3D MHD SIMULATION UPDATE

Presented By Hulin Huang

M.Abdou, A.Ying, S. Smolentsev, X.Y.Luo, N.Morley

APEX E-Meeting, August 7, 2001

OUTLINE

1. Induced Magnetic-Fields Formulation Vs Electric Potential Formulation

2. Present Effort in 3D MHD Simulation and Numerical Results

3. Progress on Boundary Conditions Improvement

Mathematical Formulation Techniques for 3D MHD Simulation

- Two methods are commonly used.

A – Electric Potential Formulation

$$\nabla^2 \varphi = \nabla \cdot [U \times B] \qquad (1)$$

$$\vec{j} = \sigma[-\nabla \varphi + U \times B] \qquad (2)$$

B – Induced Magnetic-Fields Formulation

$$\frac{\partial B}{\partial t} = \frac{1}{\mu_0 \sigma} \nabla^2 B + (B \cdot \nabla) U - (U \cdot \nabla) B \qquad (3)$$

$$j_n = \frac{1}{\mu_0} (\nabla \times \vec{B}')_n = c \ \text{(for Insulation wall, c=0)} \qquad (4)$$

- Magnetic-field induction equation was adopted previously to obtain 3D MHD results and presented at last APEX Meeting.

The Difficulty Based On The Induction Equations Comes From Correct Mathematical Description for Boundary Conditions

Previous simulations obtained using $\vec{B}' = 0$ at the boundaries (insulated walls are assumed).

This is valid for some 2-D or axisymmetrical problems, because there is only one component of the induced magnetic field. In such cases, the problem is completely closed because the additional boundary conditions on $\vec{B}'$ are not needed. It is not clear for 3D problems. Further understanding is required to model 3D boundary conditions at the interface and solid wall.

Advantages of induced magnetic field formulation:

1. High possibility to obtain convergent solutions for High Hartmann Numbers and Non- uniform Magnetic Fields.

2. Can be applied to a large magnetic field Reynold number (Re_m);

At Low Hartman Number Convergent Solutions Are Possible Based On The Electric Potential Formulations

Disadvantages of the Electric Potential Formulation:

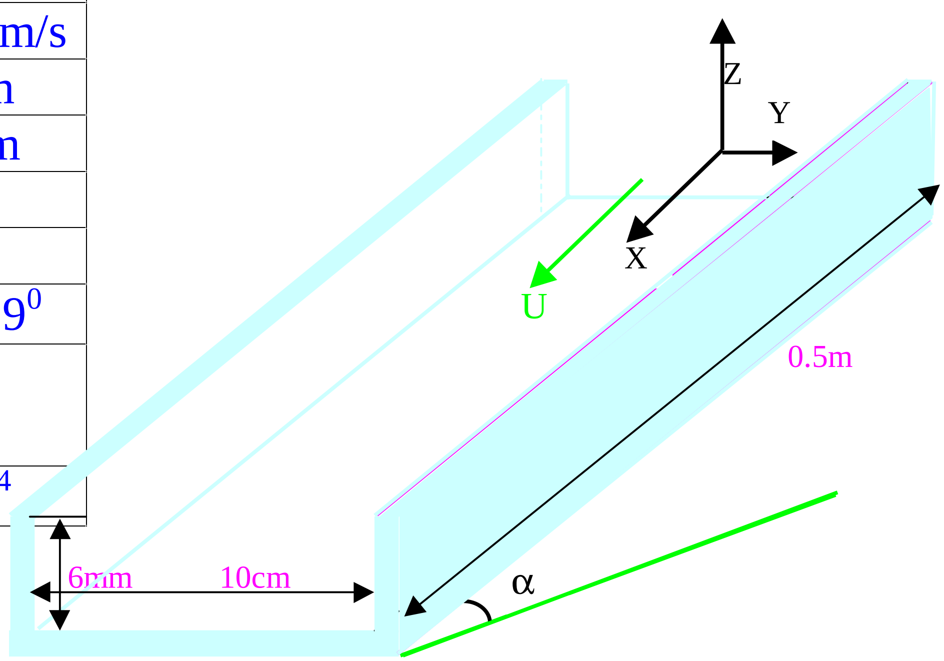
1. Poor convergence for φ equation in numerical technique because the boundary conditions of inlet and outlet are set $\dfrac{\partial \varphi}{\partial x} = 0$.
2. For the Hartmann numbers higher than about 100, the induced magnetic field can not be ignored. So, the "φ-formulation" is not applicable to most fusion problems.
3. The "φ-formulation" is valid only for small Re_m when the external magnetic field is not affected by the magnetic field induced in the liquid.

