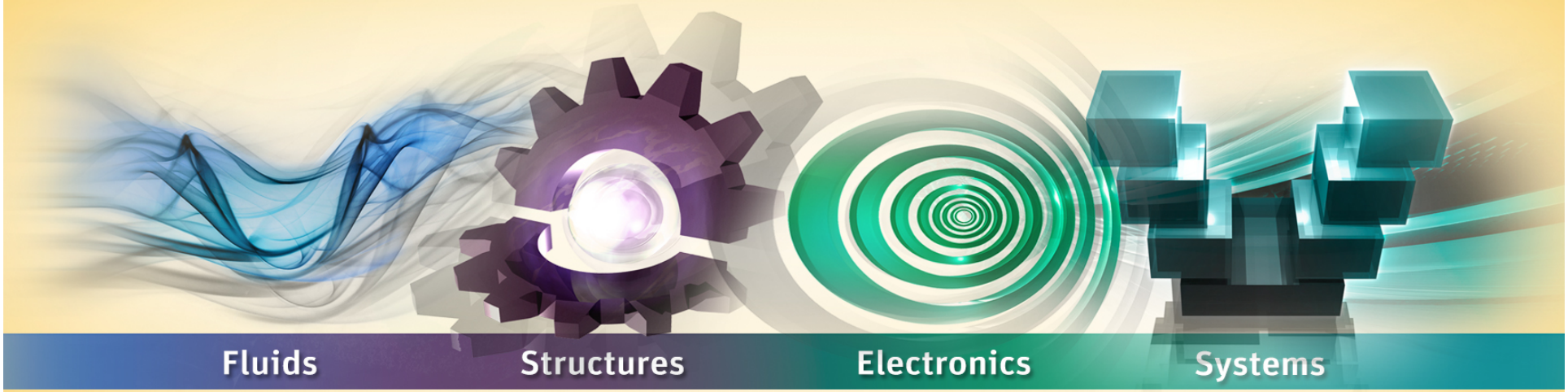
ANSYS

Realize Your Product Promise®

Critical trade-offs when using Explicit Dynamics



Bence I. Gerber
bence.gerber@ansys.com
510 549-5348

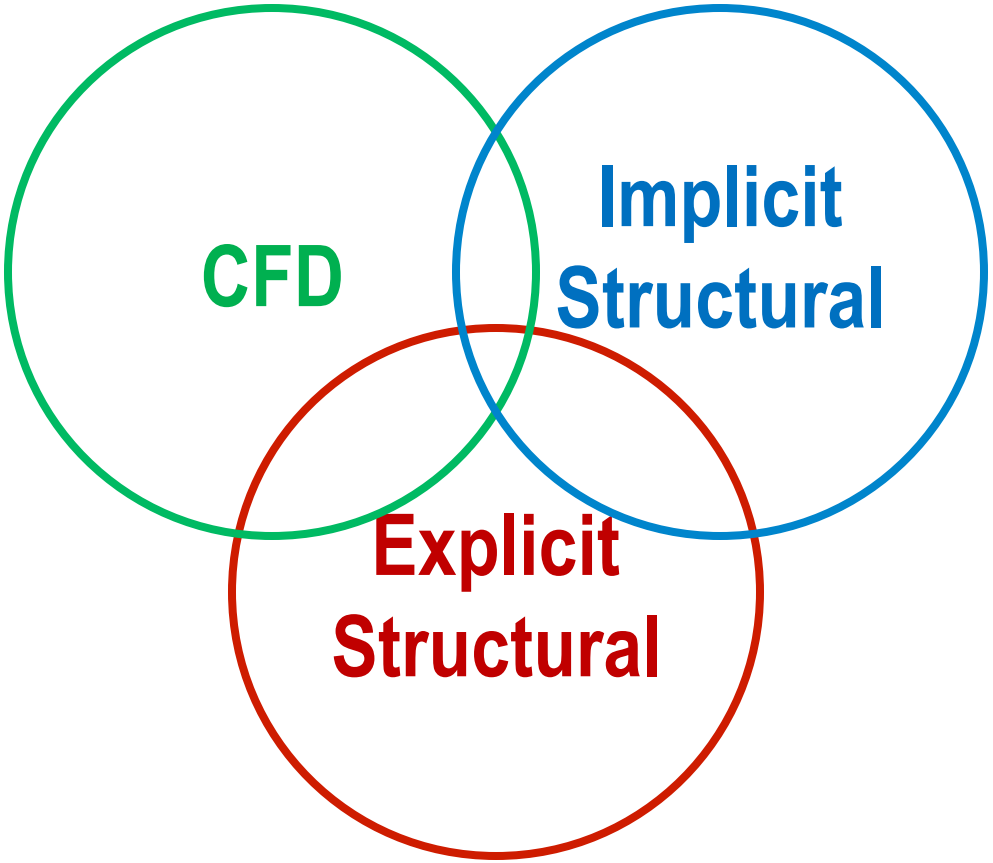
AMS Seminar Series, NASA Ames Research Center, December 9, 2014,

Outline

- Introduction to Explicit Dynamics
- Space Related Simulation Examples
- The Best Approach to Explicit Dynamics
- Looking Into the Future

 © 2014 ANSYS, Inc.

Main Engineering Simulation Tools



 © 2014 ANSYS, Inc.

Problems Well Suited for Explicit Solutions

Short duration localized phenomena

Transient dynamic wave propagation

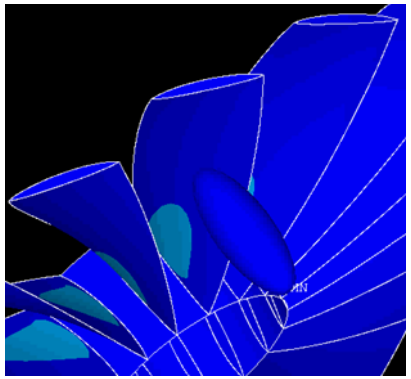
- **Gases, Liquids, Solids and their Interaction (FSI)**

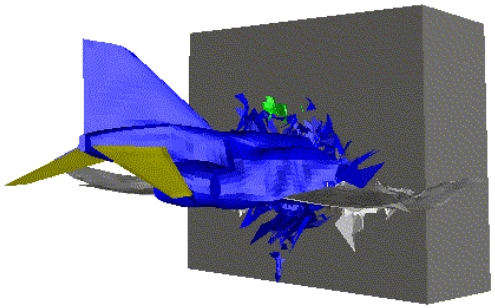
Nonlinear

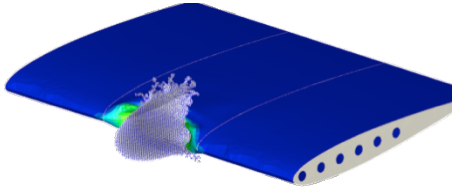
- **Material behavior**
- **Structural behavior**
- **Contact/Interaction**

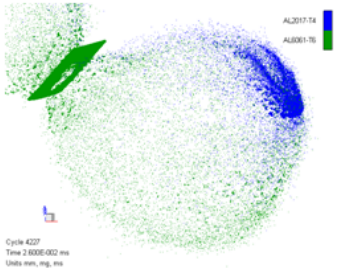
Extreme loadings

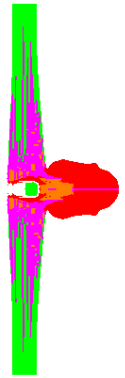
- **Extreme deformations**
  - **Large strains & strain rates**
- **Material failure**
- **Fragmentation**

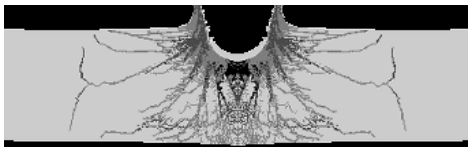












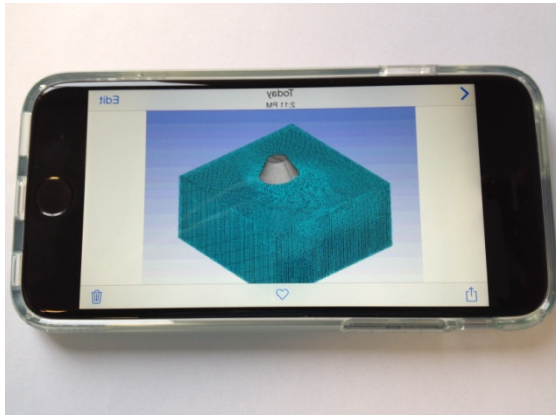
 © 2014 ANSYS, Inc.

