MUTAC Review
April 6-7, 2009, FNAL, Batavia, IL

Mercury Jet Target Simulations

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Talk Outline

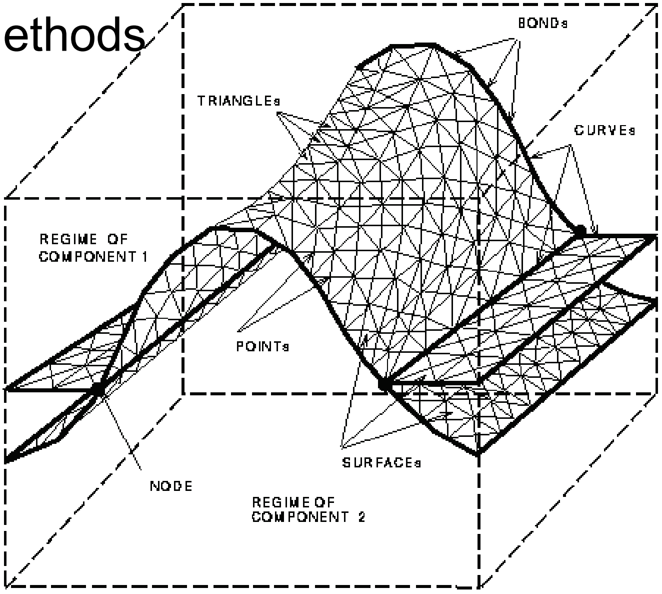
- Brief summary of the previous work
- Motivation and numerical advances of the present study
- Hydro simulations (B = 0) of the mercury jet - proton pulse interaction. Studies of the elliptic jet and reduced density cylindrical jet
- MHD simulations of the mercury jet - proton pulse interaction
- Comparison with MERIT experiment, conclusions and future plans

Main Ideas of Front Tracking and *FronTier* code

Front Tracking: A hybrid of Eulerian and Lagrangian methods

Two separate grids to describe the solution:

1. A volume filling rectangular mesh
2. An unstructured codimension-1 Lagrangian mesh to represent interface

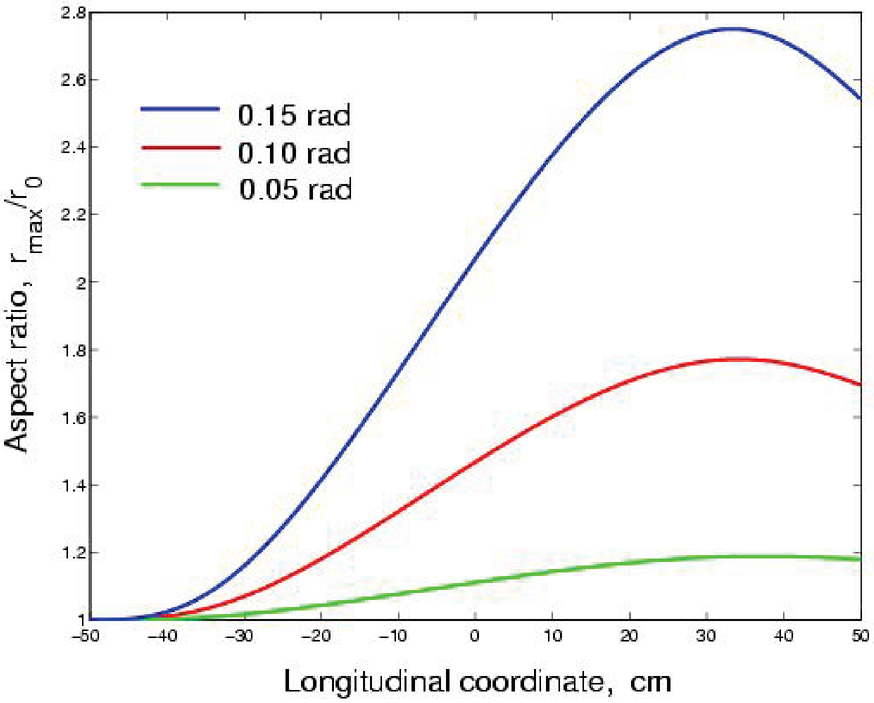


- ***FronTier*** is a code for multiphase flows based on front tracking
- Physics models include
  - Compressible fluid dynamics
  - Incompressible fluid dynamics
  - MHD
  - Flow in porous media

