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TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

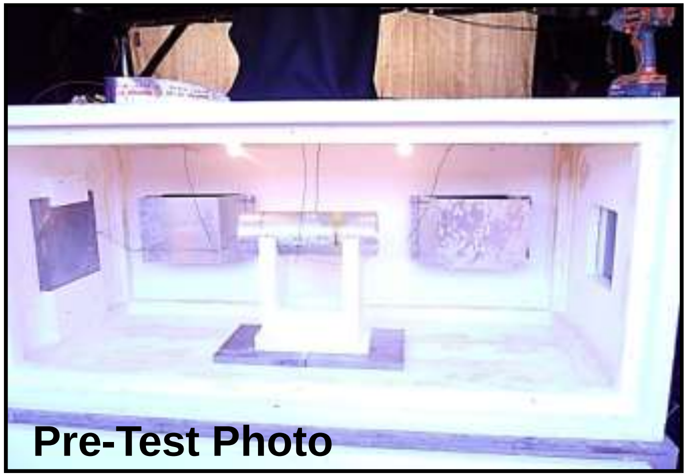
Thermal Modeling the SCO Response of a TOW2B EFP

May 2015

Distribution Statement: A

Introduction

- The TOW2B Warhead Section Assembly (WSA) currently reacts violently when subjected to Slow Cook-Off at 6°F/hour heating rate
- US Army and GD-OTS developed thermal models to assist design engineers in upgrading TOW2B warhead
- During this effort, a reconstructive β-δ phase change in HMX was applied to thermal model for LX-14
- Inclusion of phase change greatly improved the accuracy of the thermal model


Pre-Test Photo

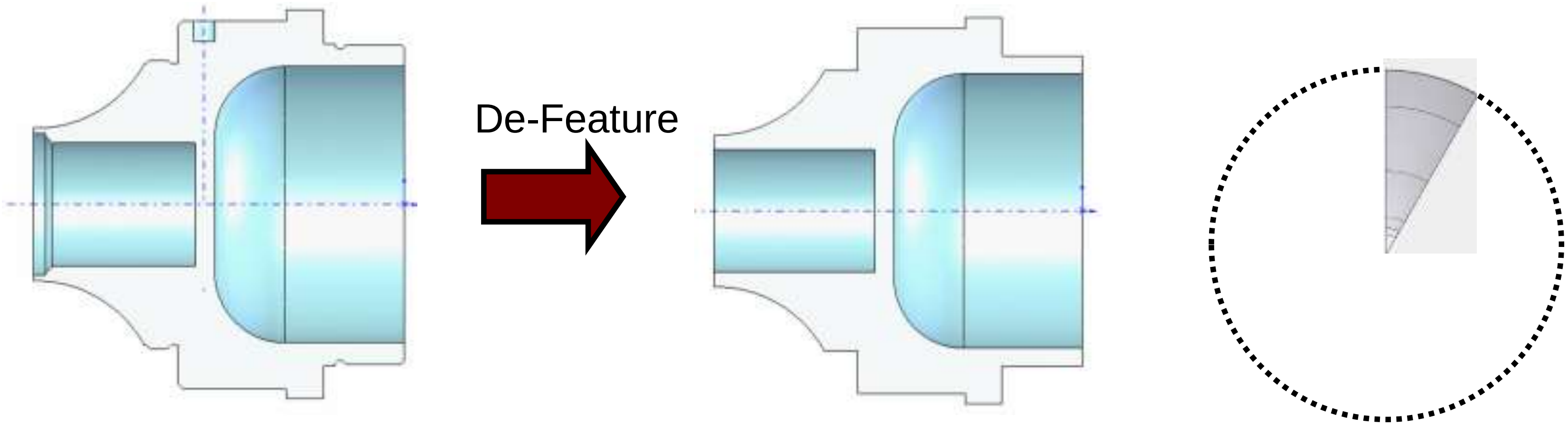

Post-Test Photo: VIOLENT RESPONSE

Baseline Modeling Methodology

- SolidWorks Simulator used for all models presented in this briefing
  - Single Phase Finite Element Modeling Code
- Standardized modeling methodology
  - Solid model of EFP simplified to reduce calculation time
  - Initial temperature in all calculations
  - Convection is the primary mechanism used to heat EFP
  - Radiation also plays a small role in heating
  - Self-heating properties of explosive modeled using Arrhenius rate equation.

