TRANSIENT HEAT TRANSFER ANALYSIS OF THE CONTAINER/EXPLOSIVE INTERFACE

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Container/Explosive Interface Study

- -Fast-Cook Off Tests
- -Heat Transfer Analysis
- -Results
- -Conclusions

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Experimental Set Up

Fast Cook Off Tests (Thiokol)

Container with Electrical Heating

-0.1 by 0.1 m (4” by 4”)
-Around 1.2 Kg of PBX 9501 (HMX Explosive)
-12 Thermocouples outside
-8 Thermocouples placed inside the explosive (at 1.5 mm or 1/16” from interface)
-3 Pressure transducers inside
-High speed (2000, 19000 fps) and normal video cameras.

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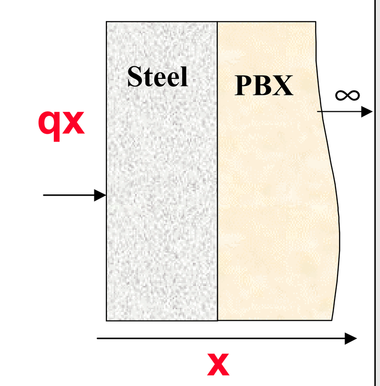
Transient Heat Transfer Model

System Analysis



Governing Equations

$$\frac{\partial T_i(x,t)}{\partial t} = \alpha_i \cdot \frac{\partial^2 T_i(x,t)}{\partial x^2}$$ i=1 for steel, i=2 for PBX

Initial condition

$$T(x,0) = To$$

Boundary conditions

$$-K_{steel}\frac{\partial T(0,t)}{\partial x} = \frac{V}{A \cdot R^2}$$

$$\frac{\partial T(\infty,t)}{\partial x} = 0$$

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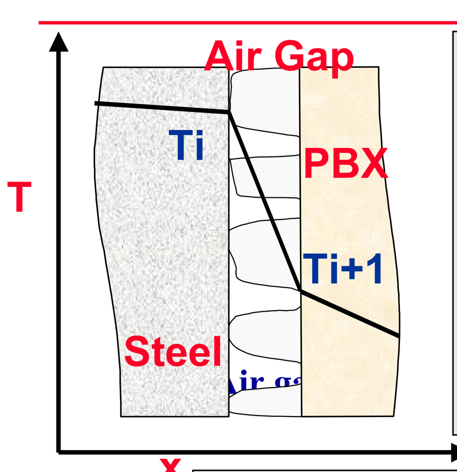
Interface analysis



Interface

$$-K_{steel}\cdot\frac{\partial T(L^-_{steel},t)}{\partial x} = -K_{PBX}\cdot\frac{\partial T(L^+_{steel},t)}{\partial x}$$

Interface (Imperfect thermal contact)

$$-K_{steel}\frac{\partial T(L^-_{steel},t)}{\partial x} = K_{air}\frac{(T_{steel}-T_{PBX})}{L_{air}}$$

$$-K_{PBX}\frac{\partial T(L^+_{steel},t)}{\partial x} = K_{air}\frac{(T_{steel}-T_{PBX})}{L_{air}}$$

Air gap in terms of thermal expansion of materials

$$L_{air} = L_{steel}[a1(T_i-To)+a2(T_i-To)^2]+L_{PBX}[b1(T_{i+1}-To)]$$

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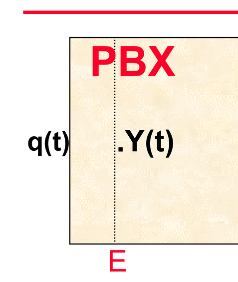
Inverse Heat Conduction Method (IHC)



Y(t): internal measurements;

qE(t): Estimated heat Flux at same location using *Duhamel* Superposition Integral

$$qE = \frac{K}{\sqrt{\pi\cdot\alpha}}\cdot\left\{\left[\frac{T_{PBX}(t)-To}{\sqrt{t}}\right]+\frac{1}{2}\int_0^t\frac{T_{PBX}(t)-T(s)}{\sqrt{(t-s)^3}}\cdot ds\right\}$$

Temperature and Heat Flux at Interface

$$T(x,t) = Y(t) + \sum_{n=1}^{\infty}\frac{(E-x)^{2n}}{(2n)!}\cdot\frac{1}{\alpha^n}\cdot\frac{d^nY}{dt^n} + \frac{(E-x)}{K_{PBX}}\left[q_E(t)+\sum_{n=1}^{\infty}\frac{(E-x)^{2n}}{(2n+1)!}\cdot\frac{d^nq_E}{dt^n}\right]$$

$$q_i(t) = q_E(t) + K_{PBX}\cdot\sum_{n=1}^{\infty}\frac{E^{2n-1}}{(2n-1)!}\cdot\frac{1}{\alpha^n}\cdot\frac{d^nY}{dt^n} + \sum_{n=1}^{\infty}\frac{E^{2n}}{(2n)!}\cdot\frac{d^nq_E}{dt^n}$$

