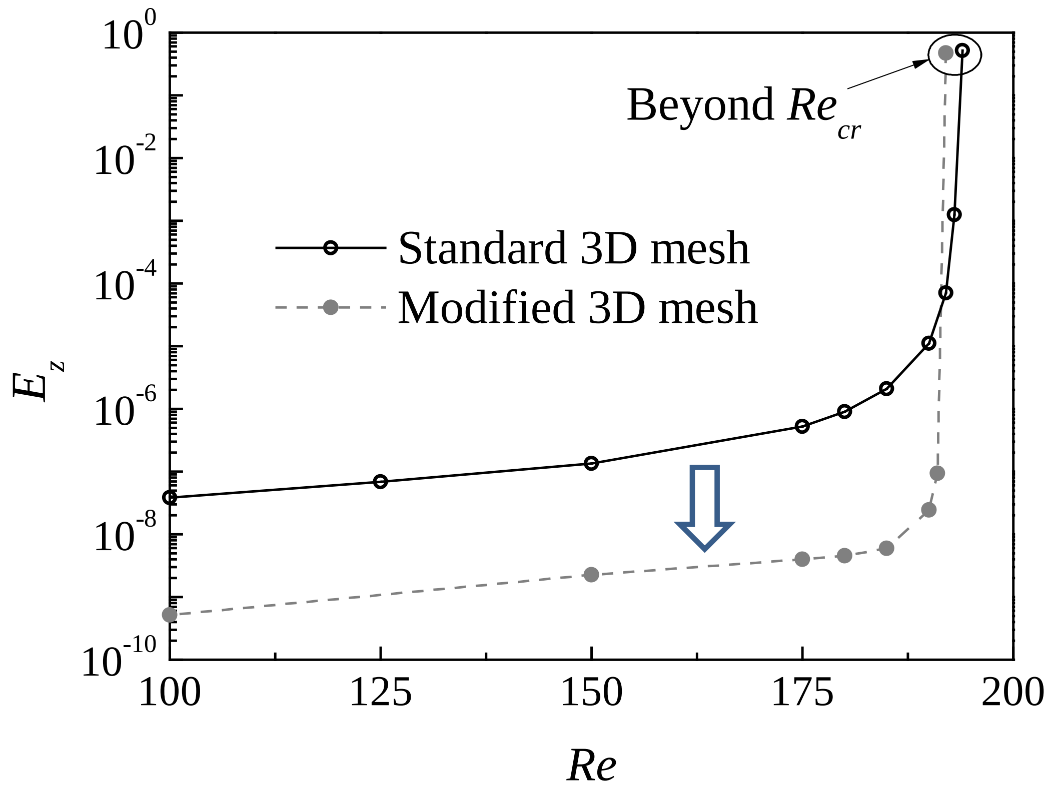


(b) *Re* = 100, $u_z = \pm 2\times10^{-6}$



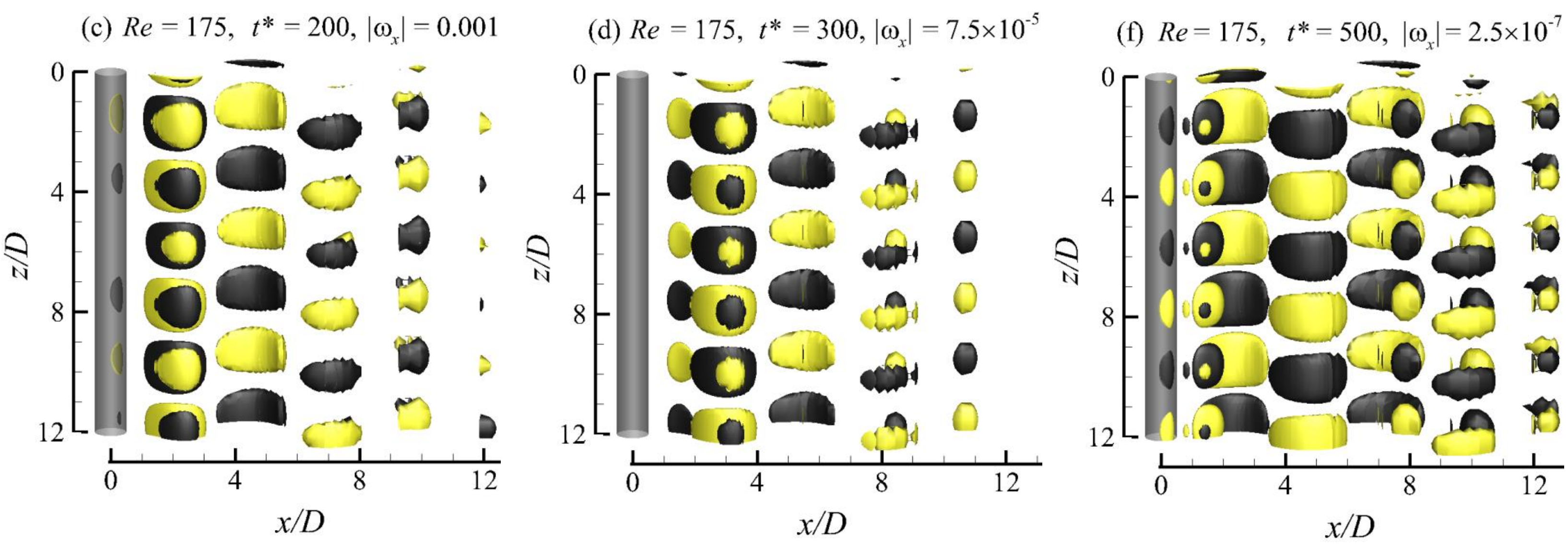
Mesh skewness → Three dimensionality (→ Stable mode A)

Advantage 1



Mesh skewness↓ → Three dimensionality↓

Advantage 1

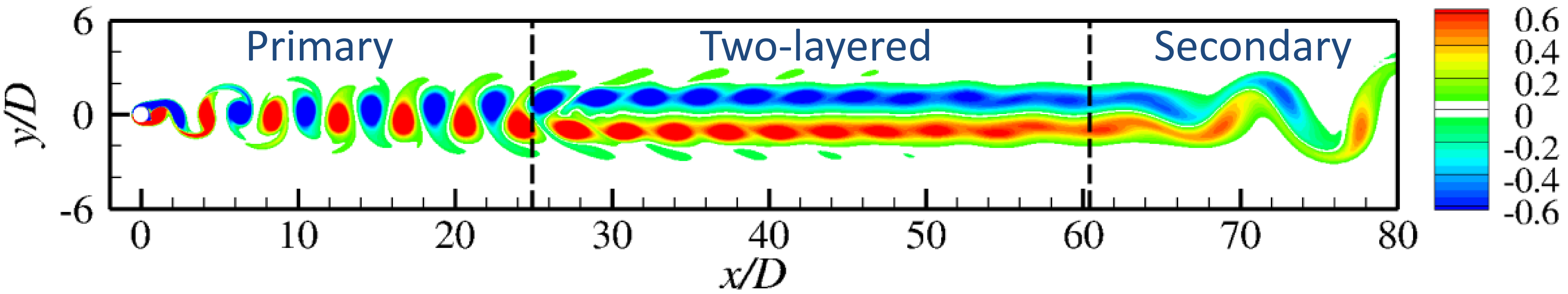


Nektar++ results: Transient growth and then decay to 2D.

Nektar++ (Fourier)	Transient initial disturbance
OpenFOAM (Replication)	Persistent disturbance (uncontrolled)
Experiment	Real-life flow with ambient disturbance

(Jiang *et al*., 2016. *Phys. Fluids* 28, 104103.)

Advantage 2



Vorticity field at *Re* = 300 calculated with 2D DNS.

Location for the onset of the secondary vortex street (*Re* = 200):

Vorobieff et al. (2002)	$x/D = 60$
Kumar and Mittal (2012)	$x/D = 100$
Thompson et al. (2014)	Not within $x/D = 280$

But there has been no mesh independence check on the far-wake mesh.

