CCFD

Fluid Simulation on Cartesian Grid

Piao Binghu

Univ. of Electro-Communications

Background of Research

Application of CFD

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Complex Geometries

Moving Boundary

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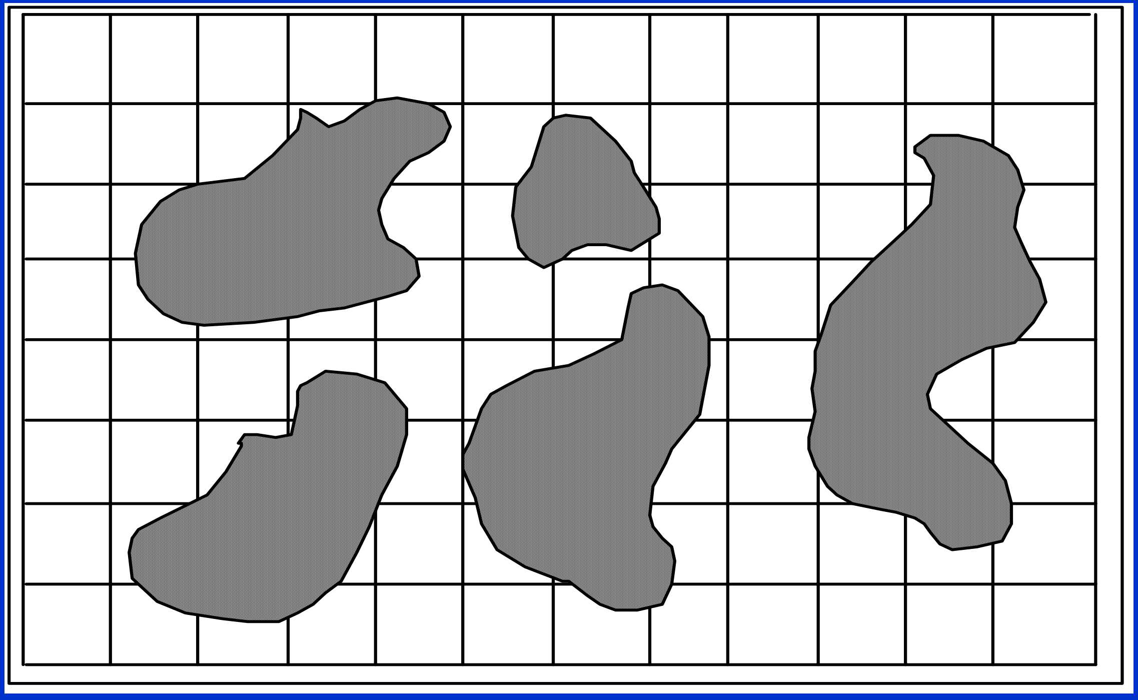
Difficultly of Grid Generation

Purpose of Research

Development of

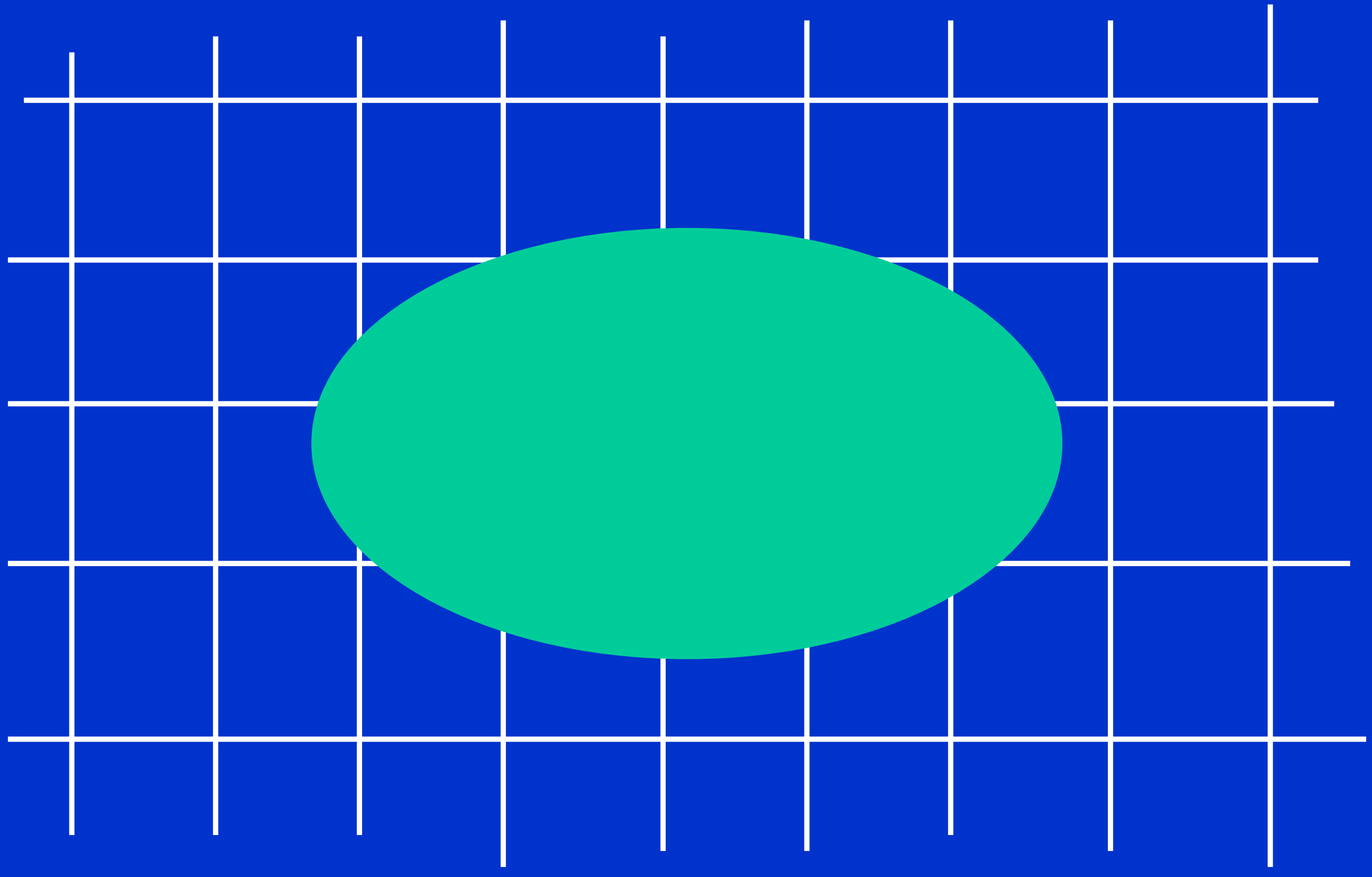
1. Automatic Grid Generator
2. Numerical Method



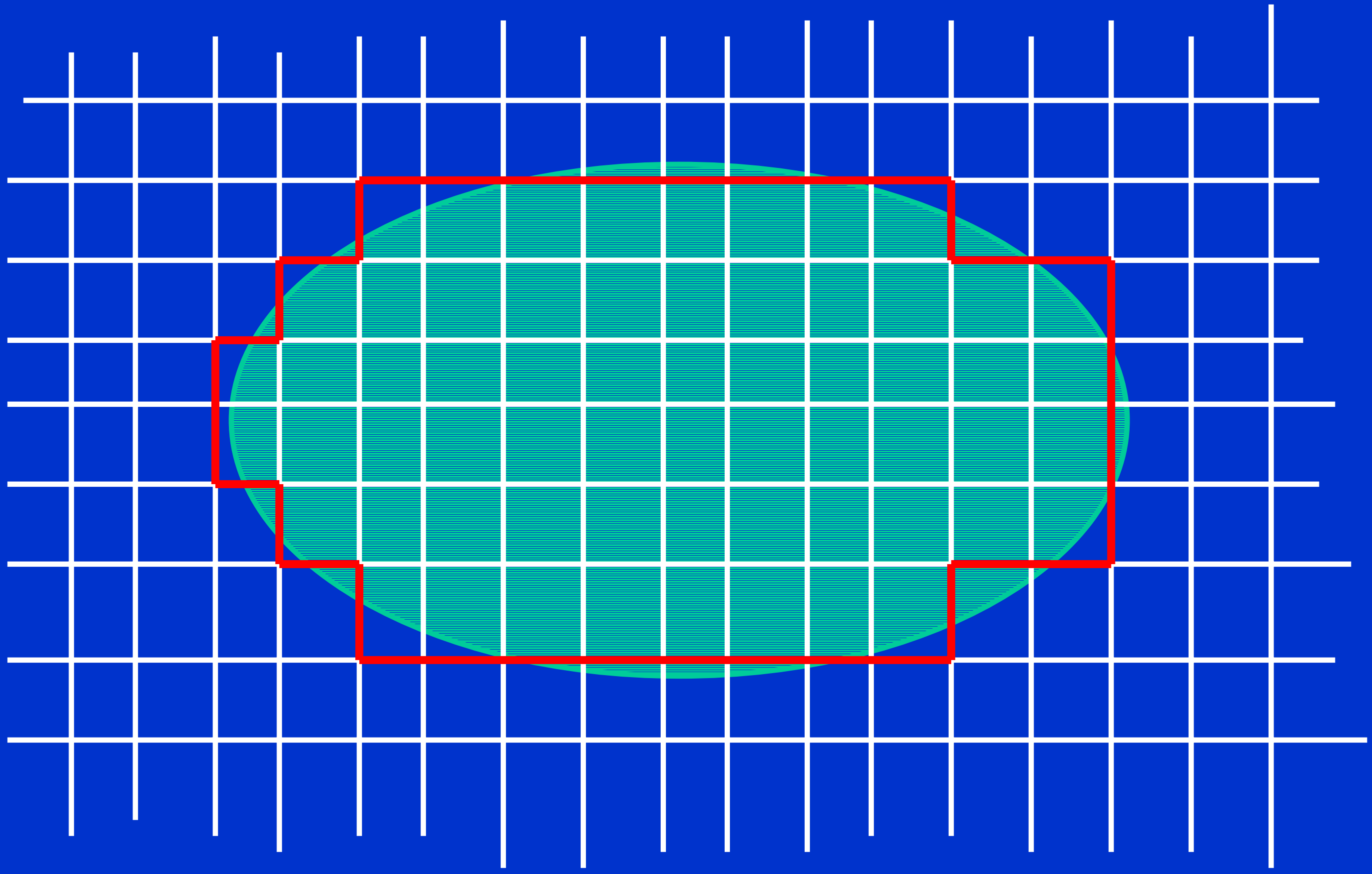
Research Areas

- Cut Cell Method
- AMR(Adaptive Mesh Refinement)
- Cartesian/Structure Hybrid Method
- Locally Body-Fitted Cartesian Grid

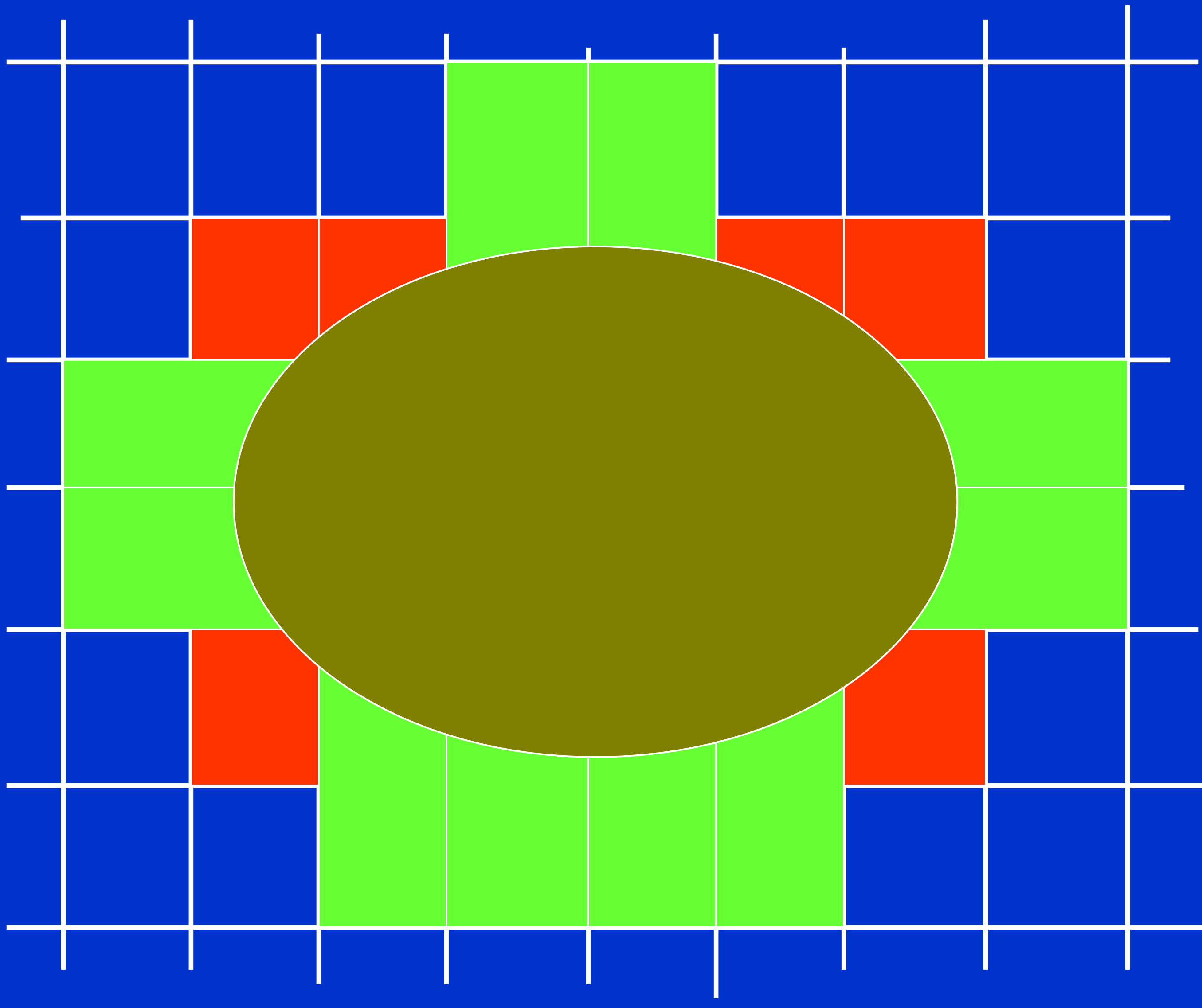
Image of Cartesian Grid



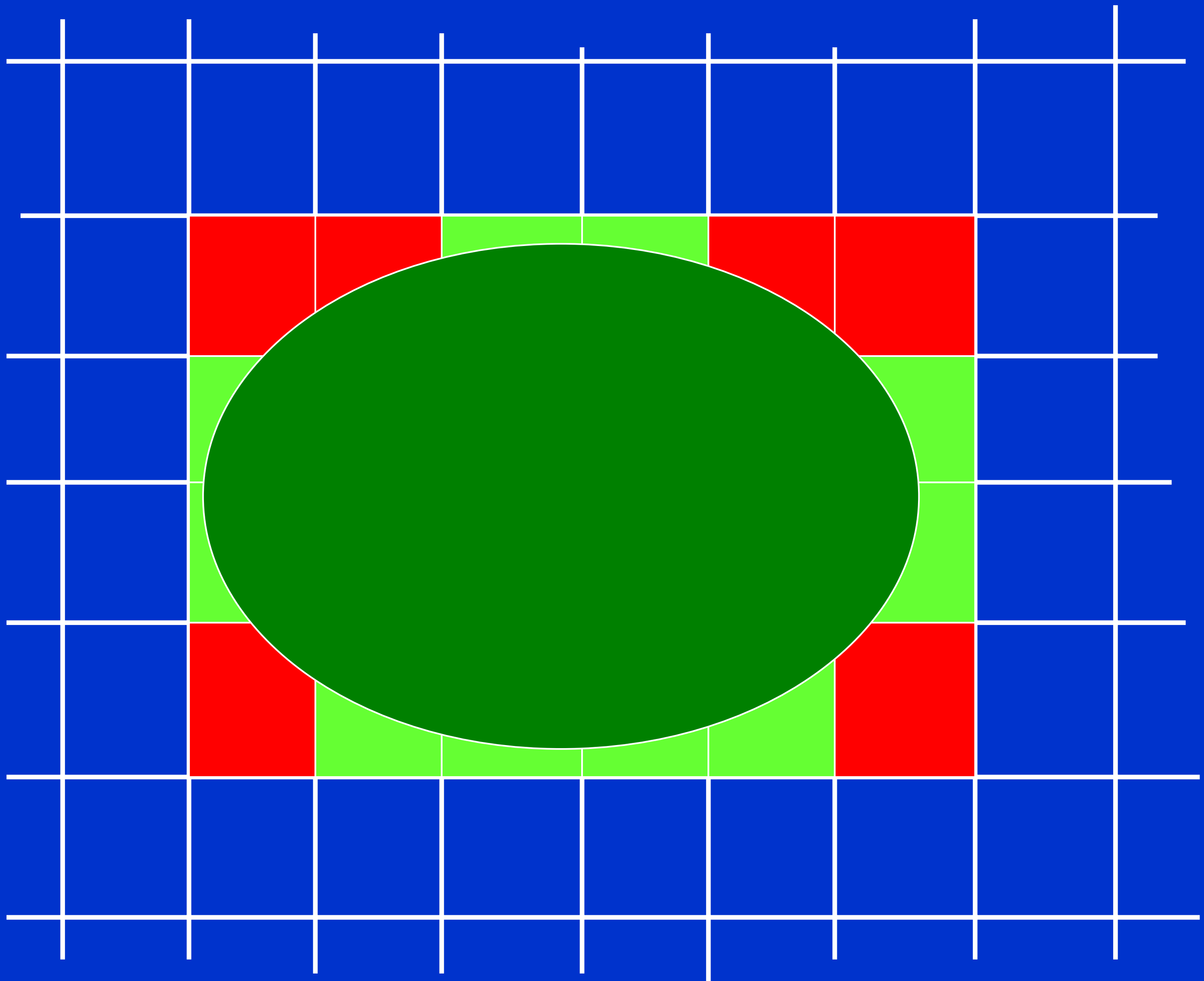
Simple Cartesian Grids



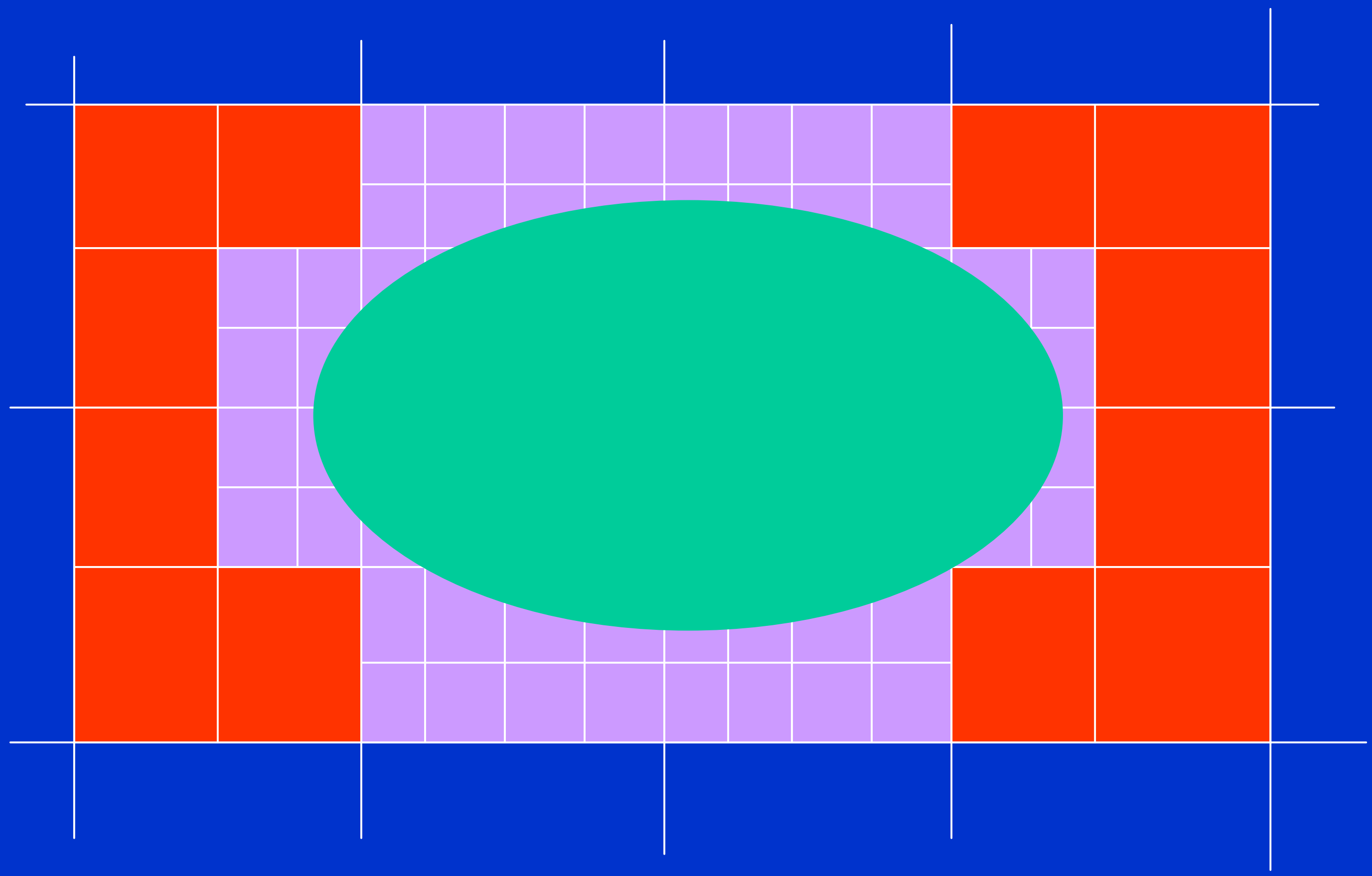
Cut Cell with Cell Merging



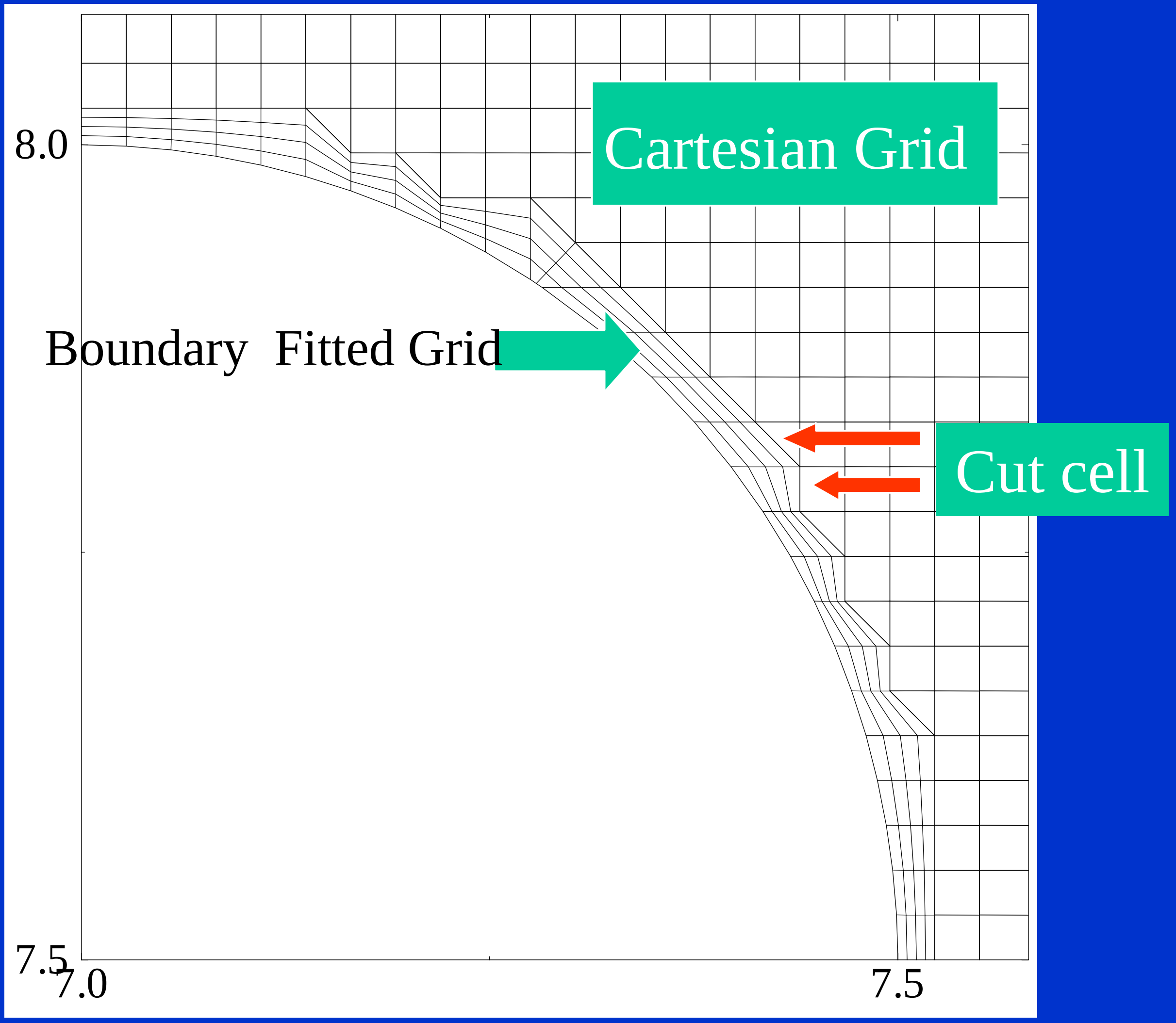
Cut Cell without Merging



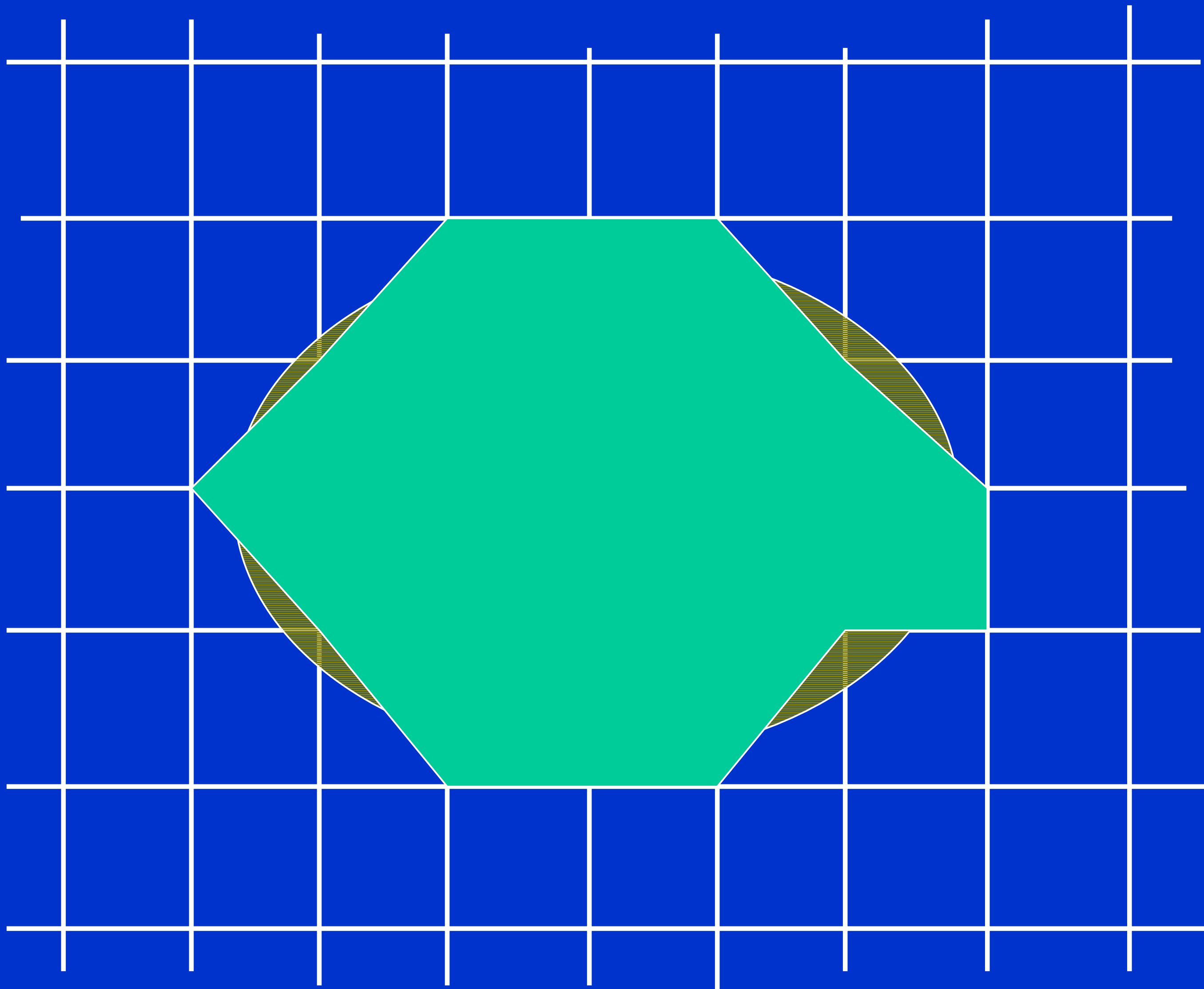
LMR(Local Mesh Refinement



Locally Body-Fitted Cartesian Grid



Diagonal Cartesian Grid



Numerical Algorithm

Computational Method

Finite Volume Method (FVM)

