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LAUNCH SERVICES PROGRAM

CRYogenic Orbital TEstbed Ground Test Article Thermal Analysis

TFAWS

August 13th-17th, 2012

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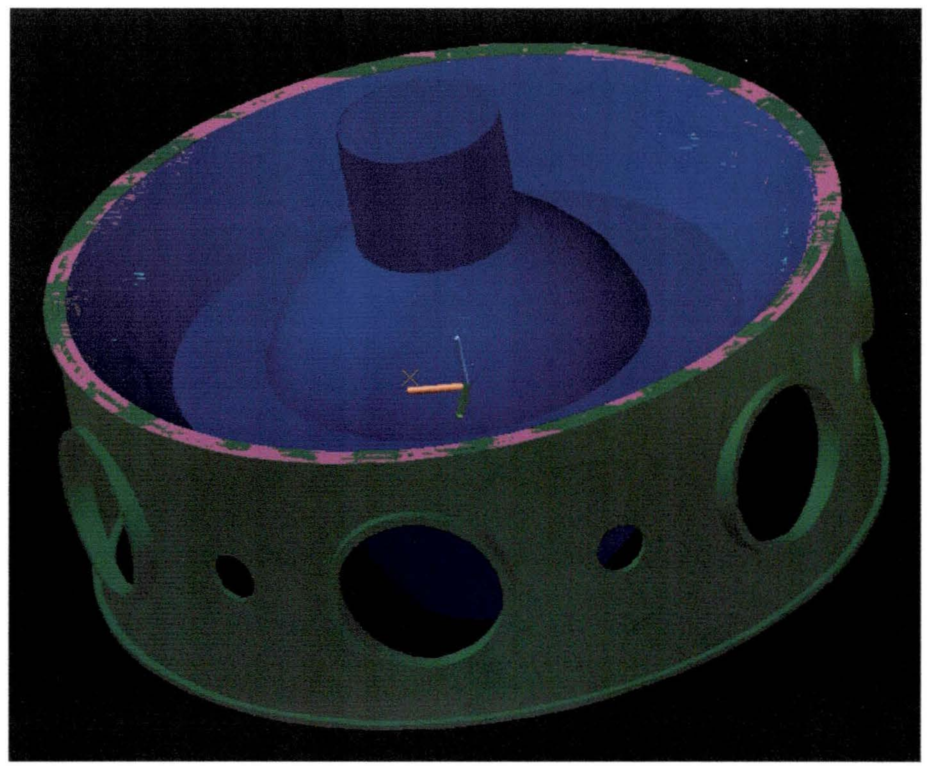
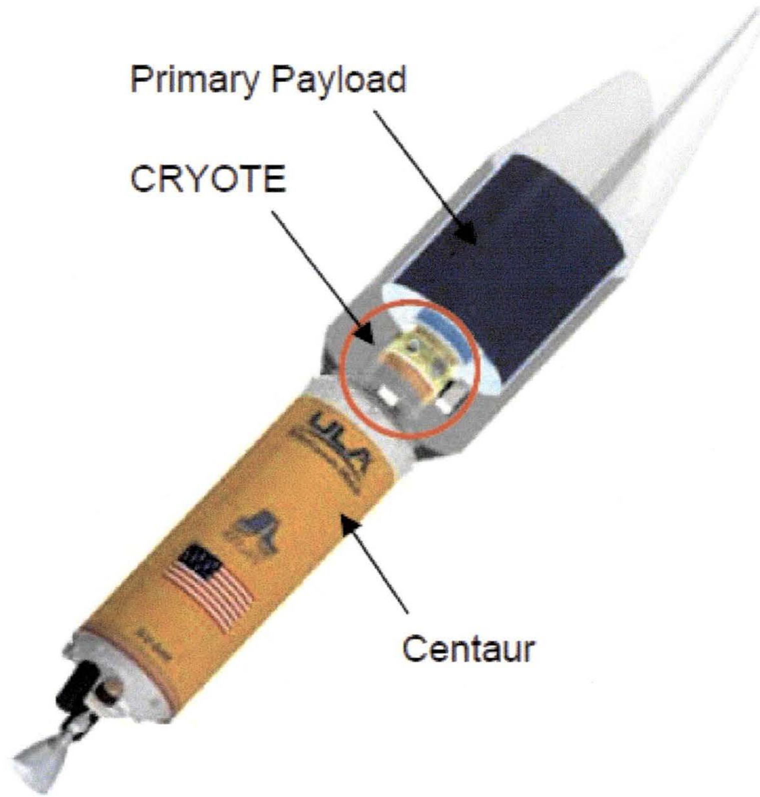


Agenda

- Introduction
- GTA Analysis Goals
- Test Facility
- Post-Test Modeling
- Post-Test Results/Correlation Efforts
- Questions/Discussion

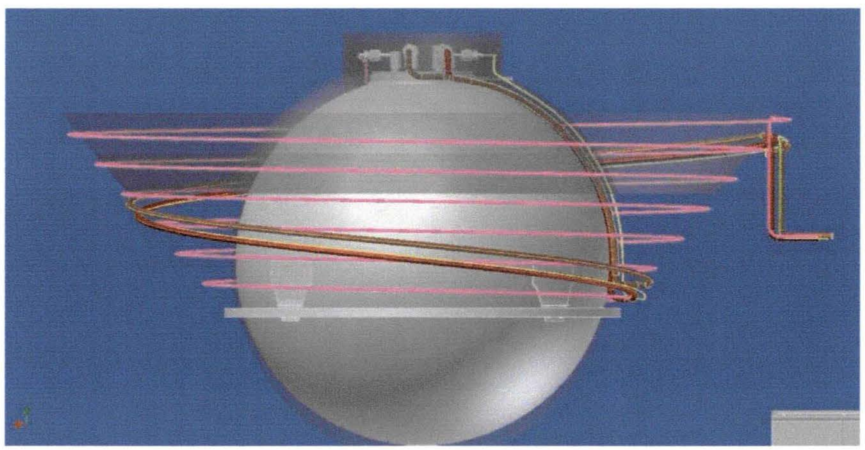
Introduction

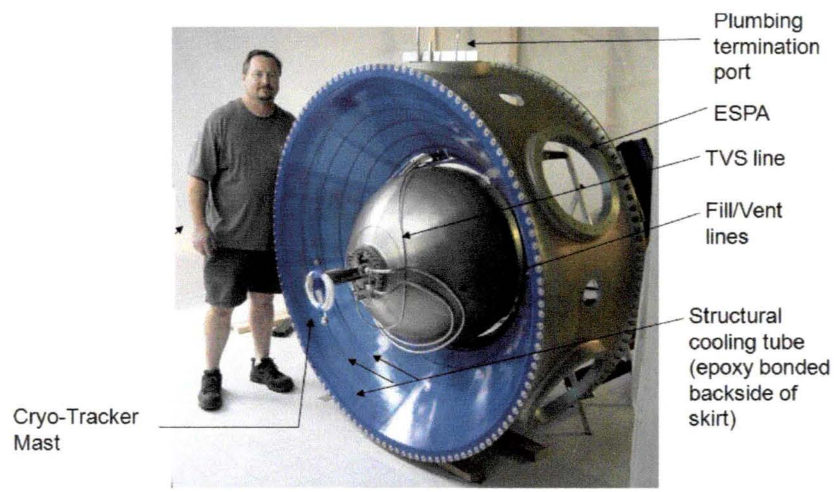
- CRYogenic Orbital TEstbed Ground Test Article
  - Multi Layer Insulation designed and applied to GTA to simulate Tank/LN2 on-orbit radiation-only environments
    - KSC Cryogenics Test Laboratory
  - Purpose of GTA test is to measure heat loads on tank/fluid during unsteady and steady state
  - GTA fitted with thermocouples at various locations
  - Unique opportunity to anchor thermal model against test data
  - Testing at MSFC in progress



GTA Thermal Analysis Goals

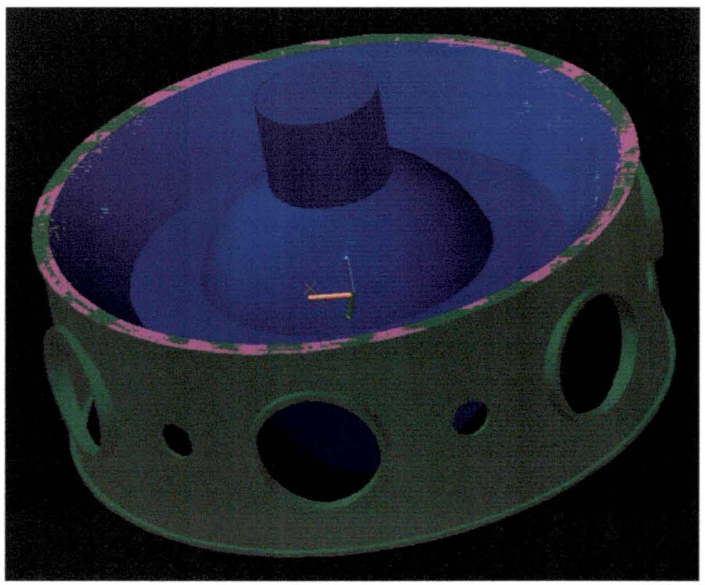
- Objectives:
  - Provide thermal performance analysis on CRYOTE GTA (e.g. analytical prediction of LN_2 boil off rates)
    - Correlate heat loads to LN_2
    - Correlate temperature responses throughout GTA
    - Evaluate MLI performance

