



CTH: A Code Family for Multidimensional Shock Physics Analysis WSSX Meeting Moscow, Russia February 7-9, 2007

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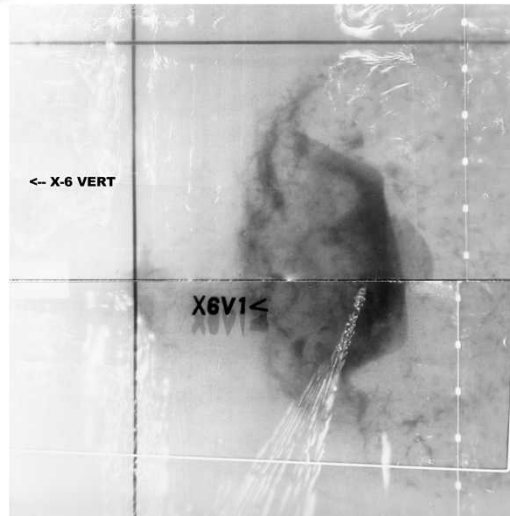
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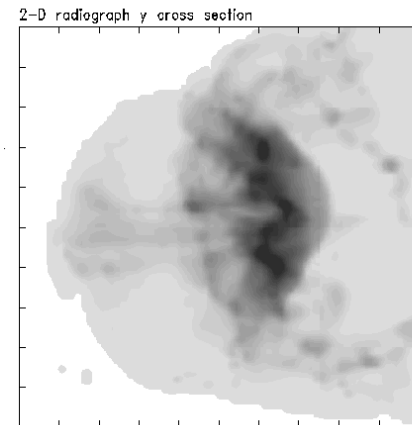
Outline

- CTH Overview
- Model Implementation Issues
- Use Case Discussion

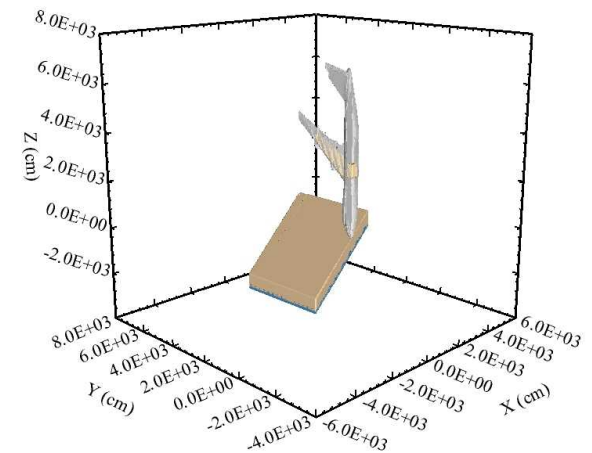
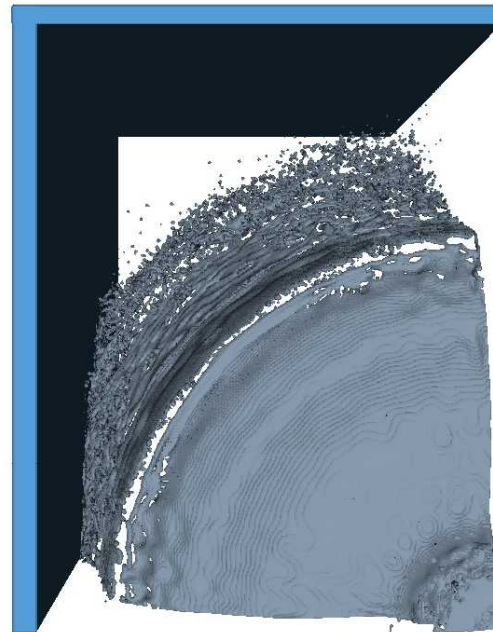
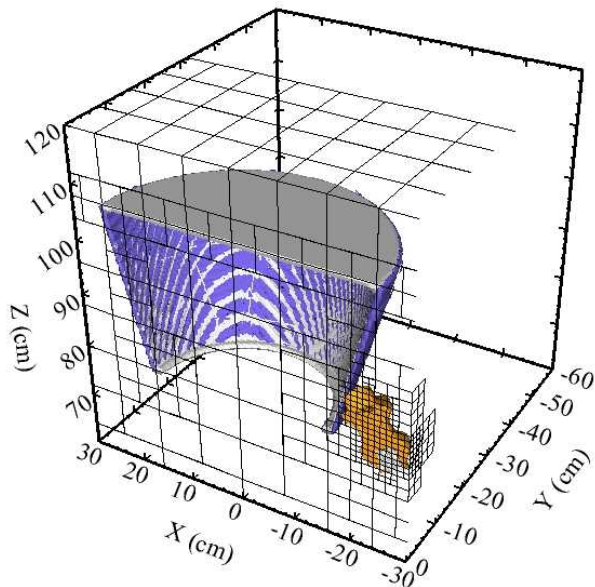
Typical CTH Problems