Fractional Step Method

Collocate Grid Method

Governing Equations

Navier-Stokes Eq.

$$\frac{\partial u_i}{\partial t} + \frac{\partial u_j u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{1}{\mathrm{Re}} \frac{\partial}{\partial x_j} \left(\frac{\partial u_i}{\partial x_j} \right)$$

Continuity Eq.

$$\frac{\partial u_i}{\partial x_i} = 0$$

Fractional Step Method

$$\frac{u^* - u^n}{\Delta t} + \frac{1}{2}\left(3N_u^n - N_u^{n-1}\right) = \frac{1}{2\,\mathrm{Re}}\nabla^2\left(u^* + u^n\right)$$

$$\frac{v^* - v^n}{\Delta t} + \frac{1}{2}\left(3N_v^n - N_v^{n-1}\right) = \frac{1}{2\,\mathrm{Re}}\nabla^2\left(v^* + v^n\right)$$

Poisson Eq. For Scalar ϕ

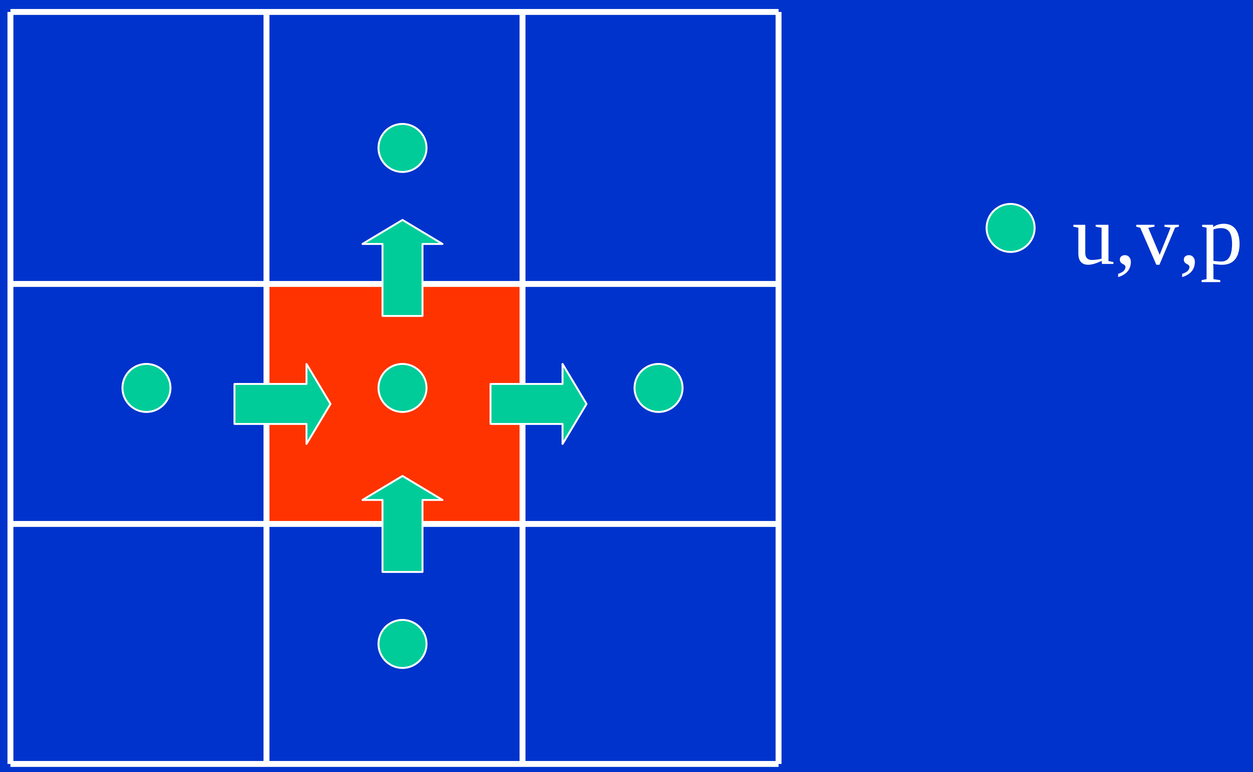
$$\nabla^2 \phi = \frac{\nabla \cdot V^*}{\Delta t}$$

Correction of velocity and pressure

$$u_i^{n+1} = u_i^* - \Delta t \frac{\partial \phi}{\partial x_i}$$

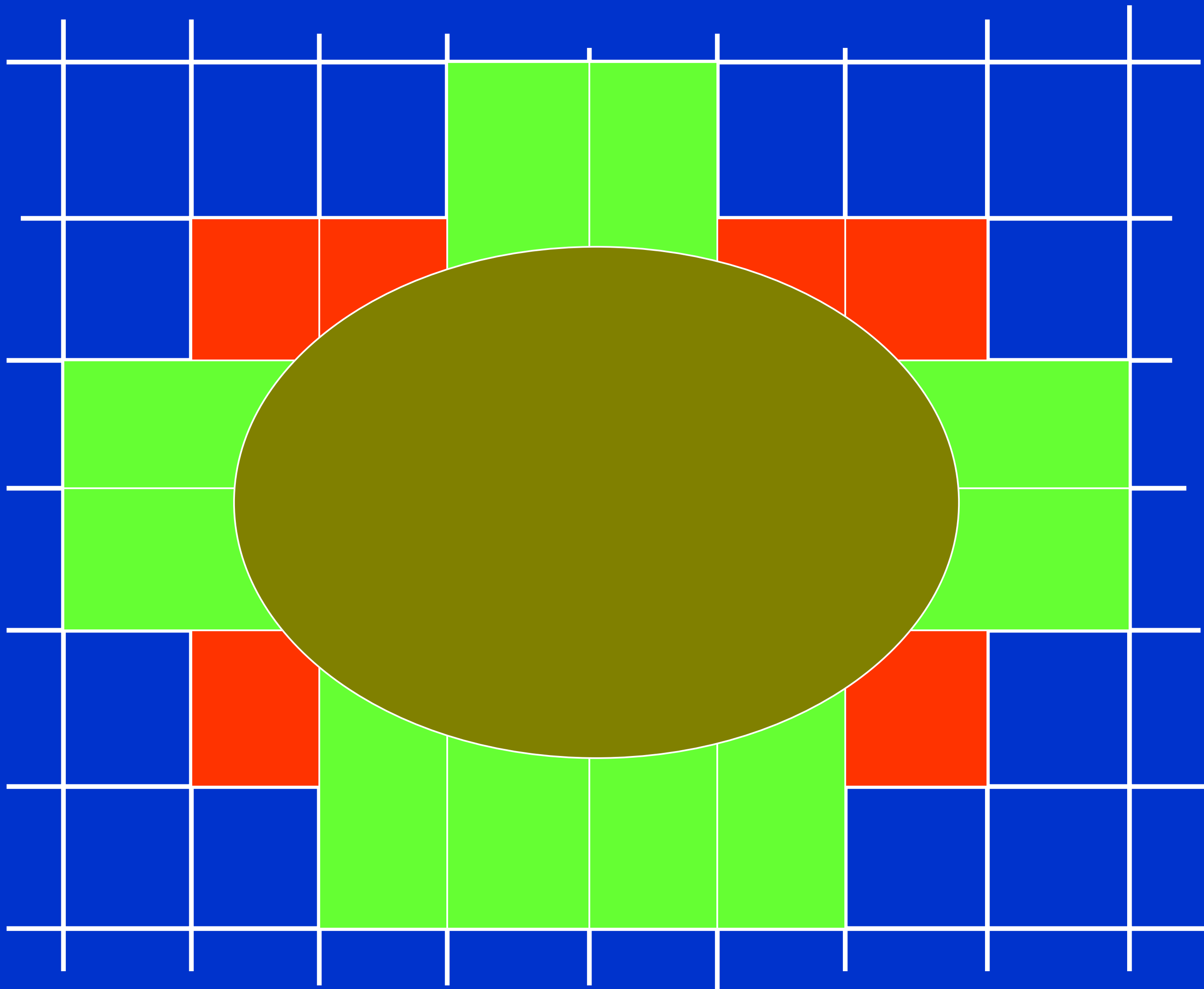
$$p = \phi - \frac{\Delta t}{2\mathrm{Re}} \nabla^2 \phi = \phi - \frac{1}{2\mathrm{Re}} \nabla \cdot V^*$$

Collocate Grid



Cut Cell Based Cartesian Grid

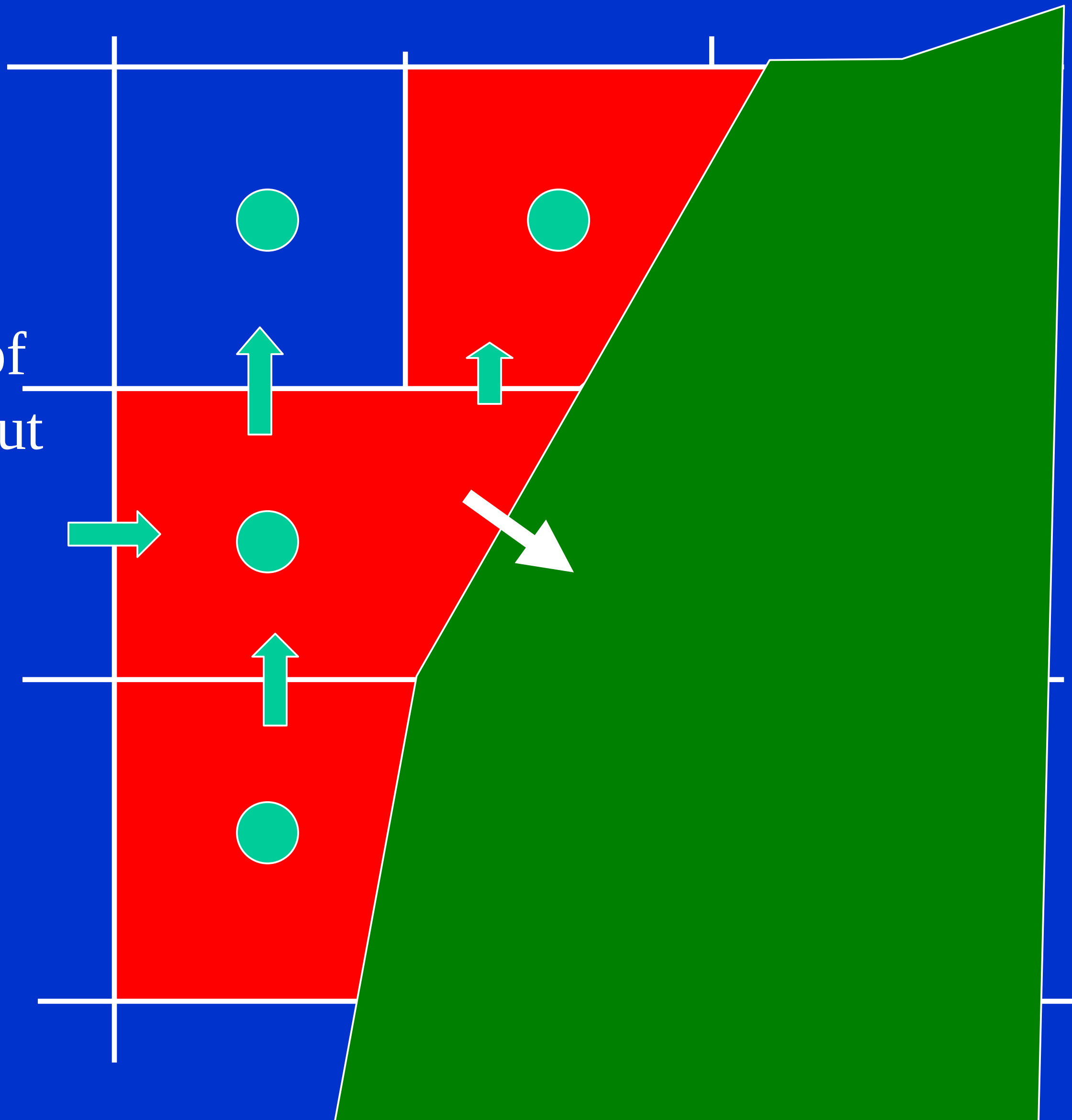
Cut Cell with Cell Merging



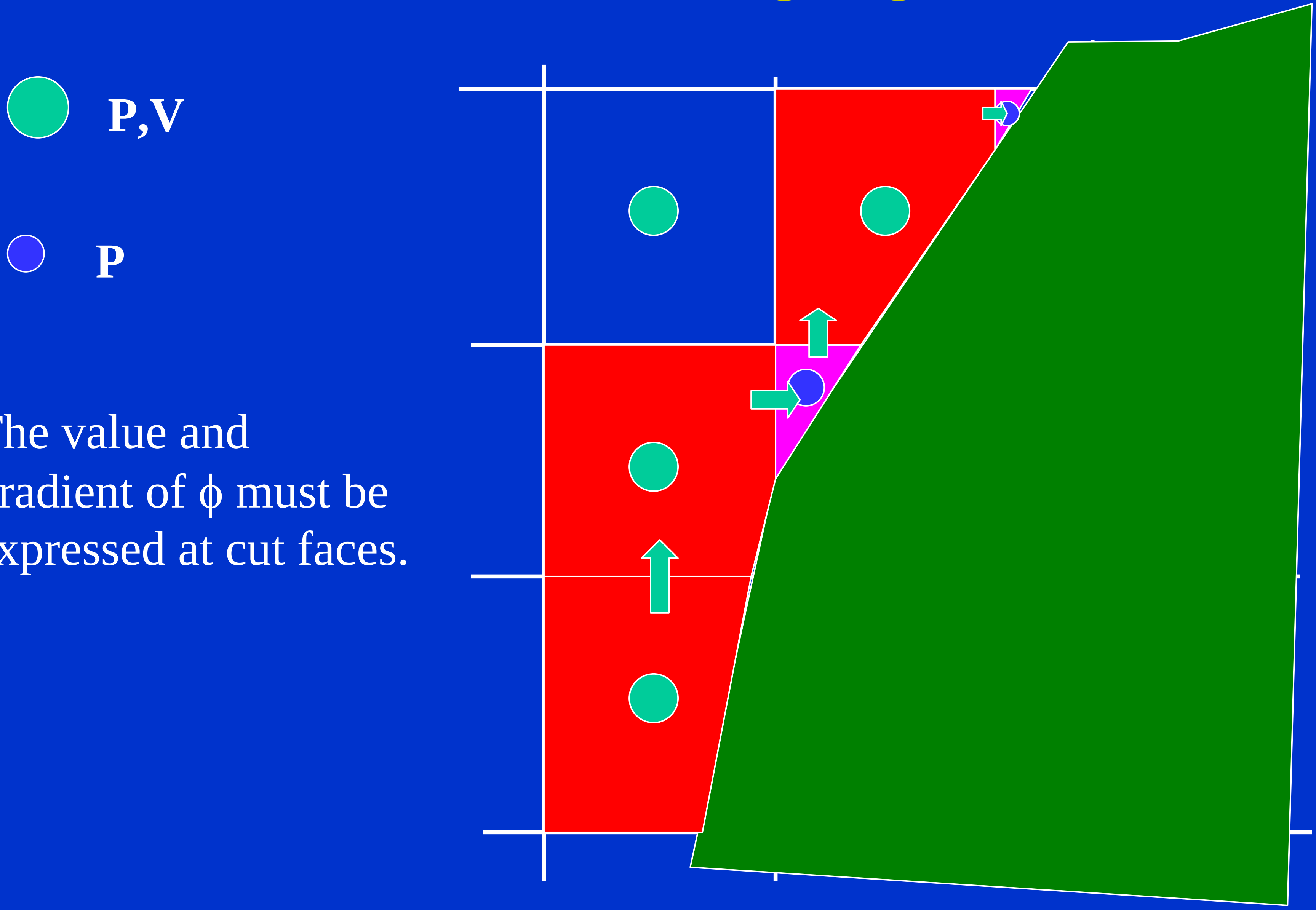
Cut Cell With Merging Treatment

Point of Cut Cell

The value and gradient of ϕ must be expressed at cut faces.



Cut Cell without Merging Treatment



The value and gradient of ϕ must be expressed at cut faces.

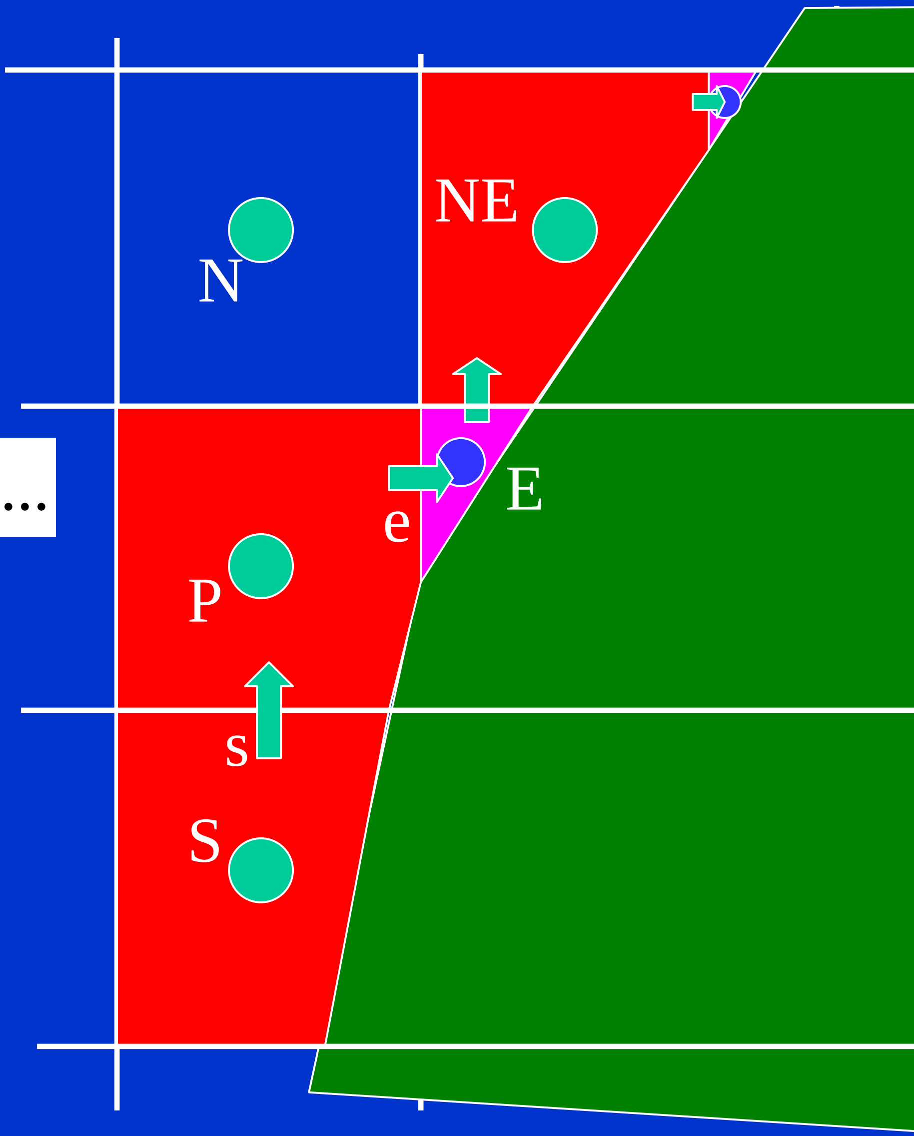
Polynomial Interpolation by S. Wei

$$\phi_s = (\phi_P + \phi_S)/2$$

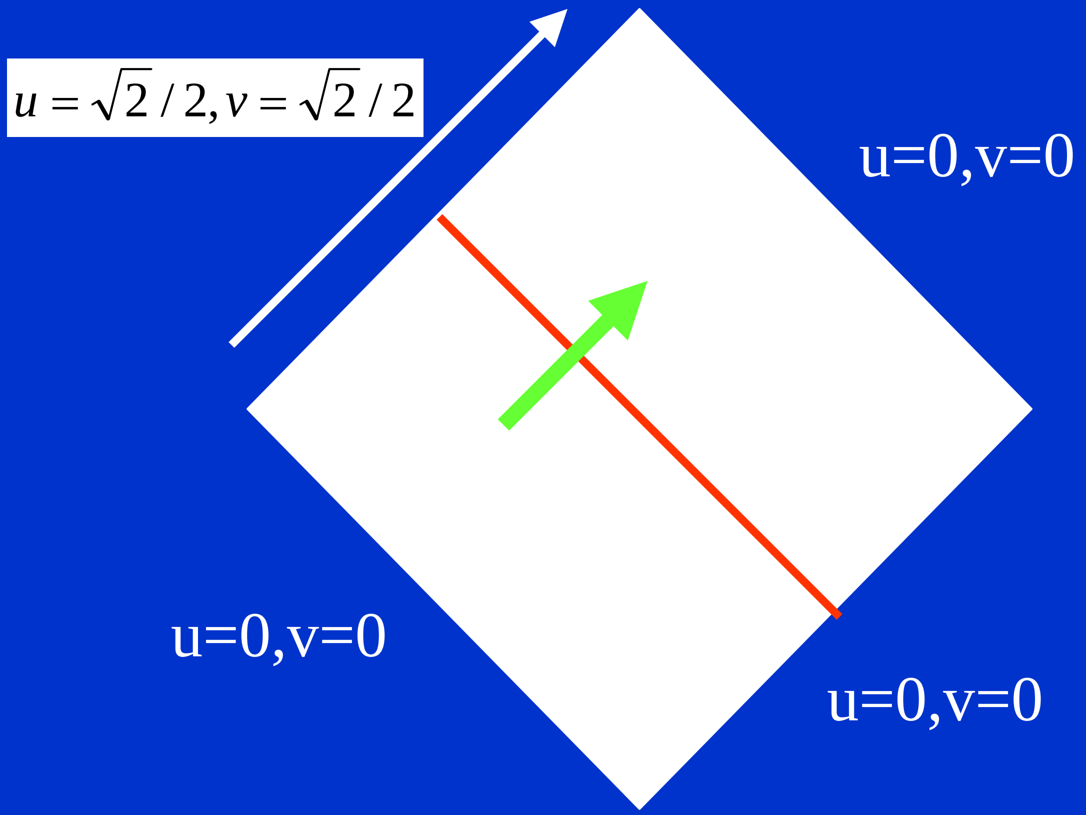
$$\phi_e = \lambda\phi_P + (1-\lambda)\phi_E$$

$$\phi = a + bx + cy + dxy + ex^2 + fy^2 + \ldots\ldots$$

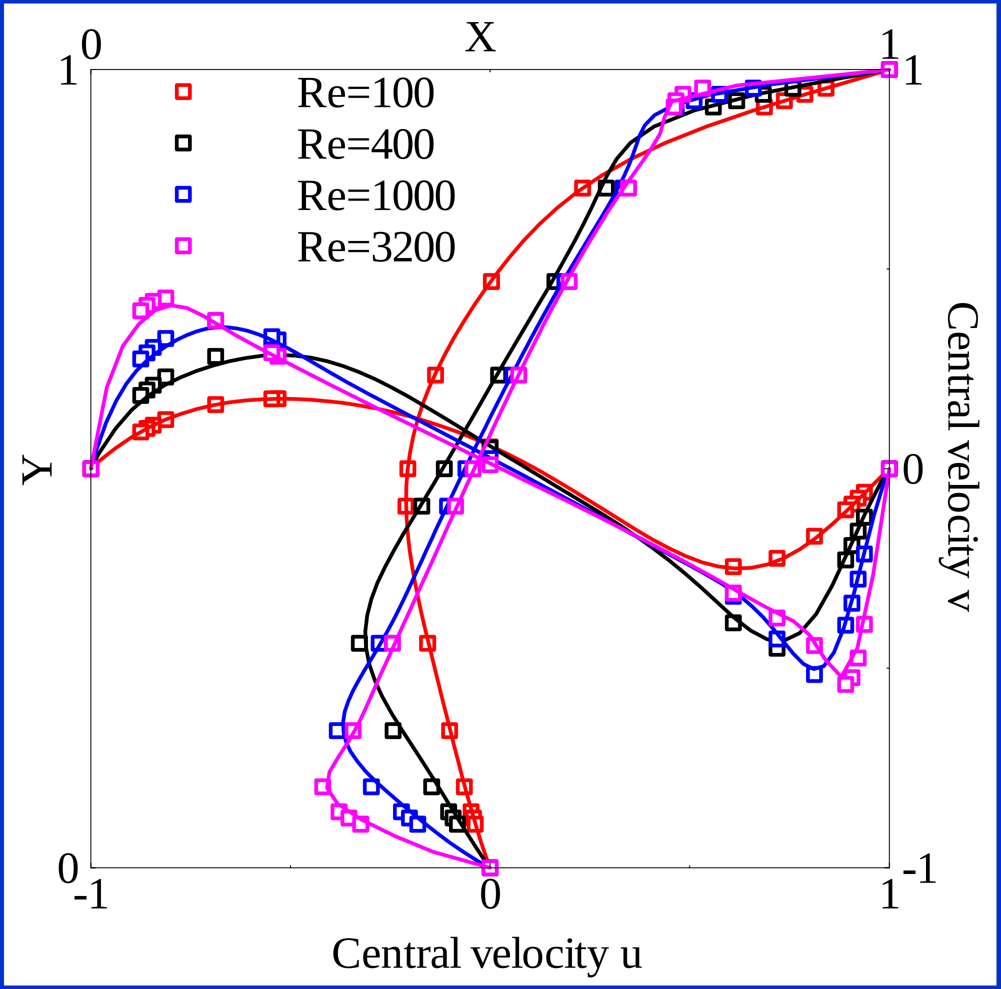
$$\phi_e = \lambda(\phi_N + \phi_{NE}) + (1-\lambda)\phi_{Cutface}$$



