

Analysis Using RELAP5-3D as Compared With a Test Mockup

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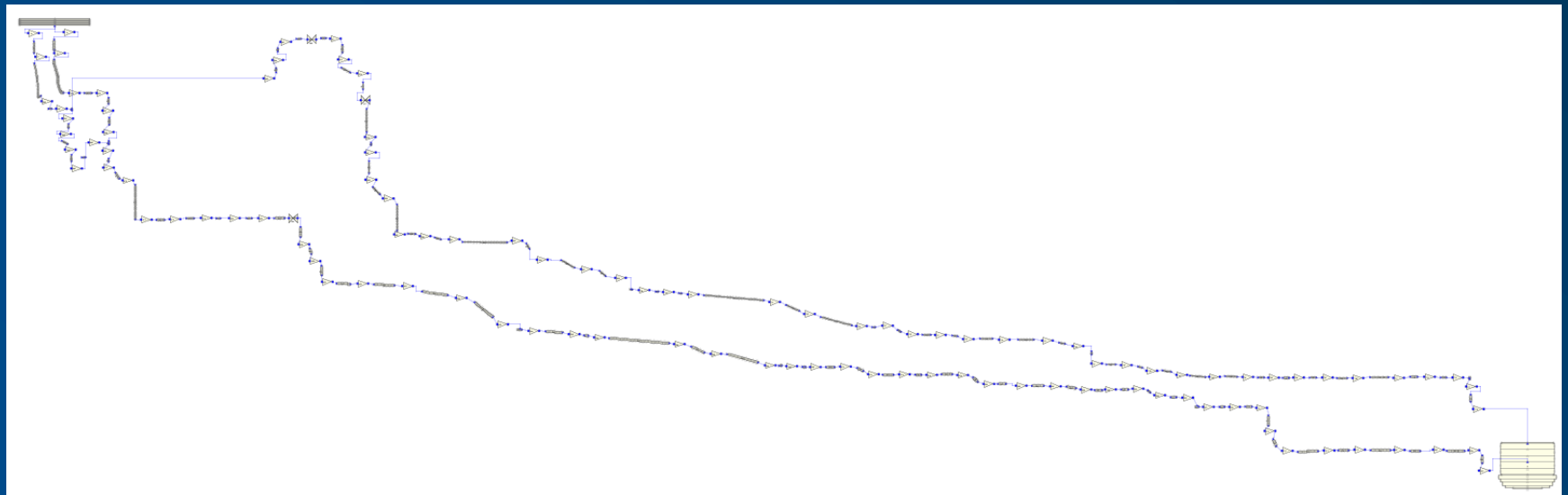
Fluid Dynamics Group

April 18, 2019

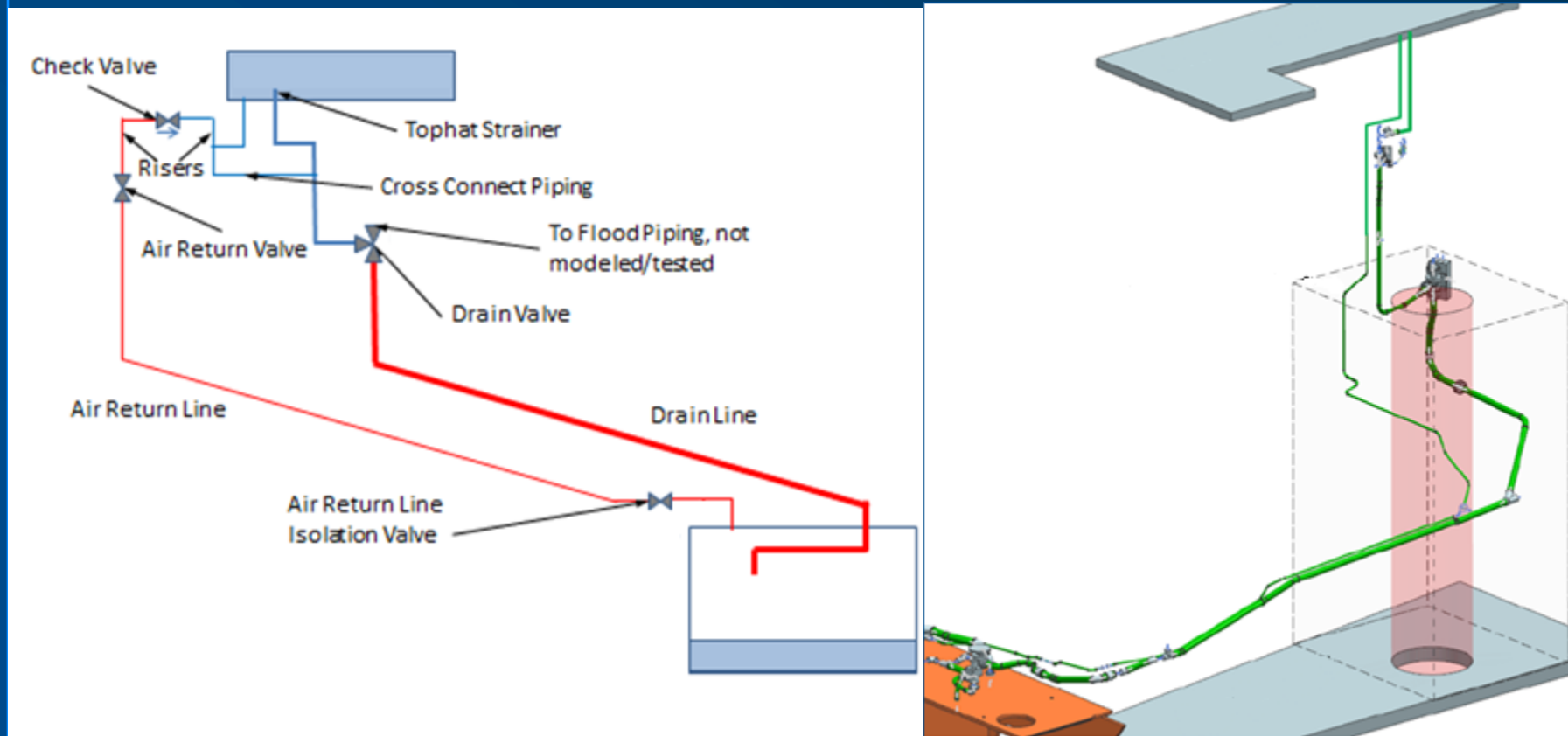
Analysis Using RELAP5-3D as Compared With a Test Mockup