← **Projectile Impact Test** →
Simulation



3DR Block 1
NMD HTK-8 LEXAN BODY 3D Development Shot (bob)
COSAVU 03/15/99 18:09:26 CTH Y=1.2125x10¹
907 Time=4.50762x10⁻⁵





CTH Code Family

- Code family consists of seven major codes
 - CTHGEN - generates initial database (deprecated)
 - CTH - integrates problem through time
 - CTHED - text editor processing/querying of restart files
 - CTHREZ - manual rezoner
 - CTHPLT - graphics post processing
 - SPYMASTER (SPYPLT) - on the fly or post processing graphics
 - HISPLT - history graphics post processing
- Software mostly written in ANSI FORTRAN 77 with some C
- The CTH family runs on all major Unix workstations, vector computers, Intel machines w/Linux, Mac's, and Windows
- CTH also runs on data parallel computers from all major vendors using MPI



CTH Capabilities

- One-, Two-, and Three-Dimensional Geometry Options
 - 1D - rectilinear, cylindrical, and spherical
 - 2D - planar and cylindrical
 - 3D - rectangular
- Adaptive Mesh Refinement (AMR)
 - Serial and Parallel
- Thermodynamic EOS with Phase Changes
- Material Strength and Fracture Models
- Porosity Models
- Energy Source Models
- High Explosive Detonation and Initiation Models
- High Resolution Interface Tracker
- Extensive Sophisticated Graphics Support
- Manual Rezonor



Conservation Equations

- Conservation of mass

$$\frac{\partial \rho}{\partial t} = -\rho \nabla \bullet \vec{V}$$

- Conservation of momentum

$$\rho \frac{\partial}{\partial t} \vec{V} + \nabla \bullet (\sigma + \mathcal{Q}) = -\nabla P$$

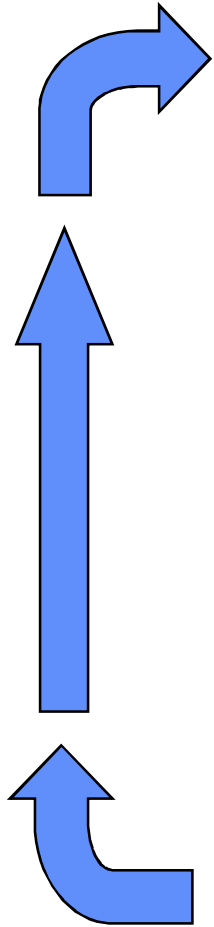
- Conservation of energy

$$\frac{\partial E}{\partial t} = -(P + \mathcal{Q}) \frac{\partial}{\partial t} \left(\frac{1}{\rho} \right) - \frac{1}{\rho} \nabla \bullet F + S$$

- Solved in conjunction with equation-of-state and constitutive models
- All current models in CTH assume that the total stress tensor can be decomposed into spherical and deviatoric parts:
 - spherical part is the Equation of State $P=f(r,E)$,
 - deviatoric part is the constitutive model $\sigma = f(\text{strain}, \dots)$



CTH Solution Sequence



- Adaptive Mesh Refinement update (if AMR calc.)
 - Refinement, if needed, every 2-3 cycles
 - Unrefinement, if needed, every 6 cycles
- Lagrangian Step
 - Lagrangian forms of conservation equations are solved for time step
- Remap Step
 - Distorted mesh is mapped onto the original mesh
- Database Modification Step
 - Database is modified based on user directives
 - e.g. Discard, Velocity addition, etc.
- Time Step Control



Lagrangian Step

LAGRANGIAN FORMS OF CONSERVATION EQUATIONS ARE SOLVED FOR THE TIME STEP

- Mesh distorts to follow motion of material. Mass conservation is trivially satisfied since no mass flows across cell boundaries.
- Momentum and energy conservation equations are solved for time step.
 - Calculate artificial viscosity (linear & quadratic terms)
 - Update velocities (from time $n-1/2$ to time $n+1/2$)
 - Update stress deviators (from time n to time $n+1$)
 - Calculate work (PdV and sdV)
 - Calculate distorted cell volume
 - Calculate thermodynamic state in distorted cell (energy balance)
- Physics models are implemented during the Lagrangian step