★ Initial calculation is performed for NSTX outboard Mid-plane film flow using the electric potential formulations based on a self- correcting procedure numerical technique.

Initial Conditions And Coordinates For NSTX Outboard Midplane and Divertor

Table 1. Operating Characteristics

Cases	Midplane	Divertor
Material	Lithium	Lithium
Thickness	h_0=2 mm	h_0=2 mm
Flow Velocity	U_0=10 m/s	U_0=10 m/s
Flow Length*1	L=0.5m	L=0.5m
Width*2	D=0.1m	D=0.1m
Froude Number	4.515	4.657
Insulation Walls	Yes	Yes
Title Angle	$\alpha=90^0$	$\alpha=24.29^0$
$Ha^{*3}=\frac{\partial B_z}{\partial x} h_0 \sqrt{\sigma/\rho\nu}$	60.4	61.5
Re Number	3.1×10^4	3.1×10^4



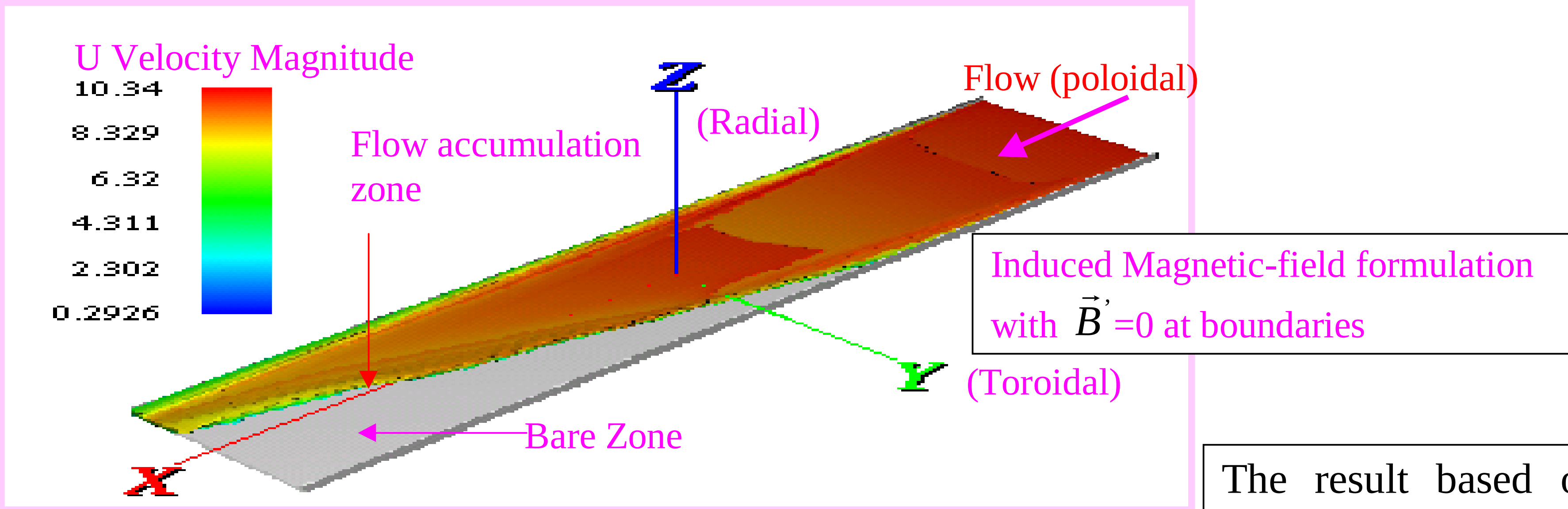
*1 Design Path = 0.9m

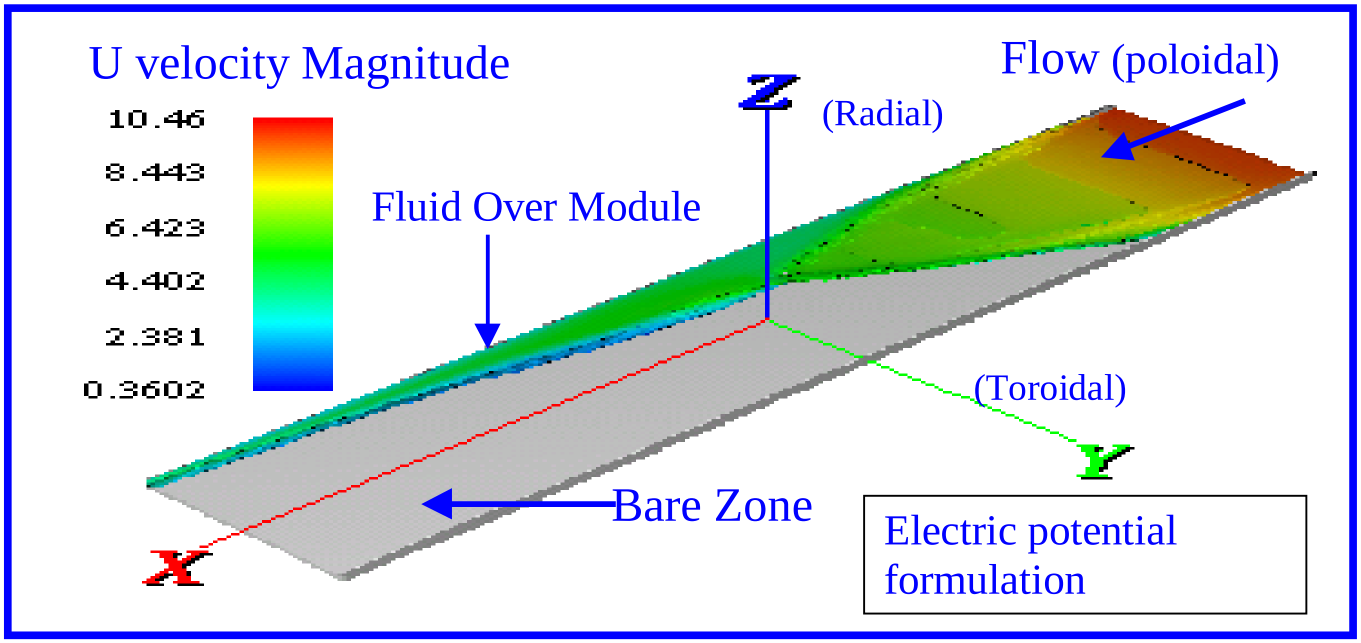
*2 Design Width = 0.3m

*3 Maximum Hartmann Number

- Calculation domain reduced to minimize memory requirement

3D Velocity Characteristics For NSTX Outboard Mid-Plane

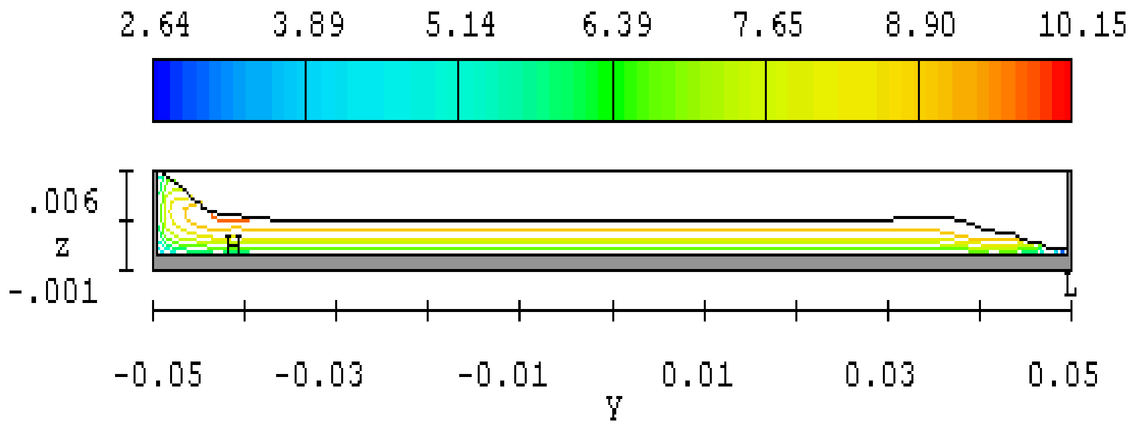