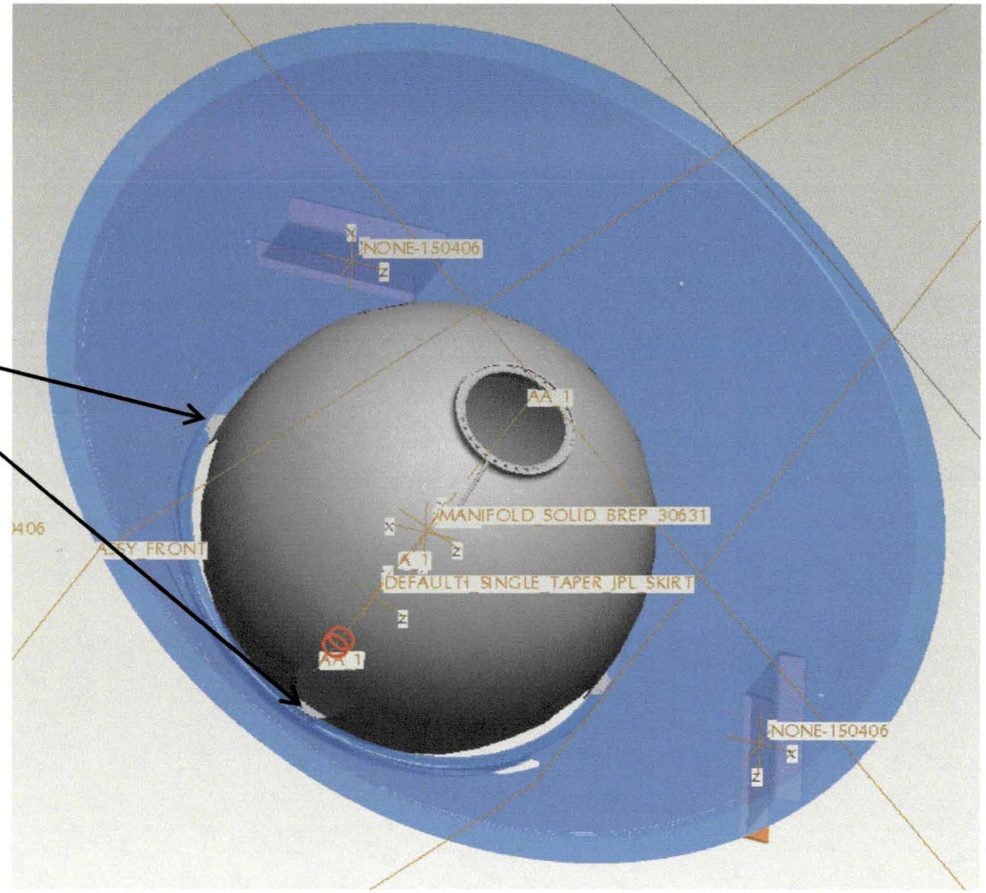




Thermal Networks

- Thermal Networks
  - MLI and Cone
  - ESPA Ring and Cone
  - MLI and Tank
  - Cone and Tank
    - 4 titanium attach points





Environments

- Vacuum Chamber Environments
  - Temp proposed to be held at a constant 292K
  - Pressure proposed to be held constant
    - Effective emissivity associated with MLI surfaces
    - $e^* = 1/(1/e_o + 1/e_i - 1) \times [1/(N+1)]$ = theoretical e*

<u>2 Radiation Analysis Groups in TD Model</u>

- Exterior Radiation Analysis Group
  - ESPA ring and outer MLI surface only
  - Exposed to vacuum chamber environments
    - Temperature set to BC of 292°K (60°F)
- Interior Radiation Analysis Group
  - Cone, inner MLI surfaces and tank

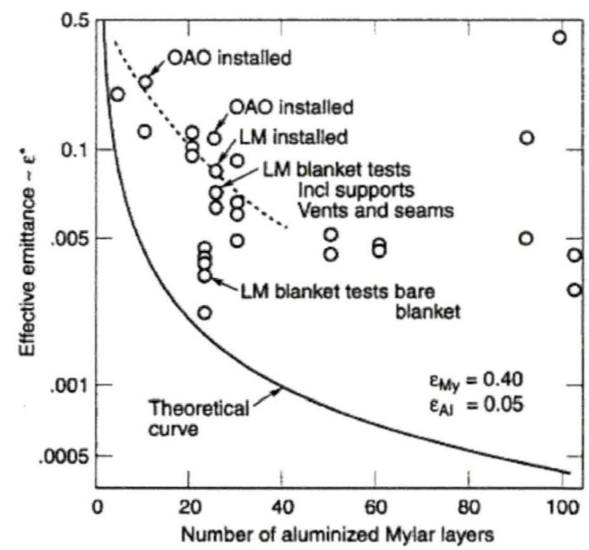
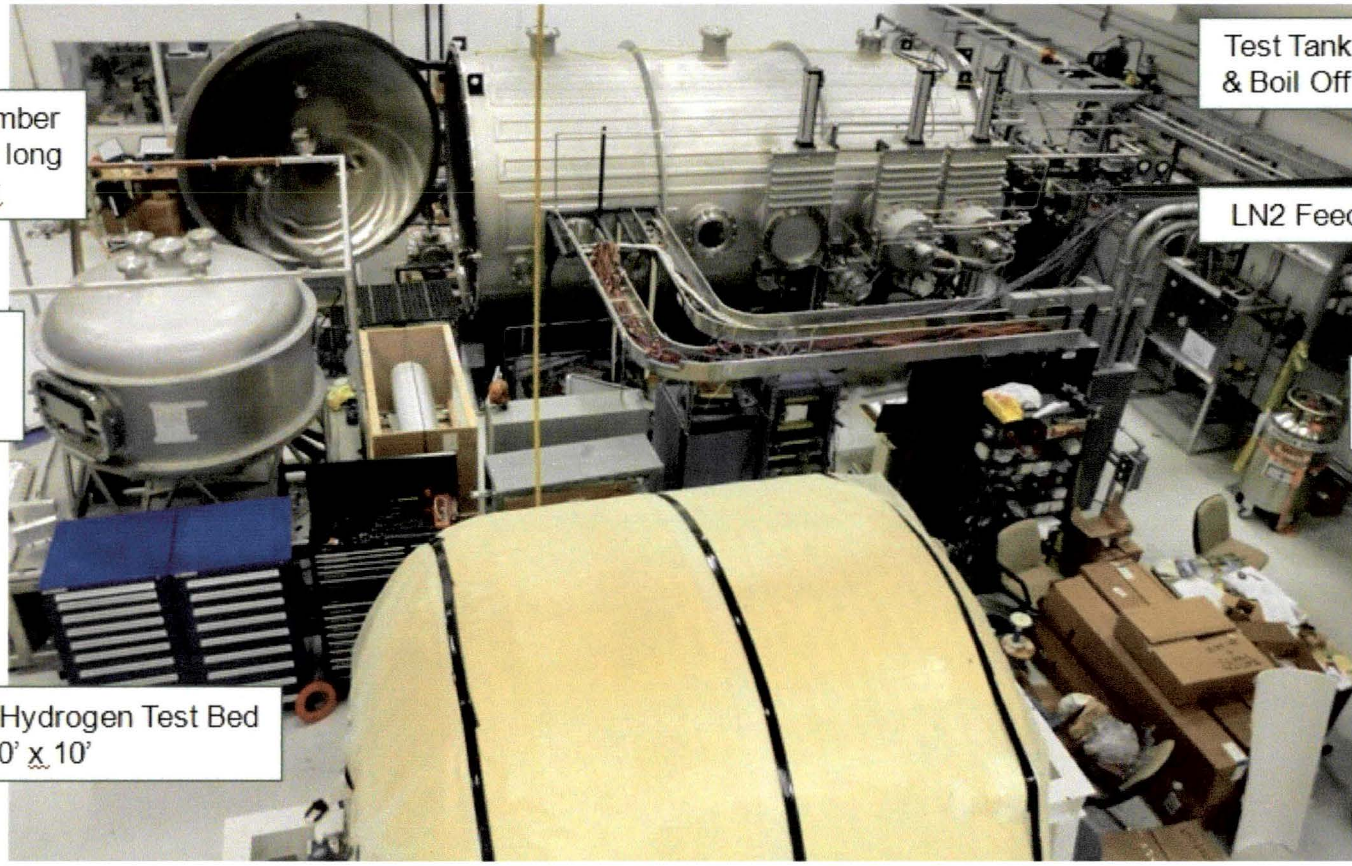


Fig. 5.3. Effective emittance vs. number of single aluminized layers.

