A preliminary plasma based flow control simulation study with 'Oracle3D'

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Outline

- **Oracle3D**
- **Plasma based flow control – What, why and how ?**
  - DBD actuators
  - Related Flow Phenomena
- **Numerical Modelling of DBD actuators**
  - Model, Mesh, Boundary conditions.
- **Results**
- **Concluding remarks**

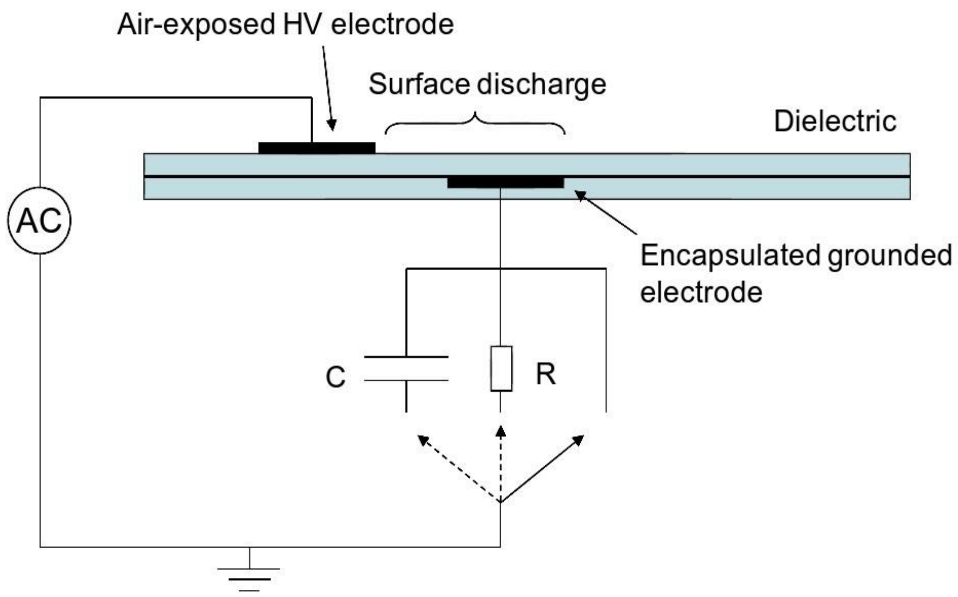
Oracle3D

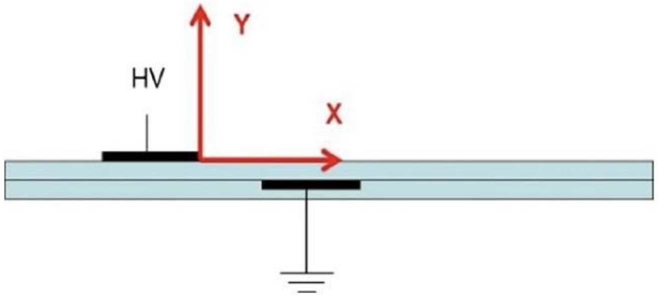
- In-house code -- EFD group, **Institut Pprime, Poitiers**
- 2D/3D, Incompressible Navier-Stokes DNS Solver
- Finite-Volume
- SIMPLE algorithm
- Multi-block geometry
- Parallelised with MPI
- Extensively validated and published

Near Future Objectives

- Three species plasma model
- All speed flow solver
- Large Eddy Simulation (LES)

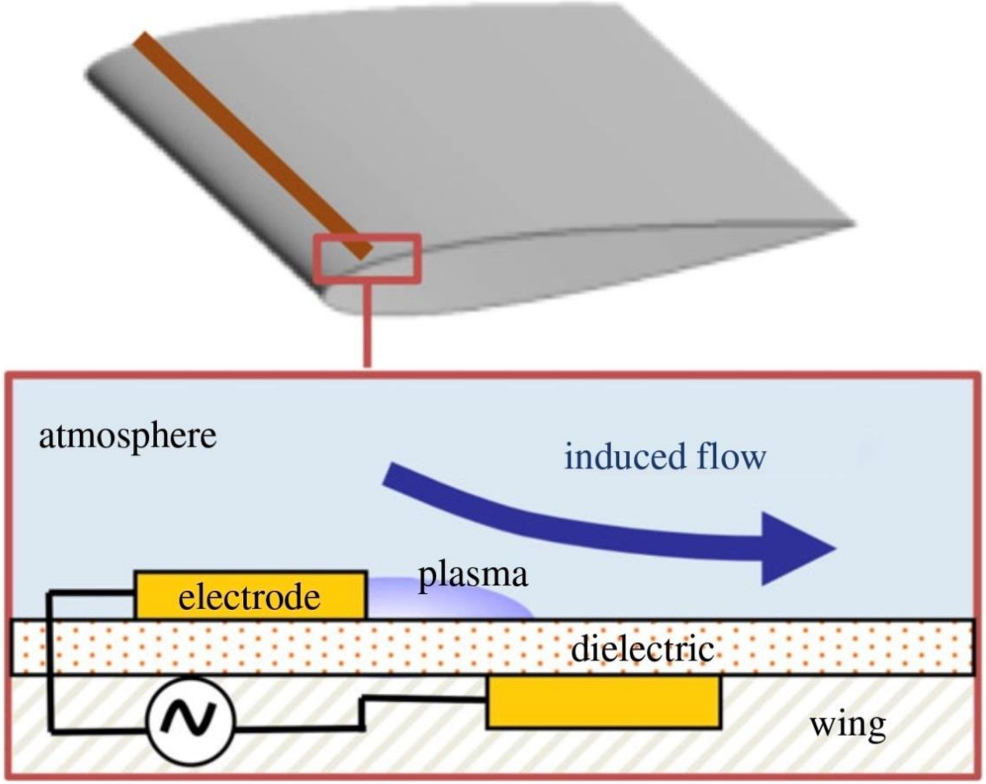
Dielectric Barrier Discharge (DBD) Plasma Actuator





Courtesy : N. Benard et al. (2014), Exp. Fluids

Plasma Based Aerodynamic Flow Control



Courtesy : Kozo Fujii (2013), Phil. Trans. R. Soc. A

Plasma Based Aerodynamic Flow Control

Courtesy : P. Audier , EFD group, Institut Pprime

Why DBD plasma actuators for flow control ?

- Simplicity of implementation
- Small, inexpensive, no moving parts, low mass
- Fast response
- Efficient force production (Normal & Tangential)
- Moderate cost of energy input
- Desirable performance at atmospheric conditions
- Complex unsteady flow actuation etc.

Numerical modelling of DBD actuators

- The Suzen-Huang body force model
- Conditions for our simulations
- Input parameters

The Suzen-Huang model

(Ref. Suzen-Huang , AIAA, 2005)

$$\mathbf{Electric}\ \boldsymbol{Potential} = \Phi + \varphi$$

Assumptions

A1. **Weakly ionized gas**

A2. λ_D **is small**

A3. ρ_c is not large

- Φ = potential due to external electric field

$$\boxed{\nabla.(\varepsilon_r \nabla \Phi\ ) = 0}$$

- φ = **potential due to net charge density in plasma**

$$\nabla.(\varepsilon_r \nabla\ \varphi) = -({}^{\rho_c}/_{\varepsilon_0})$$

$$\varphi = (-\frac{\rho_c\,\lambda_D^2}{\varepsilon_0})$$

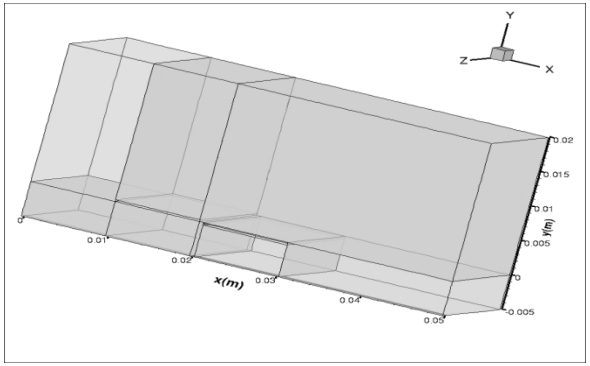
$$\boxed{\nabla.(\varepsilon_r \nabla\ \rho_c\ ) = {}^{\rho_c}/_{\lambda_D^2}}$$

