RDECOM

GENERAL DYNAMICS
Ordnance and Tactical Systems

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Modeling Methodology for Predicting SCO Performance of the Excalibur Warhead

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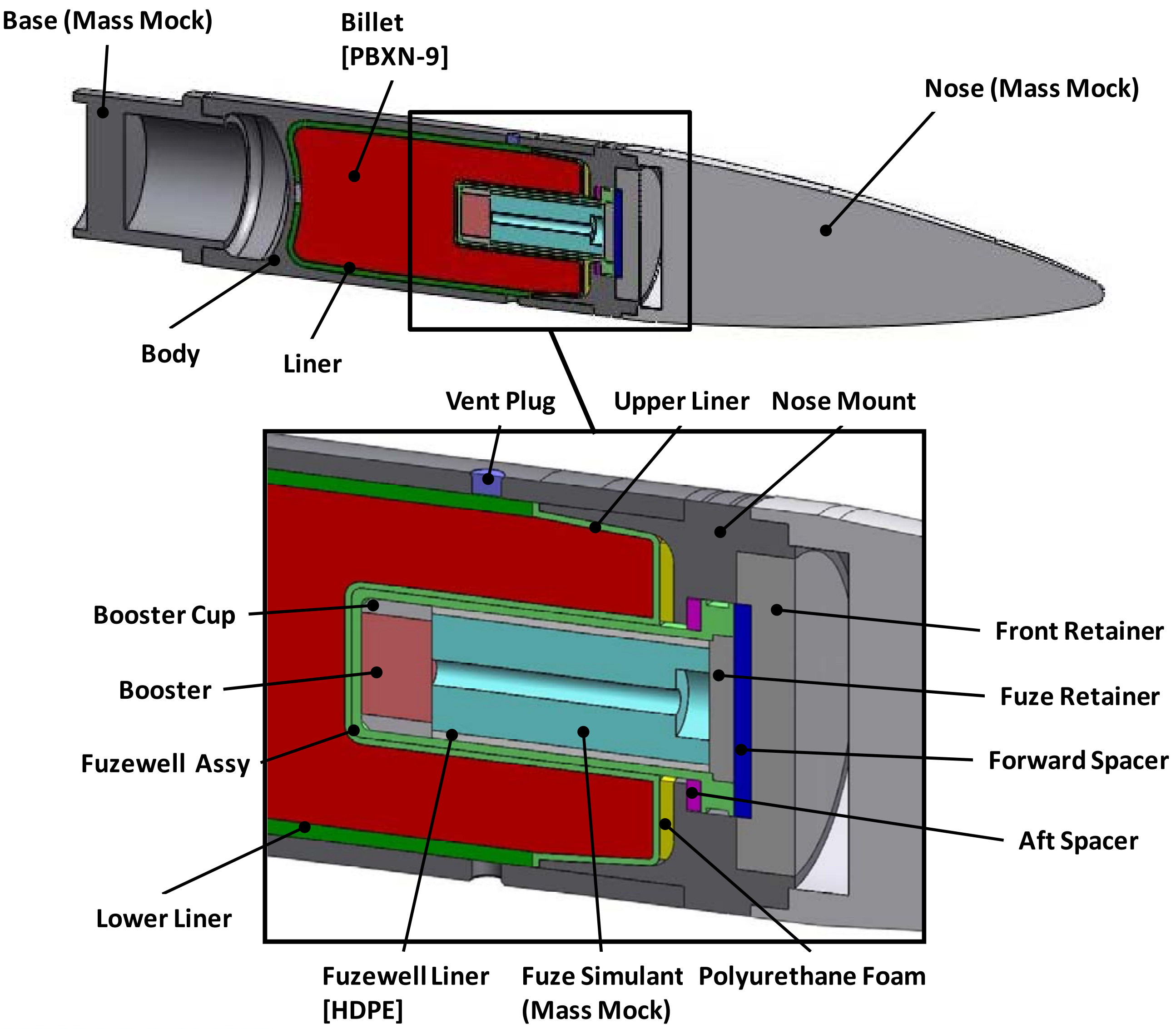
Introduction