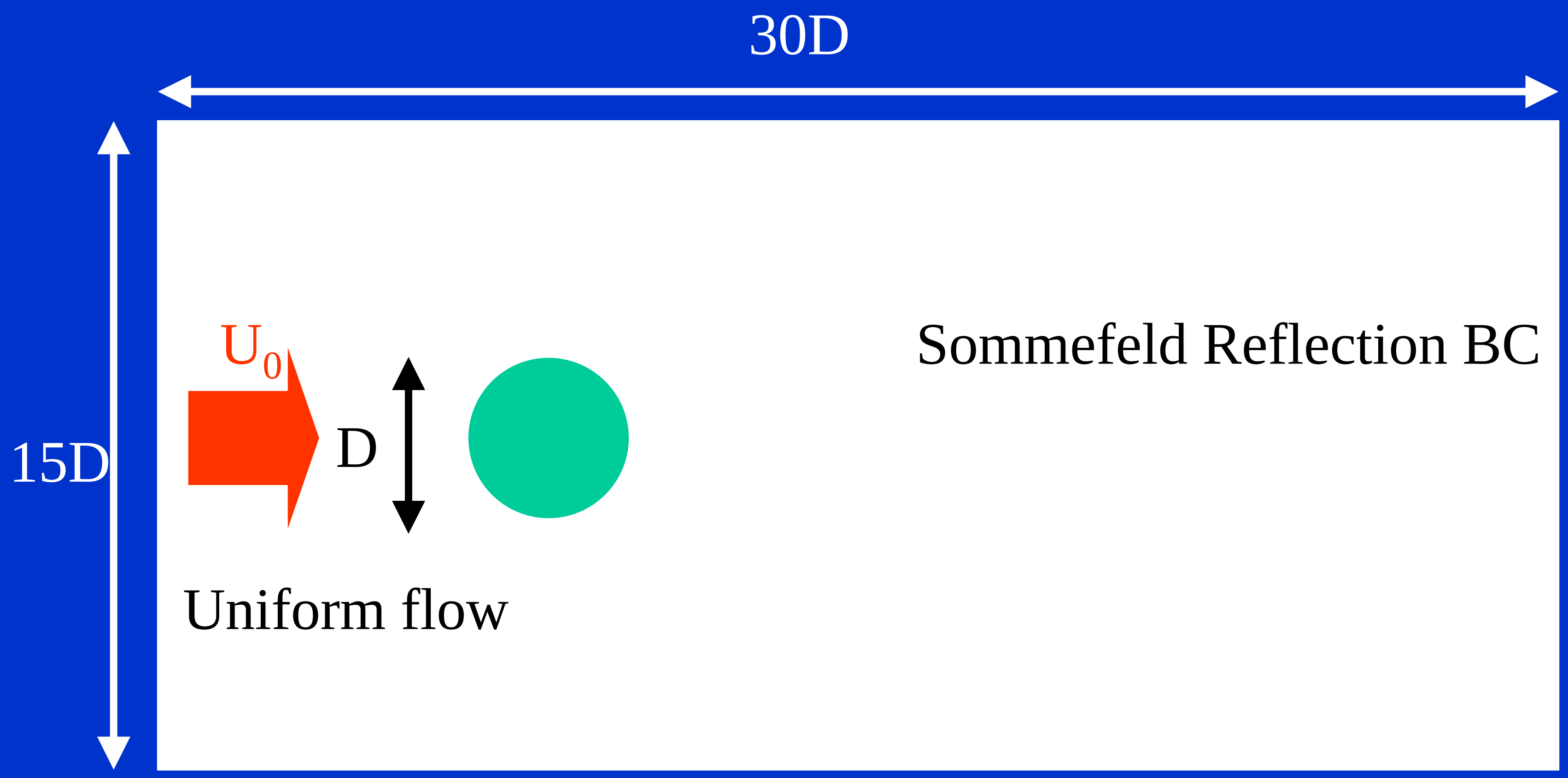
Driven Cavity Flow



Numerical resutls



Flow around a circular cylinder



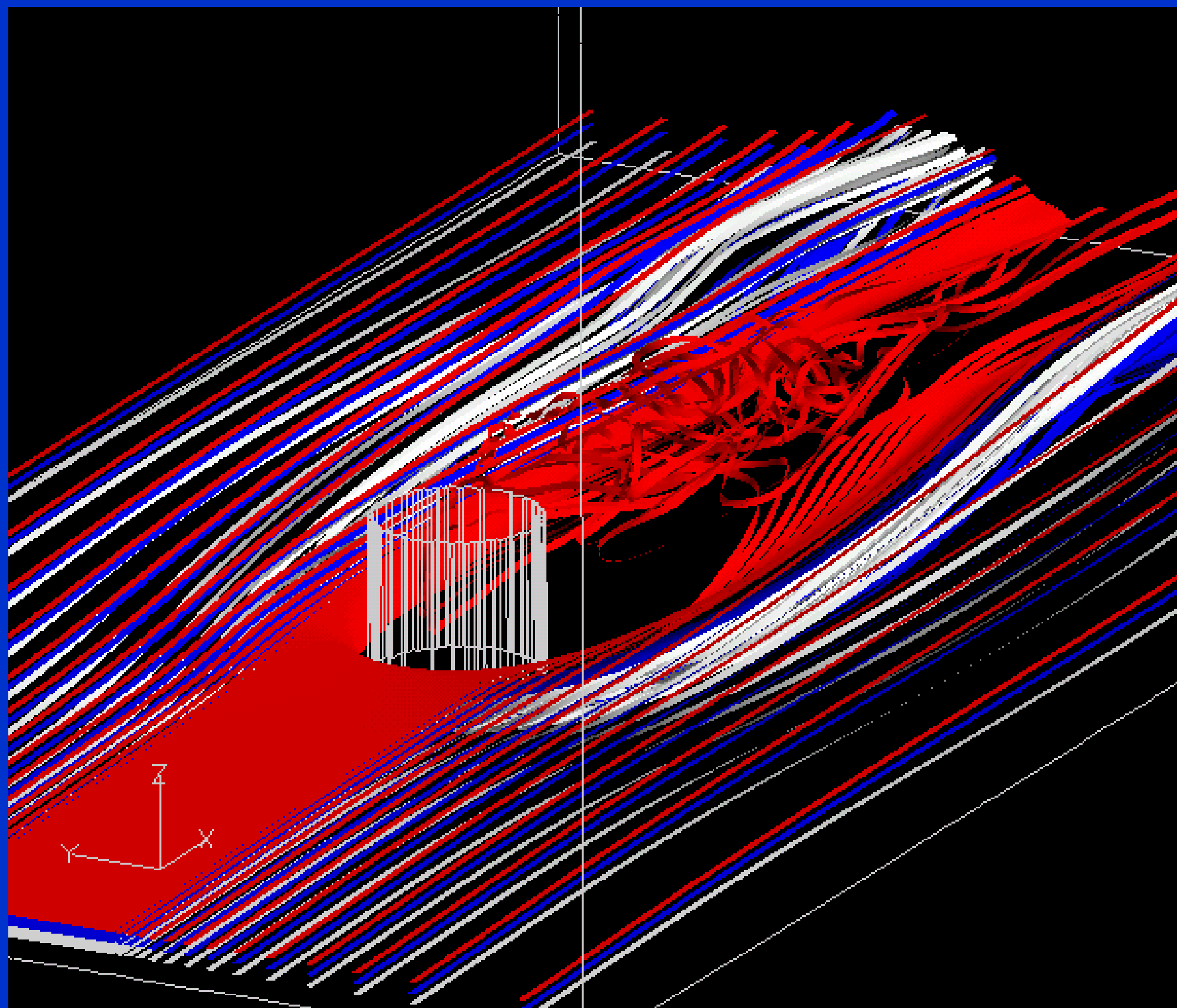
Results（Re=200）

	C_D	C_L	St
Cut Cell	**1.36±0.04**	**±0.67**	**0.20**
Body Fitted Grid	**1.34±0.04**	**±0.65**	**0.19**
Roger et al.（1988）	**1.29±0.05**	**±0.75**	**0.16**
Rosenfield et al.（1991）	**1.31±0.04**	**±0.65**	**0.20**
Rosko （1954） exp.			**0.19**
Wille （1960） exp.	**1.30**		

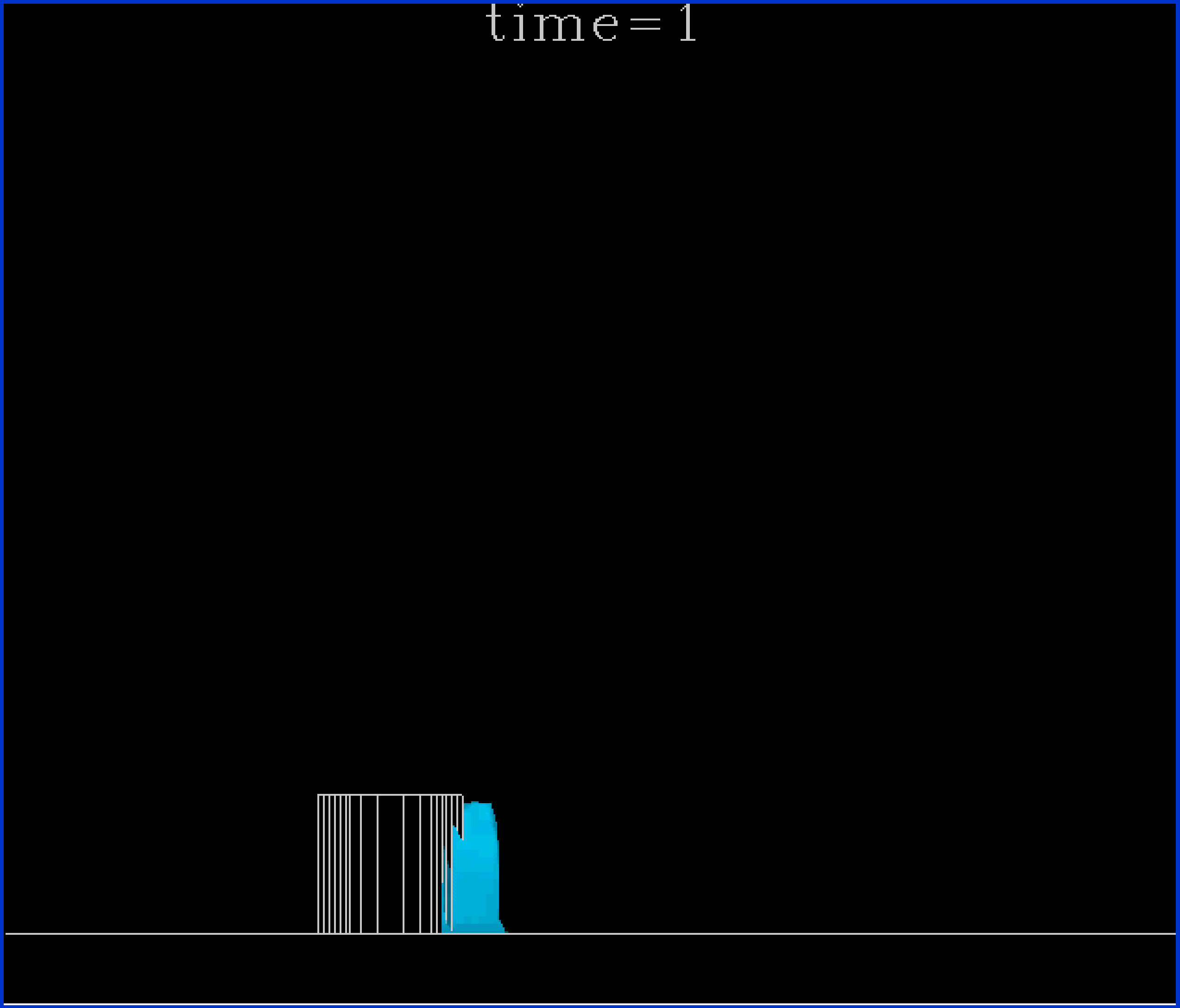
Results(Re=1000)

	C_D	C_L	St
Present Method	**1.51±0.22**	**±1.40**	**0.23**
Cell Merging Method	**1.65±0.22**	**±1.45**	**0.26**
Body Fitted Grid	**1.50±0.20**	**±1.37**	**0.25**
Mittal et al. （1997）	**1.53±0.24**	**±1.37**	**0.245**

