Computational Simulation of Blast Effects on Structural Components

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Acknowledgements

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Objectives

- Detailed coupled gas/chemistry simulations of detonations
- Large scale simulations of pressure loadings using time-accurate CFD
- Fluid/structure simulations under blast/impact loadings
- Coating materials to help make structures blast/impact resistant – polyurea
Background – Blast resistant materials (polyurea)

Polyurea
- Introduced by Texaco in 1989
- Known Advantages vs. Polyurethanes (traditional coatings)

Applications
- DoD – Civil Infrastructure
- DoD – other apps
  - Army/Navy – Spray on armor (Humvees)
  - Navy – Ship hulls (U.S.S. Cole)
- Other – Civil Infrastructure
  - Rail cars
  - Water storage tanks
  - Chemical plant infrastructure

Sources:
PCI: http://www.pcimag.com/CDA/Archives/779f754db76a7010VgnVCM100000f932a8c0
DefenseReview.com: http://www.defensereview.com/article502.html,
Polymer Materials for Structural Retrofit, Knox et al., AFRL
Background – Blast resistant materials (polyurea)

- DoD applications – *Polyurea*
  - AFRL
  - ERDC-WES
  - Army
  - Navy
  - Pentagon
    - Retrofit
- Public domain?

Source: Polymer Materials for Structural Retrofit, Knox et al., AFRL; Army Times
Blast Simulation CFD Method

- Unstructured-grid, time-accurate Euler code
- Finite volume, Runge-Kutta time marching
- Code is called PUMA2
- Has been in use at Penn State for many years, thoroughly validated on a wide range of problems
Blast CFD - Assumptions

- 75 lbs. of TNT
- Explosive is spherical in geometry
- Uniform explosion
Blast CFD - Initial Pressure Profile

Initial Pressure Profile

$p/p_0$ vs. $r/R$
Blast CFD - Pressure History

Pressure Histories at Different Locations

- $r = 1\,\text{m}$
- $r = 0.5\,\text{m}$
- $r = 0.2\,\text{m}$
Blast CFD – PUMA2
Comparisons to ConWep

Over-Pressure vs. Distance (75 lbs of TNT)
Blast CFD - Simulations Including Steel Plate

- Plate Dimensions (60in by 60in)
- 75 lbs. of TNT
- Plate located approx 3 ft away from the explosive
Loading History at the Center of the Plate
Background – Fluid/structure simulations

- Commercial codes
- Interaction
  - Loosely coupled
- Mechanisms behind protection?
- Parameters to control performance?
Focus Areas – fluid/structure interaction

- Numerical fluid/structure program
  - Material models
  - Comparison of ABAQUS and LS-DYNA
  - Comparison of PUMA2 and ConWep
  - Effect of polyurea on steel plate under blast loading

- Experimental fluid/structure program
  - Material properties
  - Validation testing
Fluid/structure interaction

- Numerical fluid/structure program
  - Material models – via literature
  - Comparison of ABAQUS and LS-DYNA
  - Comparison of PUMA2 and ConWep
  - Effect of polyurea on steel plate under blast loading
- Experimental fluid/structure program
  - Material properties
  - Validation testing
Material model - Steel

- Steel (AISI 4340)
  - Johnson-Cook material model (Kurtaran and Eskandarian, 2003)
  - A=66.7, B=100.4, n=0.26, C=0.014, and m=1.03

\[ \sigma = \left[ A + B (\varepsilon^{pl})^n \right] \left[ 1 + C \ln (\dot{\varepsilon}^*) \right] \left[ 1 - T^{*m} \right] \]

- \( \varepsilon^{pl} \): equivalent plastic strain
- \( \dot{\varepsilon}^* \): normalized plastic strain rate
- \( T^* = \frac{T - T_{room}}{T_{melt} - T_{room}} \)
Material model - Polyurea

- Polyurea (APCI)
  - Mie-Gruneisen equation of state (Fuentes 2006)
    - A hydrodynamic material model
    - A function of density and internal energy

\[
P - P_H = \Gamma \rho (E_m - E_H)
\]

\[
\Gamma = \Gamma_0 \frac{\rho_0}{\rho}
\]

\[
E_H = \frac{P_H \eta}{2 \rho_0}
\]

\[
\eta = 1 - \frac{\rho_0}{\rho}
\]

\[
P_H = \frac{\rho_0 C_0^2 \eta}{(1 - s \eta)^2}
\]

