Breaking the Barrier Between System and Component Modeling: Coupling RELAP5-3D© & FLUENT

Relevant Applications

by

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Outline

- FLUENT & RELAP5-3D© Coupling
- Introduction to Fluent Inc.
- What is CFD?
- Case Studies
- FLUENT Capabilities
- Summary
Need for Fluent & RELAP5-3D© Coupling

- Enable an entire system to be modeled using 1 dimensional features of RELAP5-3D©

- Model some components of the system in detail using the 3 dimensional features of FLUENT
Benefits of Fluent & RELAP5-3D© Coupling

◆ The performance of the system depends on the flow through each component, and vice versa

◆ Boundary condition information is transferred back and forth between the two codes

◆ Both the system and component behavior is more accurately predicted

Courtesy of Center for Multiphase Research, RPI
Fluent Coupling

- A 1-D model of the powertrain system is constructed
- The intake manifold is represented as a “CFD component”

Contours of Exhaust Gas Recirculation 18.9 ms into the cycle

Courtesy of Cummins Inc.
Fluent Coupling

- The coupled solution shows the transient flow in the manifold due to continuously updated boundary conditions.

- The system performance is more accurately predicted as well.

Contours of Exhaust Gas Recirculation

Courtesy of Cummins Inc.
Introduction to Fluent Inc.

- Fluent Inc. develops and markets fluid dynamics software for the analysis of engineering processes
- Software can be used for studying:
  - Fluid flow and heat transfer
  - Complex reactions, materials, processes
- Largest CFD vendor in the world
Major Markets Served

- Aerospace
- Turbomachinery
- Power Generation/Nuclear
- Chemicals/Petrochemical
- Automotive
- Computers/Semiconductors
- Materials/Metallurgy
- HVAC
Computational Fluid Dynamics

- Fluid flow, heat and mass transfer, phase change, chemical reaction, mechanical movement, and deformation of related solid structures
- Navier Stokes Equations
  \[
  \frac{\partial (\rho \phi)}{\partial t} + \text{div}(\rho \phi \mathbf{u}) = \text{div}(\Gamma \text{grad} \phi) + S_{\phi}
  \]
- Numerical Solution Techniques
  - Finite Difference
  - Finite Elements
  - **Finite Volume**
How CFD Analysis Works

1. User defines the problem...

2. A mesh is constructed

3. Model is set up in Fluent!

4. Solution is computed and viewed in Fluent!
Case Studies

- Tube and Shell Heat Exchanger
- Steam Generator Flows
- Coolant Control Valve
Heat Exchanger Performance Improvement

**Problem:**
- Under-performing 324 tube heat exchanger
- 700mm x 2500mm long vertical with 200mm nozzles on the tube side
- Tube side flow 90757kg/hr at 69.5 C

**Solution:**
- Replace the device
- German Chemical company retains Cal Gavin Engineers to perform analysis

Courtesy of Cal Gavin Ltd.
Axial Velocities Across the Outlet

Look for local hot spots and temperature uniformity

Maldistributed

Improved

Courtesy of Cal Gavin Ltd.
Severe Accident Steam Generator Flows

- FLUENT is used to simulate the flow in a steam generator following a severe loss of coolant accident.
- Due to blockage in the coolant loop and seals, cooling is impaired.
- The simulation is used to determine the extent of the cooling failure – whether it is restricted to the coolant piping or extends into the steam generator tubing.

Courtesy of the US Nuclear Regulatory Commission
Severe Accident Steam Generator Flows

- Temperature contours on the symmetry plane (top) show hot coolant on the top of the pipe
- Velocity vectors (bottom) show the directions of the hot and cool liquid flows
- The predicted average hot and cold temperatures are within 1.5 – 2K of the measured values

Courtesy of the US Nuclear Regulatory Commission
Severe Accident Steam Generator Flows

- Predictions of the number of tubes carrying hot flow are compared to data
- FLUENT overpredicts the region of hot flow by 16 tubes, or 7% of the total bundle
- Overall, the CFD results are in very good agreement with data and provide more information than a limited number of thermocouples can

Courtesy of the US Nuclear Regulatory Commission
Coolant Control Valve

- Dual control valve is used for automotive HVAC coolant control
- Driver and passenger can control temperatures independently
- Valve motion is simulated using the moving mesh feature
- Time-varying profiles describe the motion of the valve spools

*Courtesy of Robert Bosch Corporation*
**Coolant Control Valve**

- Deforming mesh capability has been demonstrated with the coolant control valve.
- When compared to steady-state analyses, a deforming mesh analysis produces a more realistic representation of flow through components such as valves and pumps.

Contours of Velocity Magnitude  
*Courtesy of Robert Bosch Corporation*
Fluent Capabilities

- Model Building
- Physical Models
- Multiphase Models
- Dynamic Mesh Adaption
- Moving and Deforming Mesh
- Visualization

Contours of Solid Phase

Courtesy of BASF
Fluent Capabilities

- Model Building
  - Fully integrated
  - Solid geometry modeling

- Geometry and mesh import from CAD/CAE
- Meshing
- Mesh visualization and quality diagnostics
**Fluent Capabilities**

- **Physical Models**
  - Heat transfer, species transport and reacting flows
  - Multiple reference frames, sliding mesh and mixing plane model
  - Inviscid, laminar or turbulent

*Courtesy of General Electric*
Fluent Capabilities

- Multiphase Modeling
  - Particle Tracking
  - Free Surface Flows
  - Mixture Model
  - Fluid-Fluid, Fluid-Solid

Bubble Column
Fluent Capabilities

- Dynamic Mesh Adaption
  - Improve accuracy
    - Refine the grid based on flow solution gradients or geometric details for higher resolution of flow details.
  - Increase model efficiency
    - Add grid resolution only where it is needed

Mesh Coloured by Contours of Static Pressure
Fluent Capabilities

- Moving and Deforming Mesh
  - The moving mesh uses three possible techniques:
    - moving nodes while preserving connectivity, localized re-meshing, dynamic layering
  - The result is a high quality mesh at all times during the calculation
Fluent Capabilities

- Parallel Computing
  - Parallelization available on networks of workstations or multiple processor workstations
  - Partitioning done automatically
**Fluent Capabilities**

- **Visualization**
  - 3D visualization tools
  - Animation
  - Quantitative reports
  - Integrals and averages
  - Customized reports

Plume Dispersion
Summary

- A number of industrial applications have been identified which may benefit from the coupling of FLUENT & RELAP5-3D©.
- Overall predictions of the system and component performance are expected to be more accurate