History of Explicit Dynamics

- Initial development of Explicit Solutions
  - At US National Laboratories 1960 - 1980
  - Extensive investment by US Government
  - Solutions 1D & 2D, simple models, crude meshing
  - Supercomputers used
  - Time consuming, labor intensive problem setup
- Today's state of Explicit Solutions
  - Fully integrated CAD to solution
  - Automatic meshing, material libraries
  - Easy to use GUI
  - HPC solution removes problem size limitations
- Future:
  - Simulation that speaks an engineers language
  - Modern user environment via cloud

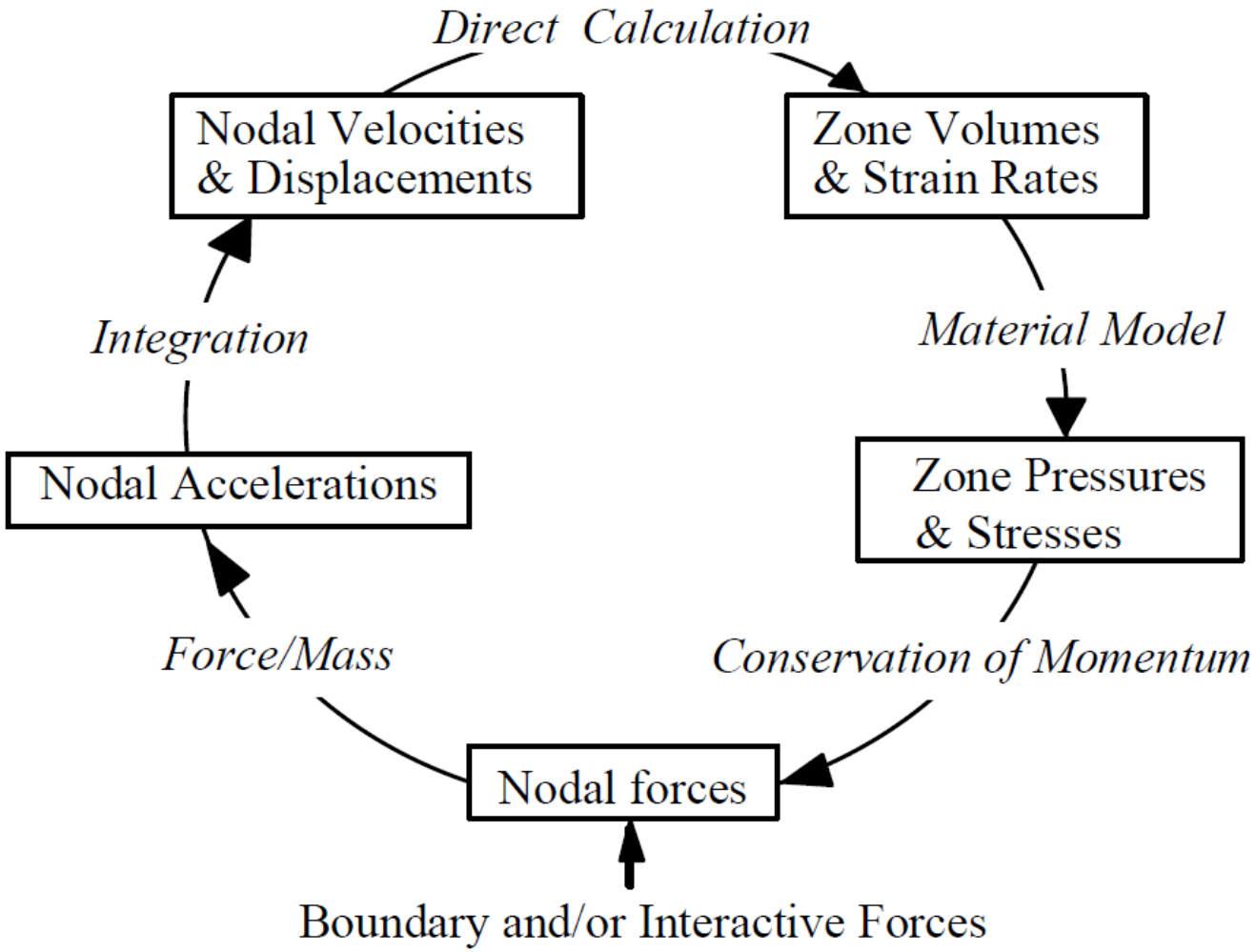






 © 2014 ANSYS, Inc.

Outline of calculations in one time step

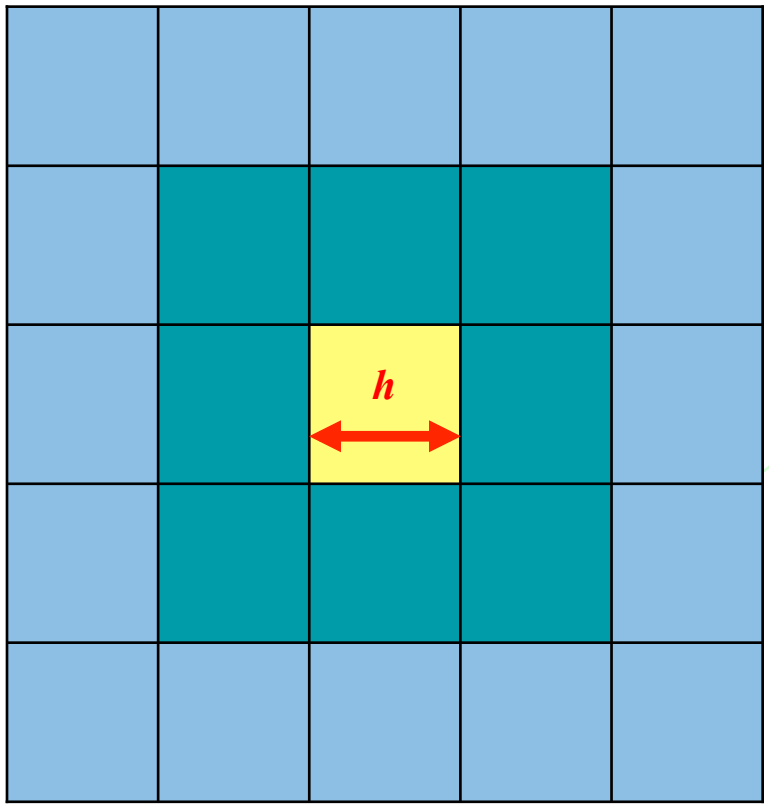


 © 2014 ANSYS, Inc.