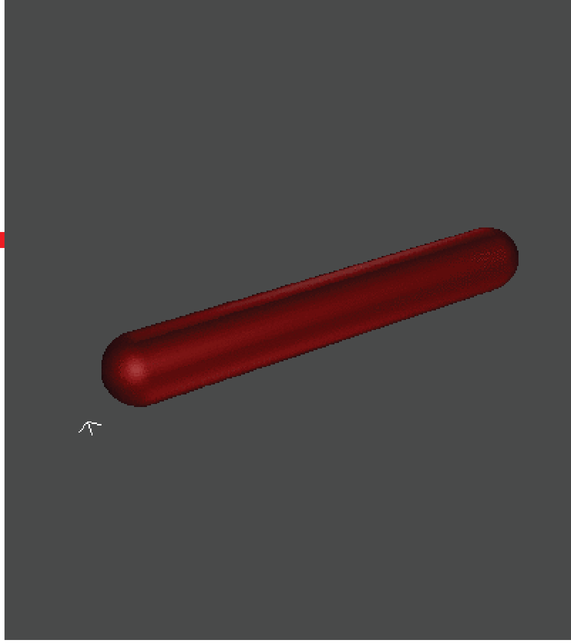
Advantages of explicit interface tracking:

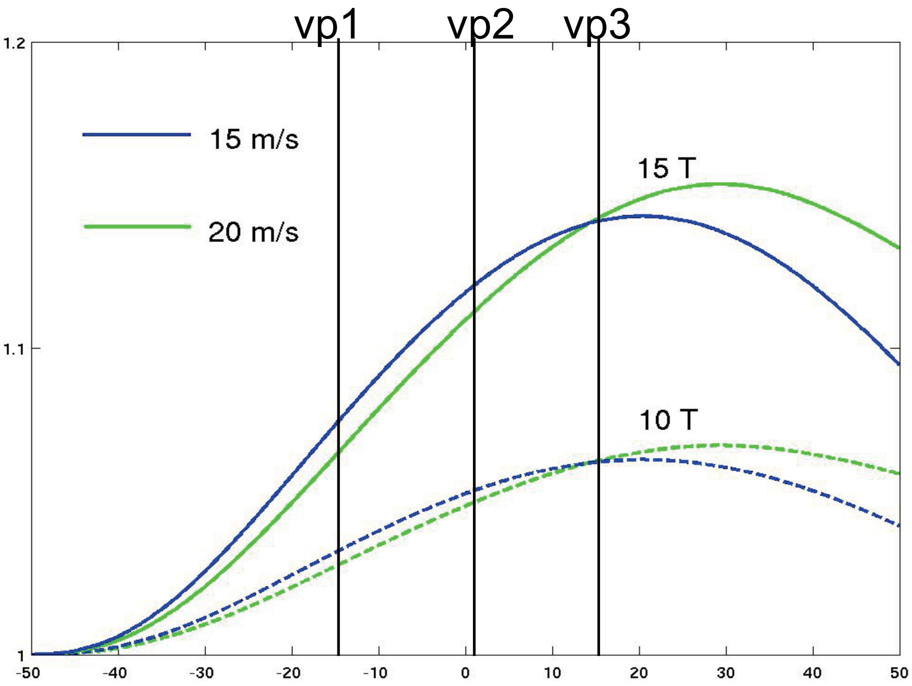
- No (or limited) numerical interfacial diffusion across interfaces
- Real physics models for interface propagation
- Different physics / numerical approximations in domains separated by interfaces

Previous work: jet entering solenoid



B = 15 T
V0 = 25 m/s





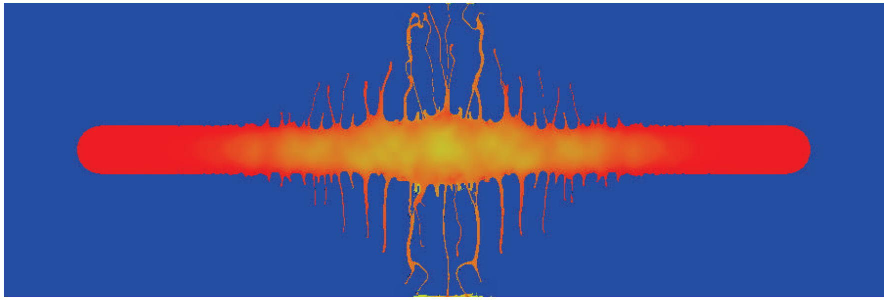
Top: Aspect ration of the jet entering 15 T solenoid

