Some slides on UCLA LM-MHD capabilities

and

Preliminary Incompressible LM Jet Simulations in Muon Collider Fields

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HIMAG attributes in a nut-shell

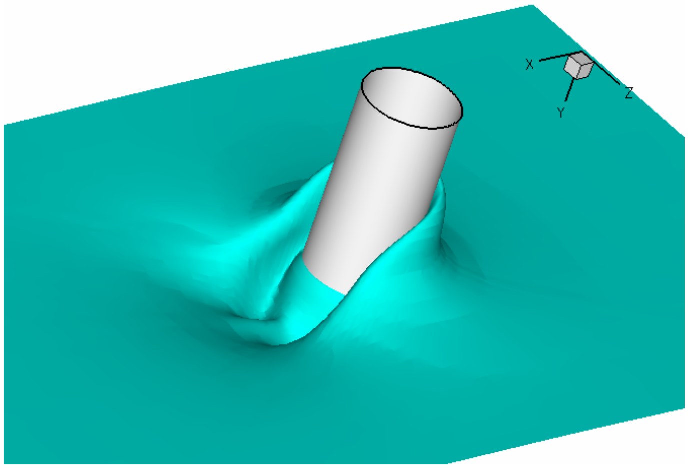
- HIMAG second order accurate, finite volume based Navier-Stokes solver on unstructured grids
  - including free surface with Level Set
  - electric potential and induction equation MHD models
- The code has been written for complex geometries and there is much flexibility in choosing a mesh: Hexahedral, Tetrahedral, Prismatic cells can be used.
- 2-D as well as 3-D flows can be simulated. A fully developed flow option has recently been created.
- The code is parallel. All problems can be run across parallel computers.
- Electromagnetics and flow physics are solved in a coupled manner. Two different formulations for electromagnetics are now available: phi and B.
- An arbitrary set of conducting walls maybe specified. Free surface flows are modeled using the Level Set method. **Multiple solid materials** can be simulated
- Graphical interfaces are available to assist users from problem setup to post-processing.
- A preliminary turbulence and heat transfer modeling capability now exists.

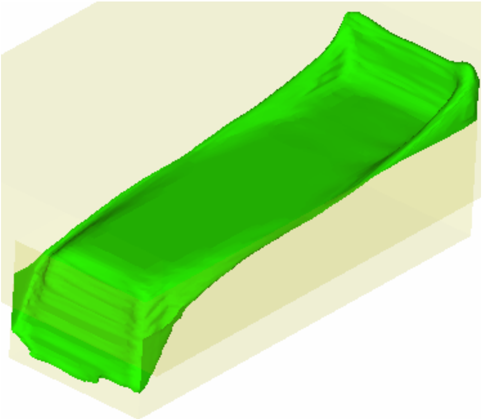
Free surface capture

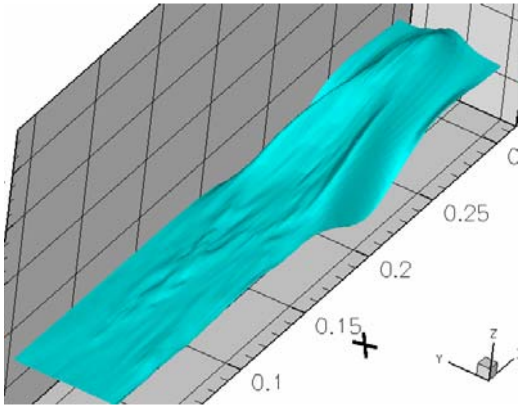
HIMAG uses the Level Set method to capture free surfaces

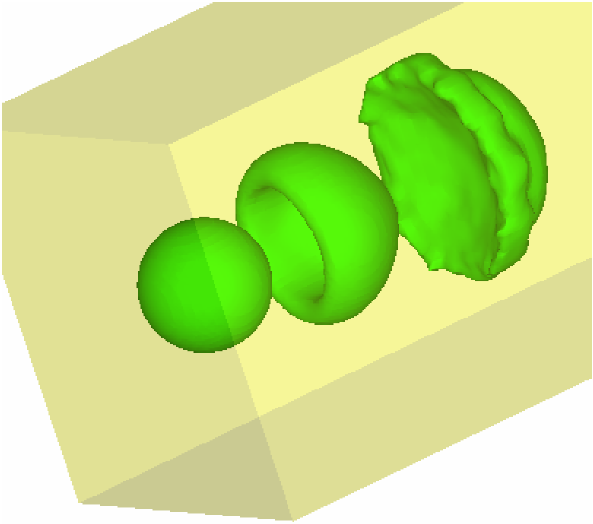
A higher order TVD procedure is used to enhance mass conservation and numerical stability