Time Step – the heartbeat of explicit

- Time step used in Explicit time integration is limited by the CFL (Courant-Friedrichs-Levy) condition.
- Stress waves must not cannot travel further than the smallest 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
- Example:
  - characteristic dimension of 1 mm
  - sound speed of 5000 m/s (like iron)
  - stability time step 0.18 µ-seconds
  - problem time of 0.1 seconds
  - will require 555,556 time steps

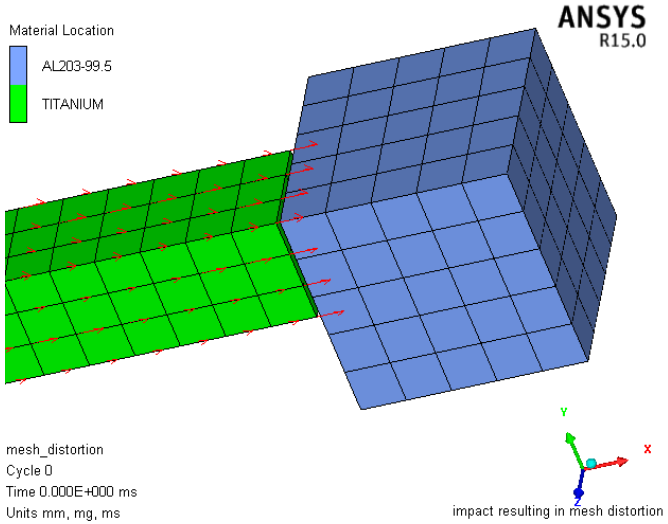
$$\Delta t \leq f * \left[\frac{h}{c}\right]_{\min}$$

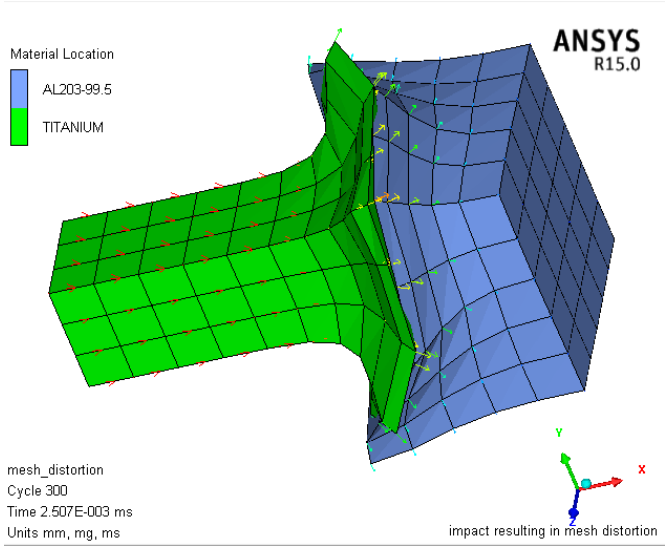


 © 2014 ANSYS, Inc.

Mesh Distortion and erosion

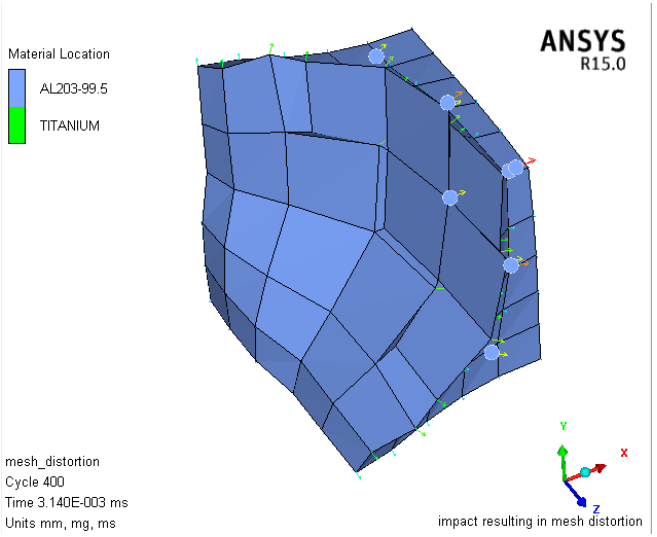
Simple impact





Distorted elements





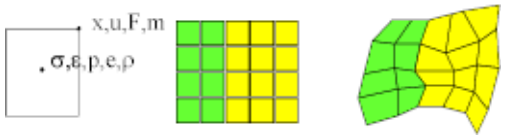
Eroded elements

Internal energy lost inertia retained

 © 2014 ANSYS, Inc.

Explicit Solution Methods

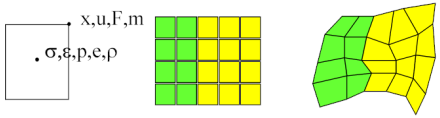
Lagrange (structures)



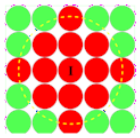
Euler (fluids)



ALE (auto remesh)

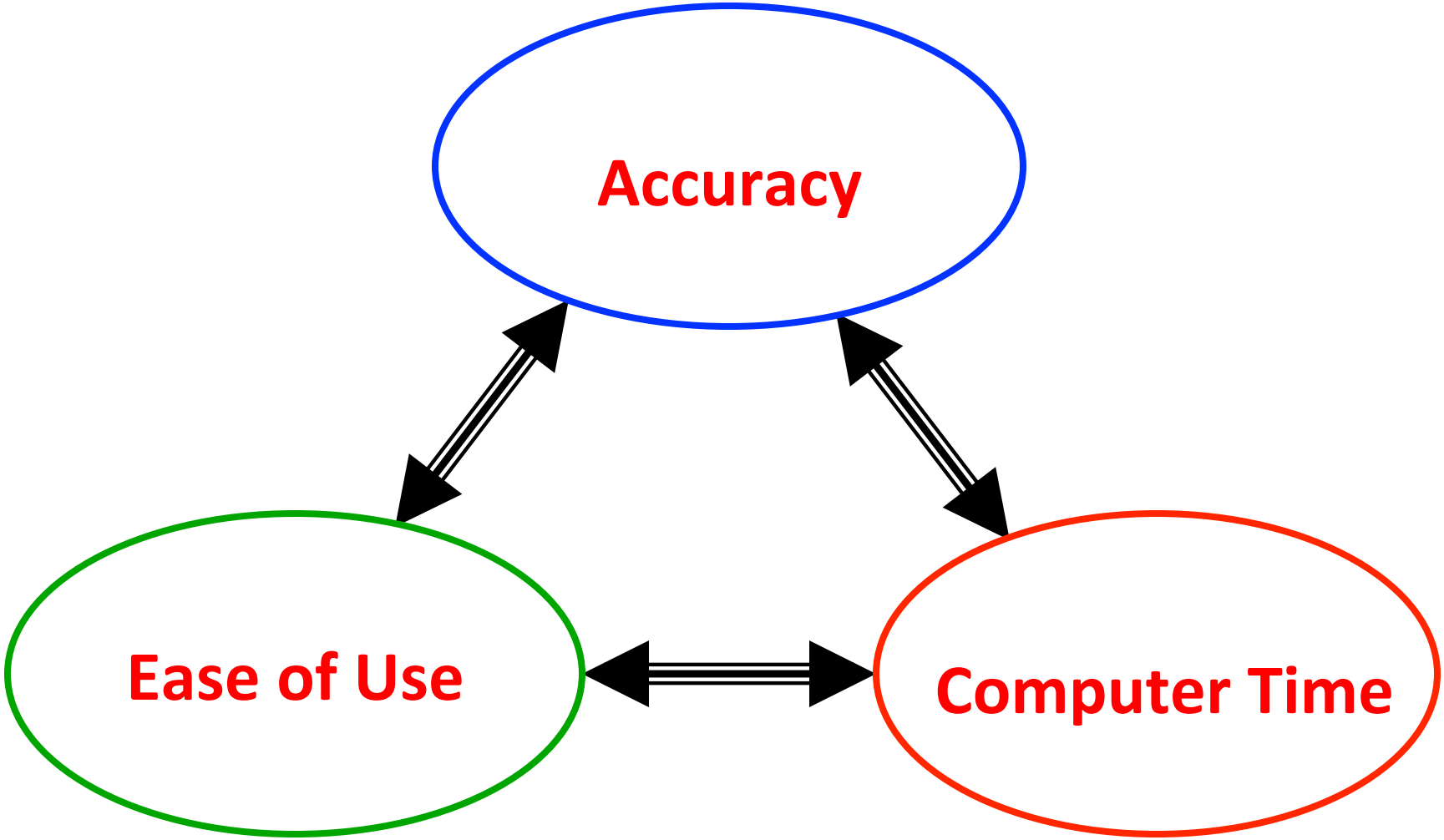


SPH (hypervelocity & brittle)



 © 2014 ANSYS, Inc.