Here - ε_r = relative permittivity of the medium

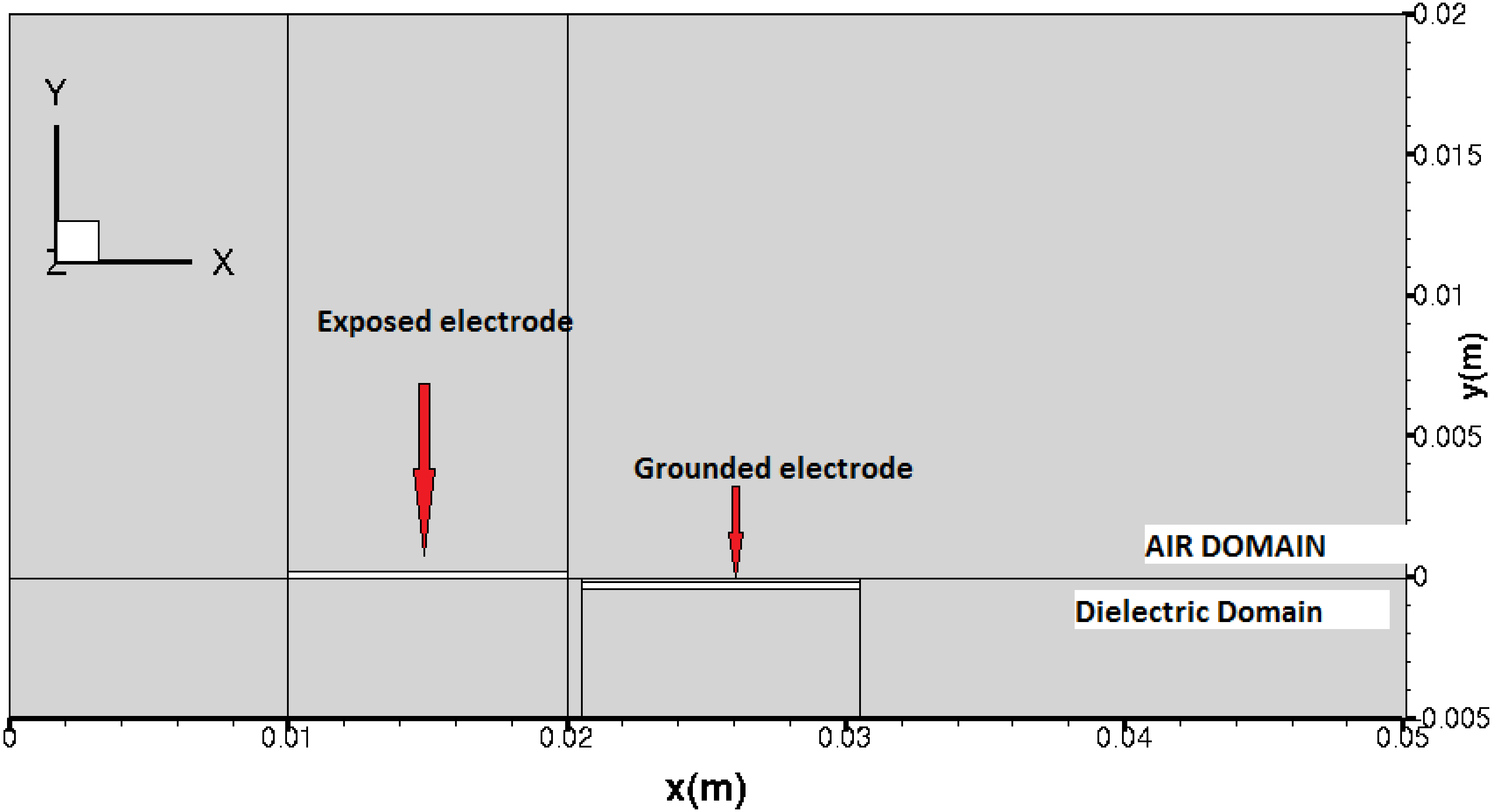
ρ_c = charge density

λ_D = the Debye Length

The DBD Model

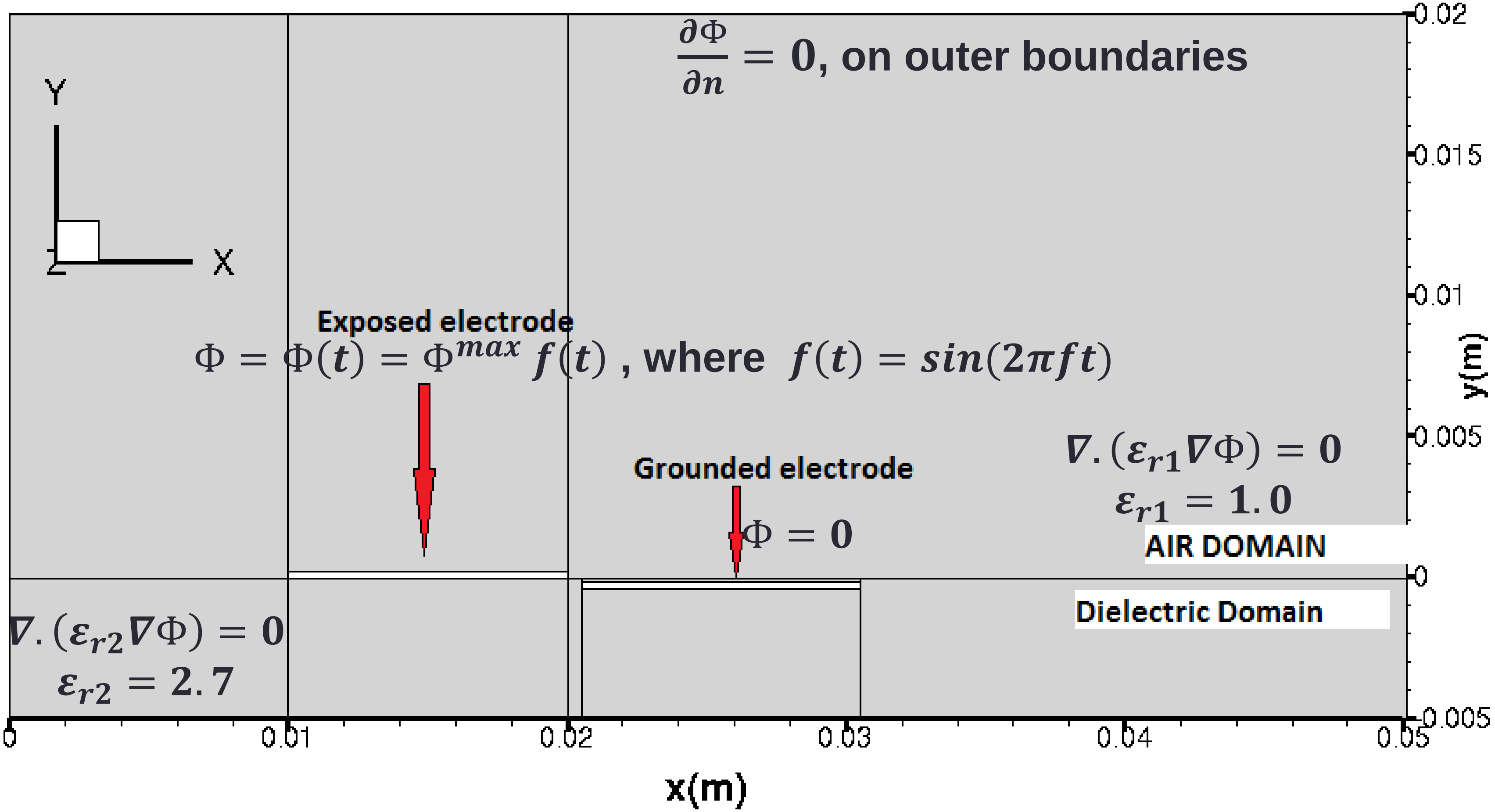


Electrod length = 10mm
Gap between electrodes = 0.5 mm
Height of electrodes = 0.25 mm
Thickness of dielectric b/w electrodes = 0.125 mm



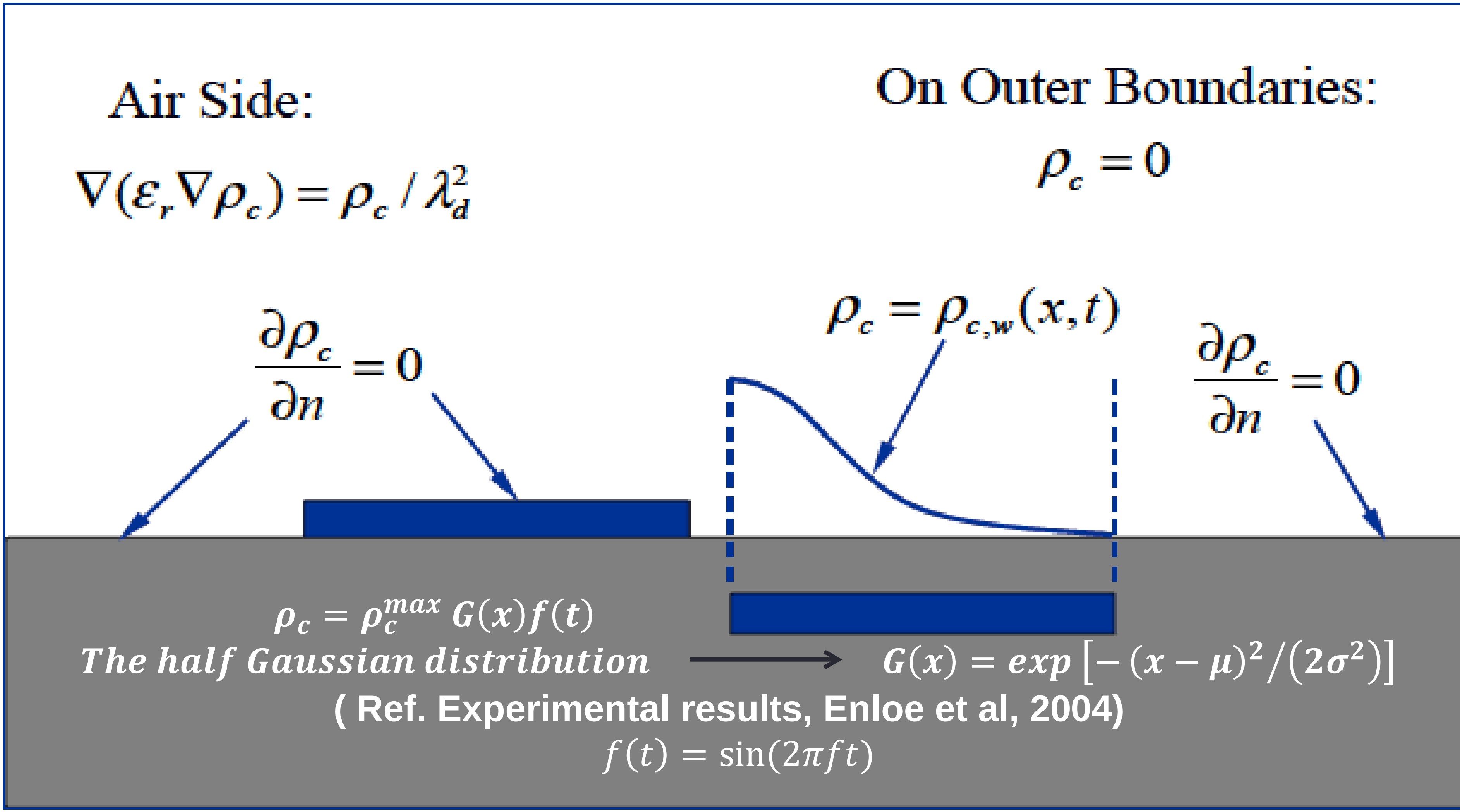
Boundary conditions

(Electrical Potential Φ)