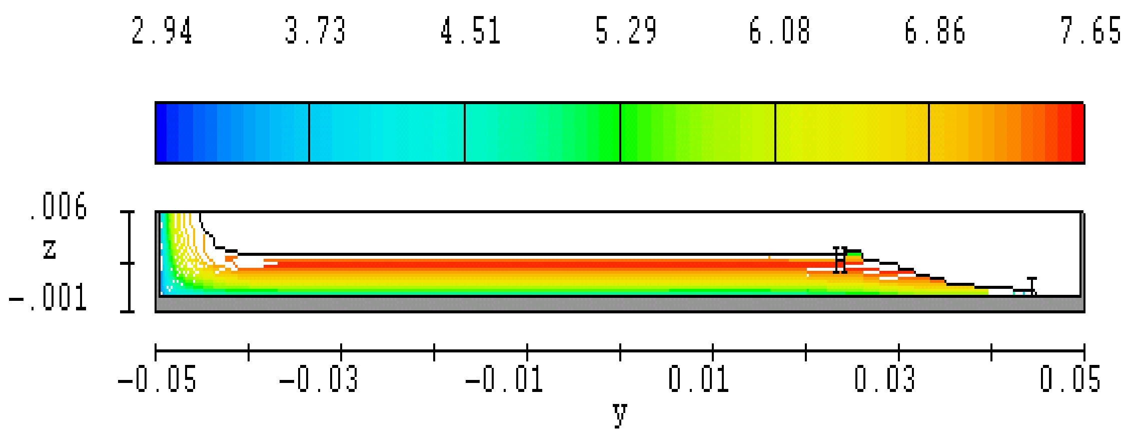
The result based on the electric potential formulation show a stronger 3D MHD effect.

The forces J×B are much harder to cause a larger bare spot and a stronger velocity reduction than that of the previous results.

U Velocity Characteristic at Fluid Separation Point



Magnetic-field induction (located at 0.135m downstream)



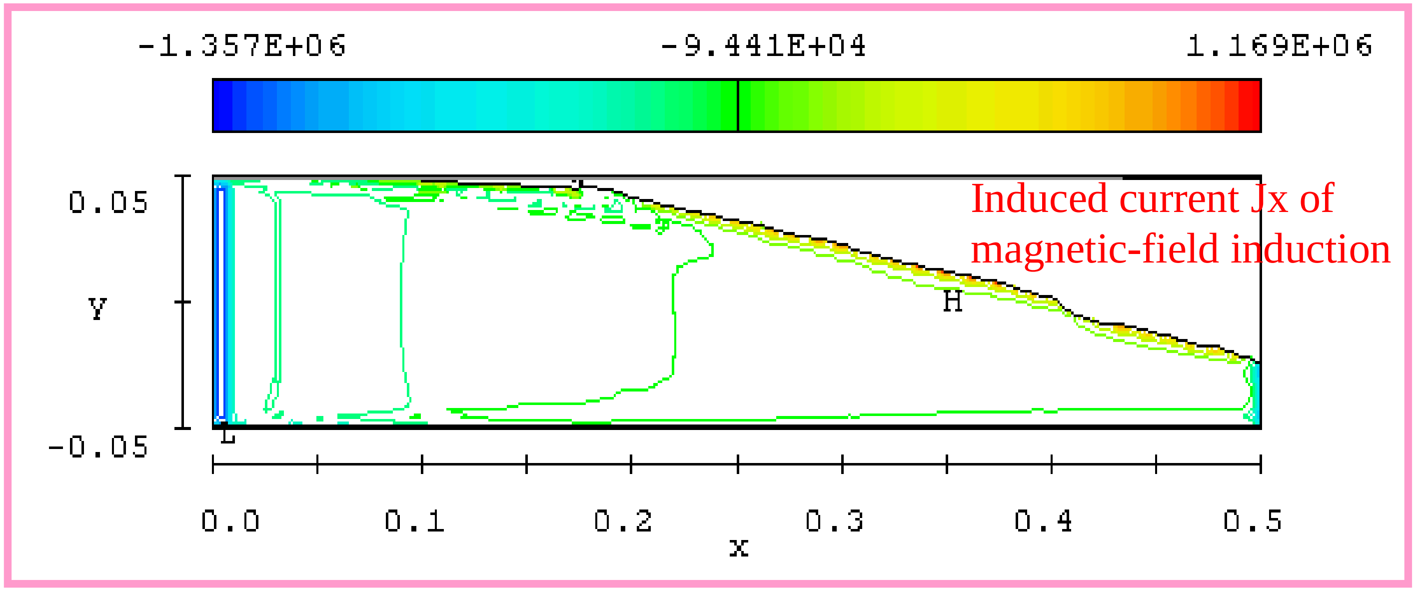
Electric potential formulation (located at 0.1m downstream)