Right: Simulations using MERIT setup

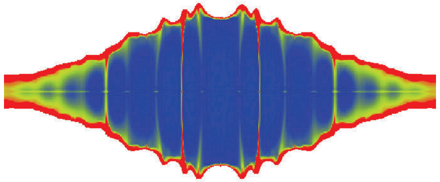
Jet - proton pulse interaction. Evolution of models.

Phase I: Single phase mercury (no cavitation)

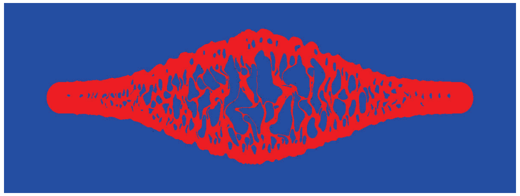
- Strong surface instabilities
- Jet oscillates after the interaction and develops instabilities



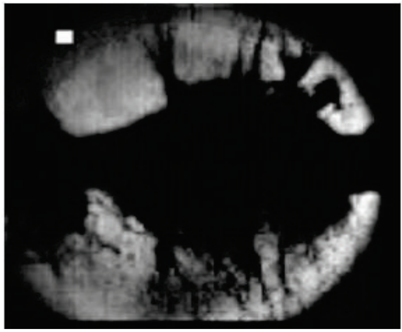
Phase II: Cavitation models



Homogeneous model



Heterogeneous model



Experiment

- Predicted correct jet expansion velocity
- Surface instabilities and jet breakup were not present in simulations

- MHD forces strongly affected the jet expansion / cavitation

New Phase of Study: Large Scale 3D Simulations

- Previous simulations were mostly 2D. 3D simulations had very limited numerical resolution

- Significant improvement of 3D interface tracking algorithms in recent years

- Large computational facilities now available (130 Teraflop BlueGene supercomputer at BNL, other resources)

- Full 3D simulations are now feasible with all physics processes resolved (direct numerical simulation of cavitation)

Example of new FronTier: 3D Jet Atomization

Motivation of the Present Study

- Understanding of the hydrodynamic response of the mercury target and explanation of all details of MERIT data is necessary for the future target design

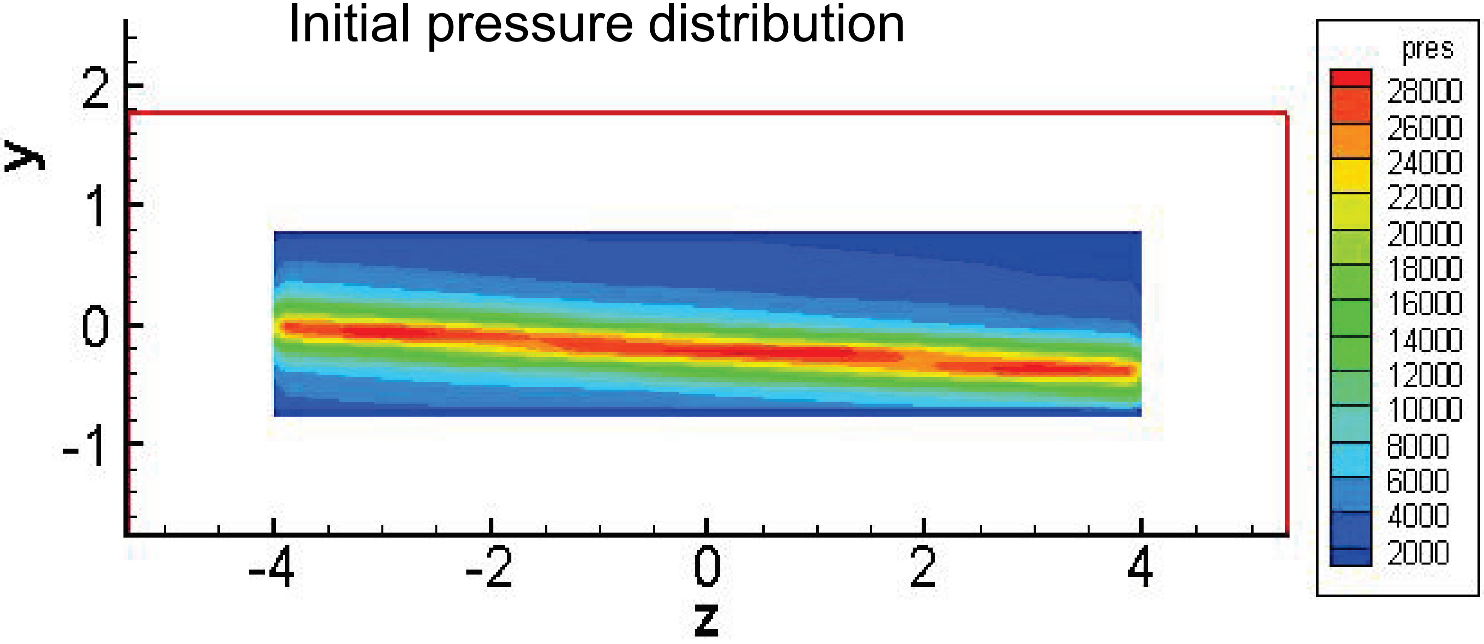
- Using improved 3D FrontTier capabilities, perform new series of full 3D simulations of the mercury target with resolved all relevant physics processes