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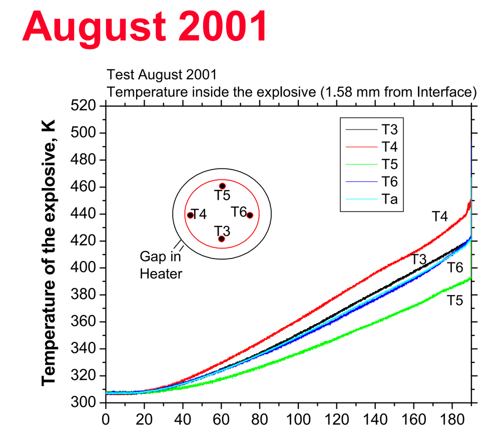
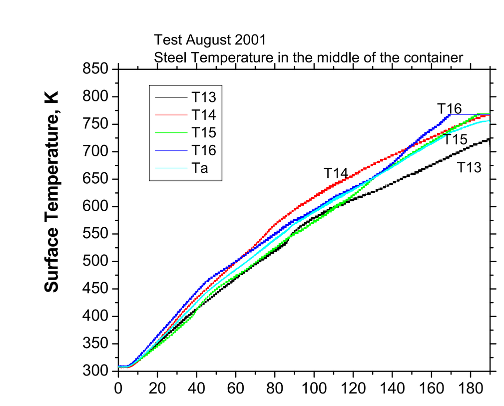
Results: Temperature

August 2001





Only 1/3 of PBX was consumed

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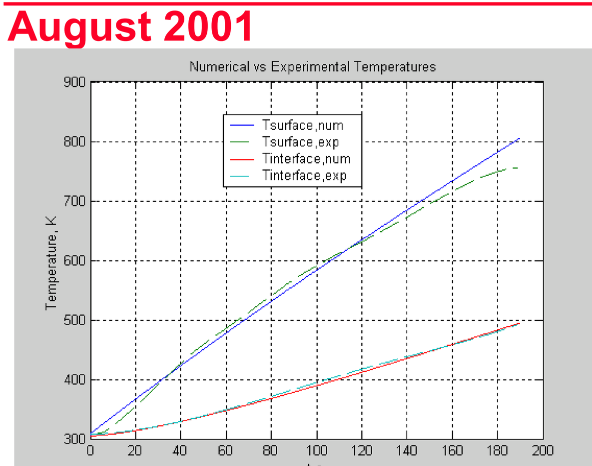
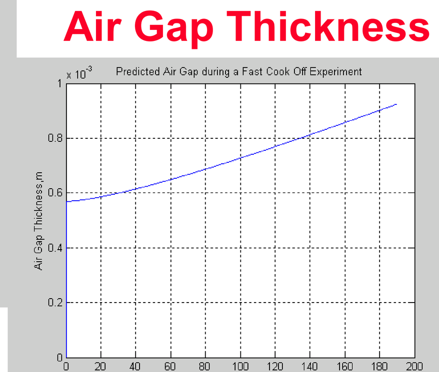
Results: Temperature

August 2001



Air Gap Thickness



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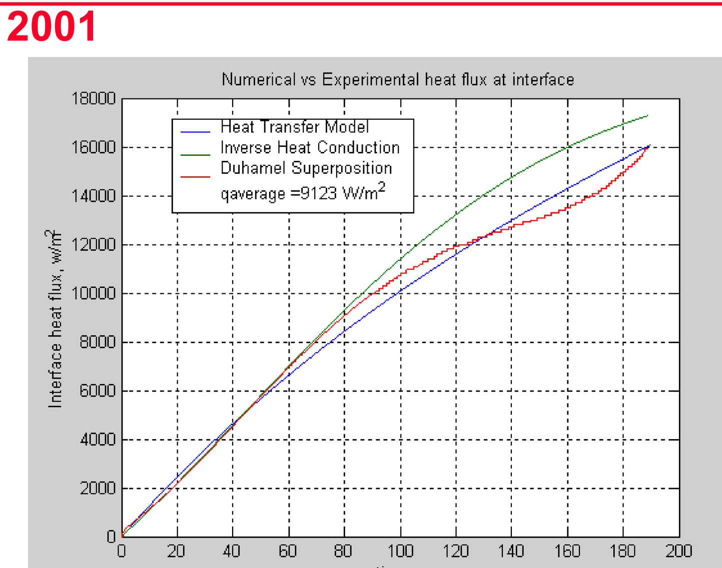
Results: Heat Flux

