Modeling Moving Systems with RELAP5-3D

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Outline

• Background
  – Purpose
  – Refresher on moving problem theory

• Quantitative Verification
  – Translation Verification Problem
  – Calculation of Acceleration
  – Resultant Body Force

• Qualitative Assessment
  – Rotational
  – Translation

• Conclusions
Purpose

• Demonstrate ability to simulate moving systems with RELAP5-3D
• Demonstrate quantitative verification of code calculated accelerations due to translational displacement
• Demonstrate quantitative verification of code calculated pressure change due to acceleration
• Qualitative assessment of simple U-tube like geometry under rotational and translational motion
• Show similarity in results from rotational and translational sample problems
Modeling moving systems

• Moving system theory and input presented by Dr. Messina last year

• Only momentum equations are modified to account for system motion
  – Thermal energy equations do not include potential or mechanical energy

• System motion is accounted for with an additional body force term
  – Modifies the apparent acceleration due to gravity

• User can input system motion as rotation or translation of (or about) the metacenter
  – Motion can be input using functional forms or tables
Quantitative Verification

• Independent calculation of the body accelerations in 3-dimensions
  – Translational accelerations are separable
  – Each direction of body motion can be aligned with streamwise direction

• Independent calculation of resultant pressure difference due to accelerations
  – Calculation of pressure change from acceleration is independent of type of motion causing the acceleration
  – Verification for translation is valid for rotation
Translation Verification

- Interconnected rectangular prism
  - 3x3 square array of pipes
  - Each pipe is 5 volumes long
  - Multiple junctions used for transverse connections

- Sinusoidal forcing functions applied in each direction

\[
x(t) = 38.1m \sin\left(2\pi \frac{t}{10.0s}\right) \\
y(t) = 152.4m \sin\left(2\pi \frac{t}{10.0s}\right) \\
z(t) = 72.6m \sin\left(2\pi \frac{t}{10.0s}\right)
\]
Translation Verification

• Verification of accelerations
  – Analytic solution by taking second derivative of displacement with respect to time

\[ a_x(t) = \frac{d^2x}{dt^2} = -\frac{4 \pi^2}{(10.0s)^2} (38.1m) \sin \left(2\pi \left[ \frac{t}{10.0s} \right] \right) \]

\[ a_y(t) = \frac{d^2y}{dt^2} = -\frac{4 \pi^2}{(10.0s)^2} (152.4m) \sin \left(2\pi \left[ \frac{t}{10.0s} \right] \right) \]

\[ a_z(t) = \frac{d^2z}{dt^2} = -\frac{4 \pi^2}{(10.0s)^2} (72.6m) \sin \left(2\pi \left[ \frac{t}{10.0s} \right] \right) \]

– Pressure change due to acceleration is given as:

\[ dp = \frac{1}{2} (\rho_K + \rho_L) a_{acc} \frac{1}{2} (L_K + L_L) \]
Translation Verification
Translation Verification

Verification of Translation Acceleration

- X-direction
- Y-direction
- Z-direction
- X-direction Analytic
- Y-direction Analytic
- Z-direction Analytic

Differential Pressure (Pa)

Time (s)

9/1/2015
Translation Verification

Verification of Pressure Change due to Translation

Verification of Acceleration due to Translation
Qualitative Assessment

• Rotational Sample Problem
  – One pipe component and one single junction
  – Formed into a square
  – Equilibrium level at midpoint of vertical legs
  – Top leg of square is 4 meters below center of rotation
  – Rotates according to:
    \[ \theta(t) = 20^\circ \sin \left(2\pi \left(\frac{t}{10s}\right)\right) \]
Rotational Sample Results

- Figure shows difference between collapsed level for middle vertical volume in the right (blue) and left (green) legs
- Deviation from zero is due to inertial effects
- Figure shows hysteresis effects
Rotational Sample Results
Rotational Sample Results
Rotational Sample Results

• Sensitivity to increased gravity
  – Gravitational constant doubled
  – Deviation from equilibrium is reduced
  – Increased gravity trying to maintain same level
Translation Sample Problem

• Same geometry as rotational sample problem
  – One pipe and one single junction forming a square
  – Equilibrium level at midpoint of vertical legs
  – X-direction displacement according to:

\[ x(t) = 1.4m \sin\left(2\pi \frac{t}{10s}\right) \]

  – Displacement function selected to maximize similarity with rotational sample problem
    • Amplitude of oscillations matches the arc length of the rotational problem
    • Same period as rotational sample problem
Translational Sample Results

• Hysteresis is greatly reduced
  – No vertical acceleration
• Deviation at extremes of oscillation compare well to rotational sample problem
Conclusions

• Quantitative verification of acceleration due to translational motion is demonstrated

• Quantitative verification of pressure change due to modified body force due to acceleration is demonstrated

• Qualitative assessment of simple geometry under rotational and translational motion is provided
  – Hysteresis effects are amplified by vertical component of acceleration in rotational problem

• Similarities in displacements in rotational and translational sample problems are shown