TFAWS Active Thermal Paper Session

Modeling the Rapid Boil-Off of a Cryogenic liquid Injected into a Low Pressure Cavity

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Thermal & Fluids Analysis Workshop
TFAWS 2016
August 1-5, 2016
NASA Ames Research Center
Mountain View, CA

Introduction

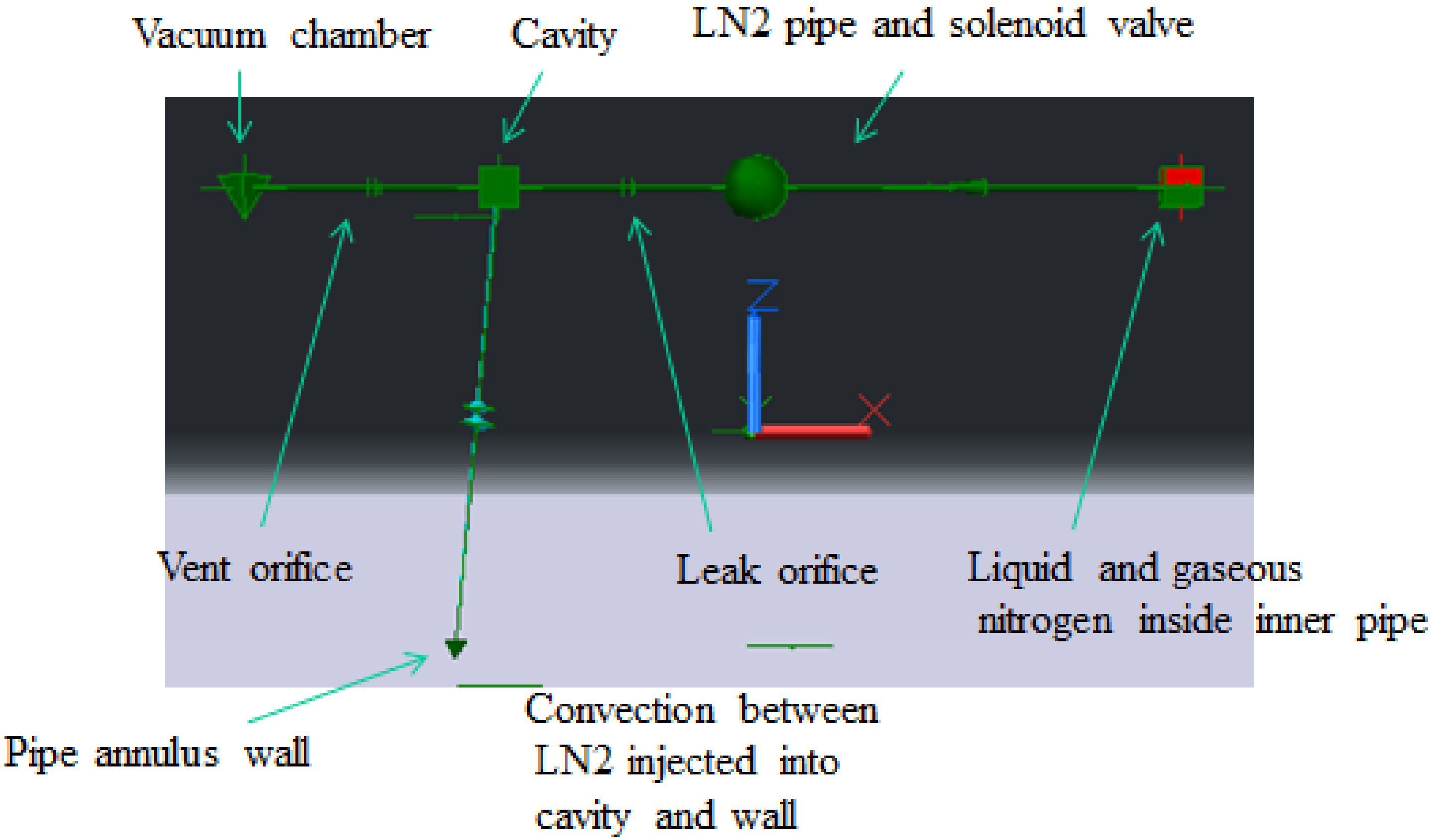
- Many launch vehicle cryogenic applications require modeling the mass flow of a cryogenic liquid into a low pressure cavity
- There are multiple difficulties in this type of simulation
  - Two phase fluid flow
  - Boil off in a lower pressure environment
  - Cryogenic liquid interaction with a warm surface
  - HTC uncertainty
- A thermodynamic/heat transfer analysis was performed using the FloCAD module of Thermal Desktop and Sinda Fluint
- The thermal simulation was backed up with cryogenic fluid test performed at MSFC
- The model was correlated with the test data