Examples of HIMAG simulations:



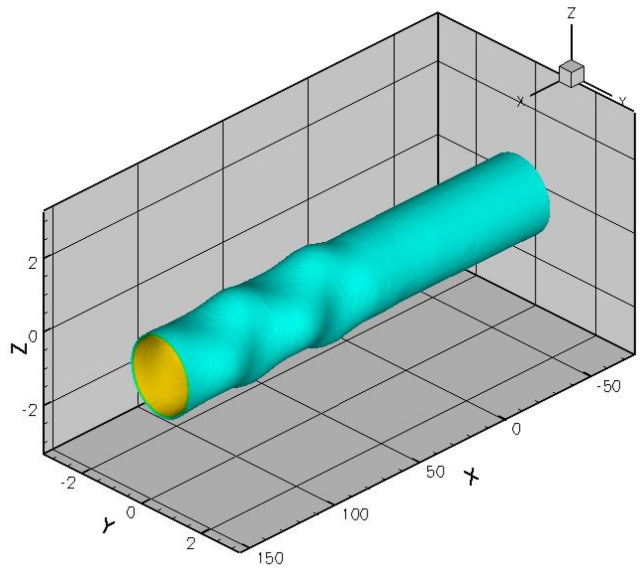


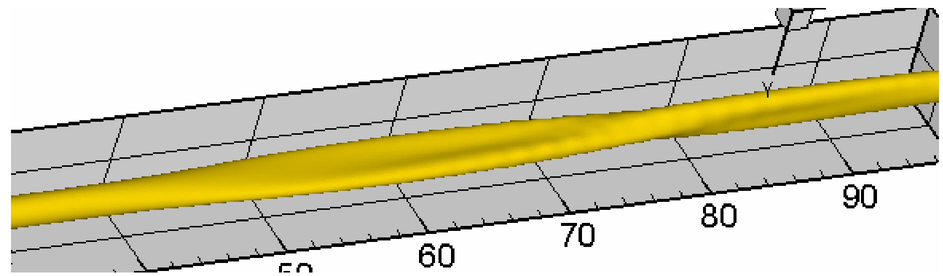




Jet flow under a 3-component applied B-field for fusion:

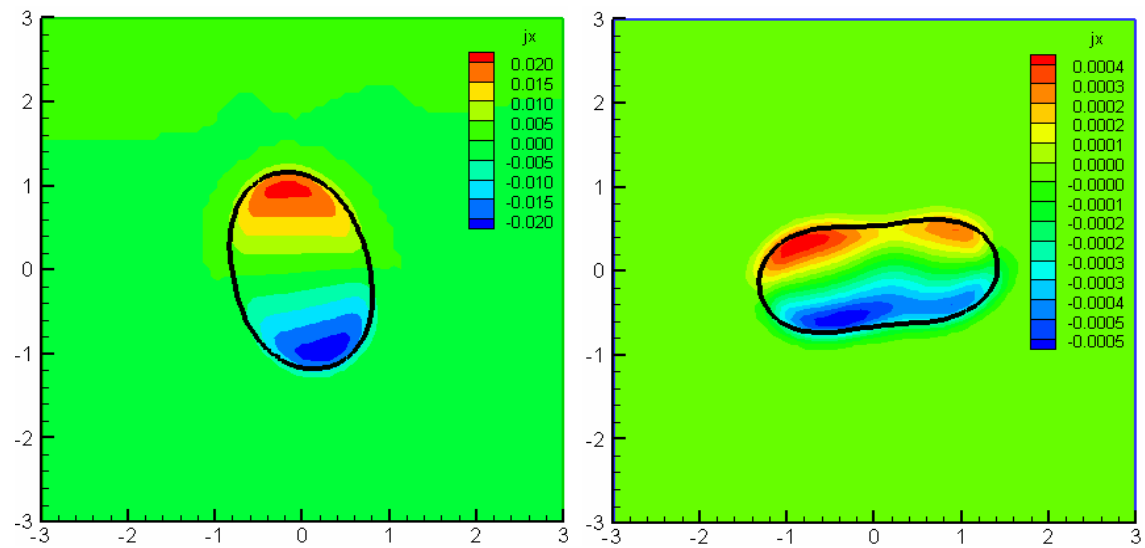
The warping of a liquid metal jet under a B-field with sharp spatial gradients is studied. The free surface can deform sizably.