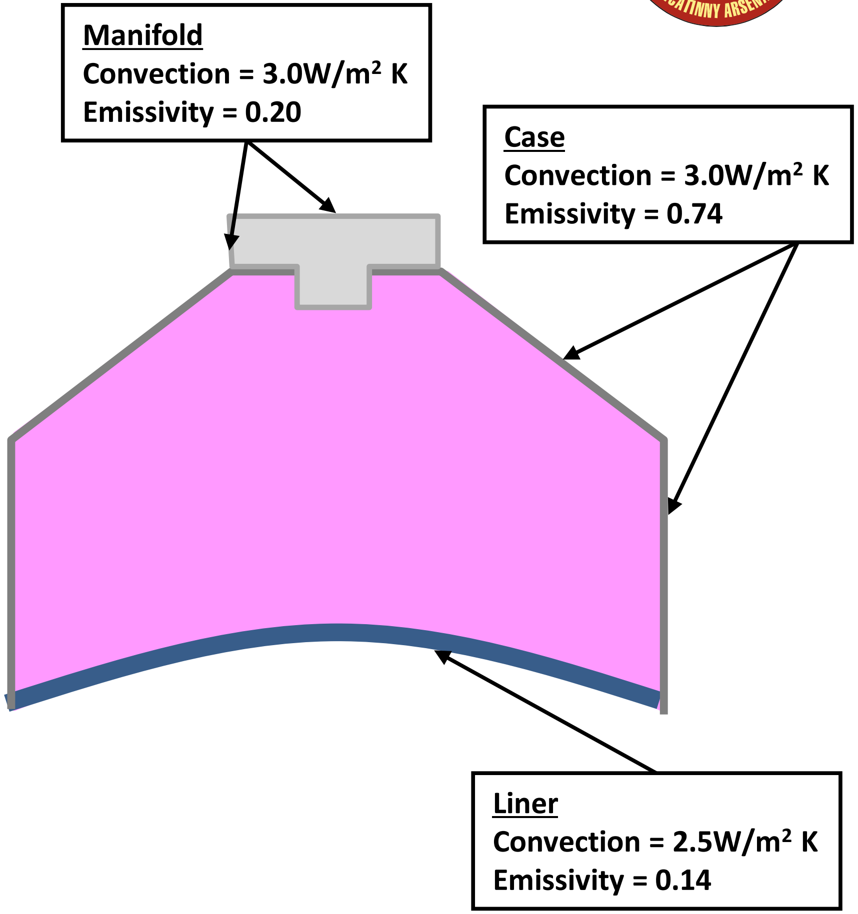
Simplify Solid Model

- The solid model used for a calculation is simplified to reduce the calculation time
  - ➢ Assemblies that are made from the same material are combined
  - ➢ Features such as fillets, chamfers are eliminated
  - ➢ Symmetry used where possible



Thermal Loads

- Convection and radiation applied to all exterior surfaces
  - 3.0W/m·K convection applied to Manifold Simulant and Case
  - 2.5W/m·K convection applied to Liner
  - Shape factor for applying radiation was 0.15 for all surfaces
  - Values were determined as model was calibrated to test data