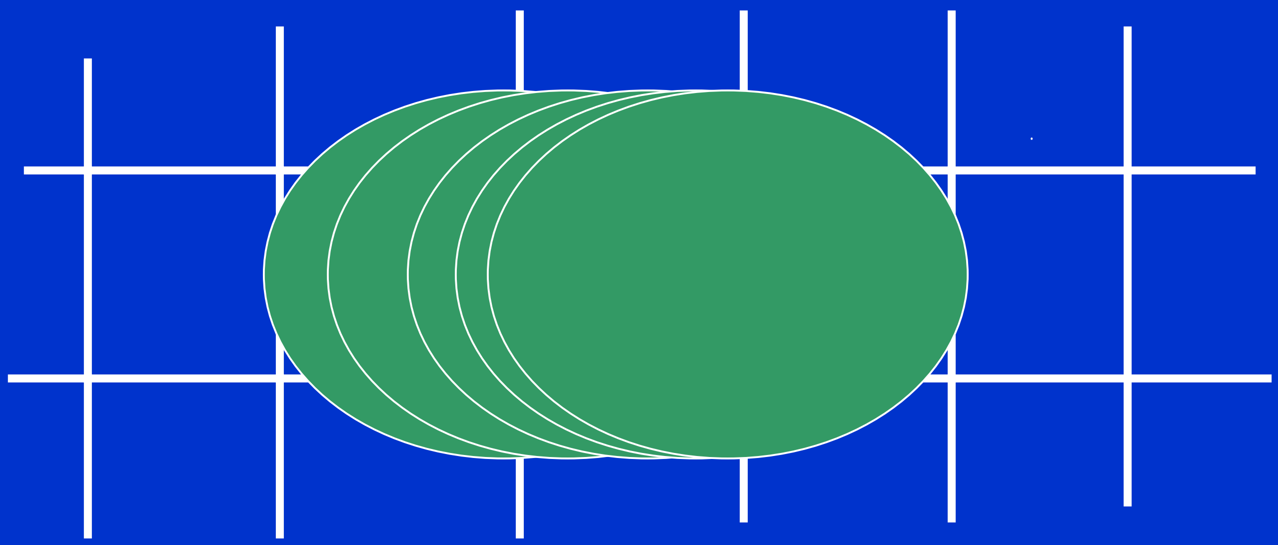
3D Finite Length Cylinder



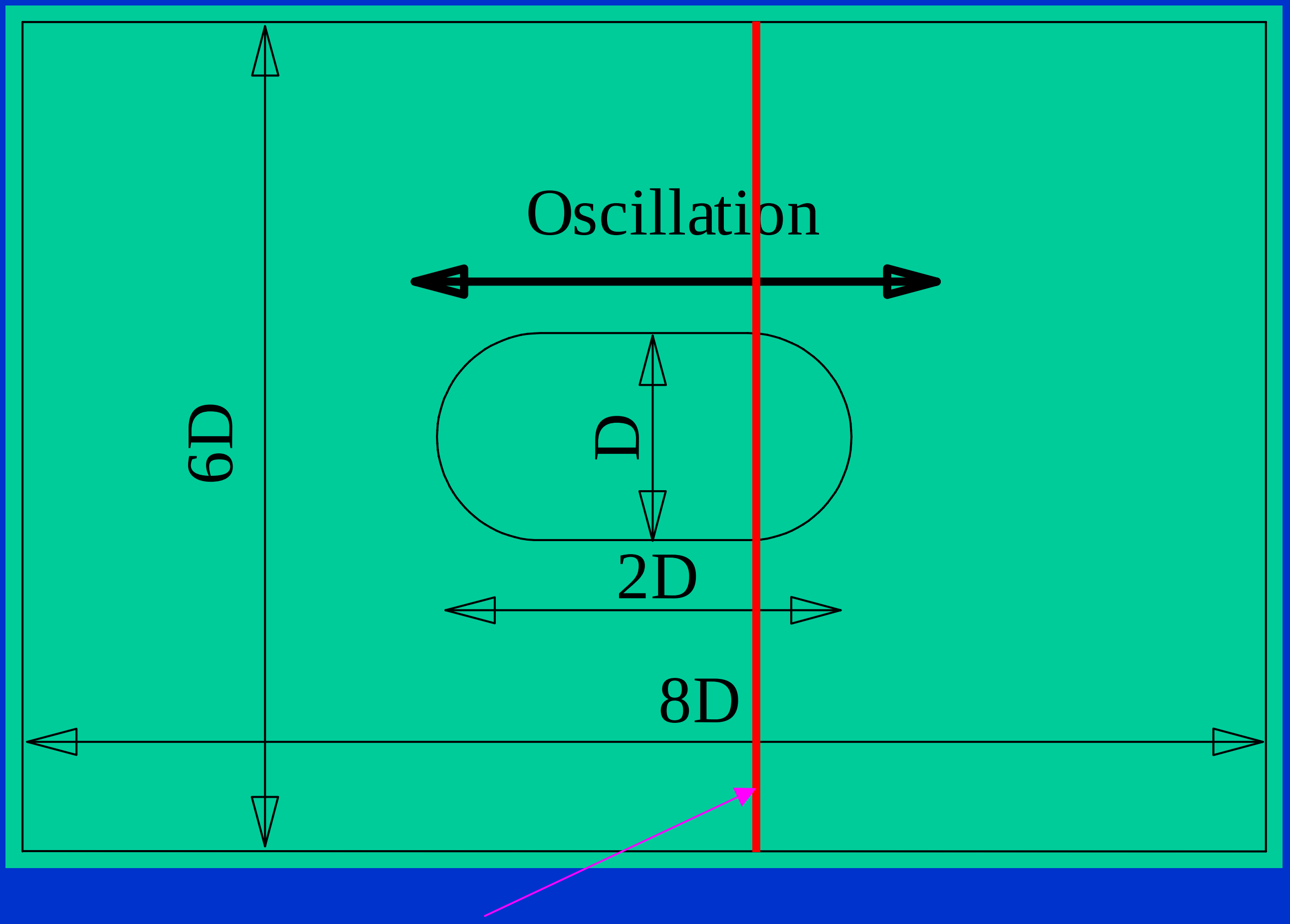
3D Finite Length Cylinder



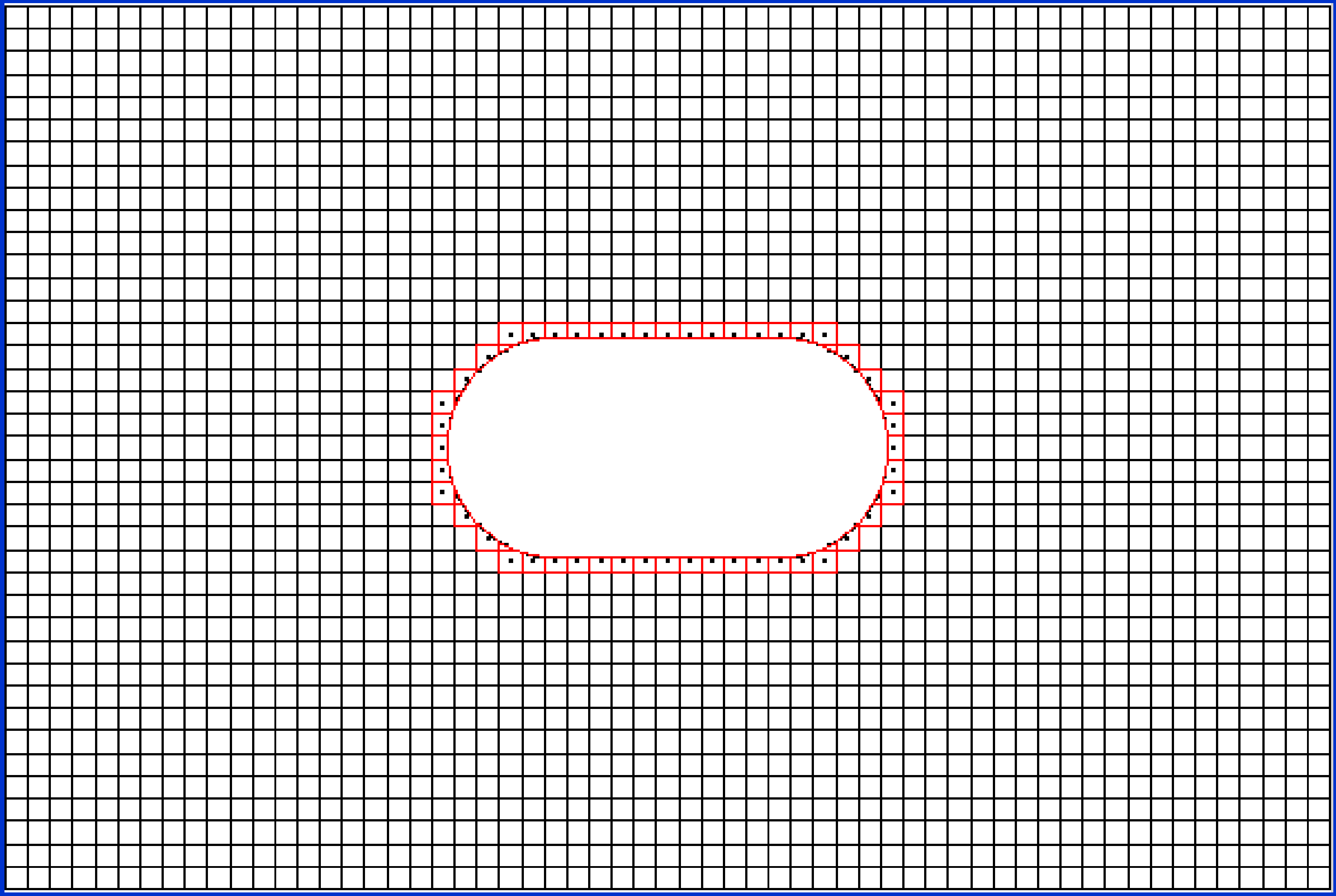
Cut Cell with Moving Boundary



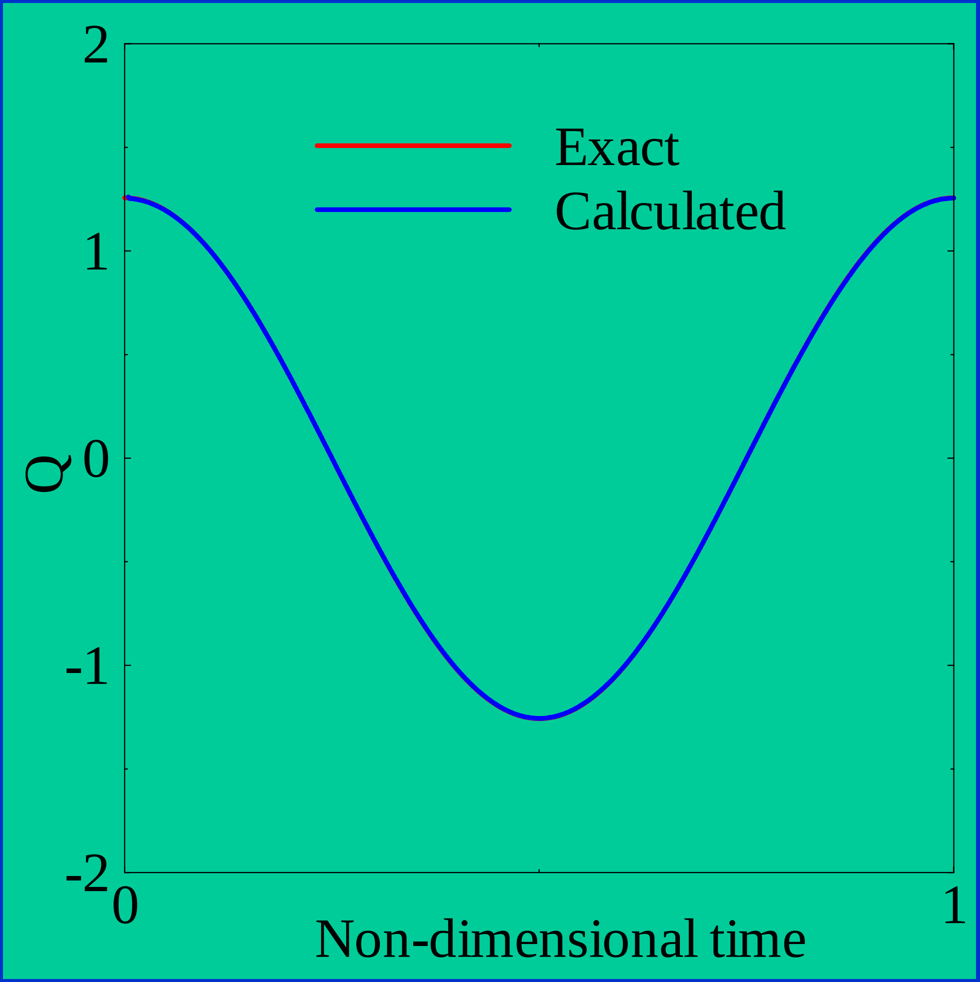
Comparison with Exact solution



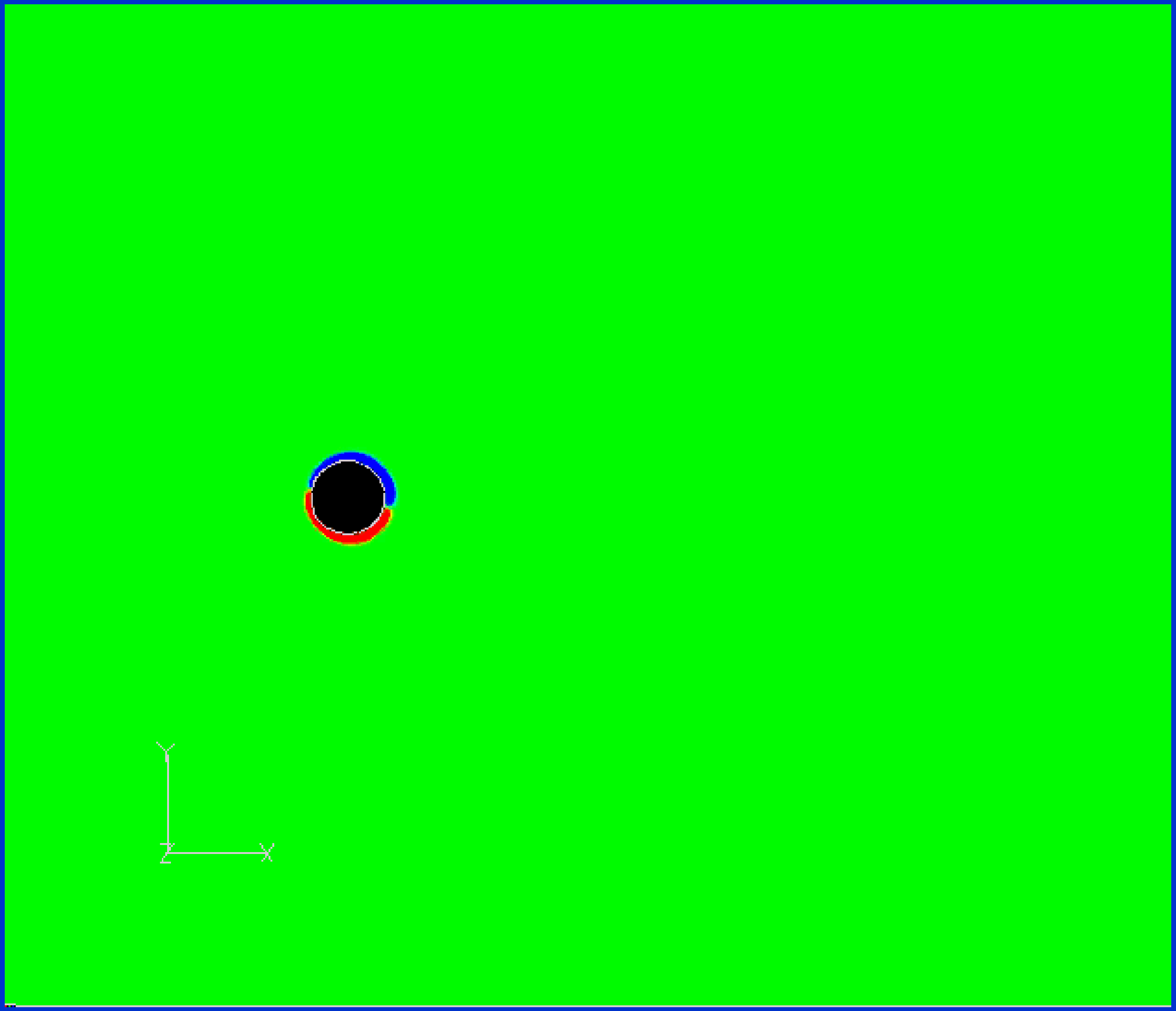
Numerical Grids



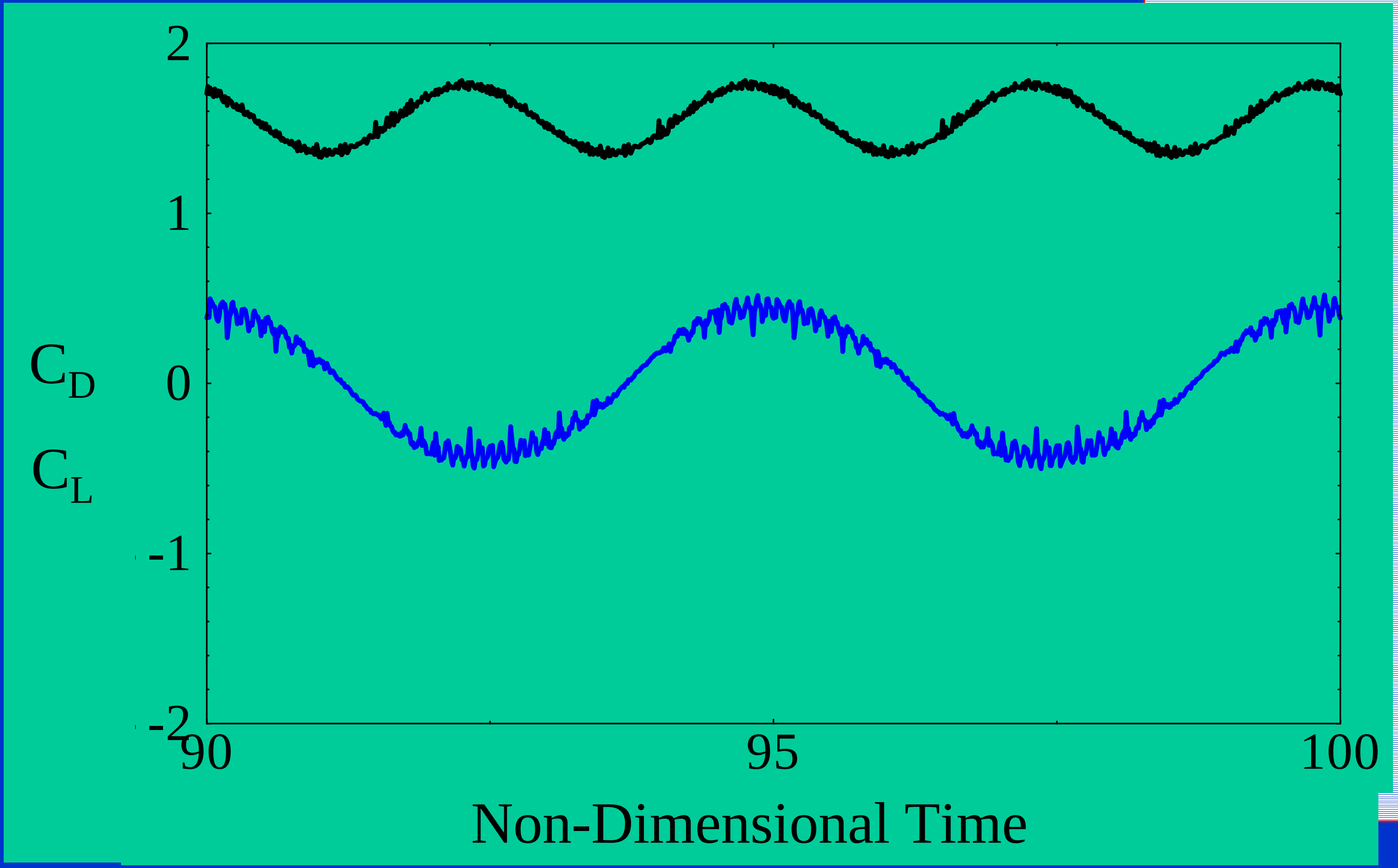
Comparison of flow rate



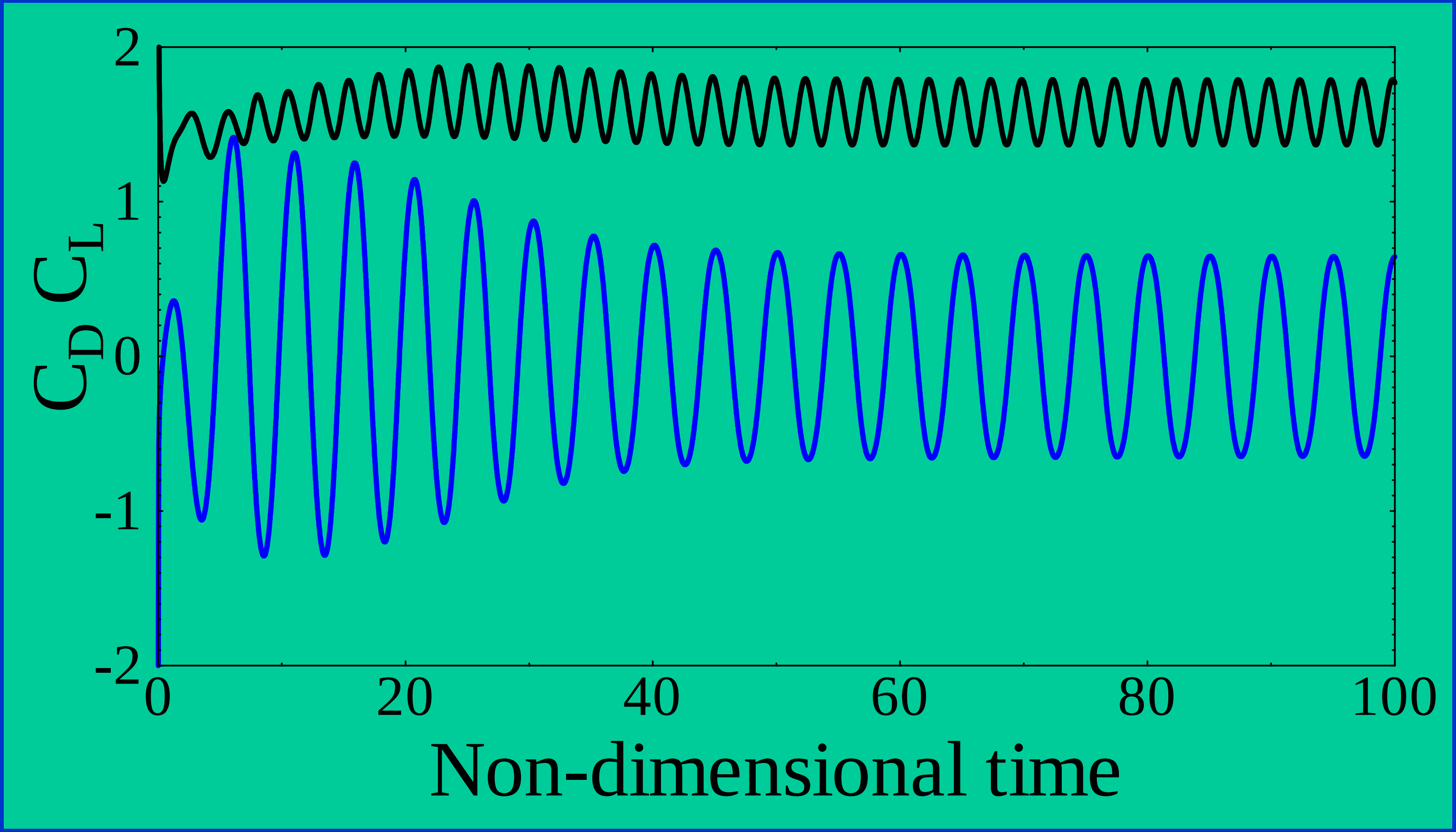
Flow around oscillating cylinder



Time histories of CD and CL



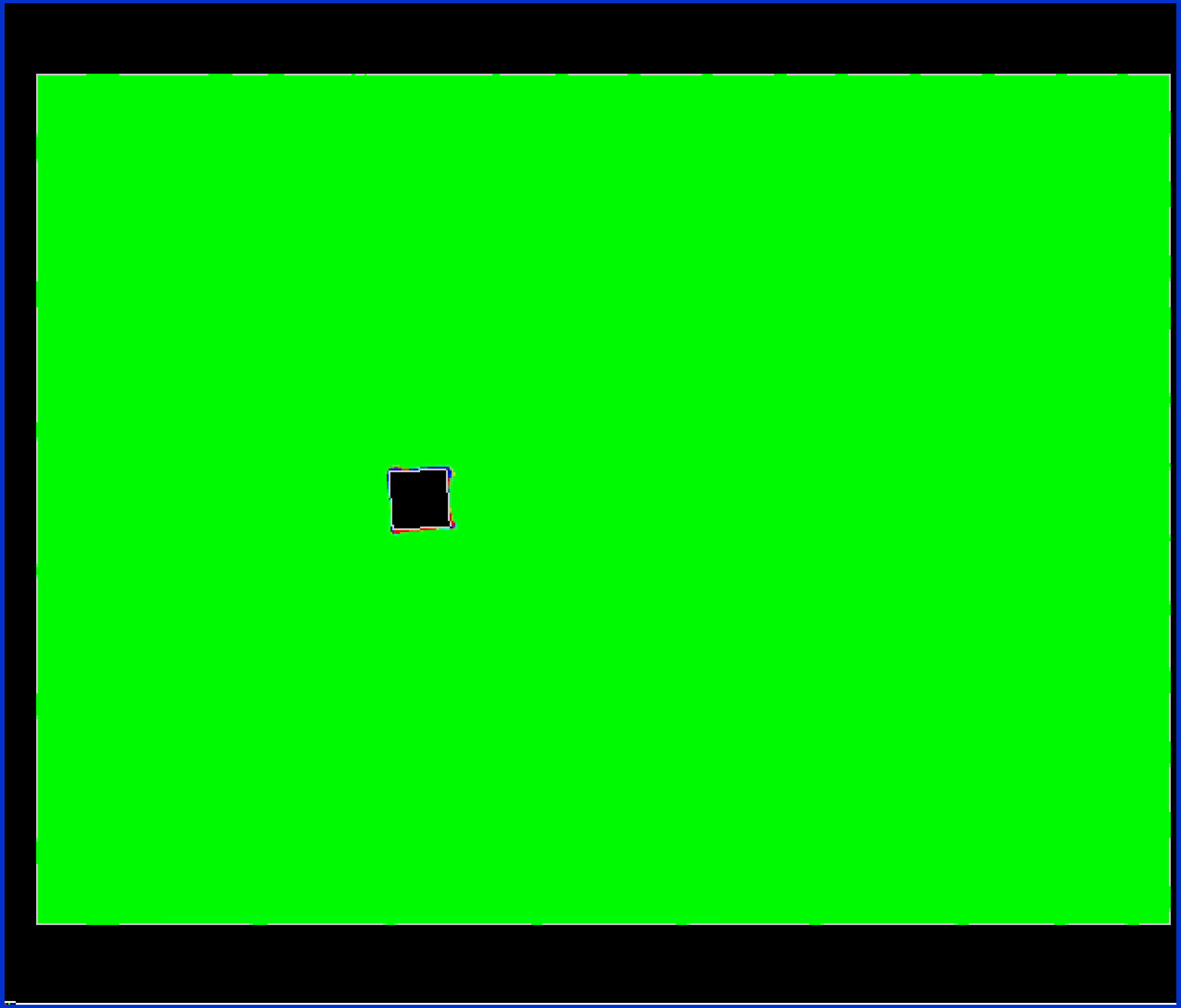
BFC with ALE



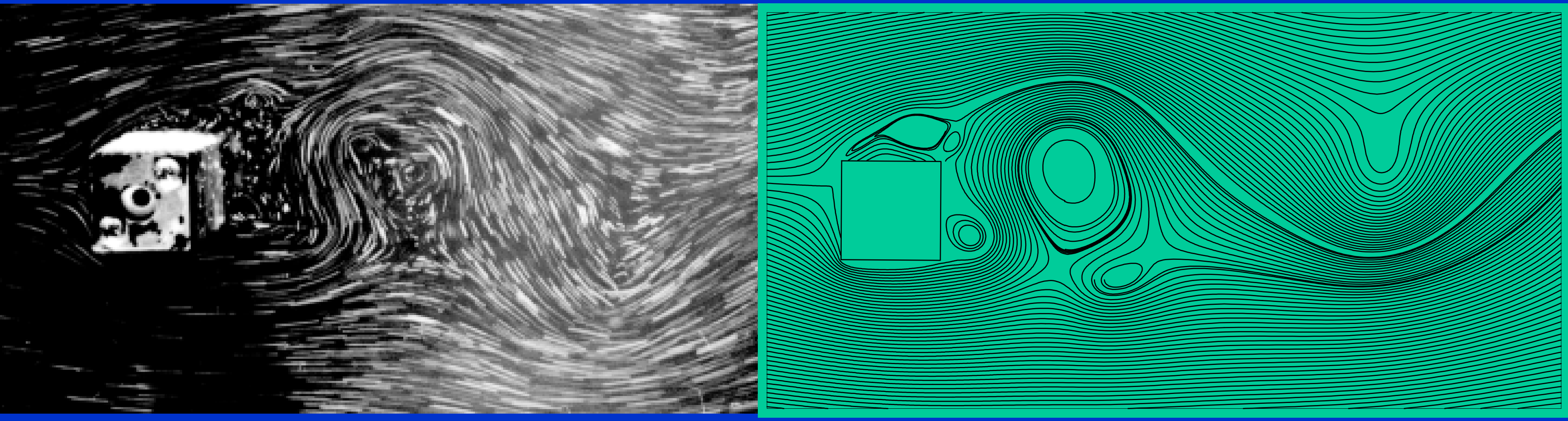
Comparison of CD and CL

	C_D	C_L	St
BFC	**1.61 $\pm$ 0.22**	**$\pm$ 0.71**	**0.20**
CutCell	**1.60 $\pm$ 0.23**	**$\pm$ 0.69**	**0.20**

Rotating Square Cylinder
Re=1370

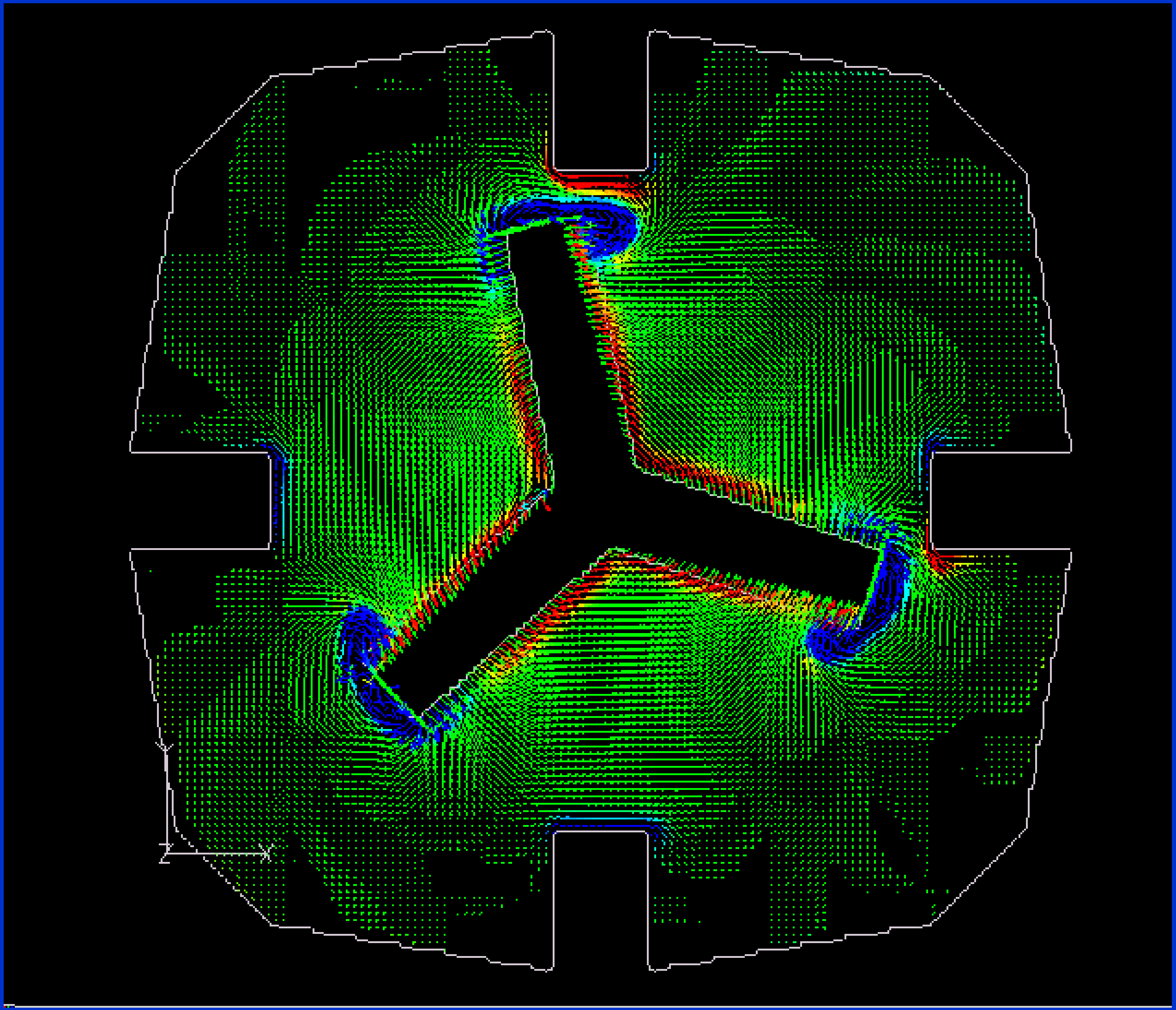


Comparison with Exp. results

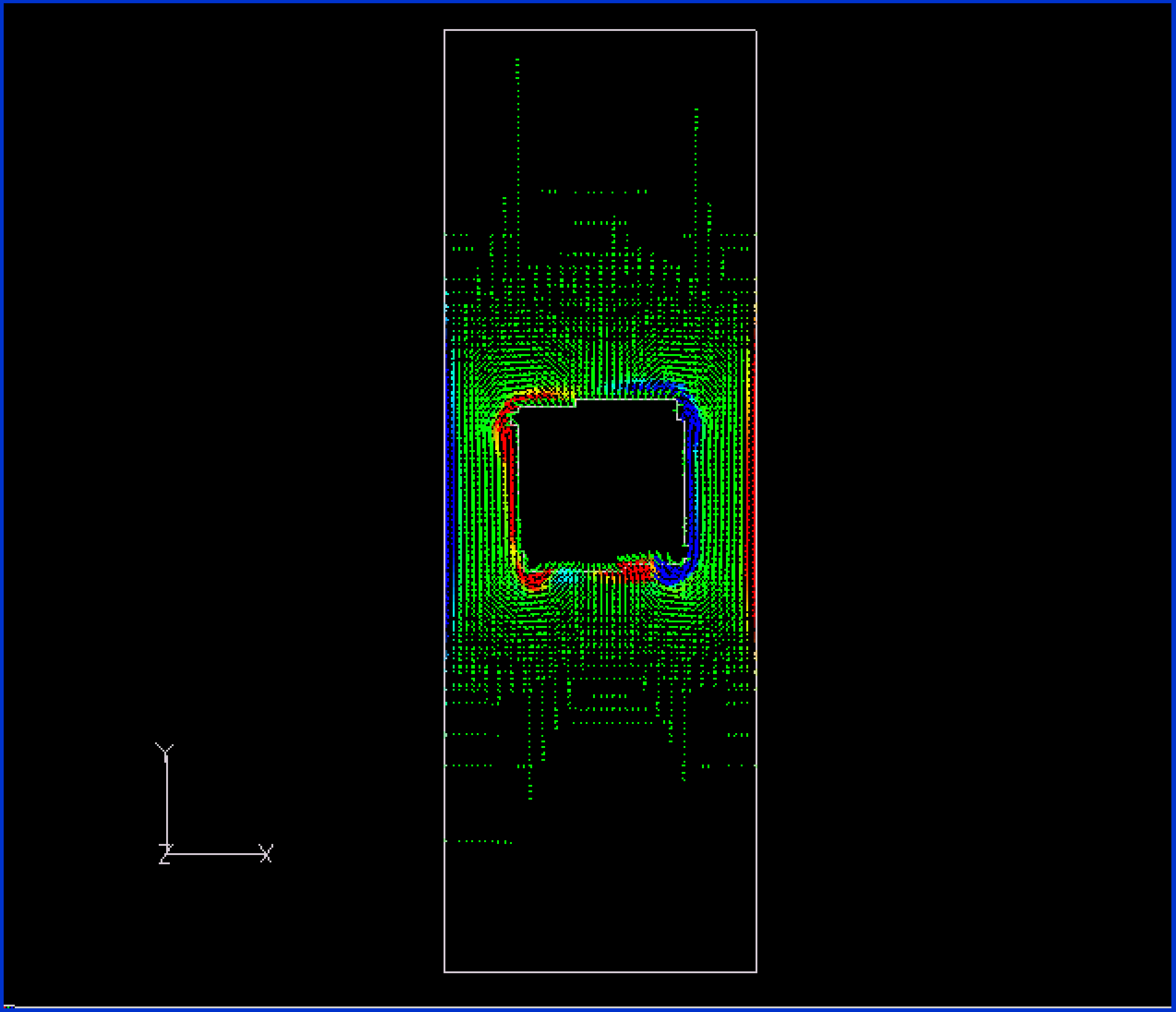


Re=1370, ω=0.628)