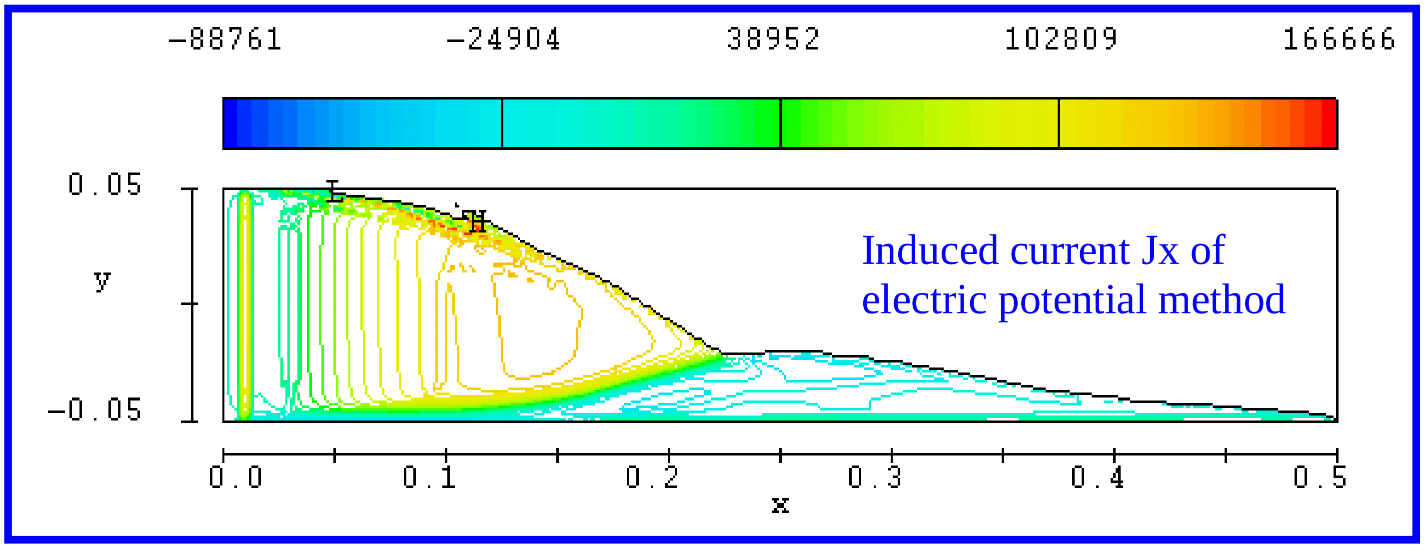
Fluid separation occurs earlier based on the electric potential formulation.

The result from electric potential formulation shows that a stronger jet velocity, while fluid spilling over the side of the module is more severe than that of previous calculation.

Next tests we will increase the chute height to better observe jet fluid velocity characteristics near the wall area.

Midplane XY plane Induced Current Contours at Z=0.75mm





More complicated induced current Jx profiles are shown based on the electric potential formulation. (Further understanding is needed)

Summary Based On Preliminary Comparison Between Two Mathematical Formulations

- Both mathematical formulations show similar 3D MHD effects.

  At NSTX outboard mid-plane
  - Flow Separation and bare spot formation
  - A high velocity jet stream near side wall

- This confirms our previous observation of 3D MHD effects based on the induced magnetic-field formulation with simplified 2D boundary conditions.

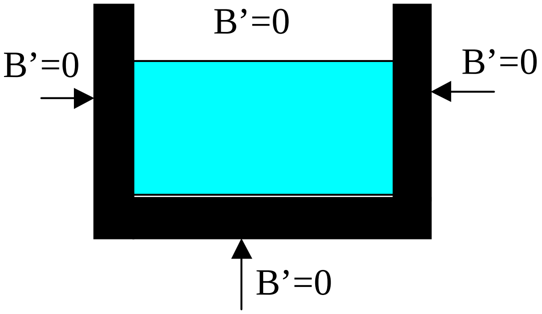
- Continued efforts are needed to better understand the results.

- Effort is needed to derive mathematically correct formulation and techniques for 3D boundary conditions.