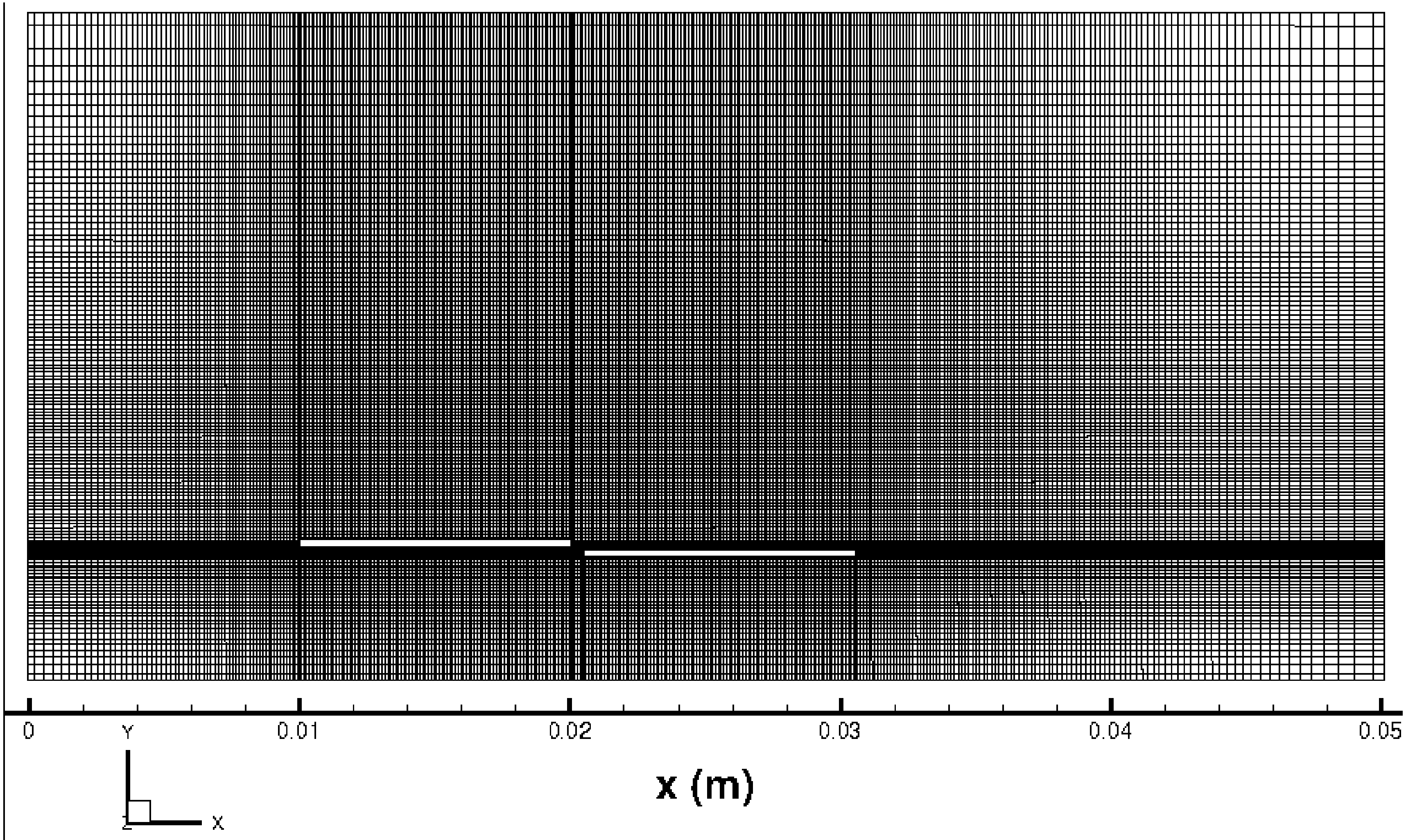
Boundary conditions

(Electric Charge density ρ_c)