Explicit Model Set-Up Trade-Offs



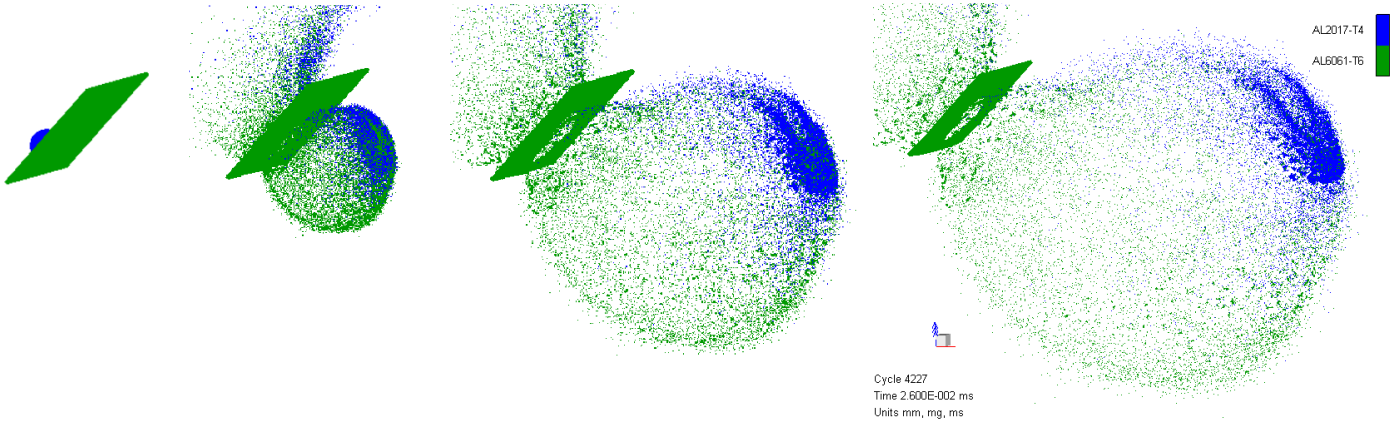
 © 2014 ANSYS, Inc.

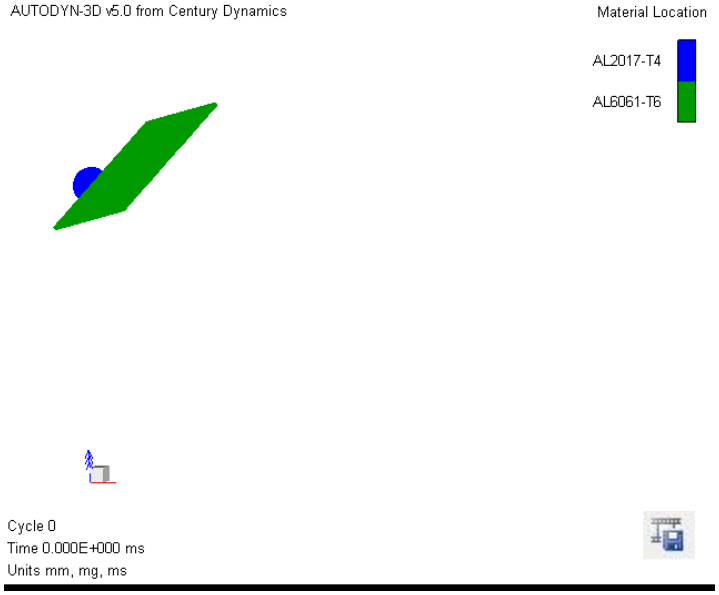
Space related simulation examples

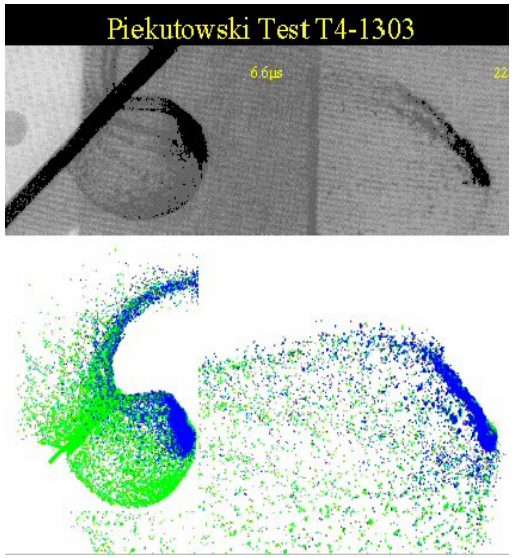
1. Hypervelocity impact
2. Planetary impact
3. Aircraft impact
4. Bird strike
5. Blade-out
6. Fragment and blast loading
7. HYDRAM
8. Splashdown

 © 2014 ANSYS, Inc.

Space Debris Impact (Hypervelocity)

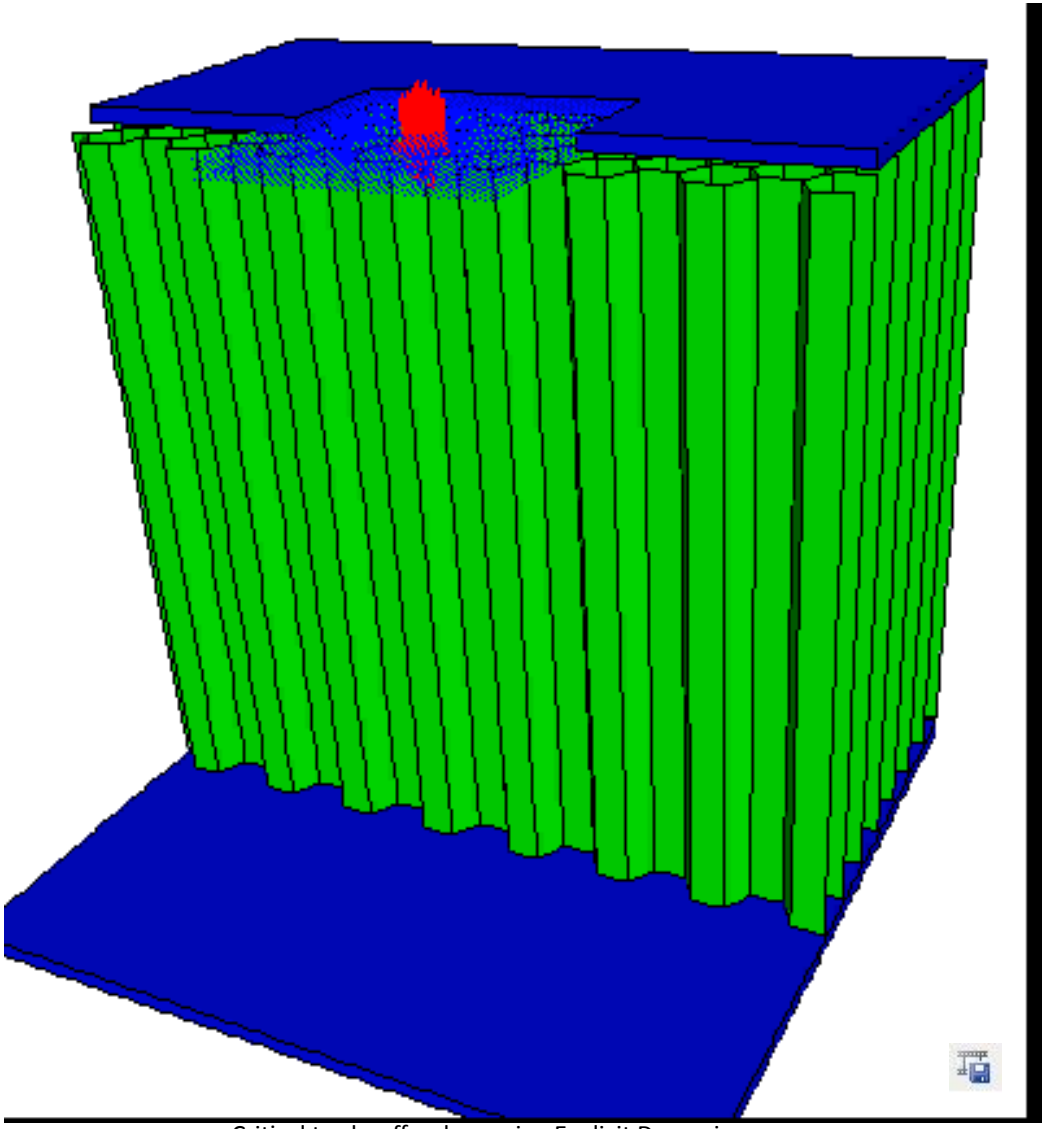






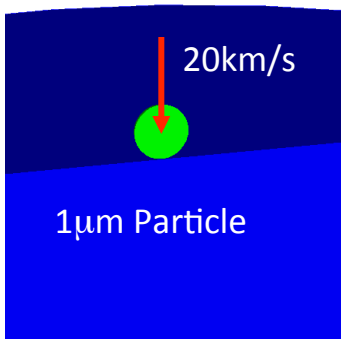
 © 2014 ANSYS, Inc.