Thermodynamic and Heat Transfer Analysis

- A thermal fluids model was constructed in Thermal Desktop to predict the pressure response and boil off
  - Mass flow of liquid nitrogen into a low pressure, warm cavity

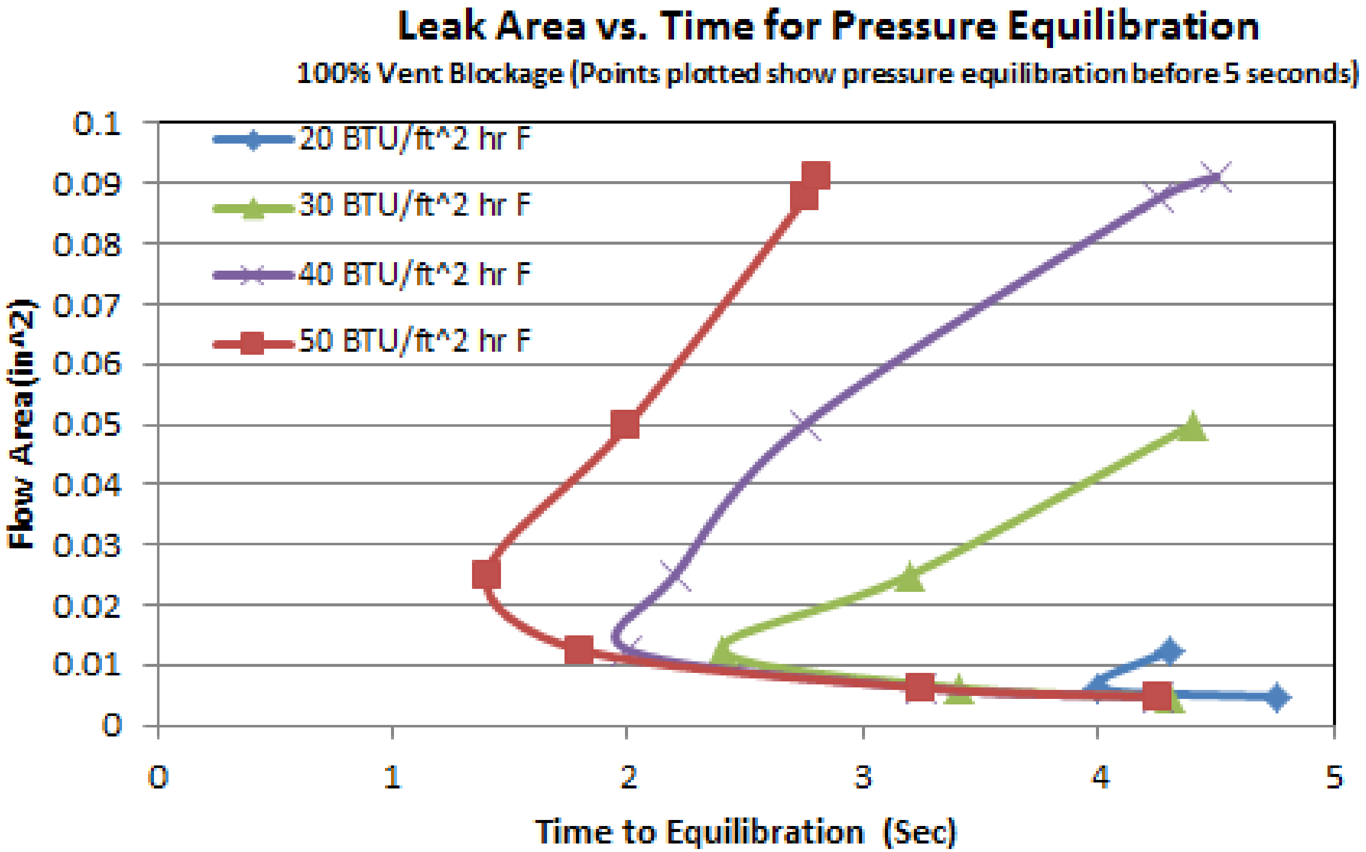
- The objective of the analysis was to predict the response of the liquid boil off
  - Pressure response due to rapid boil off
  - Prediction of fluid quality profile
  - Pressure response dependence on liquid mass flow rate
  - Effect of cavity wall temperature
  - Effect of cavity pressure
  - Model boil off and pressure response dependency on the cavity heat transfer coefficient