Manifold
Convection = 3.0W/m² K
Emissivity = 0.20

Case
Convection = 3.0W/m² K
Emissivity = 0.74

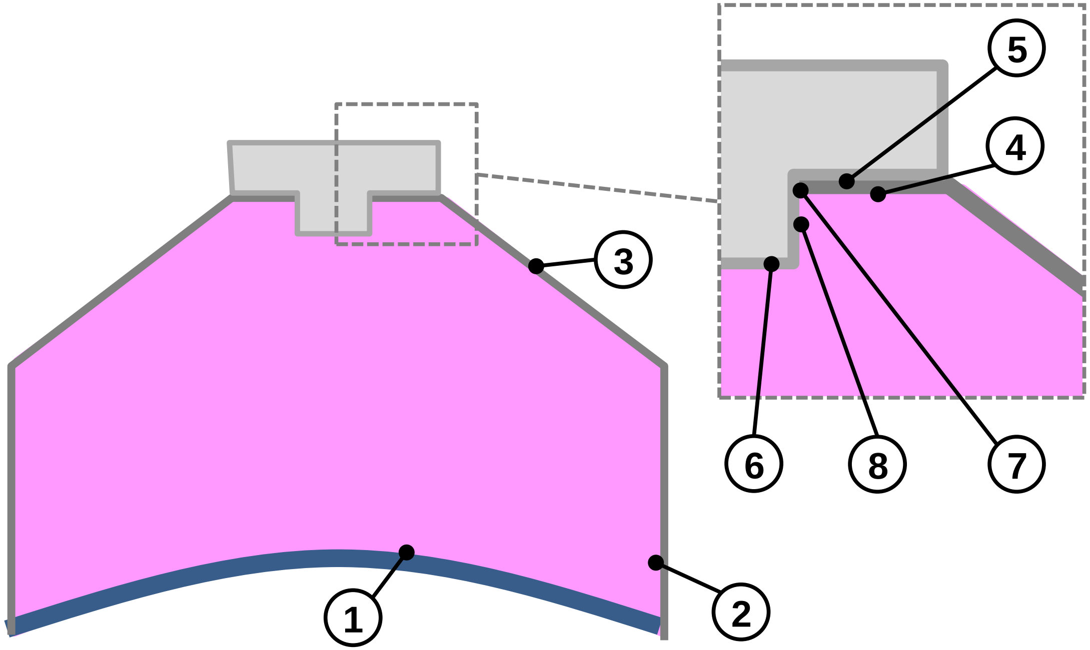
Liner
Convection = 2.5W/m² K
Emissivity = 0.14

Ambient (bulk) temperature 272F
+ 6F/hour until reaction occurs

Contact Resistance

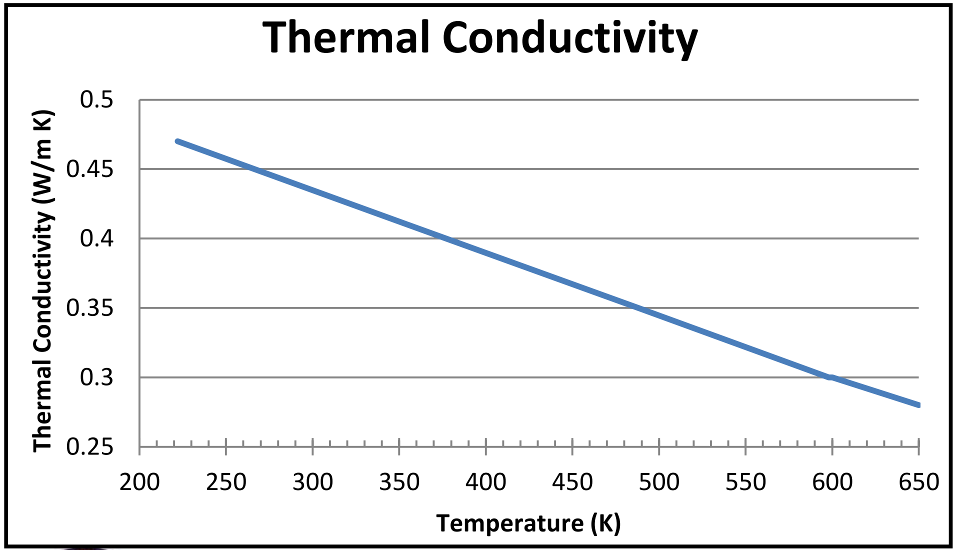
- All components modeled as touching in solid model
- However, in reality there are contact resistances between components based on:
  - Tolerances (gaps)
  - Adjacent materials
  - Interstitial materials, such as adhesives