\(C_0\) and \(s\) are material constants

\(\rho_0\) : reference density
\(\Gamma_0\) : material constant
Numerical program

- Abaqus - Explicit
- LS-Dyna
- PUMA2
Fluid/structure interaction

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Numerical analysis - ABAQUS and LS-DYNA

Area of the uniform distributed pressure load

Fixed end

1 in

5 in

99 in
Pressure time-history of the impact load
Displacement

![Displacement Graph]

- ABAQUS
- LS-DYNA
Von Mises Stress

![Von Mises Stress Graph](image_url)
Internal energy

Comparison of internal energy for mesh size 1"x1"x1"

- LS-DYNA
- ABAQUS
Fluid/structure interaction

- Numerical fluid/structure program
  - Material models
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  - Comparison of PUMA2 and ConWep
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- Experimental fluid/structure program
  - Material properties
  - Validation testing
Numerical program – Comparison of PUMA2 & ConWep

- FEM program: LS-DYNA
- Steel plate: 60”x60”x0.25”
- Steel (AISI 4340)
  - Johnson-Cook material model – literature, no failure criterion
- Load
  - PUMA2 CFD code (complex spatial and temporal loading)
  - ConWep (Blast function provided in LS-DYNA)
Background

- CFD code, PUMA2
  - Solve Euler equations
  - Neglect viscous effect
- Blast function (ConWep)
  - U.S. Army Waterways Experiment Station
  - Empirical model
Configuration of the model

75 lb of TNT

3.2 ft

Steel plate: 60"x60"x0.25"
Comparison of displacements

The graph compares the z-displacements of PUMA2 and ConWep over time. The x-axis represents time in seconds (0 to 0.008), and the y-axis represents z-displacement in inches (-12 to 0). The PUMA2 data is shown by a solid line, while the ConWep data is depicted with a dashed line.
Comparison of von Mises stress
Fluid/structure interaction

- Numerical fluid/structure program
  - Material models
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  - Effect of polyurea on steel plate under blast loading
- Experimental fluid/structure program
  - Material properties
  - Validation testing
Numerical program – Effect of polyurea on steel plate under blast loading

- Steel plate: 60”x60”x0.25”
- Thickness of coating: 0”, 0.25”, 0.5”
- Steel (AISI 4340)
  - Johnson-Cook material model
- Polyurea (Air Products)
  - Mie-Gruneisen Equation of State
- Load: PUMA2 CFD code (complex spatial and temporal loading)
Numerical program – Steel plate without polyurea
Numerical program – Steel plate with 0.25” thick polyurea
Numerical program – Steel plate with 0.5” thick polyurea
Deflection at the center

- No coating
- 0.25" polyurea
- 0.5" polyurea

Displacement (in) vs. Time (s)
Kinetic energy

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**Graph:**
- **Y-axis:** Kinetic energy (lbf-in)
- **X-axis:** Time (s)
- Three lines representing different coatings:
  - **No coating**
  - **0.25" polyurea**
  - **0.5" polyurea**

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Current focus areas – numerical program

- Sensitivity analyses
  - Model construction
  - Constitutive model selection – Polyurea (e.g. viscous or crushable foam vs. M-G)
- Numerical failure mode prediction
  - Coated plate
  - Pressure, temperature, impact
  - Relevant loading regimes
- Failure criteria prediction
  - Membrane action - polyurea
  - Interface failure - polyurea and steel
Fluid/structure interaction

- Numerical fluid/structure program
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- Experimental fluid/structure program
  - Material properties
  - Validation testing
Experimental program

- **Material properties**
  - Characterization – steel and polyurea

- **Validation Testing**
  - Impact and/or Blast
    - Coated and uncoated
    - Varying coating thickness
  - Locations
    - PSU CITEL
    - Others
Coupon testing - Steel

- ASTM E8
- Extensometer - displacement
Results – stress vs. strain

![Graph showing stress vs. strain](image)
Material constants for JC model

- Using a least squares fitting method
  - Material constant A = 66.7 (ksi)
  - Material constant B = 100.4 (ksi)

\[
\sigma = \left[ A + B (\varepsilon_{pl}^n) \right] \left[ 1 + C \ln (\dot{\varepsilon}^*) \right] \left[ 1 - T^{*m} \right]
\]
Current focus areas – experimental program

- Coupon testing – Polyurea (APCI)
- Validation testing specimen prep
- Validation testing determination and matrix development
Summary
Questions?

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