COMPARISON: RELAP5-3D© SYSTEMS ANALYSIS CODE & FLUENT CFD CODE MOMENTUM EQ. FORMULATIONS

Richard R. Schultz, Richard A. Riemke, & Cliff B. Davis, INEEL

Greg Nurnberg
Fluent Corporation

RELAP5 User's Group
West Yellowstone
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Content of Presentation…

- *Background*
- *Comparison of RELAP5-3D and Fluent capabilities*
- *Discussion of momentum equation formulations in Fluent and RELAP5-3D*
- *Description of calculation*
- *Discussion of results*
- *Observations*

Since RELAP5-3D© & Fluent Have Been Coupled—Questions Arise Regarding…

- *When is it appropriate to use Fluent vs RELAP5?*
- *Since RELAP5 has 3-dimensional hydraulics: will you obtain the same answer in a 3-D calculation that you would when using Fluent?*
- *Which code is best for what purpose?*

CFD Codes Such as Fluent Are…

- *Commonly used to analyze complex flow patterns in localized regions of a system.*
- *Attractive due to their first-principles approach.*
- *Reliant on a fine mesh discretization to model region of interest.*
- *Limited to analysis of problem sizes defined by practical computing times and resources.*
- *Have only limited capability for analyzing behavior of two-phase flow systems. For example commercial CFD codes do not have the steam tables.*

Systems Analysis Codes—Such as RELAP5-3D—Were Developed:

- *To model behavior of entire system—such as a PWR.*
- *From the start to analyze behavior of 1-D, two-phase transient problems.*
- *With all correlations, flow regime maps, thermodynamic properties, etc required to analyze the multitude of two-phase conditions that occur during transition from high pressure single-phase condition to low pressure two-phase conditions.*

Comparison of Fluent & RELAP5-3D© Capabilities

Software	Single-Phase		Two-Phase	
	1-D	2- or 3-D	1-D	2- or 3-D
Fluent	Not used	Preferred tool	Not used	Superior for special applications—generally unable to model phenomena behavior over wide thermodynamic ranges & through phase transitions. No steam tables.
RELAP5-3D	Preferred tool	Input assumptions required	Preferred tool	Preferred tool for analyses of integral system behavior and applications that require analyses over wide fluid thermodynamic state ranges & through phase transitions.

For Analysis of Single-Phase Flow Behavior—Differences Between Fluent & RELAP5-3D Stem…

- *From field equation formulations.*
- *RELAP5 uses first-order numerical scheme.*
- *Fluent used with first- or second-order numerical scheme.*

Presentation Focuses on Differences in Momentum Eq Formulations

- *1-D RELAP5 momentum eq—for vapor (liquid is similar):*

$$\alpha_g \rho_g A \frac{\partial v_g}{\partial t} + \frac{1}{2} \alpha_g \rho_g A \frac{\partial v_g{}^2}{\partial x} =$$

$$- \alpha_g A \frac{\partial P}{\partial x} + \alpha_g \rho_g A B_x - (\alpha_g \rho_g A) FWG\ (v_g)$$

$$- \Gamma_g A (v_{gI} - v_g) - (\alpha_g \rho_g A) FIG\ (v_g - v_f)$$

$$- C \alpha_g \alpha_f \rho_m A \left[\frac{\partial (v_f - v_g)}{\partial t} + v_f \frac{\partial v_g}{\partial x} - v_g \frac{\partial v_f}{\partial x} \right]$$

Description of Terms…

- *LHS describe time rate of change of velocity and momentum flux.*
- *1st & 2nd terms on RHS give contributions from system pressure and body forces.*
- *3rd term on RHS accounts for influence of wall friction on flow.*
- *4th, 5th, and 6th terms on RHS ensure momentum is conserved at interface when two-phase flow is present.*
- *No terms included to model influence of viscous stress between adjacent fluid layers moving in system.*

No Terms Included to Model Influence of Viscous Stress Between Adjacent Fluid Layers…

$$\tau_{ij} = \left[\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right] + \frac{2}{3} \mu \frac{\partial u_l}{\partial x_l} \delta_{ij}$$

- Viscous stress term includes contributions from viscous stresses:
  a. acting on control volume surface stemming from adjacent fluid
  b. acting on physical walls
  c. that follow from normla interfacial drag.
- Of these, item a stresses not included.