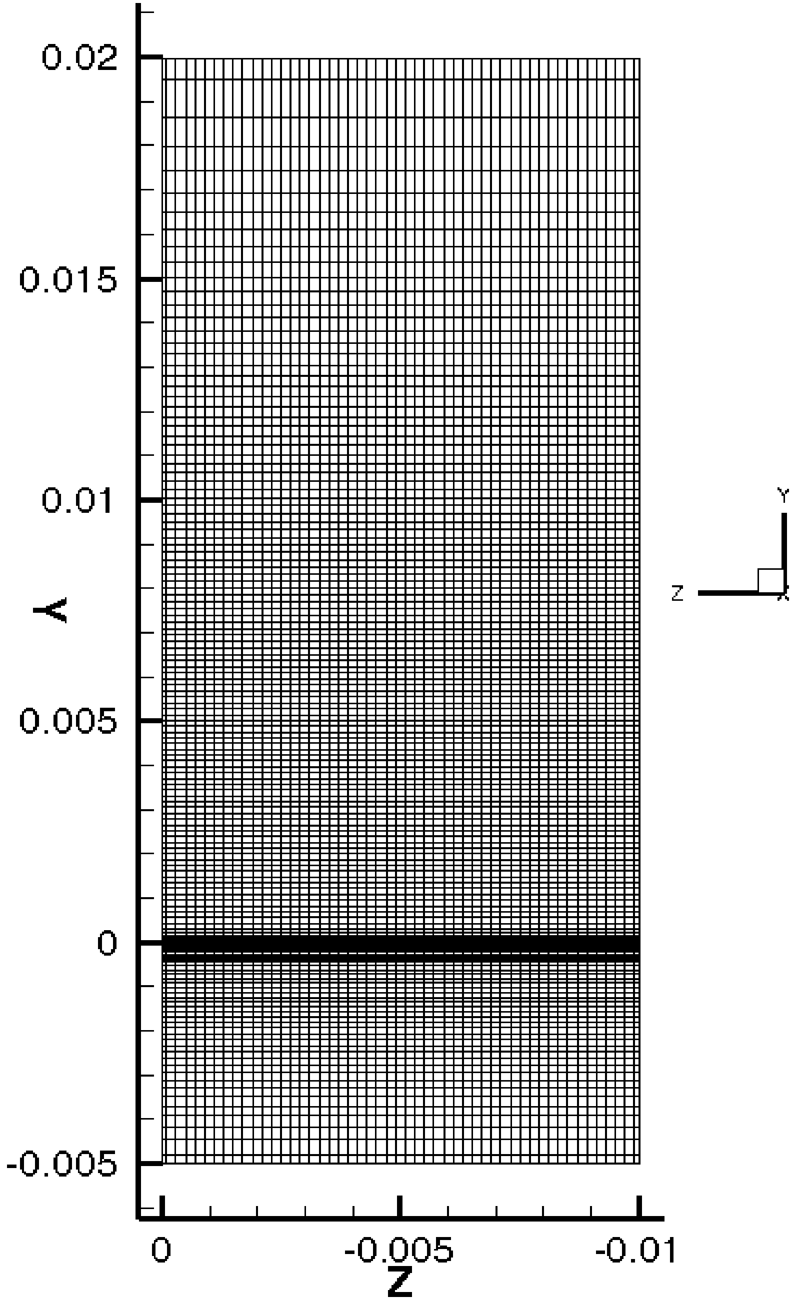


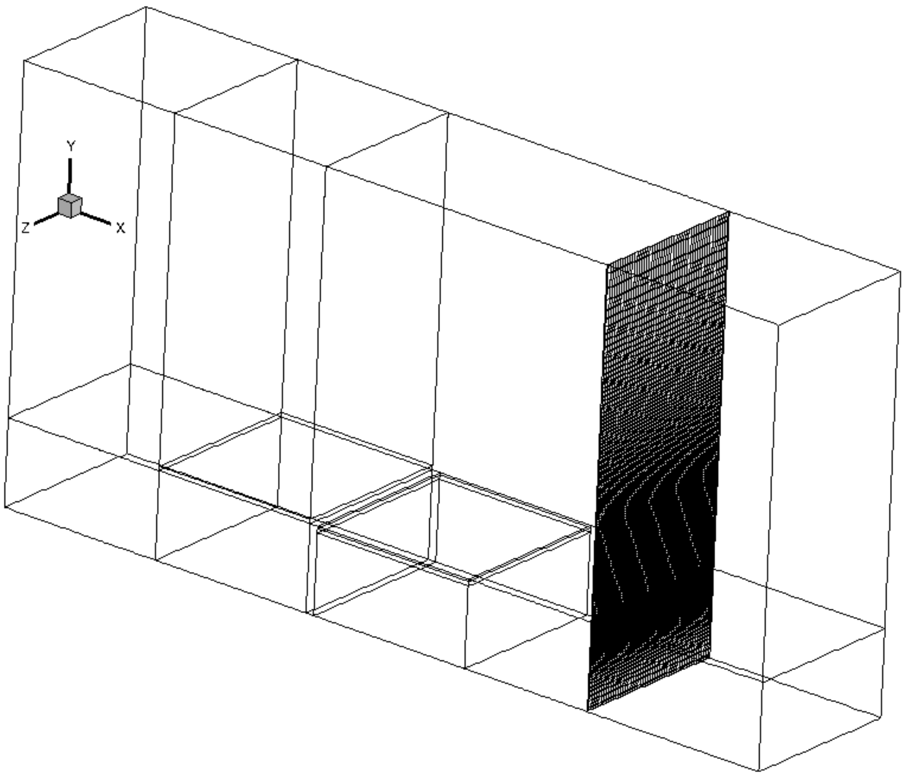
The block-structured orthogonal grid

More than 2.5 million control volumes



The block-structured orthogonal grid





Input Parameters

- **Some parameters taken for the current problem**

Quiescent Air

Maximum charge density $\boldsymbol{\rho_c^{max}}$ **= 0.0008 C/m³**

Amplitude of AC potential Φ^{max} =***5.0 kV***

Frequency of applied AC voltage ***f = 4.5 kHz***

The Debye Length λ_D ***= 0.001 m***

Density of air **= *1.225 kg/m³***

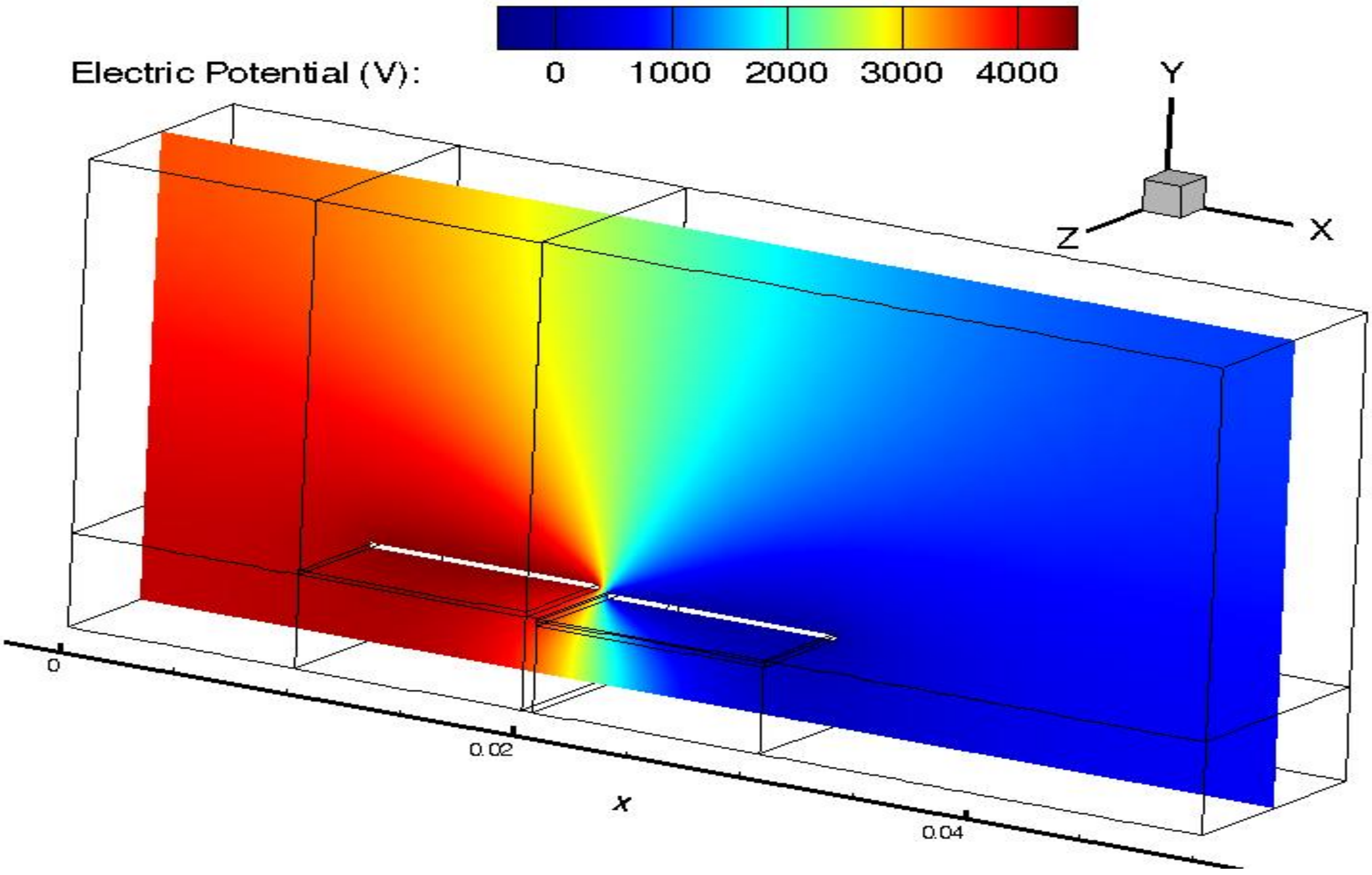
Viscosity of air **= *1.85 * 10⁻⁵ kg/(m.s)***

RESULTS

- 3 Dimensional results
- Comparison of 3D results with 2D results

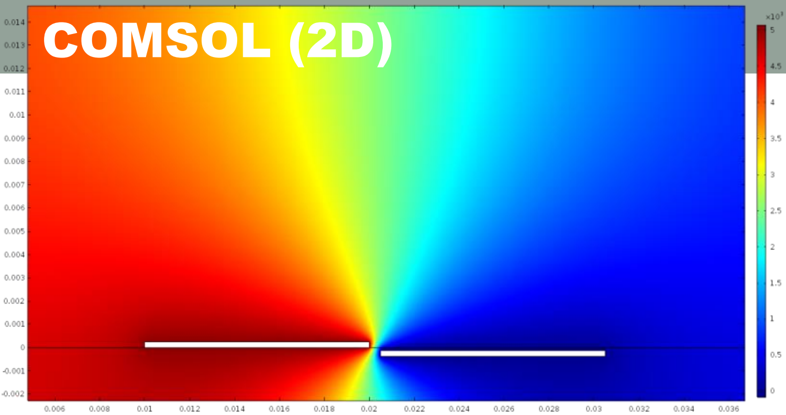
Results

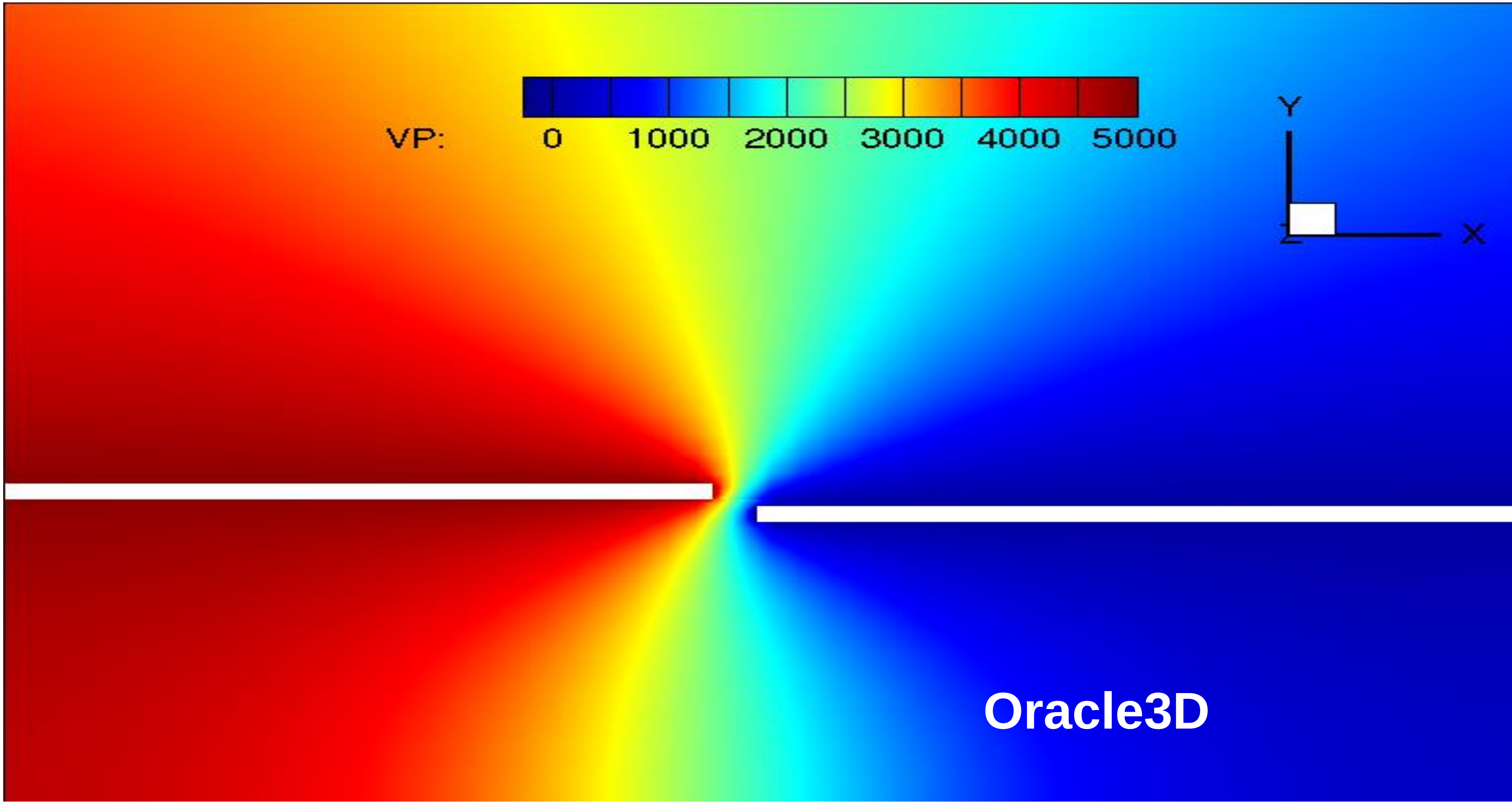
(Electrical Potential)