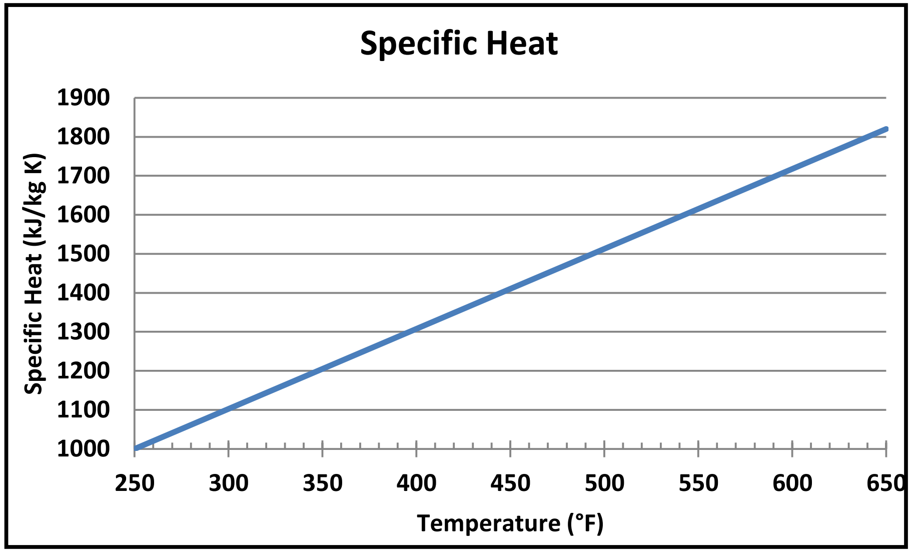
Gap	Location	Interface Material	Thickness (mm)	Resistance (K/W)
1	Liner – Billet	MEK+Poly	0.1016	0.12
2	Billet Slope – Case Slope	Charge Bonder	0.0508	0.05
3	Billet OD – Case ID	Charge Bonder	0.1016	0.10
4	Billet Top – Case Top	Charge Bonder	0.7366	18.05
5	Manifold – Case Top	Part Touching	-	47.62
6	Manifold – Case Flat	Air	0.3048	220.25
7	Manifold OD – Case ID	Air	0.3302	297.65
8	Manifold OD –Billet ID	Air	0.2921	219.16



Material Properties

Property	Units	LX-14	Stainless Steel	Aluminum	Tantalum
Density	g/cc	1.873	8.00	2.70	16.60
Emissivity	-	-	0.74	0.20	0.14
Thermal Conductivity	W/m K	0.35 – 0.47	16.0	166.9	59.4
Specific Heat	kJ/kg K	1.000 – 1.820	500.0	896	138.6
Activation Energy	J/mol	2.206E+05	-	-	-
Heat of Reaction	J/kg	5.95E+06	-	-	-
Pre-Exponential	1/s	5.00E+19	-	-	-