Jet at the real aspect ratio, and exaggerated aspect ratio on the left.

Right: Jet deformation and Axial current density at two cross sections



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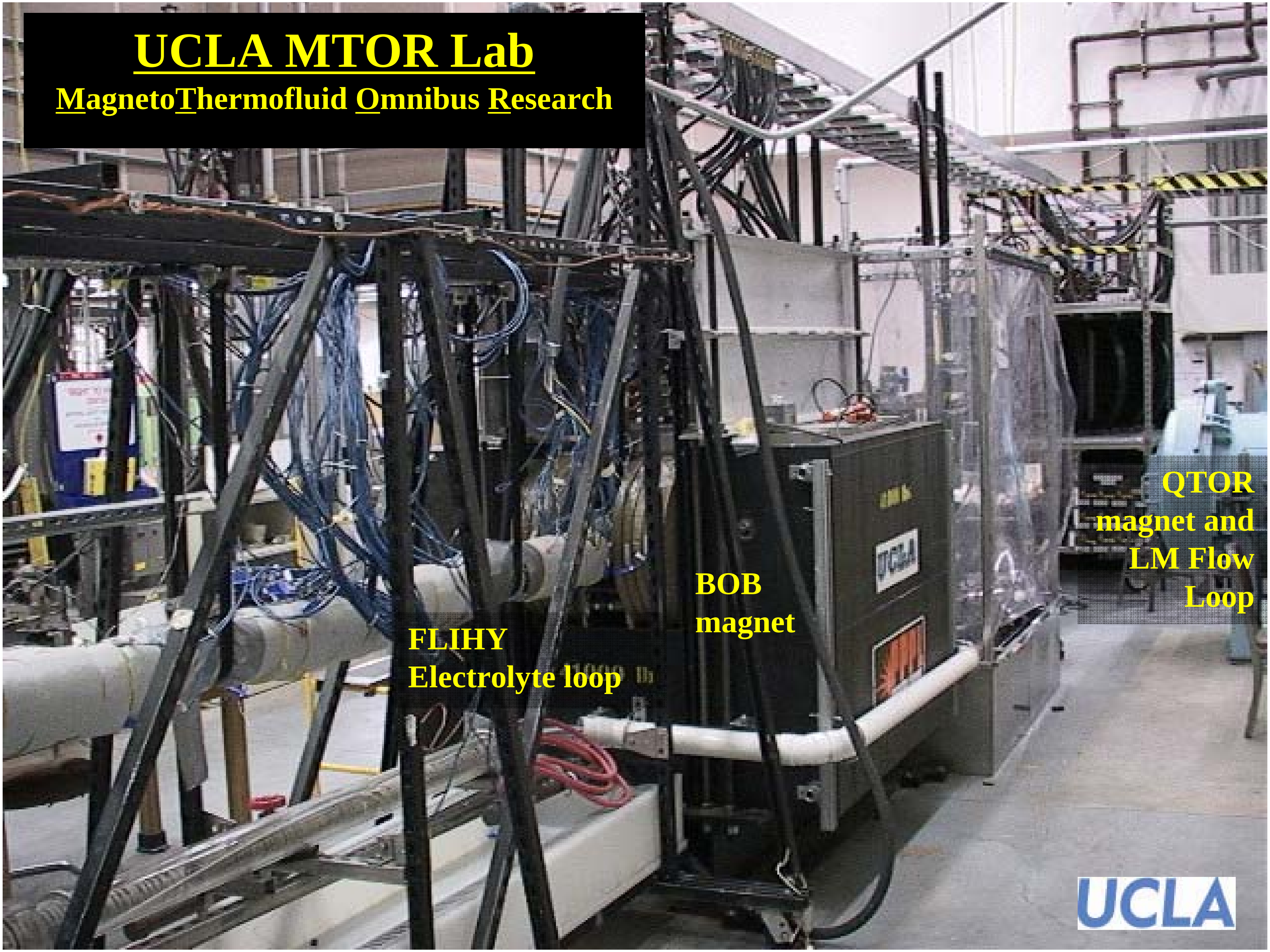
MagnetoThermofluid Omnibus Research

