ANSYS® Explicit Dynamics and AUTODYN® Applications

Ashish Jaiswal
ANSYS Inc.
Explicit Dynamics and AUTODYN Applications

- Street Blast
- Mine Blast
- Marine Blast
- Can Crush
- Drop Tests
- Missile Impact
- Aircraft Impact
- Blast In a Building
- Explosive Mining
- Portable Explosive Devices
# Why Use Explicit Dynamics?

## Impact Response of Materials

<table>
<thead>
<tr>
<th>Solution</th>
<th>Impact Velocity (m/s)</th>
<th>Strain Rate (/s)</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Implicit</td>
<td>&lt; 50</td>
<td>&lt;10-5</td>
<td>Static / Creep</td>
</tr>
<tr>
<td></td>
<td>50 - 1000</td>
<td>10-5 - 10-1</td>
<td>Elastic</td>
</tr>
<tr>
<td></td>
<td>1000 - 3000</td>
<td>101 - 101</td>
<td>Elastic-Plastic (material strength significant)</td>
</tr>
<tr>
<td></td>
<td>3000 - 12000</td>
<td>106 - 108</td>
<td>Primarily Plastic (pressure equals or exceeds material strength)</td>
</tr>
<tr>
<td>Explicit</td>
<td>&gt; 12000</td>
<td>&gt; 108</td>
<td>Vaporization of colliding solids</td>
</tr>
</tbody>
</table>
# Why Use Explicit Dynamics?

**Impacts at Low and High Velocity**

<table>
<thead>
<tr>
<th>VELOCITY</th>
<th>LOW</th>
<th>HIGH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deformation</td>
<td>Global</td>
<td>Local</td>
</tr>
<tr>
<td>Response Time</td>
<td>ms - s</td>
<td>µs - ms</td>
</tr>
<tr>
<td>Strain</td>
<td>&lt;10%</td>
<td>&gt;50%</td>
</tr>
<tr>
<td>Strain Rate</td>
<td>&lt; 10 s⁻¹</td>
<td>&gt; 10000 s⁻¹</td>
</tr>
<tr>
<td>Pressure</td>
<td>&lt; Yield Stress</td>
<td>10-100 x Yield Stress</td>
</tr>
</tbody>
</table>
Wave Propagation

Computes wave propagation

AUTODYN-2D v11.0 from Century Dynamics

ABS. VEL (m/s)

Constant pressure applied to left surface for 1 ms
Stability Time Step

To ensure stability and accuracy of the solution, the size of the time step used in Explicit time integration is limited by the CFL (Courant-Friedrichs-Levy[1]) condition. This condition implies that the time step be limited such that a disturbance (stress wave) cannot travel further than the smallest characteristic element dimension in the mesh, in a single time step.

The time steps used for explicit time integration will generally be much smaller than those used for implicit time integration.

- e.g. for a mesh with a characteristic dimension of 1 mm and a material sound speed of 5000 m/s. The resulting stability time step would be 0.18 µ-seconds. To solve this simulation to a termination time of 0.1 seconds, it would require 555,556 time steps.
**ANSYS® Explicit Dynamics and AUTODYN®**

- Non-linear dynamics programs
- Components of ANSYS® Workbench™
- Model the non-linear response of solids, fluids and gases and their interactions
- Can be used to study a wide range of events involving impact and blast loadings
- Provide a detailed understanding of the transient dynamics involved
- Determine the expected deformation and damage
- Provide insight into ways damage could be mitigated
  - **Design**
  - **Protection**
ANSYS® AUTODYN® Solutions

Lagrange (FE) Solvers
(Solids, shells, beams)

Structural Response
Complex Materials

Euler (CFD) Solvers
(Multi-material, Blast)

Solid / Gas / Fluid Flow
Blast Waves

Solid Impact

Coupling

Bonding / Contact

Fragmentation

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Lagrange Solvers

Use meshes that are imbedded in material and move and distort with the material

Three element types

- Solid
- Shell
- Beam

Provide the most efficient and accurate method for computing structural response
Lagrange Solvers

Erosion

If excessive material movement occurs, the mesh may become highly distorted

inaccurate and inefficient solutions

Mesh tangling (terminates solution)

This problem can usually be avoided by application of an erosion algorithm

• Extremely distorted cells are removed from the problem

• Element strain over 200% when eroded
Euler Solvers

Use meshes that are fixed in space

• Usually rectilinear

• Materials are advected through the mesh as they flow or deform

Avoids problems of mesh distortion and tangling that are prevalent in Lagrange simulations with large flows

Provides the best solution for gas/fluid flow

Provides an alternative solution for the extreme deformation of solids
Euler Solvers

AUTODYN has two Euler solvers

- **Multi-material Euler Solver**
  - General Euler solver capable of modeling and tracking the motion of multiple materials (with strength)

- **Euler Blast Solver**
  - Designed for efficient and accurate blast solution
    - 2nd Order
    - Hydrodynamic (no stress tensor)
    - Single material, ideal gas
**ALE (Arbitrary Lagrange Euler) Solver**

Uses solid meshes that are imbedded in material and move and distort with the material.