Self Heating of Explosive

- 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

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

ρ = Density

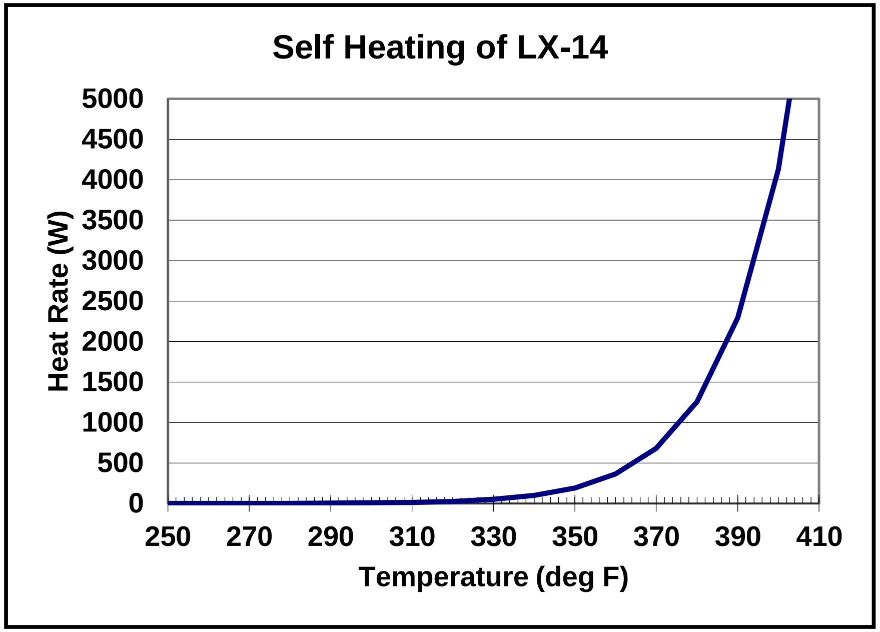
Q = Heat of Reaction

Z = Pre-Exponential Factor

E = Activation Energy

R = Universal Gas Constant

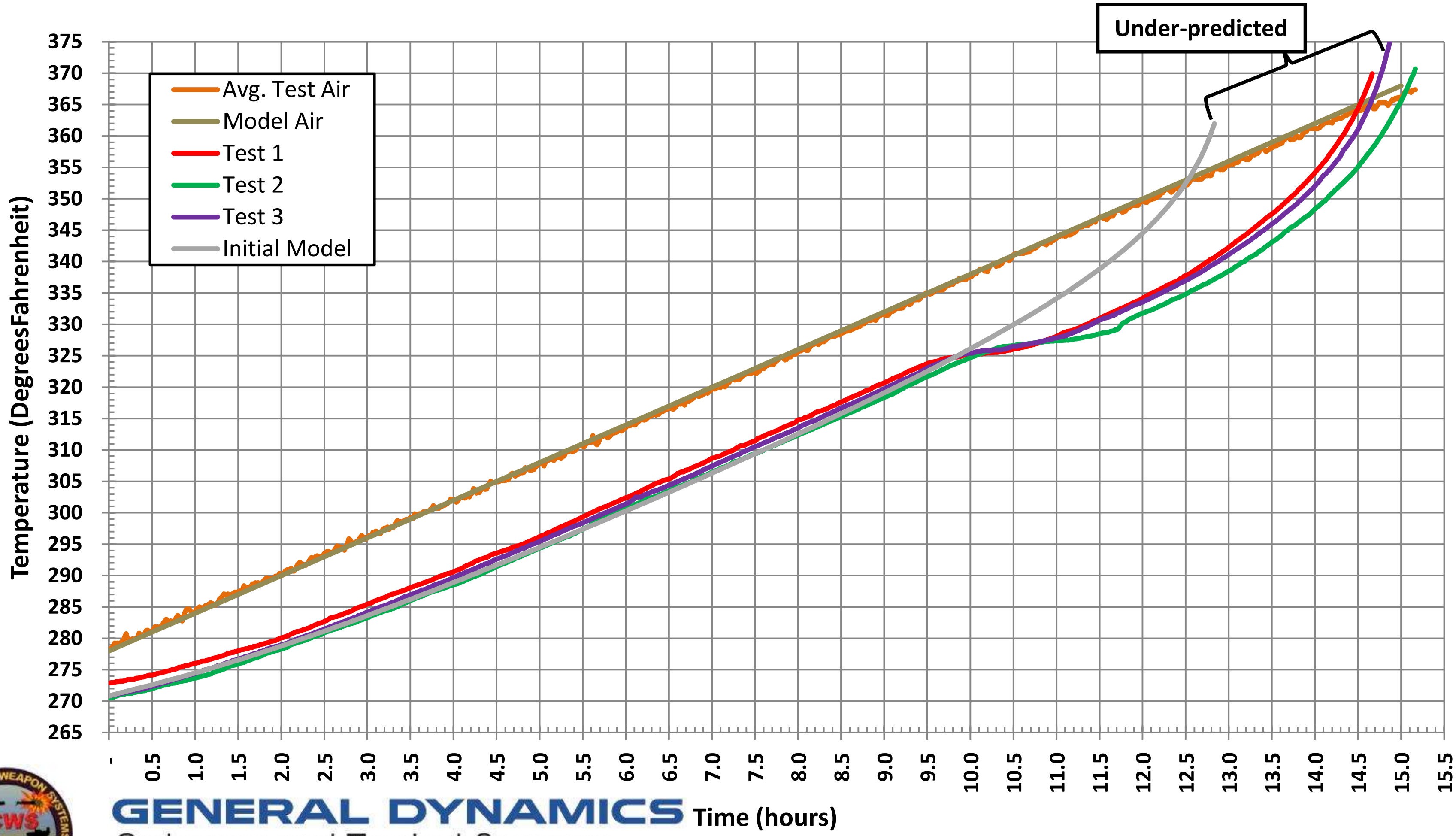
T = Absolute Temperature



AMRDEC

Initial Calculation Results

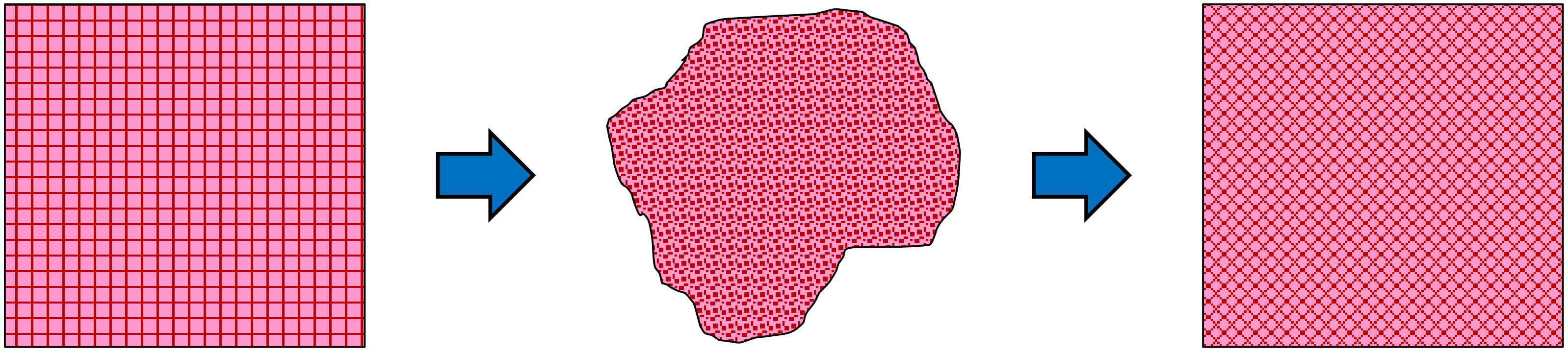
- Initial calculation results accurately predict test results to 325°F
- Slowing then occurs (3 tests shown), which model does not predict



GENERAL DYNAMICS
Ordnance and Tactical Systems

Phase Change in HMX

- Levitas[1] study shows that HMX undergoes a reconstructive β-δ phase change at 432K (318°F) via a "virtual melting mechanism"
- Internal stress energy relaxed by phase change is 28.866 kJ/kg



β phase

Pressure builds due to thermal expansion within a confined space, producing internal stresses