Effort Is Needed to Derive Mathematically Correct Formulation and Technique to 3D Boundary Condition Description

Technical I. Extended Wall Boundary

It is true that the induced magnetic fields equal to zero at some distance far away from the wall. Based on this fact, the calculation domain for the problem is extended, while the boundary condition $\vec{B}' = 0$ is assigned at the extended wall surface (rather than at the real physical boundary).

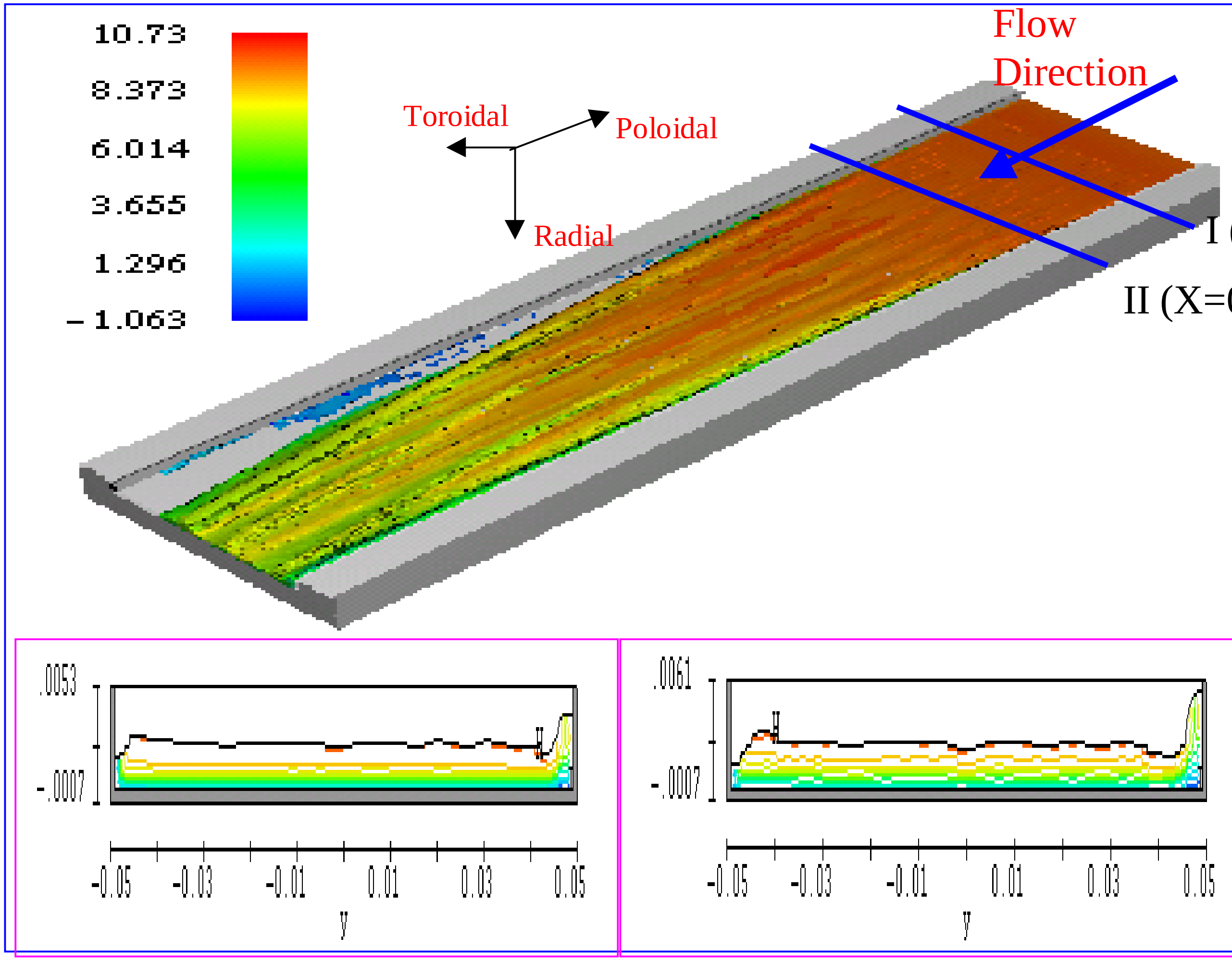


In the wall regions, the induced equation (3) is reduced to 3 Laplace Equations, i.e, its source term is zero because of no fluid flow there.

For this treatment, we are still not clear how to handle the current boundary conditions at the interfaces between the fluid and inside wall surface. Furthermore, numerical technique to realize this model is still very difficult.