- A mixed air-water fluid system was evaluated which was a particularly well suited candidate for RELAP5-3D analysis
- An on-site test mockup was constructed to serve as a means for validating the RELAP5-3D results

Fluid System RELAP5-3D Model (Represented in SNAP)



Test Mockup Overview



Presentation Overview

- Comparison of relevant primary results from a prior RELAP5-3D analysis to test mockup results
- Modification of the prior RELAP5-3D analytical model to better match comparable test mockup results
- Variations of the modified RELAP5-3D analytical model were developed to match other test mockup configurations for comparison

Prior RELAP5-3D Analysis and Test Comparison

- Prior RELAP5-3D analyses included one case for specific comparison to planned testing (Test Configuration 1)
- Test Configuration 1: Initially full upper volume; empty lower tank; inclusion of a 0.5" NPS check valve
- Prior RELAP5-3D analysis calculated a modestly lower minimum pressure (~5%) than the test mockup results

RELAP5-3D Analytical Model Modification

- Four modifications were made to the RELAP5-3D analytical model in an attempt to match the test mockup
 1. Including a small air amount in the upper volume
 2. Reducing the air temperature in the lower tank
 3. Reducing the tophat strainer fluid resistance
 4. Introducing a low point into the drain line
- Minimum upper volume pressure increased above that of the test (within 5%). Other characteristics match more precisely

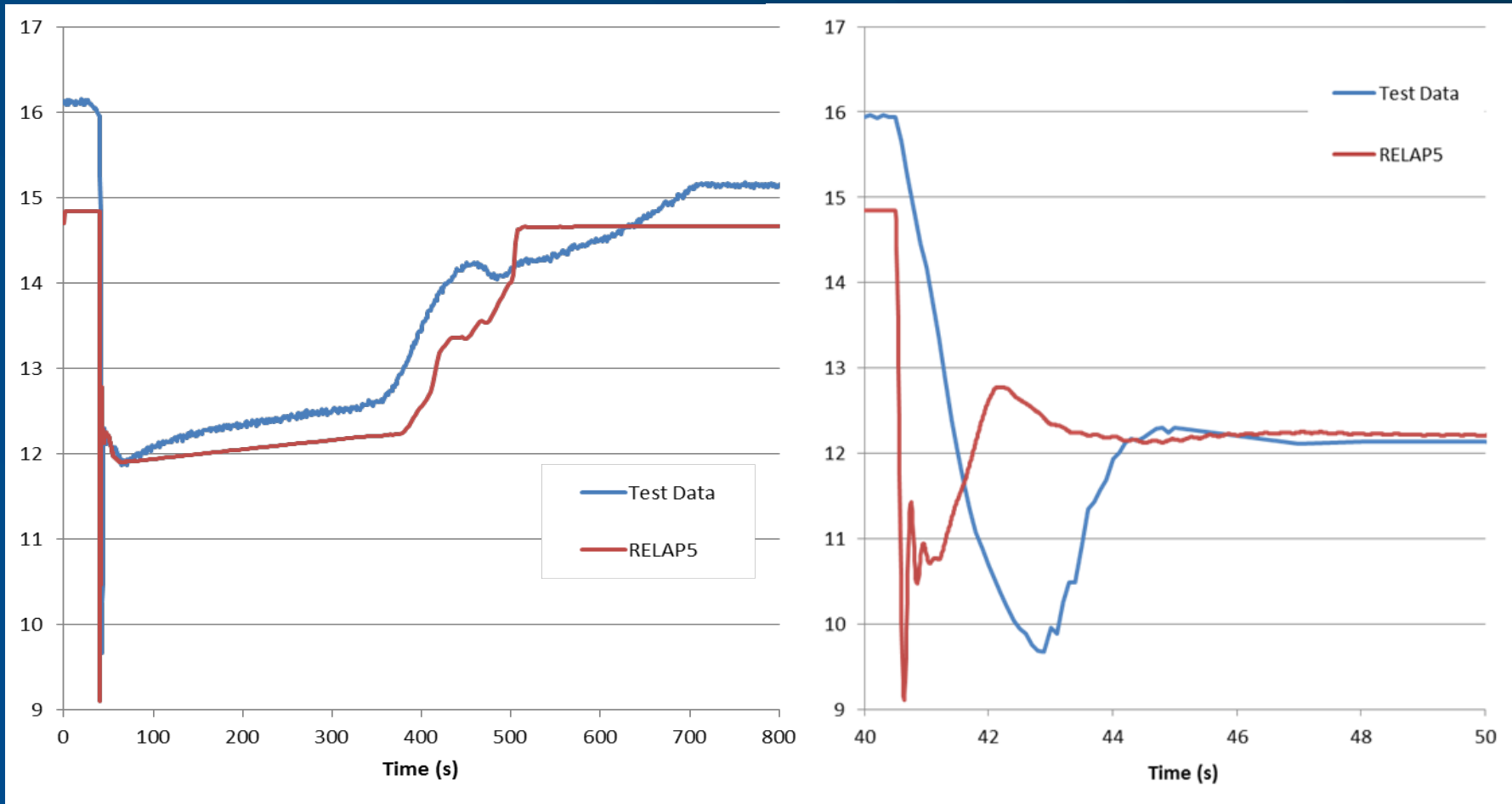
RELAP5-3D Analytical Model Variants

- There were a total of 18 Test configurations – 1-16, 7a, and 7b
 - Configurations 1, 2, and 3 are functionally identical, with configuration 4 having minor differences
- The modified RELAP5-3D model was adjusted in an attempt to match test mockup configurations
- The RELAP5-3D model variant results show generally good agreement with the test results

