A Case Study in High-Volume Parametric Evaluations using GOTHIC™

Zachry Nuclear's Analysis Division

Introduction

In traditional applications, GOTHIC simulations are built and executed manually, one at a time, through the software's graphical user interface (GUI). As industries continue to adopt probabilistic, risk-informed approaches to analytical issues, Zachry Nuclear has seen increased demand for flexible automation capabilities to perform complex parametric or stochastic sampling studies varying multiple input parameters in thermal hydraulic scenarios to characterize either the range or bounding response of the system. GOTHIC's command files provide a scripting language that allows the software to be applied to such situations, rapidly executing hundreds or thousands of simulations through automatic generation, execution, data-processing, and selection of subsequent input parameters for evaluation.

Background

Zachry Nuclear has recently combined GOTHIC's capabilities with other tools to create an automated framework that can rapidly build, run, evaluate and report results for any number of GOTHIC cases. For applications requiring many cases to be derived from one or more base models, this approach can save hundreds or thousands of man-hours.

This approach was recently applied to support probabilistic risk analysis for a U.S. nuclear facility to determine the risk benefit of proposed modifications to the main steam system. The analysis predicted peak ambient temperatures for critical equipment in the Turbine Building in response to a spectrum of high energy line breaks (HELB) from the main steam system. Break scenarios covered many potential break locations, break sizes, and break orientations, all occurring under varying plant initial conditions, which can include different mass and energy profiles based on the assumed operating state (*e.g.*, hot full power, hot zero power) or different environmental conditions (*e.g.*, summer, winter).

For each unique combination of initial conditions, break location, and break orientation, the analysis determined the limiting break size, above which the critical equipment temperature limit would be exceeded. At the conclusion of the parametric study, over 360,000 individual GOTHIC simulations had been evaluated.

The example described in this summary is specific to a Turbine Building HELB analysis, but the approach can be applied to any conceivable GOTHIC simulation.

Approach

The GOTHIC model of the Turbine Building used in this study included 770 cells, about 520 of which represented areas containing steam piping. The base model was manipulated through the GUI to set the required initial conditions, such as initial temperatures and ventilation lineup. The automated study systematically stepped through each of the 520 break locations in the model, determining critical equipment temperatures for breaks in each of the 6 primary break directions (north, south, east, west, up, and down). Figure 1 depicts one such simulation in which the high-energy steam plume is oriented toward the location of nearby critical equipment.

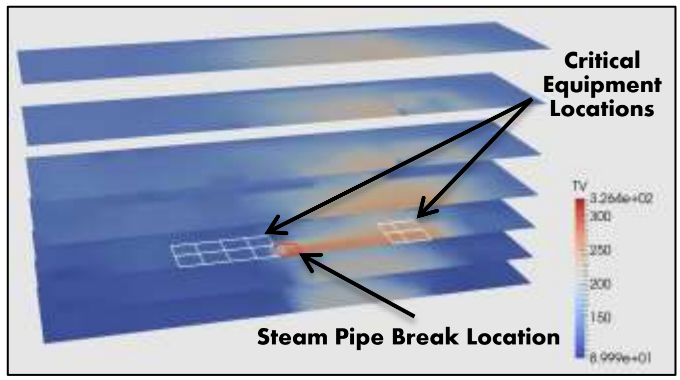

Figure 1 – Example of GOTHIC Predicted Temperature Profile in Turbine Building.

The overall automation approach may be summarized as a nested operation performed on each base model, as shown in Figure 2. The automation scheme iterated on break size for each break location/orientation until the limiting break size was found. For this application, the limiting break size was the largest pipe break that did not exceed critical equipment temperature limits.

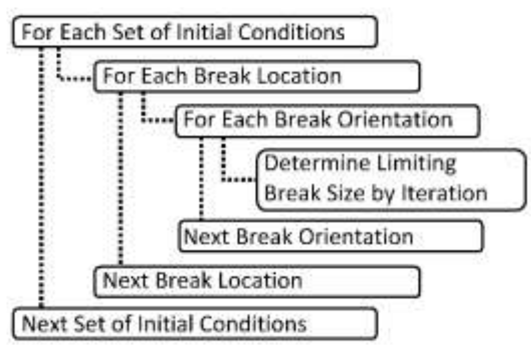

Figure 2 – Summary of Automation Scheme.