Thermal Desktop Fluids Model



Pressure Response vs. Wall HTC and Liquid Mass Flow Rate

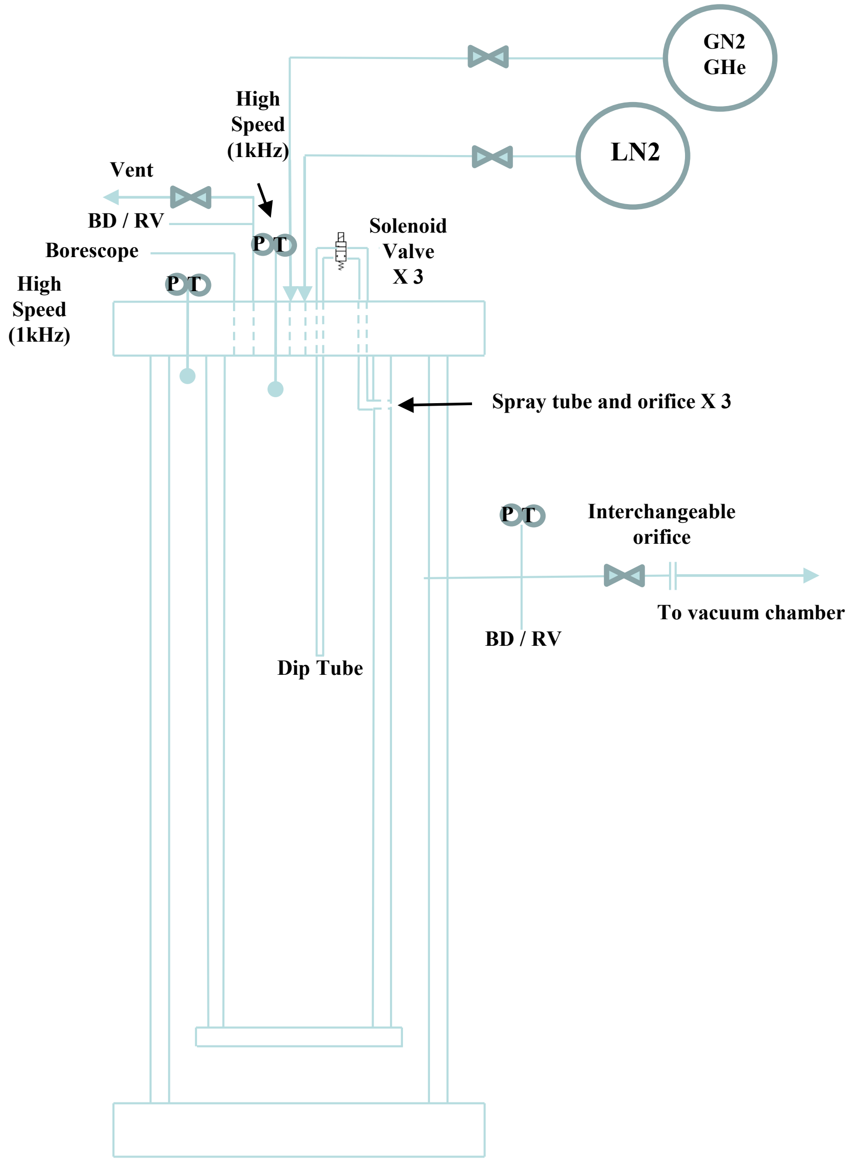
Liquid nitrogen mass flow rate was varied by changing the flow area



