MPM Workshop 2013

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**Project Goals**

- Add full Lagrangian capability into CTH
- Fully coupled fluid-structure interactions
  - Numerical method integrated into CTH
    - Common input between CTH and Lagrange method
  - Coupled to Adaptive Mesh Refinement (AMR)
    - Dynamic load balancing between CTH and Lagrange method
- Improve strength and failure mechanics
  - Lagrangian fracture mechanics
  - Reduce advection errors in damage and failure
- Fast, Robust and Easy to use
Challenges

- Interface existing CTH data structure
  - Create new data structure for Lagrangian capabilities using Fortran 90
  - Interface new data structure to CTH
- Interface existing CTH models
  - EOS, strength and failure models
    - New material interface for Lagrangian materials
  - Lagrangian fracture coupled to CTH
    - Material switching and void insertion
- Visualization
  - Using Spymaster for on-the-fly and post visualization
  - Interface new data structure to Spymaster
CTH Overview

CTH is a massively-parallel shock-physics code.

- Eulerian shock wave physics computer code solving conservation equations of mass, momentum, and energy for up to 98 simultaneous materials including gases, fluids, solids, and reactive materials
  - Analytic & Tabular Equation-of-State representations
  - Advanced Strength & Fracture models
  - Adaptive Mesh Refinement
- Applications (partial list):
  - National Missile Defense (NMD), Nuclear Emergency Response (NEST), Weapon effects & vulnerability
  - Armor, Anti-Armor, Munitions Design, Blast Effects
  - Planetary Science, Asteroid Impact & Planetary Defense
- CTH licensed to hundreds of external DOE & DoD agencies and their subcontractors
  - 600+ users

32,000 processor Cielo calculation showing nearby blast on aluminum and steel structure
Fluid-Structure Interaction

- Applications
  - Blast on target
  - Ballistics
  - Biomechanics
  - Damage and failure mechanics

- History
  - Charles S. Peskin
    - Immersed boundary method Heart valve modeling
  - Los Alamos National Lab (LANL)
  - Sandia National Laboratories (SNL)
    - Notables: S. W. Attaway, G. C. Bessette, D. A. Crawford, R. L. Bell
Lagrangian Numerical Method to Use?

- Finite Element versus Particles
- Long history of both methods being used for Lagrangian Numerics
  - Los Alamos National Laboratories
    - Many projects over the past 50+ years looking at coupling methods
    - Finite element versus finite volume versus particles
  - Los Alamos National Laboratories – Particle-In-Cell (PIC)
  - Los Alamos National Laboratories – Fluid Implicit Particle (FLIP)
  - Sandia National Laboratories – Fortissimo (2008)
  - Sandia National Laboratories – Zapotec II (2011)
  - NAVSEA - DYSMAS (DYNA-GEMINI)
  - Others, Material Point Method, Smooth Particle Hydrodynamics, etc.
- Mesh objects versus material insertion
- Adaptability to future numerical methods in Hydrodynamics
Choice: Particles (Markers)

Why?

- Material Point Method (MPM) and material tracking
  - MPM (Sulsky, D., Chen Z. and Schreyer, H. L.)
  - Both use structured background grid for gradient computations (no neighbor searching)
- History of working well in a finite volume shock hydrocode
  - Challenges in finite elements in a finite volume
  - Integration into a finite volume numerical framework by Bryan Kashiwa at Los Alamos National Laboratory
- Next generation failure mechanics
  - No element boundaries
  - Lagrangian fracture mechanics in a finite volume shock code
- No unstructured meshing
- Massively parallel
  - Dynamic load balancing based on marker count on processors
- Adaptive Mesh Refinement
  - Marker combining and splitting
Marker Methods

- 1D, 2D and 3D
- Interface into existing material insertion capability in CTH
  - Diatom insertion of marker fields
- Strength
  - Track material behavior through grid to marker differences (Material tracking)
  - Compute stress and accelerations on markers and update to grid (MPM)
- Boundary Conditions
  - Symmetric, outflow, inflow and outflow
- Failure
  - Material switch from shear supporting to hydrodynamic
  - Void insertion based on marker failure
  - No failure
- Massively parallel marker capability with/without AMR
  - Ghost markers
  - Combining and splitting
- All existing CTH material models have been integrated
  - All EOS models
  - Full stress tensor or deviatoric tensor options (except GEFFS and PSDAM)
  - All failure models
Marker Methods – cont.