Prior RELAP5-3D Analysis and Test Mockup Results

- Minimum upper volume pressure:
 - By original analysis: 9.1 psia
 - By comparable test: Average 9.51 psia
 - Difference: < 5%

Upper Volume Pressure: Original Analysis vs Test



Modification of the RELAP5-3D Analytical Model:

1. Upper Volume Air Inclusion

- The RELAP5-3D analytical model contains no air in the upper volume
- The upper volume in the test mockup is filled via hose, and is vented during the fill. Per the test procedure, those performing the test are to “Make every effort to ensure there are no bubbles in the tank”
- Inclusion of a small amount of air in the RELAP5-3D analytical model upper volume (0.5% of the volume) matches test mockup initial pressure profile results
- The exact volume of air trapped in the test mockup upper volume was not verified

Modification of the RELAP5-3D Analytical Model:

2. Lower Tank Air Temperature Reduction

- The analytical model initially sets all air and water to the same temperature
- The test mockup included the upper volume and piping located inside a temperature-controlled building, with additional exterior piping spanning to the lower tank located outside the building
- The relevant tests were performed in February 2018, contributing to colder temperatures within the lower tank

Modification of the RELAP5-3D Analytical Model:

2. Lower Tank Air Temperature Reduction (continued)

- Reducing the initial air temperature within the lower tank in the RELAP5-3D analytical model results in closer agreement with the test mockup results
 - The pressure results after the initial pressure drop have similar profiles
 - The pressure at steady state is equivalent
 - The temperature of the lower tank during the test was not measured; the temperature used in the RELAP5-3D analytical model was found by iteration
 - Heat transfer to the environment was not considered

Modification of the RELAP5-3D Analytical Model:

3. Tophat Strainer K Factor Reduction

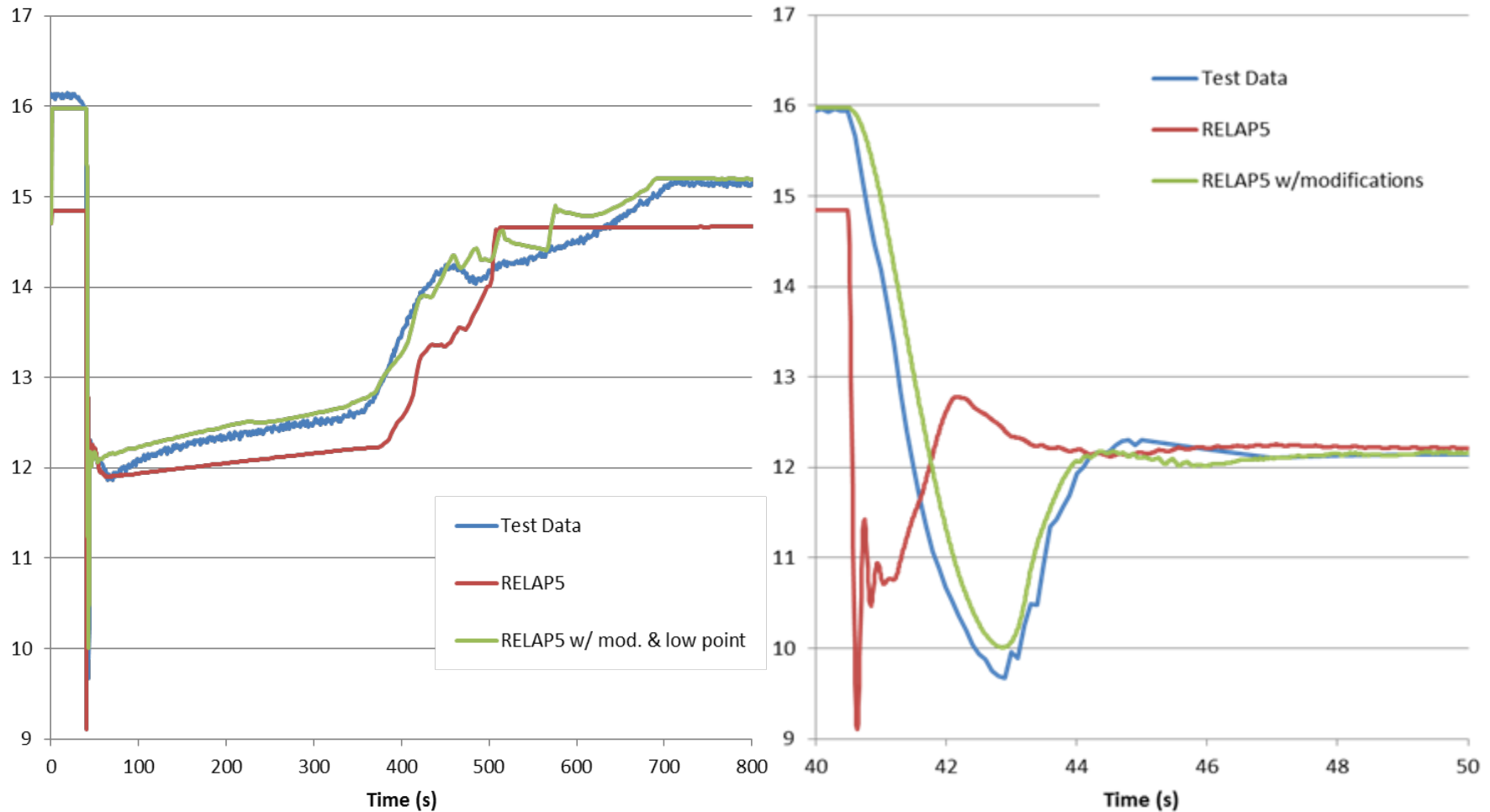
- The upper volume connects to the drain line through a tophat strainer
- The fluid resistance minor loss (K factor) for this strainer has not been empirically tested, and was estimated in the RELAP5-3D analytical model based on reference data for similar geometries
- Reducing the K factor for the tophat strainer in the RELAP5-3D analytical model by 50% more closely matches the test mockup results, specifically at the point where the upper volume pressure begins to increase more sharply

