Three Dimensional Pore Modeling and Laminar Dividing Flow

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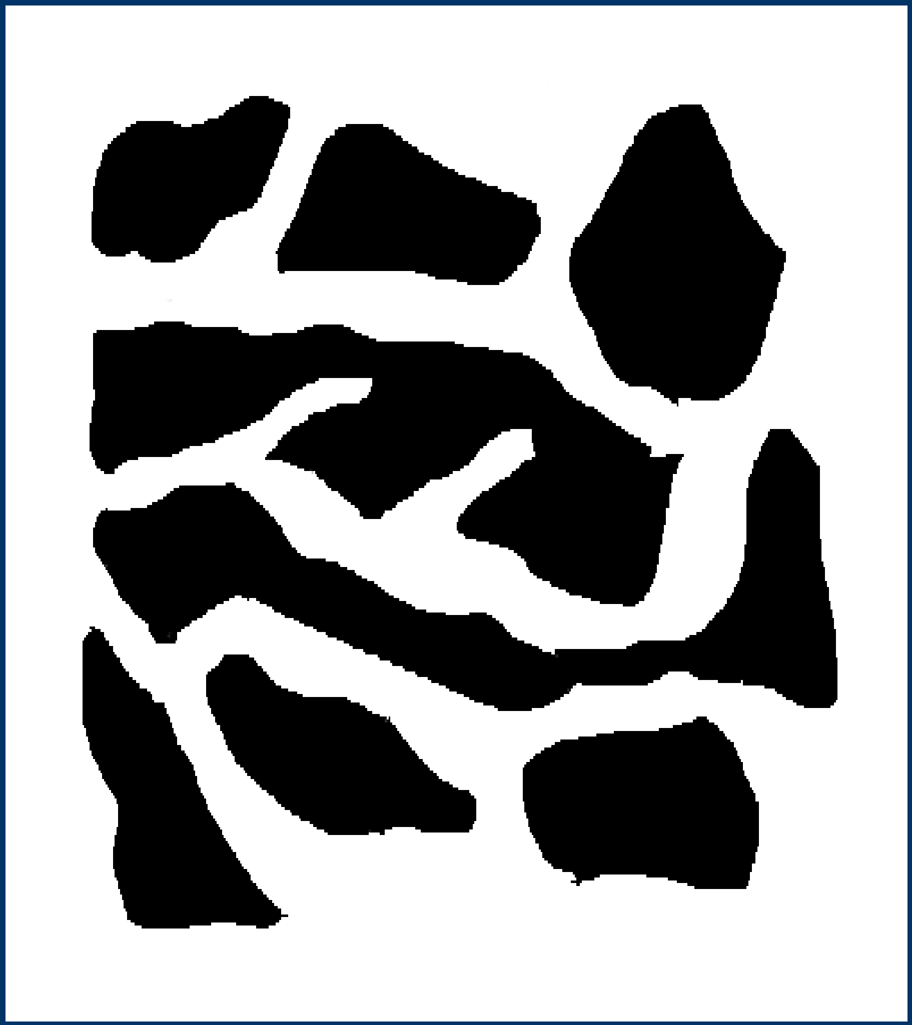
Evan Lemley
Department of Physics and Engineering
University of Central Oklahoma

Current Research

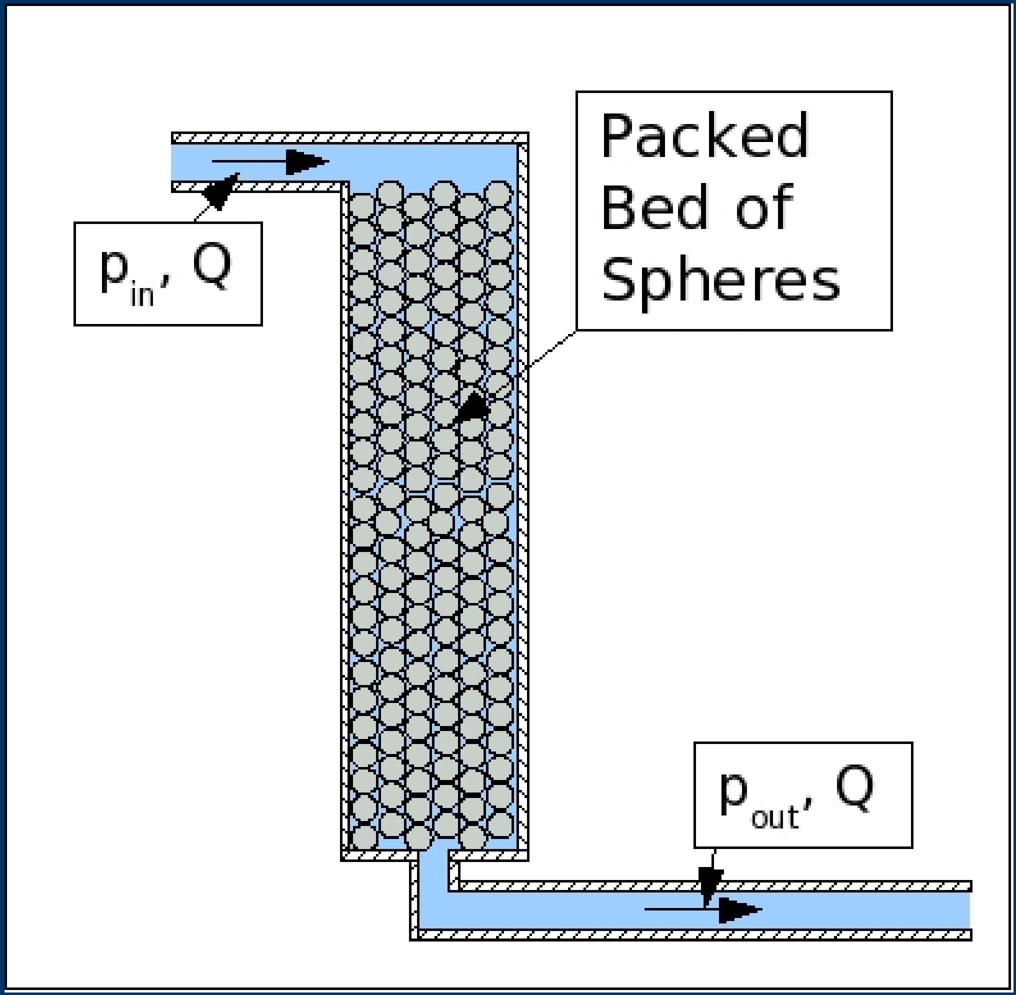
- Collaborative Effort with Dimitrios Papavassiliou and Henry Neeman from OU (began Fall 2004)
- Simulation of Flow of Fluids through Porous Media
- Code FTPM – Flow Through Porous Media. *Solves for velocity and pressure at pore junctions in a randomly generated pore network.*

Naturally Occurring Porous Media



- Sandstone, Limestone, Blood Vessels in Tissue, Soil, etc...
- Pore Sizes μm to mm
- Flow induced by pressure, buoyancy, capillarity

Artificial Porous Media



- Packed Beds, Gas and Liquid Filters
- Sphere sizes μm to cm
- Hold-up for chemical reaction, thermal processing, or filtering

Basics of Porous Media

- Low Speed Flow – Darcy's Law

$$\frac{dp}{dx} = \frac{\mu}{\kappa} u$$

$p = pressure \quad x = position$

$\mu = viscosity \quad \kappa = permeability$

$u = filtration \quad velocity$

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- High Speed Flow – Forsccheimer's Law

$$\frac{dp}{dx} = \frac{\mu}{\kappa} u + \rho \beta u^2$$

$\rho = density$

$\beta = Forccheimer's \quad Coefficient$

-
- Packed Beds – Ergun's Equation (empirical)

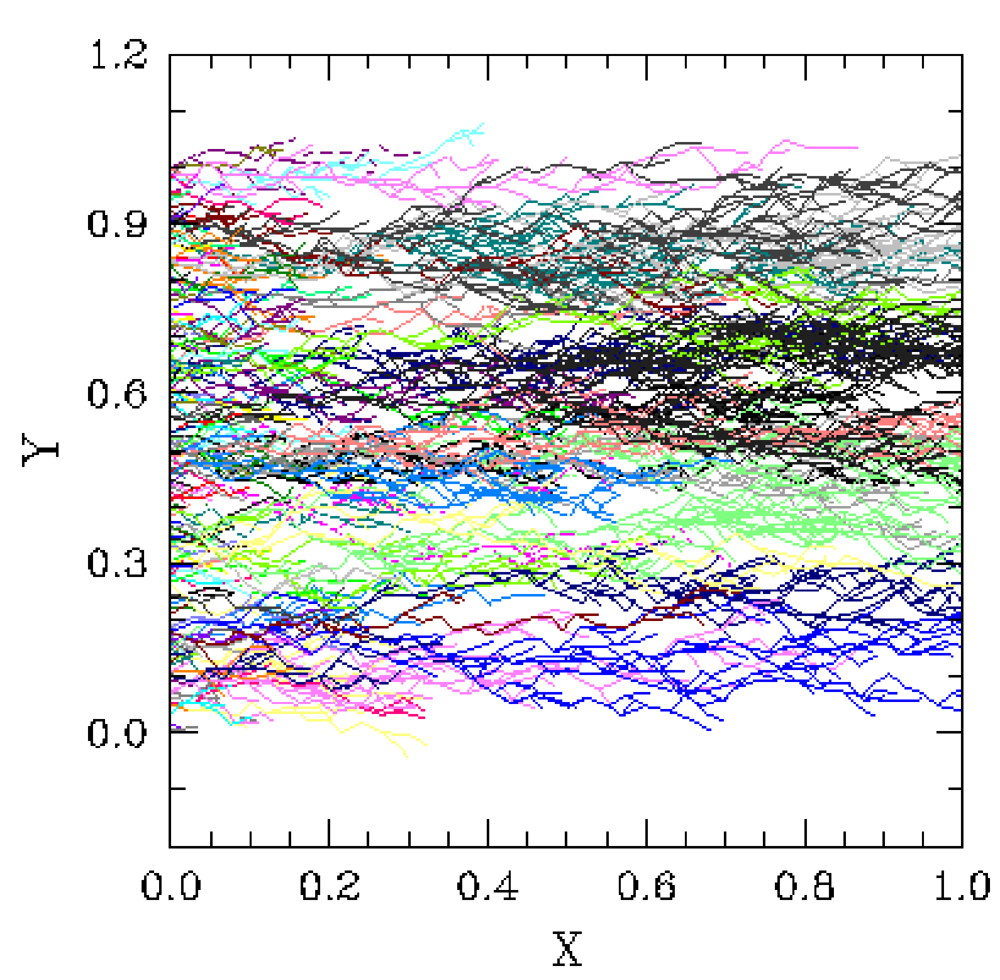
$$\frac{-\Delta p}{\Delta L} = \frac{150 \mu}{d_p^2} \frac{(1-\phi)^2}{\phi^3} u + \frac{1.75 \rho (1-\phi)}{d_p \phi^3} u^2$$