Test Facility

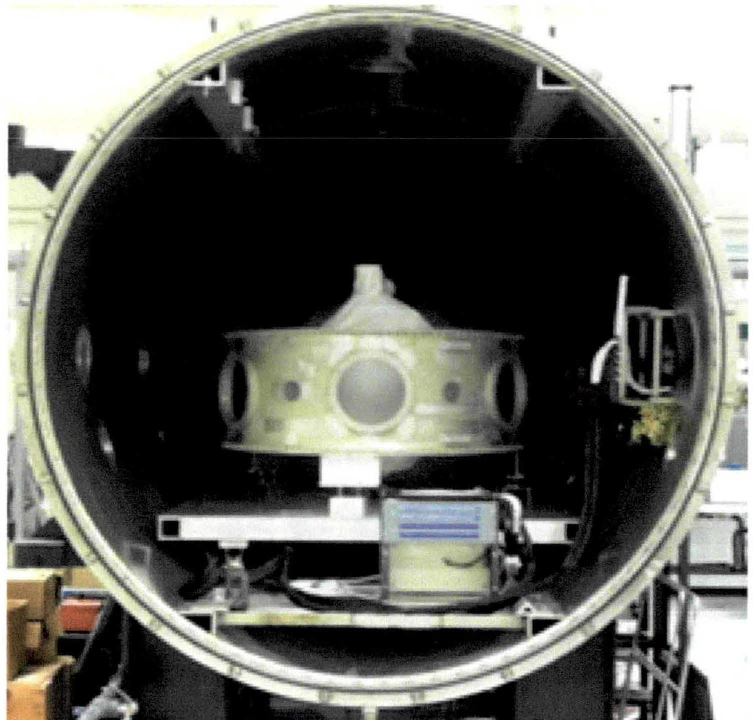
Exploration Systems Test Facility (ESTF) at MSFC

Test Facility



Test Facility

- Testing commenced 11-18-2011
- CRYOTE GTA was initially filled to ~90% full w/LN2
- LN2 was conditioned to 18psia before steady state measurements (tank @ 14.7psia during fill)
- Received 'Fill' and 'Steady State' data sets from test team on 12-1-2011



CRYOTE Installed in ESTF

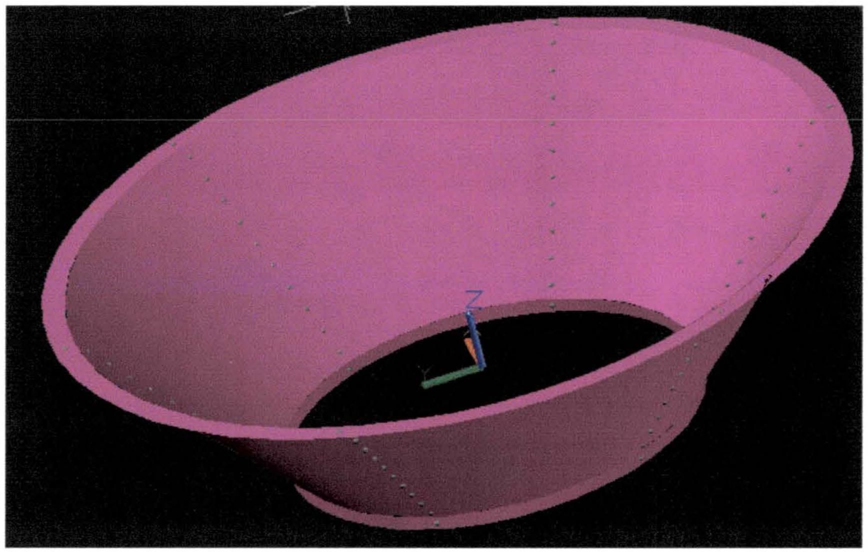
Post-Test Thermal Desktop Modeling

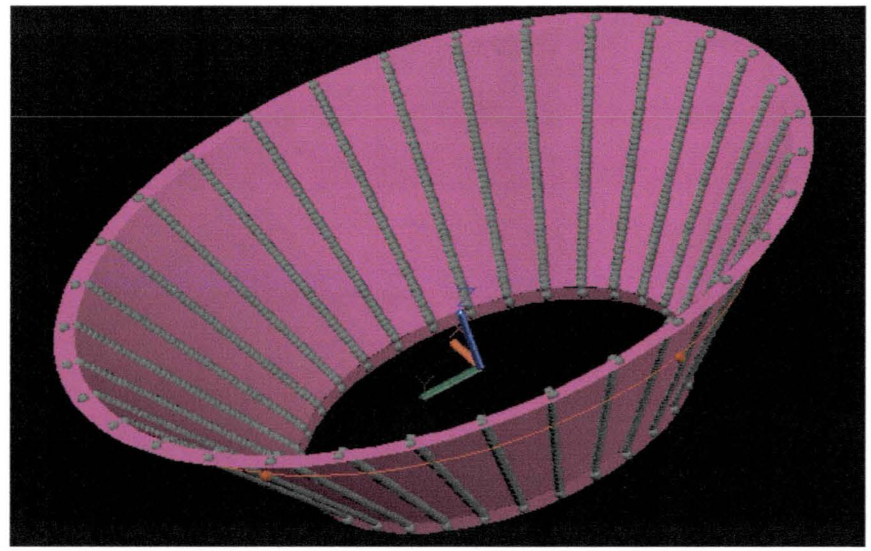
Post-Test TD Modeling

- Pre-test modeling very useful for finding heat loads to LN2 but not necessarily much else
  - Due to low fidelity nature of baseline model
  - Extremely difficult to assign broad surface temperatures to thermocouple locations
- Refined goals were to capture thermal gradients along:
  - Skirt surfaces
  - Tank surfaces
- Refined goals required refined modeling

Post-Test Modeling

Thermal Mesh Quality Refinements - Skirt



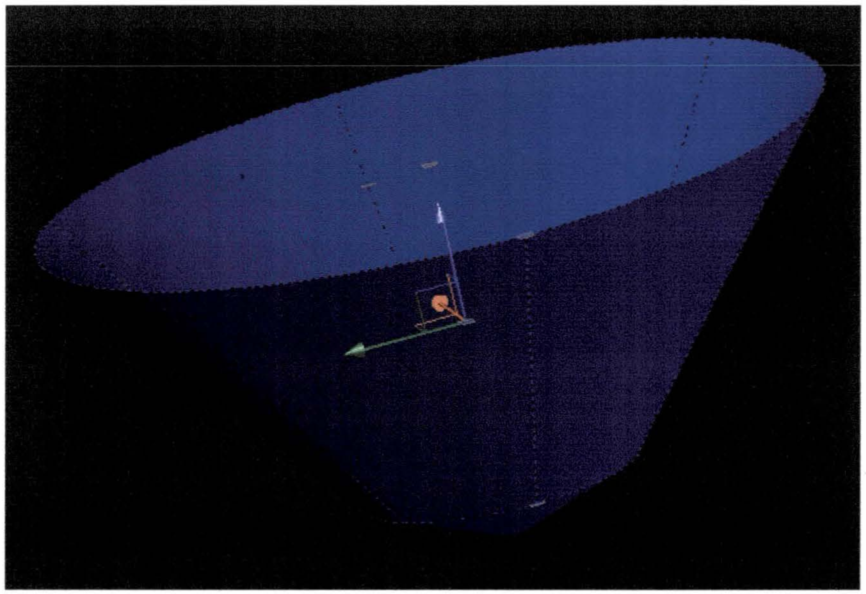


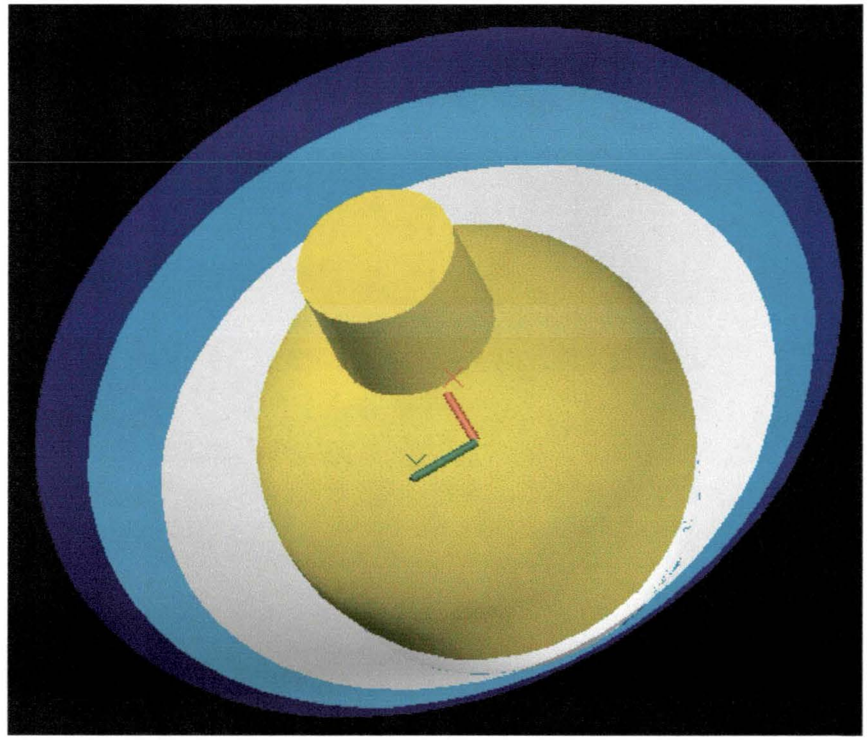
Pre-Test Model:
-72 TD/RC Nodes
-6 Angular Sections