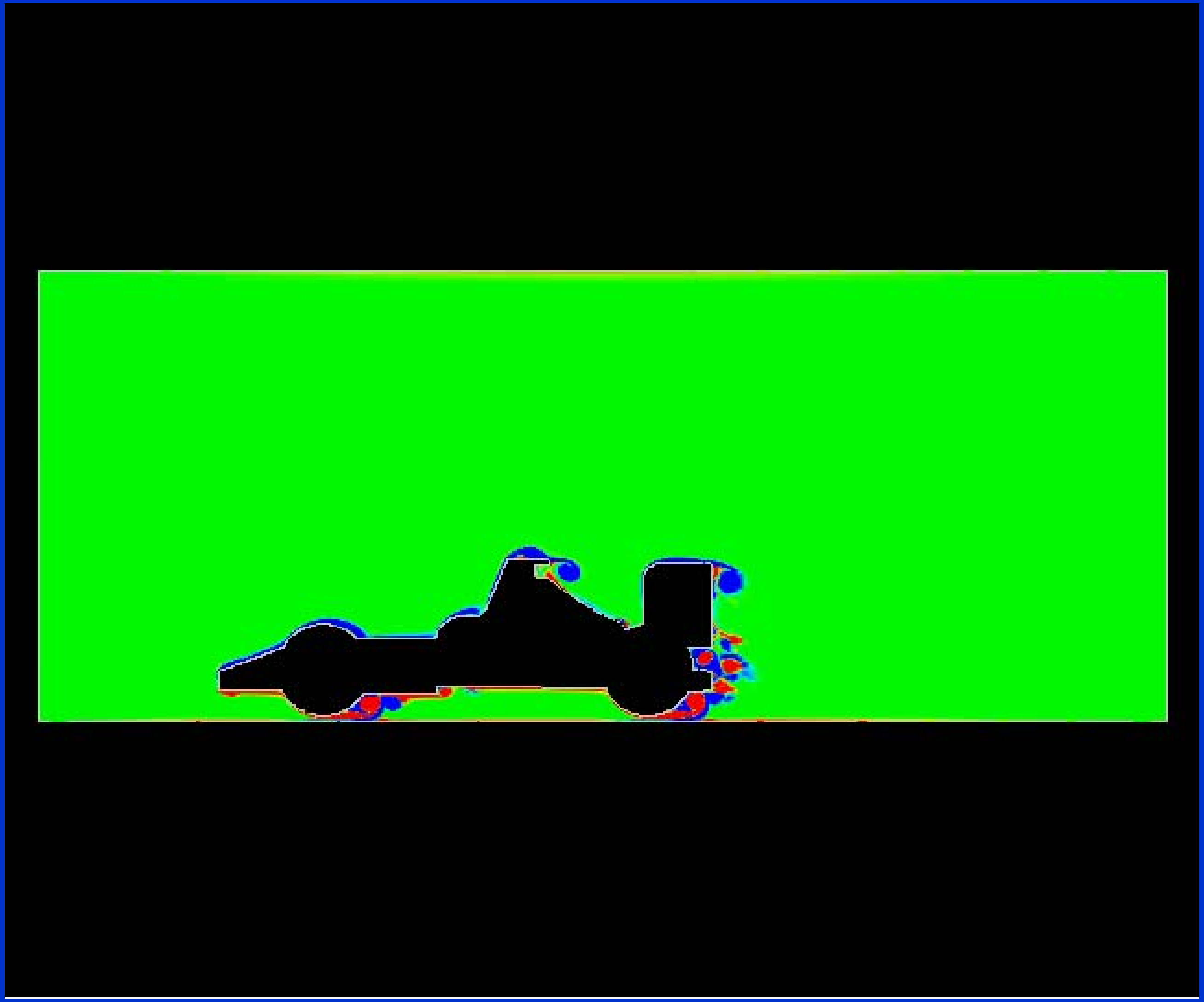
Flow in a 2D Mixer



2D Mixer

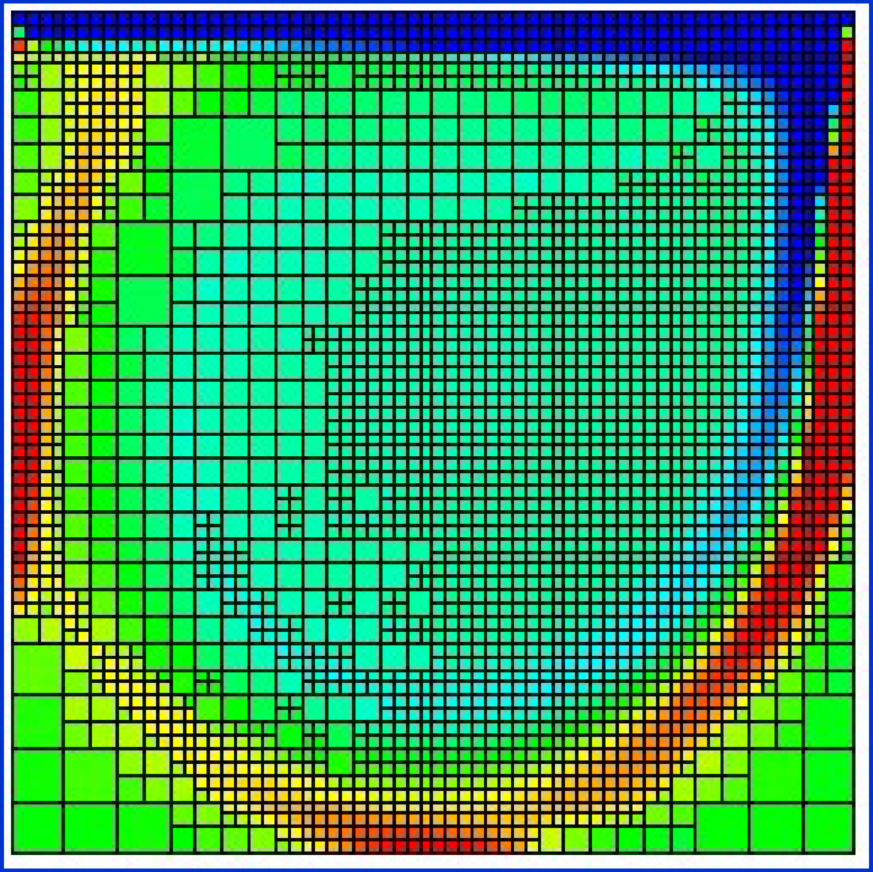


Flow around a F1

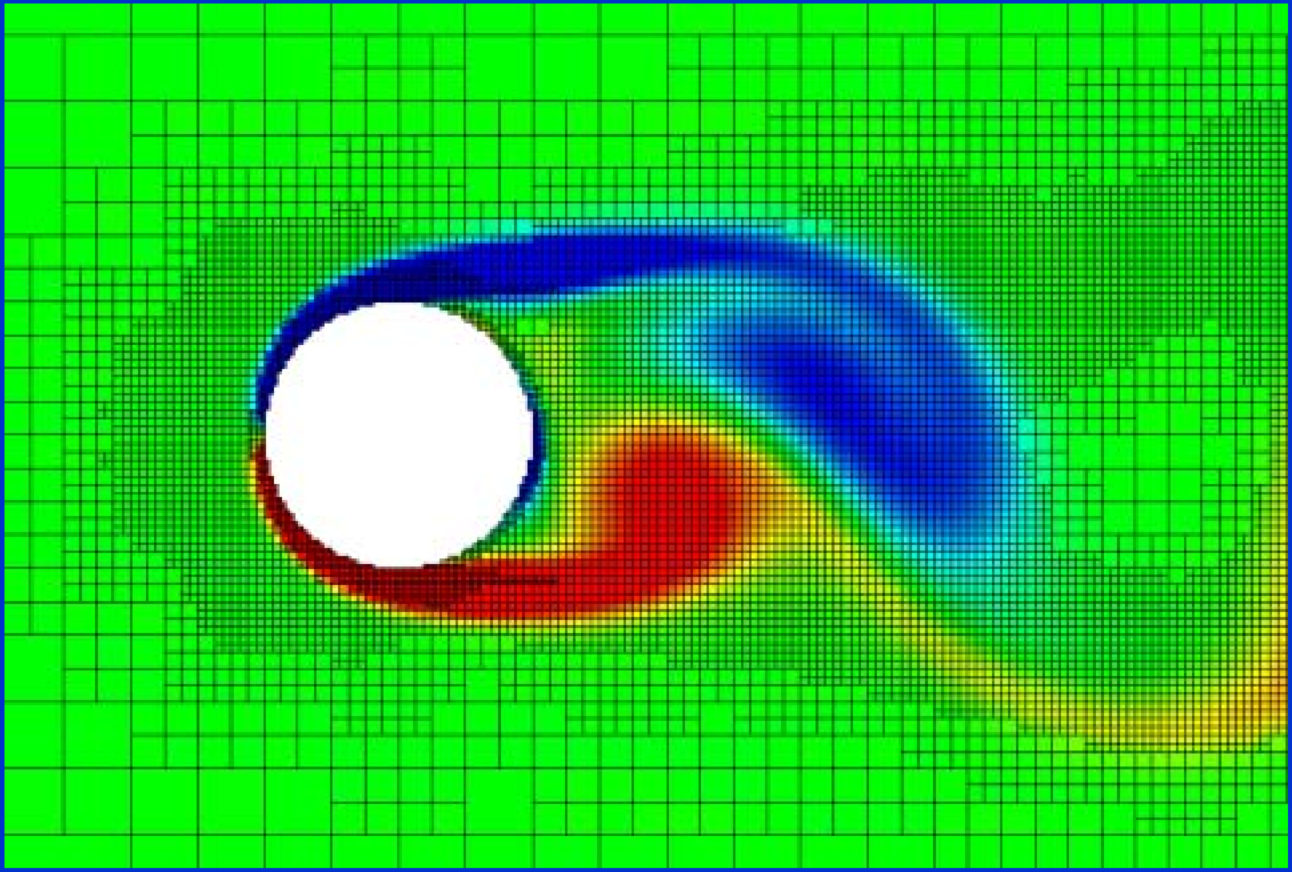


LMR and AMR Techniques

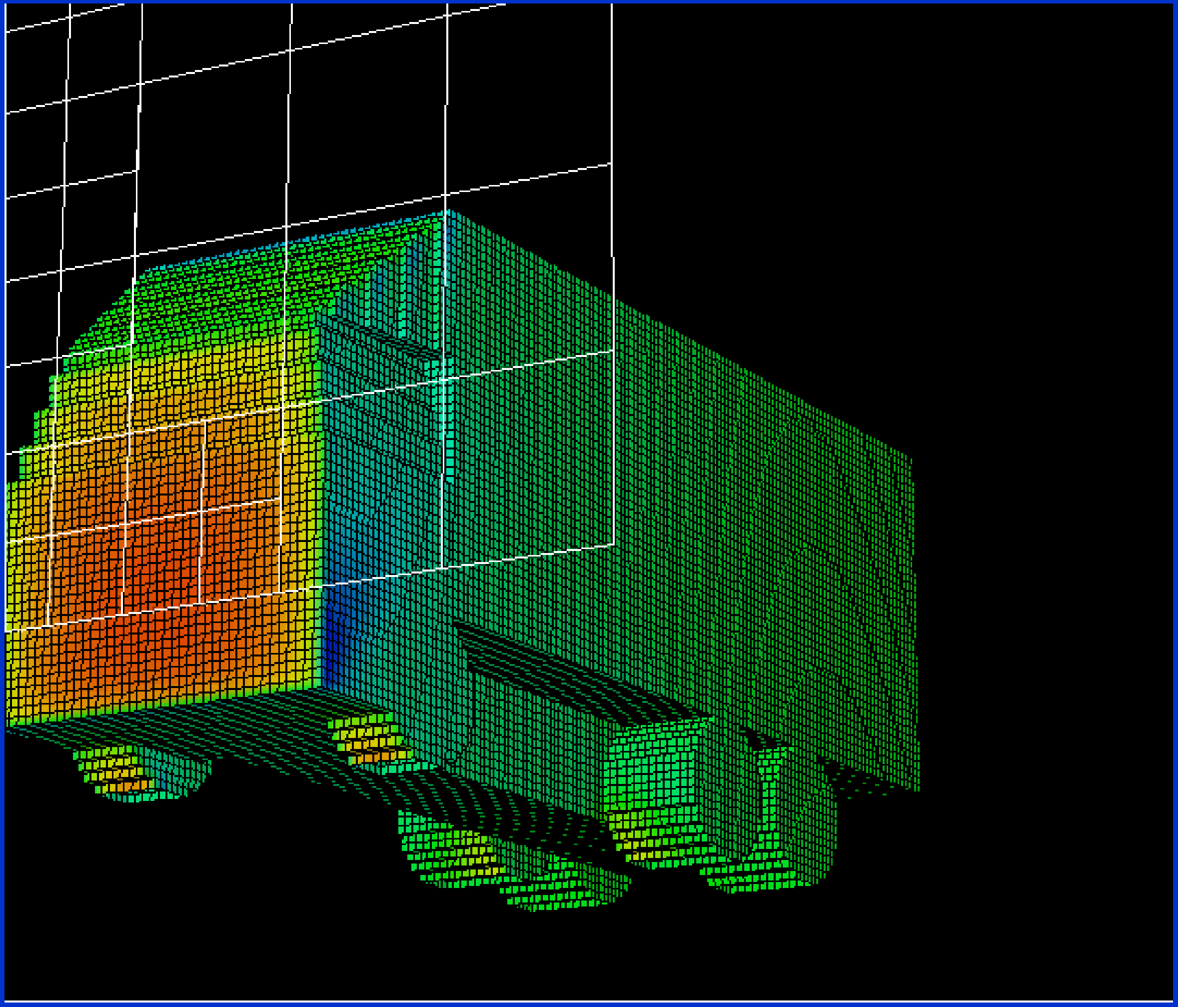
Flows in Driven Cavity



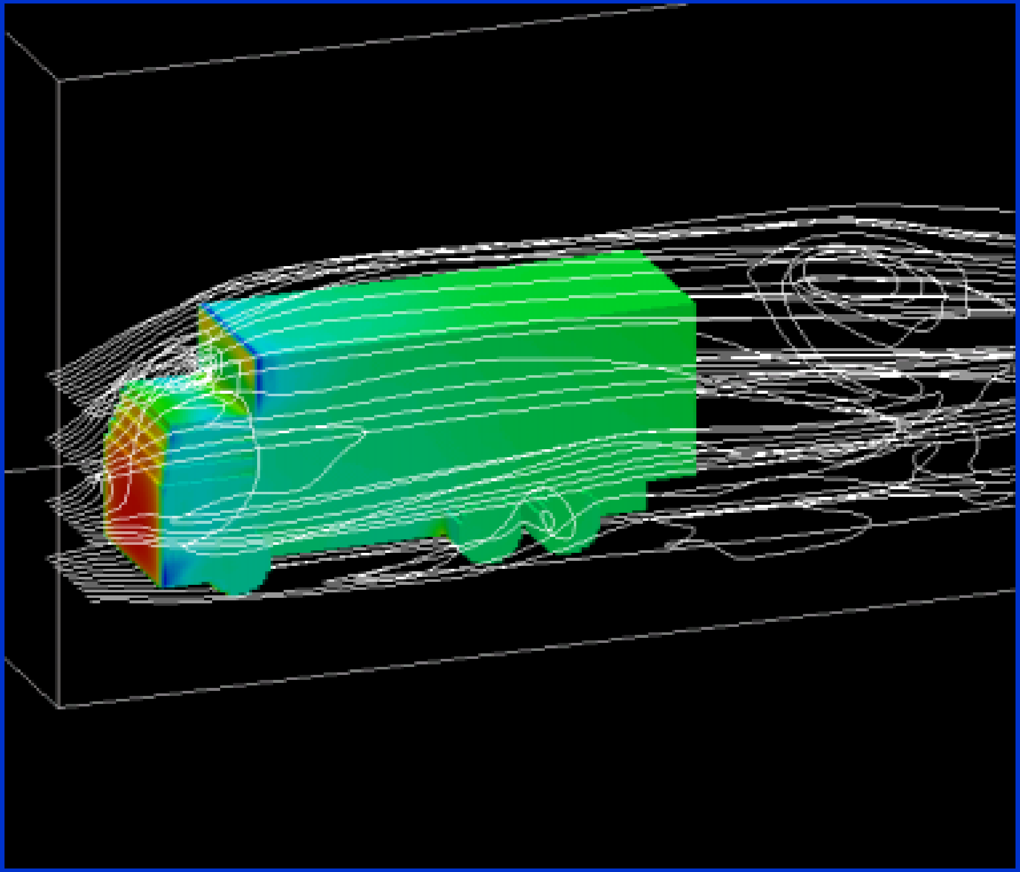
AMR for a Cylinder



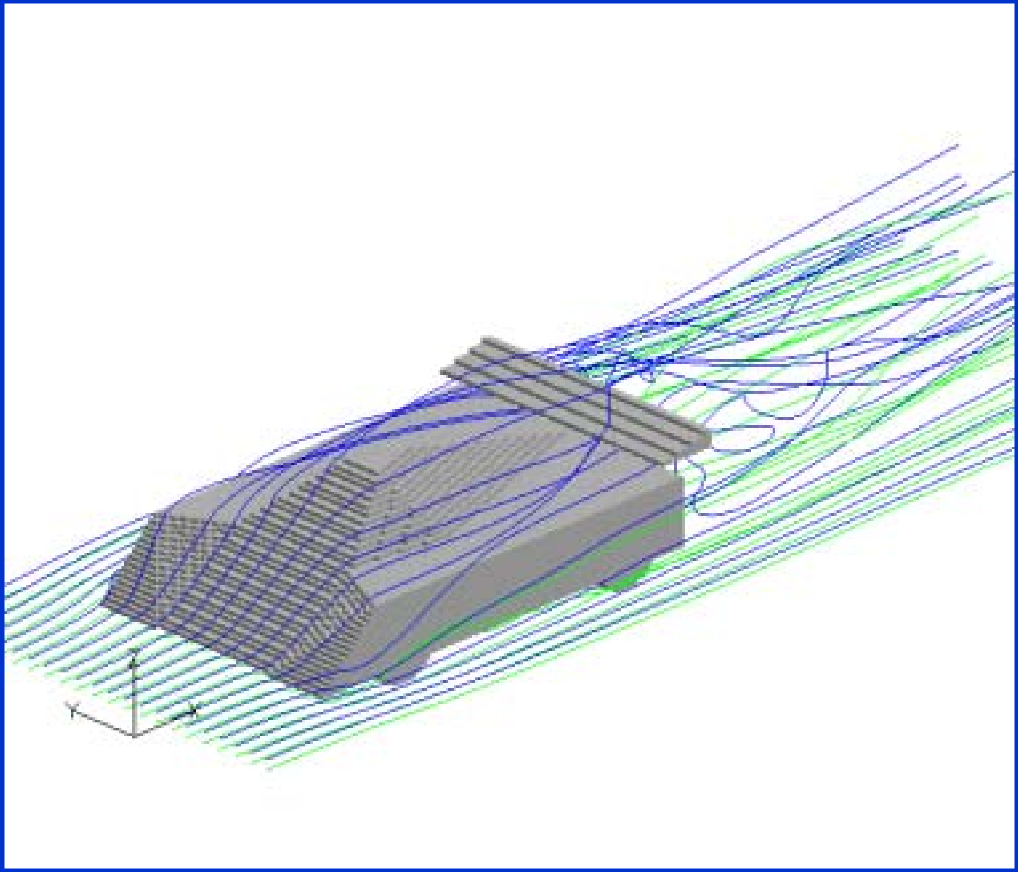
AMR on Track



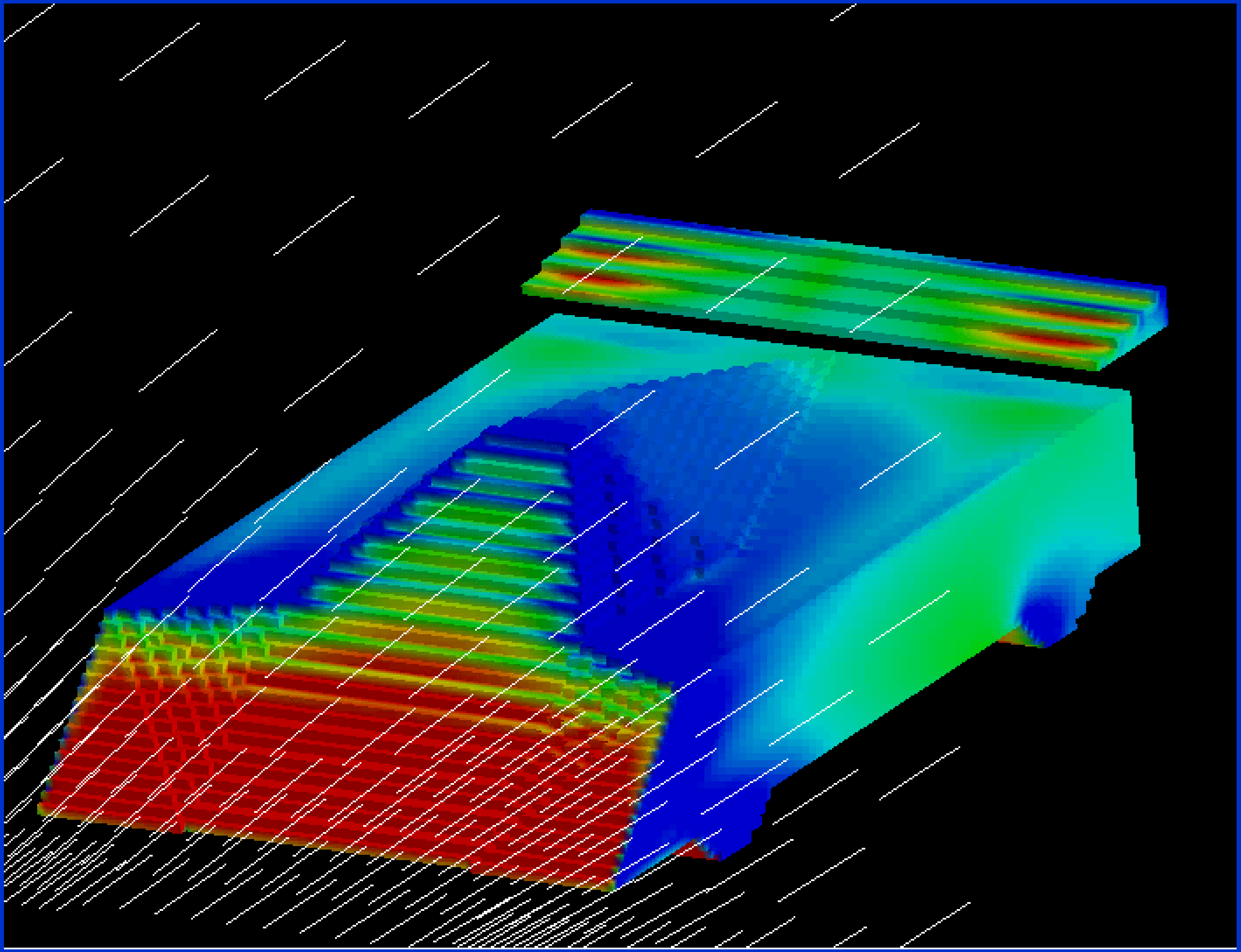
AMR on a Track



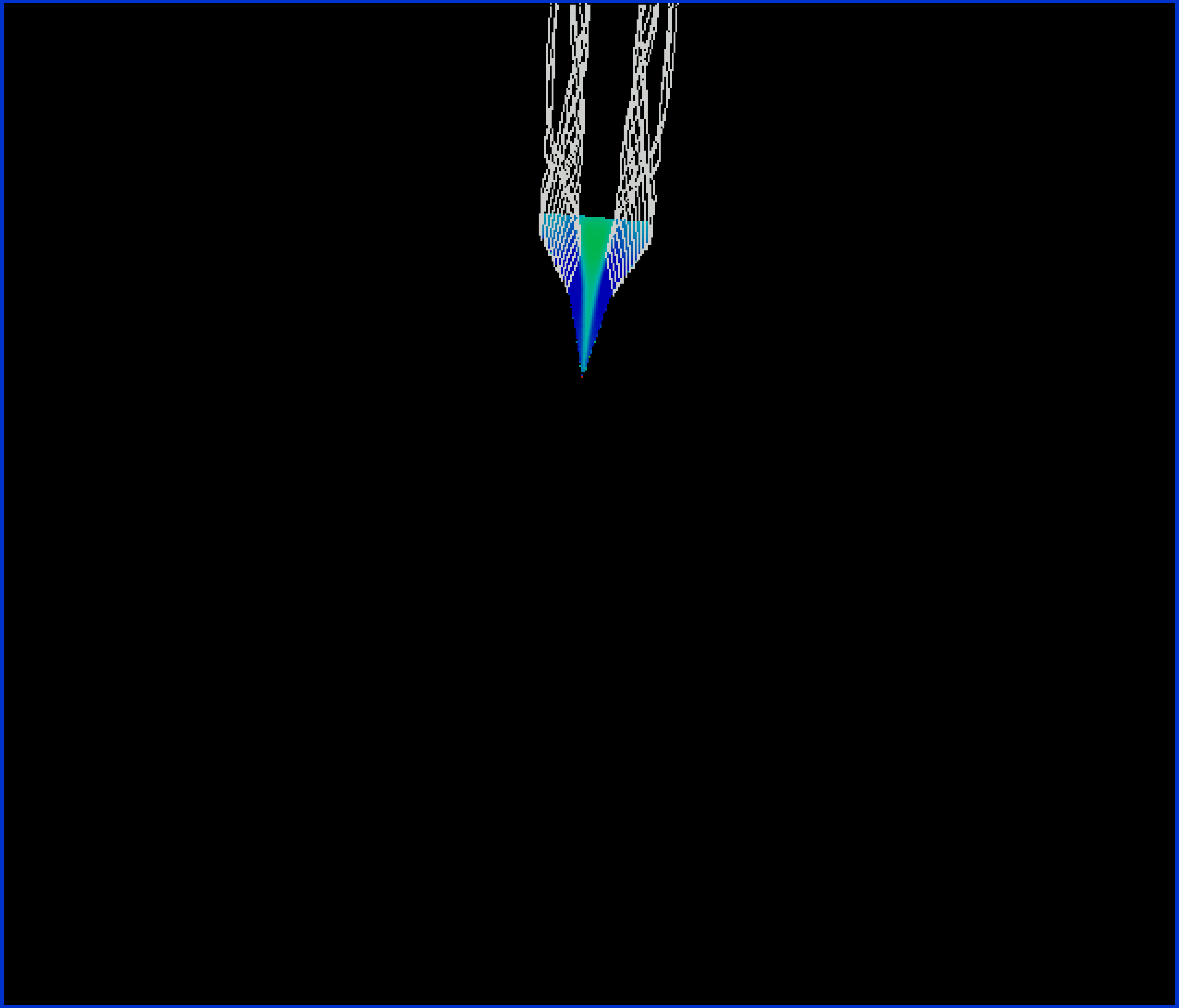
AMR on a Car



AMR on Car

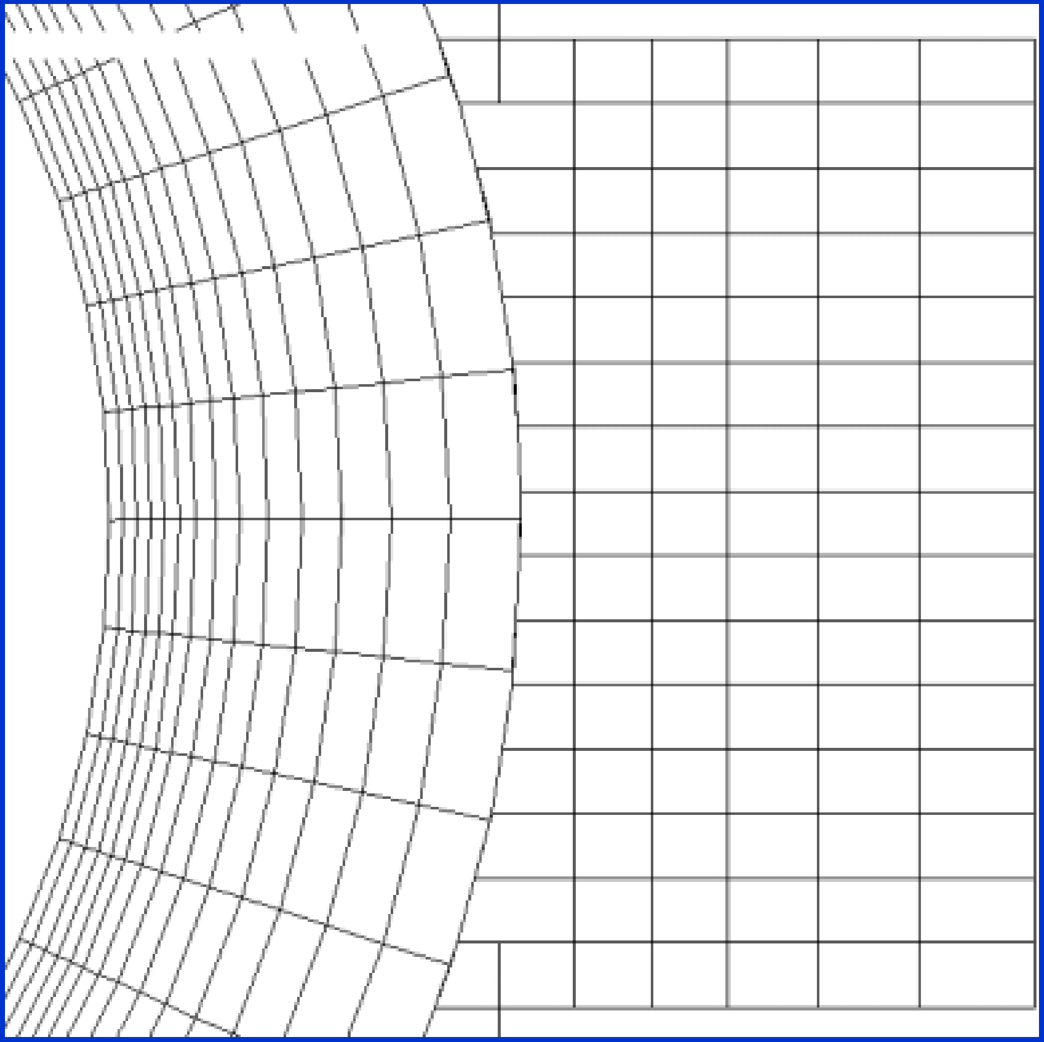


Paper Plane

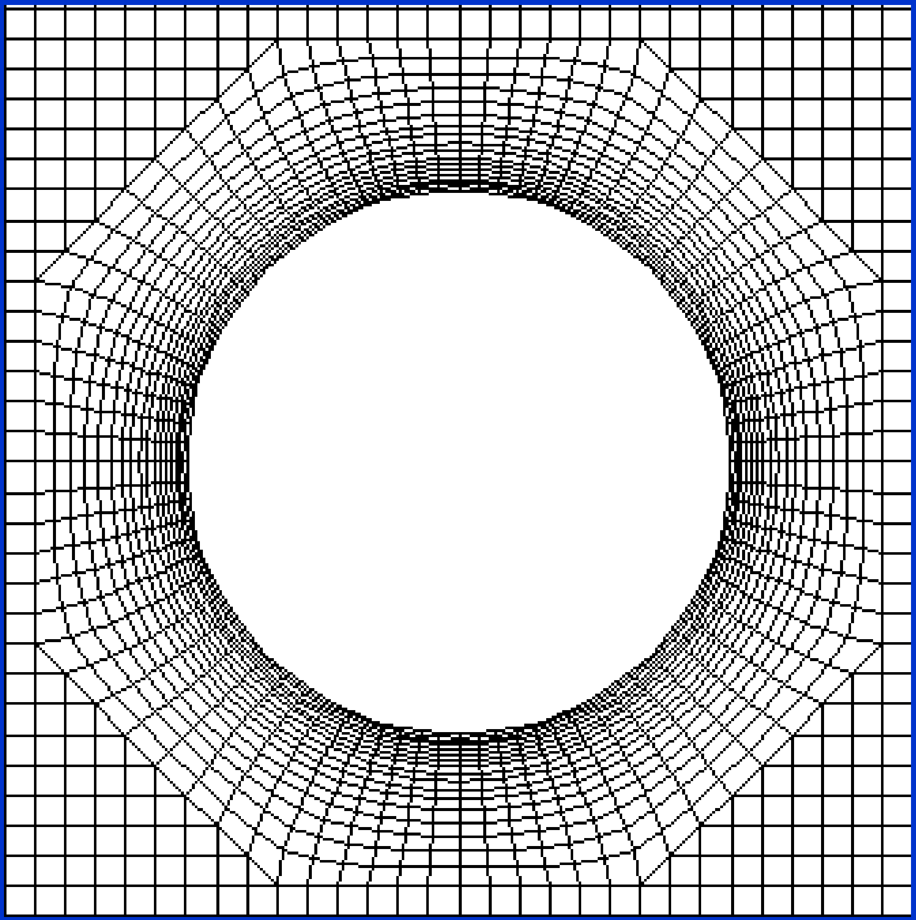


Cartesian/Structure Hybrid

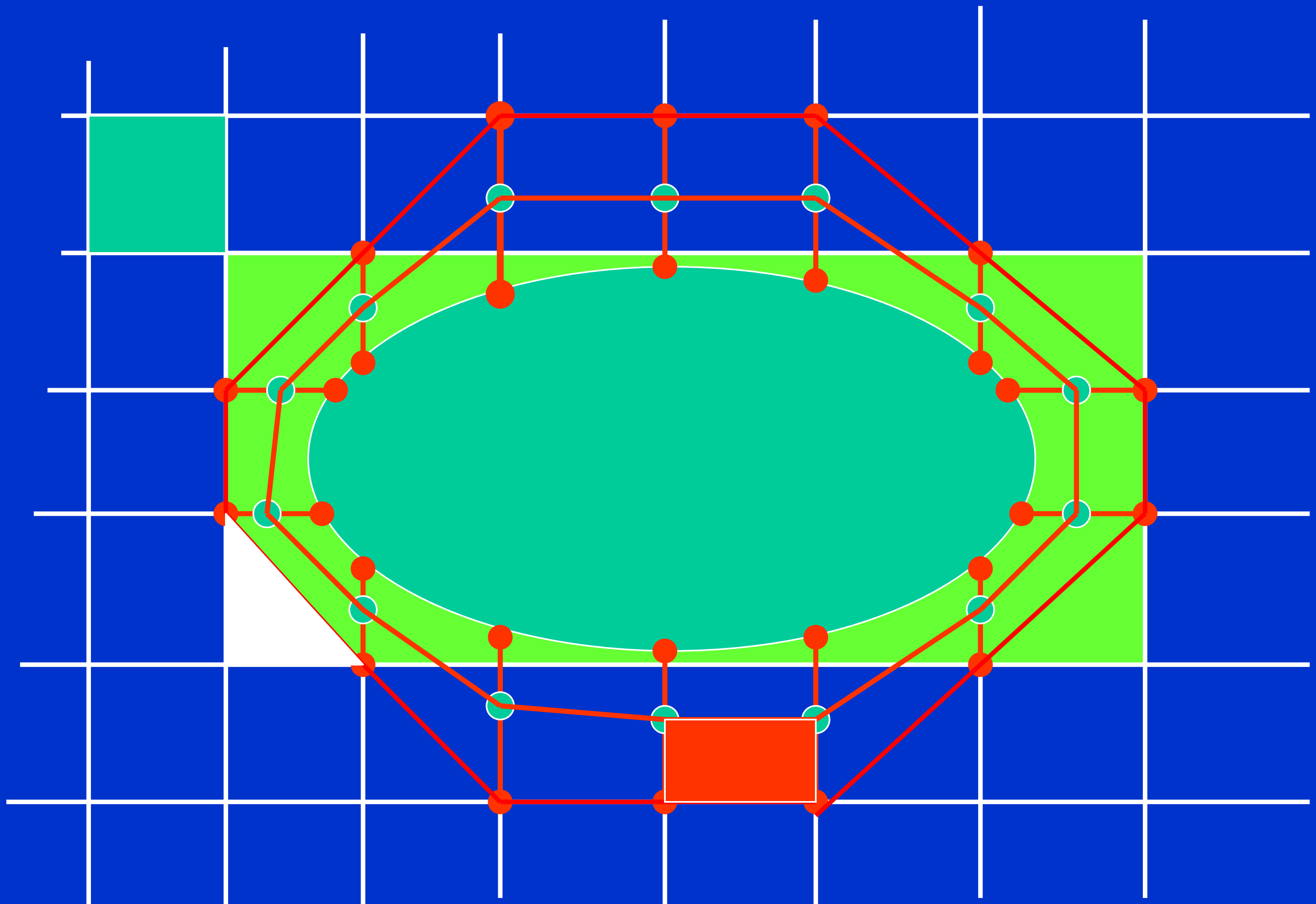
Cartesian/Structured Hybrid Grid



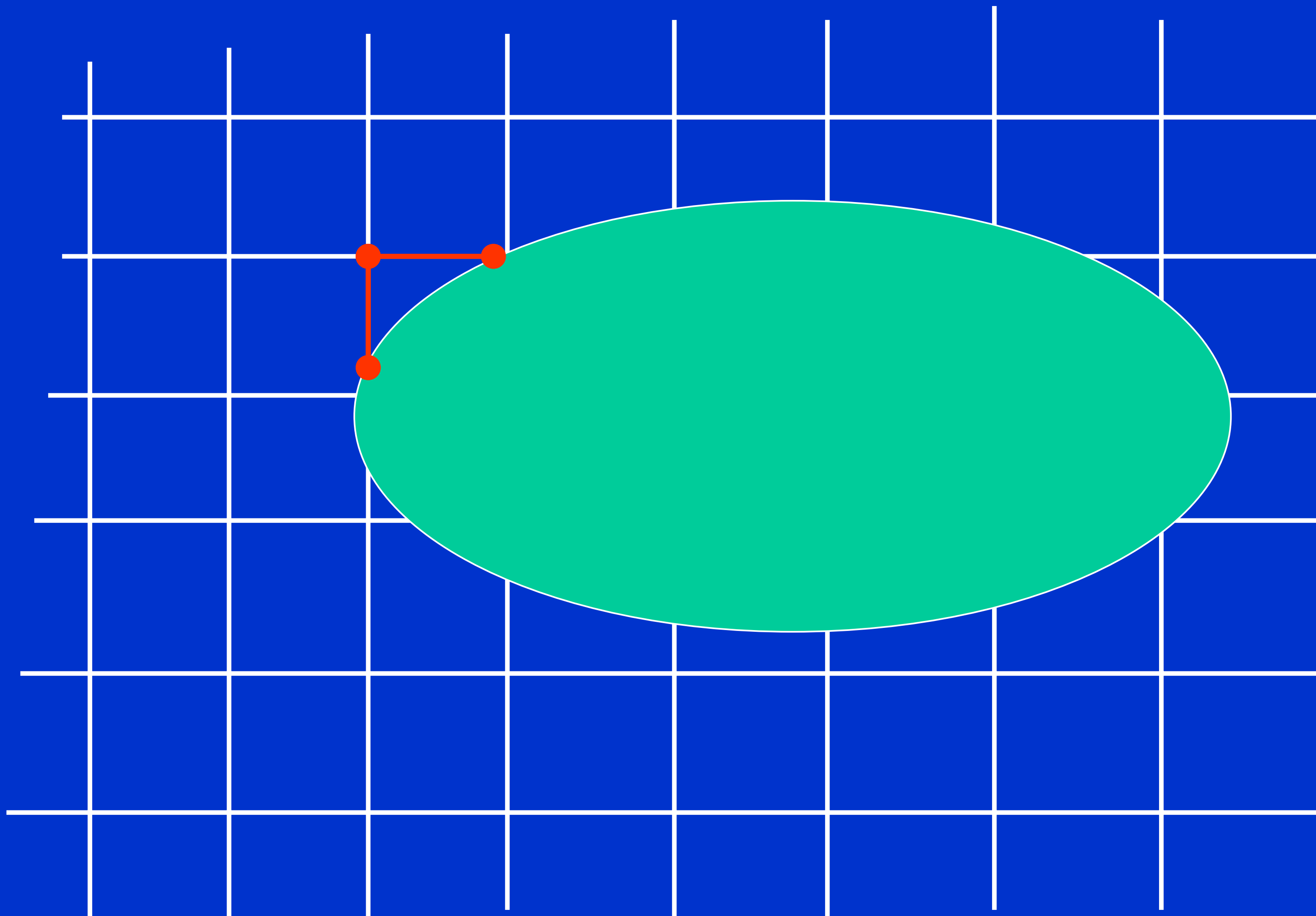
LBFCGM (Locally Boundary Fitted Cartesian Grid Method)