$\phi = porosity$

$d_p = mean \quad sphere \quad diameter$

Pore Network Simulation FTPM – random pipe networks

3-D projection to X-Y plane, 200 networks, $\theta = \pm 60^o$, $\varphi = \pm 30^o$
P(c=1)=P(C=3)=0.3, porosity=*0.1*



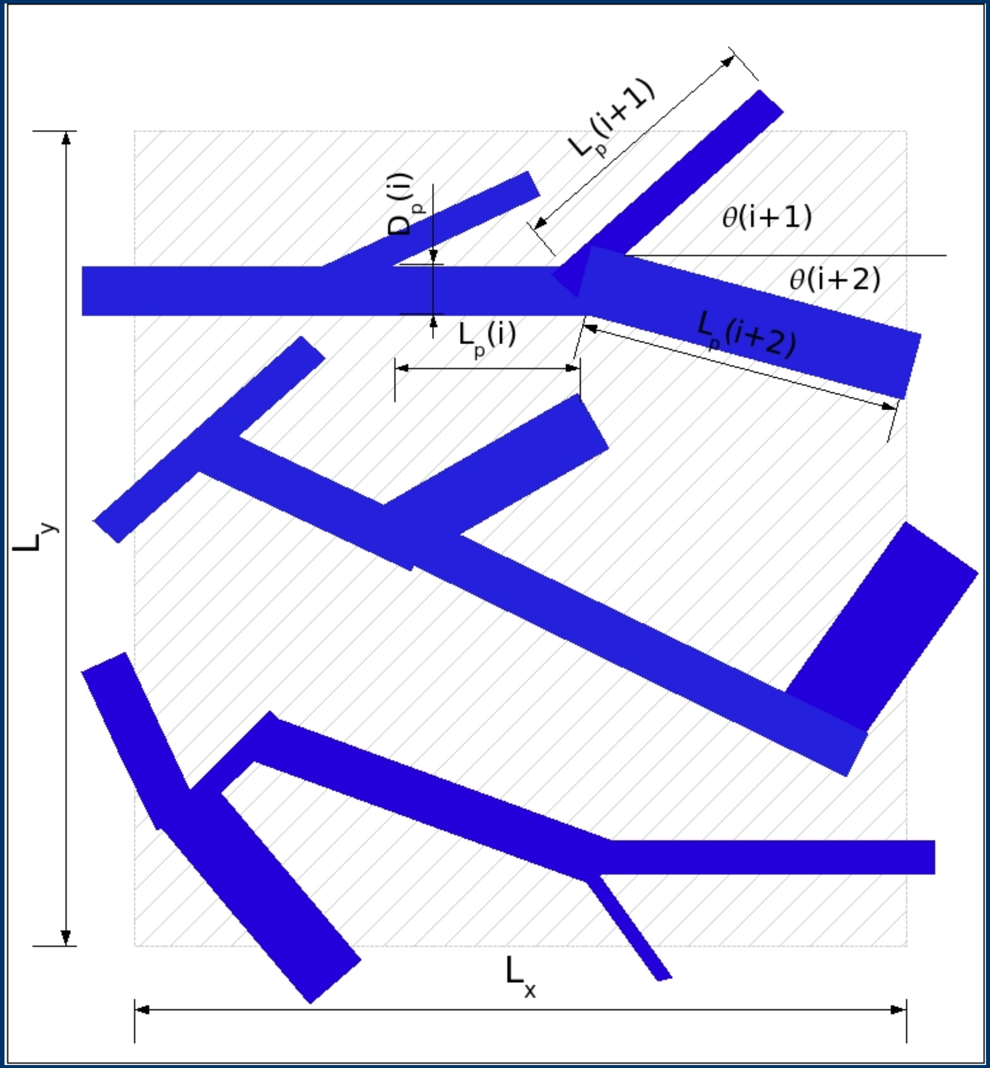
Pipe Network Principles

1)Conservation of mass at all pipe junctions.
2)Conservation of energy at all pipe junctions.
3)Relationships between velocities in child pores (if more than one child pore).
4)Relationships between pressures in child pores (if more than one child pore)

Modeling in FTPM

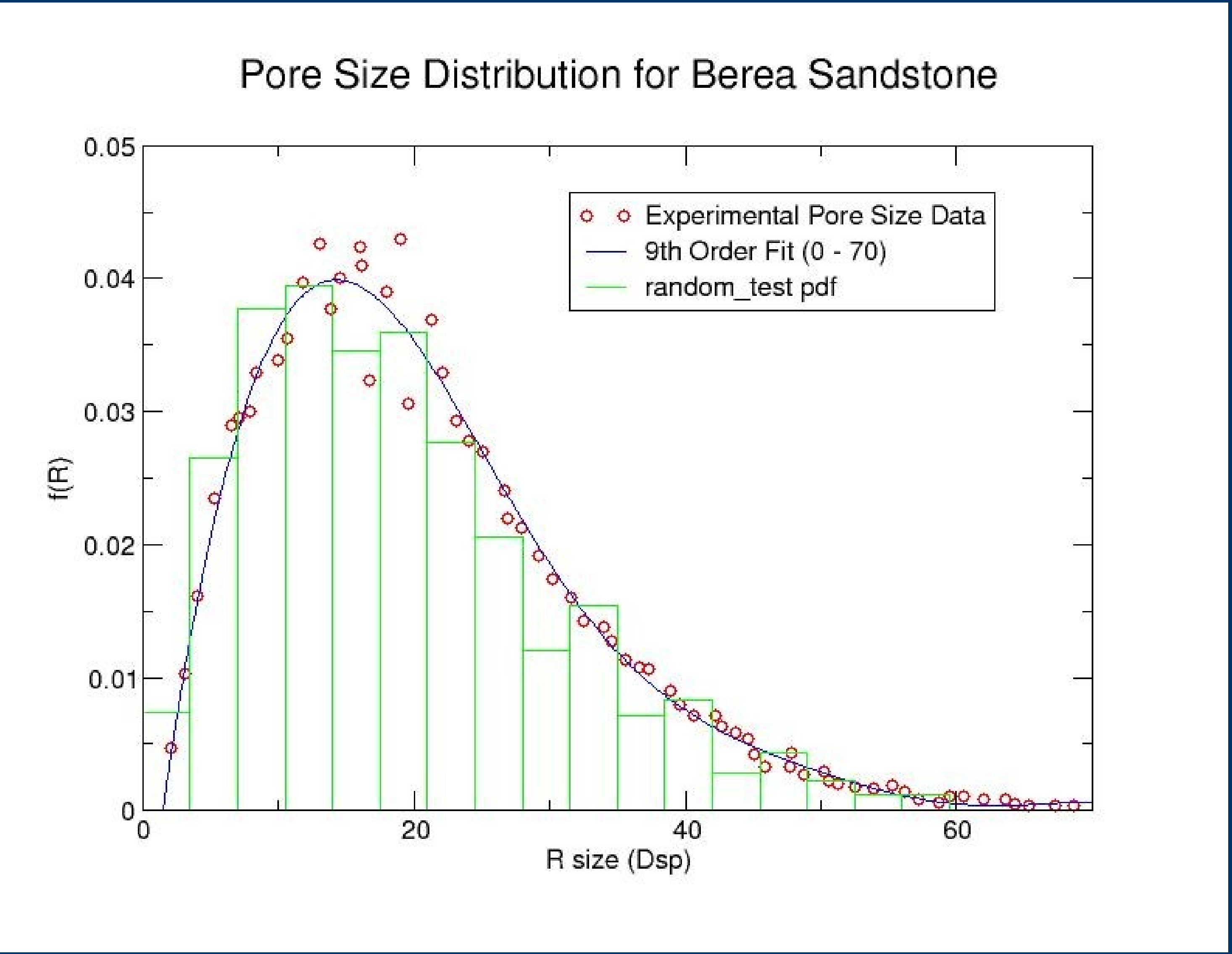
1)Monte Carlo creation of random pore networks.
2)Solution of pipe network equations with Newton's Method.
3)Pipe Network Principle #4 makes solution possible.