- Perform full benchmark of simulations with MERIT data and fine-tune FronTier models

- After the benchmark, FronTier can be used for reliable predictions of future targets. Especially important if new experiments are not planned for the near future

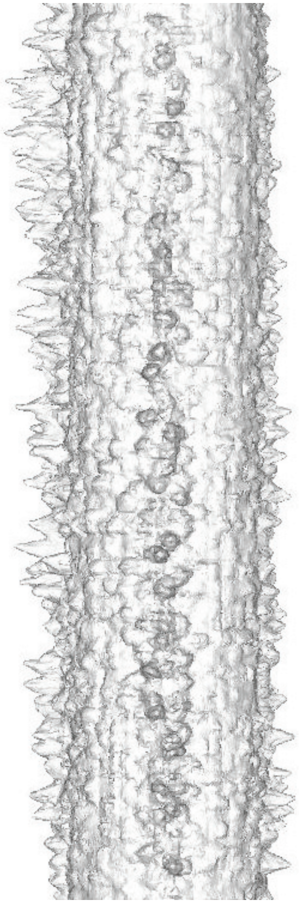
Simulation setup for proton-jet interaction

- Two scenarios tested: cylindrical and elliptic jet
- Parameters: Length = 8cm, Radius = 0.8 cm, Density = 5.3 g/cc
- Sergei Striganov’s energy deposition calculation for 24Gev, 10TP beam is used. The peak pressure is 30,000 bar