Model Validation by Test

- A cryogenic test was performed at MSFC to determine the wall heat transfer coefficient and reduce model uncertainty
- Liquid nitrogen was injected into a warm, low pressure cavity
- An extensive array of temperature and pressure measurement devices captured the thermodynamic response of the system
- Measured data compared to model predictions
- Model was correlated

Test Set Up



GN2
GHe
LN2
High
Speed
(1kHz)
Vent
BD / RV
Borescope
P T
High
Speed
(1kHz)
P T
Solenoid
Valve
X 3
Spray tube and orifice X 3
P T
Interchangeable
orifice
To vacuum chamber
BD / RV
Dip Tube

LN2 Inner Pipe – Stainless Steel

- 6” Sch. 40 x 46” long
- Bottom Closeout 1” thick
- Pressure via P1
- LN2 Dipstick Stainless Steel: ½” x 0.049” wall x 30” with 1 ell
- Note: Pipe described herein has a 6” x 0.1875 x 6” long tube above it. See Test Article Overview.
- Fill level ~46” at run (between TC 8 and 9), note TC liquid rake (TCs 1-10).

Test Set Up

LN2 Flow Path – From left to right

- Pre-valve: ½" x 0.035" wall x 14" long with long ell
- Valve: ASCO Red Hat, 8222G002LT
  - orifice = 5/8"
  - Cv = 3.8
- Post-valve: ½" x 0.035" wall x 3" long entering standard tee. Flow enters branch and leaves run
- These tubes are insulated with ~2" of fiberglass insulation. Lab Temp is ~70 deg F
- Note: TC31 is downstream of valve in tee. TC31 measures fluid temperature re-entering inner pipe headed to sized orifice.

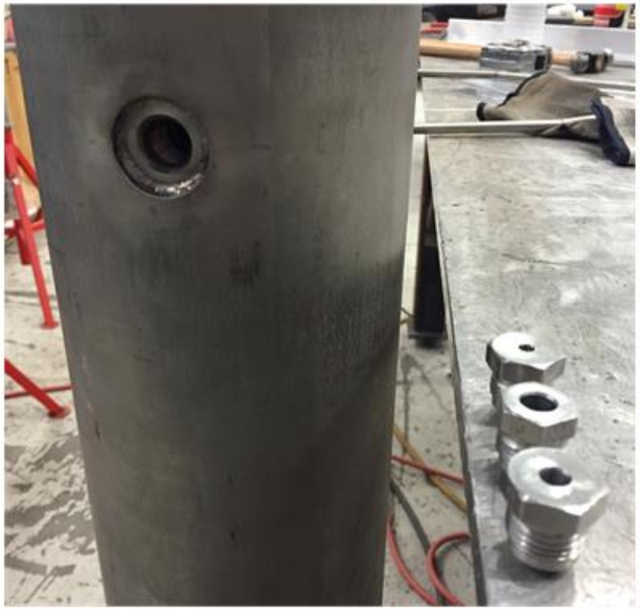
LN2 Flow Path – Returning inside LN2 pipe down to orifice

- Enters through bulkhead fitting then a swagelok tee pointing downward.
- Copper line, ½” x 0.032” wall x 10”long
- Ell into orifice.