The mesh within any material region can be continuously adjusted in arbitrary and predefined ways (automatic rezoning).

The most efficient way of calculating blast response of structures that do not deform significantly.

Mesh distortions cannot easily be avoided if gross deformation or failure of structures occurs.

- Euler-Lagrange Coupled approach
Mesh Free Solver

Uses the Smooth Particle Hydrodynamics Method (SPH)

• Lagrange particle method (particles are imbedded in material)

• No mesh distortion/tangling problems

Provides most accurate solution for modeling fracture and fragmentation of brittle materials

Applied very successfully to problems involving impacts into ceramics and concrete

Not recommended to model ductile materials
Body Interactions

- Bonded (joined)
  - Unbreakable bonds
  - Breakable Bonds

\[
\left( \frac{\sigma_n}{\sigma_{n^{\text{limit}}}} \right)^n + \left( \frac{|\sigma_s|}{\sigma_{s^{\text{limit}}}} \right)^m \geq 1
\]

- Frictionless (contact)

- Frictional (contact)
  - Static
  - Dynamic

\[
\mu = \mu_d + (\mu_s - \mu_d) e^{-\beta v}
\]

- Reinforcement
  - Reinforced Concrete
Body Interactions In Explicit Dynamics

Lagrange meshes and SPH nodes can be joined at coincident nodes to form a single component

• SPH solver models regions of high deformation

• Lagrange solution elsewhere
Coupling

Euler-Lagrange Coupling allows regions modeled with Euler and Lagrange meshes to interact.

- Coupling is in space and time
- Boundaries of Lagrange meshes act as flow constraints within the Euler meshes

![Diagram of coupling between Euler and Lagrange meshes](image)
Contact, Erosion and Coupling can be used simultaneously in an analysis

- Failure and fragmentation of components
- Venting of fluids / gases through failed / fragmented components
- Combined shock (blast) and impact (fragment) loading of structures

Major advantage over other programs
Materials

AUTODYN can model Gases, Fluids and Solids under extreme loading conditions

Accurately predict the dynamic response of metal, composite, ceramic, glass and concrete materials

- **Elastic response**
- **Plastic flow**
- **Fracture and fragmentation**
  - Natural fragmentation model

**Detonation/deflagration**

- **High Explosives (HE)**
- **Slow burning propellants and pyrotechnics**

**Ignition and growth model**

- determine conditions under which explosives might detonate sympathetically as a consequence of impact or blast loadings.
AUTODYN® - Parallel Processing

- 3D simulations can be run in parallel
  - Cluster of PC’s running Windows
  - Linux/Unix
  - MPI or PVM

- Manual and automatic domain decomposition

- Highly scalable

- Includes Contact and Coupling (FSI)
Explicit Meshing Requirements

- Uniform element size (in finest zoned regions)
  - Smallest element size controls the time step
  - Explicit analyses compute dynamic stress waves that need to be accurately modeled as they propagate through the entire mesh

- Element size controlled by the user throughout the mesh.
  - Not automatically dependent on geometry.
    - Implicit analyses have static region of stress concentration where mesh is refined (strongly dependent on geometry).
    - In explicit analyses, the location of regions of high stress constantly change as stress waves propagate through the mesh.
    - Mesh refinement is usually used to improve efficiency.
      - Mesh transitions should be smooth for maximum accuracy.

- Hex meshing preferred.
  - More efficient.
  - Sometimes more accurate for slower transients.
The multi-solver approach allows AUTODYN to address a wide range of applications:

- Street blasts
- Blasts in buildings
- Mine blast
- Marine blast
- Portable explosive devices (IEDs)
- Vulnerability of stored munitions
- Explosive Mining
- Warhead design (Shaped Charges)
- Projectile / bullet / warhead impacts
- Aircraft impacts
- Body armor
- Drop Tests
- Crushing
- Forming
Street Blasts

- Euler Blast Solver
- Rigid structures

Oklahoma City Federal Building Bombing
Street Blasts

Street Blast in Manhattan
Blasts in Buildings

- Blast loading and building response
  - Euler-Lagrange coupling
  - Euler Blast Solver
  - Deforming structures (solids, shells, beams)
Mine Blast

Euler-Lagrange Coupling

- Lagrange solvers used for vehicle and soil
- Euler solver for the air blast

Blast & fragment loading
Euler-Lagrange Coupling

- Multi-material Euler solver used for the detonation and air blast / underwater shock
- Vessel can be modeled as a rigid body or deformable

Above water explosion

Underwater explosion

Deforming vessel
Marine Blast

LPG Tanker Explosion

ABS Consulting
Extreme Loads and Structural Risk

Passenger Ferry

CDC (Certain Dangerous Cargoes) Barge Explosion
In Kabul suicide car bomber rammed bus killing 4 and wounding 29.