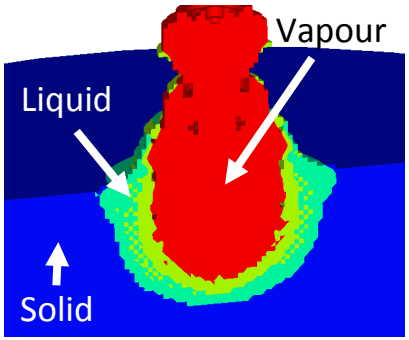
Hypervelocity Impact on Honeycomb



Planetary Impact

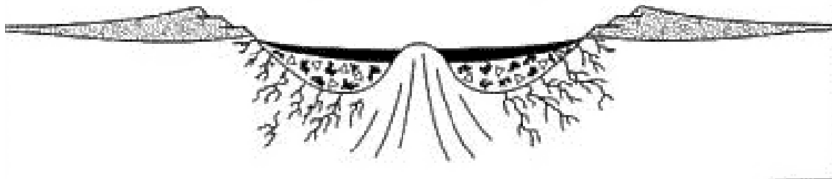
Micro Meteoroid Impacts



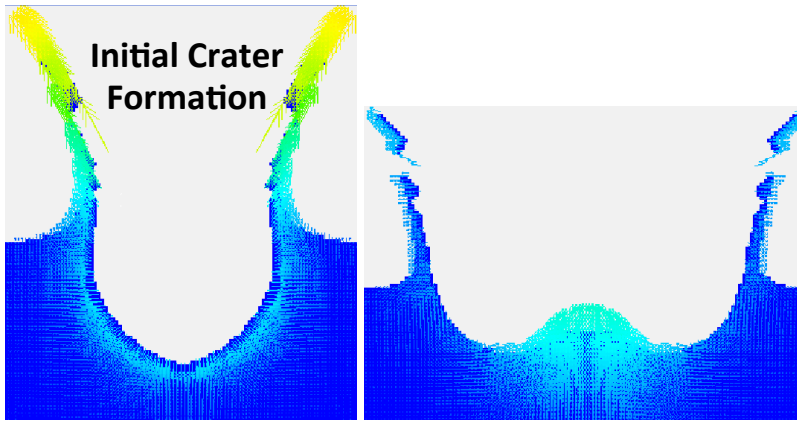


Planetary Impacts

Understanding the evolution of planetary geology



20km Projectile



Courtesy, Emily Baldwin, University College London

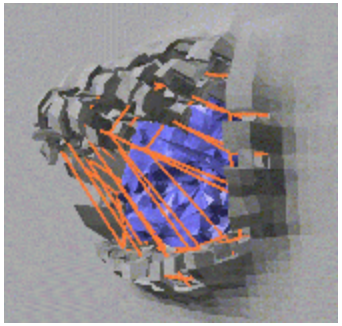
20km/s Impact on Geological Material

 © 2014 ANSYS, Inc.