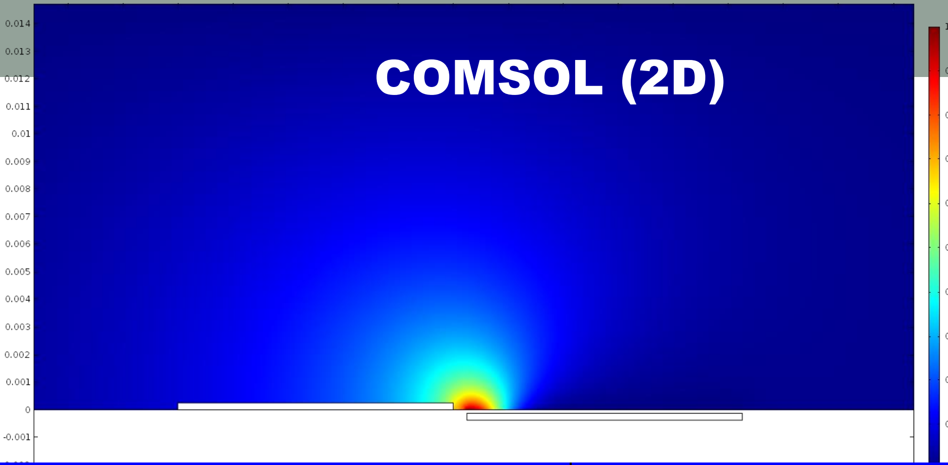
Results

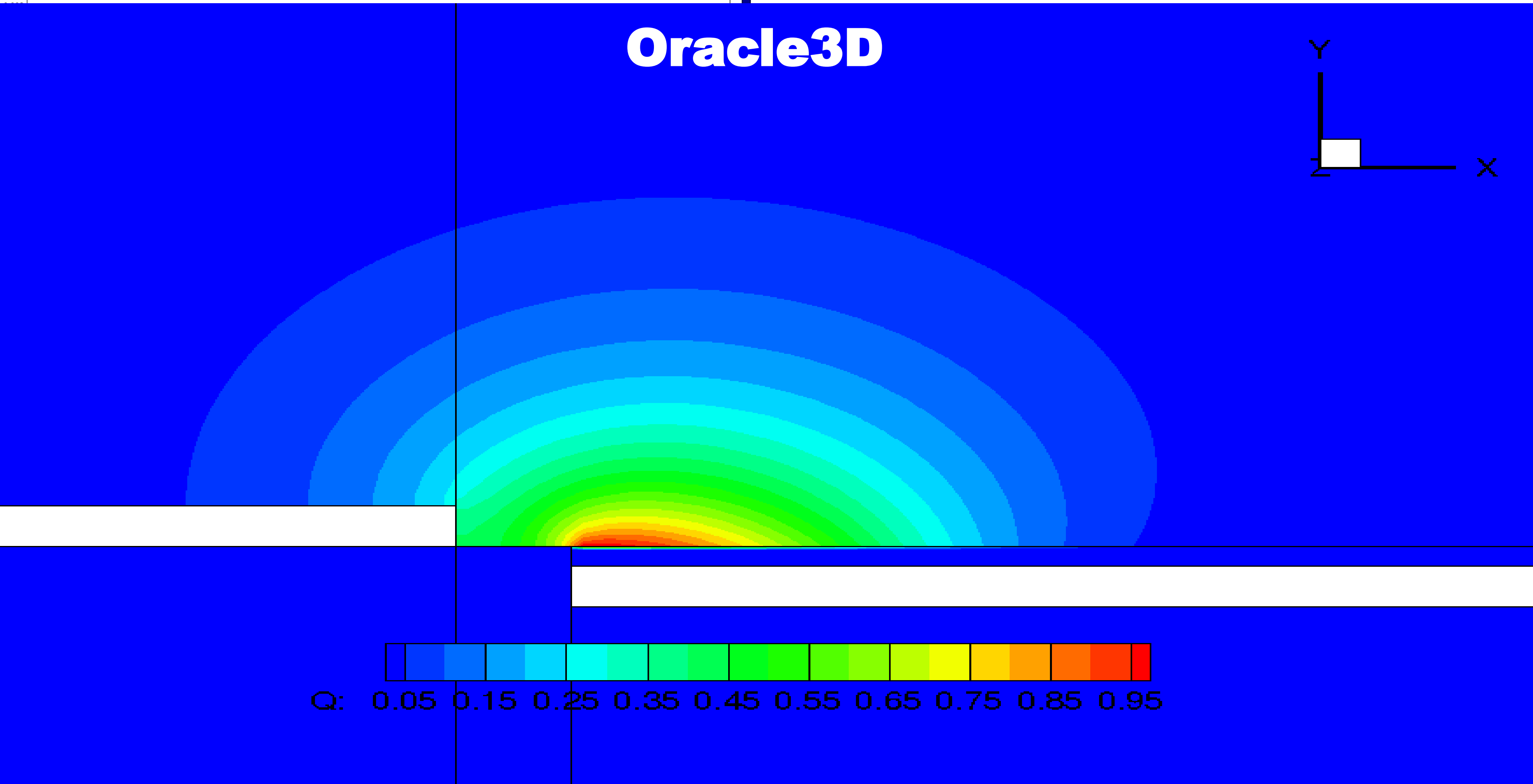
(Electrical Potential)



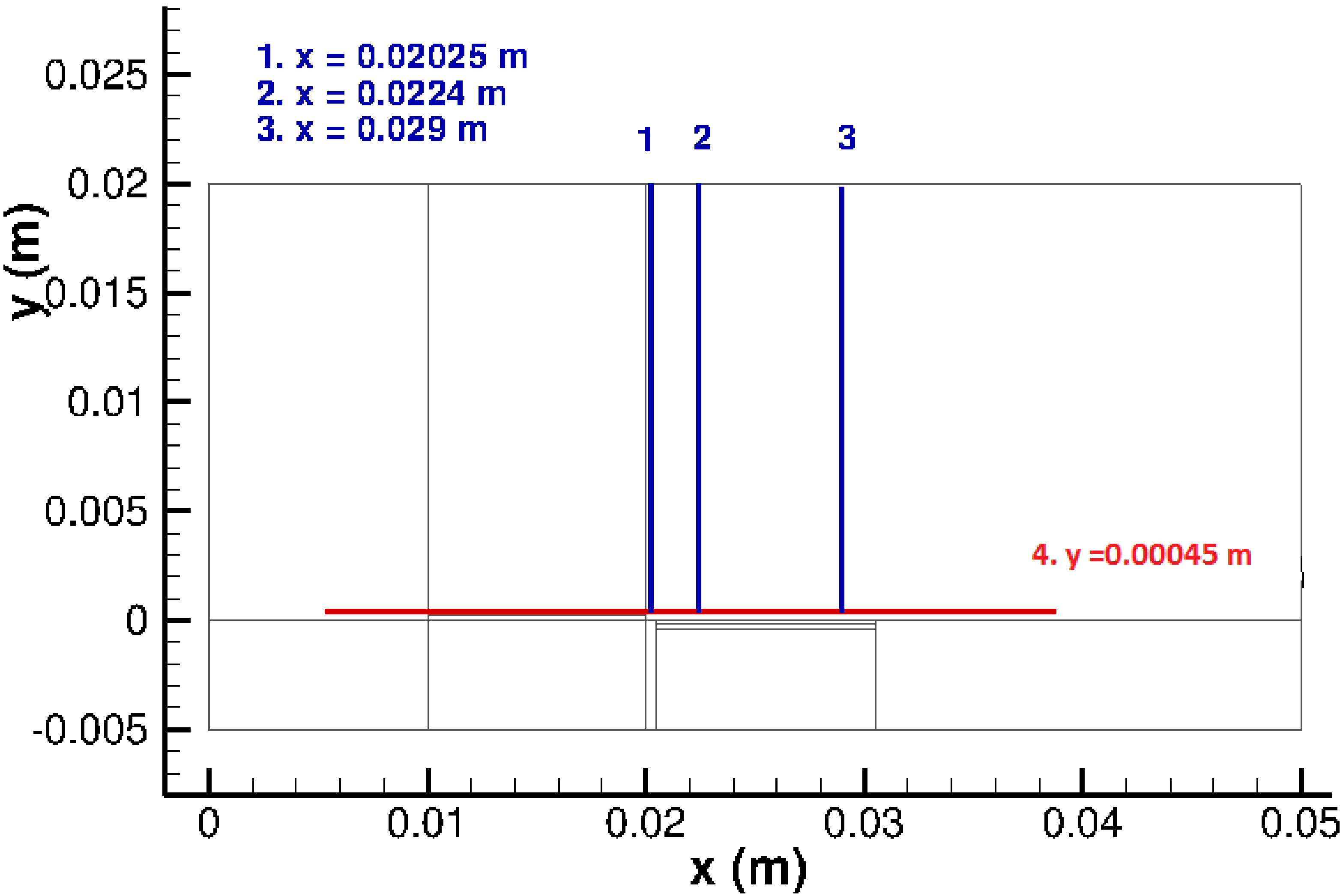


Results
(Charge density)