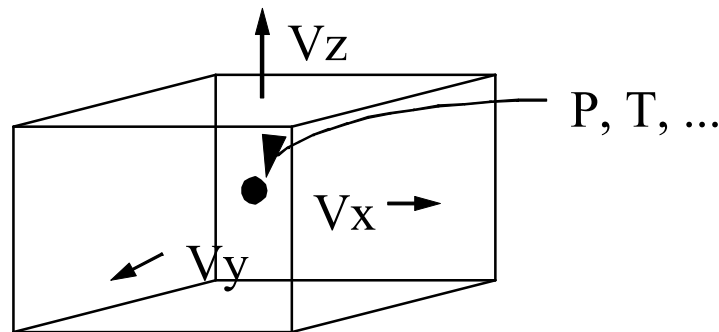
Remap Step

DISTORTED MESH IS MAPPED ONTO THE ORIGINAL MESH RESULTING IN MOTION OF MATERIAL THROUGH THE MESH

- Volume, mass, momentum, kinetic energy, internal energy, and internal state variable flux between cells is calculated
 - Momentum and kinetic energy cannot both be conserved. Four convection options are available in CTH
 - Multidimensional equations are replaced with several one-dimensional equations (operator splitting)
 - Second-order van Leer scheme used to calculate fluxes
 - High resolution interface tracking algorithm used to reconstruct material interfaces
- Thermodynamic state in each cell is calculated
 - Material fracture criterion checked, if satisfied:
 - void inserted
 - pressure magnitude reduced

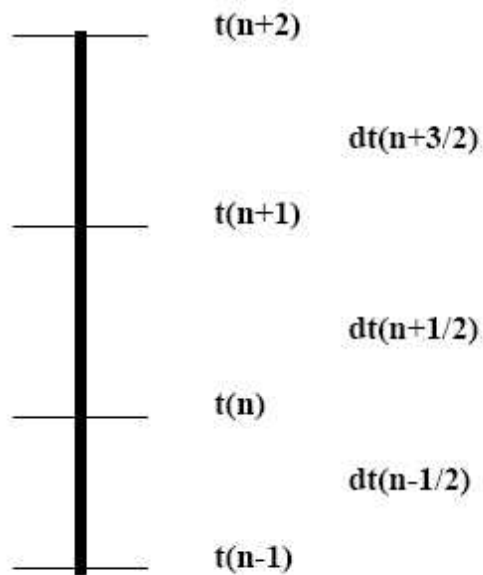
Mesh and Computational Cell

- Mesh is Generated From 3 Sets of Spatial Coordinates
 - $\{x_i\}$, $\{y_j\}$, $\{z_k\}$ define cell boundaries
 - Each cell is a rectangular parallelepiped (box)
- Spatial & Temporal Positions
 - Most variables are cell centered and defined at the time step
 - Velocities are on and normal to the cell face and half time step centered



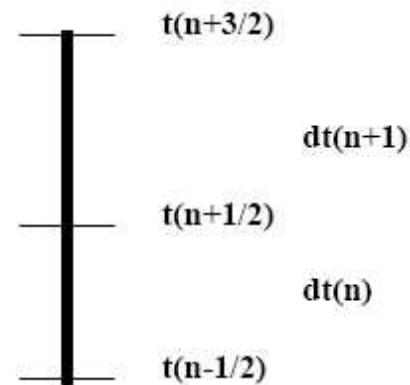
Temporal Mesh

Primary Temporal Mesh



Primary Variables Defined

Secondary Temporal Mesh



Velocity Defined



Modeling Fiber Reinforced Composites



CTH Constitutive Model Implementation

Current Material Model Features

- Isotropic
- Deviatoric and spherical stress and strain fields
- Equation of state (EOS) for spherical field
- Constitutive model for deviatoric stress field
- Only updates deviatoric stress and model state variables



CTH Constitutive Model Implementation

New Material Model Features

- **Coupled EOS with constitutive model**
 - Example – Porosity coupling, where porosity influences the EOS
- **Non isotropic**
 - Assumptions: Can be divided into spherical and deviatoric components
 - Error must be minimal from neglecting coupled spherical and deviatoric components
 - Example – Transverse Isotropic Model
- **Only updates deviatoric stress, model state variables, and coupled variables**



Use Case



Goal

- **Improve ability to model system response for a class of materials that is light enough to be mounted on vehicles**
- **Be able to model both the ballistic response of the material as well as the structural performance**
- **Model the effect of layered systems**
 - **Metal/ceramic composites**
 - **Glass/plastic composites**
 - **Reinforced concrete**
- **Optimize system to protect personal and high value assets**