- The objective of this presentation is to describe a thermal modeling methodology used to analyze Slow Cook-Off in the Excalibur Warhead
- Modeling Goals are as follows:
  - To gain understanding of heat transfer in the Excalibur warhead when exposed to slow heating environment
  - Use this understanding to design mitigation methods that ensure the Excalibur warhead burns (Type V Reaction) during slow heating environment

Excalibur SCO Test Article

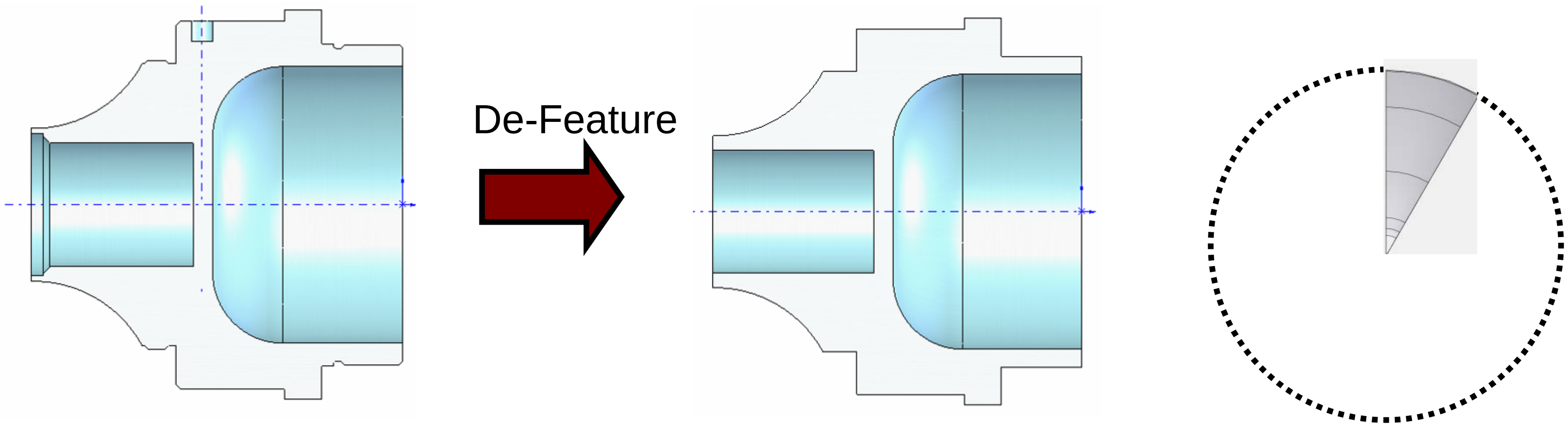


Methodology

- Steps used for thermal modeling and analysis
  - De-Feature Model
  - Apply Contact Resistances
  - Define Material Properties
  - Define Thermal Loads and Constraints
  - Run Thermal Model
  - Compare Model to test results

De-Feature Solid Model

- “De-featuring” a solid model means parts are simplified or combined in an effort to reduce computational size of the model.
  - Assemblies made from the same material can be combined
  - Features such as fillets and chamfers are eliminated
  - Symmetry used where possible
    - Use “wedges” on axisymmetric parts or assemblies