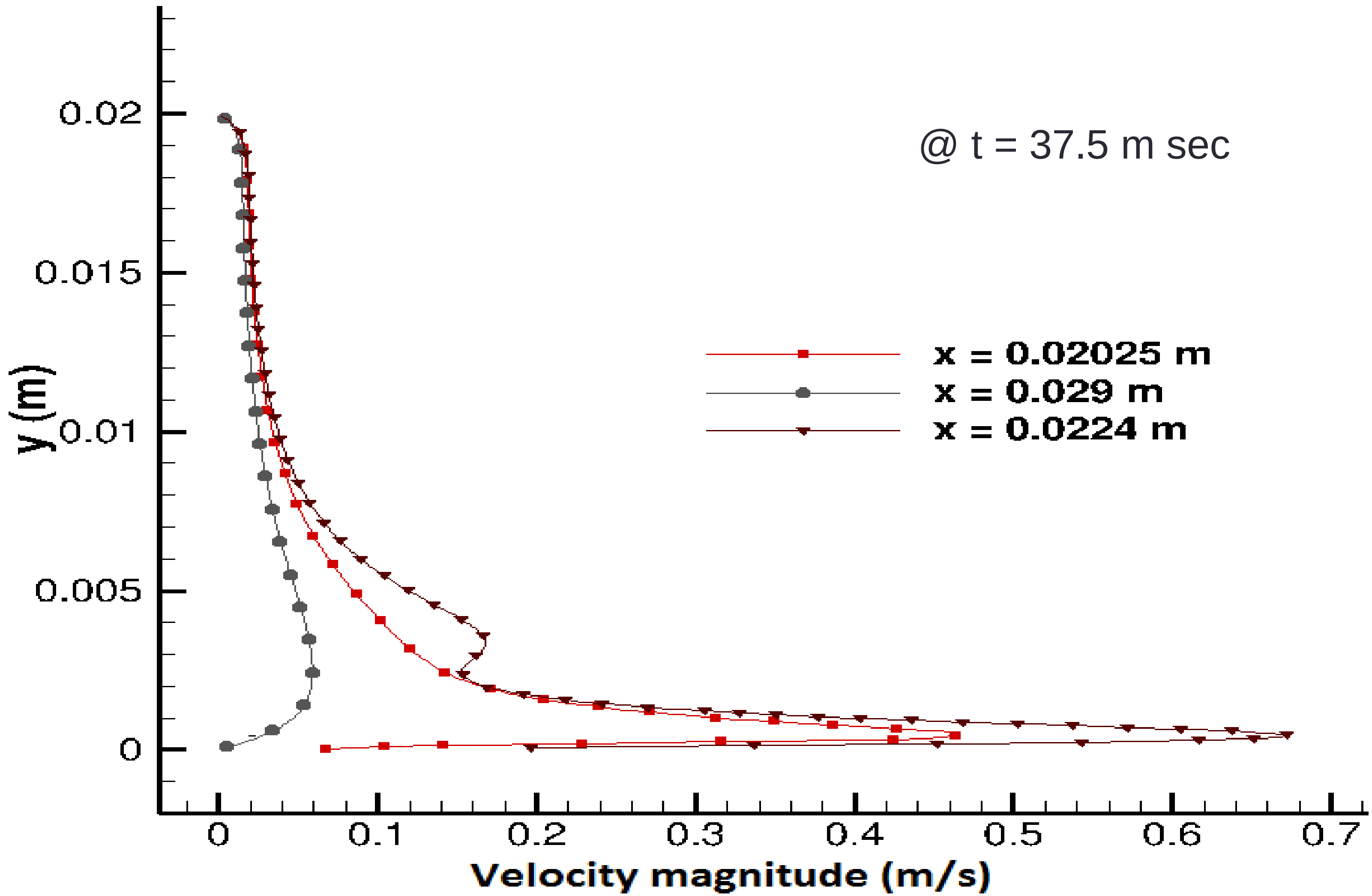




Velocity profiles

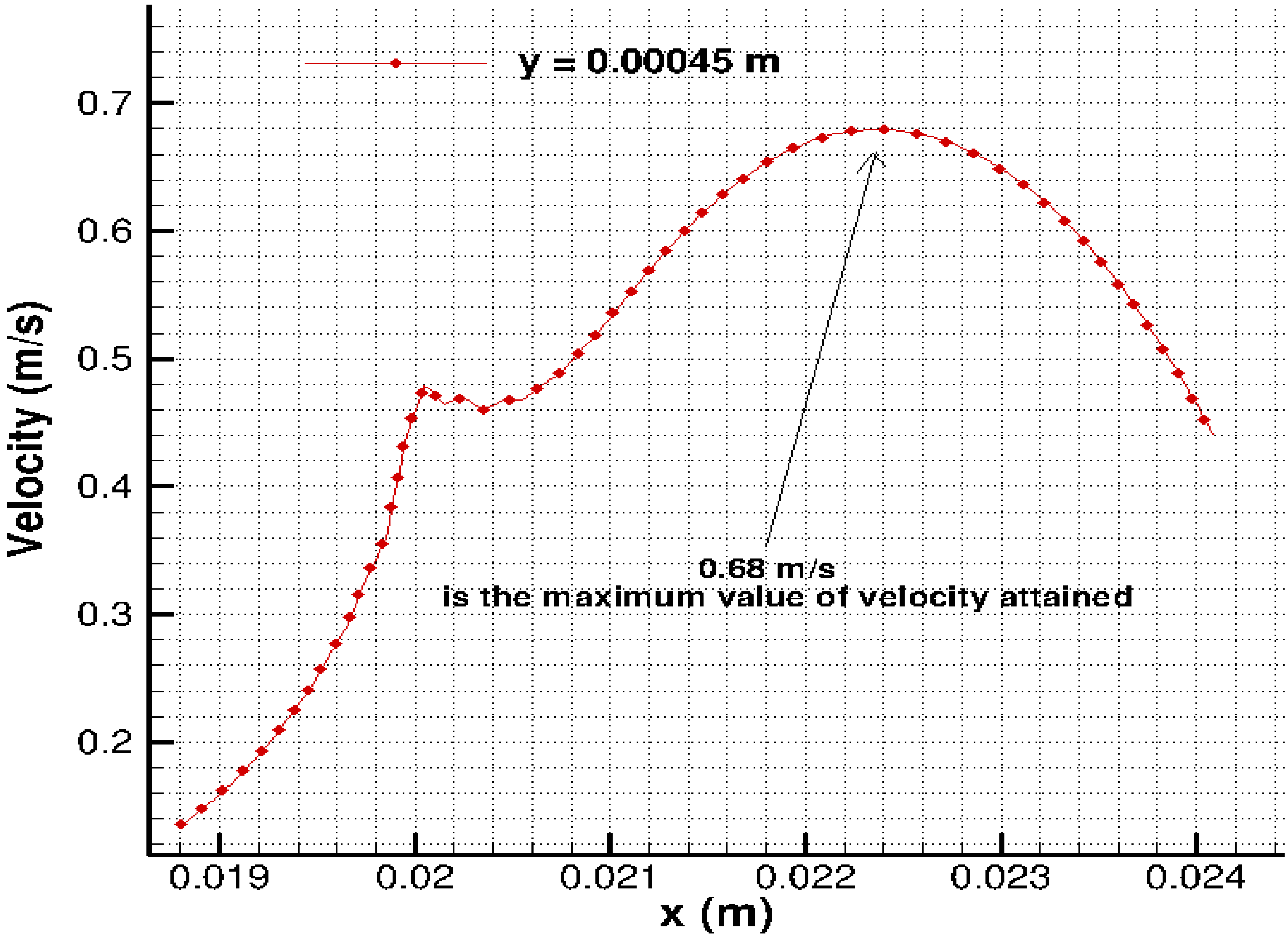


Velocity magnitude Profiles

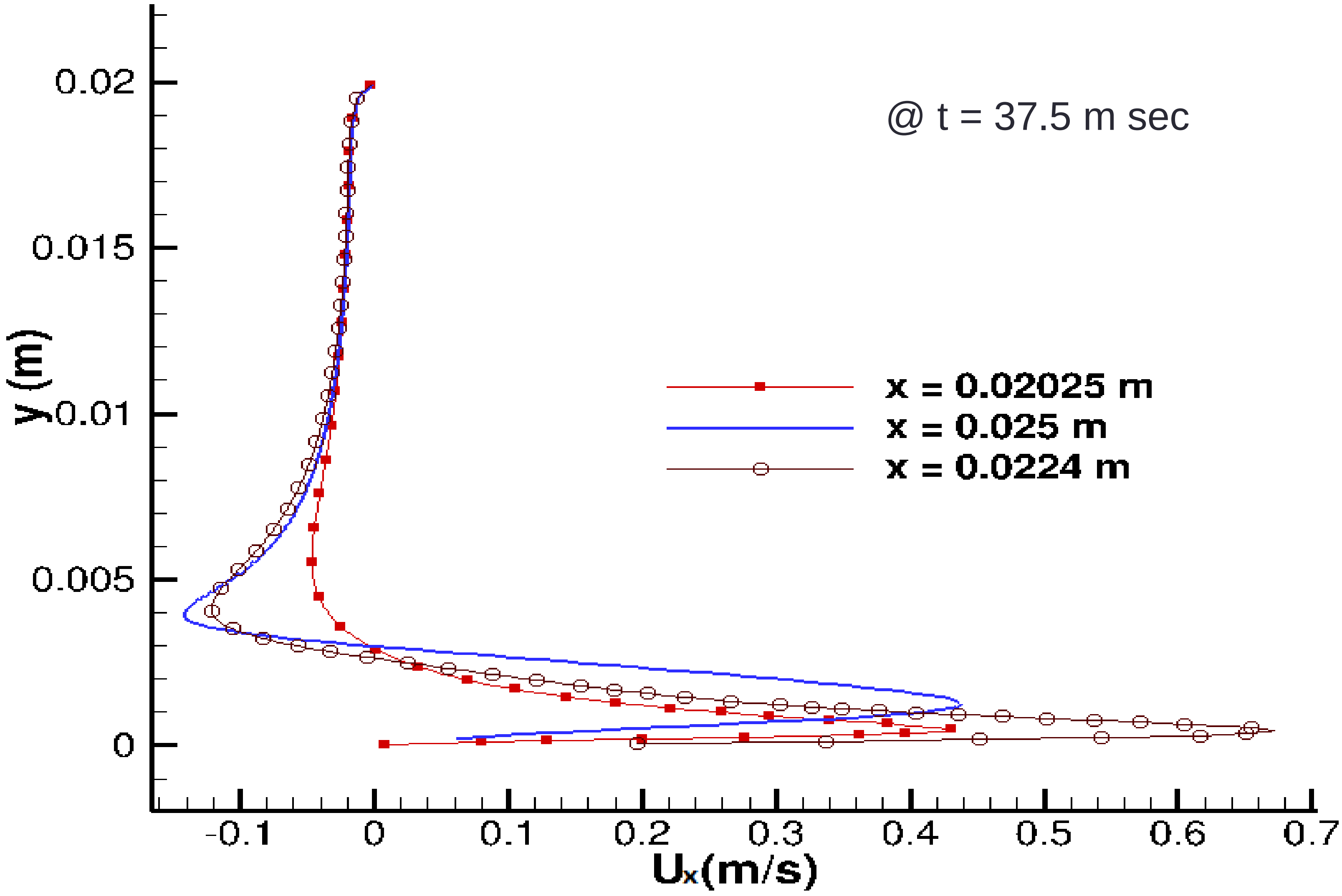


Maximum Velocity attained

@ t = 37.5 m sec