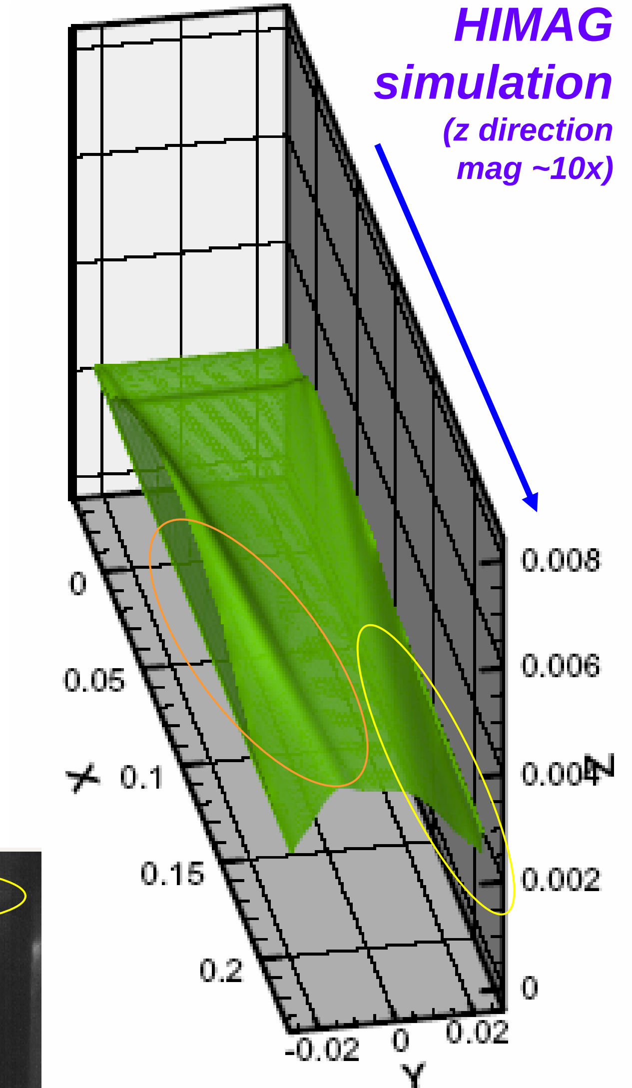


Experiments and Modeling of 3D MHD flows (both films & jets) show interesting free surfaces features

- ❑ Film flow example pictured: both numerical & experimental results show that the free surface height variation is **asymmetric** in span wise direction when both toroidal and normal field components are applied. Features like
  - ridge formation (orange ellipses) and
  - wall separation (yellow ellipses)

  are observed
- ❑ Drag is also significant and film height doubles in the first 20 cm

HIMAG simulation
(z direction mag ~10x)



5 cm wide Ga-In-Sn flow in a "NSTX-like" scaled toroidal and poloidal field

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Preliminary Muon Collider Simulation
Jet Parameters

- Horizontal solenoid with center at 0,0,0
- Field approximated as a single coil with the inner diameter 30 cm, outer diameter 40 cm, and length 100 cm. The total current is 7200 X 78 X 24 = 13478400 A.
- Nozzle outlet at x (longitudinal) = -40 cm and y (vertical) = -4 cm
- Nozzle tilt is 0.1 rad in xy plane (pointing only slightly upwards but mostly horizontal)
- Nozzle outlet radius is 5 mm
- Nozzle is not simulated, idealized inlet boundary conditions used with no MHD forces for first 5 cm.
- Jet initial average velocity is 25 m/s
- Mesh is uniform 50x50x200, space is 4x4x80 cm