Initial pressure distribution

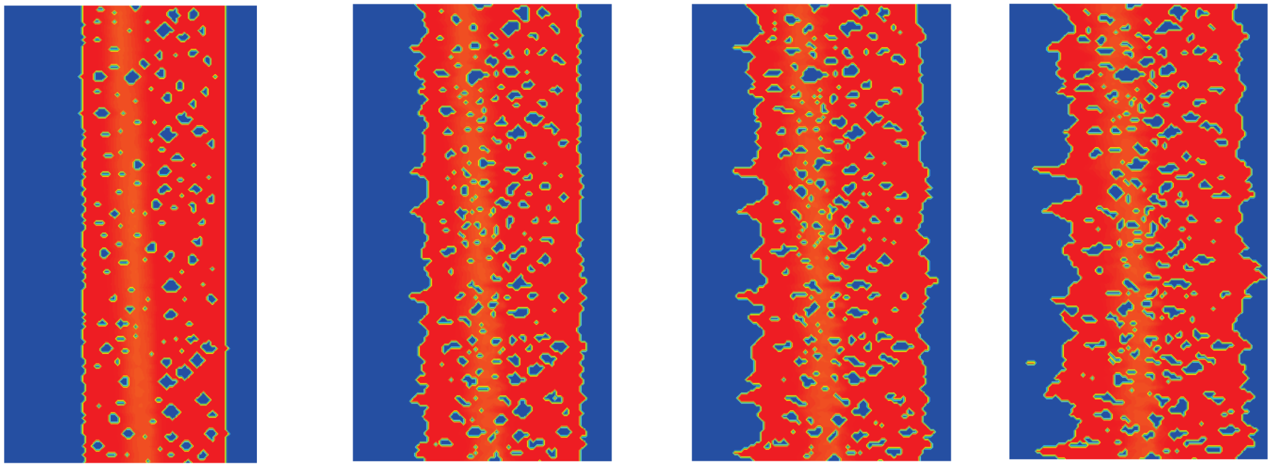
Simulation Results

Surface filaments
at 160 microseconds



- The energy deposition profile:

$$\sigma_x = 0.13394\text{cm} \ \sigma_y = 0.07894\text{cm}$$

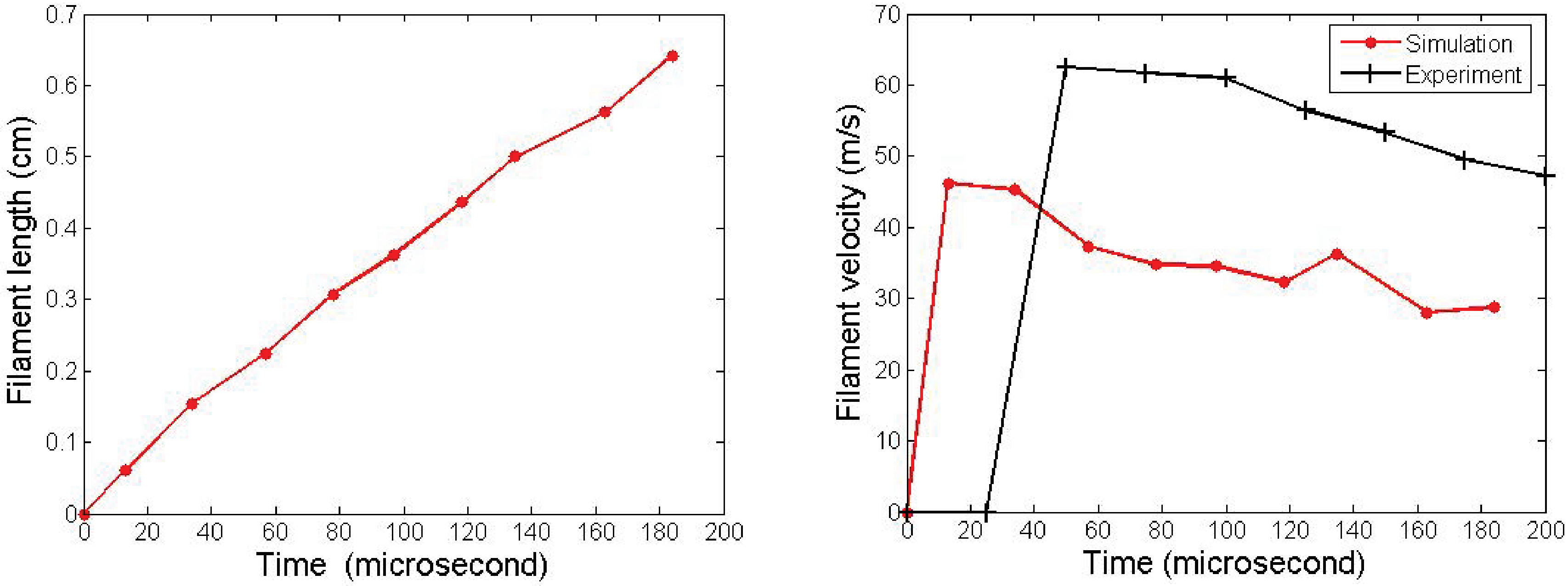


Density at time (microseconds)