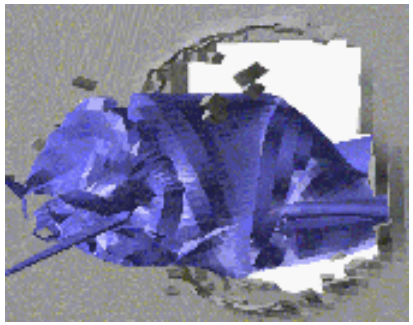
Airplane Impact on Reinforced Concrete



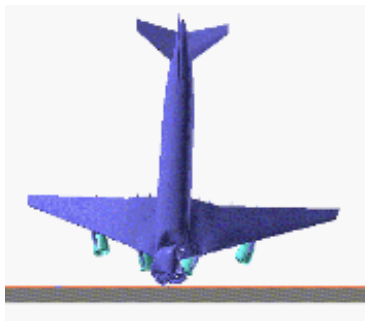
1m RC



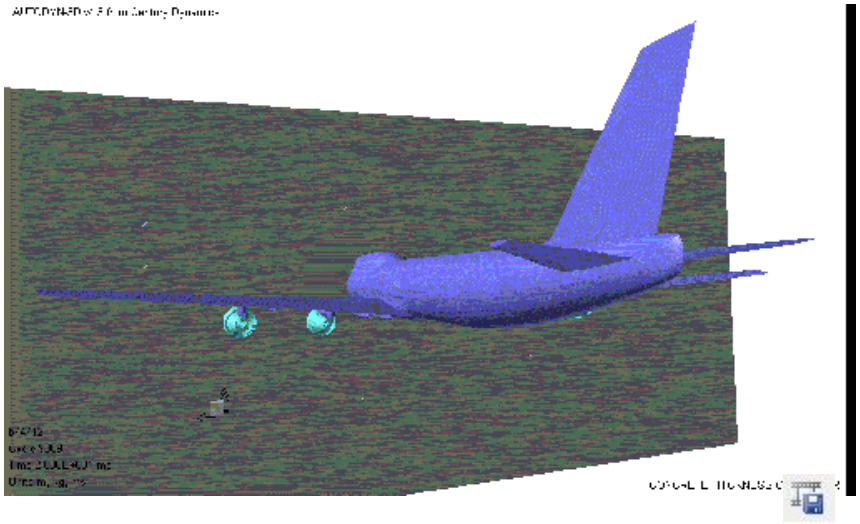
2m RC



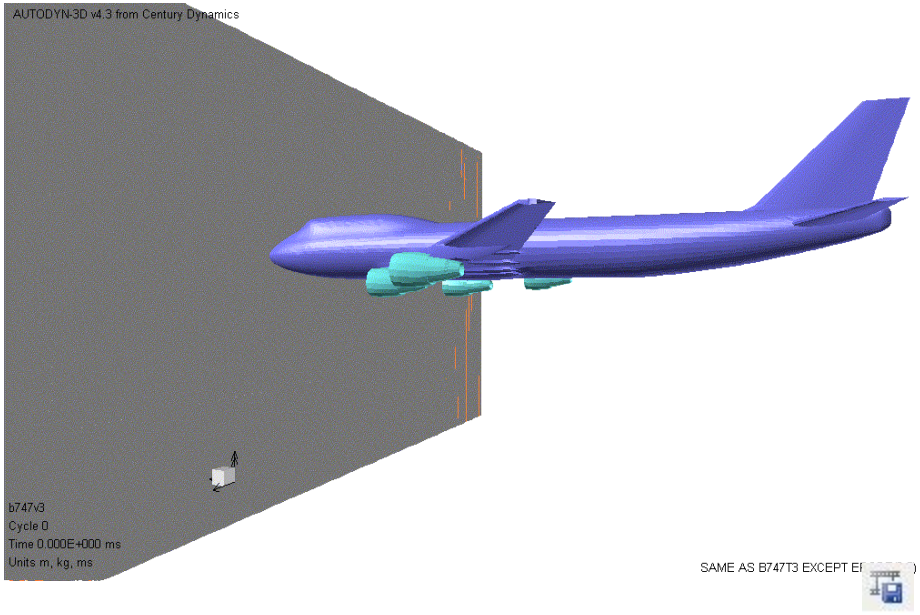
2m No rebar



3m RC



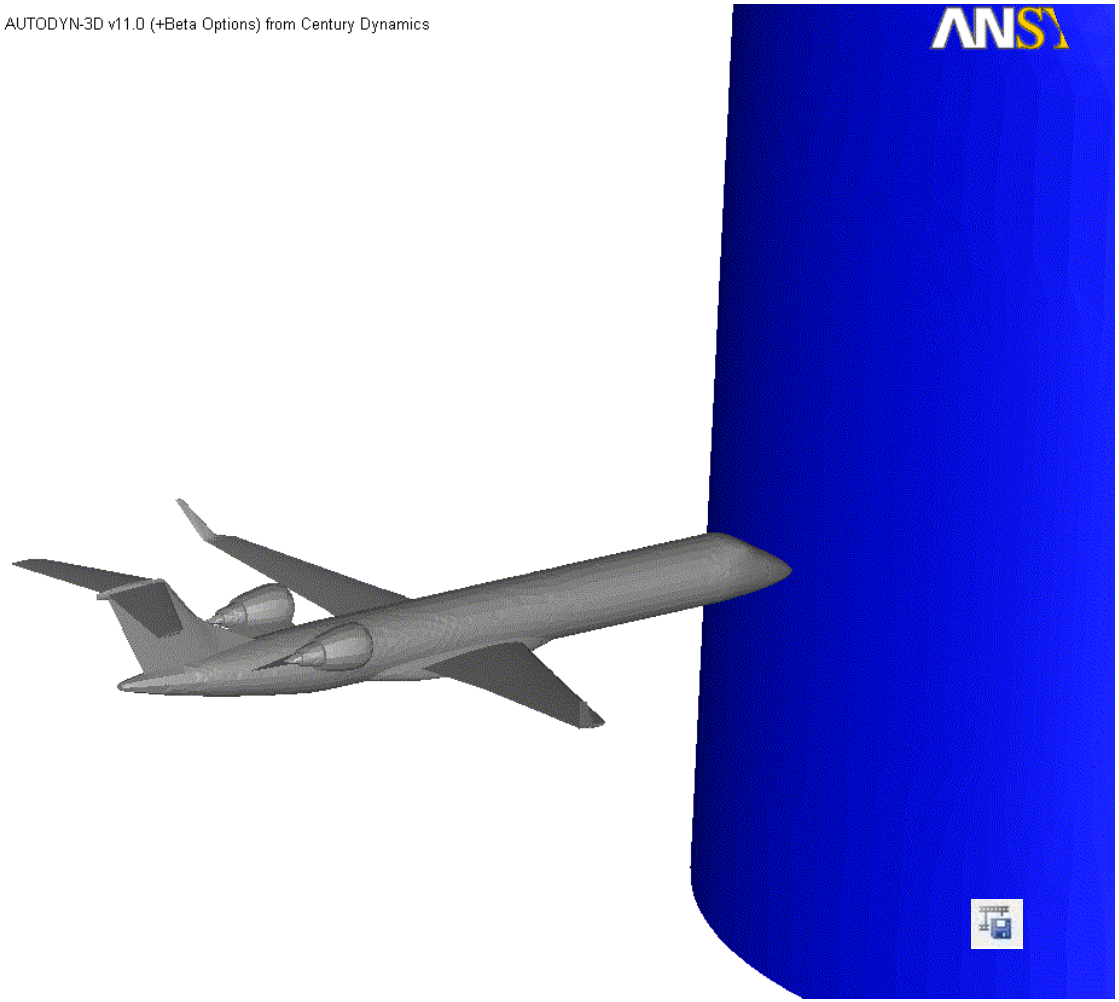
1m RC



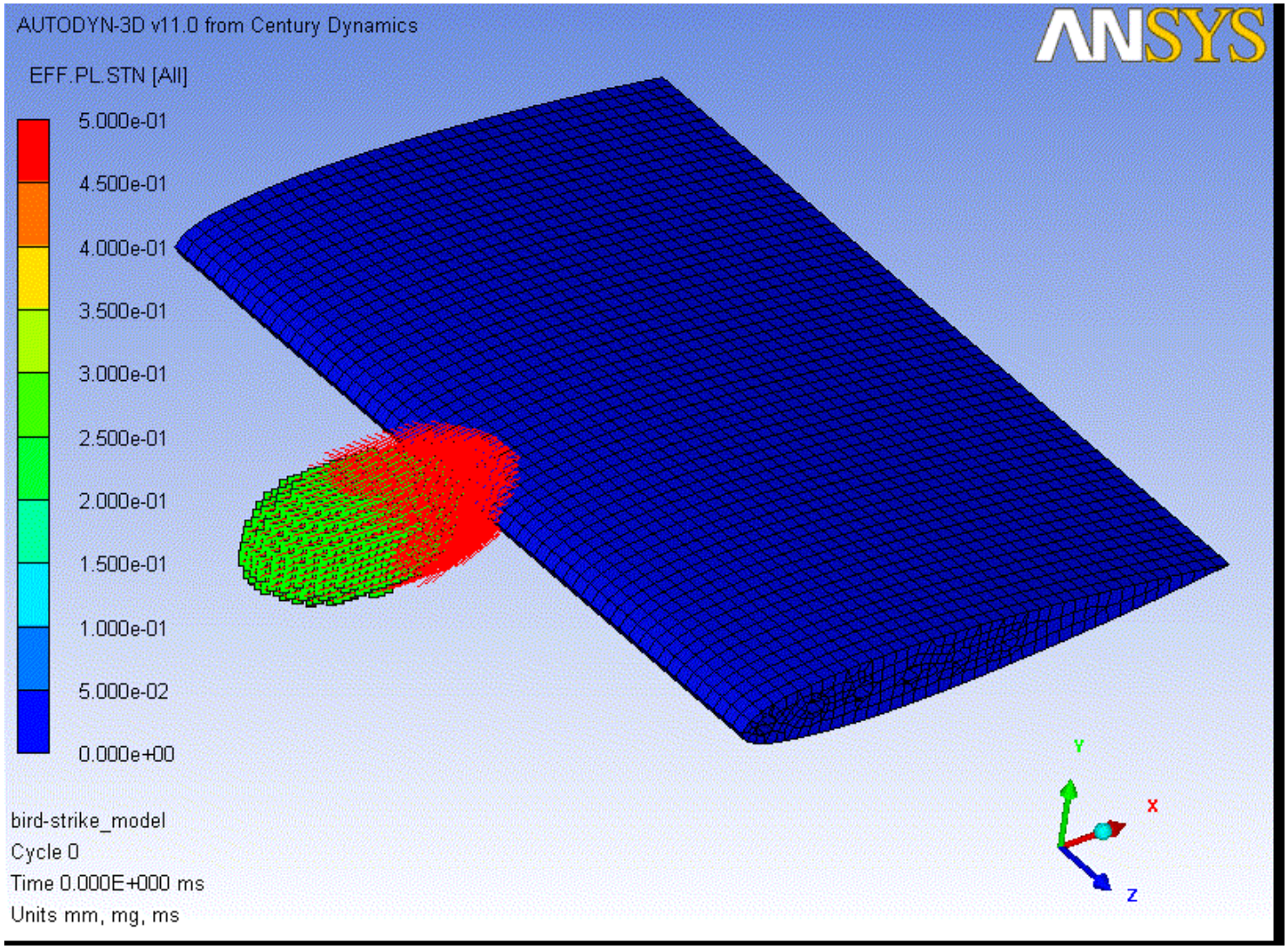
3m RC

 © 2014 ANSYS, Inc.