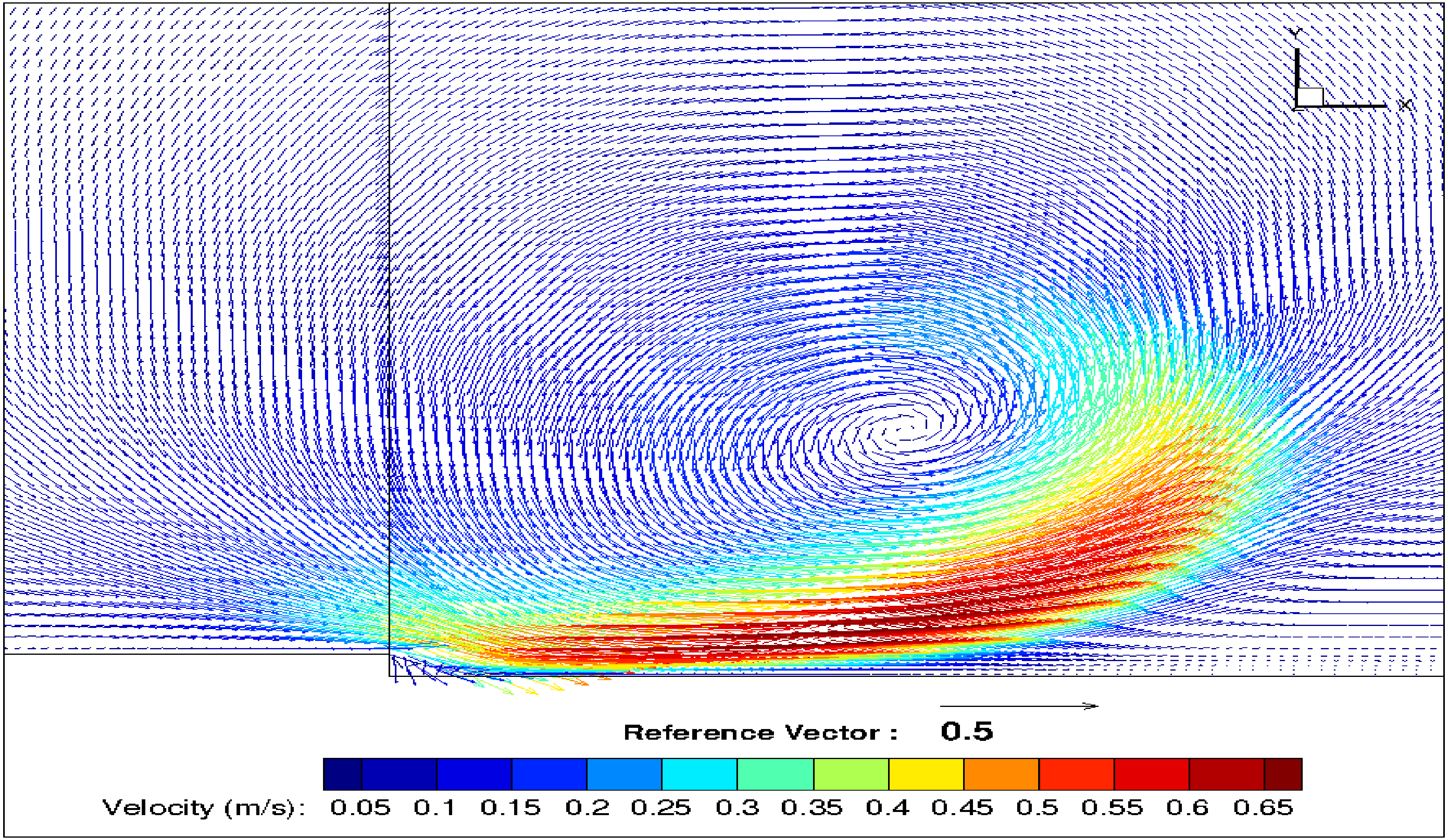
Ux profiles



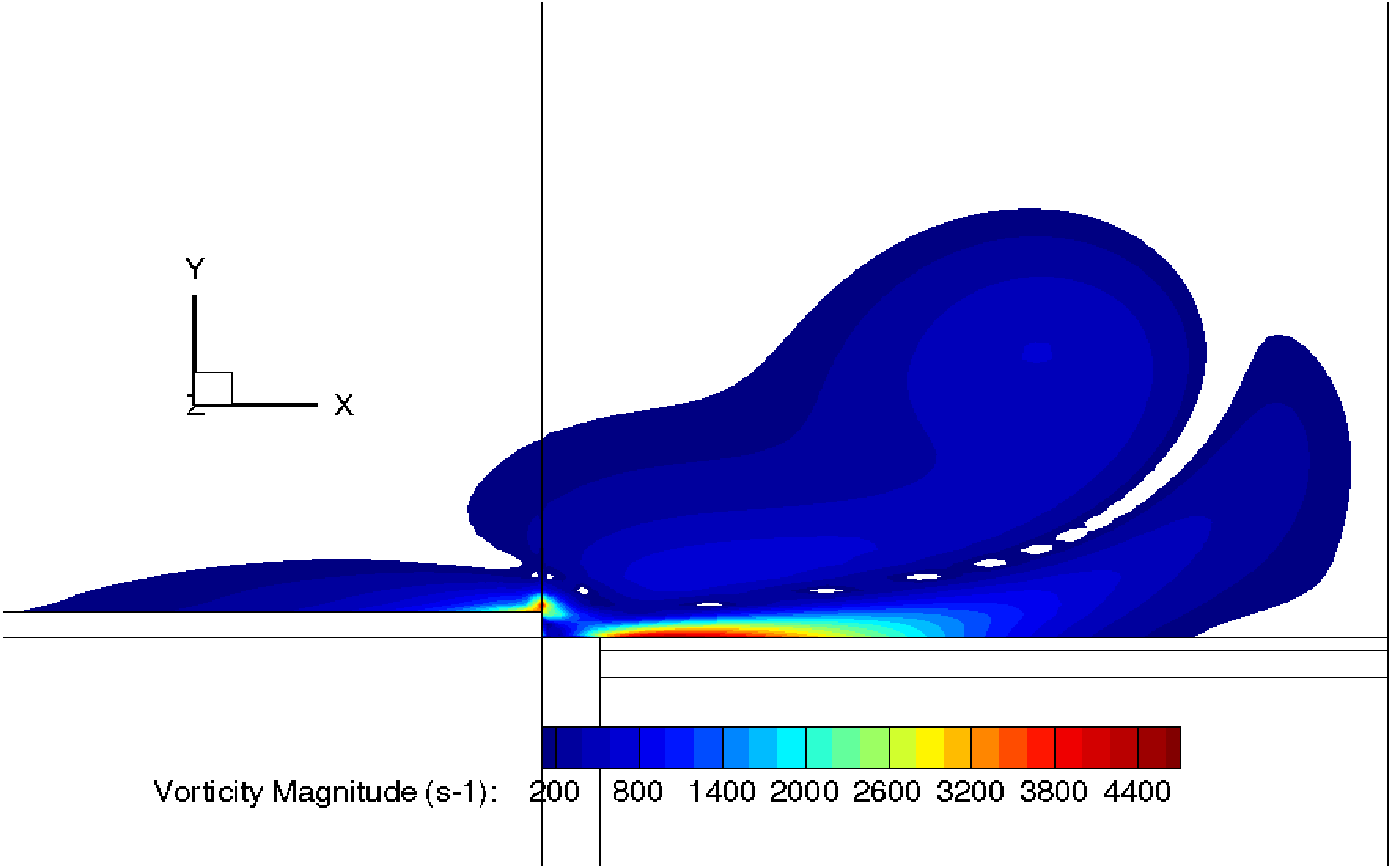
0.02
0.015
0.01
0.005
0
y (m)
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Ux(m/s)
@ t = 37.5 m sec
x = 0.02025 m
x = 0.025 m
x = 0.0224 m