20 130 200 250

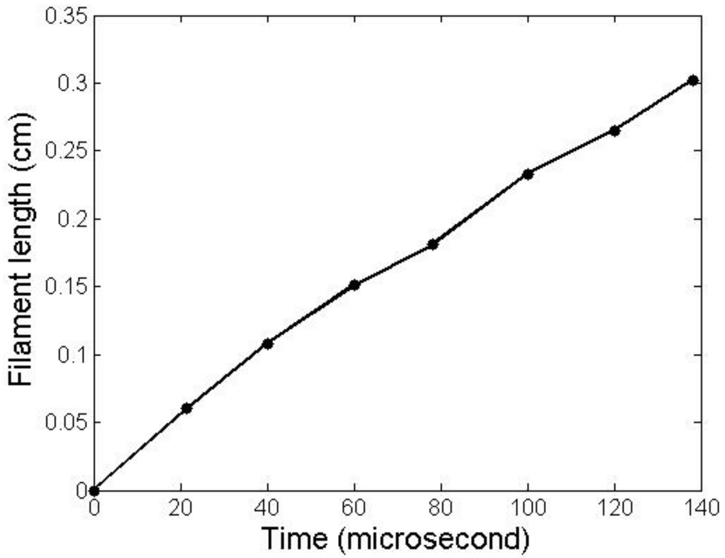
Growth of Filaments

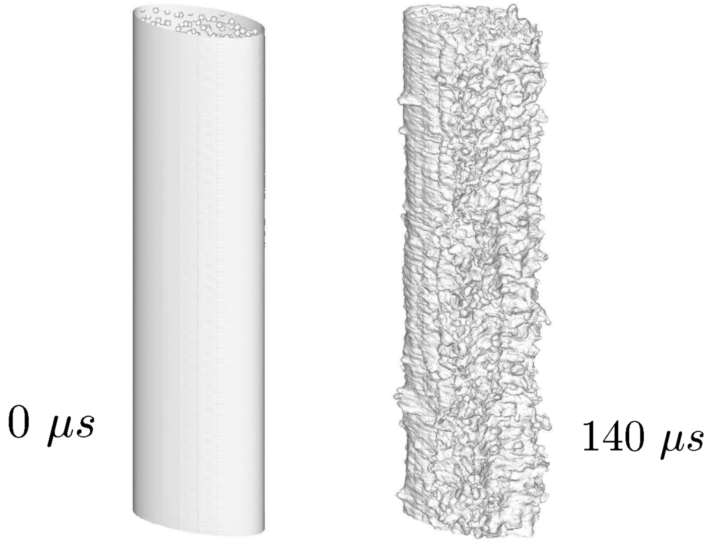
- The length and velocity of the fastest growing filament
- The velocity reduction is not caused by the air drag



Elliptic Jet

- The energy deposition parameters are
  $\sigma_x = 0.33\text{cm} \ \sigma_y = 0.27\text{cm}$
- The filament velocity along minor axis is much larger than that along the major axis.
- The velocity is smaller compared to the cylindrical case as the initial energy profile is much flatter
- The absolute value of the peak energy deposition has much smaller effect: the increase of the peak value by 2 does not lead to significant velocity increase

