PUMA Scaling Distortion Analysis: *A Method*

Marcos G. Ortiz
Information Systems Laboratory
&
Mirela Gavrilas
Nuclear Regulatory Commission

Contents of Presentation

- Objective
- Top Down Scaling: *Purpose and Overview*
- System Description: *Application*
- Equation development: *Fundamental Step*
- Non-dimensional parameters: *Scope*
- Impact of distortions: *Results*
- Conclusions
- References

Objective

The objective of this presentation is to show a novel approach to identify and assess, quantitatively, the impact of scaling distortions in a system's model. We use PUMA as the example in which the analysis method is applied.

Top Down Scaling

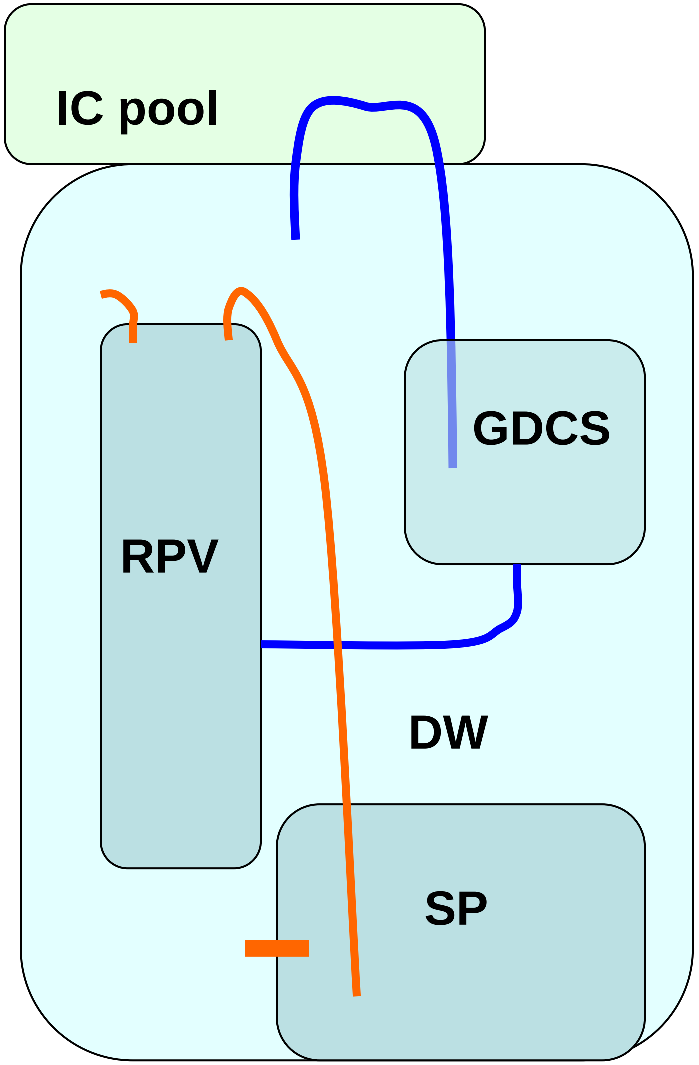
- The purpose of integral test facilities is to generate data for code assessment, in which dynamic system interactions are captured.
- The scaling analysis bridges the results from the test facility to the expectations of the prototype. Identifying and evaluating the impact of unavoidable scaling distortions is part of this analysis.

- The analysis requires a set of system equations, with non-dimensional coefficients, that describe the behavior of the system in non-dimensional space.

- The Approach, applied and expanded here, was first developed and used for the AP600 design [References 1 through 4].

System Description

The System (PUMA) is an array of tanks, heat sources, heat exchangers, and spaces interconnected with ducts, valves, and vents, designed to emulate a number of advanced boiling water reactors.