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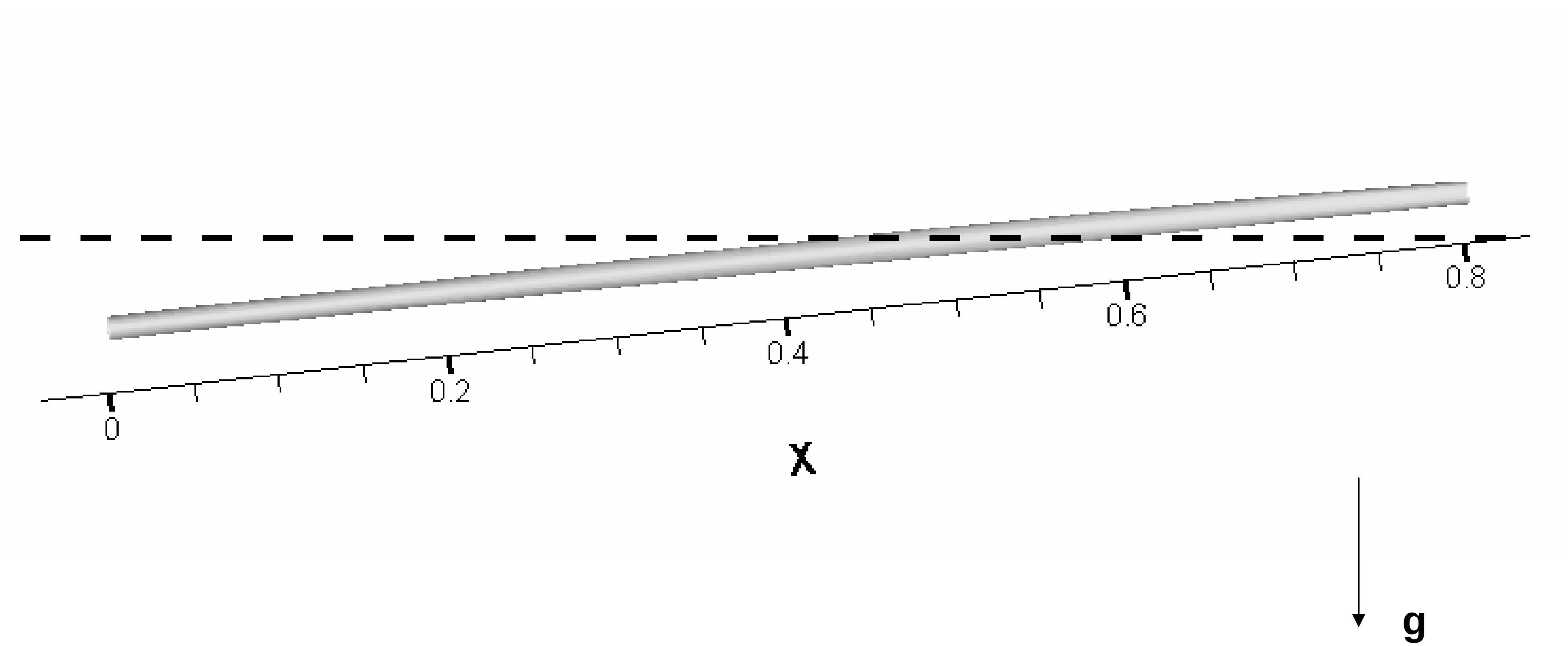