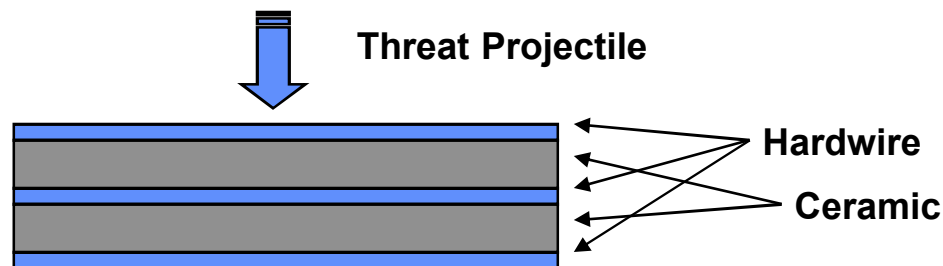


Desired Features

- **Simulate the performance of ballistic-resistant materials when subjected to various threats**
- **Optimize for:**
 - **Multi-hit capability**
 - **Minimum weight**
 - **Machinability or formability**
 - **Cost**
 - **Thickness**
 - **Longevity**

Hardwire Composites

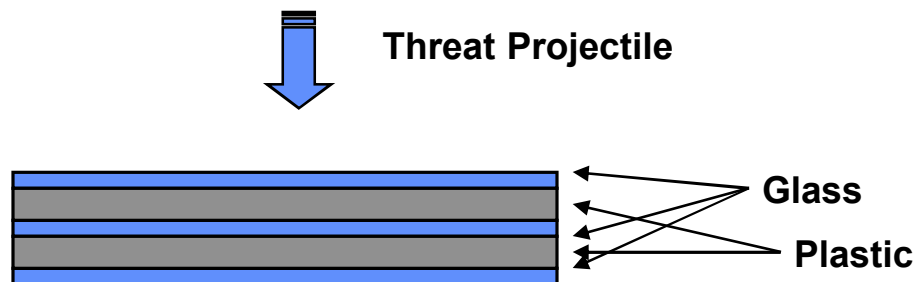
- **Hardwire composite structures – layered product that uses multiple layers of wire weaves that package squares of silicon carbide ceramics**
- **Hardwire (0.50-Caliber Rated) product has been found to be more effective as RHA plate with twice the mass**
 - **Modeling individual strains of wire will not be practical**
 - **The interaction of the wire/ceramic system under impact and shock loading is not well understood**
 - **Predicting the overall structural strength may allow the material to be used as a primary structure, not just a bolt-on material**





Glass/Plastic Composites

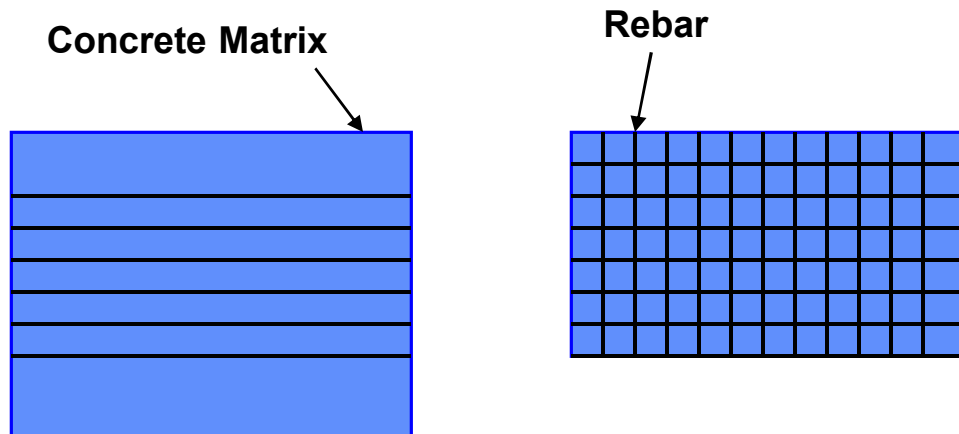
- Layered glass/plastic composite structures – layered product that uses multiple layers glass and plastic
- Transparent armor
 - Model glass as brittle material
 - Model plastic with sufficient accuracy to capture important interactions with glass
 - Unknown importance of interaction with thin glue bonds between layers





Reinforced Concrete

- **Three-dimensional composite structures – steel rebar in 3D lattice with concrete matrix**
- **Facility protection**
 - **Model concrete as brittle material**
 - **Model rebar with sufficient accuracy to capture important interactions with glass**
 - **Important interactions between rebar and concrete matrix**





Conclusions

- CTH a useful platform for model development
- CTH extensively used in the US DOE and DOD complex for a wide variety of shock physics and large deformation analysis
- System level modeling at ~1 cm resolution requires accurate subgrid models of complex material behavior
- Predictive models for ceramic not available for routine analysis