The automation is managed using common scripting languages such as Microsoft Visual Basic or Python. Changes to the GOTHIC model for each simulation, such as updated break location, orientation, or break size, are accomplished using GOTHIC command files.

GOTHIC™ incorporates technology developed for the electric power industry under sponsorship of EPRI, the Electric Power Research Institute.

Numerical Applications Division of Zachry Nuclear Engineering, Inc.
High-Volume Parametric Evaluations using GOTHIC™

Output and Results

The output of the study included tabulated results indicating the limiting break size in each of the evaluated cases, suitably arranged for use in subsequent probabilistic risk assessments. In addition to the standard GOTHIC output files, the automated parametric study also supports generating GOTHIC space- and time-type data files for each simulation, along with a summary report documenting critical parameters with graphical outputs, and a video file graphically depicting the transient, similar to that shown in Figure 1. For high-volume parametric studies, these options may be disabled to conserve available data storage space.

GOTHIC also includes a feature to summarily display results from many separate simulations by calculating a bounding curve based on any number of user-specified cases. These are referred to as envelope sets, and an example is shown in Figure 3. Here, the bounding profile is shown as the heavy black curve calculated in this case from about 20 different temperature profiles. Envelope sets can be used to calculate either an upper or a lower bounding profile.

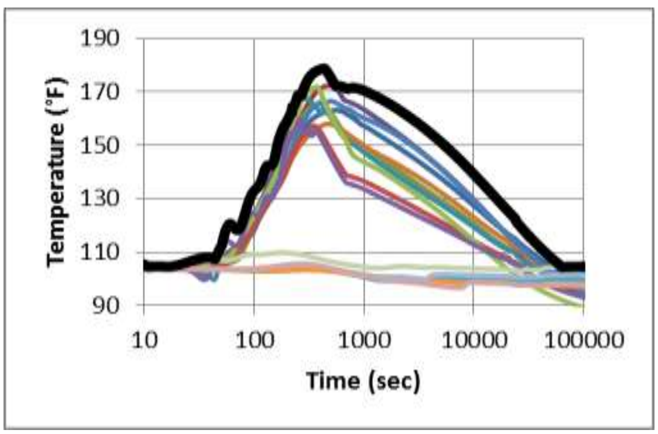

Figure 3 – Example Result with Bounding Curve.

Computational Statistics

GOTHIC includes a number of features that make it very computationally efficient like parallel processing and advanced matrix solution schemes; however, the time required to perform any parametric or stochastic study with GOTHIC depends on many factors, such as:

- Complexity of the base GOTHIC model
- Number and scope of variable parameters
- Number and speed of available processors
- Adequacy of the base model for the application

For this Turbine Building HELB study, the simulation performance statistics may be summarized as follows:

Total simulations performed: 360,000
Average processor speed: ....3.5 GHz
Total number of cores used:.......36
Completion rate (per core): ....1,000 per day
Total computing time: ....10 days
Retained case files: ....220 GB unzipped

Potential Applications

Probabilistic Risk Analysis (PRA)

- Examples: HELB, internal flooding, beyond design basis events, emergency planning

Risk-Informed Safety Margin Characterization (RISMC)

- Examples: GSI-191, external flooding

Best-Estimate Plus Uncertainty (BEPU)

- Examples: LOCA, other Chapter 15 analyses

Benefits

- Minimizes human errors in setting up, running, and evaluating cases.
- Efficient, automated evaluation of results for data processing and iteration.
- Tailored data output for immediate support of downstream analyses, as required.
- GOTHIC command files retain the QA and input error checking inherent to the software.
- Provides an improved understanding of system response to a spectrum of events to identify trends or determine if a single scenario or a broader range of cases is considered limiting.

Summary

As risk-informed analysis becomes more prevalent in the industry, the need for parametric evaluations of thermal-hydraulic systems will increase. GOTHIC's existing capabilities are ideally suited to evaluate the underlying thermal-hydraulic scenarios upon which the industry's risk conclusions will be based. This is one example of how Zachry Nuclear is able to provide comprehensive analysis solutions in an efficient and cost-effective manner to provide additional margin or operating flexibility.

Contact

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