Post-Test Model:
-1504 TD/RC Nodes
-32 Angular Sections

Post-Test Modeling

Thermal Mesh Quality and Surface Refinements - MLI





Pre-Test Modeling:

-Represented as a single surface

-"Overall" effective emissivity value used

-72 TD/RC Nodes

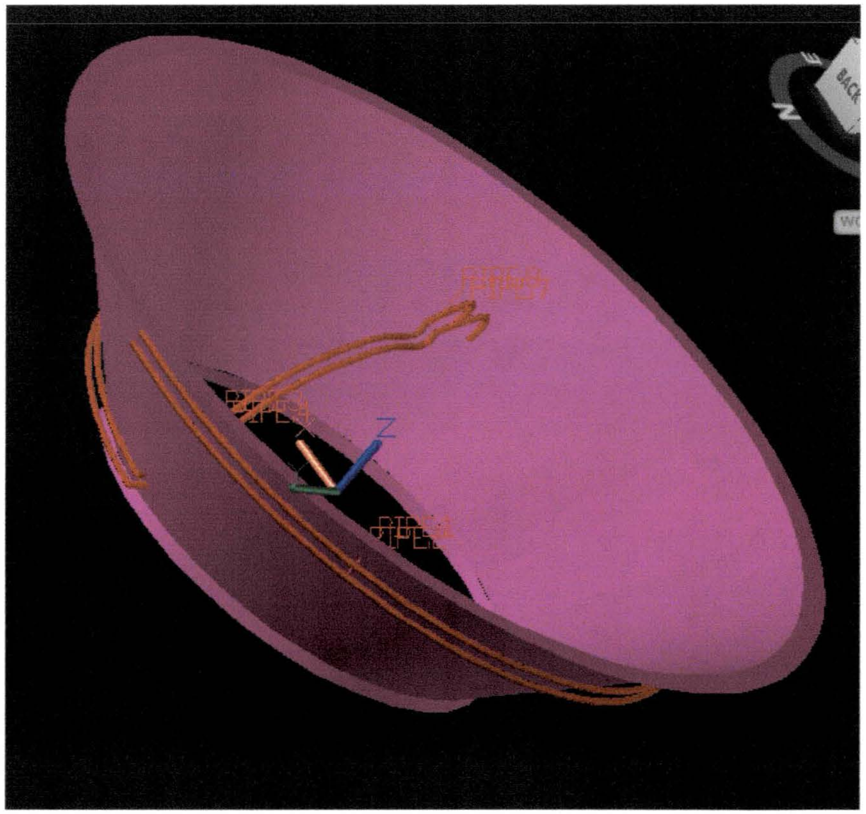
Post-Test Modeling:

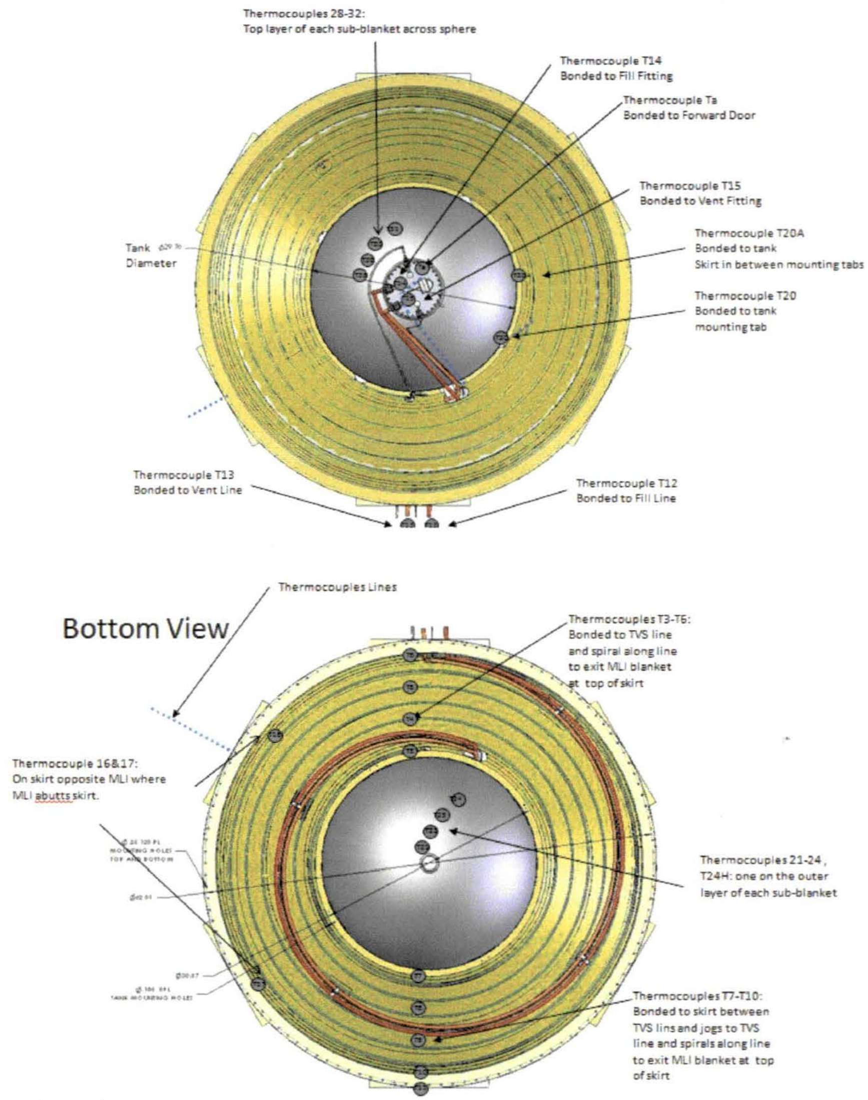
-Represented as 4 separate sub-blankets (per Johnson's MLI blanket sketches)

-5024 TD/RC Nodes

Post-Test Modeling

<u>Fill and Vent Lines Added:</u>
-Use of FLOWCAD Pipes
-Set to BCs for fill modeling





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Post Test Modeling

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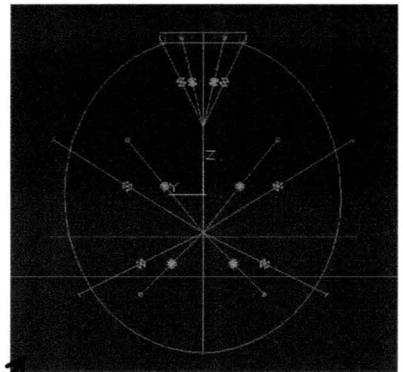
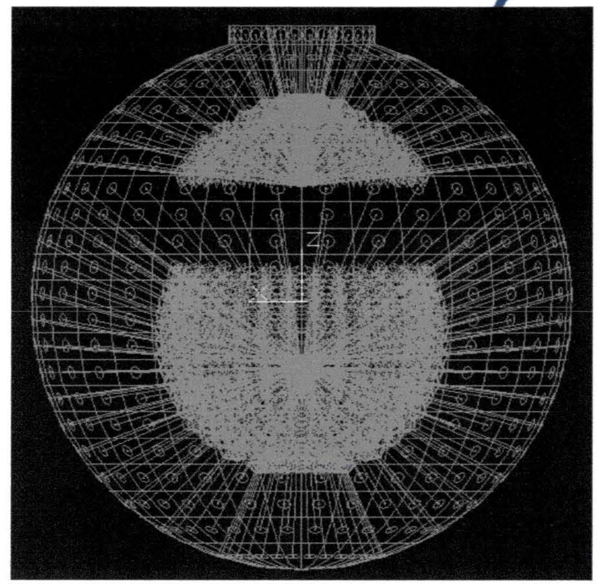
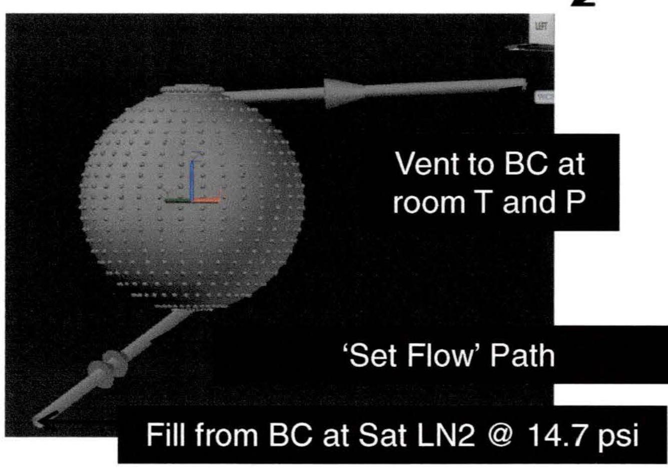