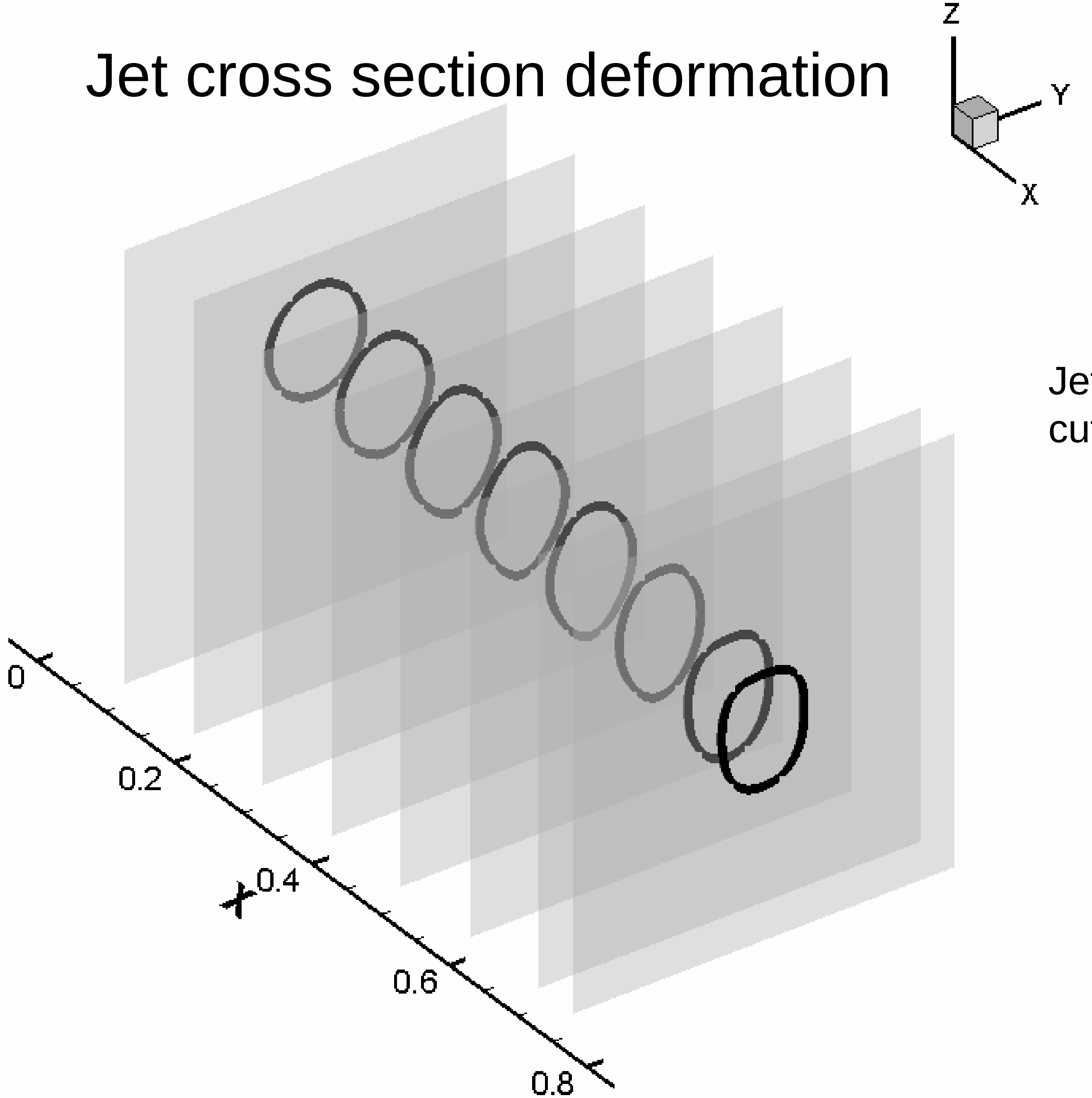
Jet trajectory relative to the magnetic axis of the solenoid.