Melted HMX

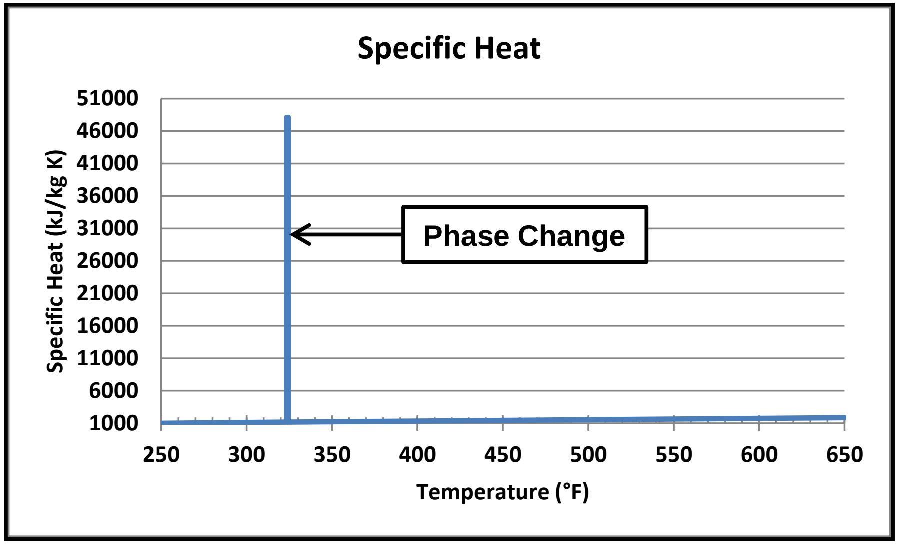
When HMX melts, the elevated pressure causes a change in the nucleation energy

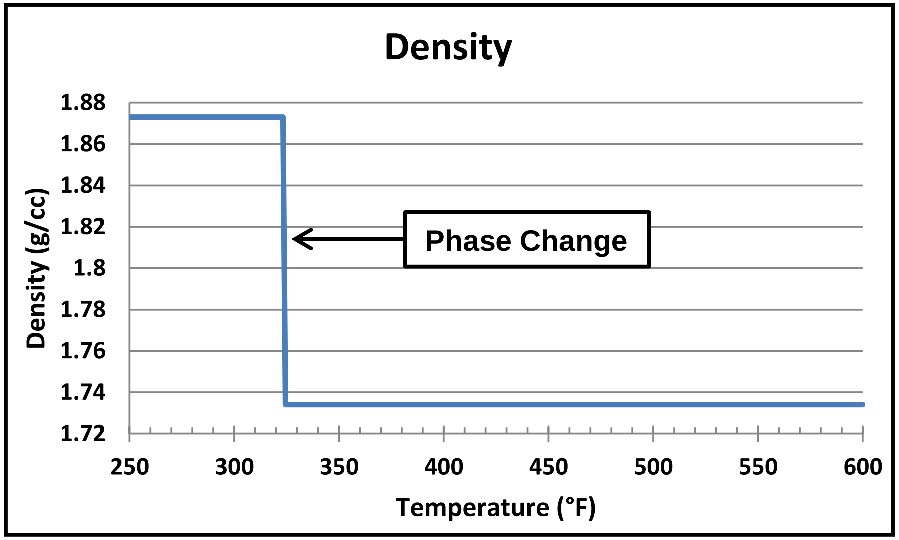
δ phase

The change in nucleation energy causes the HMX to immediately recrystallize into an unstressed δ-phase