De-Feature

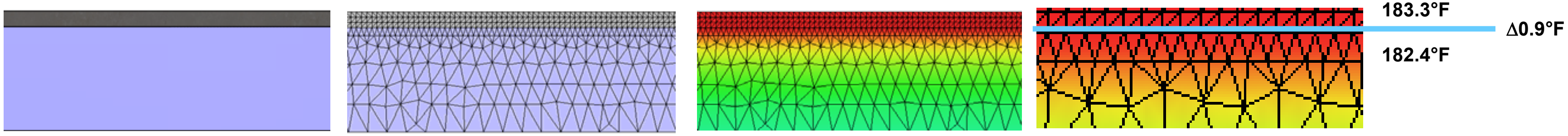
Apply Contact Resistances

- Presence of gaps caused by tolerances can change how heat transfers across material interfaces
- Contact resistances can be applied between surfaces
  - Interfaces must be line to line
  - Resistance value calculated based on gap thickness and thermal conductivity of filler material (air, RTV, etc.)
    - Gap Thickness = t [m]
    - Thermal Conductivity = k [W/m•K]
    - Contact Resistance = t/k [K•m2/W]
    - Resistance increases as gap thickness increases
    - Resistance increases as thermal conductivity decreases

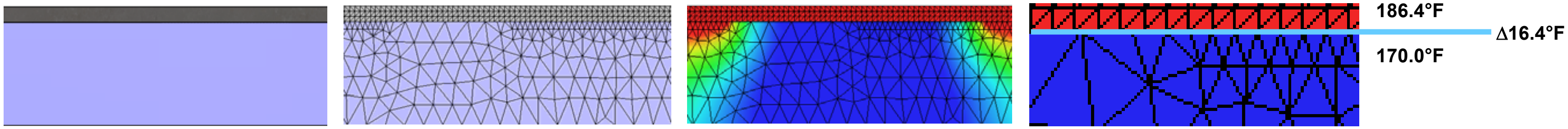
Line-To-Line Interfaces

- The three cases below illustrate how interface conditions can change thermal transfer
  - One hour calculation with convection applied to upper surface

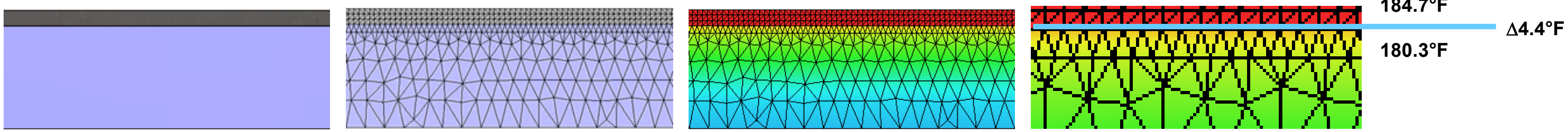
A perfect, line-to-line interface between two parts allows for ideal heat transfer



Accidentally putting in a gap can change the heat transfer across the interface



Contact Resistance representing 0.01” air gap (0.010 m^2•K/W)



Define Material Properties

- Material properties required for thermal model:
  - – Density
  - – Thermal Conductivity
  - – Specific Heat
  - – Kinetic Constants
    - Activation Energy
    - Pre-Exponential Factor
    - Heat of Reaction

Basic Material Properties

- Basic Material Properties are input as constants or as a function of temperature
  - Density
  - Thermal Conductivity
  - Specific Heat
- Material properties for explosive formulations are not always published so the Rule of Mixtures can be applied based on the component materials

$$k = \sum \left(f_i \bullet k_i \right) = f_1 k_1 + f_2 k + \ldots + f_i k_i$$

$$f_1 = \frac{wt\%_1 / \rho_1}{wt\%_1 / \rho_1 + wt\%_2 / \rho_2 + \ldots + wt\%_i / \rho_i}, \quad f_2 = \frac{wt\%_2 / \rho_2}{wt\%_1 / \rho_1 + wt\%_2 / \rho_2 + \ldots + wt\%_i / \rho_i}, \text{ etc…}$$