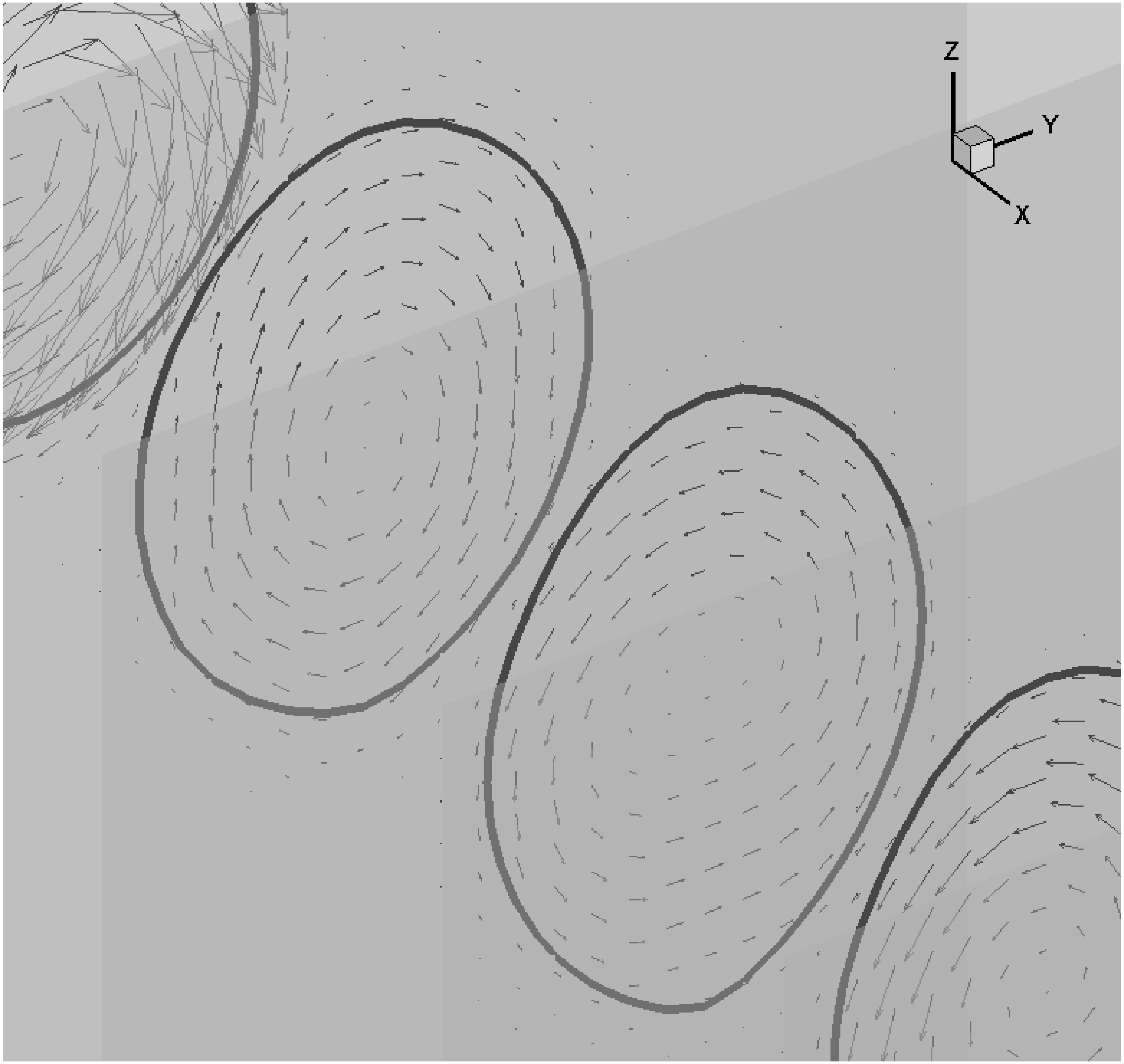
Magnification in x:y is 1:2

Solenoid center is at x = 0.4 in this simulation

Jet cross section deformation



Jet cross sections cut every 10 cm



Zoomed in view. Sections at X = 10, 20, 30 and 40 cm.

Reversal in induced current direction occurs between X = 20 and X = 30 cm.