Modification of the RELAP5-3D Analytical Model:

4. Drain Line Low Point Addition

- The RELAP5-3D analytical model drain piping either continually slopes downwards or is horizontal from the upper volume to the lower tank
- The test mockup was intended to match the analytical model, but as fabricated, a local drain piping low point was introduced
- Creating a drain line local low point in the RELAP5-3D analytical model with a slope of 2.5° more closely matches the test mockup results in the pressure behavior observed prior to steady state

Upper Volume Pressure: RELAP5-3D Original and Modified Analysis vs Test



Test Mockup Configurations (18)

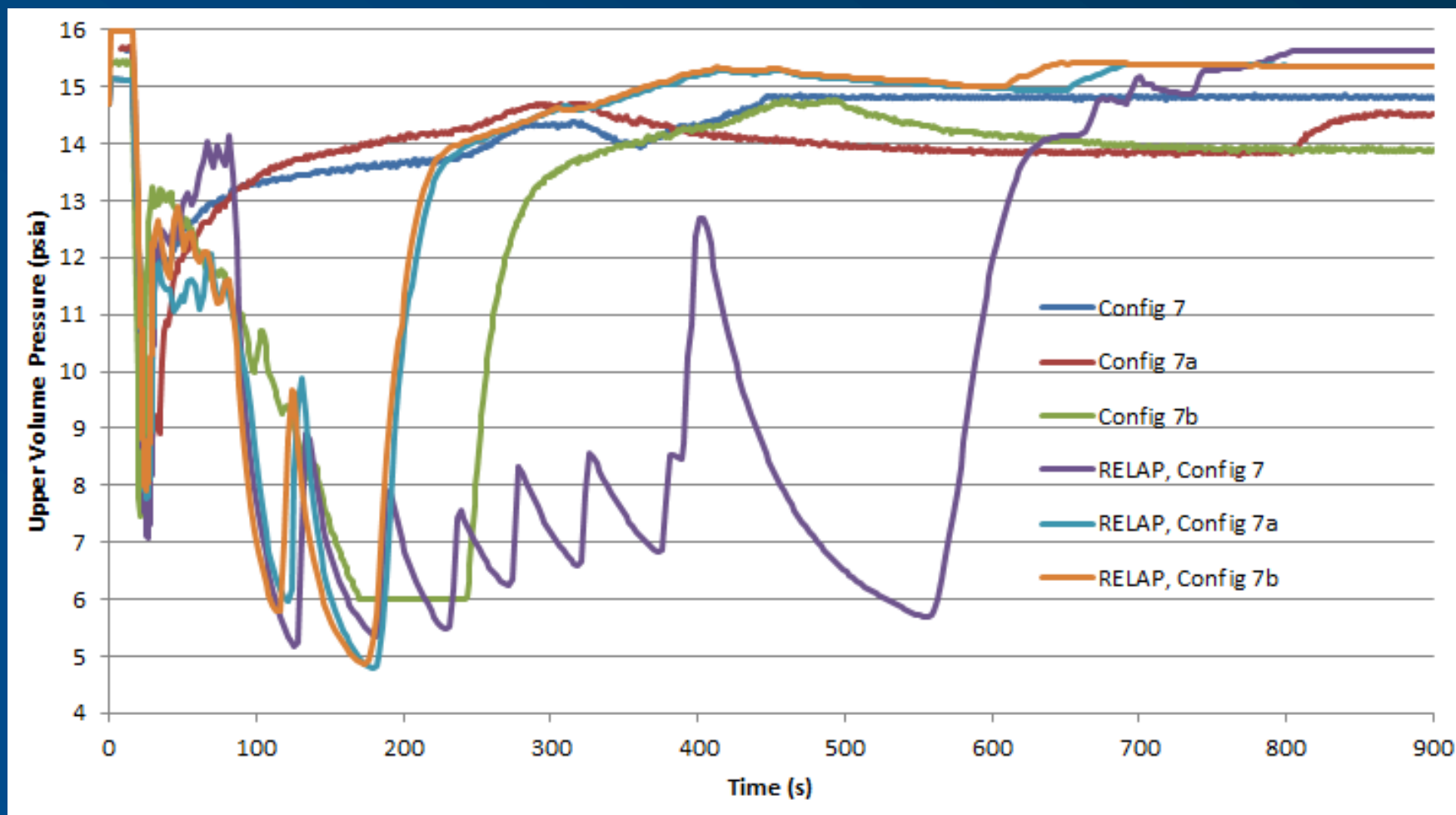
- **1, 3, 4, 5:** Baseline with lower tank (0%, 25%, 50%, and 75%) full
- **2:** Equivalent to Configuration 1
- **6:** Cross-connect piping removed
- **7, 7a, 7b:** Check valve and cross-connect removed with lower tank (0%, 75%, 75%) full, respectively. 7b also contains extra water in the air return line
- **8:** Check valve size increased to 1 inch NPS
- **9:** 20 in. risers added to elevate the piping containing the check valve
- **10:** Upper volume pressurized to 5 psig
- **11:** Alternate Drain Configuration (ADC) added to better represent component geometry
- **12-16:** Operational variations with the ADC