k = thermal conductivity of each component

f = volume fraction of each component

wt% = weight percentage of each component

ρ = density of each component

Self Heating Properties

- An Arrhenius rate equation is used to calculate the self-heating properties of the explosive as a function of temperature
- Activation Energy, Heat of Reaction and Pre-Exponential Factor are the kinetic constants
- Activation Energy and Pre-Exponential factor must be calculated by ASTM-E 698-05, if not published
    - Standard Test Method for Arrhenius Kinetic Constants for Thermally Unstable Materials Using Differential Scanning Calorimetry and the Flynn/Wall/Ozawa Method

$$\text{Heat Rate} = \rho\, Q\, Z\, e^{-E/RT}$$

ρ = Density

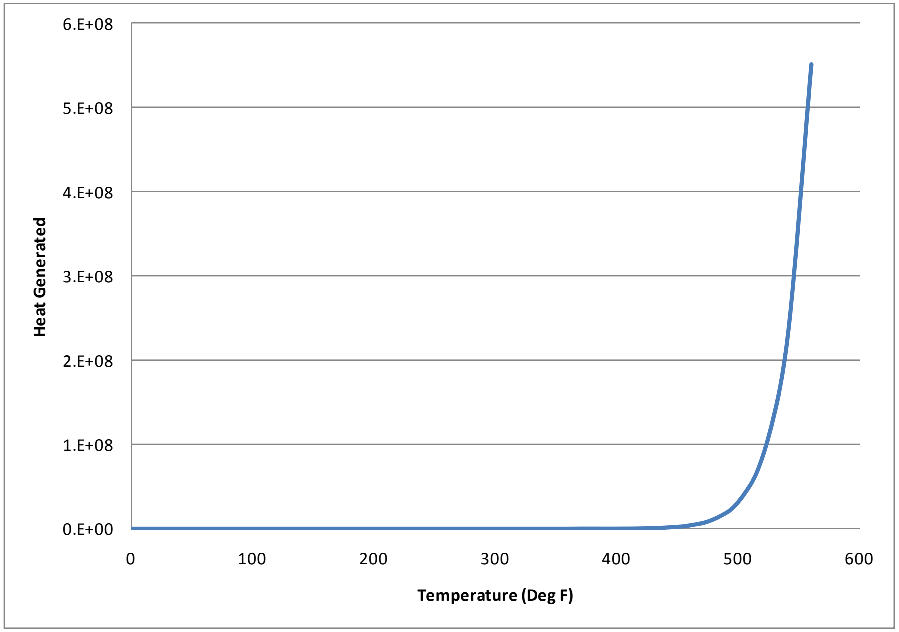
Q = Heat of Reaction

Z = Pre-Exponential Factor

E = Activation Energy

R = Universal Gas Constant

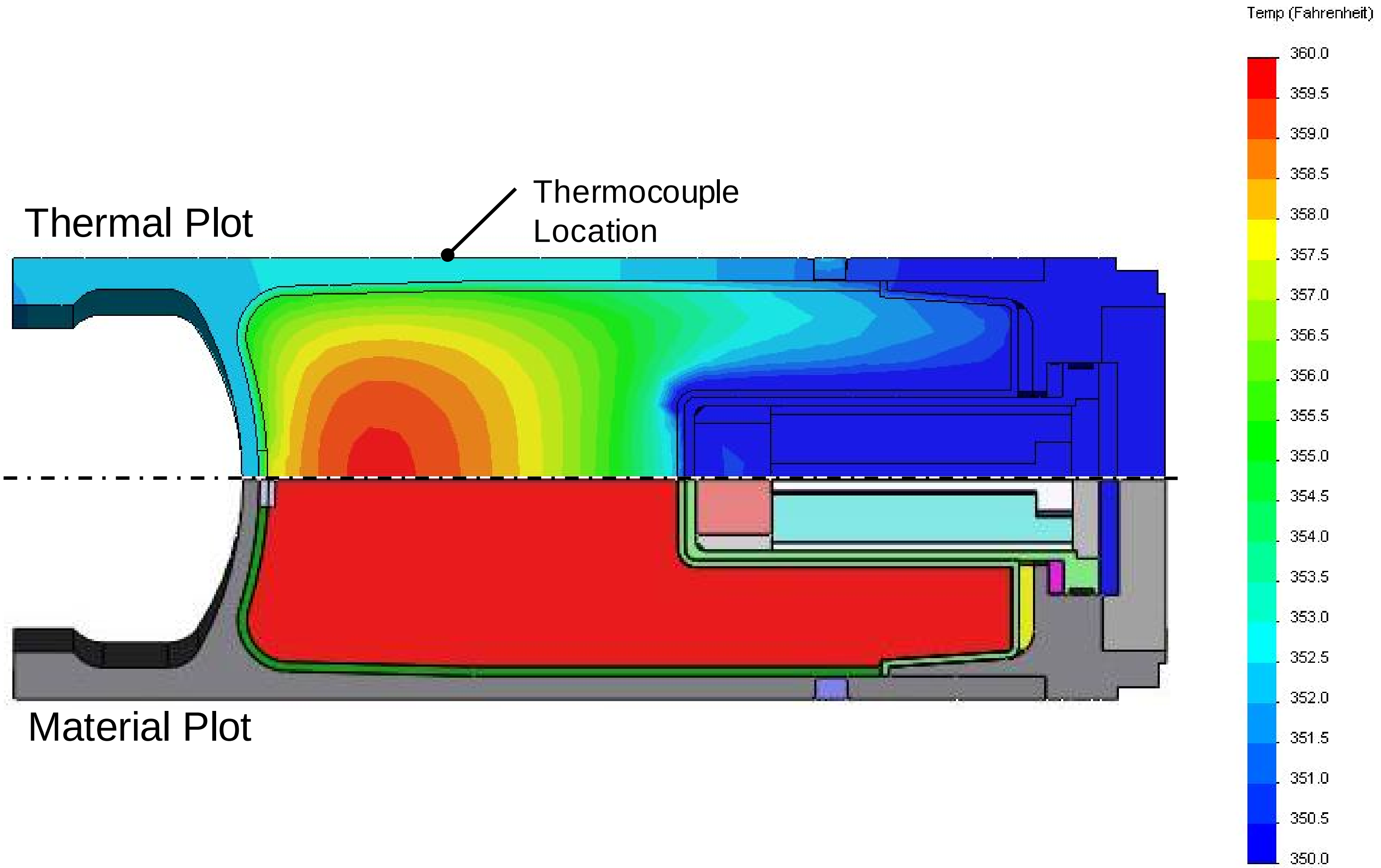
T = Absolute Temperature



Thermal Loads and Constraints

- The initial temperature of all components is the start temperature to be used during SCO tests
  - 122°F most common
- Convection is applied to all surfaces that will be exposed to moving air within the oven.
  - Convection Coefficient: 12 $W/m^2 K$
  - Bulk Temperature of convective medium heated at 50°/hour or 6°/hour, depending on test conditions intended for study
- Self heating properties of explosive applied as heat power generated as a function of temperature