Effects of Phase Change

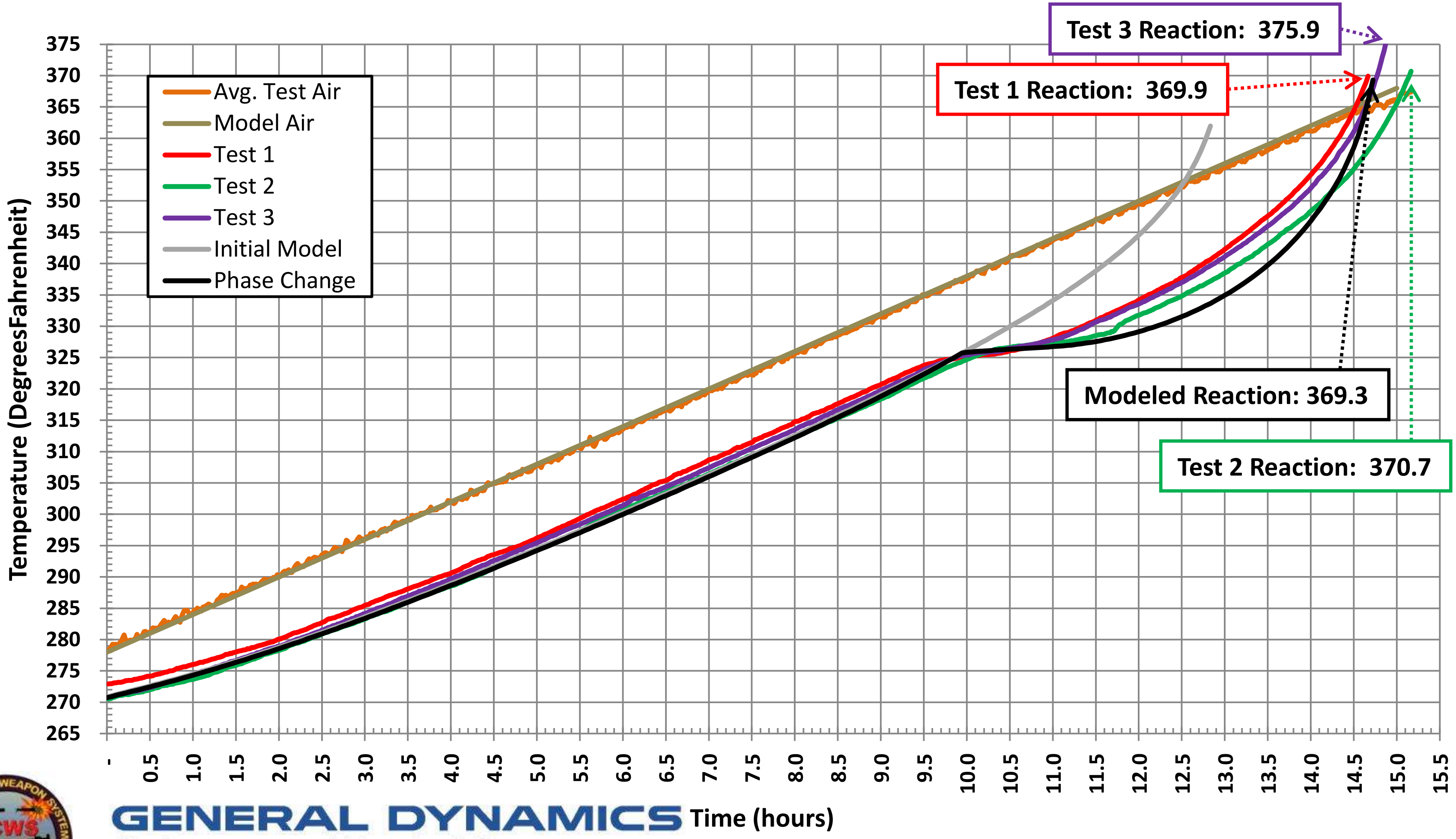
- The reconstructive portion of the β-δ phase change occurs at 432.6K (319°F), which is 0.6K above when the melting occurs
- It is assumed the entire phase change occurs within this 0.6K window
- Dividing the relaxed stress (28.866 kJ/kg) by 0.6 equals 48.110 kJ/kg·K - which are the units for Specific Heat
- A “step” is applied to Specific Heat of HMX between 323°F and 324°F
  - 3K (5°F) added to temperature to compensate for binders in LX-14, which produces a better match for the test data
- Levitas also reports that the density of HMX drops from 1.905 g/cc to 1.773 g/cc. Using the Rule of Mixtures, the density of HMX drops from 1.873 g/cc to 1.734 g/cc





Results Including Phase Change

- Inclusion of HMX phase change provides a much more accurate prediction of SCO performance



Conclusions

- SCO Test data showed the heating rate of the TOW2B EFP consistently slowed between 325ºF and 330ºF
- The slowing effect was not captured by thermal models being used at the time, resulting in under-prediction of air temperature and time required for reaction to occur
- A literature search revealed that HMX undergoes a phase change near the temperatures where the heating slowed
- Application of the phase change into the thermal model significantly improved the accuracy in predicting both time and temperature
- The phase change technique should be applicable to any pressed HMX-based explosive

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