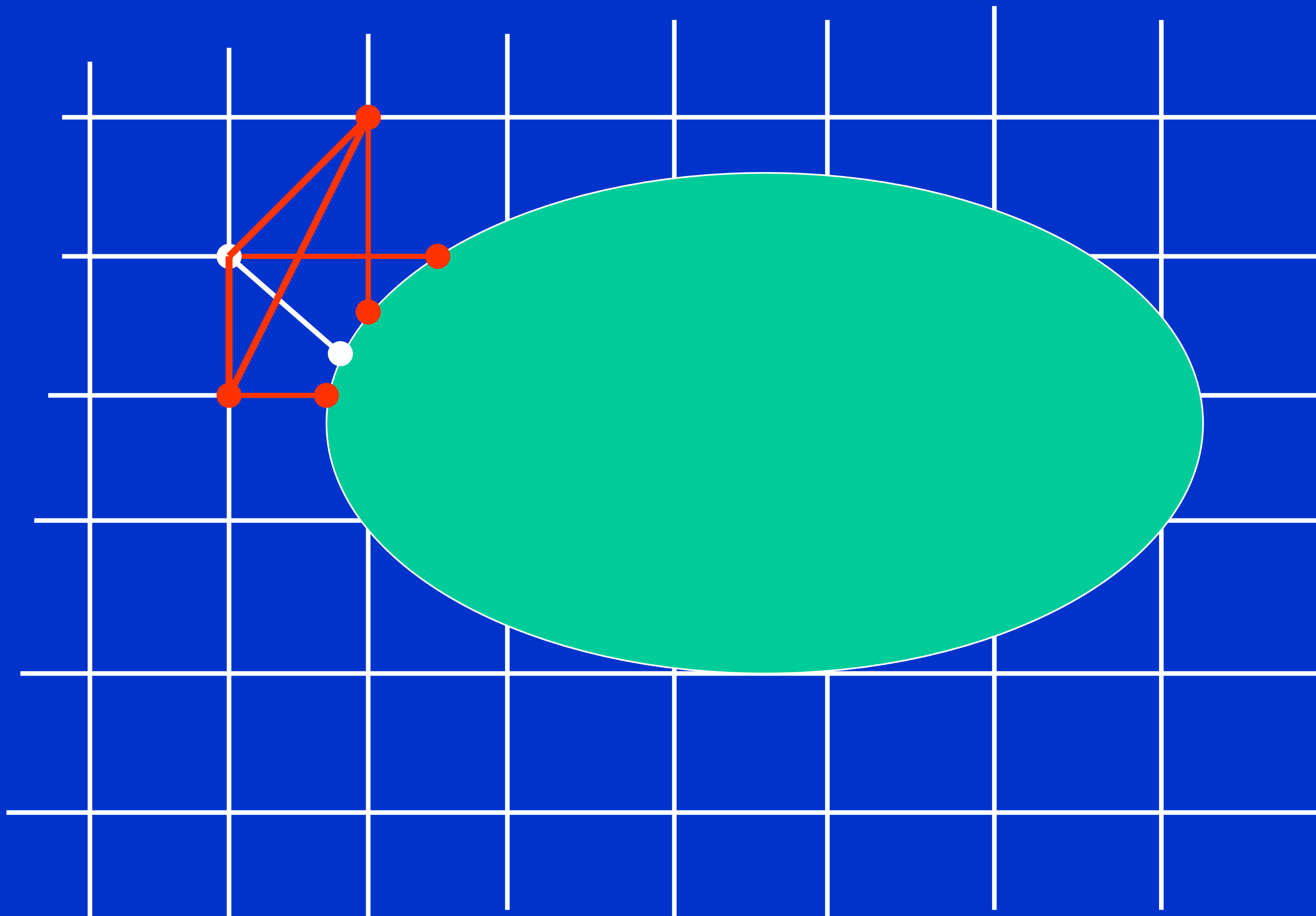
BFC generating based Cut Cell



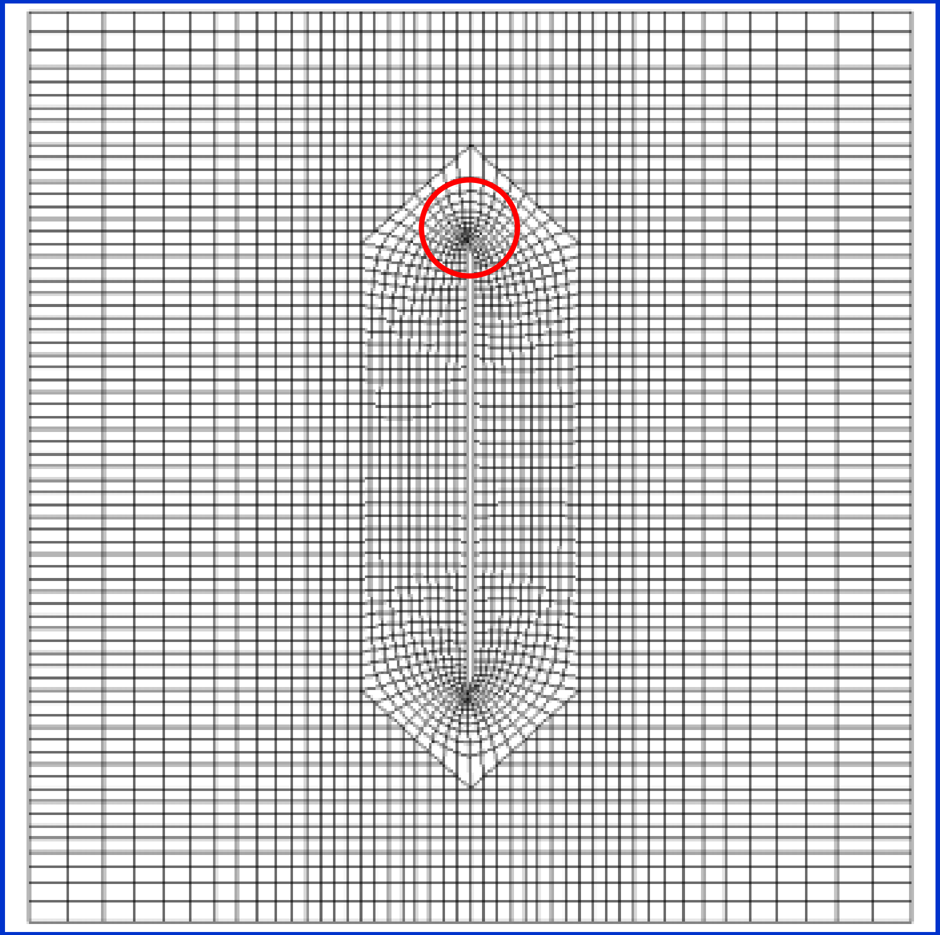
Some Special Treatment

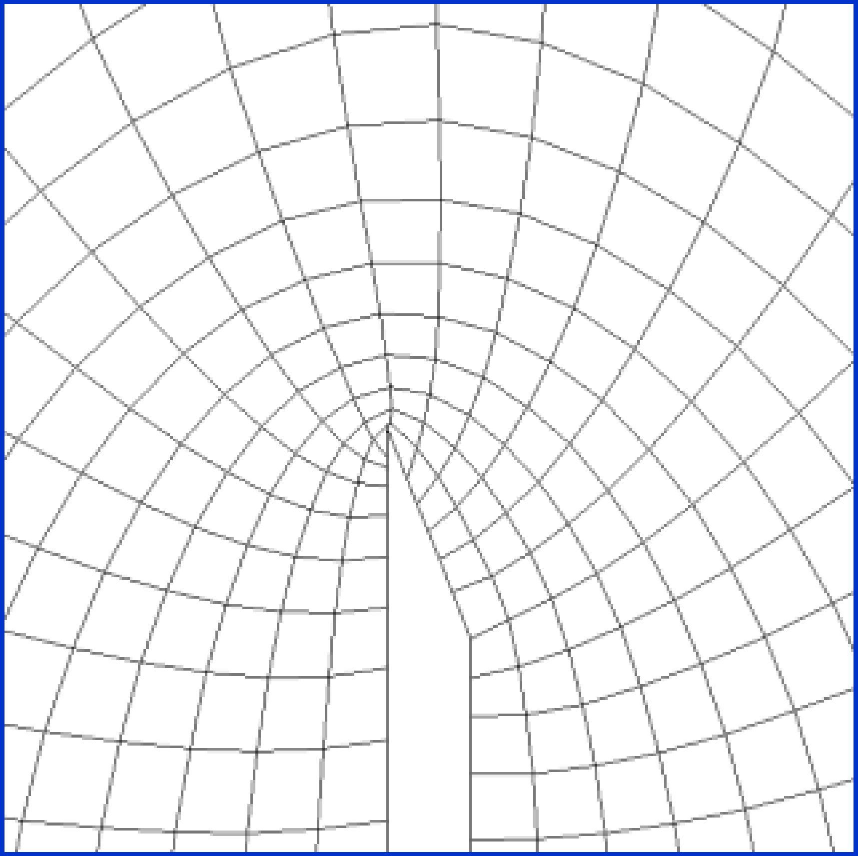


Special Treatment

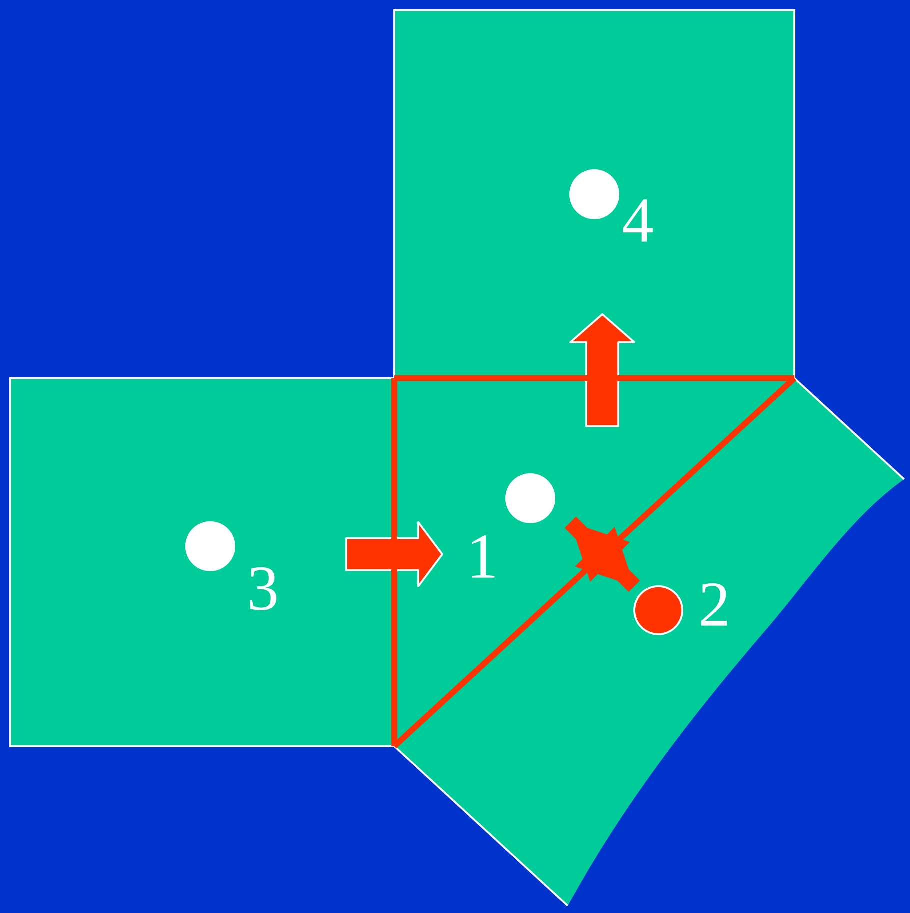


LBFCGM for Thin Body





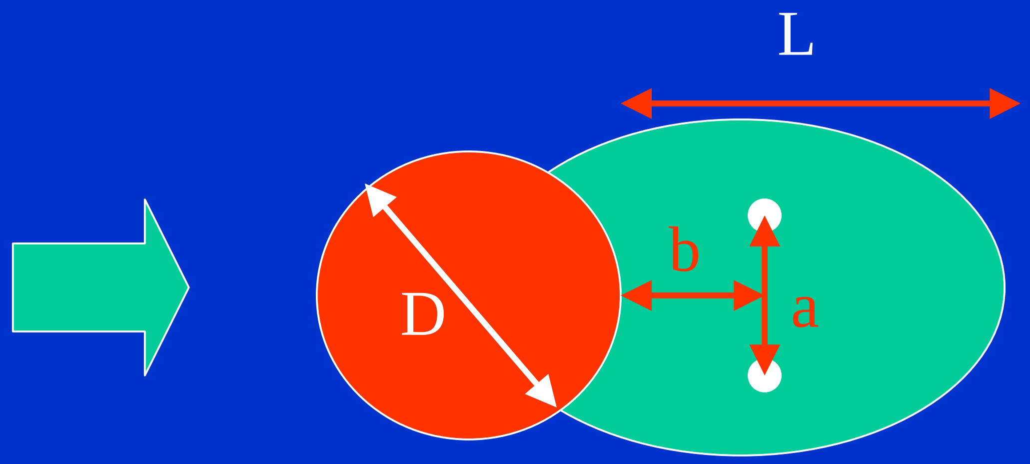
Treatment at connect cells



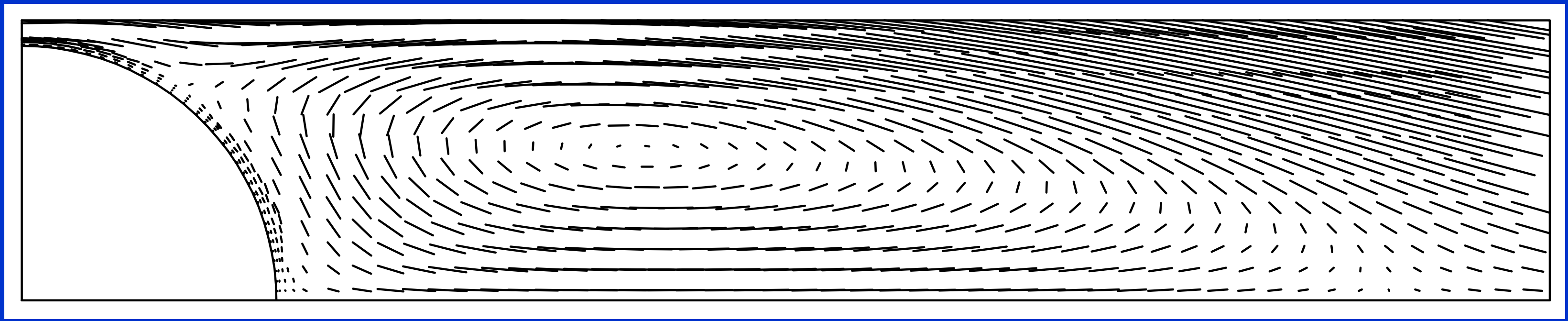
Numerical Results at Re=200

	C_D	C_L	St
Present Method	**1.34±0.04**	**±0.62**	**0.21**
Cell Merging Method	**1.31±0.05**	**±0.66**	**0.20**
Body Fitted Grid	**1.34±0.04**	**±0.65**	**0.19**
Roger et al.（1988）	**1.29±0.05**	**±0.75**	**0.16**
Rosenfield et al.（1991）	**1.31±0.04**	**±0.65**	**0.20**
Rosko （1954） exp.			**0.19**
Wille （1960） exp.	**1.30**		

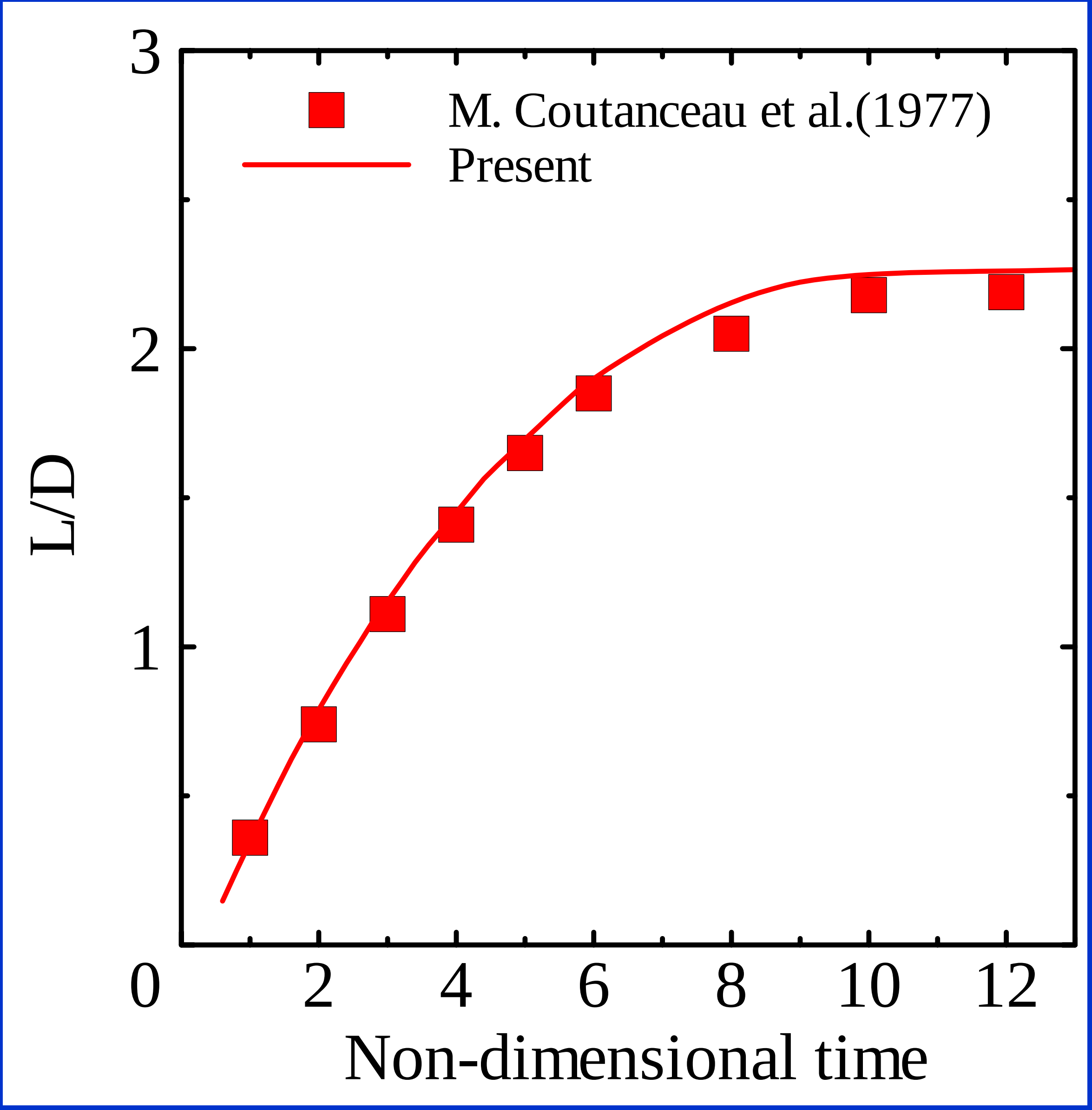
Early Stage of the Wake



Re=40 (T=12)

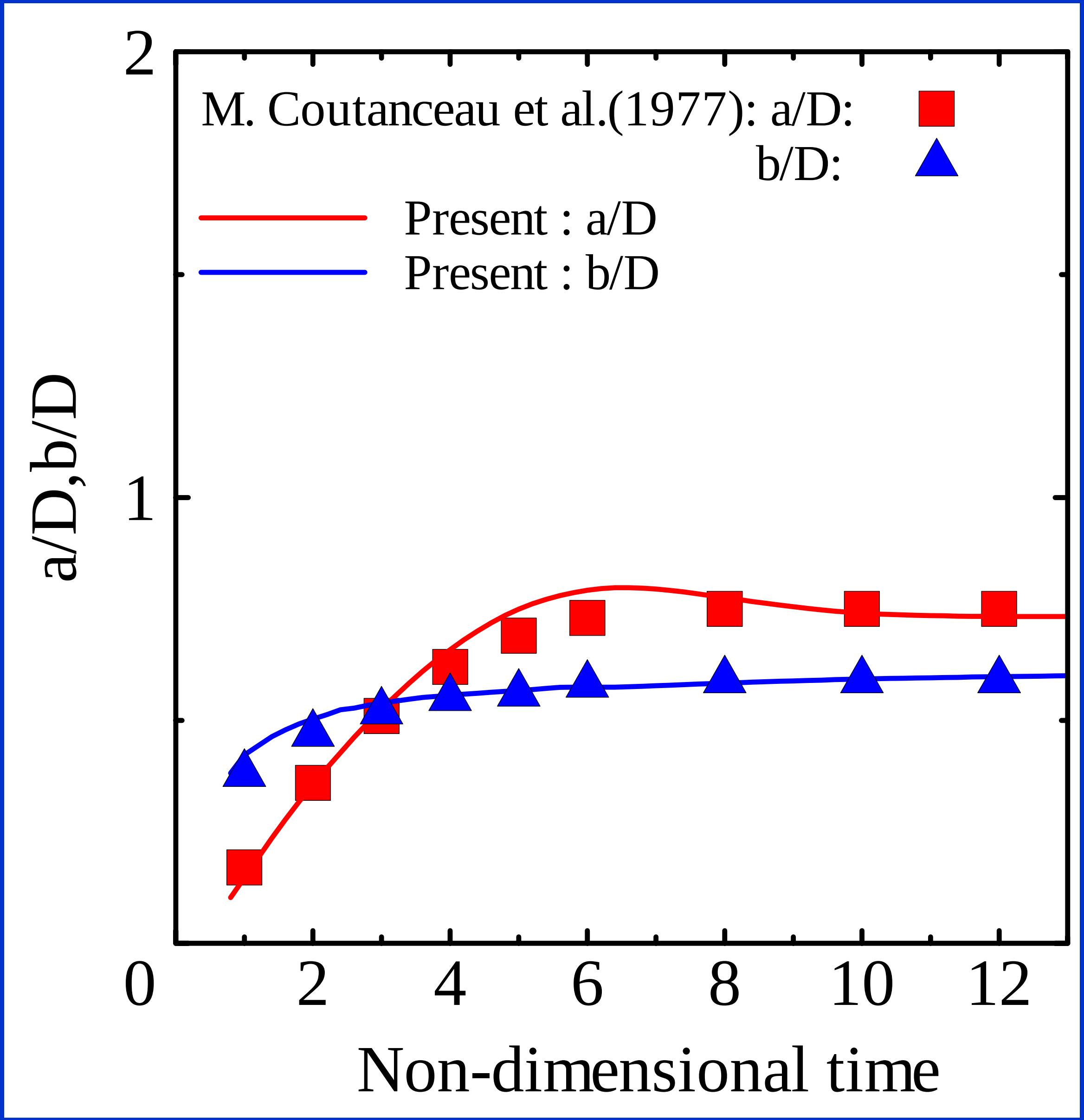


L/D Re=40



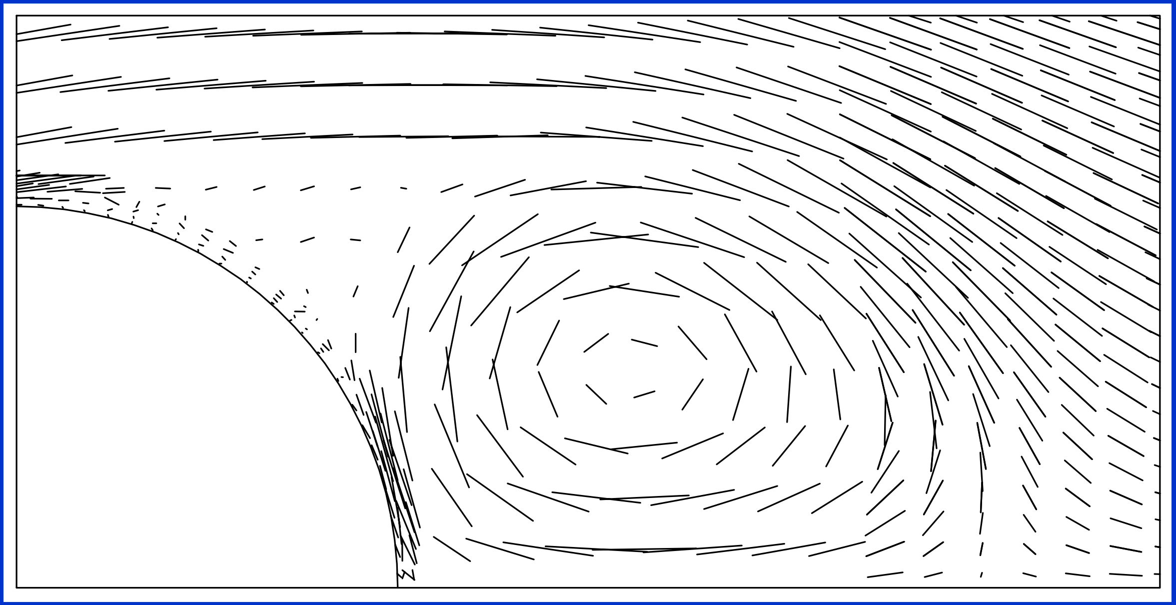
M. Coutanceau et al.(1977)
Present
L/D
Non-dimensional time
0
1
2
3
2
4
6
8
10
12

a/D,b/D Re=40

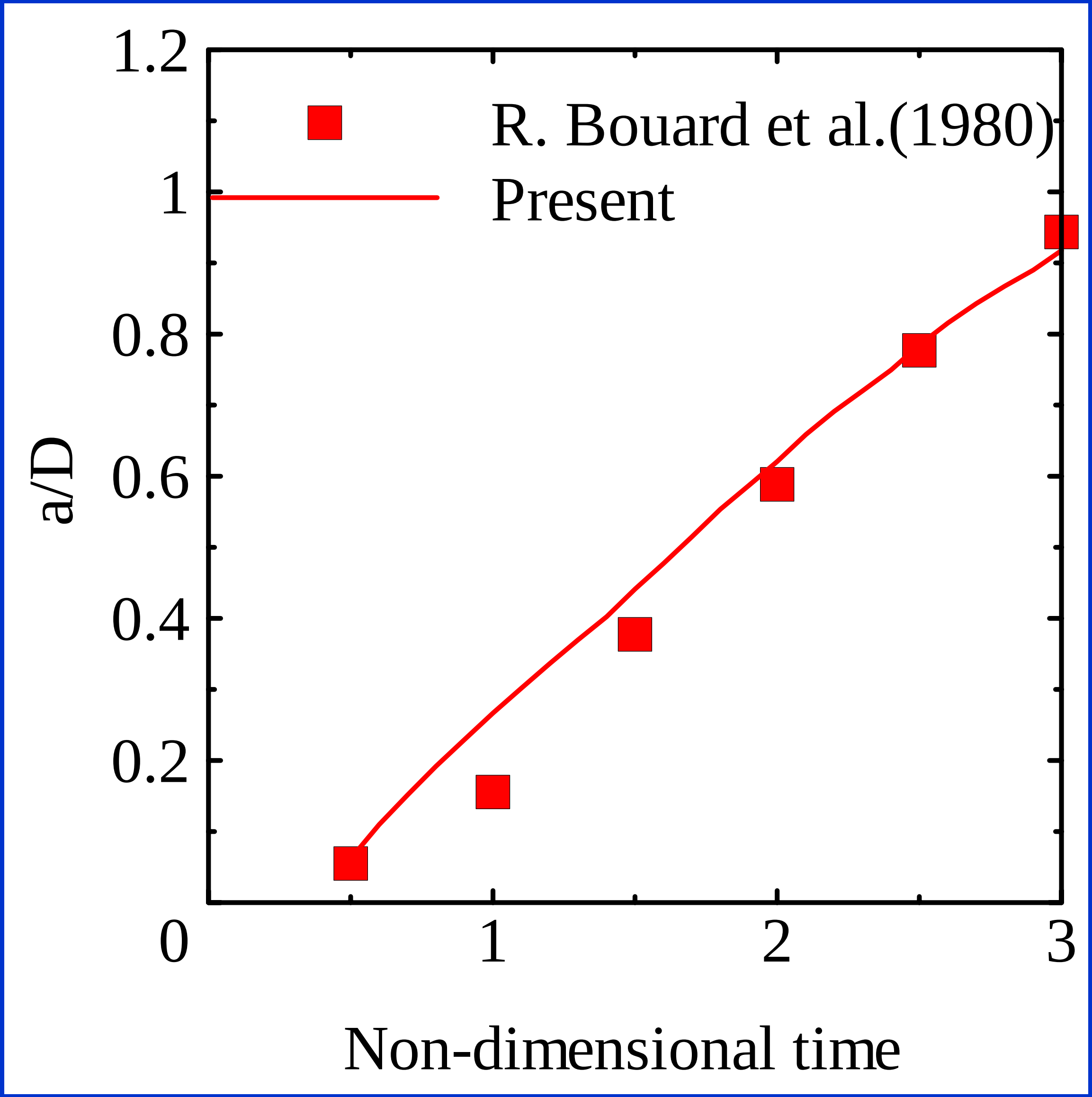


M. Coutanceau et al.(1977): a/D:
b/D:
Present : a/D
Present : b/D
a/D,b/D
0
1
2
2
4
6
8
10
12
Non-dimensional time

Re=3000 (T=2.5)