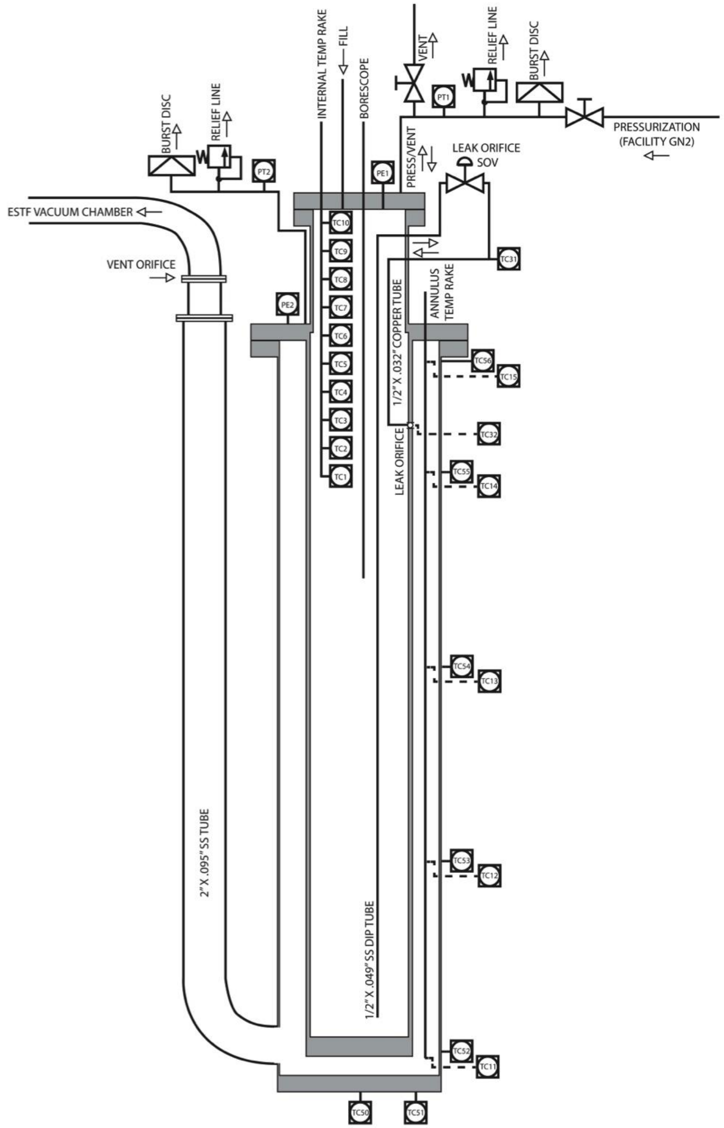
LN2 Injection Tube on left
Dipstick on right