Monte Carlo – Pipe Network Creation



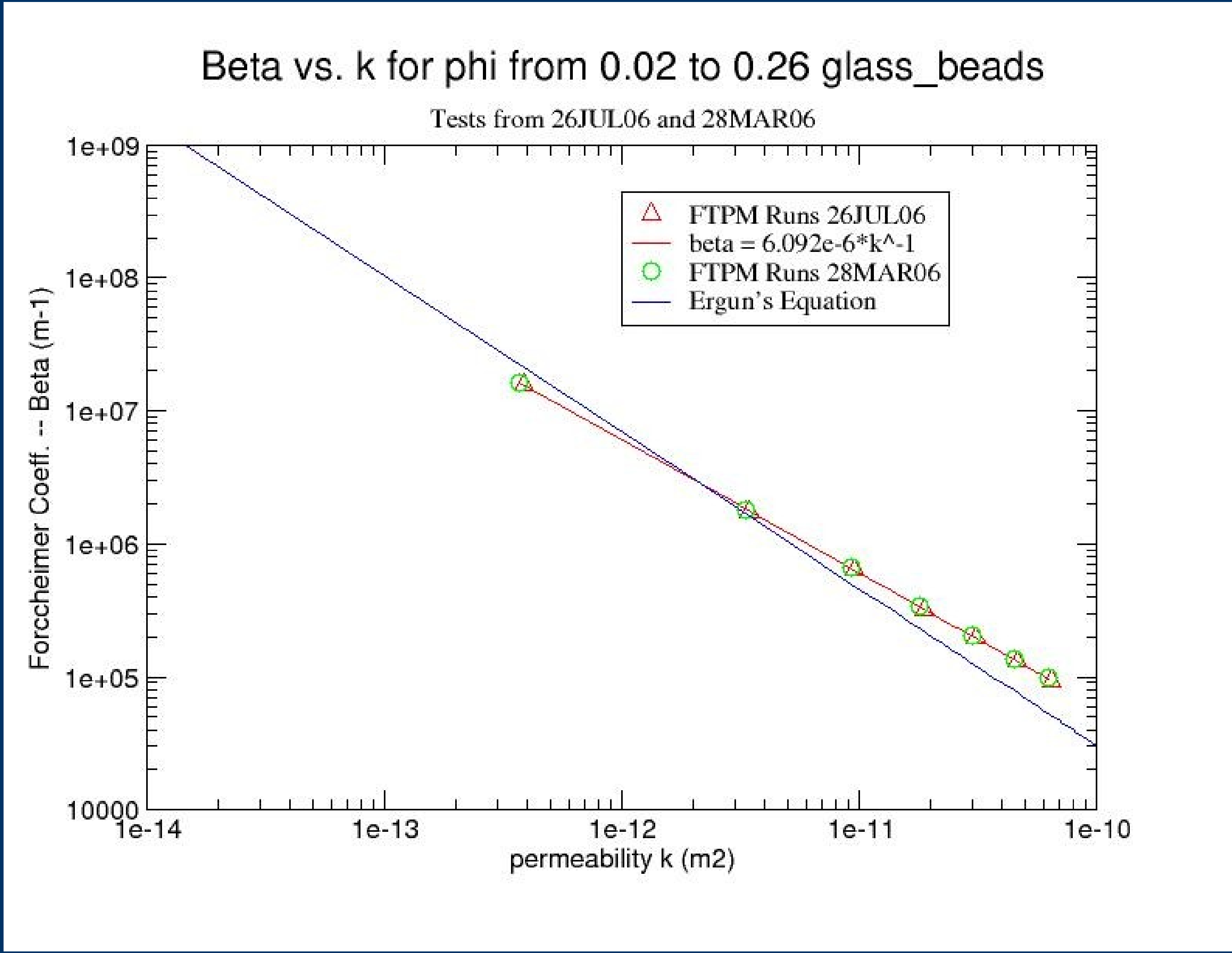
- Sample from normal or beta distributions with mean and std. dev. of diameters
- Sample from empirical pore size distributions.

Polynomial fits to Sandstone

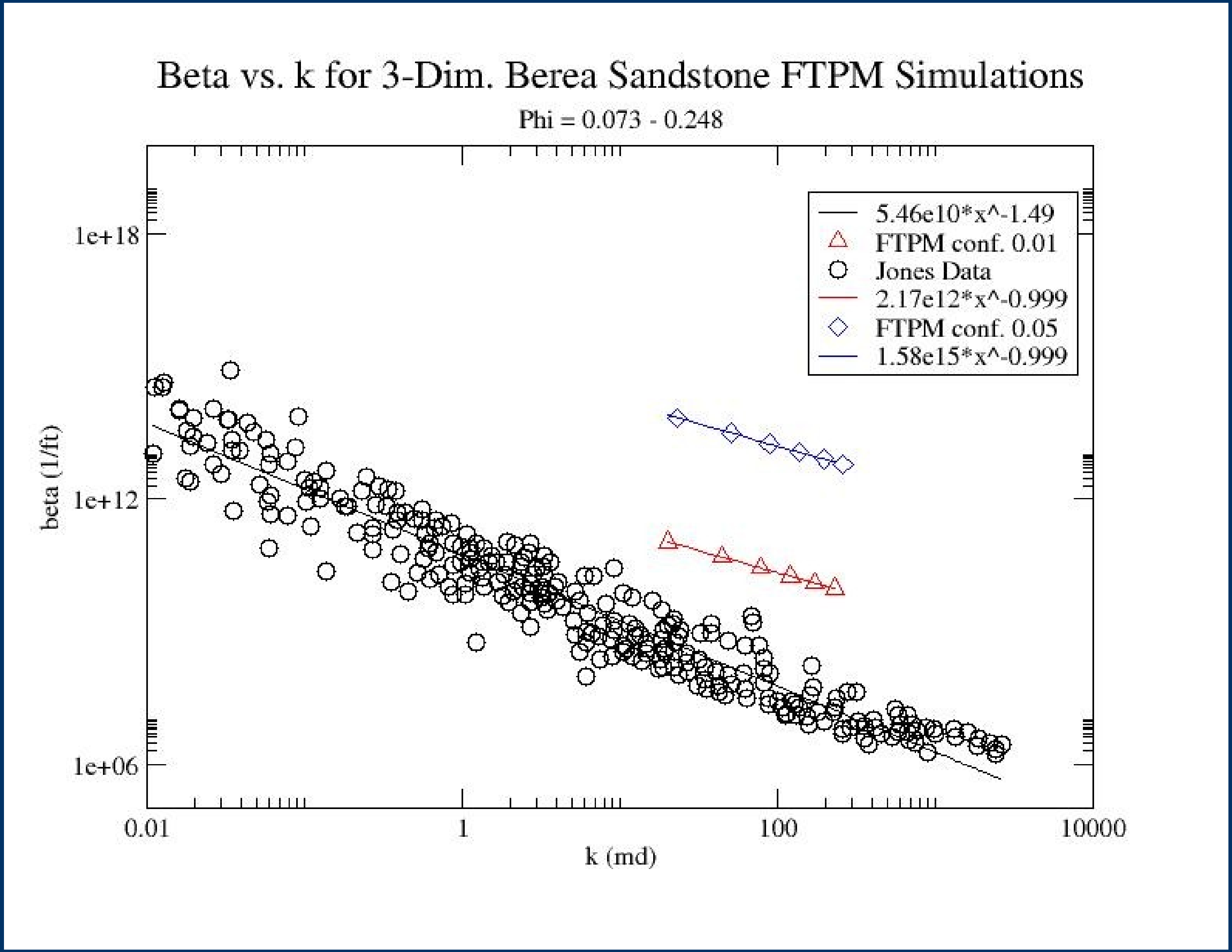


- Piecewise Polynomial fits to 0 – 9 ninth order for sandstone and glass beads
- Data from Yanuka

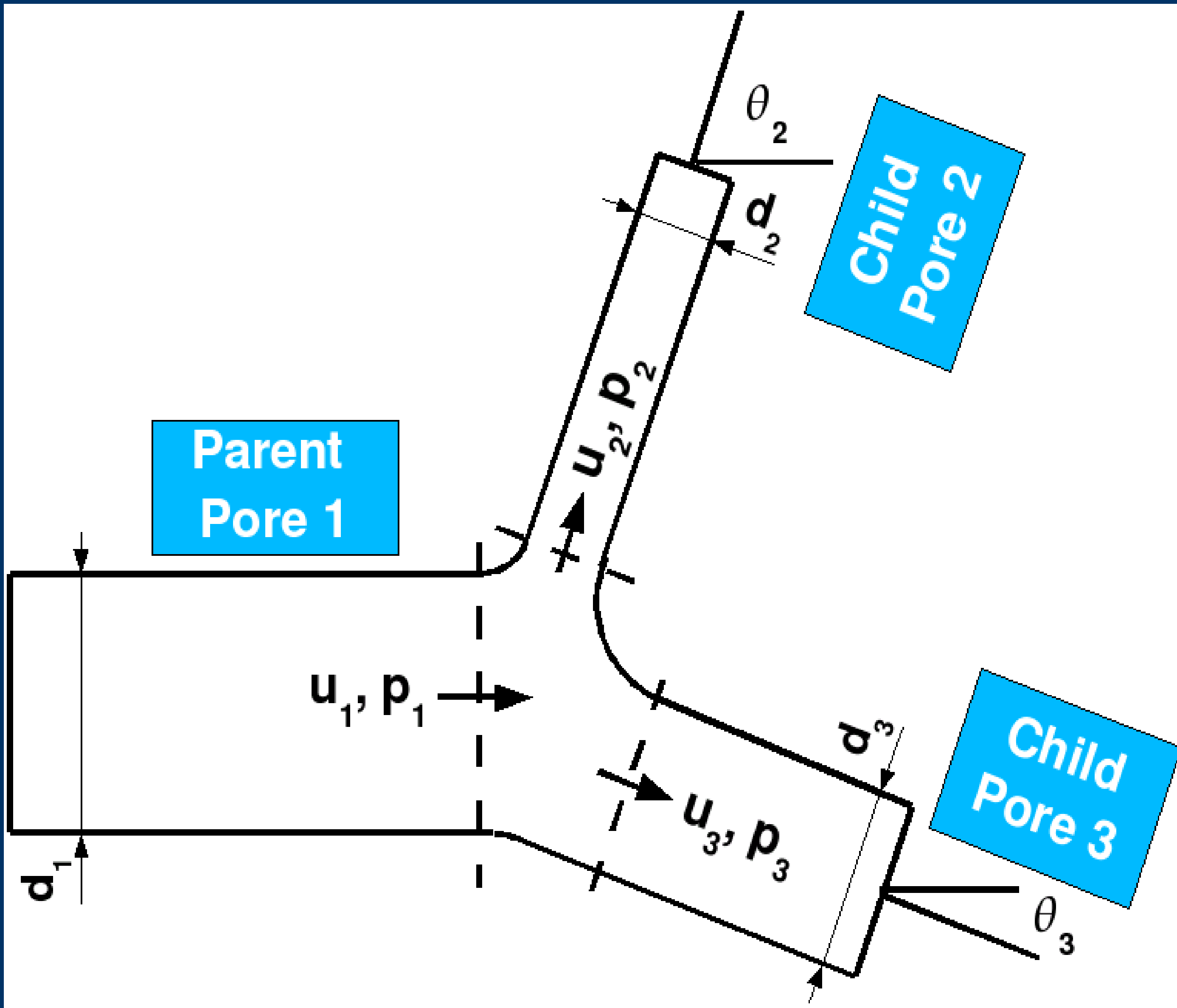
3-Dim. FTPM Verification for Glass Beads