Velocity Characteristic At Outboard Midplane for Extended Wall Boundary Condition

(Note: Coordinates were set different from that of previous cases)

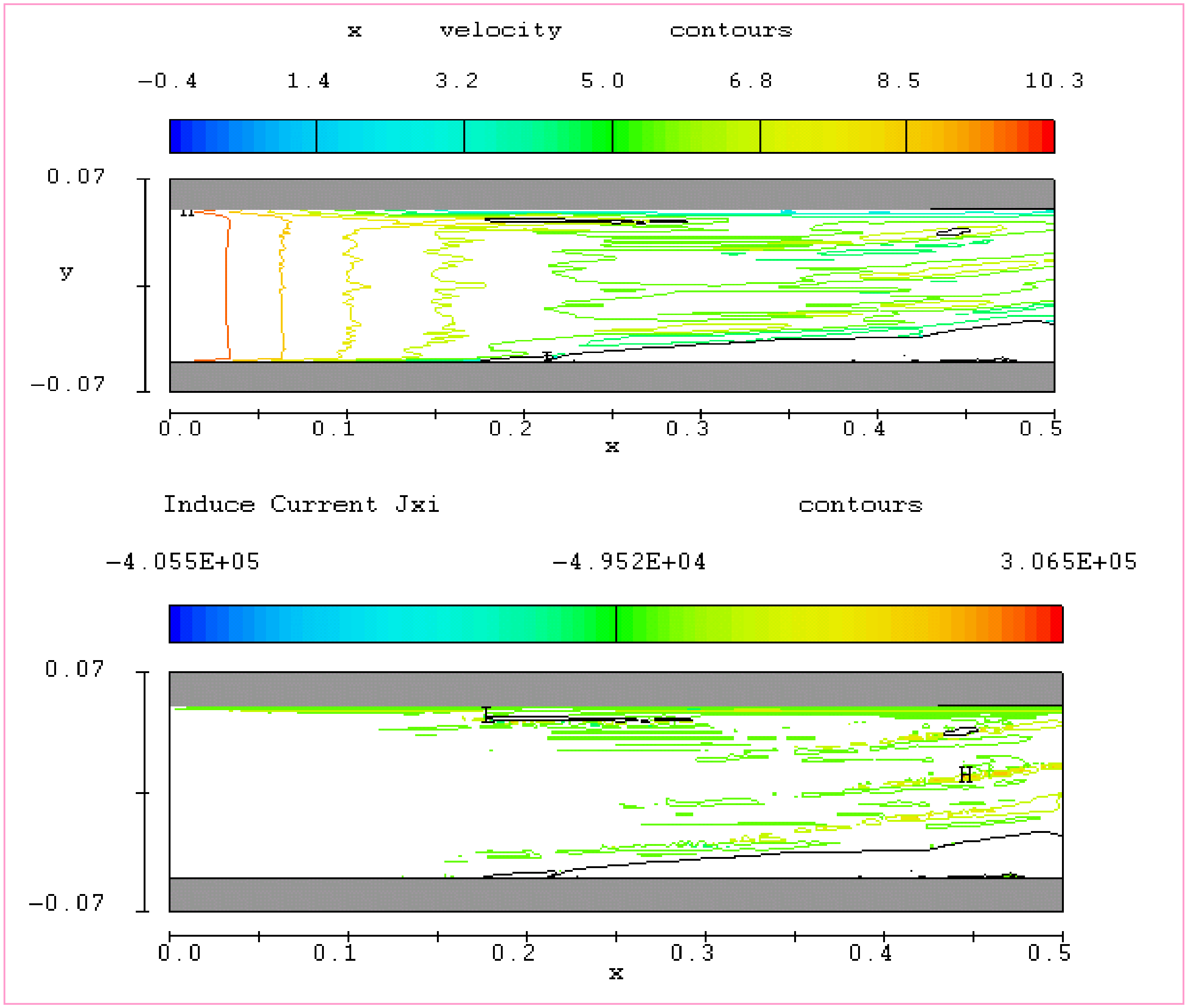


A benign flow condition is observed

- fluid separation starts at further downstream
- the pushing force is weaker leading to a small bare region.