LN2 Flow Path – Orifices

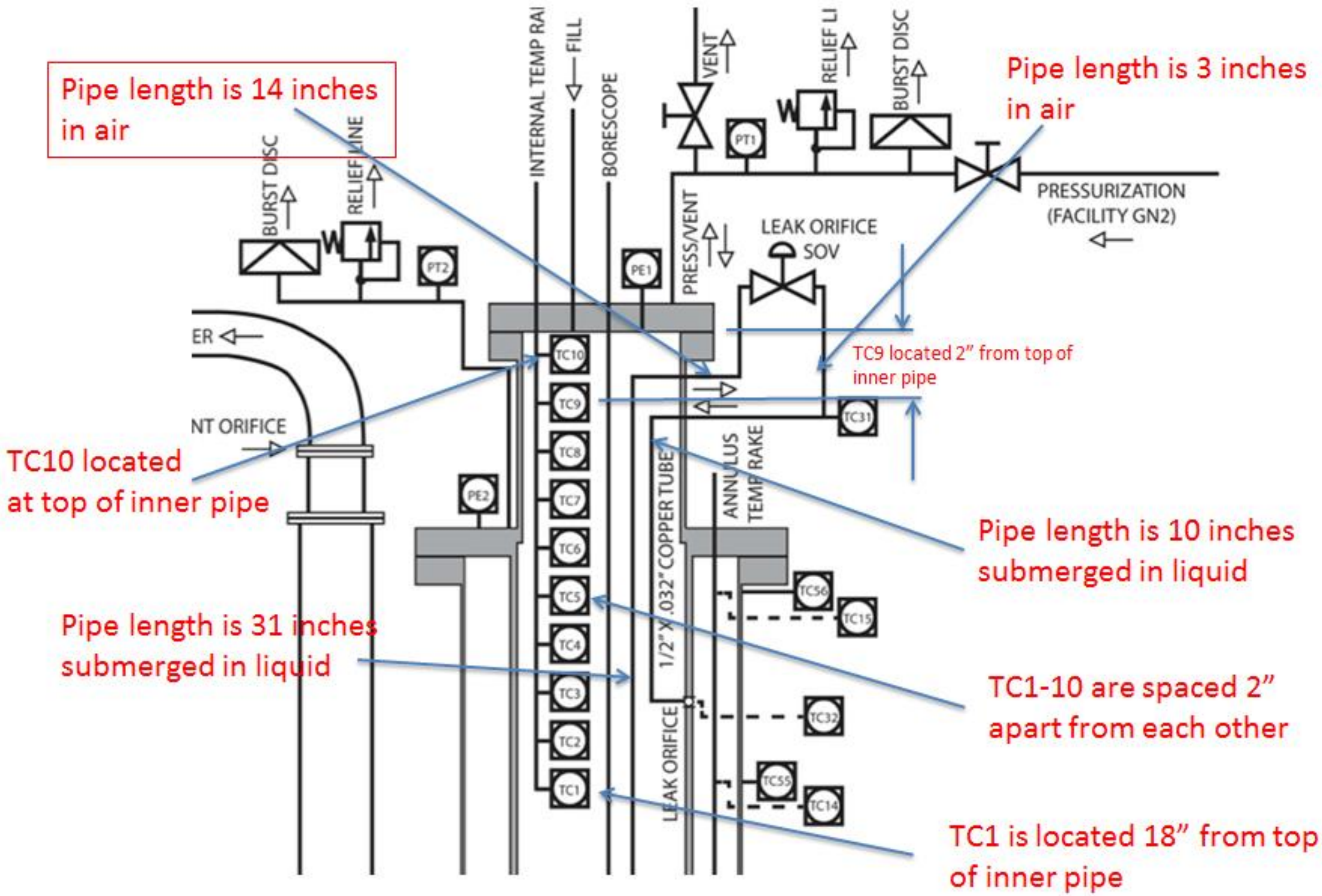
- Orifice size varies per test. We started with the smallest requested liquid orifice first
  - 0.178" diameter
  - 0.252" diameter
  - 0.357" diameter



Test Instrumentation



Test Instrumentation



Test Results

- 16 test cases were simulated
- Pre-test model was validated
- Model adjustments were not required
- Heat transfer coefficients were correlated
  - Pre-test HTC range was 20 to 50 Btu/ft^2 hr F
  - Testing showed heat transfer coefficients to be at the lower end of the pre-test range
  - The HTC decreased as the liquid mass flow decreased
  - HTC profile was dependent on cavity pressure response

Summary

- The thermodynamic simulation accurately predicted the pressure response and boil off of the cryogenic liquid

- The heat transfer coefficient varied and was highly dependent on cavity pressure and the liquid mass flow rate

- A twinned tank two phase lump accurately predicted the pressure response and boil off of the cryogenic liquid

- It is imperative to account for a large uncertainty in the heat transfer coefficient in thermodynamic heat transfer simulations