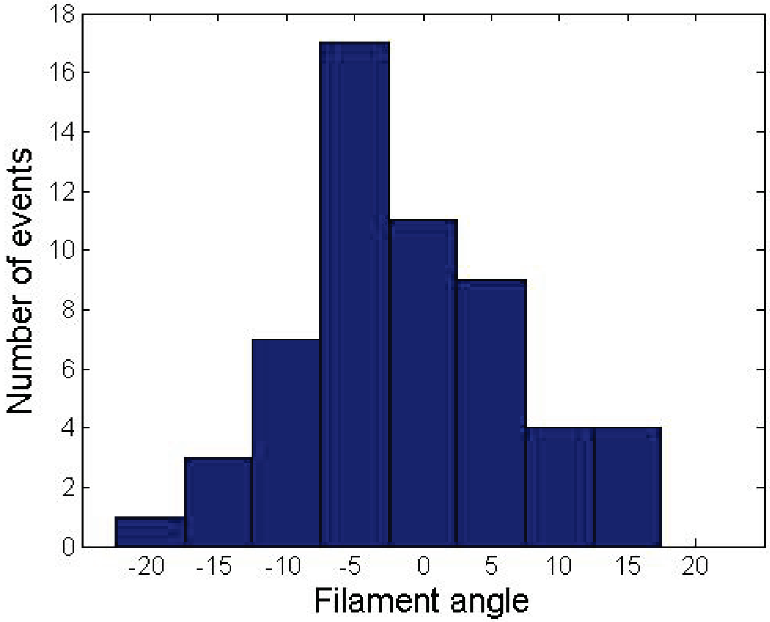




Elliptic Jet: Direction of Filaments

- Directions of filaments was evaluated at various surface points

- Filaments grow in the normal direction to the surface



Conclusions of Hydro Simulations

- The expansion of the jet and the growth of the filaments on jet surface are noticed in the simulations of both circular and elliptic case. This is consistent with experimental observation
  - Cavitation is critical for the formation and evolution of jet instabilities. Without cavitation, the surface filaments stop growing after a few microseconds.

- The filaments reach their maximal velocity when they first protrude out of the jet surface. For circular case, the average filament velocity is 36m/s. The small velocity reduction is not related to the air drag.

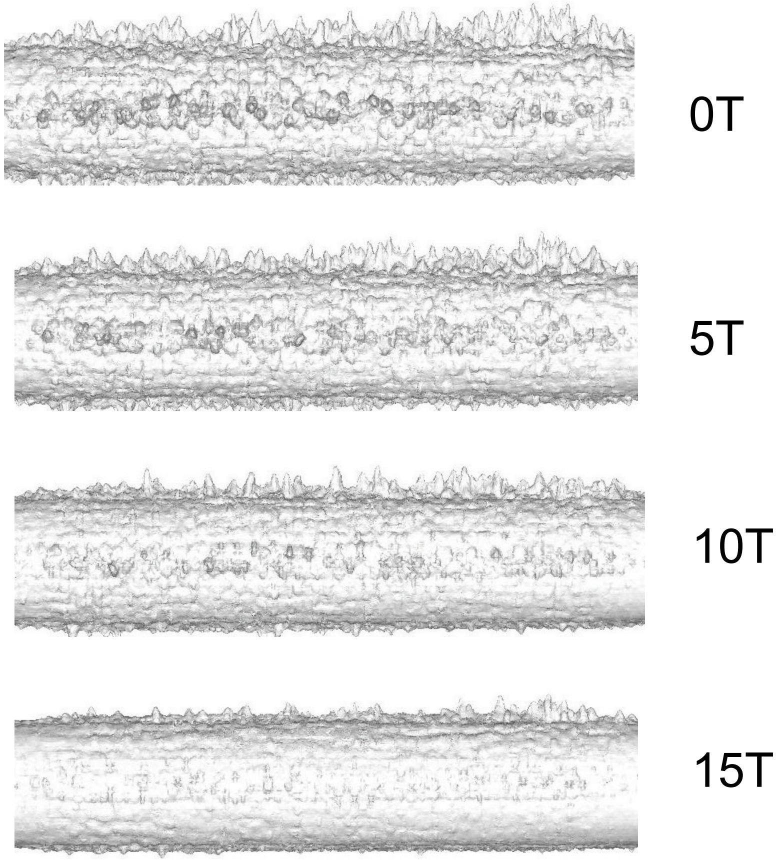
- For elliptic jet, the filament velocity along the minor axis is much larger than that along the major axis.

- Lower velocity of filaments in elliptic jet are caused by much flatter energy deposition profile

- The delay of filament growth found in experiments is not observed in the simulations.

MHD Stabilizing Effect

- Right: From top to bottom, the jet surface at 150 microsecond under longitudinal magnetic field.
- Both the interior velocity and the surface velocity of the jet are decreasing with the increasing magnetic field.
- The MHD stabilizing effect is weaker than the corresponding 2D simulations where circular current exists in filaments.