3-Dim. FTPM Verification for Berea Sandstone



Pore Split Modeling



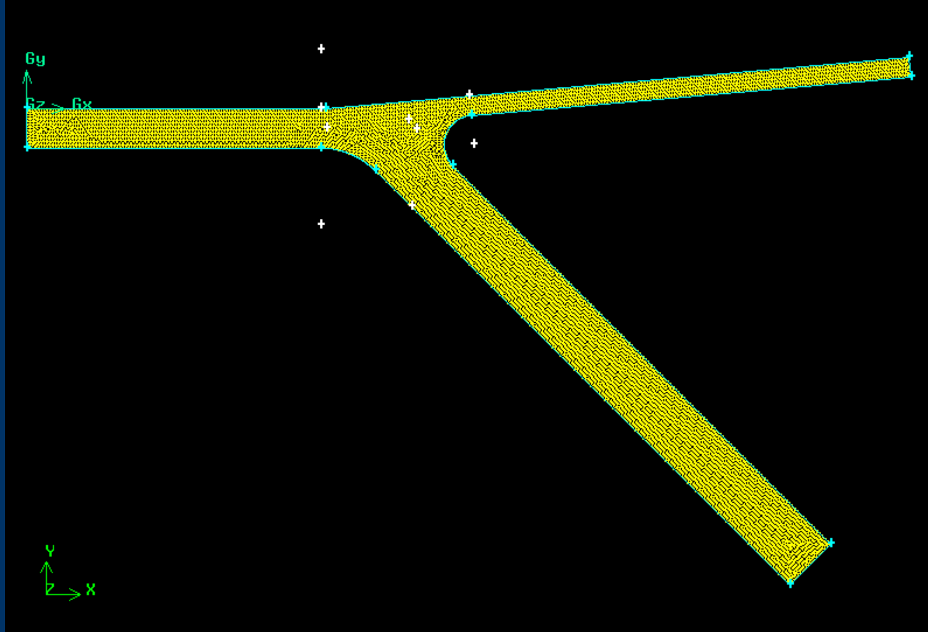
- Pore split models have significant overall effect on pressure, velocity results
- FTPM assumes that pressures and velocities are equal in the child pores.
- Flow amount is proportional to area of child pore.
- Dependence on angles?

Pore Splitting - CFD

- CFD – Computational Fluid Dynamics
- Fluent – heavily used in research and industrial settings.
- Lack of data for pressure losses in things other than standard pipe fittings and could be scaling issues.
- Pressure losses in arbitrary geometries needed.
- What is dependence on how much flow goes each way in the split?

