Using Computational Fluid Dynamics to Solve Fluid Flow Problems

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Tackle difficult fluid flow problems using computational approaches

Solve problems using computational fluid dynamic (CFD) tools
- Gambit: grid generator
- Fluent: finite volume solver. Solves Navier-Stokes, continuity and energy equations

\[
\begin{align*}
    & u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = - \frac{1}{\rho} \frac{\partial p}{\partial x} + \nu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \\
    & u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = - \frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right)
\end{align*}
\]

Use computational codes and finite volume discretization
Benefits

- Apply to industry, mechanics and bio-engineering
- Requires less experiments
- Less error in measurement
- Model fluid transport problems in the brain
- Model reactions
Steps of This Project

- Model basic two-dimensional fluid flow problems
- Model heat diffusion in two-dimensions \( \frac{\partial T}{\partial x} = Bi(T_{\text{inf}} - T_f) \)
- Model species transport problems \( \frac{\partial c}{\partial x} = Bi(C_{\text{inf}} - C_f) \)
- Model liquid reactions
- Model bubble reactions
  - Elliptical bubble
  - 3-D bubble
- Model fluid flow in the brain
Porous Model

Inflow
0.01 m/s

Outflow

Tissue (porous zone)

Capillary

Outflow

Velocity Profile

Velocity Profile w/o high velocities

1.21e-01

1.00e-02

0.00e+00

0.00e+00

0.00e+00

0.00e+00
\[ \Delta p = -\left( \frac{\mu}{\alpha} + C_2 \frac{1}{2} \rho \nu^2 \right) \Delta m \]

**x-momentum**

\[
\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + S_x
\]

\[ S_x = -\left( \frac{\mu}{\alpha} u + C_2 \frac{1}{2} \rho |u| u \right) \]

\[ \alpha \text{ was set to } 1e08, \Delta m \text{ was set to } 0.0001, \text{ and } C_2 \text{ set to } 0 \]

**y-momentum**

\[
\rho u \frac{\partial u}{\partial x} + \rho v \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \mu \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + S_x
\]

\[ S_x = -\left( \frac{\mu}{\alpha} v + C_2 \frac{1}{2} \rho |v| v \right) \]
**Bubble Reaction**

A + 2B → C + 2D

Velocity Profile

Steady State Reaction with laminar flow

\[
\frac{\partial}{\partial t} (\rho Y_i) + \frac{\partial}{\partial x} (\rho u Y_i) = -\frac{\partial}{\partial x} (\rho D_x \frac{\partial Y_i}{\partial x}) - \frac{\partial}{\partial y} (\rho D_y \frac{\partial Y_i}{\partial y}) + R_i + S_i
\]

- \(R_i\) is the rate of production of species by chemical reaction
- \(S_i\) is the rate of creation by addition from the dispersed phase
Mass Fraction of A

Mass Fraction of B

Mass Fraction of C

Mass Fraction of D
**Ellipse Bubble Reaction**

- Same boundary conditions as the circular bubble except velocity: 0.1 m/s

Velocity Profile

\[ A + 2B \rightarrow C + 2D \]
Preliminary Results of 3-D Bubble
**Conclusion about Fluent**

- Solves the continuity, navier-stokes, energy equations and species transport equations

- Capable of porous models

- Capable of modeling reactions
  - Allows the user to write his/her own reactions

- User-defined functions are possible to expand Fluent’s capabilities
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