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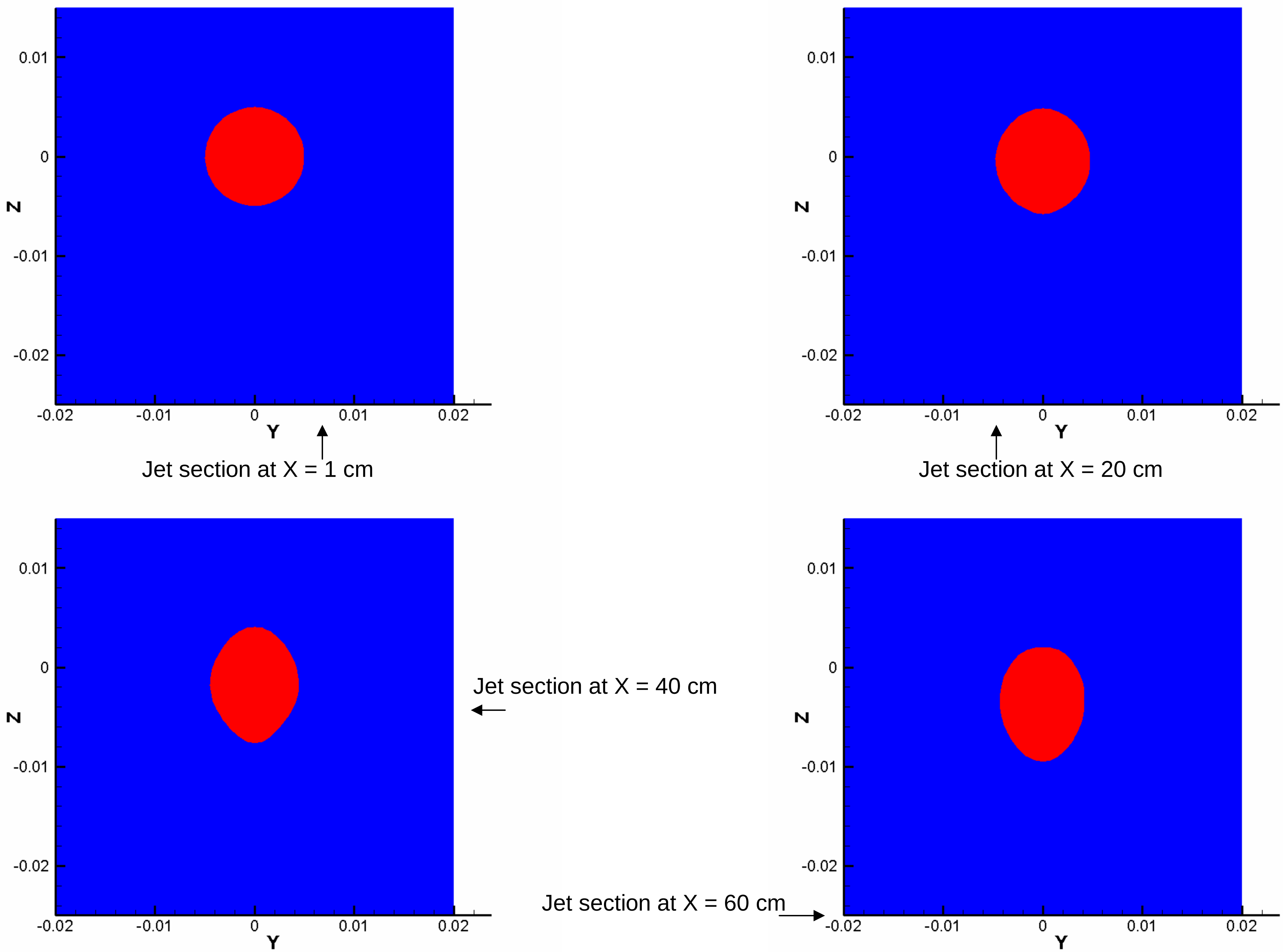
0.01
0
Z
-0.01
-0.02
-0.02
-0.01
0
0.01
0.02
Y
Jet section at X = 1 cm
Jet section at X = 20 cm
Jet section at X = 40 cm
Jet section at X = 60 cm

Remarks

- Neglect of electrically conducting nozzle in such a strong field is a big simplification – transition from nozzle to free surface flow will likely be an initial disturbance affecting jet shape. Future simulations should include this nozzle.
- For future simulations, higher resolution should be used
- This simulation executed in 1day on 16 3GHz Xeon processors at UCLA
- Experiments at UCLA experimental facility using gallium alloy possible at low field ~1.5T, or higher field with magnet upgrade (if any interest I will look for suitable magnet in fusion community)

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