Batch Fluent Runs -- 585

- Gambit Journal Writer (Input Creation)
  - Automated Gambit Geometry Generation
  - Automated Fluent Input File Generation
  - Automated Batch Script to run fluent for all desired geometries
- Gambit Journal Writer (Output Creation)
  - Parsing of fluent output
  - Radial Averaging of Pressures and Velocity results.
  - Consolidated Output Files.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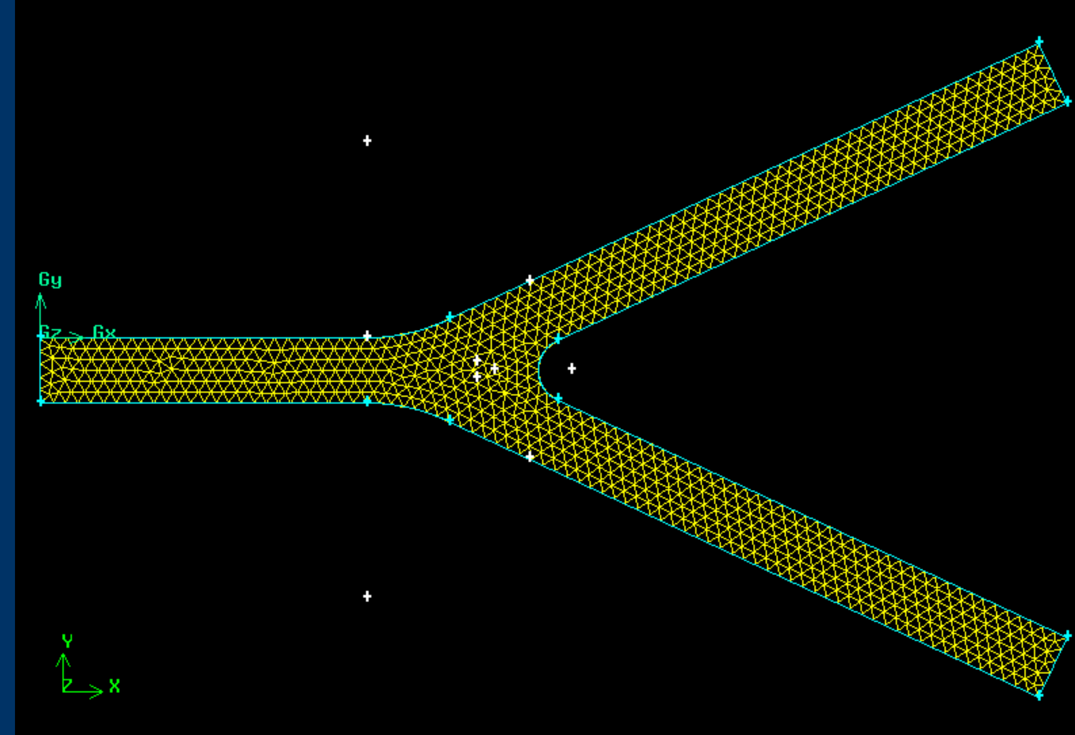
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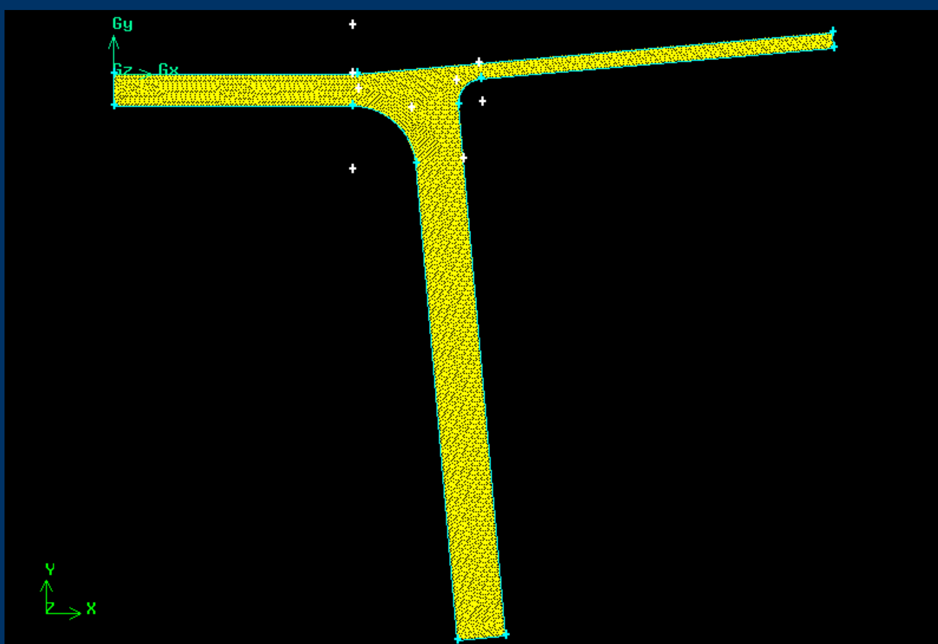
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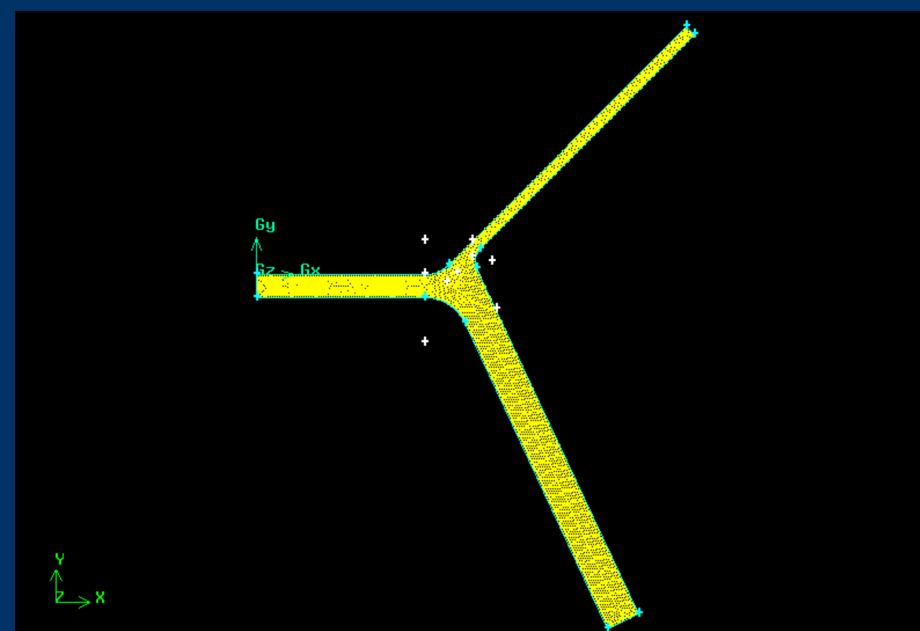