Almost all injuries attributed to flying shards of glass.

To reduce the hazards of flying glass shards, the German Defense Ministry is assessing various safety concepts for bus windows using:
- Full-scale bus experiments
- AUTODYN simulations

Standard glazing

Polycarbonate Glazing
Vulnerability of Stored Munitions

Detonation of 27 tons of munitions in a masonry Explosive Storage House (ESH)

Sympathetic Detonation

Cooperative work with DPA DOSG (I Barnes, CA Hoing), presented at Debris From Explosions Technical Meeting San Antonio, USA, 27 August 2004
Bullet Penetration of Mild Steel
(338 Winchester Magnum)

a. AUTODYN Simulation

b. Shot 9 Cross-Section

Courtesy Sandia National Lab.
Missile Attacks

Bullet/Projectile Impacts – Lagrange Contact + Erosion
Aircraft Impact

Passenger Jet Impacting the World Trade Center

The Impact
Aircraft Impact

Phantom Jet Impact On Concrete

Sandia Test, 1988
The car of the CASE-2 has still enough kinetic energy to flatten the car body, although the energy is 1/4 time smaller than the CASE-1.

The underestimated strength of the floor does not affect the final results under the present numerical assumptions. The fact of item i) provides us the rational reason for the neglecting the ribs of the car body.

The material strength of the train-car floor in this case is assumed 1/10 weaker than the other cases.

i) The car of the CASE-2 has still enough kinetic energy to flatten the car body, although the energy is 1/4 time smaller than the CASE-1.

ii) The underestimated strength of the floor does not affect the final results under the present numerical assumptions. The fact of item i) provides us the rational reason for the neglecting the ribs of the car body.

The material strength of the train-car floor in this case is assumed 1/10 weaker than the other cases.

Train crash on JR-West Fukuchiyama Line (Japan 2005)
Train Crash

Train crash on JR-West Fukuchiyama Line

Top Impact

Side Impact

Courtesy of CTC, Tokyo, Japan
Body Armor

Bullet Impact on Kevlar Helmet

Light gas-gun

Helmet

KEVLAR® Helmet

Touch Probe

Courtesy Tham Ching Yang, IHPC, Singapore
Body Armor

Bullet Impact on Kevlar Helmet

Predicted damage

Damage observed

Courtesy Tham Ching Yang, IHPC, Singapore
Crushing

Crush Tests
Drop Test

Drop Test of Printed Circuit Board (PCB)
Drop Test

Drop Tests on Reinforced Concrete
Drop Test

Vacuum cleaner canister drop

Images courtesy of Electrolux
Drop Test

Pencil drop test

Courtesy of Lamy GmbH, Heidelberg
Drop test simulation of a laptop

- **Drop height**: 2 feet (impact velocity = 3.5 m/s)
- **Parts**: are initially bonded (breakable) together
Drop Test

Mechanical failure 1: separation of battery cover
Drop Test

Mechanical failure 2: separation of the hinge
Drop Test

Drop Test of Bottle Containing Air and Fluid

- **Must solve in AUTODYN in Workbench 12.1**
- **Can be solved in Explicit Dynamics in 13.0**
Sporting Goods

Baseball Bat
Sporting Goods

Golf Club

golf_sand_ng_ero
Cycle 0
Time 0.000E+000 ms
Units mm, mg, ms
Explicit Dynamics Licenses
- ANSYS Explicit STR

ANSYS Explicit STR is an entry level license allowing the use of Explicit Dynamics for STRuctural applications

Integrated in ANSYS Workbench using common (mechanical) GUI providing ease-of-use and productivity, through 2 analysis systems

- Explicit Dynamics system (Lagrange only)
- Explicit Dynamics (LS-DYNA Export) system

Does not include use of Eulerian fluid capabilities in Explicit Dynamics.
Explicit Dynamics Licenses
- ANSYS AUTODYN

Provides access to all AUTODYN and Explicit Dynamics capabilities

Currently provided through 2 Workbench systems

- Explicit Dynamics analysis system
- AUTODYN component system

Finite Element (FE), Finite Volume (Euler), Meshfree (SPH) solvers and coupling

Wide ranging applications covering all those for Explicit STR license, plus

- Special impact problems such as Hypervelocity Impact (HVI)
- Explosions, blast and blast-structure interaction (FSI)
AUTODYN and Workbench
AUTODYN and Workbench

Explosive Detonated under a Humvee

- 30mm thick plate
- 100mm thick plate

Front View

Bottom view

Interior View
AUTODYN and Workbench

Explosive Detonated under a Humvee

30mm plate

100mm plate
AUTODYN and Workbench

Detonation of a Truck Bomb
A Success Story In Homeland Security
QUESTIONS ?