(need more efforts to understand the results)

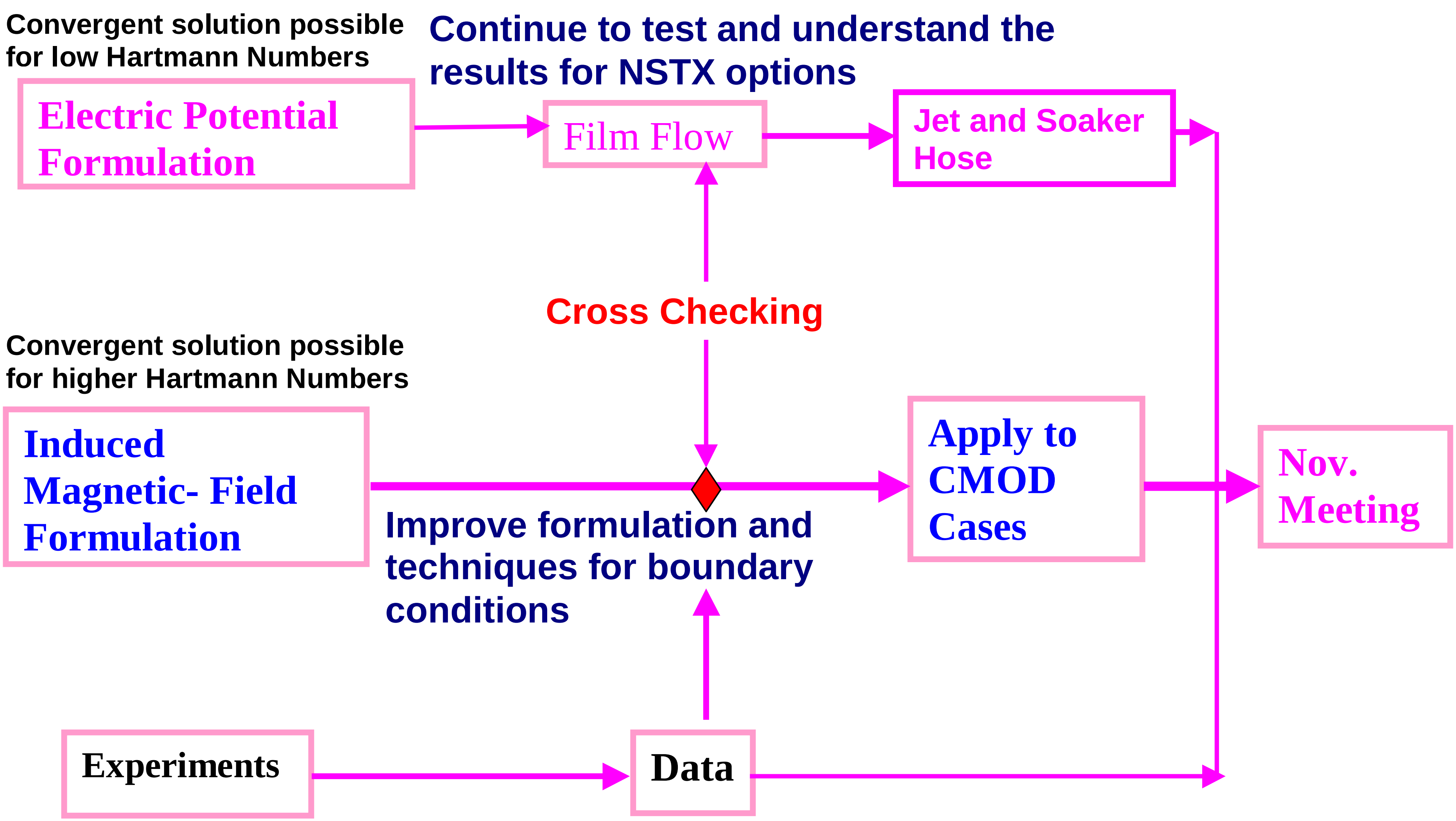
XY Plane Velocity and Current Contour at Z=0.7mm



The U velocity profiles near the inlet remain “M” Shape, but as it proceeds downstream it becomes more turbulent

Similar to other results, the Jx current density profile is not symmetry, which interacts with the normal filed to generate y direction force pushing the fluid to one side.

CONCLUSION


Convergent solution possible for low Hartmann Numbers
Electric Potential Formulation
Continue to test and understand the results for NSTX options
Film Flow
Jet and Soaker Hose
Cross Checking
Convergent solution possible for higher Hartmann Numbers
Induced Magnetic- Field Formulation
Apply to CMOD Cases
Nov. Meeting
Improve formulation and techniques for boundary conditions
Experiments
Data