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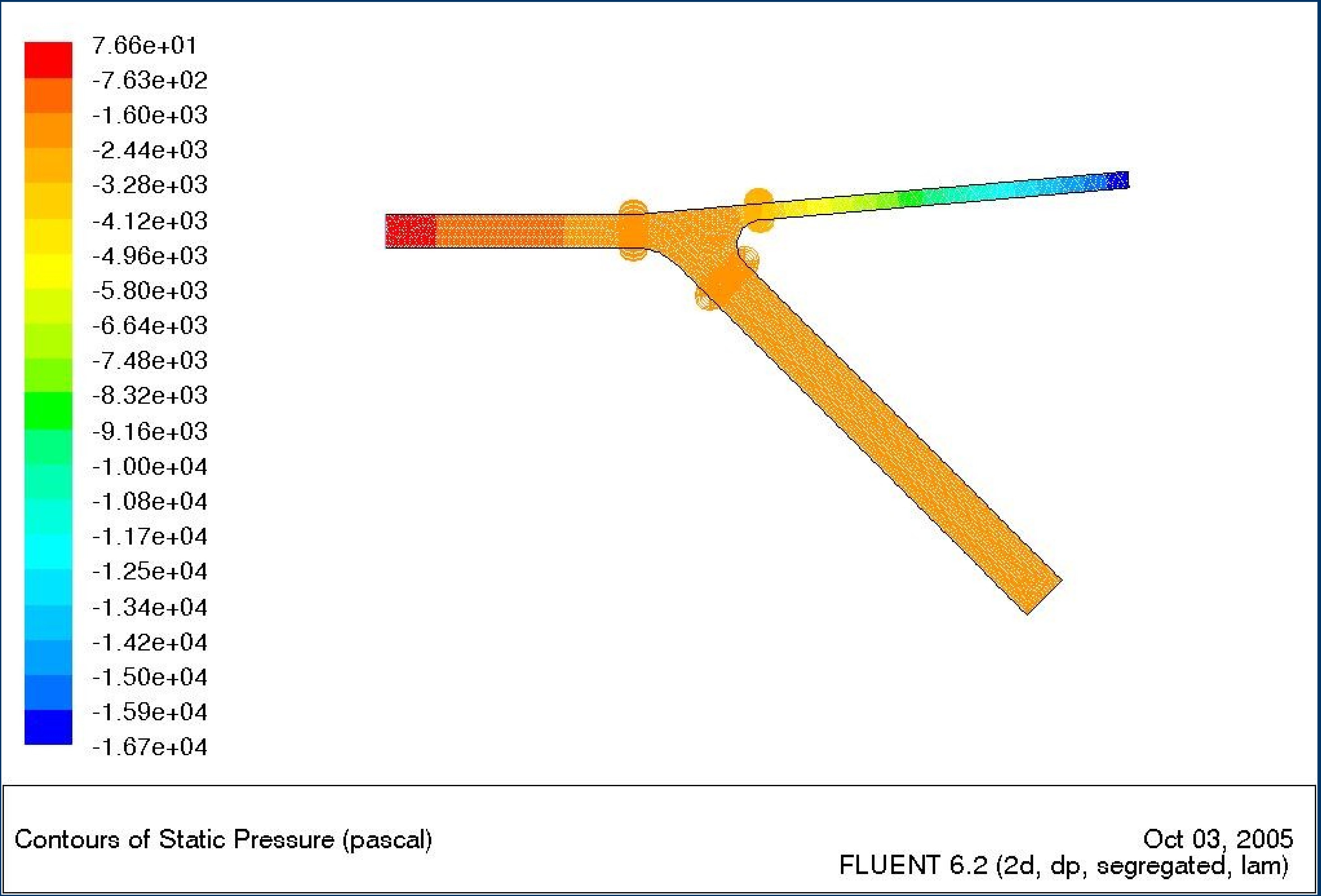
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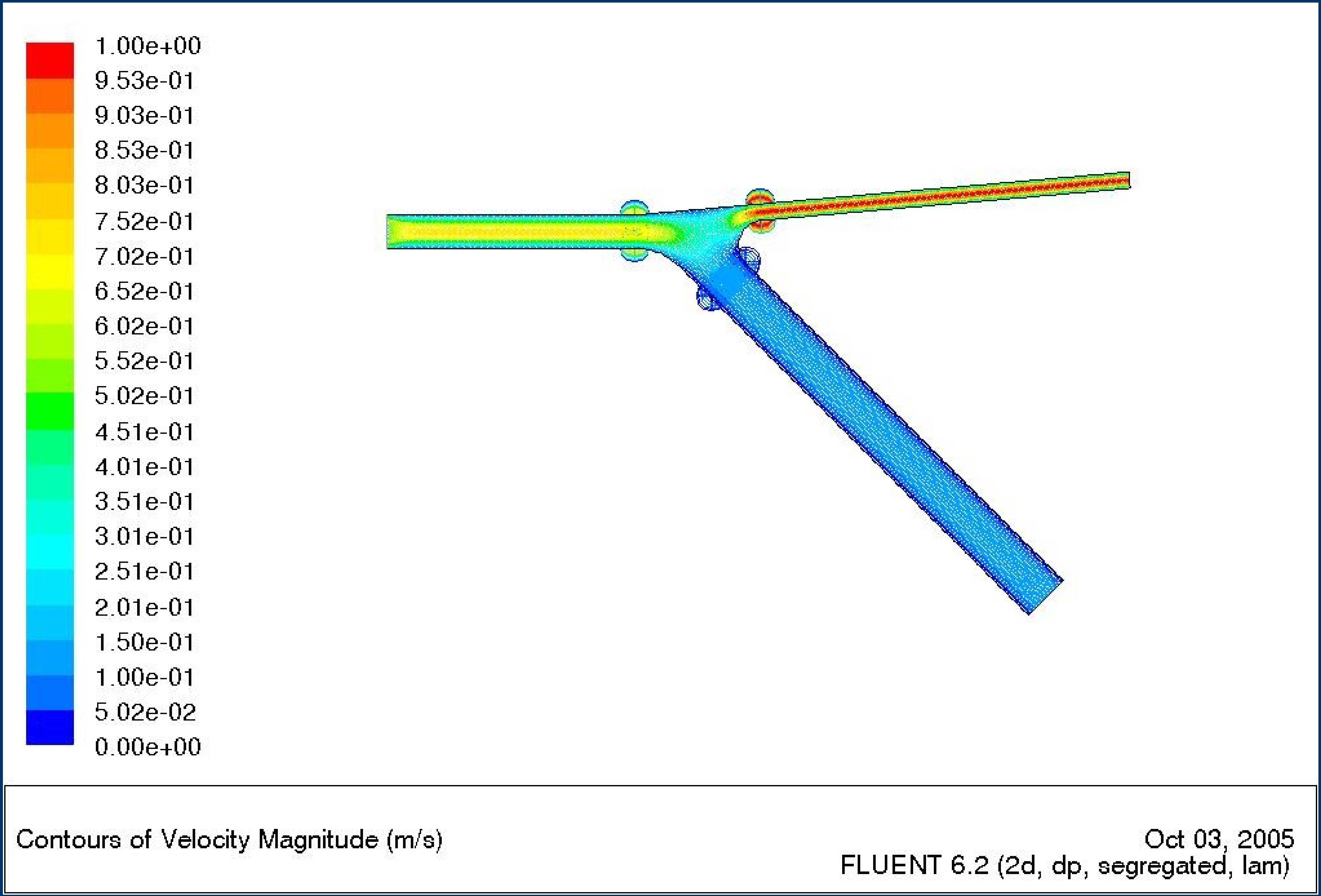
Contours of Static Pressure (pascal)
Oct 03, 2005
FLUENT 6.2 (2d, dp, segregated, lam)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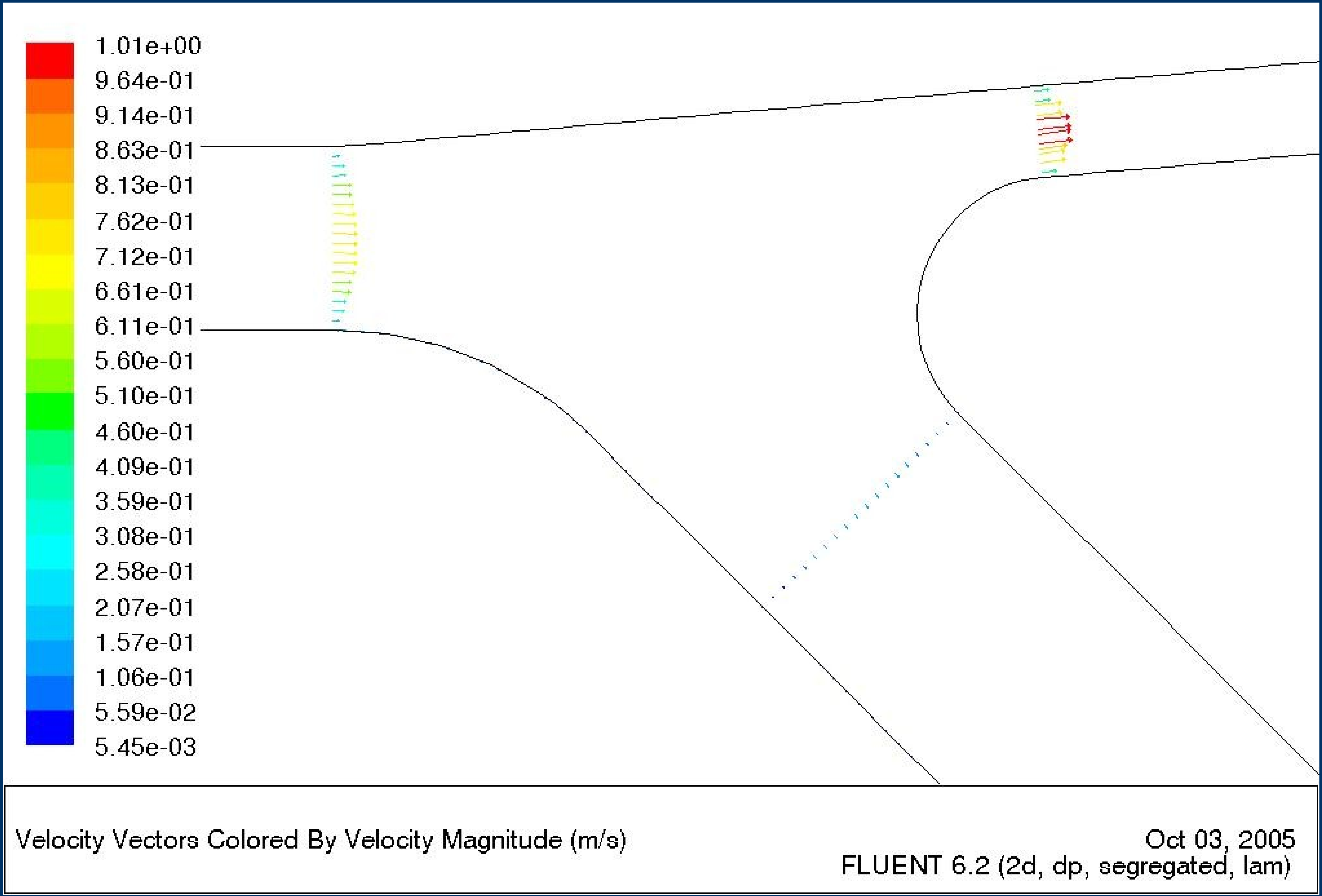
Contours of Velocity Magnitude (m/s)
Oct 03, 2005
FLUENT 6.2 (2d, dp, segregated, lam)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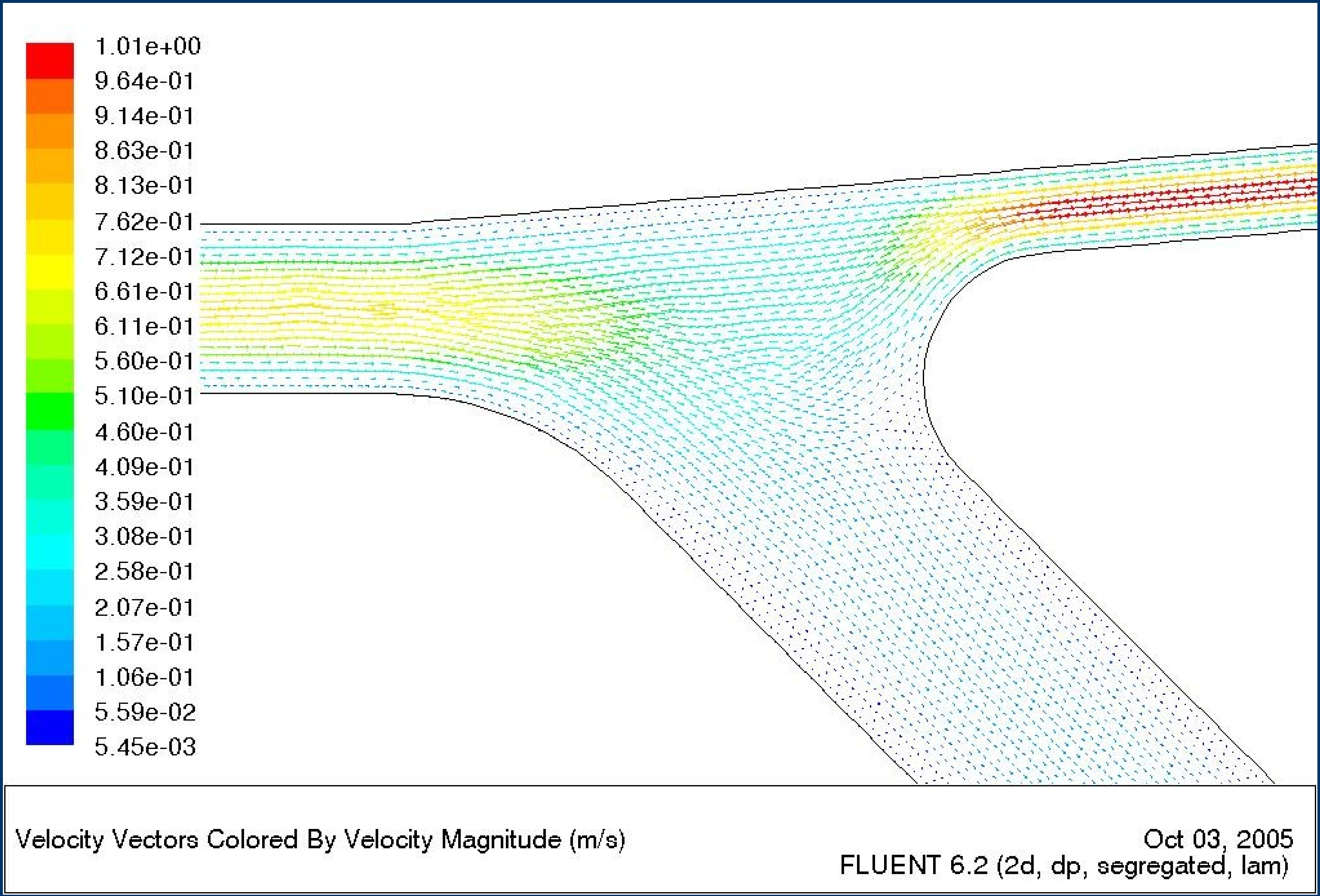
Velocity Vectors Colored By Velocity Magnitude (m/s)
Oct 03, 2005