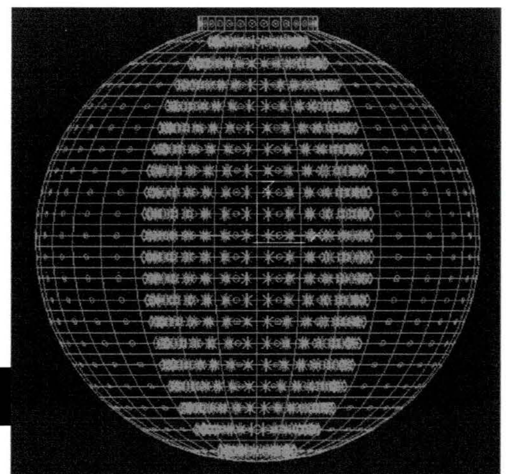
Pre-Test Tank Model:
- 24 TD/RC Nodes
- 2 Lumps (liquid/vapor)

Post-Test "Fill" Tank Model:
-704 TD/RC Nodes
-Divided into 20 equal sections/surface areas
-20 Lumps (Core)
-AKA "The Beast"



Post-Test "Steady State" Tank Model:
-704 TD/RC Nodes
-Divided into 20 equal sections/surface areas
- Reduced to 2 Lumps (Liquid/Vapor) to decrease analysis time





Post-Test Results/Correlation Efforts

1.) Fill Operations

a.) Tank Temperature Gradients

b.) Fill Data

c.) Skirt Temperature Gradients

2.) 'Steady State' Operations

a.) Boil Off Rate of LN2

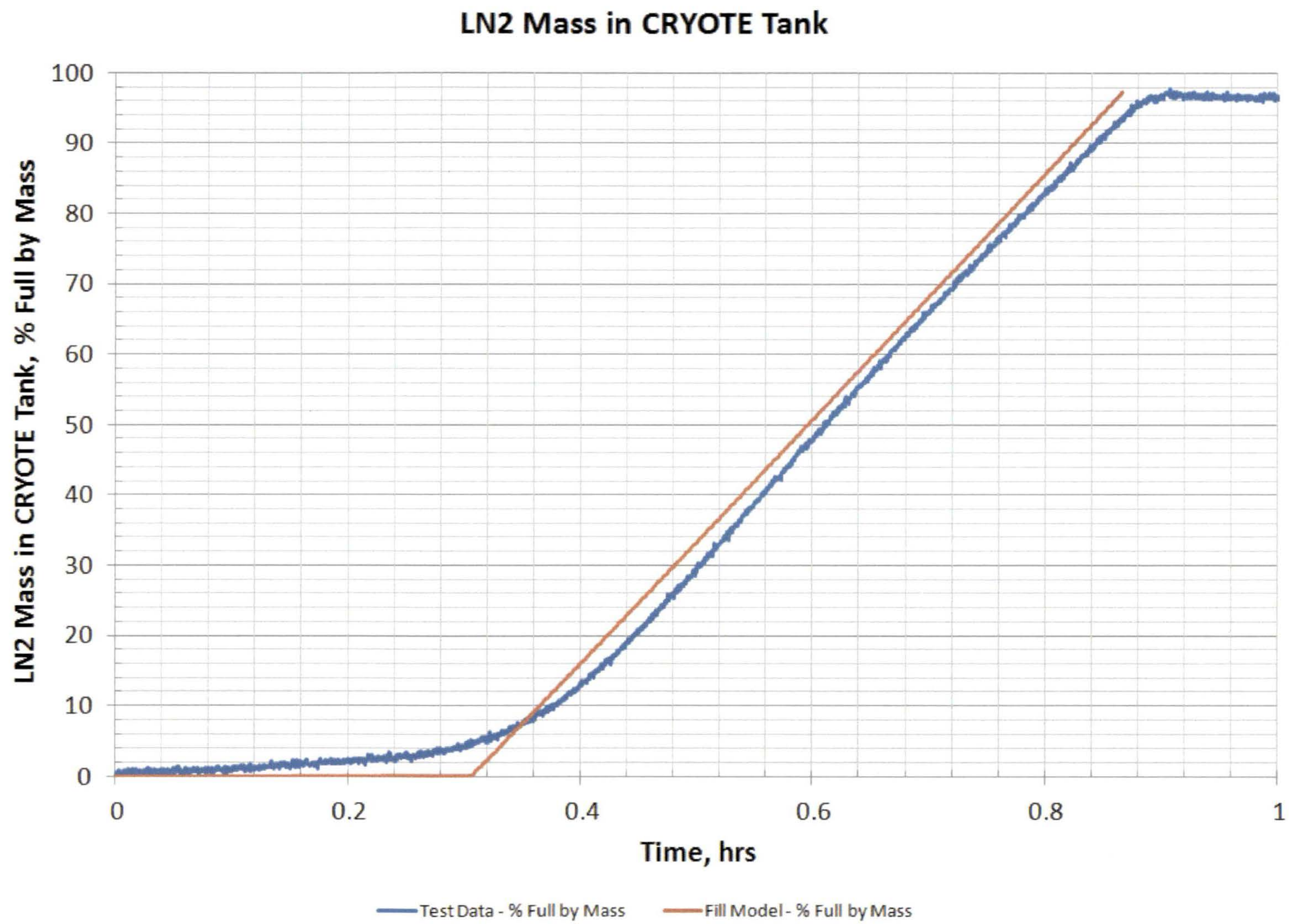
b.) Skirt Temperature Gradients

Tank Gradients

- Located in this directory, open the .avi file named:

  "Tank Temperature Gradients - 75% Fill"