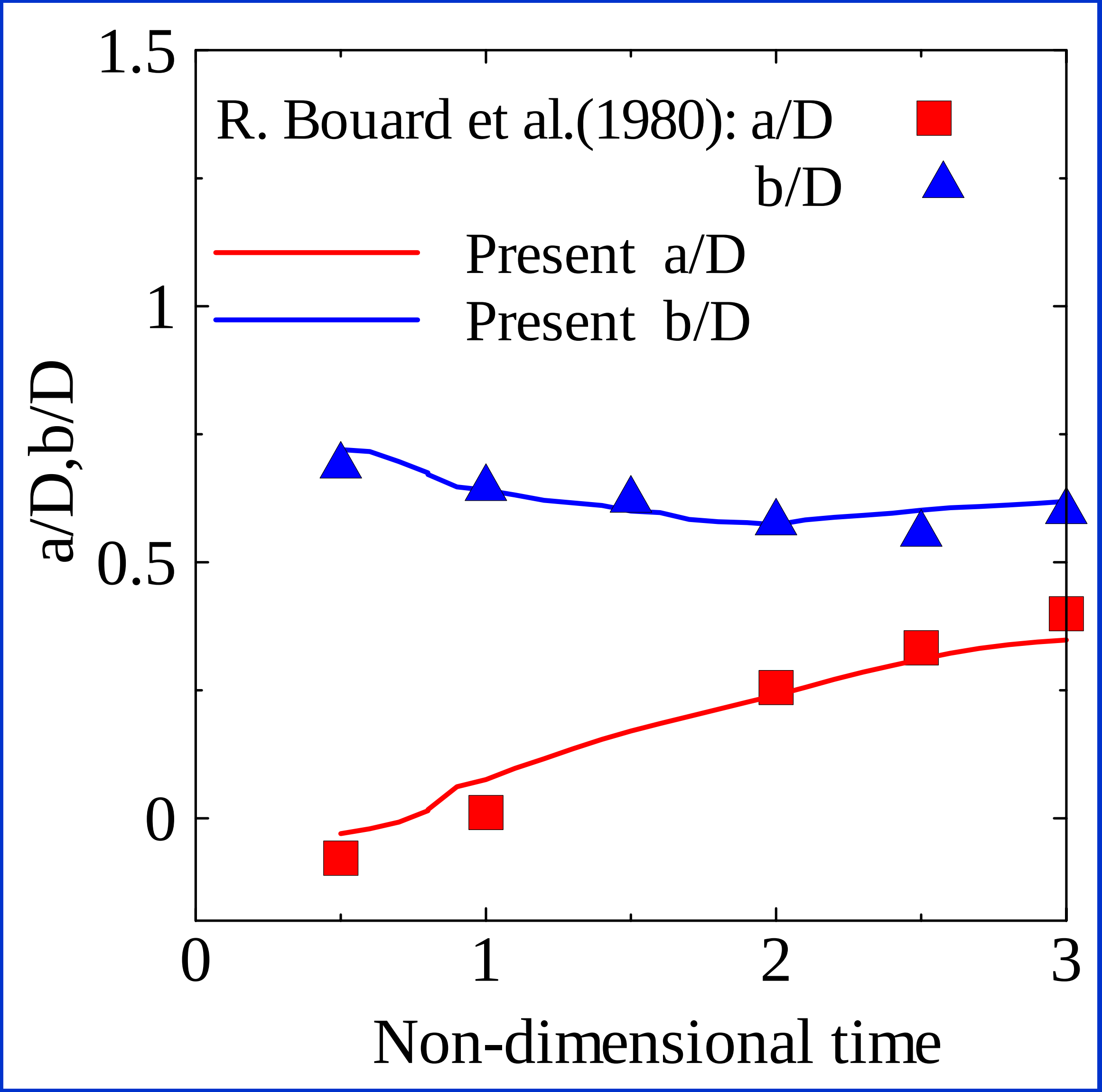


L/D Re=3000



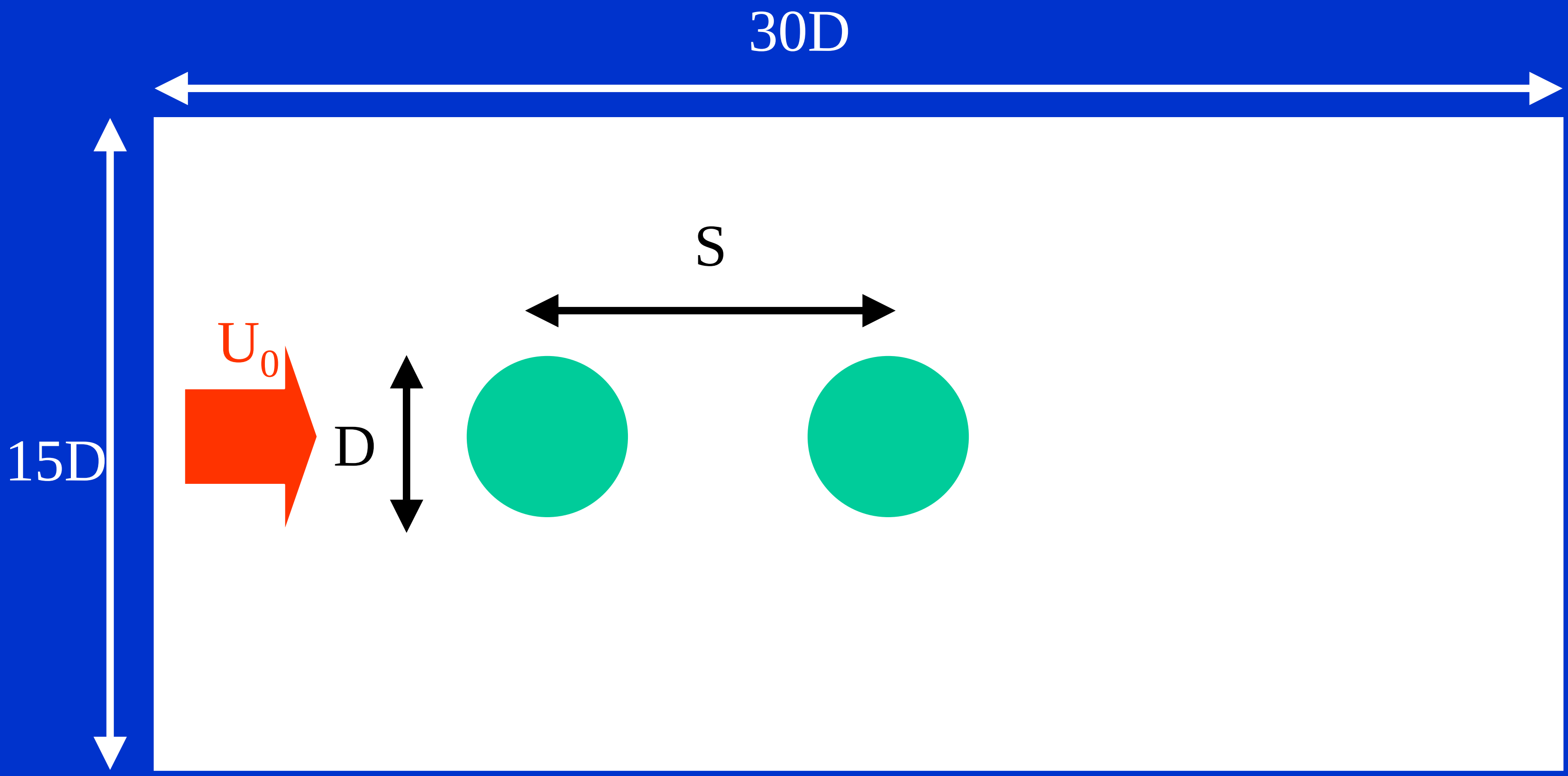
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
a/D
Non-dimensional time
R. Bouard et al.(1980)
Present

a/D,b/D Re=3000

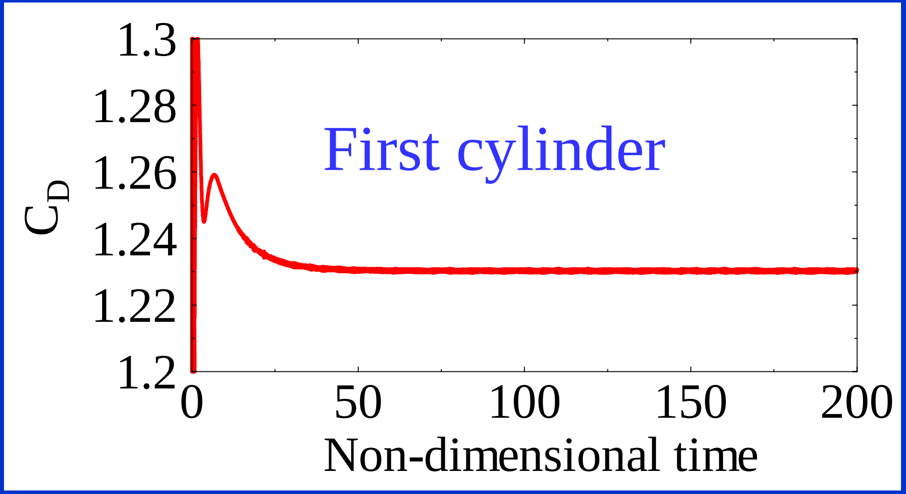


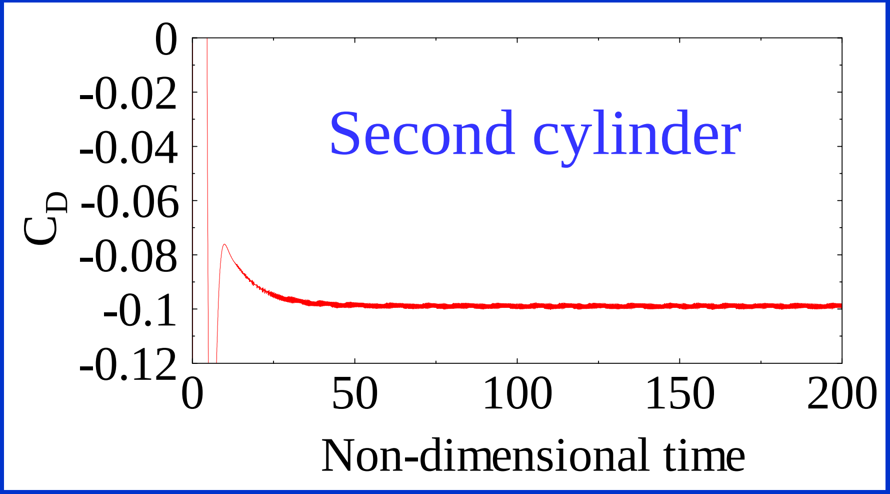
R. Bouard et al.(1980): a/D
b/D
Present a/D
Present b/D
1.5
1
0.5
0
0
1
2
3
a/D,b/D
Non-dimensional time

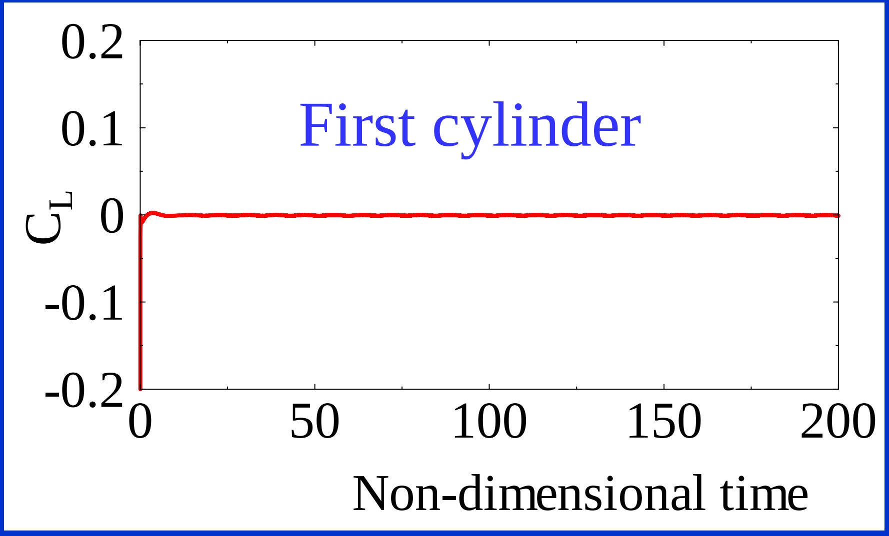
Flow around Two-Cylinders

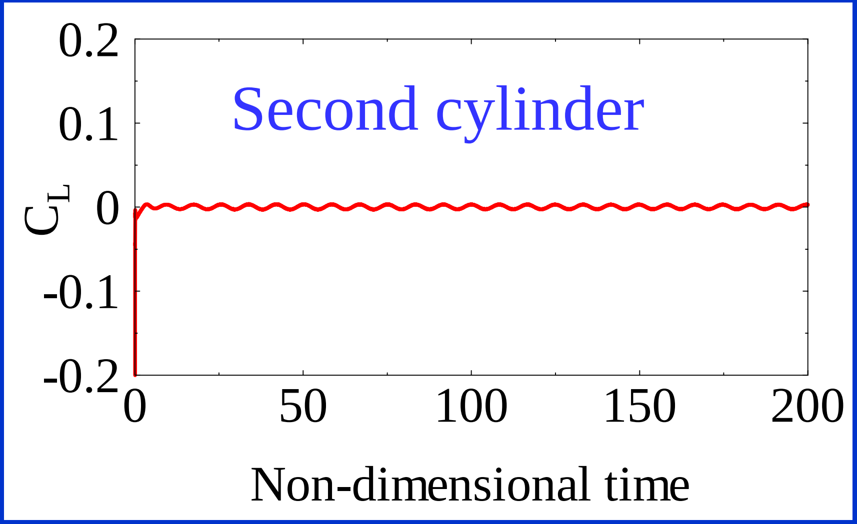


CD and CL (Re=100, S/D=2.5)

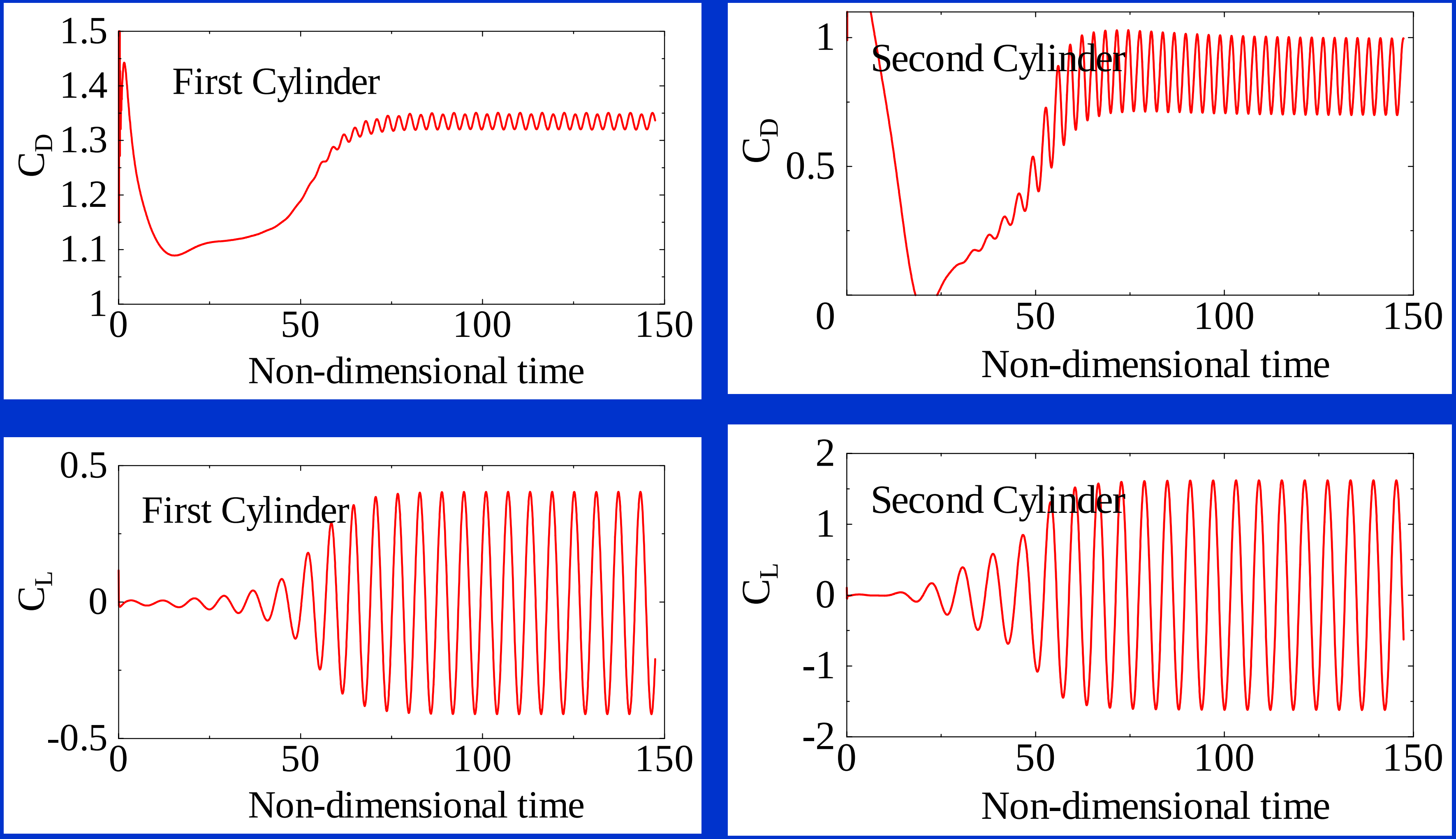








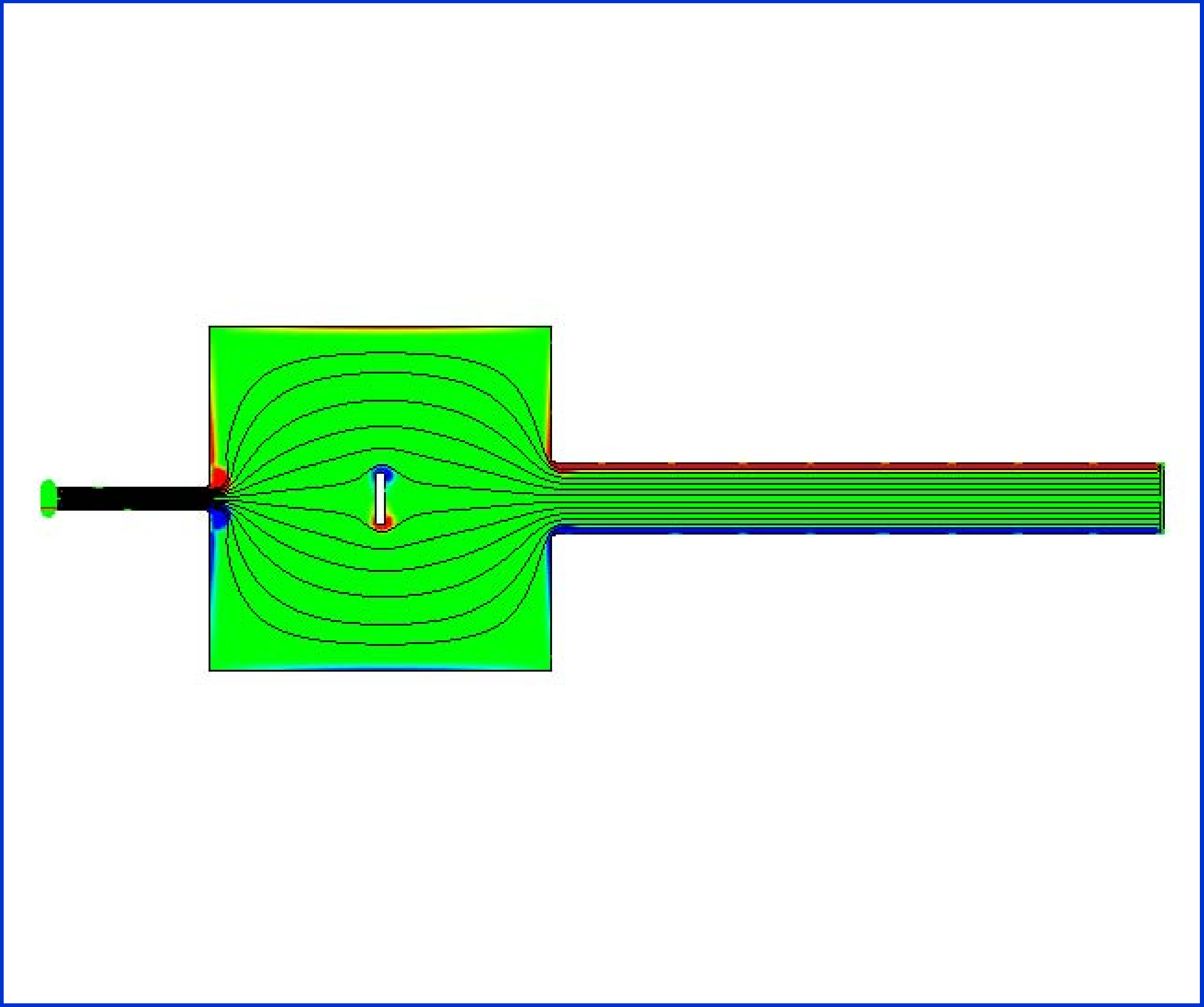
CD and CL (Re=100, S/D=5.5)



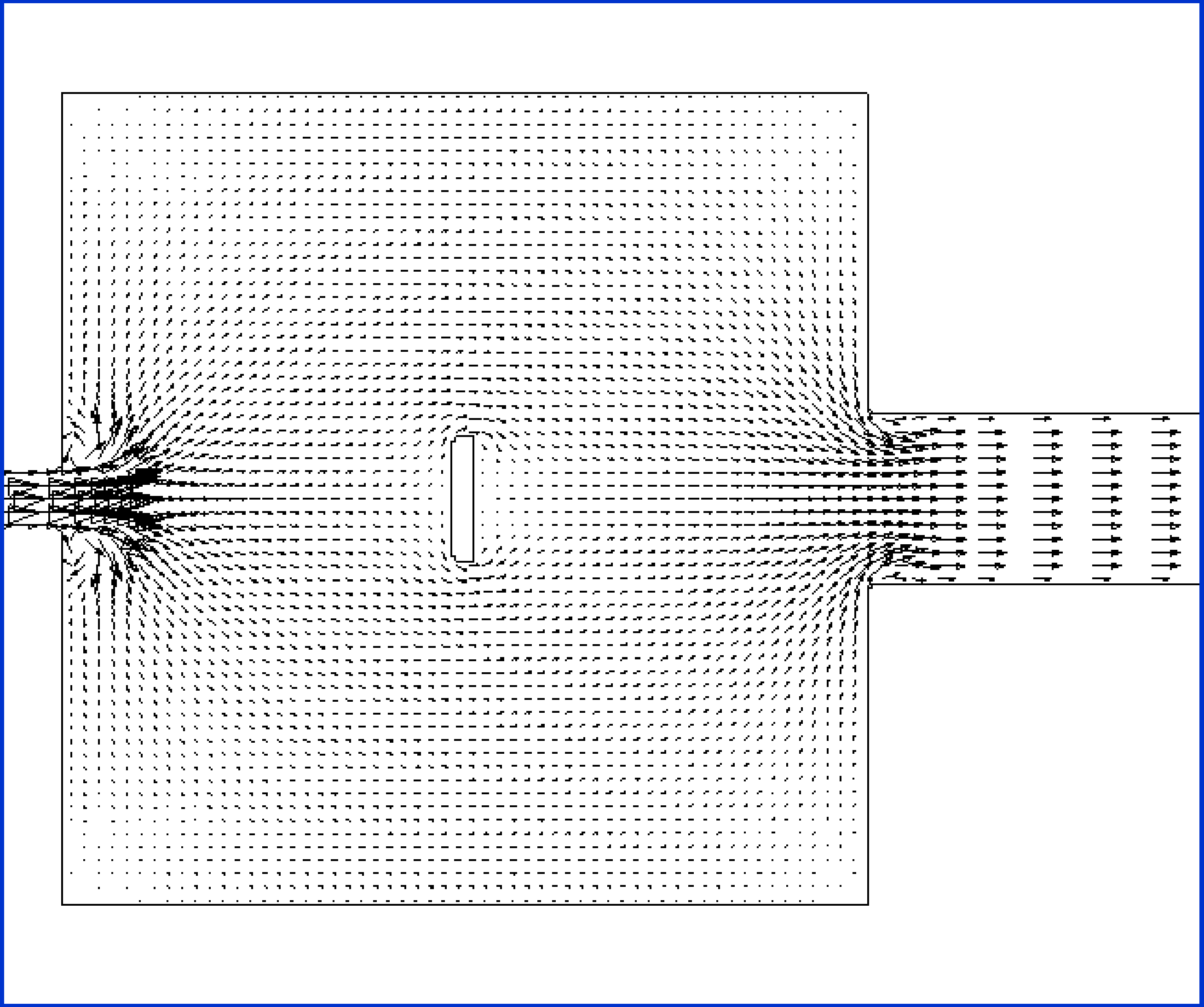
Comparison of results (Re=100)

S/D			First cylinder	Second cylinder
2.5	Present	C_D	1.230±0.001	-0.098±0.001
		C_L	0.000±0.001	0.000±0.003
		St	---	---
	S. Mittal et al.（1997）	C_D	1.271±0.0	-0.075±0.0
		C_L	0.000±0.0	0.000±0.0
		St	---	---
5.5	Present	C_D	1.334±0.014	0.849±0.150
		C_L	0.000±0.404	0.000±1.621
		St	0.165	0.165
	S. Mittal et al.（1997）	C_D	1.433±0.015	0.952±0.164
		C_L	0.000±0403	0.000±1.741
		St	0.168	0.168