August 2001



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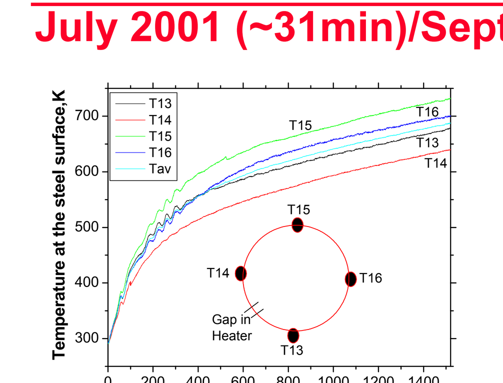
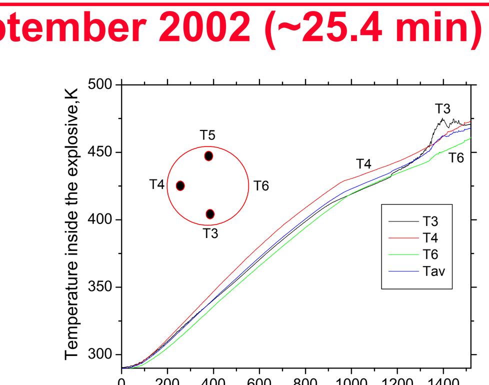
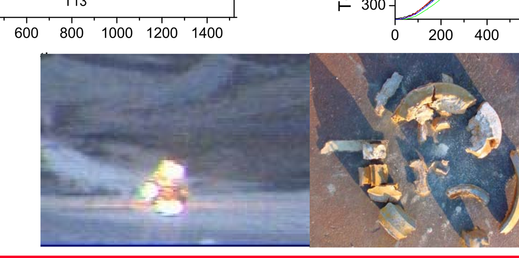
Results: Temperature

July 2001 (~31min)/September 2002 (~25.4 min)







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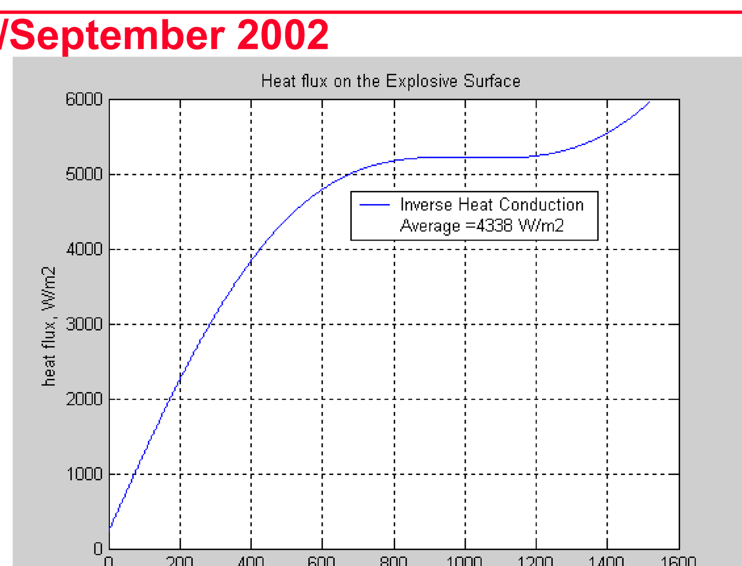
Results: Heat Flux

July 2001/September 2002



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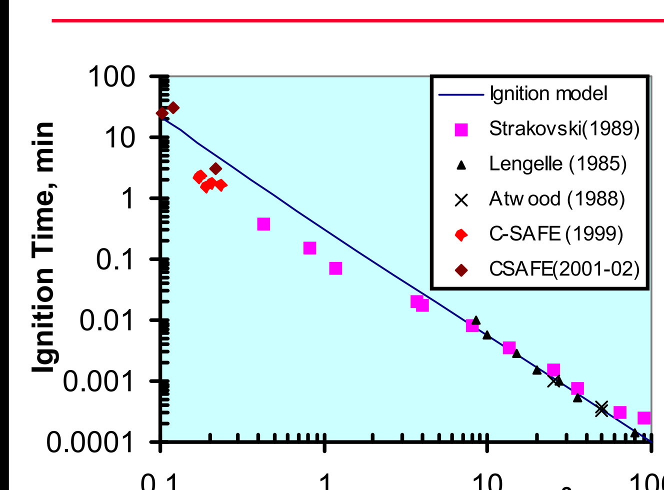
Results: Ignition Model for HMX*



Time~31min

Time~3min

*Beckstead(1994)

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Concluding Comments

-The heat transfer model determined that there was a contact resistance at the container/explosive interface.

-The contact resistance was consistent with the thermal expansion of the materials.

-Thermal expansion creates an air gap at steel-PBX interface, which in turn delays ignition.

-The fast-cook off experiments are in good agreement with the ignition model for HMX explosives proposed by Beckstead.

-Relatively slow cook off (~30 minutes) is much more violent than fast cook off (~3 minutes)

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