Airplane Impact on Structure

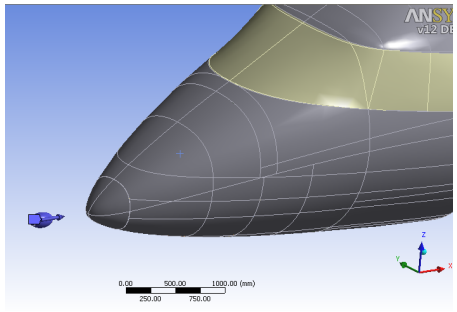


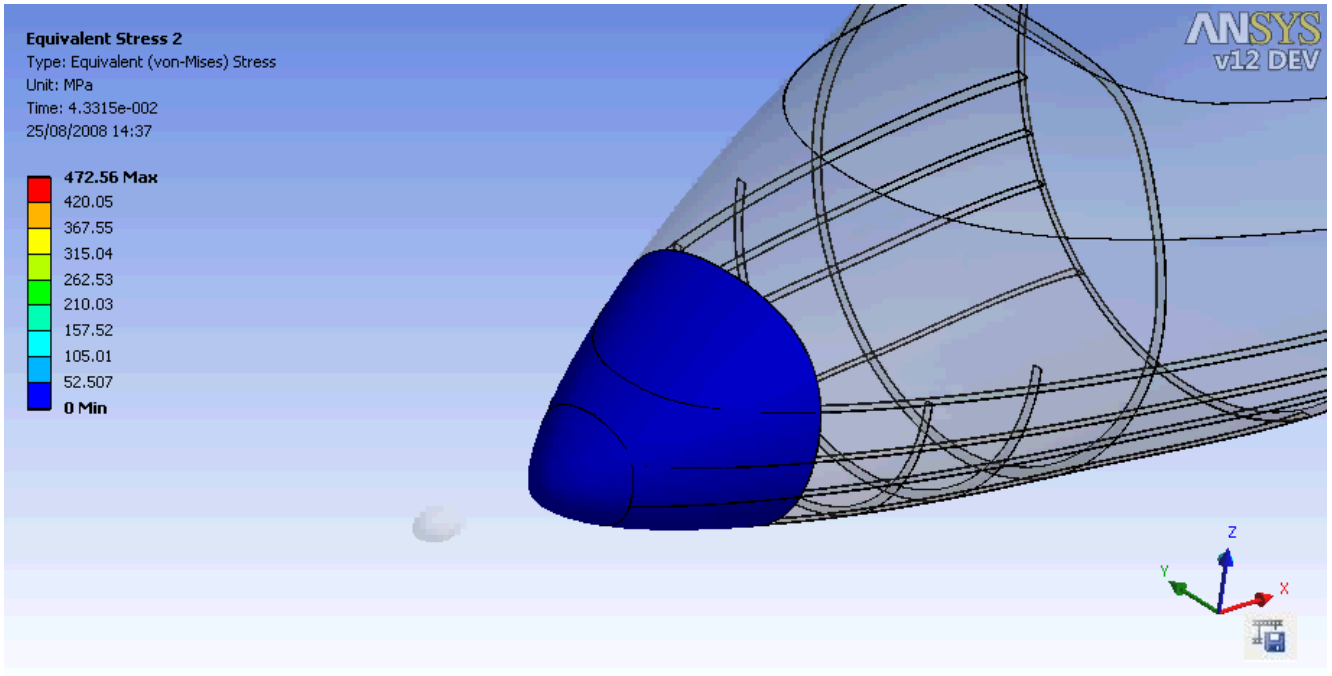
Bird Strike on a Wing



 © 2014 ANSYS, Inc.

Bird Strike on Nose of an Airplane

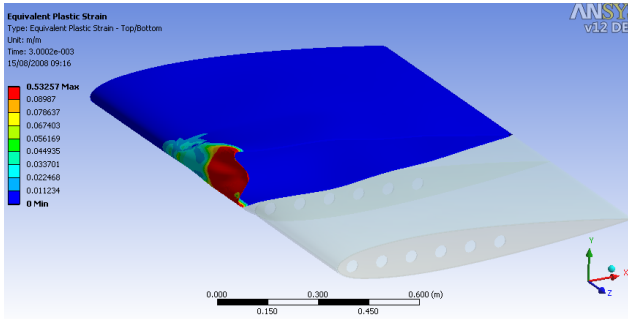


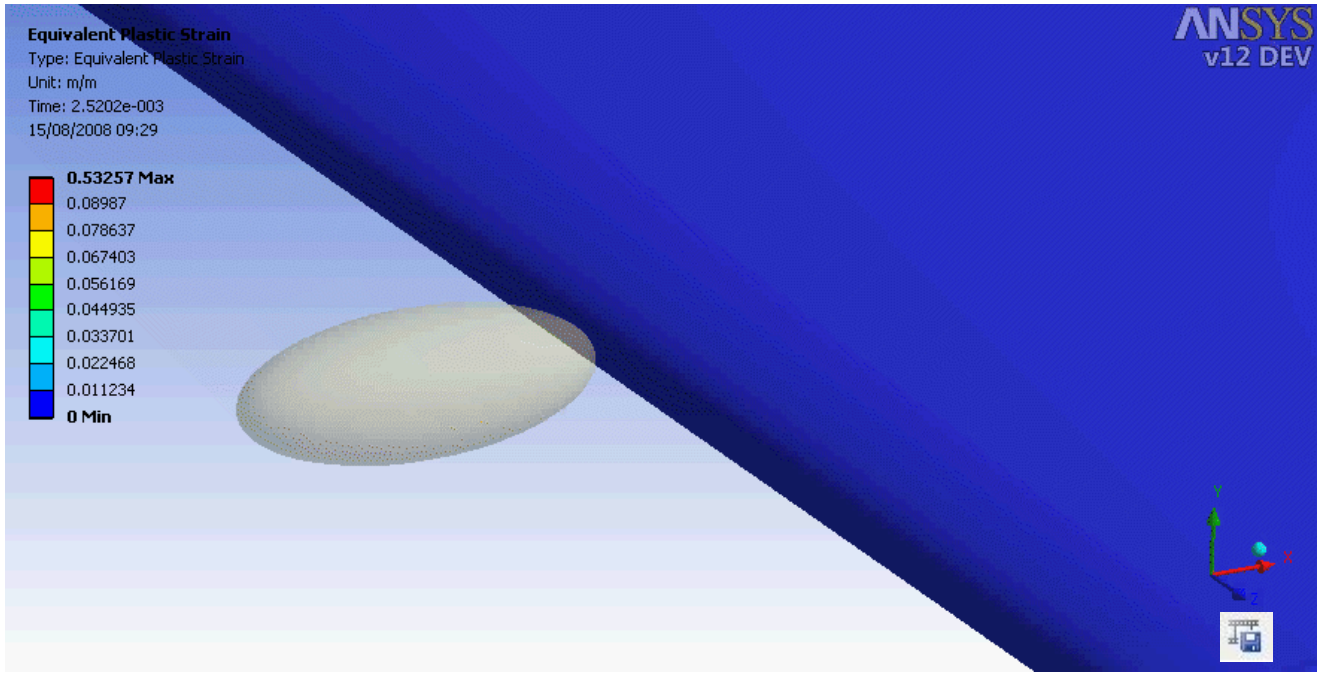


Animation of impact on nose

 © 2014 ANSYS, Inc.

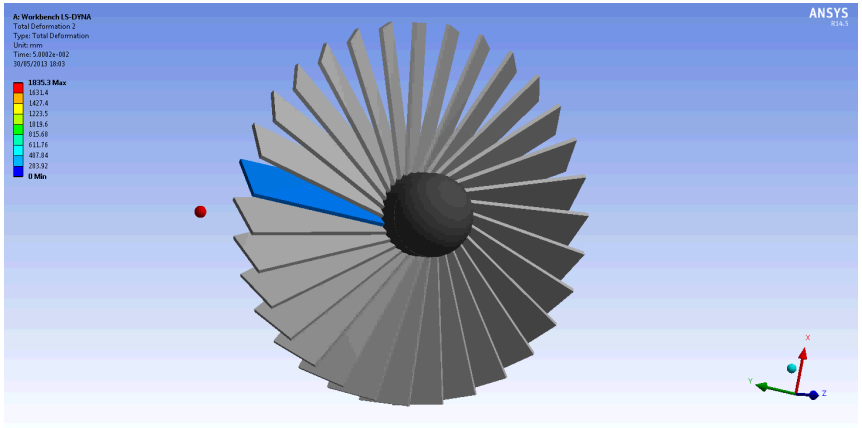
Bird Strike on the Wing of an Airplane

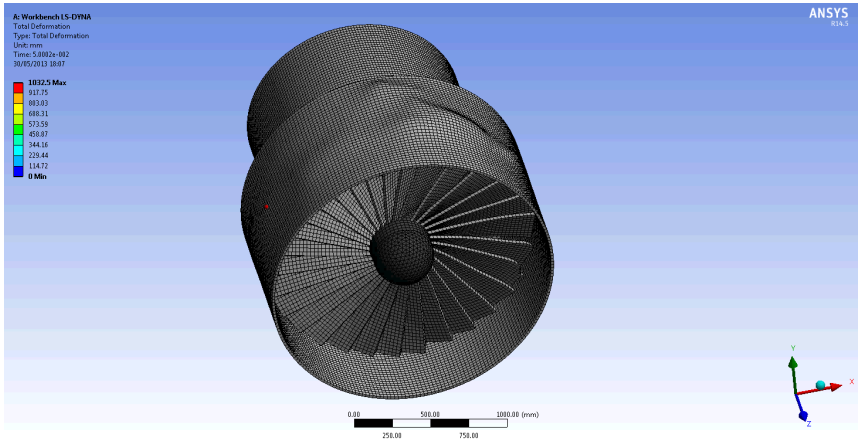




 © 2014 ANSYS, Inc.