LN2 Mass in CRYOTE Tank

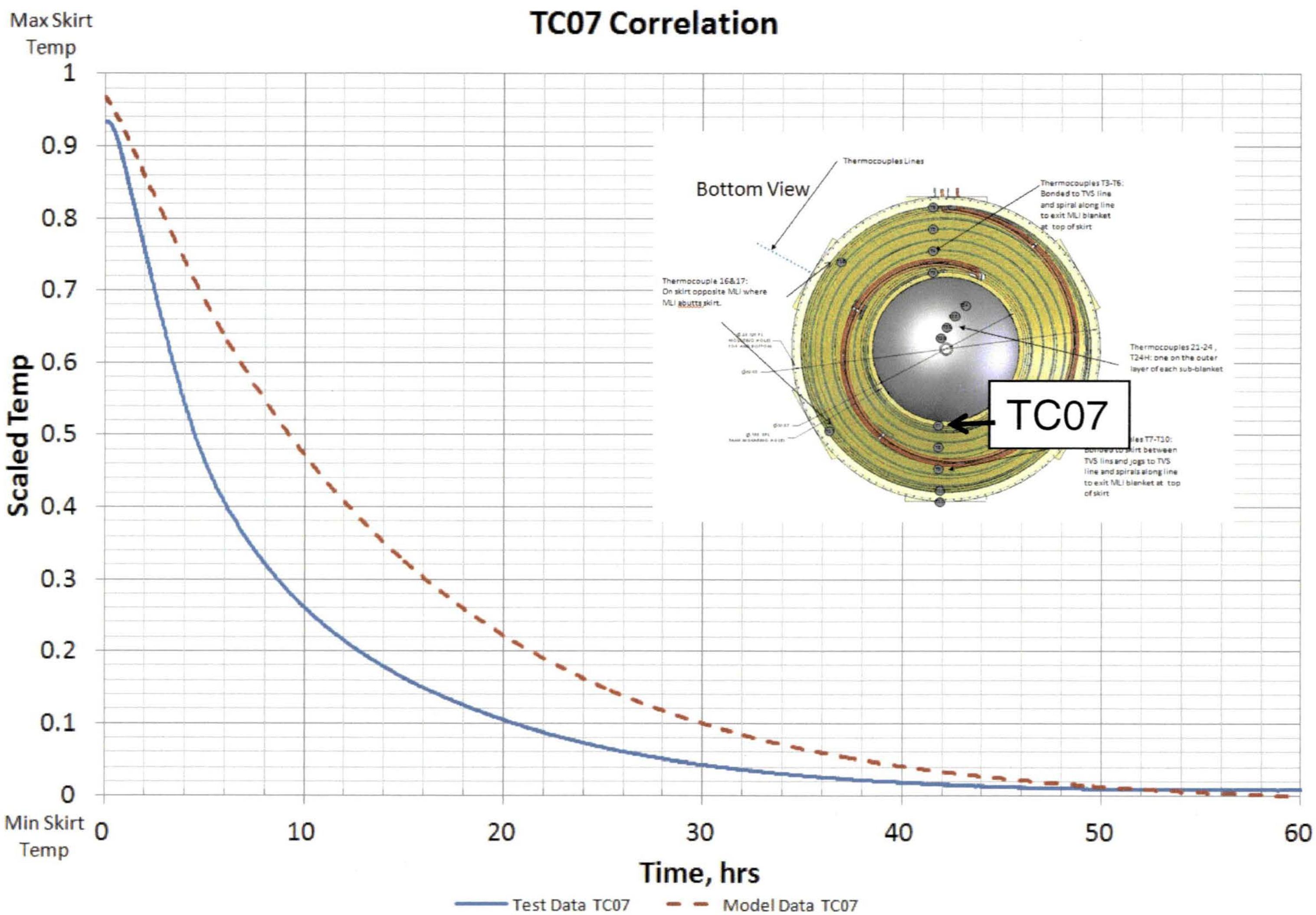


Skirt Temperature Gradients

- Located in this directory, open the .avi file named:

  "Skirt Temperature Gradients - 75% Fill"

TC07 Test/Model Correlation



Note: Min/max skirt temps correspond to min/max temps seen from TC07-TC11

TC08 Test/Model Correlation

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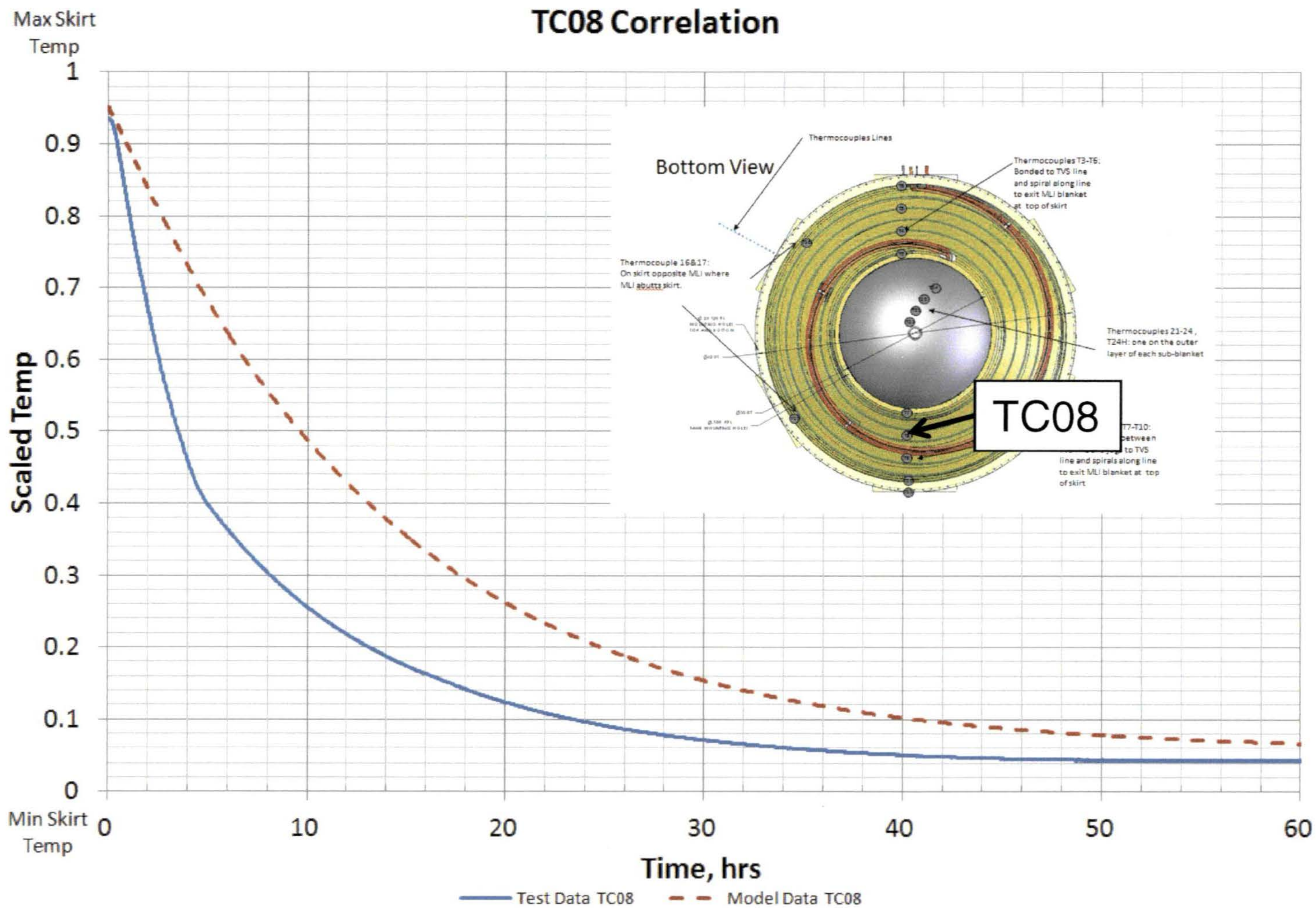

Note: Min/max skirt temps correspond to min/max temps seen from TC07-TC11

TC09 Test/Model Correlation

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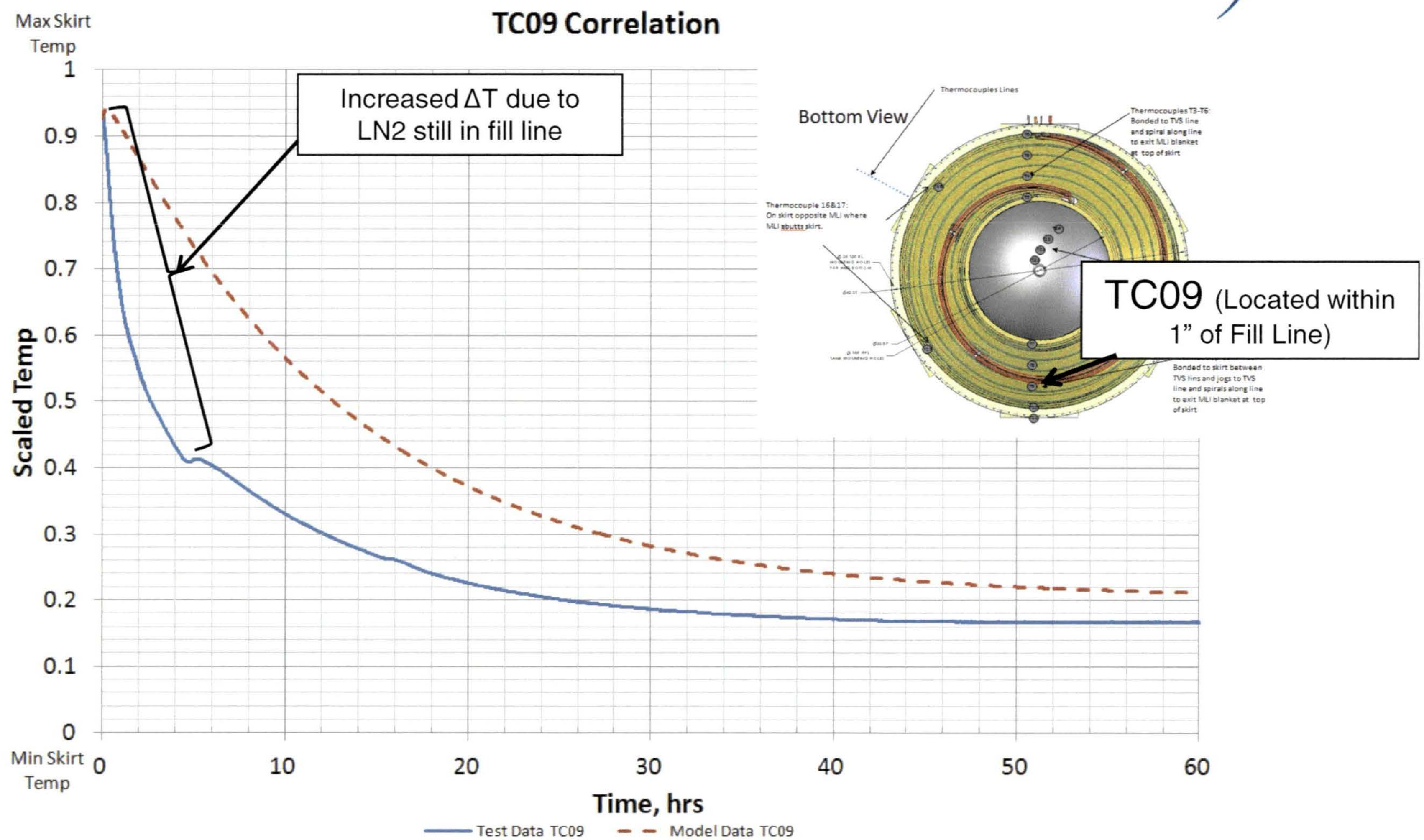