Viscous Stresses Acting on Control Volume Surface Stemming from Adjacent Fluid …

- *Generally small for reactor applications in vessel and steam generators where solid structures in fluid paths or short lengths in radial direction result in form loss, wall friction, and interphase friction.*
- *Terms for momentum equation tangent and normal to interior boundary treated in special manner since fluid in RELAP5 is modeled as inviscid (i.e., viscous stresses acting on control volume surface caused by adjacent fluid are not included.*
- *Therefore, free slip at walls is assumed.*

When RELAP5 was Improved to Enable Modeling in 2- & 3-Dimension…

- *Momentum flux in momentum eq was formulated by including off-diagonal terms for each direction—that formerly had not been included.*

$$\vec{v} \bullet \nabla \vec{v} = \begin{bmatrix} v_x \frac{\partial v_x}{\partial x} + v_y \frac{\partial v_x}{\partial y} + v_z \frac{\partial v_x}{\partial z} \\ v_x \frac{\partial v_y}{\partial x} + v_y \frac{\partial v_y}{\partial y} + v_z \frac{\partial v_y}{\partial z} \\ v_x \frac{\partial v_z}{\partial x} + v_y \frac{\partial v_z}{\partial y} + v_z \frac{\partial v_z}{\partial z} \end{bmatrix}$$

- *Therefore, original eq, say for x-direction, includes v_x derivative terms WRT y and z.*

And RELAP5 Momentum Equations Are Represented by more General Equation…

$$\rho\left[\frac{\partial \vec{v}}{\partial t} + \vec{v} \bullet \nabla \vec{v}\right] = -\nabla P + \overline{\sigma} + \rho \overline{f}$$

- *Where 3rd, 4th, 5th, and 6th terms on RHS of earlier equation (slide 8) are represented by σ term.*
- *Interactions between fluid streams not included.*
- *Hence RELAP5 will not give good representation of eddies and flow circulations in tanks and plena.*

In Contrast, Fluent Momentum Equation Formulation Is Based On…

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j} + \rho g_i + F_i$$

- *Where stress tensor given on slide 10.*
- *Turbulence simulated by inputting various models to represent viscous stress term—such as Reynolds-Averaged Approach, Boussinesq Approach, etc.*

Summary of Differences of These Momentum Equation Formulations…

- *Fluent modeling of turbulence limited by simplifying assumptions inherent to chosen turbulence model.*
- *RELAP5-3D:*
  - *Does not include full account of fluid viscous stress distribution.*
  - *Working fluid is invisid.*
  - *Losses stemming from wall friction accounted for by using f(L/D) factor on fluid velocity head.*
  - *Hence large velocity gradients adjacent to walls inherent to "no-slip" condition at wall surface.*

Implications: Different Momentum Equation Formulations in RELAP5 & Fluent…

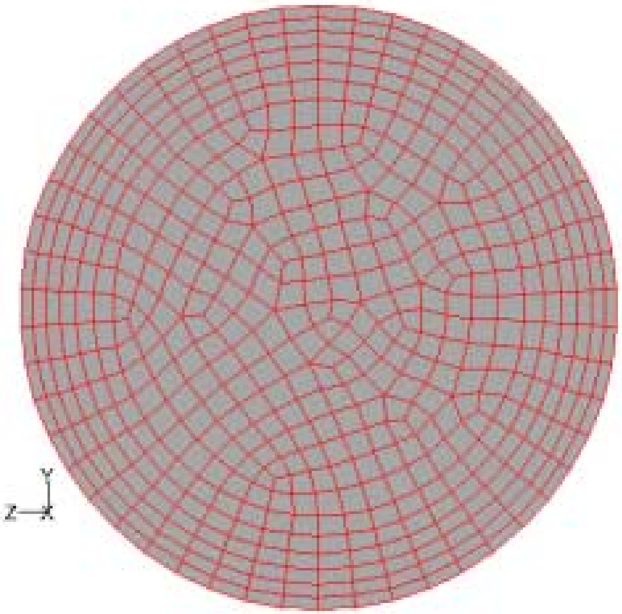
1. *Fluent will model the large velocity gradients present adjacent to walls and will also model fluid eddies that arise in flow passages and plenum-like structures.*

2. *RELAP5 will not account for the large velocity gradients adjacent to walls and the resulting effects of the wall on the fluid behavior.*