RELAP5-3D Analytical Model Variations and Test Mockup Configurations

- Varying the modified RELAP5-3D analytical model to match test mockup configurations 4-16 produced generally good agreement, with the exception of configurations 7 and 7a
- Each RELAP5-3D model variant would require further iteration on entrained air and temperature considerations to achieve the same level of convergence shown for Configuration 1
- Configurations 7 and 7a:
 - In the test mockup, water begins flowing down the air return line, reversing shortly after the drain valve is opened
 - In the RELAP5-3D analytical model, water continues to drain down the air return line, resulting in very low pressures in the upper volume (similar to Configuration 7b)
 - The model can be refined to better approximate the test mockup by adding extra fluid flow resistance loss at the air return line elbow/abrupt reducers

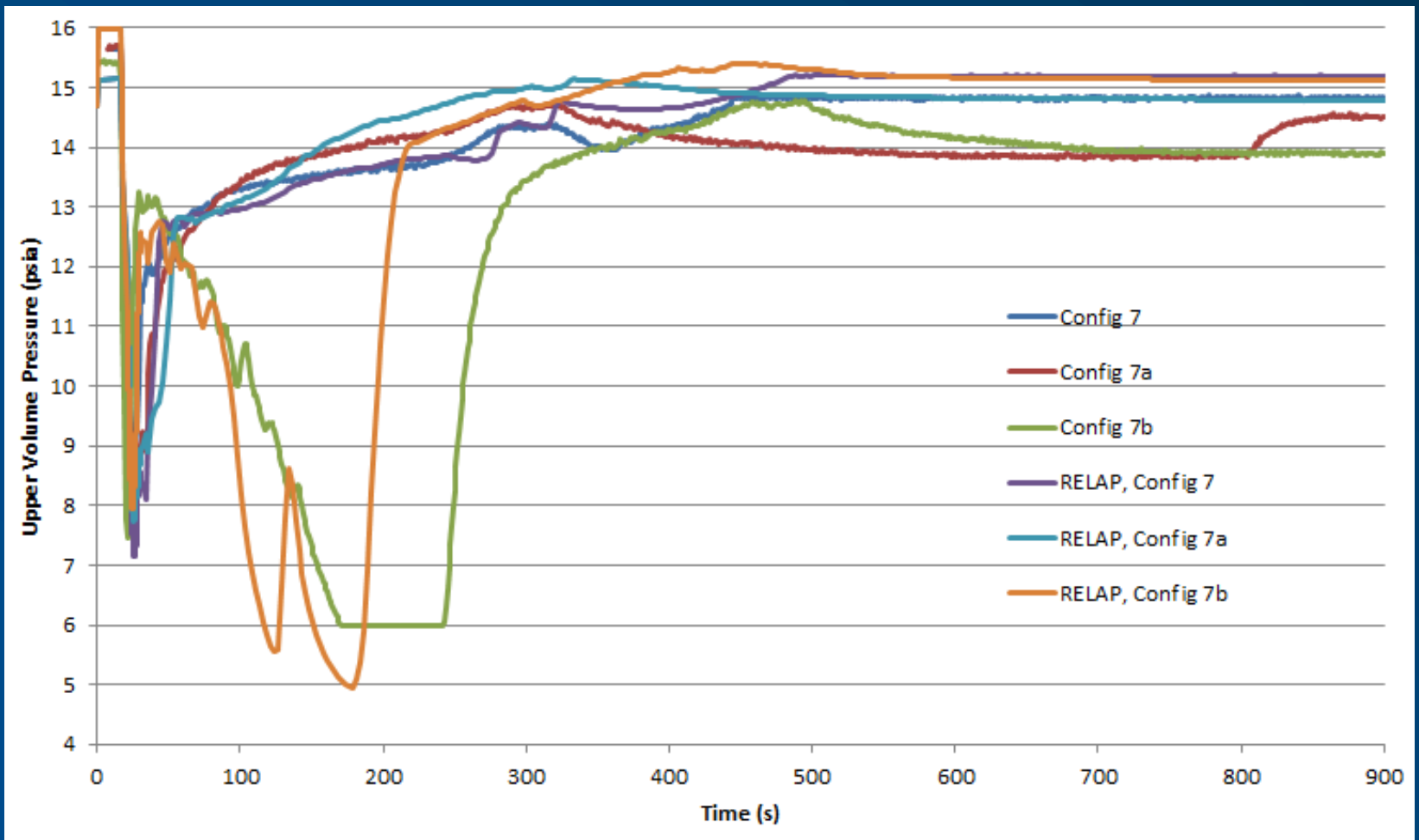
Upper Volume Pressure:

Test Configurations 7, 7a, and 7b versus the RELAP5-3D Analytical Model



Upper Volume Pressure:

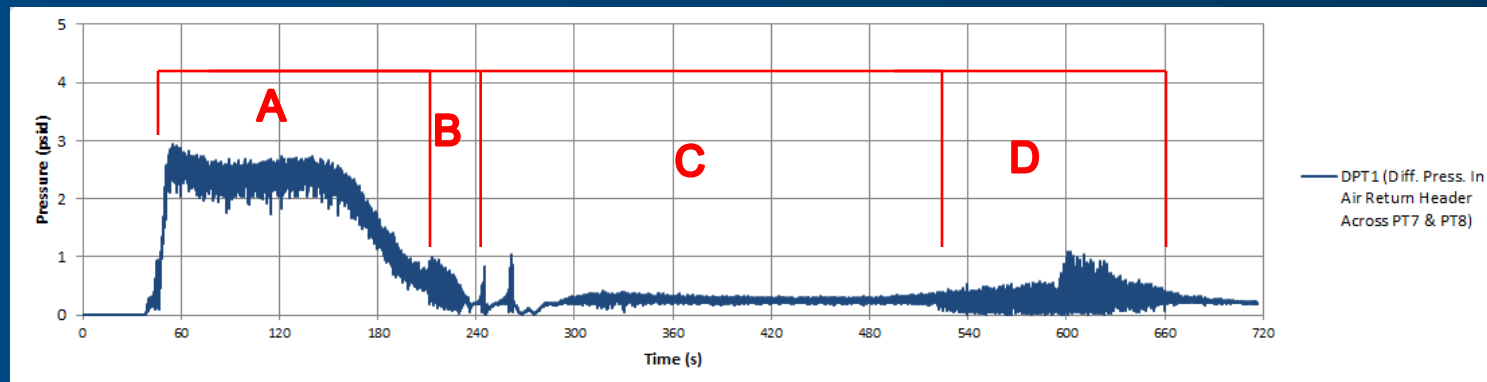
Test Configurations 7, 7a, and 7b versus the RELAP5-3D Analytical Model With Added Fluid Flow Resistance