FLUENT 6.2 (2d, dp, segregated, lam)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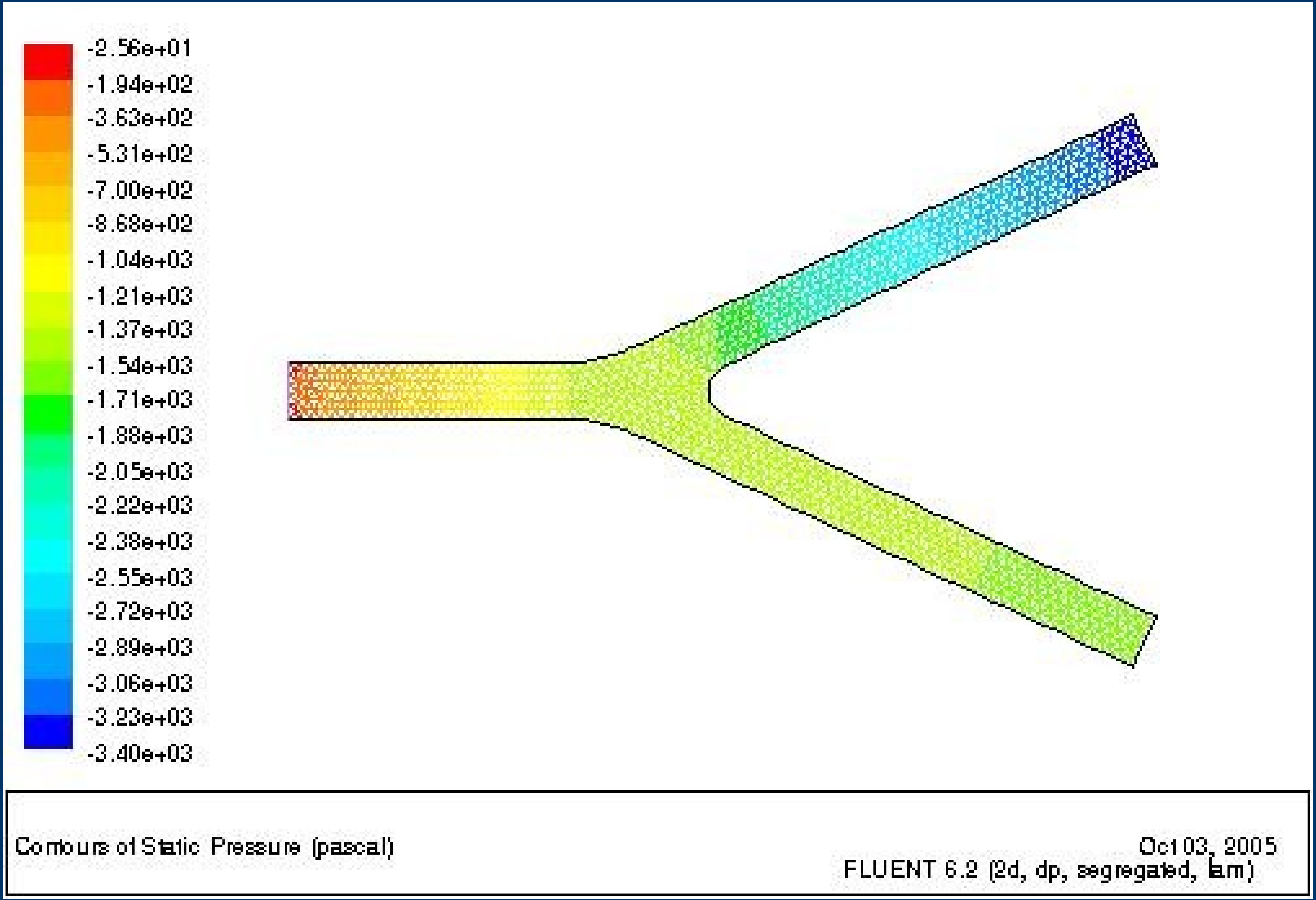
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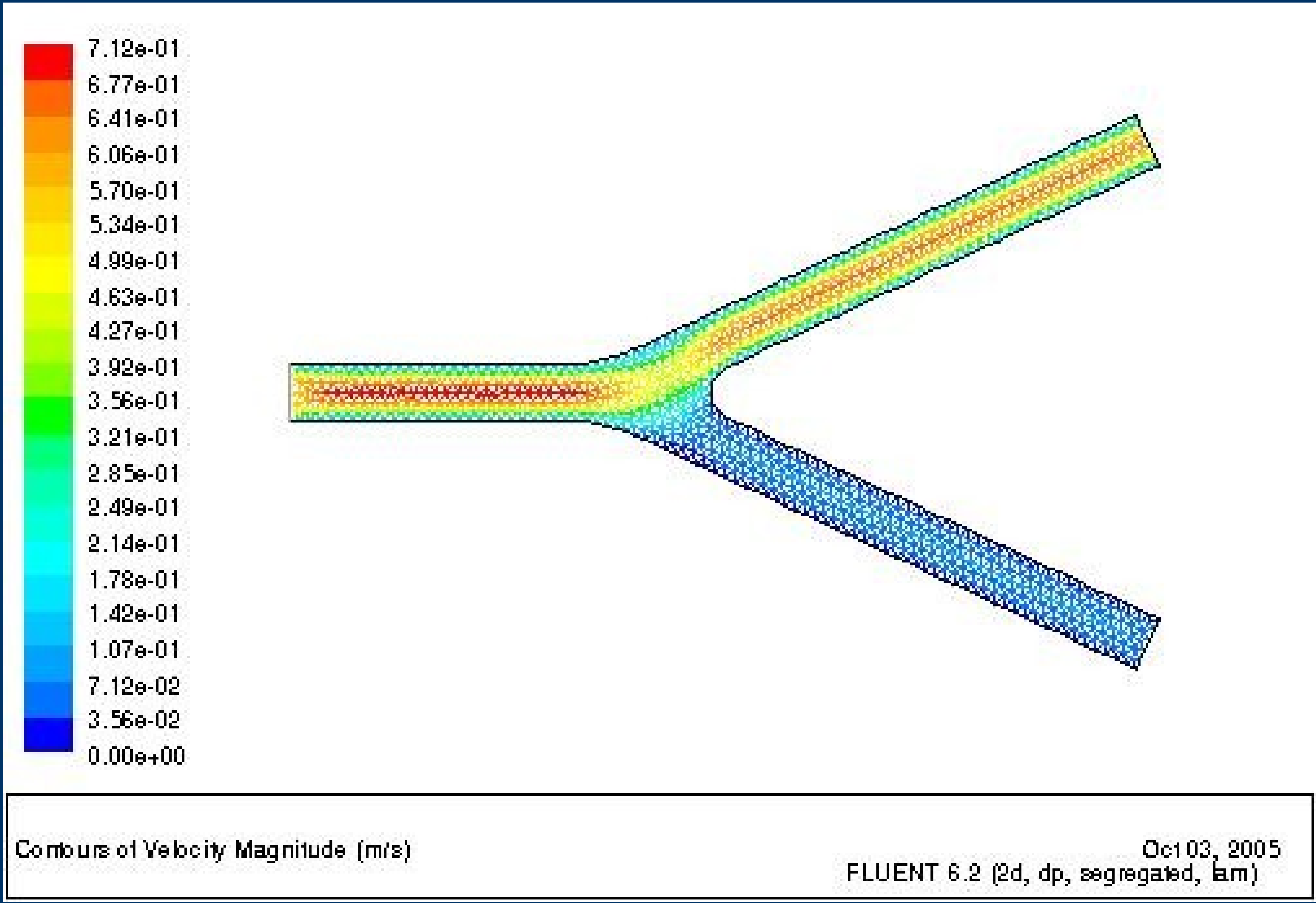
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Oct 03, 2005
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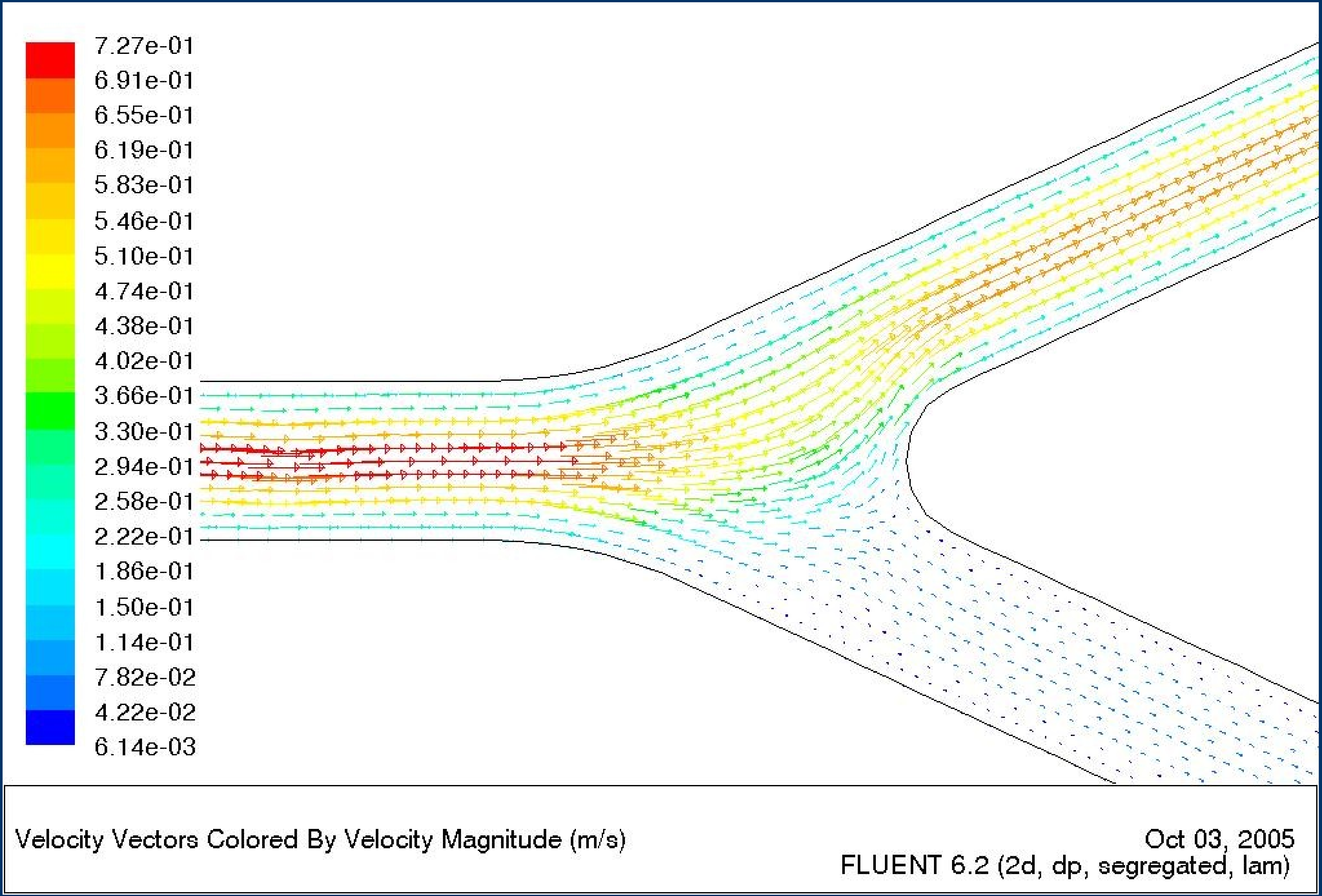
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Velocity Vectors Colored By Velocity Magnitude (m/s)
Oct 03, 2005
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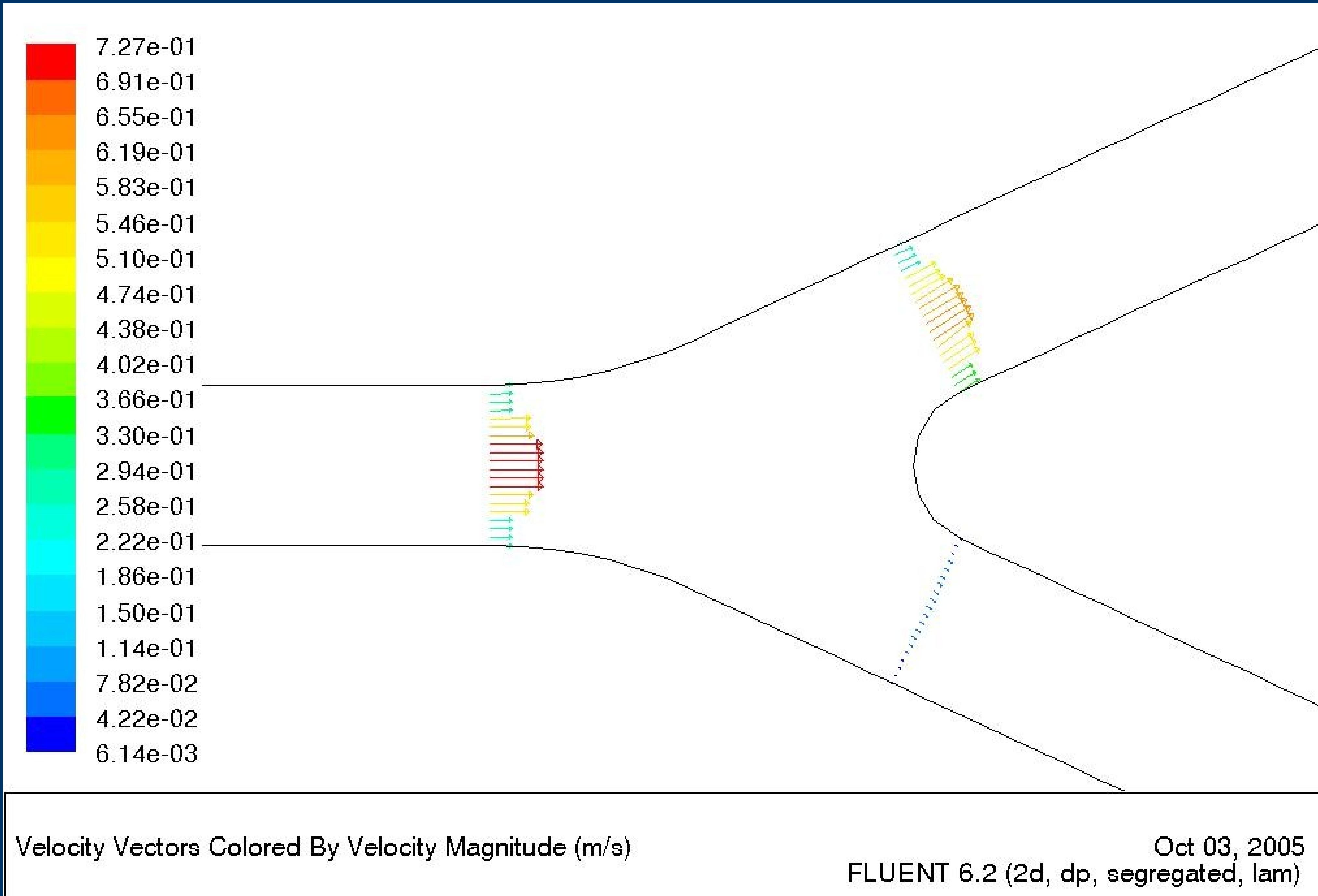
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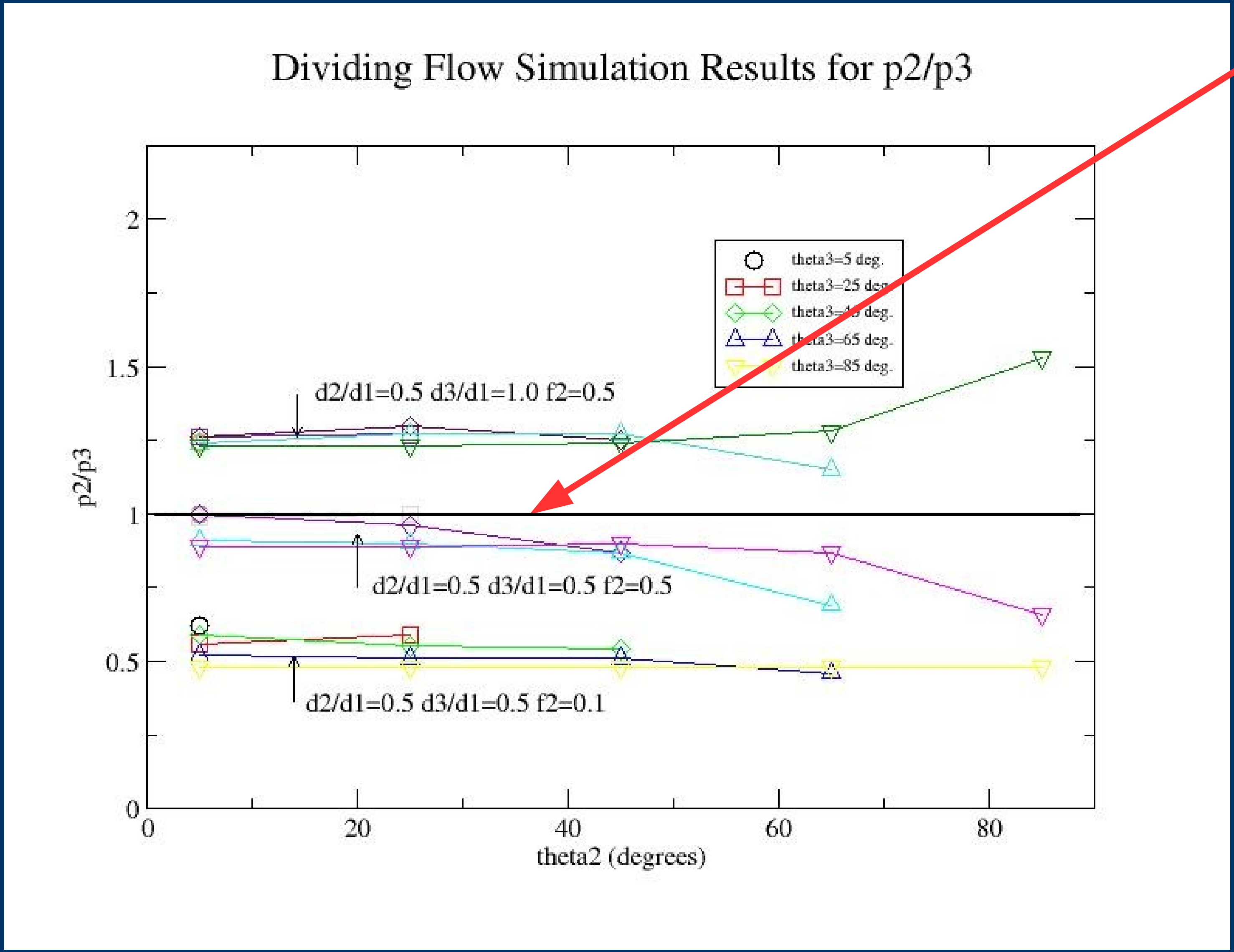