Note: Min/max skirt temps correspond to min/max temps seen from TC07-TC11

TC11 Test/Model Correlation

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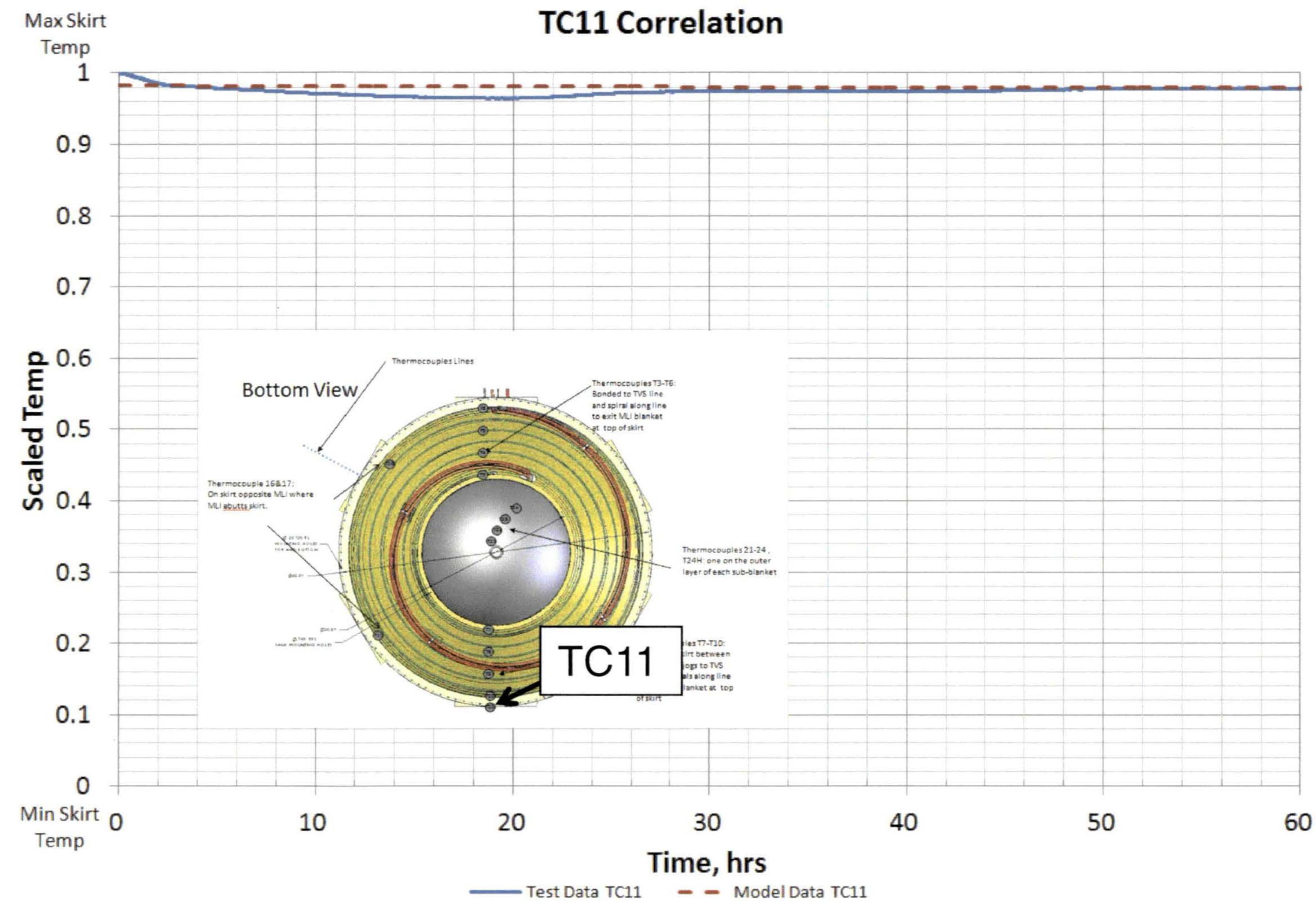

Note: Min/max skirt temps correspond to min/max temps seen from TC07-TC11

Skirt Gradients

- Located in this directory, open the .avi file named:

"Skirt Temperature Gradients - Fill to Steady State"