The Equations

Each component of the model will have one or more dynamic equation (derived from mass, momentum, and energy balances) which are selected based on the nature of the component. The examples below correspond to the reactor pressure vessel and the GDCS tank level. In the end, we must have a closed system of equations.

$$\frac{dp_R}{dt} = \frac{1}{V_R \zeta_R} \left[\begin{array}{l} \dot{m}_G \left\{ h_G - \mu_G + v_G \dfrac{\mu_{fg}}{v_{fg}} \right\} \\ - \dot{m}_{break} \left\{ h_f - \mu_f + x h_{fg} - x \mu_{fg} + \left(v_f + x v_{fg} \right) \dfrac{\mu_{fg}}{v_{fg}} \right\}_R \\ - \left(\dot{m}_{SRV} + \dot{m}_{DPV} \right) \left[h_g - \mu_g + v_g \dfrac{\mu_{fg}}{v_{fg}} \right] + \dot{q}_{core} - \dot{q}_{ICS} \end{array} \right]$$

Energy balance

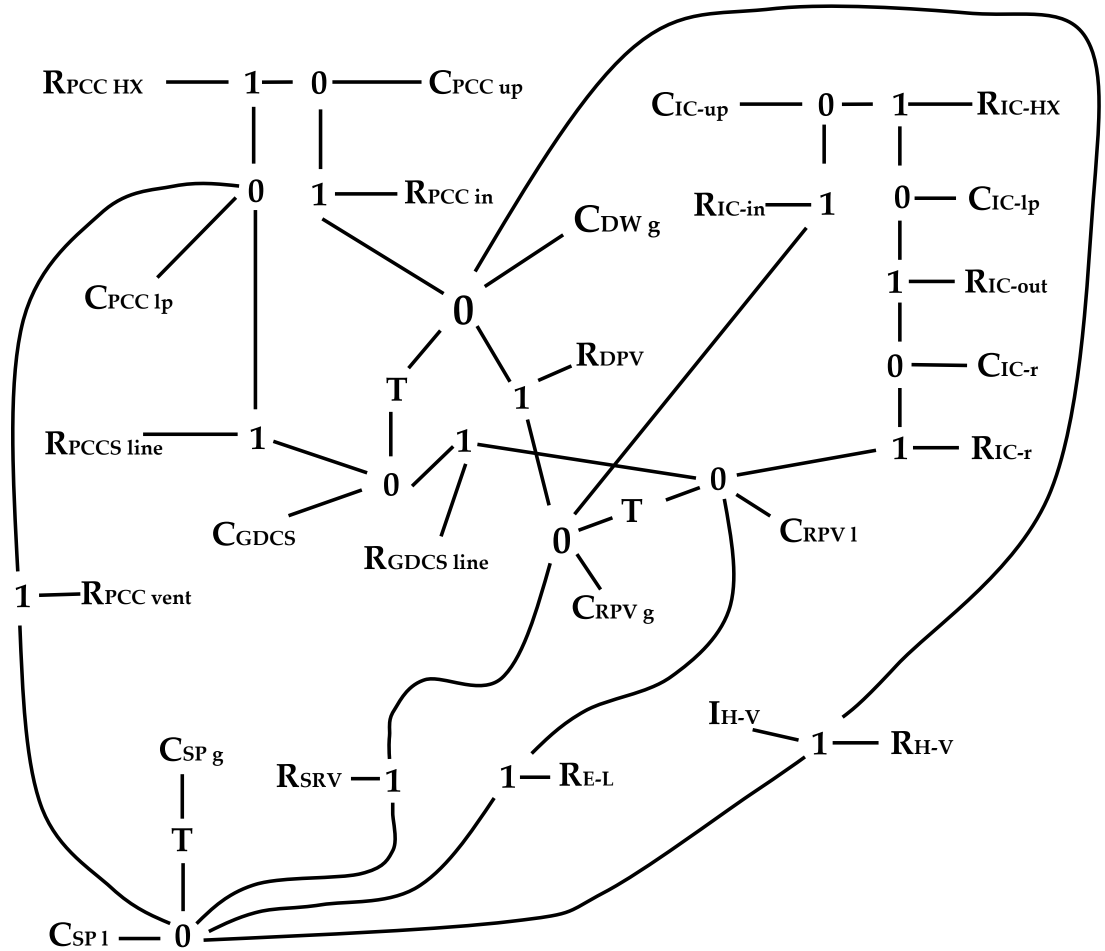
Mass balance

$$\left(\frac{A_G}{\rho_G g} \right) \frac{dP_G}{dt} = - \frac{P_G + \rho_G g \Delta H_{G-line}}{R_{G-break}} - \frac{P_G + \rho_G g \Delta H_{G-line} - p_R}{R_{G-line}}$$

The System Model

We use a lumped parameter approach (Bond Graph) to model the system, with enough detail and simplification, as required by the analysis.