Check Valve Activity

- The check valve in the air return line exhibits chattering (flutter) in both mockup testing and RELAP5-3D analytical results
- Check valve chatter observation acuity varied between the test runs
- Some valve chatter was observed in the analytical model, which approximated Configurations 5, 9, 10, and 11 observations
- Configurations 4 and 8, however, showed a poor fit between test mockup and RELAP5-3D analytical results
- The RELAP5-3D check valve component functions as either fully open or fully shut; some chatter observed in the test mockup may be due to partially-opened valves

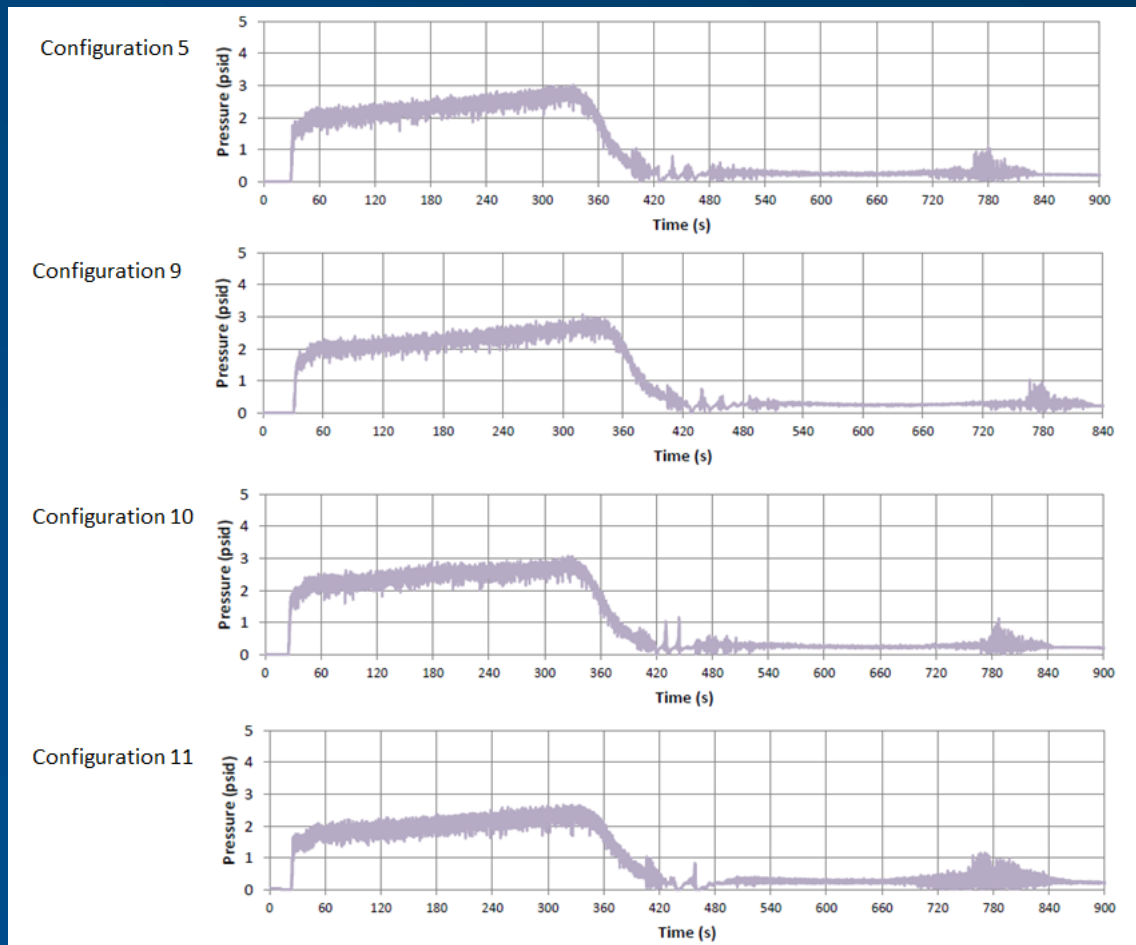
Test Mockup Check Valve Activity



- A: Normal draining; 95% of water is drained during this time
- B: Normal draining ends; flow rate of air can no longer keep check valve fully open
- C: Drain flow reverses; water is draining down the air return attachment from the upper volume, through cross-connect piping and into the drain header; air is flowing down the cross-connect piping and up the drain connection to the upper volume
- D: Unstable two-phase contra-flow occurs in the air return attachment to the upper volume; heavy check valve chatter occurs