To Examine Effect of Momentum Equation Formulations on Calculated Behaviors…

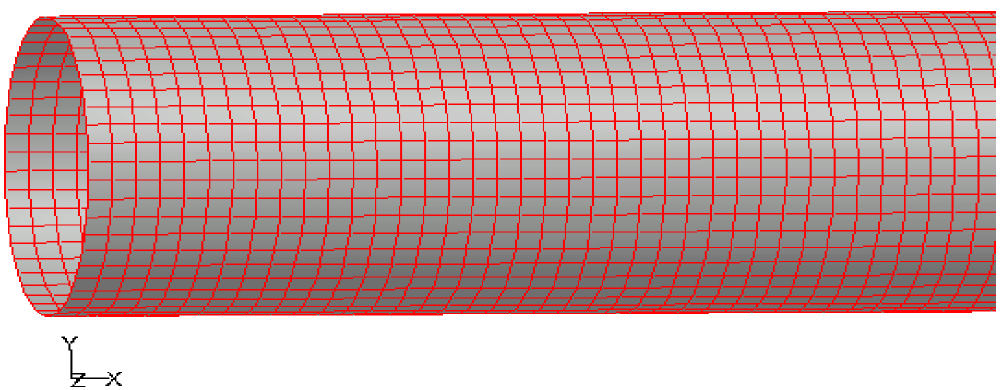
- *Calculation of fully-developed pipe flow was performed using Fluent and RELAP5-3D.*
- *Based on Nikuradse, 1932 data.*
- *Working fluid: water; Reynolds number = 110,000; room temperature.*
- *L/D = 25; diameter = 2 m; length = 50 m.*
- *Inlet velocity to pipe: uniform velocity = 0.0553 m/s*