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LN2 Boil Off Correlation

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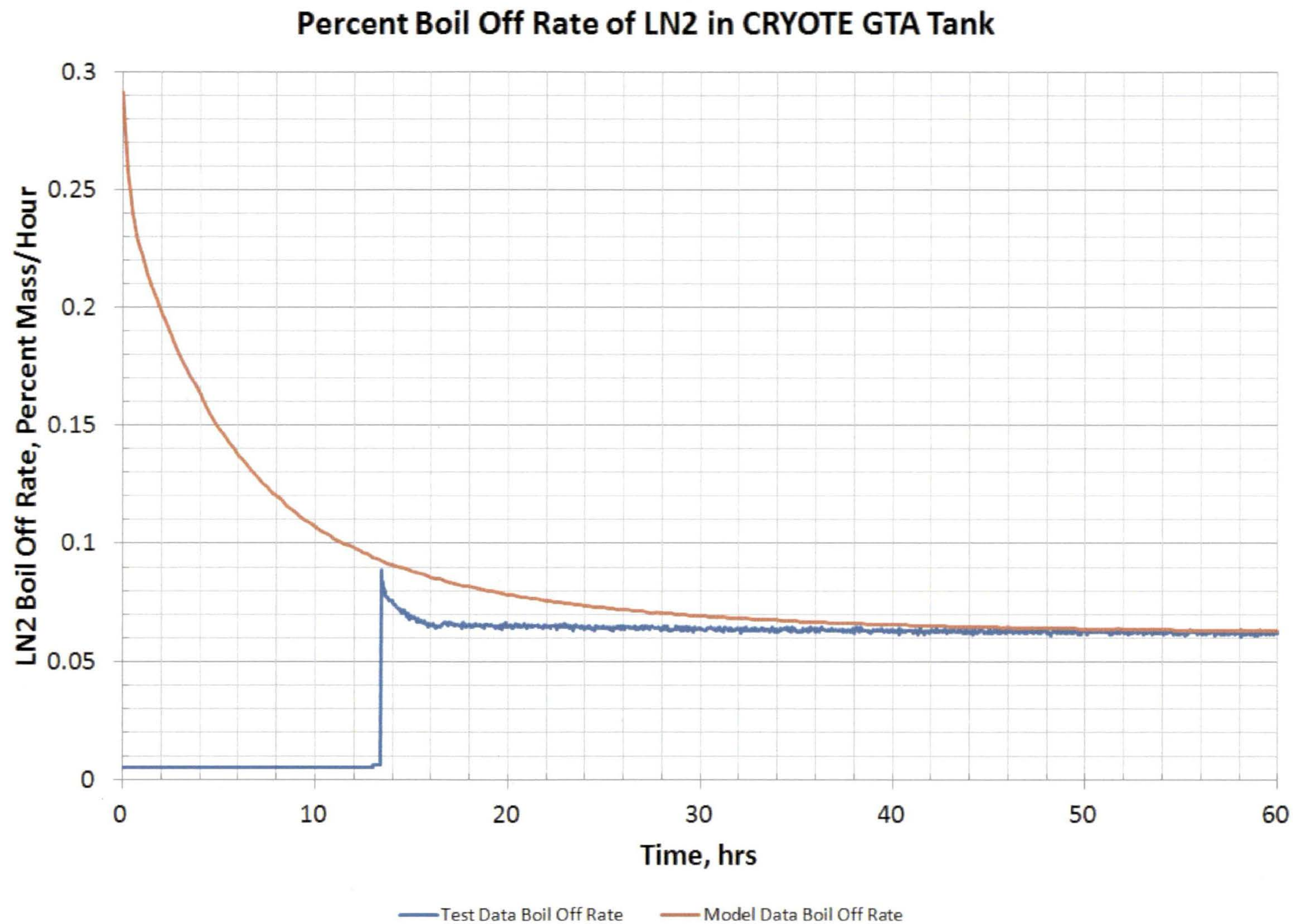
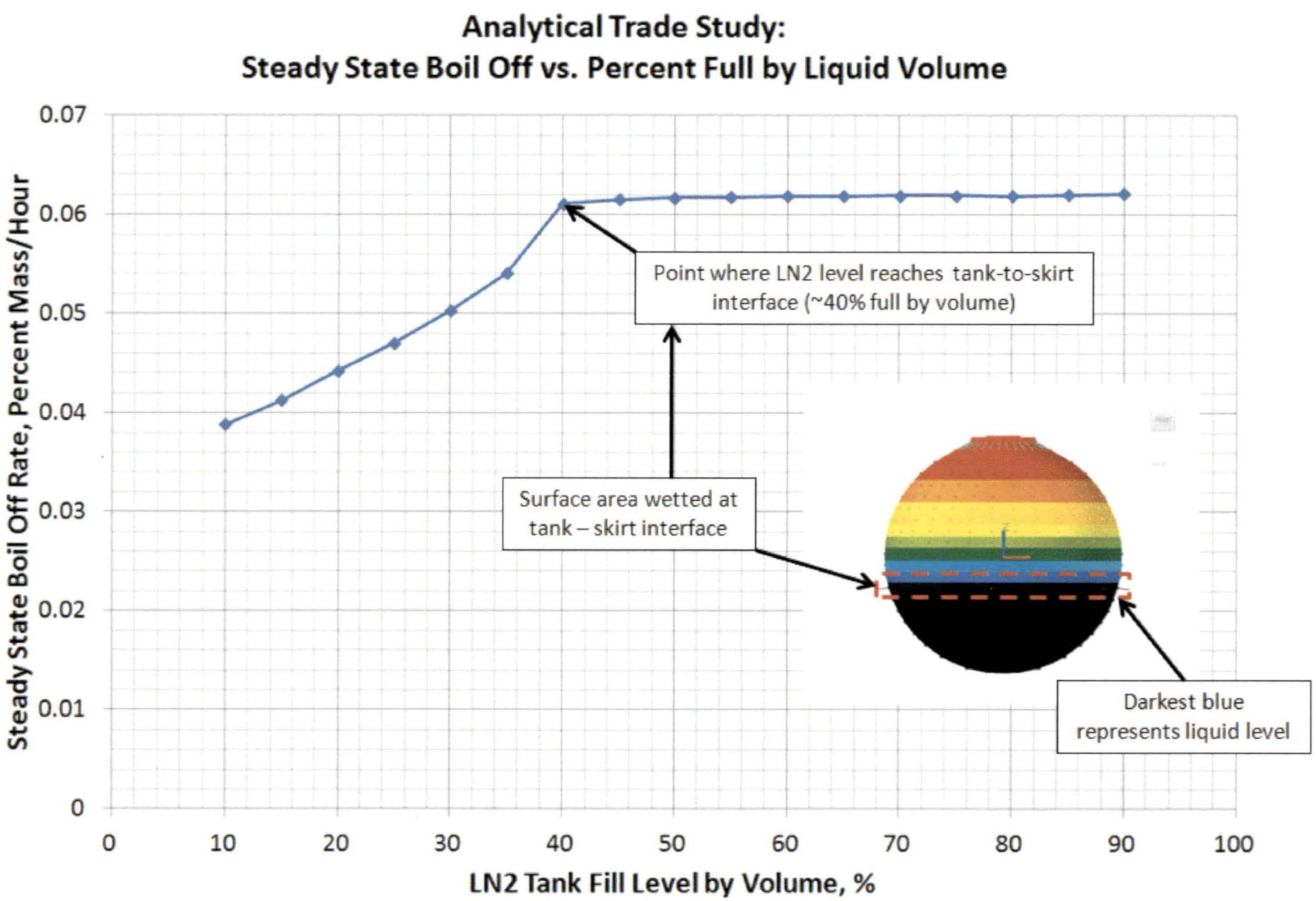
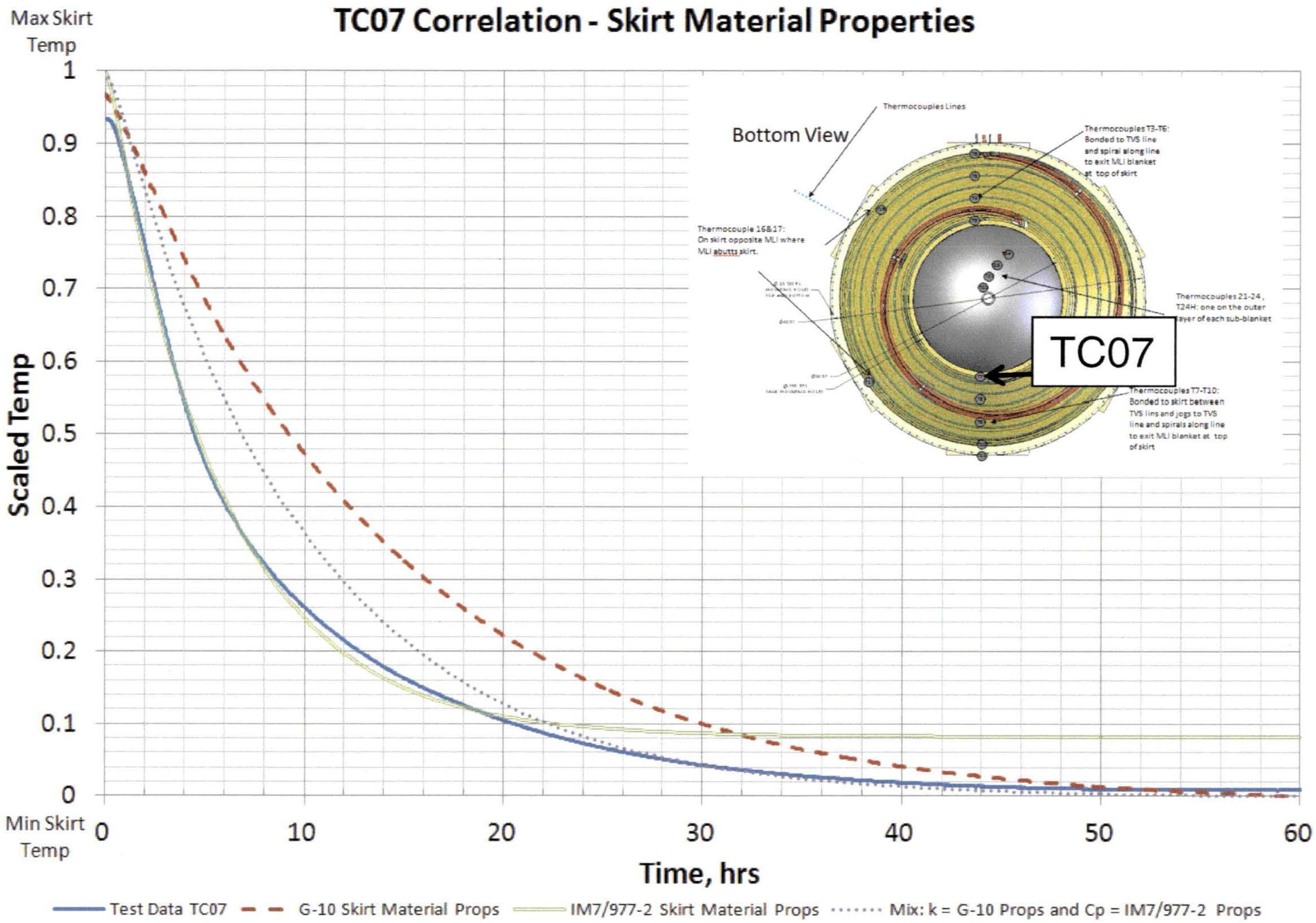


Boil Off vs. LN2 Fill Level



Skirt Material Props Parametric



Note: Min/max skirt temps correspond to min/max temps seen from TC07-TC11

Conclusions & Recommendations

- Pre-test modeling gave accurate prediction for steady state heat loads to tank and LN2
  - Due to granularity of model surfaces, not appropriate for correlating temperature at specified thermocouple locations
- Post-test modeling provided fidelity necessary to make appropriate correlations throughout CRYOTE GTA
  - Should use caution when looking at unsteady state predictions
    - Thermophysical properties used for composite skirt were approximated as G10 props
    - Actual skirt was constructed out of a LOX compatible resin – combination of G-10 and IM7-977-2 props
- As long as fill level stays above ~35% by volume, steady state heat leak should remain relatively the same

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Conclusions & Recommendations

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- Modeling 4 separate MLI sub-blankets proved successful
  - e^* values used were based on: $e^* = 1/(1/e_o + 1/e_i - 1) \times [1/(N+1)]$
    - e^* value used for inner 3 blankets was lower
    - e^* value used for outer blanket was higher
      - Due to outer Beta cover (assumed to be part of 4th outer blanket)
- Validated contact conductance coefficients used for tank flange-to-composite skirt interfaces
  - Pre-test modeling assumed contact surface areas were rough in texture
    - Estimated contact conductance values were between 0.02 to 0.15 BTU/hr-R
  - Final correlated contact conductance value was in above range
  - Final HTC from tank to composite skirt to was slightly higher
    - Additional conductance from length of tank flange to tank

Questions?