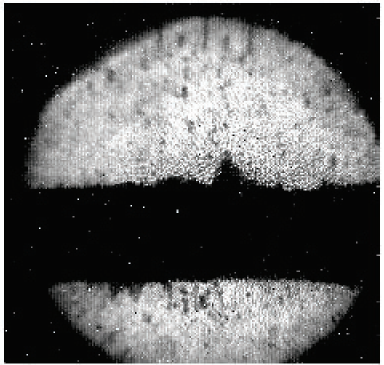
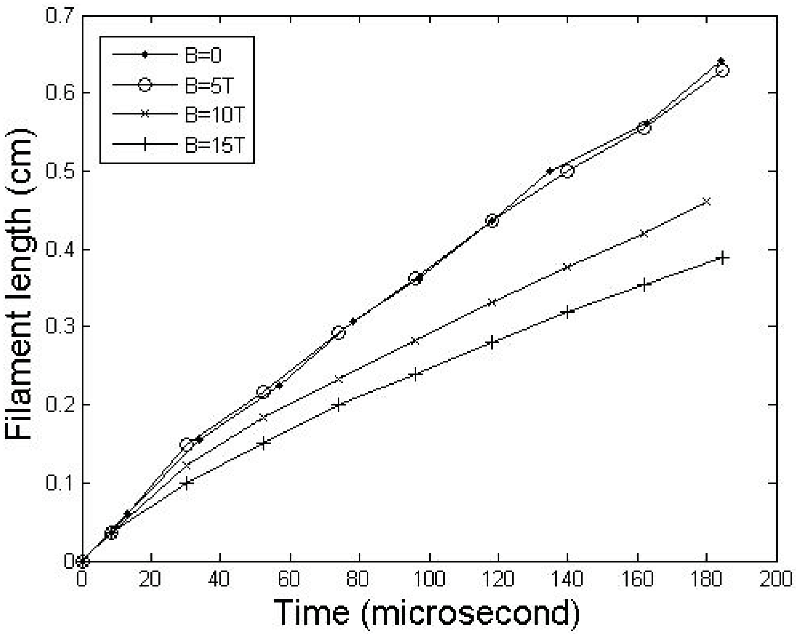


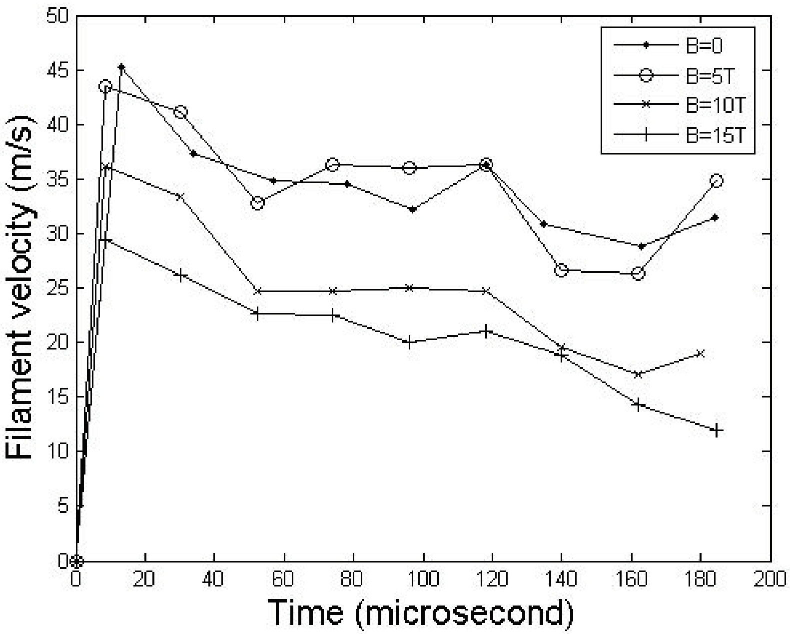
Image from the experiment, B=10T

Growth of Filaments

- The length and velocity of the fastest growing filament.

magnetic field	5T	10T	15T
experiments	54 m/s	50 m/s	35 m/s
simulations	36 m/s	27 m/s	22 m/s





Conclusions and Future Plan

- New robust algorithm for topological change of 3D surface, 3D bubble insertion method coupling with the MHD code enabled large scale 3D simulations with complex geometry.
- Performed simulations of cylindrical and elliptic jets interacting with magnetic fields
- Surface instability and MHD stabilizing effect were noticed in the simulations. However, the filament velocity in the simulations was about 25% smaller than the experimental value.
- The delay of filament formation was not observed in simulations.

- Need to clarify the physics of the observed delay of the jet disruption
- Further study of the jet entrance in the magnetic field will be performed and the contribution of several factors (velocity profile, turbulence etc) will be tested
- Further study of mercury jet - proton pulse interaction
- Comprehensive benchmark with MERIT experiments