Thermal Plot at 6°F/hr Heating

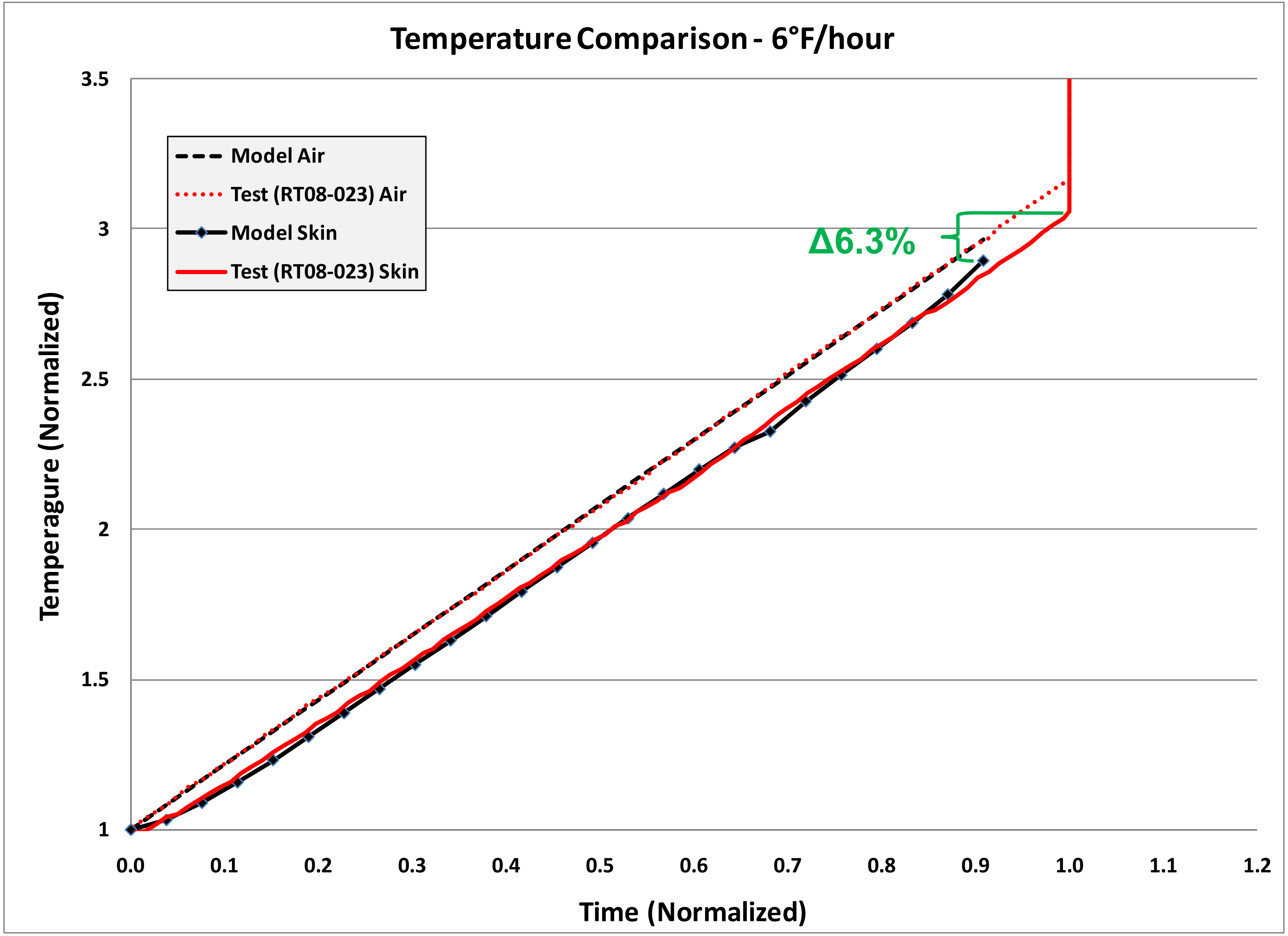


Thermal Plot

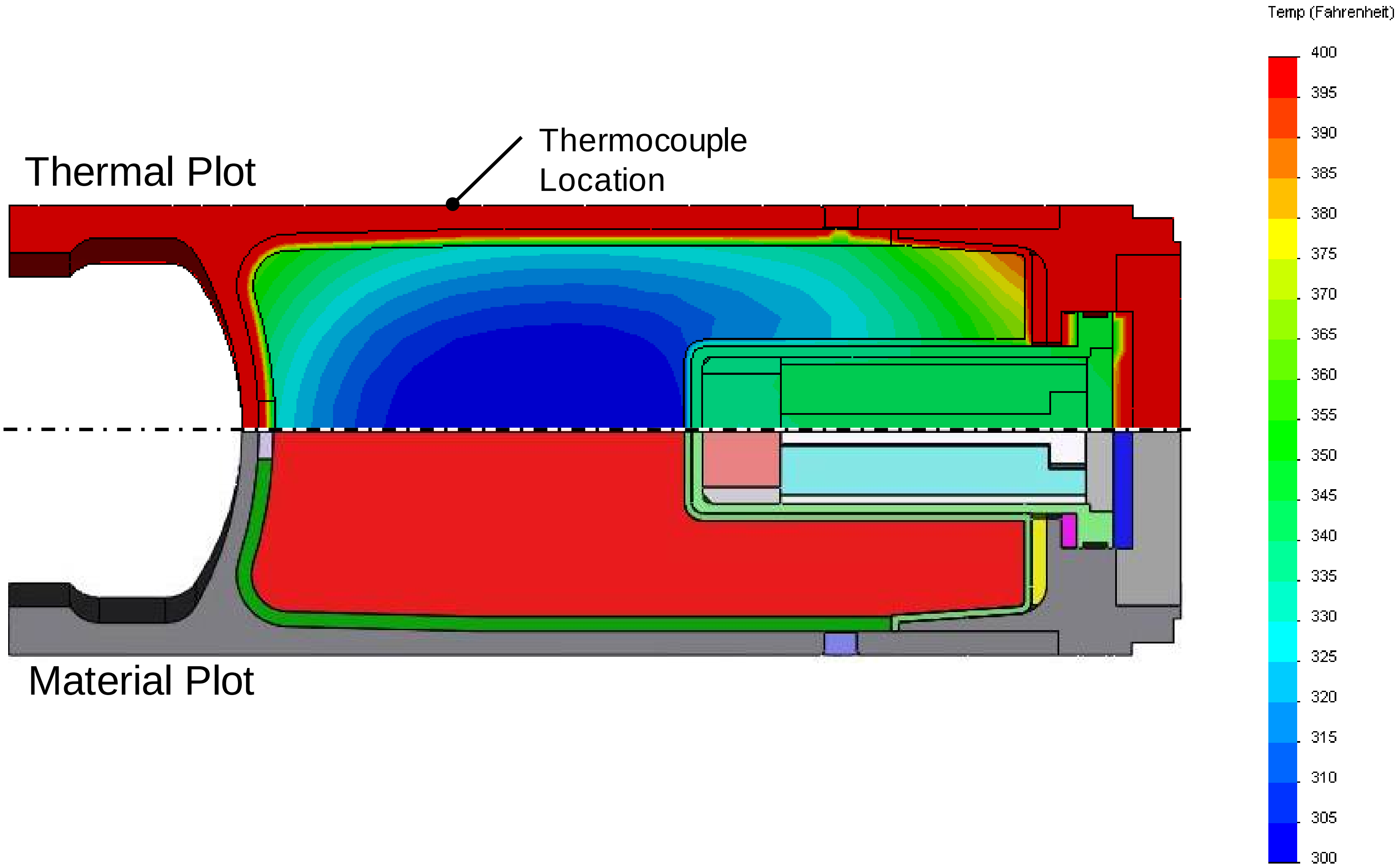
Thermocouple Location

Material Plot

Test Data Comparison at 6°F/hr



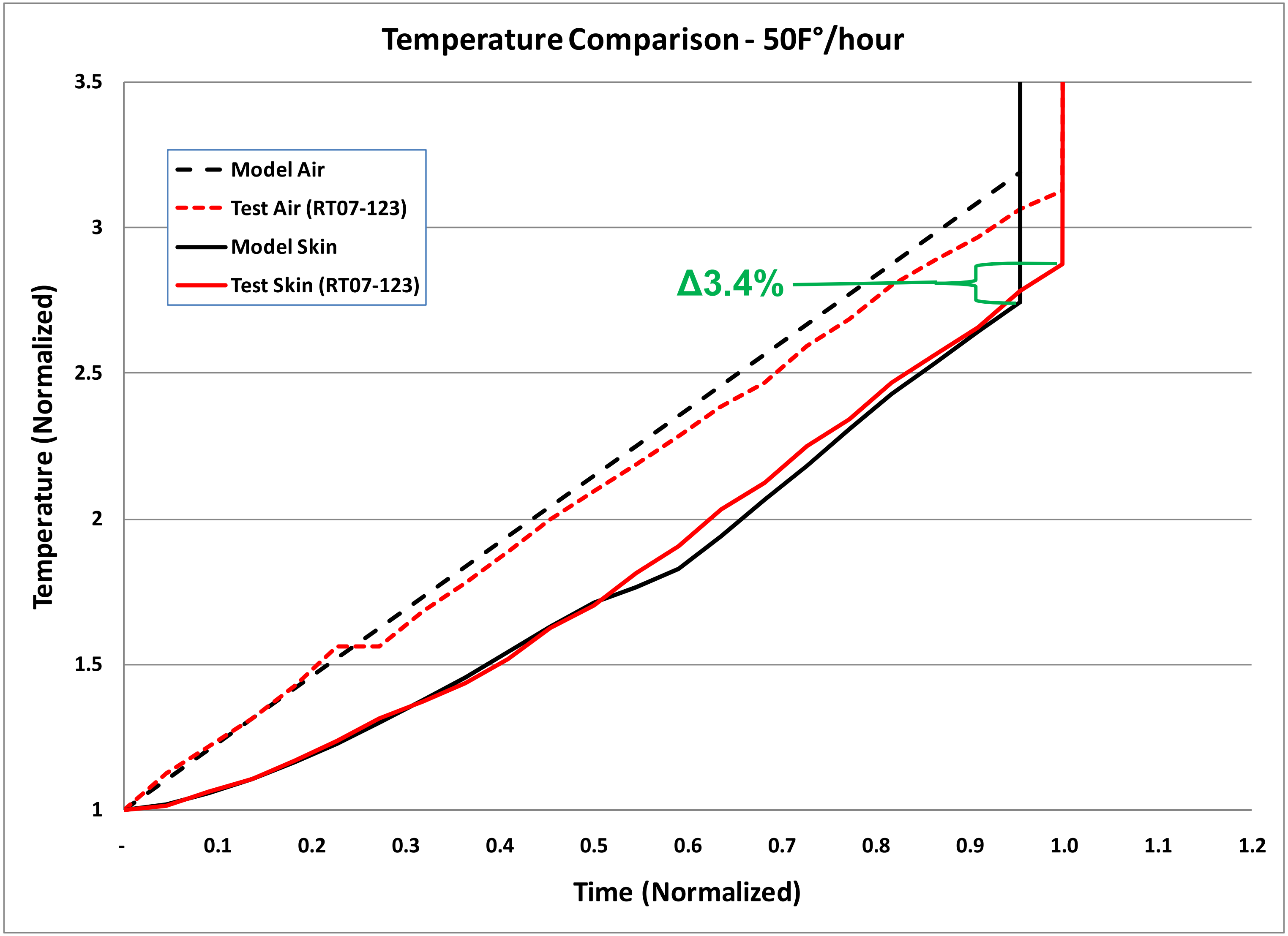
Thermal Plot at 50°F/hr Heating


Thermal Plot

Thermocouple Location

Material Plot

Test Data Comparison at 50°F/hr



Conclusions & Future Work

- Conclusions
    - A standard methodology has been developed for predicting SCO reaction times and temperatures
        - Accurate within 7% at 6°F/hour heat rate on Excalibur
        - Accurate within 4% at 50°F/hour heat rate on Excalibur
    - Method can be applied to other systems
- Future Work
    - Continue to gather test data and compare to models
    - Develop burn models to calculate what happens after reaction takes place
        - Models only predict reaction time and temperature, not Type

Acknowledgements

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