Simulation of Hypervelocity Impact of a Whipple Shield

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GTC 2016
April 4-7, 2015
San Jose, CA
Hypervelocity Impact

Impact Velocity > 2.5 km/sec

Space Debris

Missile Impact
Hypervelocity Impact

- Velocity > 2.5 km/sec
- Metal behaves like a fluid when impacted at these velocities
  - SPH a particle based method is necessary to model the structures
- Deformation is very large so classic Finite Elements (FE) cannot handle the deformation of the last plate
  - High Order FE can be used to model the 3rd plate as the impact velocity of the resulting particles are on the order of 700 m/sec (speed of a typical bullet)
Hypervelocity Impact
Simulation Software

- The IMPETUS Afea Solver®, a Nonlinear Transient Dynamic Explicit Solver that takes full advantage of GPU Technology.
- High Order Quadratic and Cubic Finite Elements
  - Handles very large deformations without numerical instabilities
- $\gamma$SPH Solver (Next Generation SPH)
  - Accurate Pressure Computation
  - Eliminates the classic SPH tensile instability problem
Hypervelocity Impact

Hardware

➢ All simulations were run on a single workstation

➢ Single Core of the CPU used

➢ 1 NVIDIA Tesla K40
Hypervelocity Normal Impact

Reference Experiment

Projectile: Aluminum Sphere
Diameter = 9.53 mm

Target: Aluminium Plate (3 Cases)
Thickness: 0.8mm, 1.549mm, 4.039mm

Material Model: Elastic Perfectly Plastic + Mie-Gruneisen EOS
**Hypervelocity Normal Impact**

Reference Experiment (cont’d)


<table>
<thead>
<tr>
<th>Case</th>
<th>Plate Thickness (mm)</th>
<th>Impact Velocity (m/sec)</th>
<th>SPH Particles</th>
<th>Simulation Time (μsec)</th>
<th>Run Time (hr)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>0.8</td>
<td>6680</td>
<td>1,084,351</td>
<td>7.1</td>
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<td>2</td>
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<td>3</td>
<td>4.039</td>
<td>6680</td>
<td>3,683,551</td>
<td>8.4</td>
<td>10.85</td>
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</table>
Hypervelocity Normal Impact


Test 4-1289
Plate thickness=0.8mm

Test 4-1291
Plate thickness=1.549mm

Test 4-1353
Plate thickness=4.039mm

Simulation Results
Simulation Results

Hypervelocity

Normal Impact

Hypervelocity Impact
Piekutowski_4-1289
Hypervelocity Oblique Impact

Reference Experiment
Thiot Ingenierie Test Lab

Projectile: Aluminum Sphere
Target: Aluminium Plate
Material Model: Elastic Perfectly Plastic + Mie-Gruneisen EOS
## Hypervelocity Oblique Impact

### Reference Experiment

**Thiot Ingenierie Test Lab**

<table>
<thead>
<tr>
<th>Plate Thickness (mm)</th>
<th>Impact Velocity (m/sec)</th>
<th>SPH Particles</th>
<th>Simulation Time (μsec)</th>
<th>Run Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4050</td>
<td>812,712</td>
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<td>1.2</td>
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</tbody>
</table>
Hypervelocity Oblique Impact

Sphere Diameter = 3.0 mm  Velocity = 4050 m/s

Plate thickness=2.0 mm with a 32° Tilt

Simulation Results
Simulation Results

Hypervelocity

Oblique Impact

Thiot Ingenierie Test Lab
Hypervelocity Impact

Thiot Ingenierie Test Lab
### 3 Plate Whipple Shield

**Projectile:** *Aluminum Sphere*

**Target Plates:** *Aluminum*

*Projectile and Plates 1 and 2*

**Material Model:** *Elastic Perfectly Plastic + Mie-Gruneisen EOS*

**3rd Plate**

**Material Model:** *Johnson-Cook*

<table>
<thead>
<tr>
<th>Plate Thickness (mm)</th>
<th>Impact Velocity (m/sec)</th>
<th>SPH Particles</th>
<th>Cubic Hex Elements (64 nodes/element)</th>
<th>Simulation Time (μsec)</th>
<th>Run Time (hr)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>6680</td>
<td>4,207,687</td>
<td>11,250</td>
<td>80</td>
<td>14.93</td>
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</tbody>
</table>
3 Plate Whipple Shield

Finite Element (Last Plate)

SPH
3 Plate Whipple Shield

Contour of Effective Stress

Time=80.0μs
Simulation Results

Hypervelocity

3 Plate Whipple Shield
3 Plate Whipple Shield
Impact of 3 Panels by a Spherical Projectile
Velocity 6680 m/sec
Contact Info

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