• Composite model integration with markers
  – Initializing marker with material direction using existing layering techniques
  – Separate strain rates for markers in layers
  – With multifield can track layer interaction for delamination and other failure processes

• Plate, shell and beam theories added to CTH
  – Implemented existing plate theory from Los Alamos National Laboratory
  – Working with Los Alamos National Laboratory to add new shell theory

• Discard

• New mass footprint of marker fields
  – Second order accurate and sharp object interfaces

• New material models
  – Full-stress tensor with MPM
  – Integration of deformation tensor
  – Hyperelastic Models
    • Mooney-Rivlin
    • Transverse-Isotopic Mooney Rivlin
  – Stochastic models
    • Research on stochastic energetic ignition models
Using Markers

• Sample Input:

```
mark
mmat 1 6
mmat 2 4
stren 3
endmark
```

- Marker start
- Material (field) number
- Markers in linear direction
- Strength option
- Marker end
Using Markers
Select Options

• Strength options
  – Material tracking (stren 1)
  – Material Point Method (MPM) (stren 3)

• Energy options
  – Irreversible energy only (senrg 1)
    • Add only irreversible energy from stress power
  – Total energy, classical CTH, (senrg 2)
    • Total and irreversible energy from stress power
    • Controlled release of energy during fracture (reversible)

• Failure options
  – No failure (fail 10)
  – Reduce deviatoric stress (fail 2)
  – Field switching (fail 1)
    • Marker (fmat 0) or CTH type material (fmat 1)
Using Markers
Select Options cont.

• Split and Combine
  – Momentum conserving techniques
  – AMR or non-AMR problems
  – Set limit number of markers in one cell to combine (mcomb #)
  – Set lower limit number of markers in one cell to split (msplit #)

• Plates, shells and beams
  – Plate option from LANL
  – Set by field (mplate “field #” “h” “integration”)
  – Shells and beams to be added in the future
Triple Plate

- Two-dimensional cylindrical
- Rod impacting flat plates
- Velocity is 500 m/s
Triple Plate

$V_{mag}$ at 0.00e+00 seconds

$V_{MAG}$ (m/s)

-10 to 10 on the Y-axis and -15 to 15 on the X-axis.
Oblique Composite Plate

- Two dimensional rectangular
- Thin metal projectile
- Velocity of 100 m/s
- Composite
  - $[0^\circ, 90^\circ, 90^\circ, 0^\circ]$
Oblique Composite Plate

Graph showing composite failure across X (cm) and Y (cm) with a color scale indicating:
- 1 - No Failure
- 2 - Matrix Failure
- 3 - Complete Failure

Time 0.0 µs
Elastic Ball

- Three dimensional rectangular
- Elastic ball
- Velocity 500 m/s
Elastic Ball

Time 0.0 µs
Future Directions

• Thin structure mechanics
  – Shock support method for membranes/shells

• Integration of Convective Particle Domain Insertion (CPDI)
  – University of Utah collaboration
    • Summer student Michael Homel and Rebecca Brannon
  – Technique developed to expand a marker domain based on deformation

• Implicit Continuous Eulerian (ICE++)

• Multifield
  – Multiple velocities for each field (material) in a finite volume
  – Momentum, energy and mass interactions

• New material models
  – Fracture and failure
  – Non-linear elasticity in shock
  – Stochastic fields
Conclusions

- Beta release of Markers in CTH version 11.0
  - March 2013
  - User manual

- Full Lagrangian method coupled into CTH
  - Reduce advection errors
  - Failure mechanics
  - Framework for new constitutive models
    - Hyperelastic constitutive models

- Marker options
  - Strength
  - Failure
  - Energy

- Robust and easy to use technique for modeling fluid-structure interaction
  - No unstructured meshing
  - Fully coupled
  - Common “look and feel” input
  - Quick “total time-to-solution”
Questions?