Once the system components and various paths of interaction have been identified (as in the topological diagram to the right), we proceed to extract the governing equations from the model.



The Non-dimensional Equations

We identify reference values, including a characteristic time to non-dimensionalize the equations.

The example below corresponds to the GDCS tank. The terms made of reference values that multiply each non-dimensional variable (*) are the non-dimensional coefficients, or Π's

$$\frac{dP_G^*}{dt^*} = \frac{\rho_{G0} g t_0 A_{PCCX} U_{PCCX} T_{DW0} T_{DW}^*}{A_{G0} P_{G0} \left(h_{fg0}\rho_{f0}\right)_{DW} \left(h_{fg}\rho_f\right)_{DW}^*} - \frac{\rho_{G0} g t_0 A_{PCCX} U_{PCCX} T_{ICS-pool0} T_{ICS-pool}^*}{A_{G0} P_{G0} \left(h_{fg0}\rho_{f0}\right)_{DW} \left(h_{fg}\rho_f\right)_{DW}^*}$$

$$- \frac{\rho_{G0} g t_0}{A_{G0} R_{G-break0}} P_G^* - \frac{\left(\rho_{G0} g H_{G-line0}\right)\rho_{G0} g t_0}{A_{G0} P_{G0} R_{G-break0}}$$

$$- \frac{P_{G0}\rho_{G0} g t_0}{A_{G0} P_{G0} R_{G-line0}} P_G^* - \frac{\left(\rho_{G0} g H_{G-line0}\right)\rho_{G0} g t_0}{A_{G0} P_{G0} R_{G-line0}} + \frac{p_{R0}\rho_{G0} g t_0}{A_{G0} P_{G0} R_{G-line0}} p_R^*$$

For example, this is Π_{57}

Identifying and Assessing Distortions

We find distortions and their impact on several levels:

- If the test system and the prototype have the same physical configuration (as they should), they have the same equations. Otherwise, the test facility is missing some prototypical function.

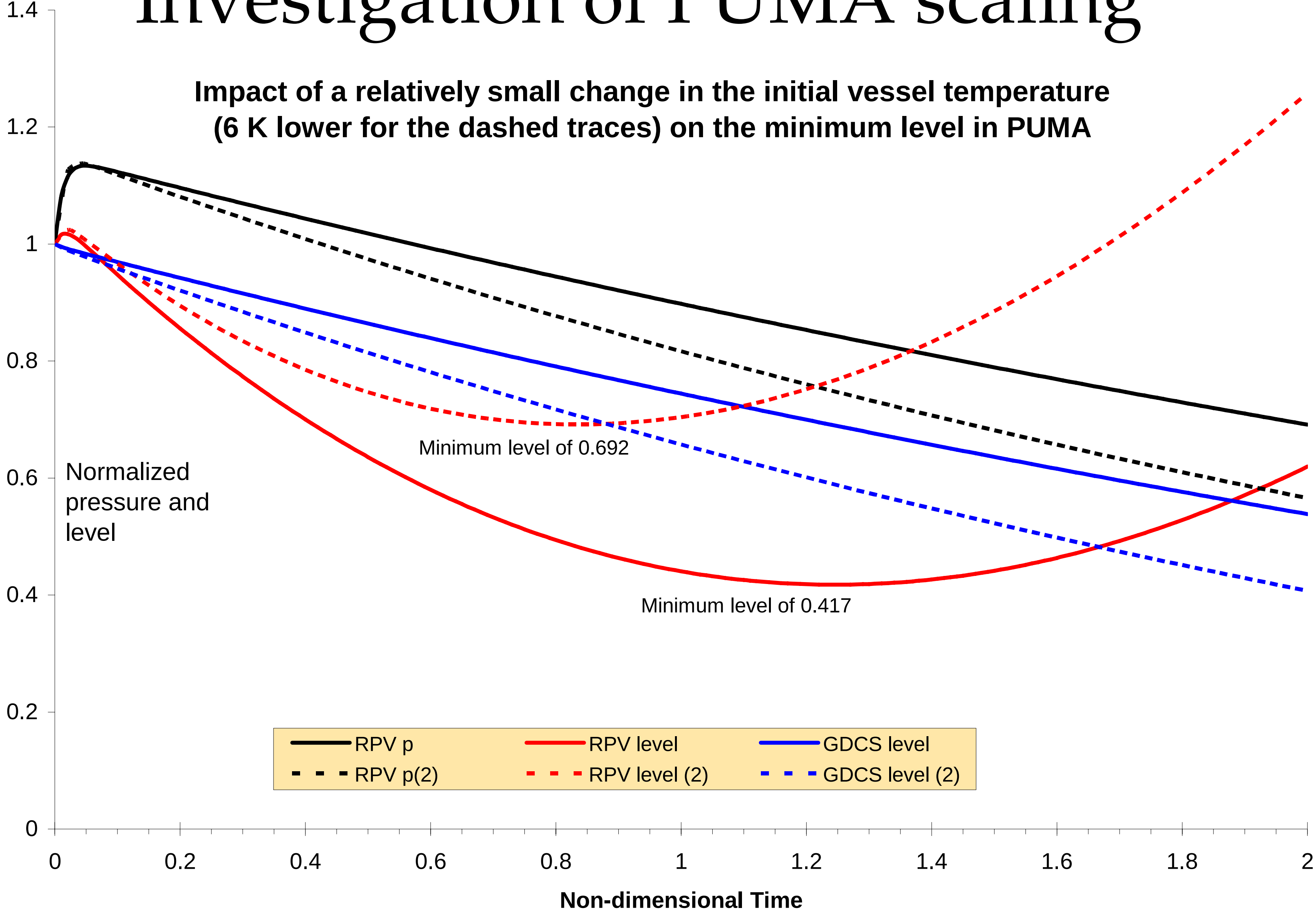
- All reference values are chosen so that the * variables are of order one ($x^*=x/x_0$). That means that the magnitude of the coefficients in each equation is an indication of their dominance and can be ranked from most dominant to negligible. Such ranking should be the same in both systems. Discrepancies are indication of distortions. To be perfectly similar the equations of one system must be the same as the other if multiplied by some scaling factor.