Velocity Vectors

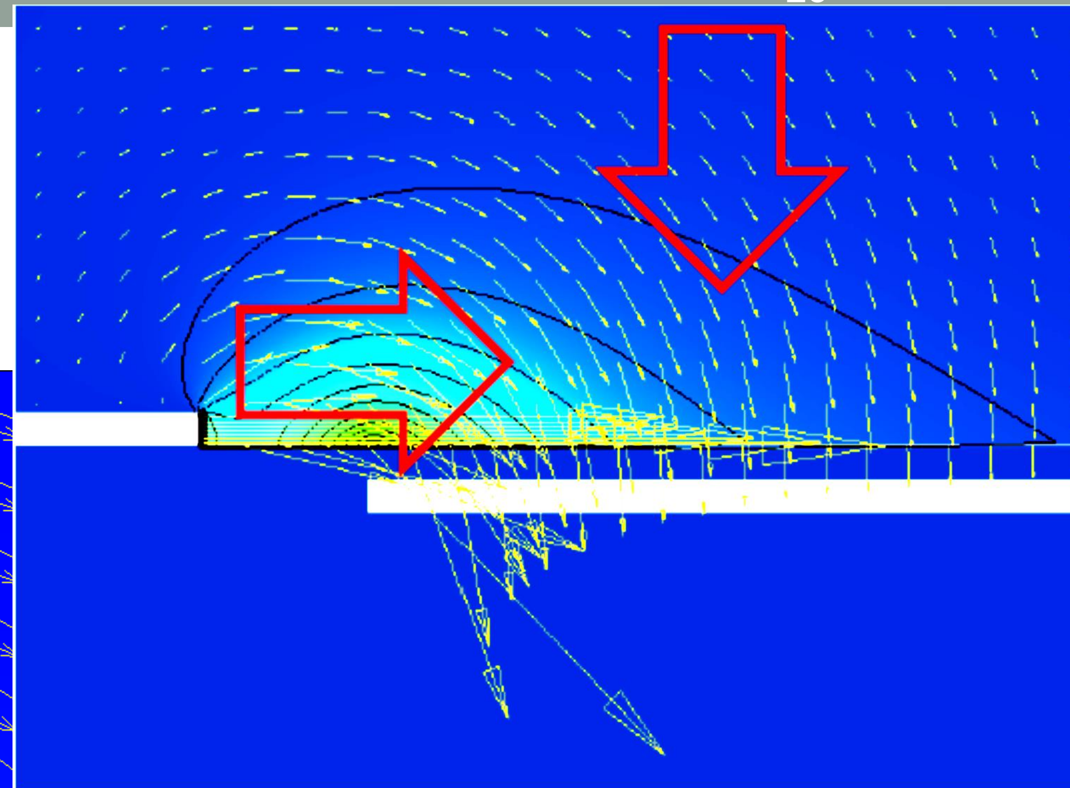
@ t = 37.5 m sec



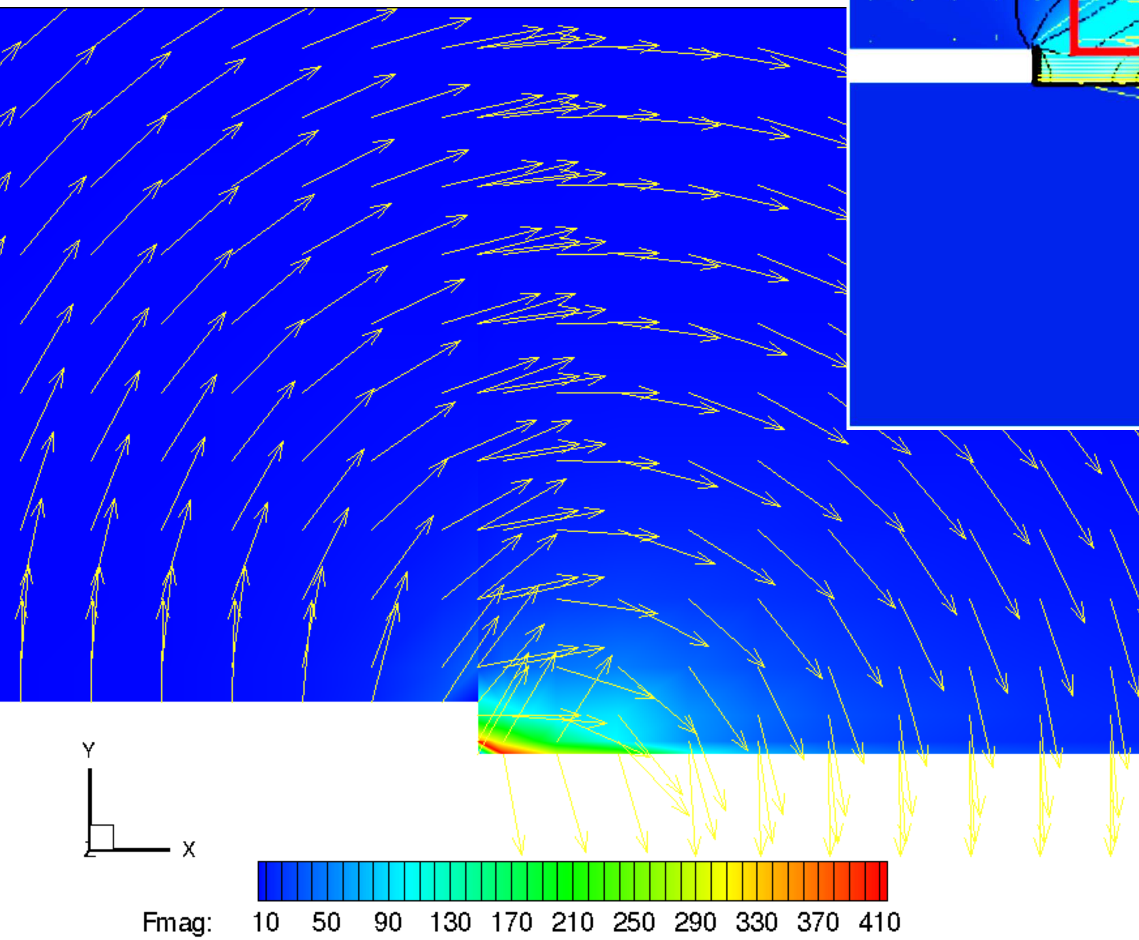
Vorticity magnitude



Force Vectors



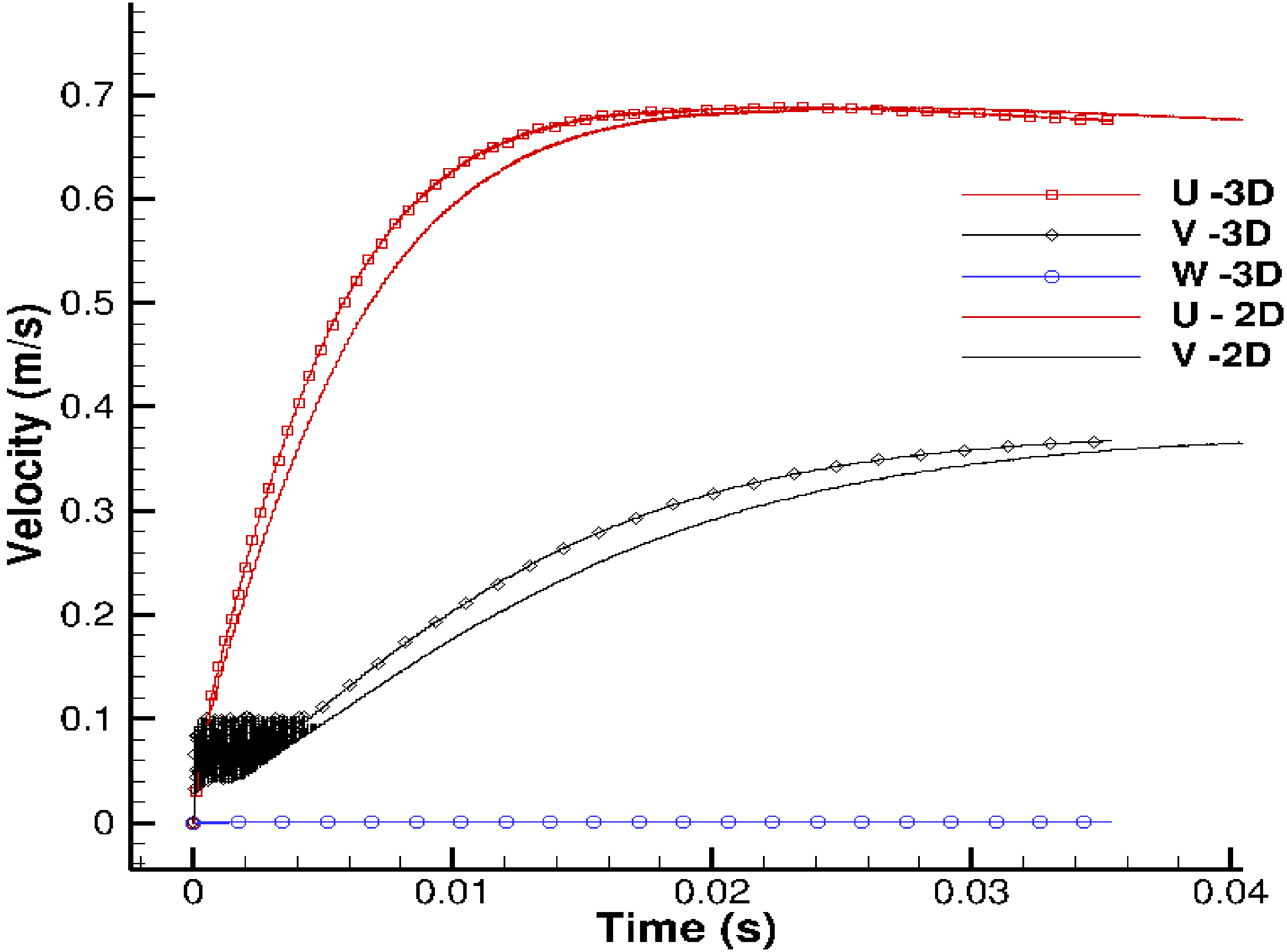
Phd. Thesis, Kengo Asada, 2014
University of Tokyo



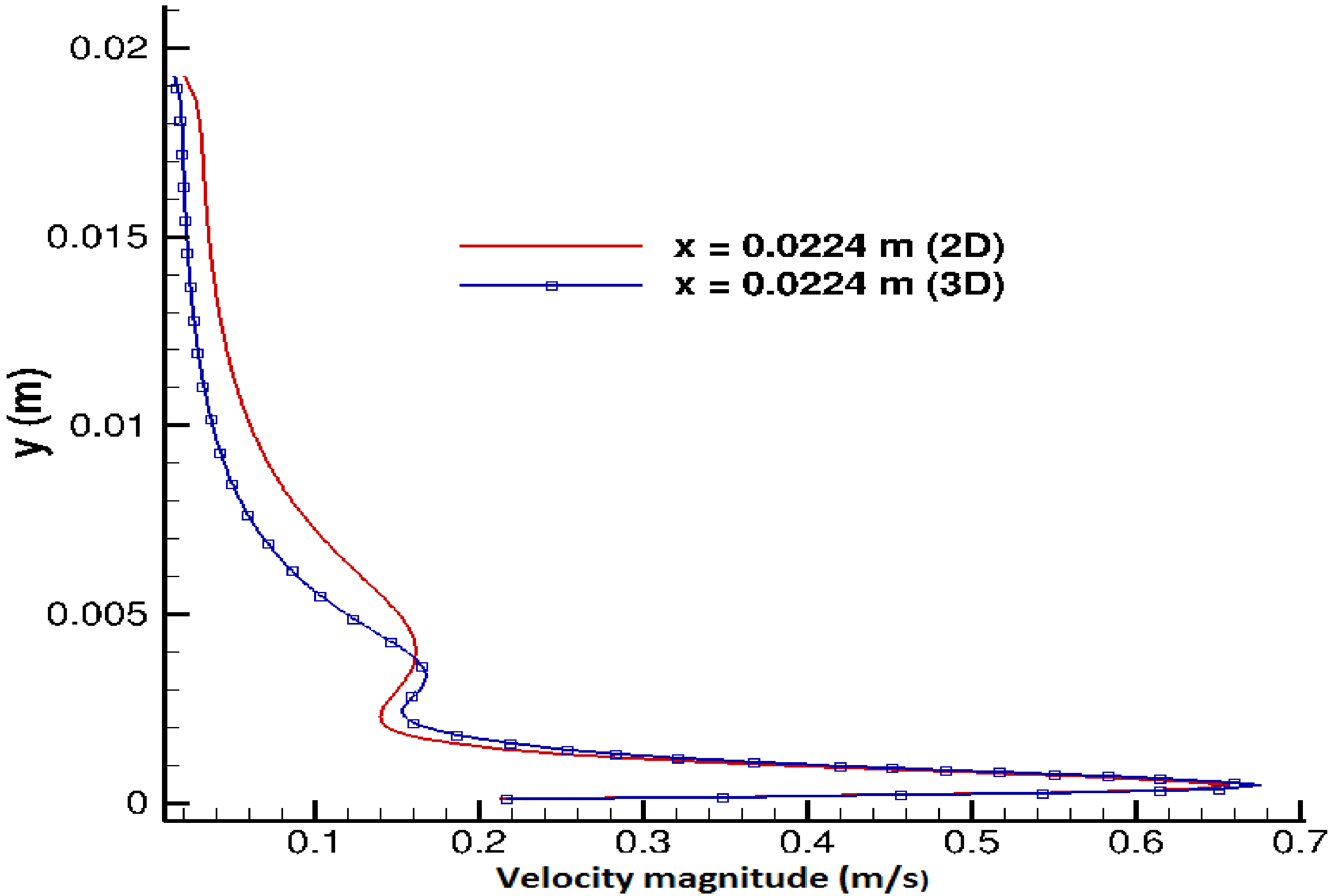
Oracle3D

Comparison 3D & 2D results

(The velocity components)



Comparison 3D & 2D results



Conclusions

- Effects of DBD plasma actuator were well modelled with 'Oracle3D'
- Good agreement between 'Oracle3D' results and Comsol 2D results was observed
- For this configuration and parameters ($\Phi^{max} = 5.0$ kV & f = 4.5kHz) the flow essentially is 2 dimensional .
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THANK YOU ALL .