Advantage 2

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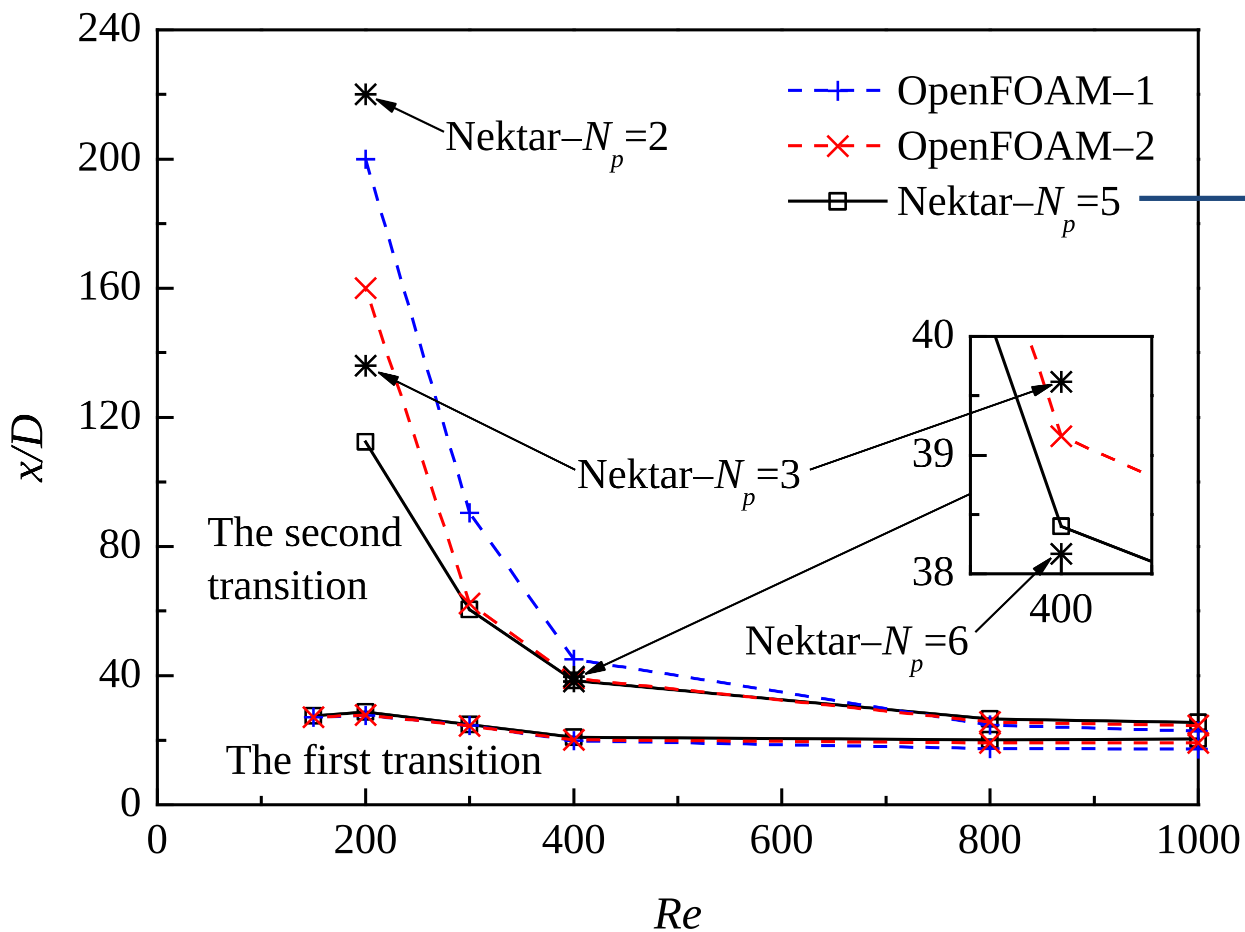

~ 2000 elements for $x/D < 2$ and 44,000 elements for $x/D = 2 – 400$

For extremely mesh-sensitive cases, Nektar++ shows better convergence.

(Jiang *et al.*, 2019. *J. Fluid Mech.* 867, 691–722.)