- If distortions (Π differences) are amongst the least dominant coefficients, their relative magnitude with respect to the dominant coefficients is a measure of their significance. We can go one step further.

Identifying and Assessing Distortions (2)

- We evaluate the distortion by numerically integrating the governing equations of both, test system and prototype, while tracking the performance of a pre-selected figure of merit.
- We can conduct sensitivity calculations around the parameters that affect the identified distortion. The impact of the departure from the prototype on the figure of merit performance becomes a quantitative assessment of the distortion.
- The approach is limited by the level of detail that one can include in the equations.
- The following are preliminary results from an analysis of PUMA.

Investigation of PUMA scaling



Summary and Conclusions

- It is unlikely to be able to have a test facility perfectly scaled to a prototype.
- This approach is rigorous, and though labor intensive, provides insight into the dynamic interdependencies of the system.
- The result is a handy tool to determine the quantitative impact of scaling distortions for analysis and for test design.
- We must extend the method to investigate the impact of multiple distortions simultaneously.
- Of course, this “system’s approach” is limited by the level of detail that one chooses. Non-homogeneities of states (T, P’s, etc) present a challenge to developing a representative model.

References

1. Banerjee, S., M. G. Ortiz, T. K. Larson, D. L. Reeder. "Scaling in the safety of next generation reactors," Nuclear Engineering and Design, vol 186, 1998, pp 111-133.
2. Banerjee, S., M. G. Ortiz, T. K. Larson, D. L. Reeder. "Scaling In The Safety Of Next Generation Reactors," Eigth International Topical Meeting on Nuclear Reactor Thermal-Hydraulics, Kyoto, Japan, September 30 - October 4, 1997, Proceedings Volume 1 pp 508-527
3. Ortiz, M. G., S. Banerjee, T. K. Larson. ``A Systems Approach To The Scaling Analysis Of Integral Test Results," Presented at The Fifth International Topical Meeting on Nuclear Thermohydraulics, Operations & Safety (NUTHOS-5), Beijing, China, April 13-18, 1997. Published in the Conference Proceedings, pp Q1-Q7
4. Ortiz, M. G., Nielson, C. E., Sloan, S. M., Teerlink, L. ``Top-Down Scaling Analyses of AP600 Integral Test Data In Support Of The RELAP5 Adequacy Assessment" INEL-96/0117, April, 1997