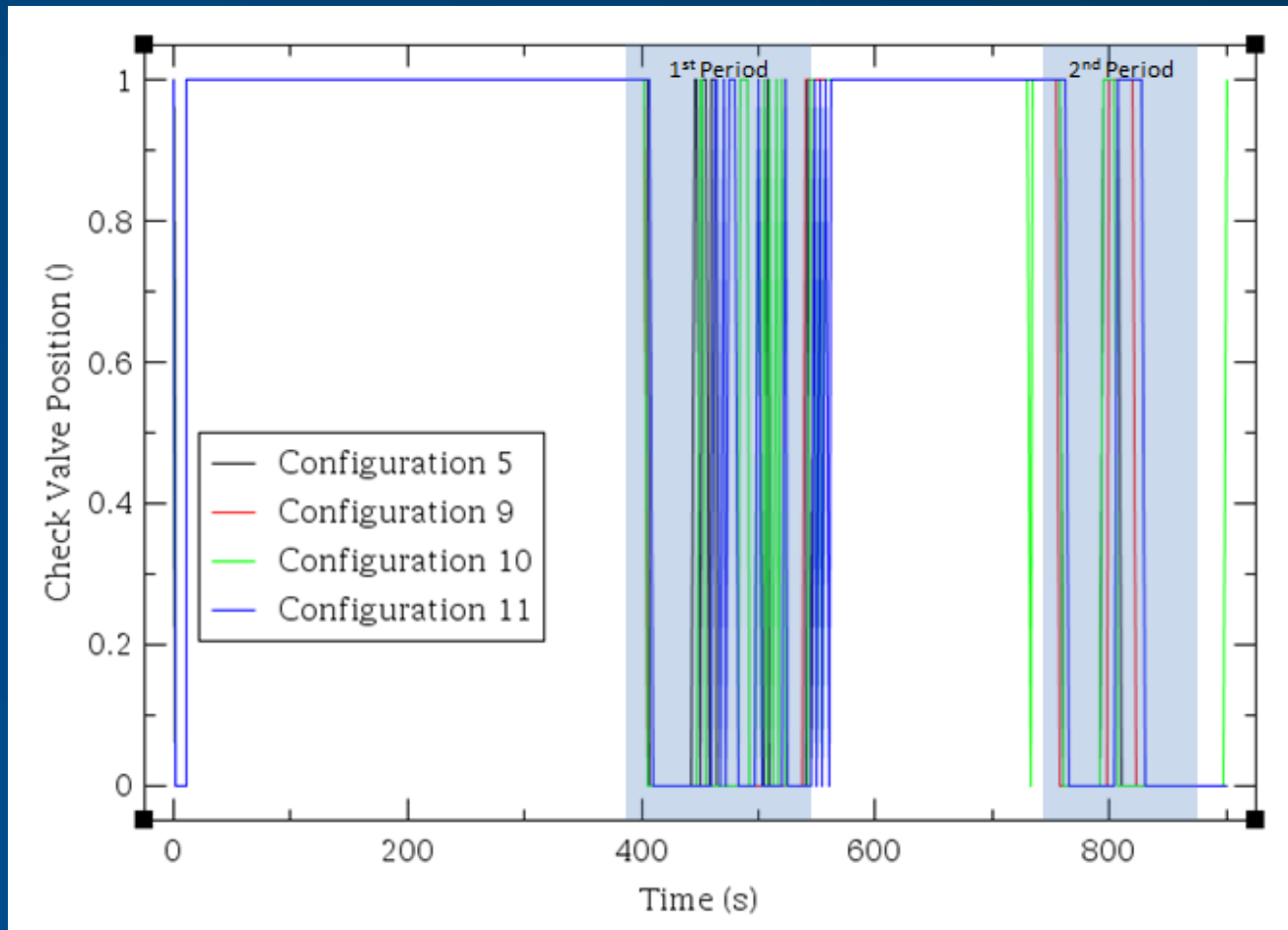
Test Mockup Check Valve Activity

Test Mockup Configurations 5, 9, 10, and 11



Check Valve Activity

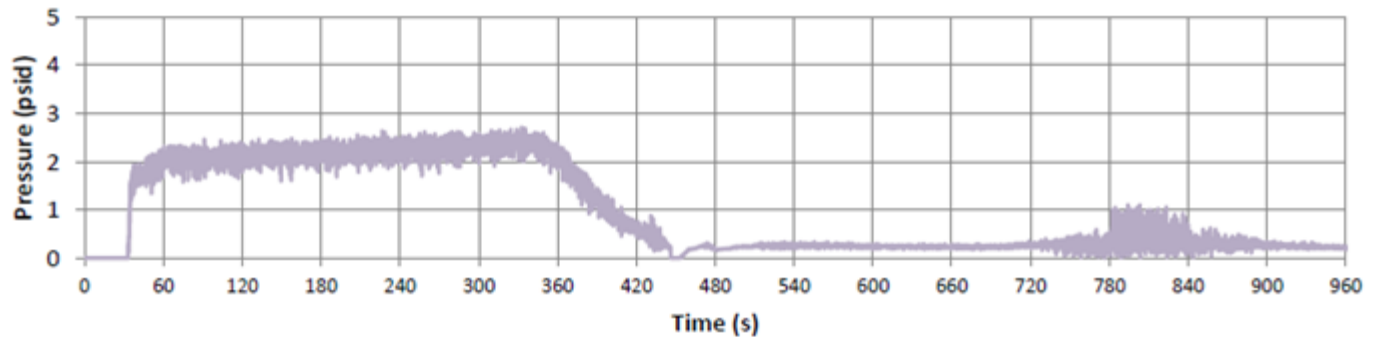
Test Mockup Configurations 5, 9, 10, and 11 imposed over RELAP5-3D analytical models