Fluent Model



End view

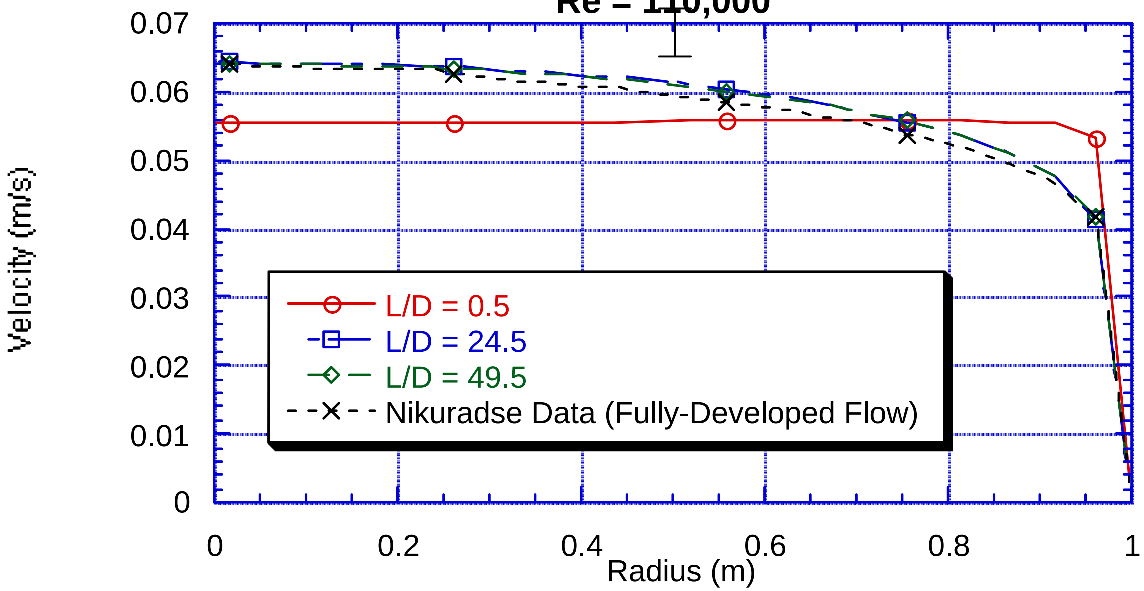
Isometric view



210,000 cells

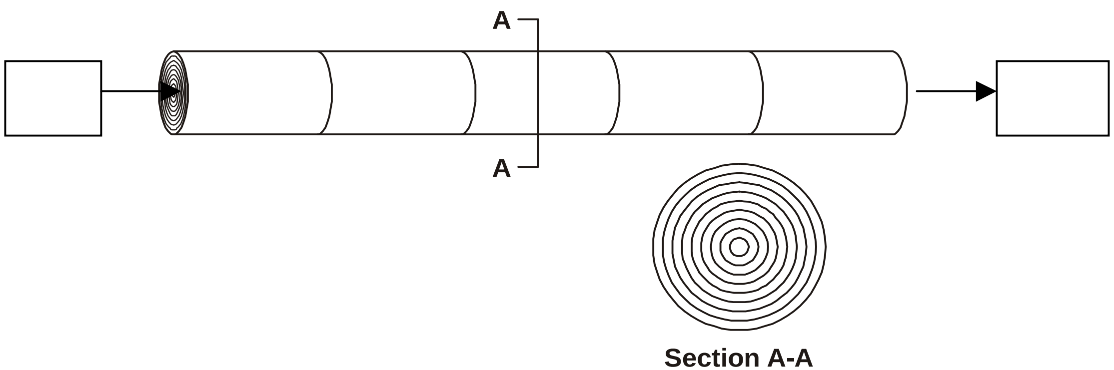
Fluent Calculation Compares Well with Data

Figure 1. Comparison: 3-D Fluent Model & Nikuradse Data
Re = 110,000



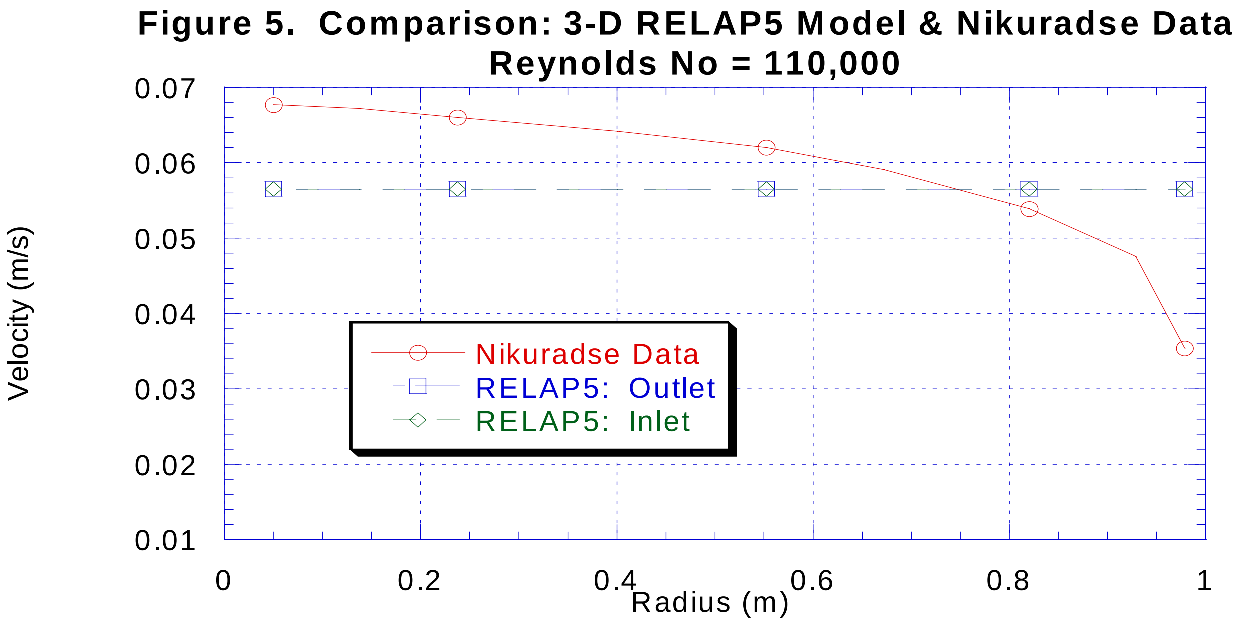
At L/D = 0.5 undeveloped flow has flat profile. At large L/Ds fully-developed profile matches data.

RELAP5-3D© Model



- 10 axial cells & 9 radial rings

RELAP5-3D Calculation Gives Flat Velocity Profile Throughout Pipe Length



Observations…

- *RELAP5 momentum field equations differ from Fluent momentum equations principally by manner in which viscous stresses are modeled (not considering two-phase flow accommodations present in RELAP5 equation set.*
- *While Fluent is limited by simplifying assumptions inherent to turbulence model to simulate viscous stresses—RELAP5 does not account for all ingredients necessary to describe viscous stress distribution.*
- *At wall RELAP5 has “free-slip” condition while Fluent has “no-slip” condition.*

Observations—continued…

- *Due to manner momentum equations are formulated:*
  - *Fluent models large velocity gradient adjacent to wall very nicely.*
  - *RELAP5 calculation does not show large velocity gradients adjacent to wall.*
- *Fluent calculation gives excellent comparison to data.*