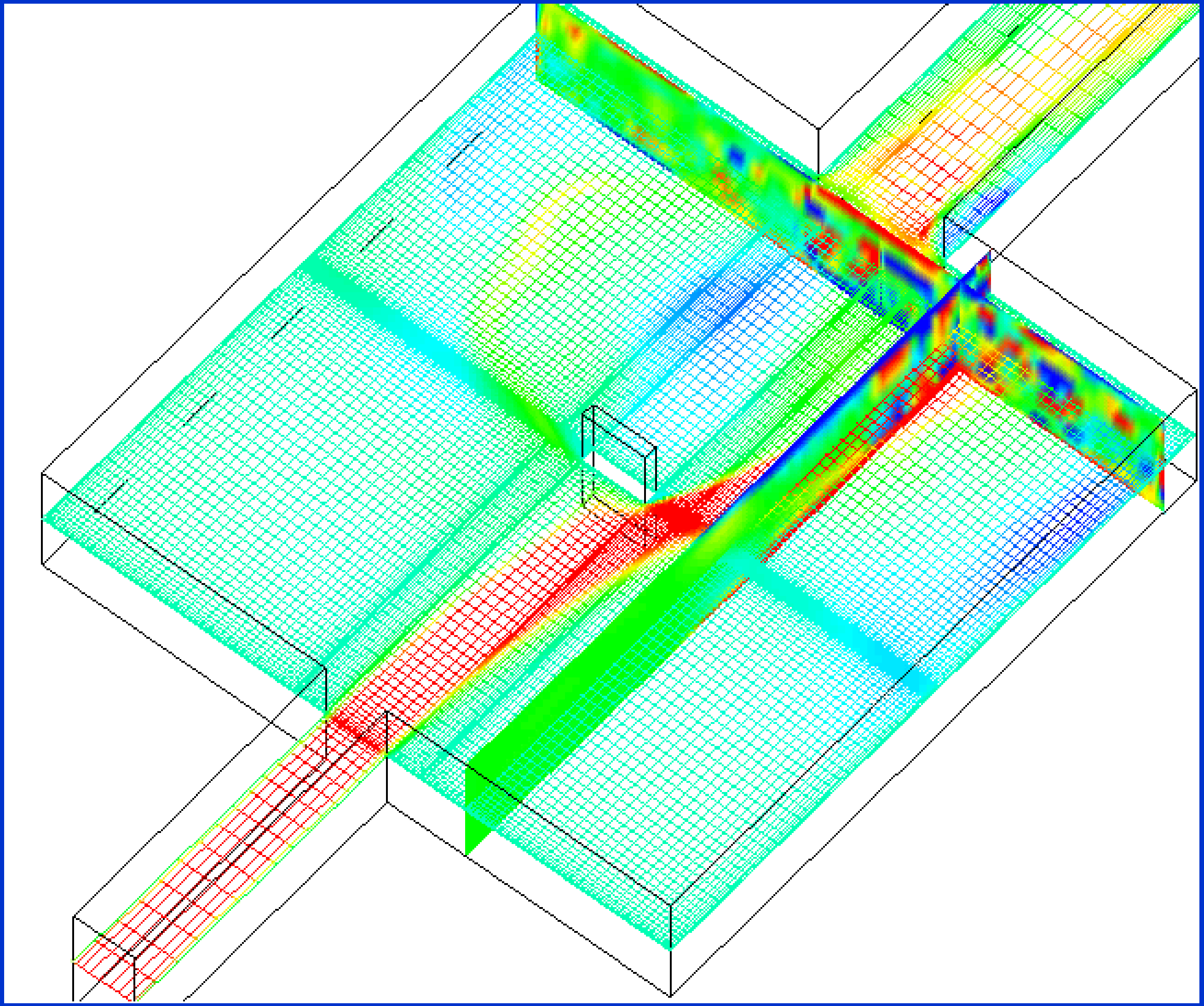
2D Inlet Flow of a Fluidic Flow Meter



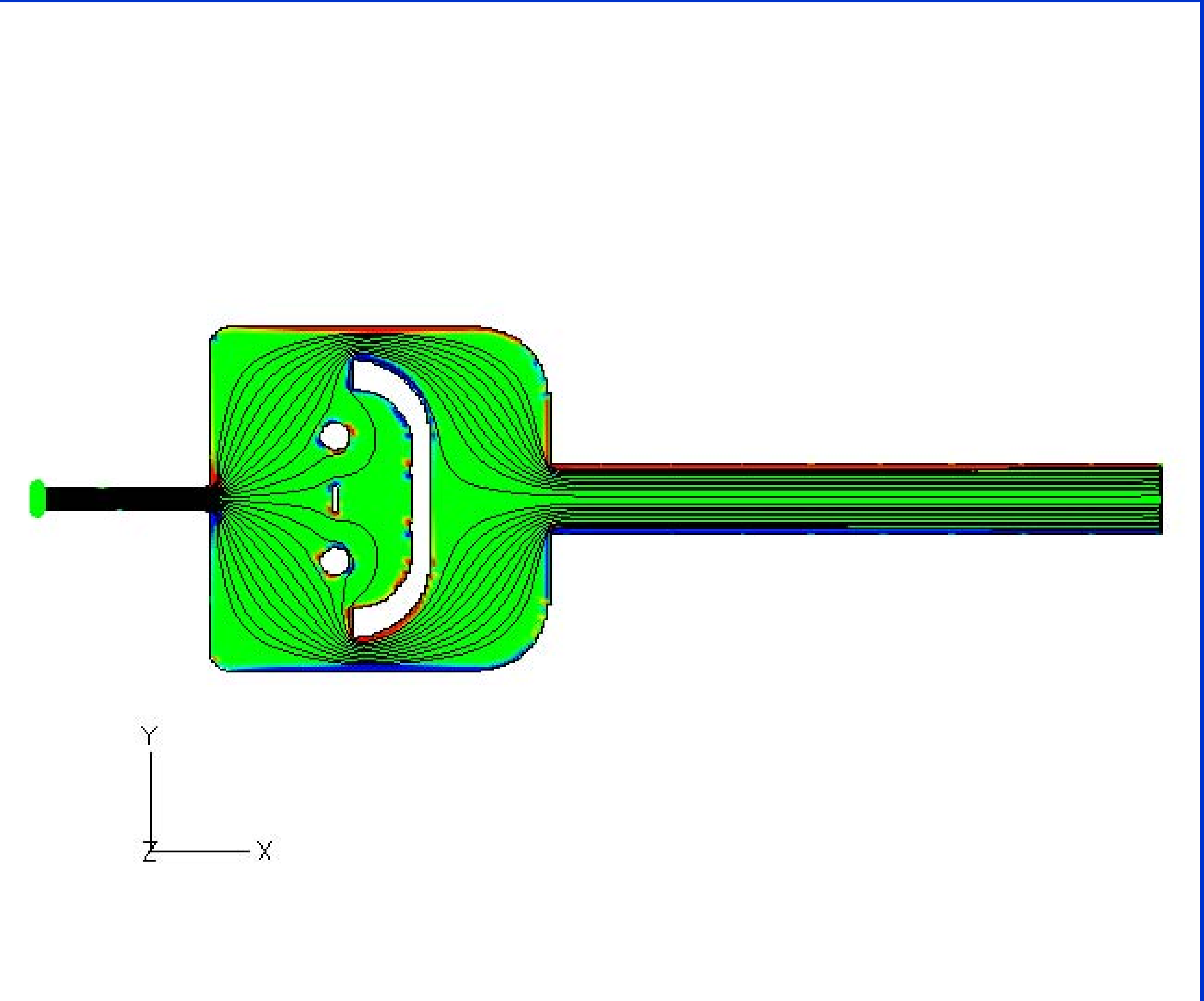
The Vectors



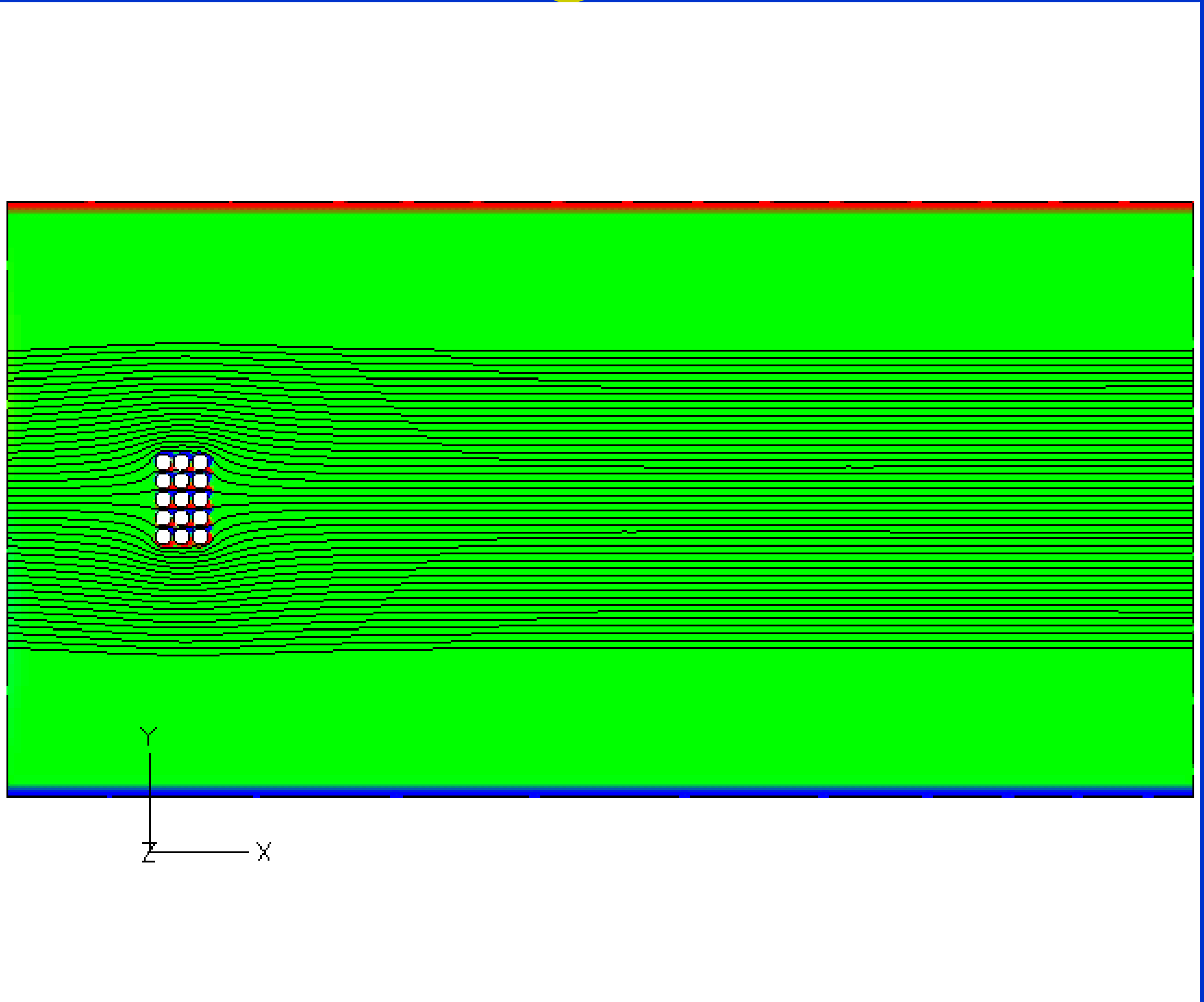
3D Inlet Flow of a Fluidic Flow Meter



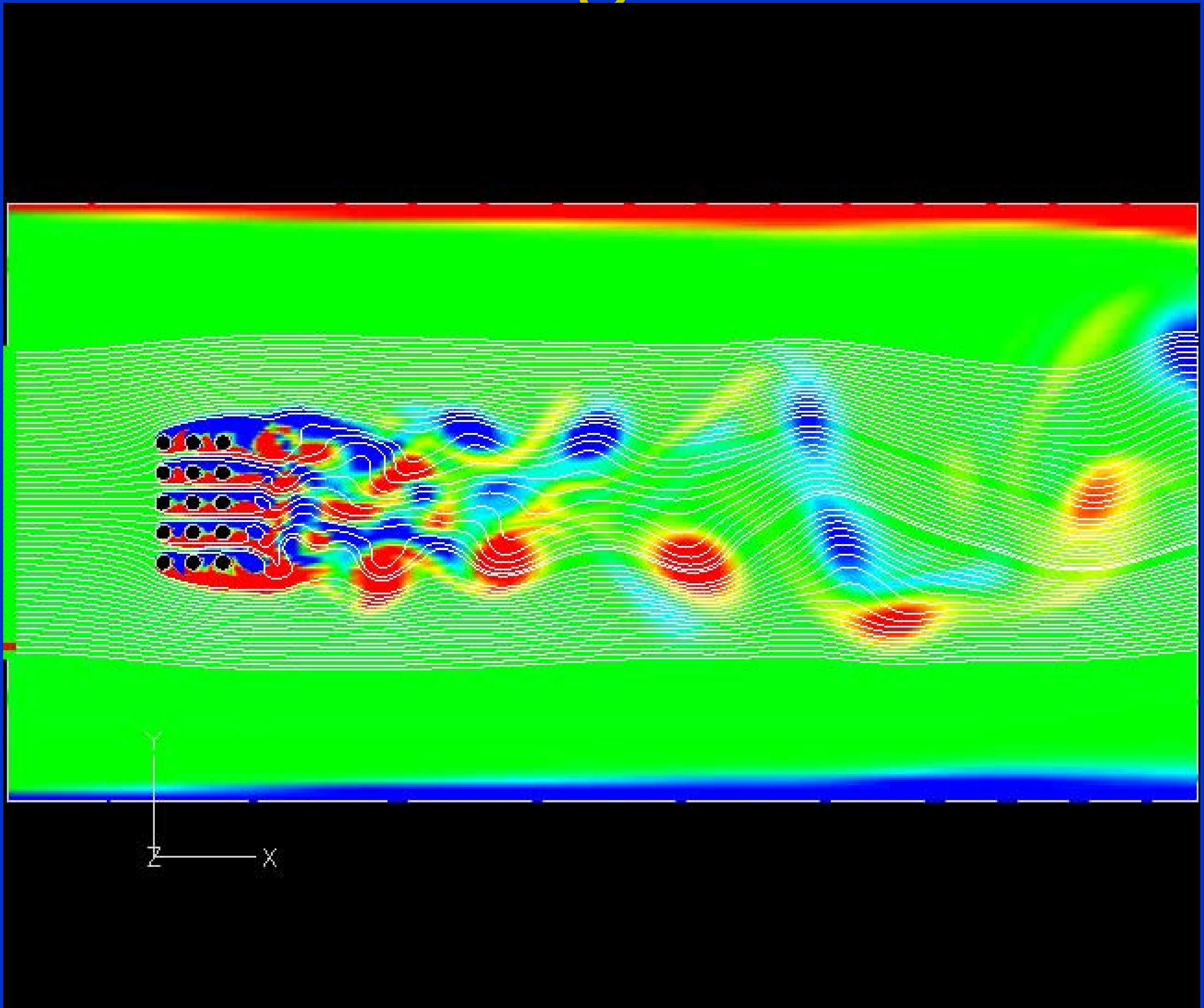
Inlet Flow of a Fluidic Flow Meter With Complex Geometry



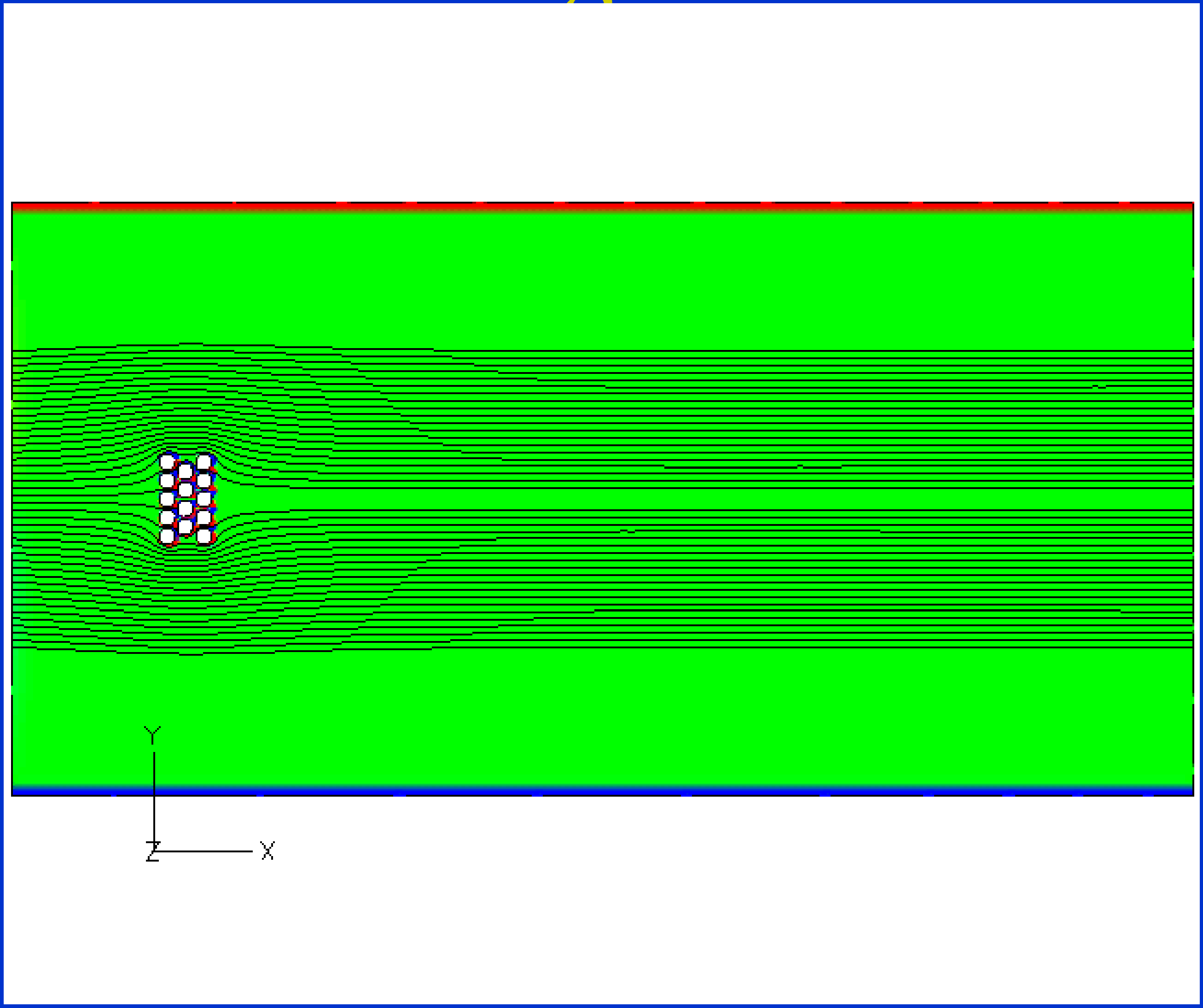
Tube banks with tandem arrangement



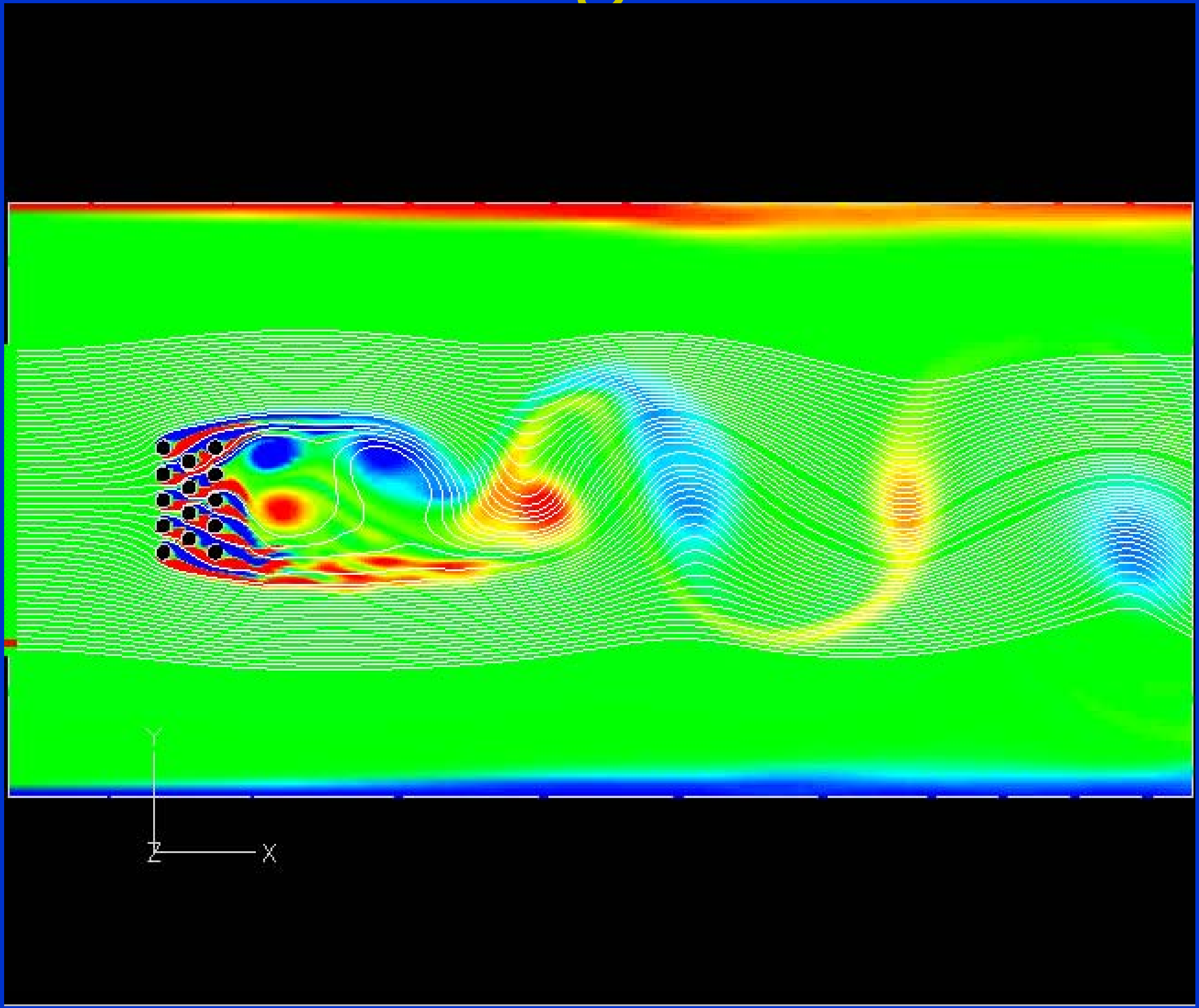
Tube banks with tandem arrangement



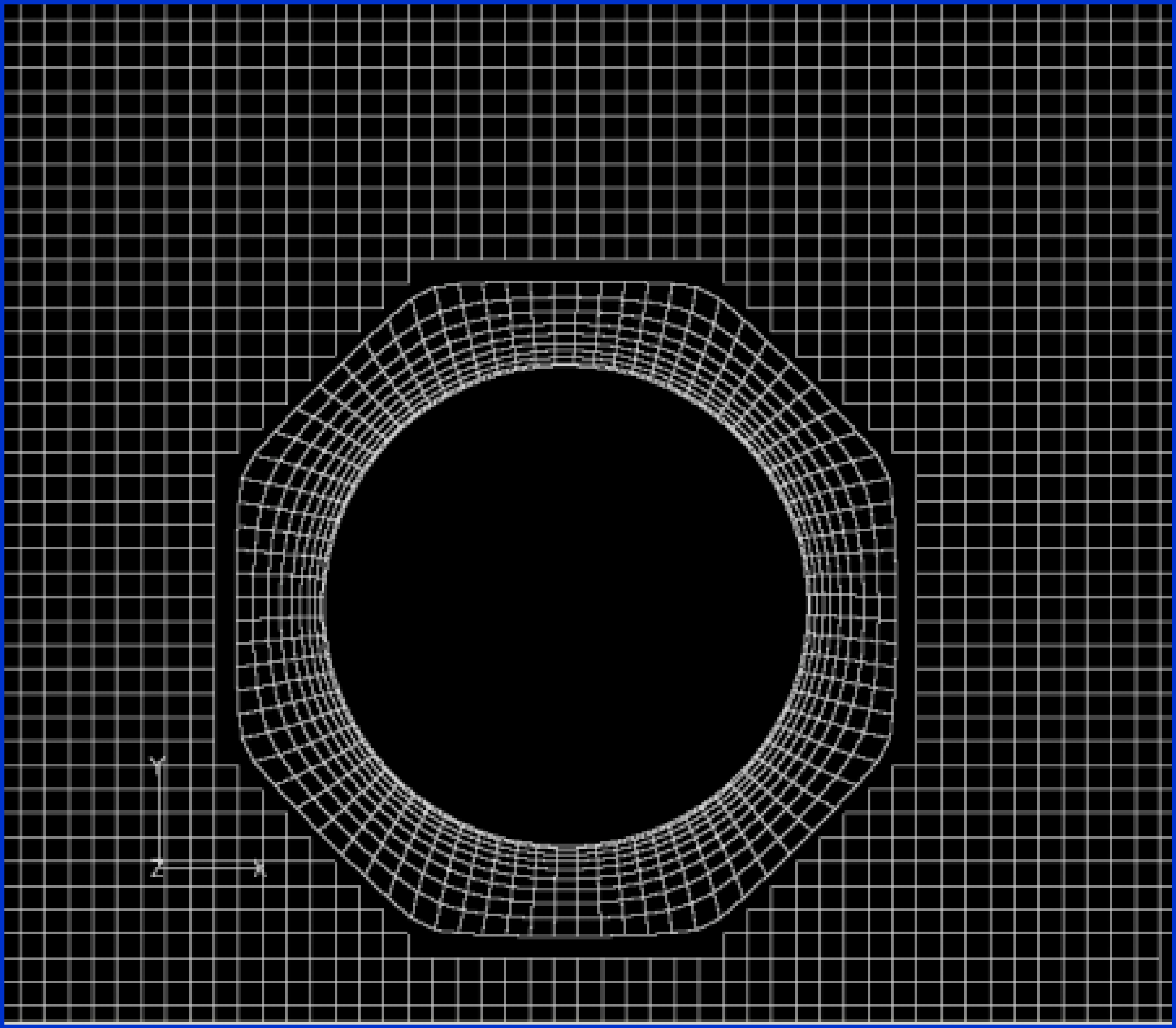
Tube banks with staggered arrangement



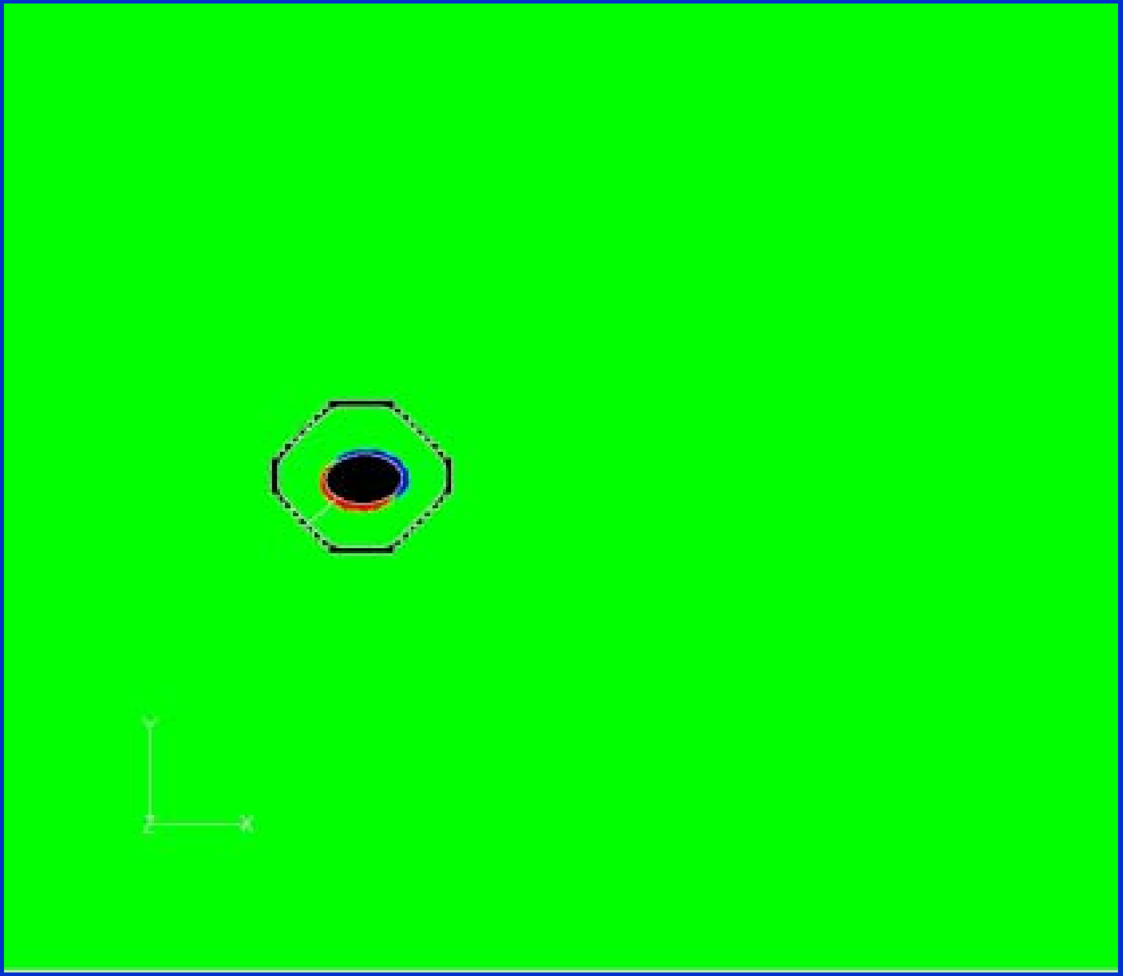
Tube banks with staggered arrangement



Moving Boundary Problem



Moving Boundary Problems



Thank You!