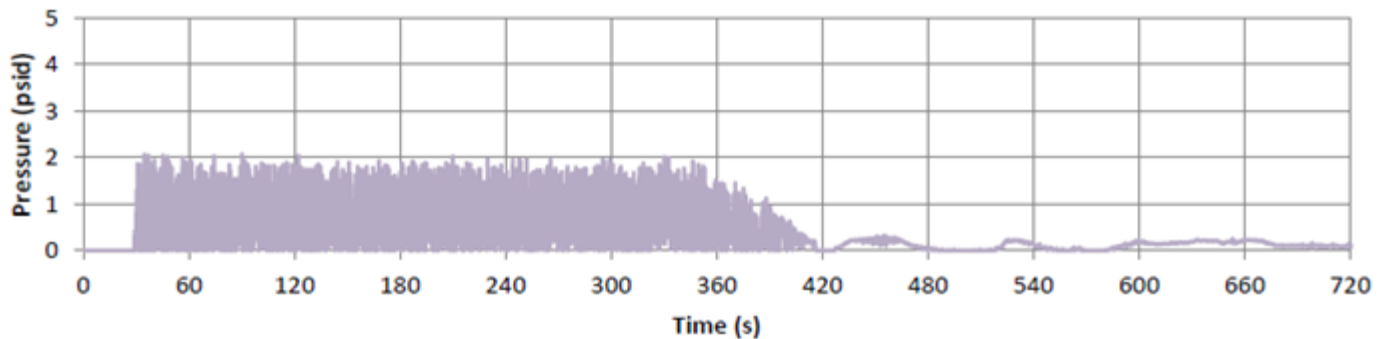
Test Mockup Check Valve Activity

Test Mockup Configurations 4 and 8

Configuration 4

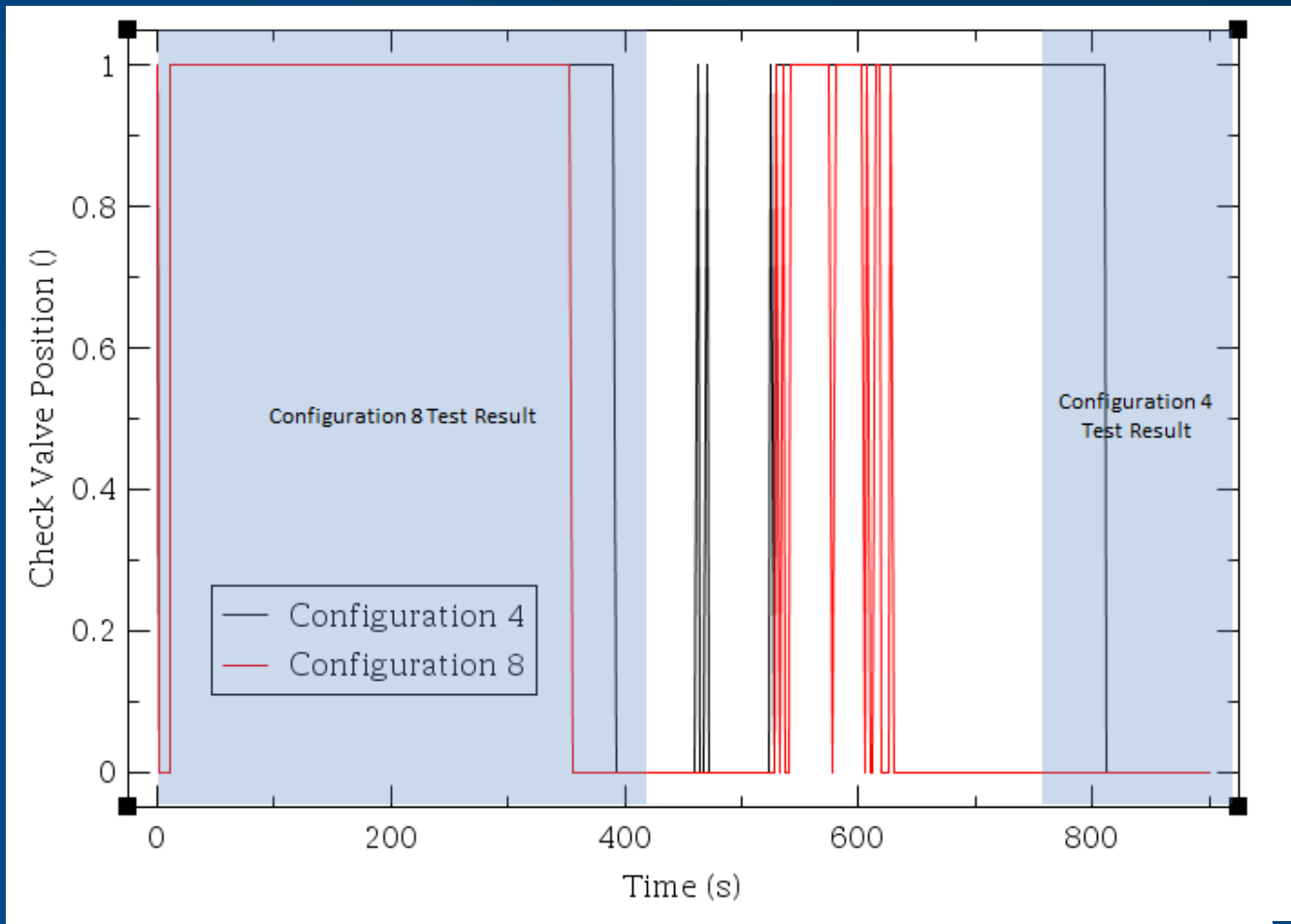


Configuration 8



Check Valve Activity

Test Mockup Configurations 4 and 8 imposed over RELAP5-3D analytical models



Conclusions

- The critical minimum upper volume pressures calculated in the prior RELAP5-3D analysis have been verified through mockup testing to within 5%
- RELAP5-3D analytical modeling was shown to accurately replicate the test mockup when accounting for fabrication inconsistencies
- Check valve activity in the RELAP5-3D analytical model shows some agreement with the test mockup, but analytical limitations prevent the same behavior observed during the test mockup from being calculated in the model
- Further GDEB RELAP5-3D analytical modeling of check valves may be warranted for better accounting of system fluid dynamics

Acknowledgements

- The following GDEB personnel are acknowledged for their association with this technical effort:
 - K. Collier, Fluid Dynamics
 - A. Pillman, Fluid Dynamics
 - C. Kendrick, Fluid Dynamics
 - S. Maeby, VIRGINIA Ship Systems
 - D. Mittelman, VIRGINIA Ship Systems
 - A. Andrin, Engineering Technical Services
 - M. Derosier, Engineering Technical Services