Corresponds to area dependent flow assumption in FTPM.

Pressures in child pores are roughly equal.

Angle is mostly unimportant.

When non-area dependent flows are assumed strong dependence on flow fraction.

Pressure Losses

- Comparison of pressure loss results to standard values attempted.
- Simulated pressure losses significantly larger than expected.
- Standard pressure loss data is for *turbulent* flow through fittings. Pore flow is mostly *laminar*.
- Very small amount of published data for laminar flow through fittings (does not fit with large scale piping applications).
- Small amount of published data confirms much larger losses than turbulent flow.
- Manuscript in preparation on pressure losses in arbitrary geometry splits.

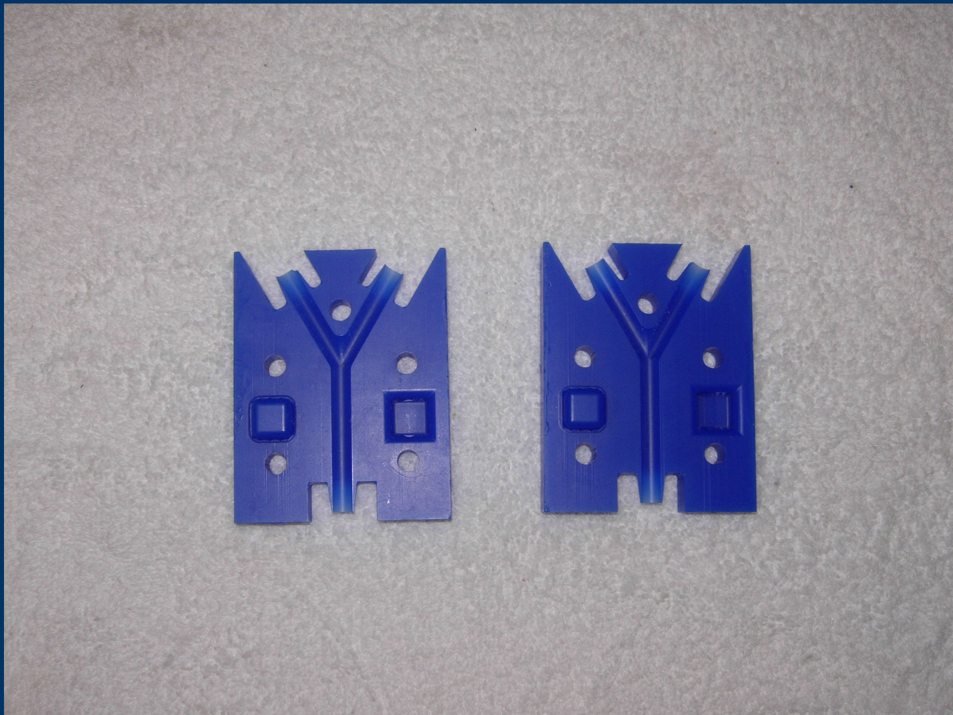
Ongoing/Future – Experimentation and More Simulation

Project 1

- 2&3 dim. scaled experiments to measure pressure losses in arbitrary splitting geometries.
- Simulation guides experiments.
- Manufacture of geometries on CNC milling machine.

Project 2

- Entire pore networks scaled and manufactured on CNC milling machine.
- Same experimental apparatus as individual splitting.
- Translating pore networks from FTPM to IGES format – interpreted by CNC mill.



UCO UG Engineering Physics Students Involved
Generation 1&2 – Chadd Fleming
Generation 3 – Justin Hawkins & Jon Blackburn

First 2 prototypes were made on a a 3-dim. printer at Rose State College in collaboration with Prof. Heidi Heilhecker.

Current prototypes have been made on a Roland 650 Computer-Controlled Mill

Acknowledgements

- ACS – PRF Summer Research Fellowship – Summer 2005
- Jackson College of Graduate Studies and Research – UCO – Current Student Support
- Dimitrios Papavassiliou and Henry Neeman from OU
- Students – Chadd Fleming, Justin Hawkins, and Jon Blackburn