Turbine Fan Blade-out

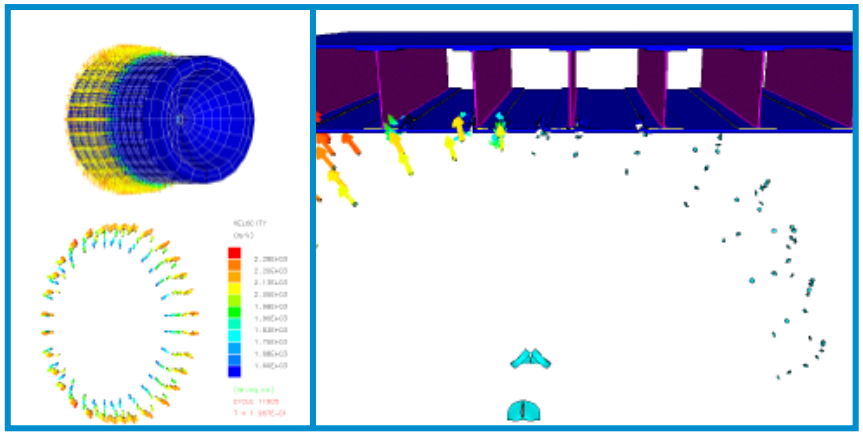




 © 2014 ANSYS, Inc.

Blast and Fragment Loading

Carbon Fiber Reinforced (CFRP) wing
Rocket Propelled Grenade (RPG) weapon
Air Blast modeled using the Euler Blast solver
RPG casing (fragments) and wing box components modeled using Lagrange solvers
Euler-Lagrange coupling used for the blast loading
Lagrange contact and erosion used for the fragment loading



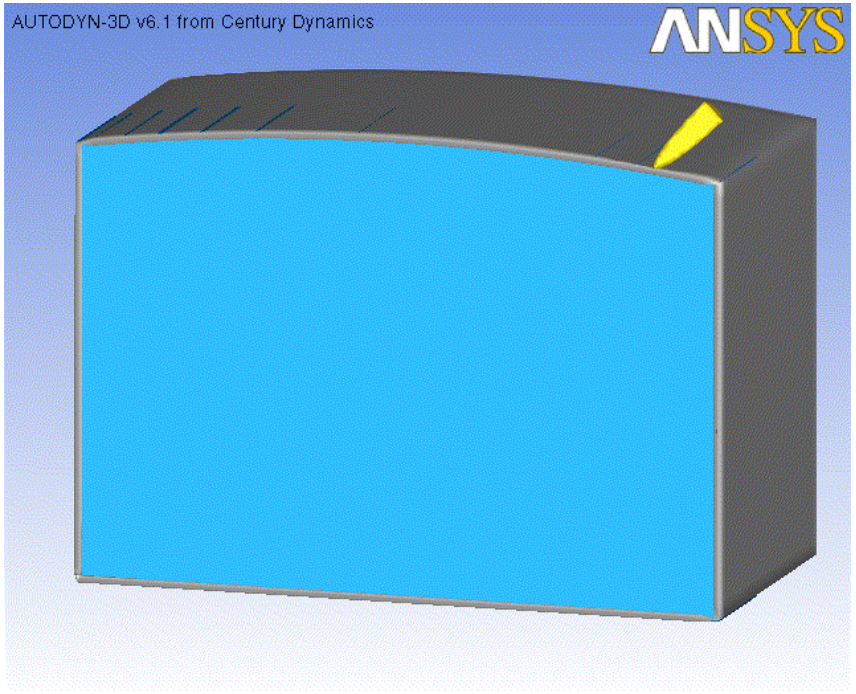




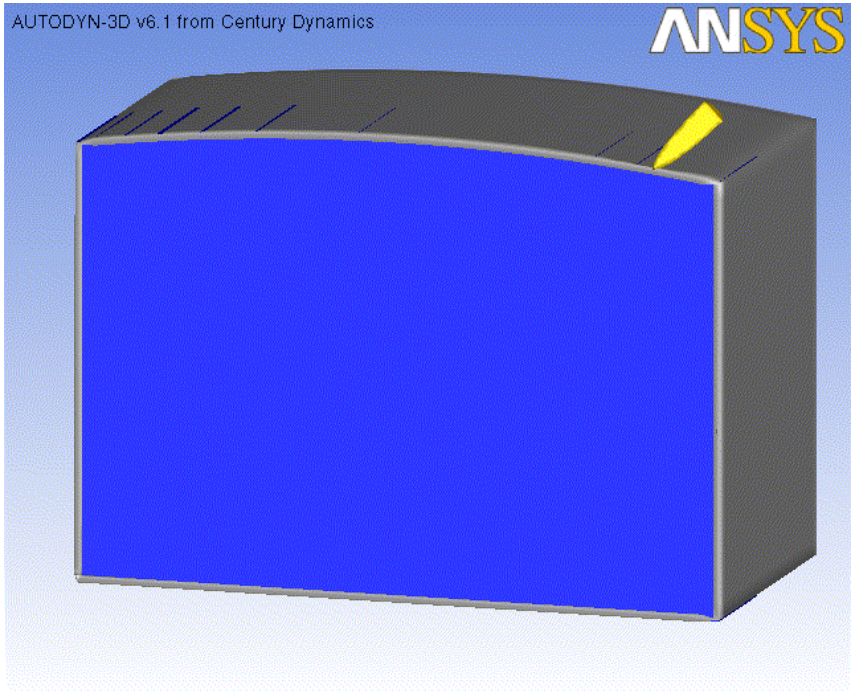
Bullet Impact Into Fuel Tank (HYDRAM)

Impact of a 12.7 mm round at 1044 m/s on an aluminum fuel tank

Material Location

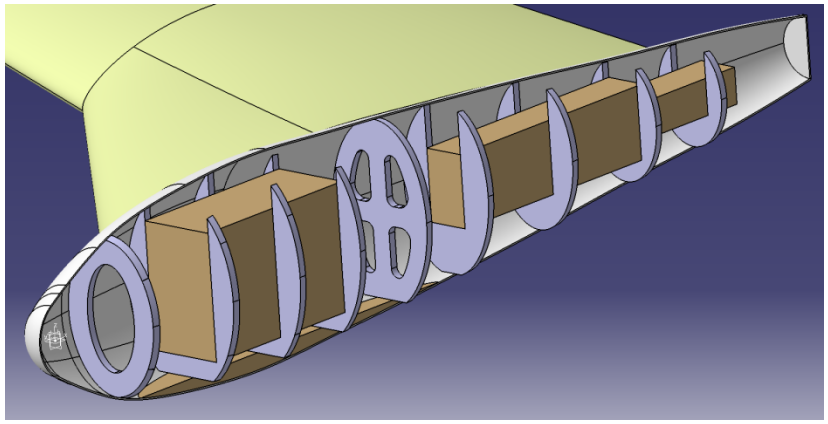


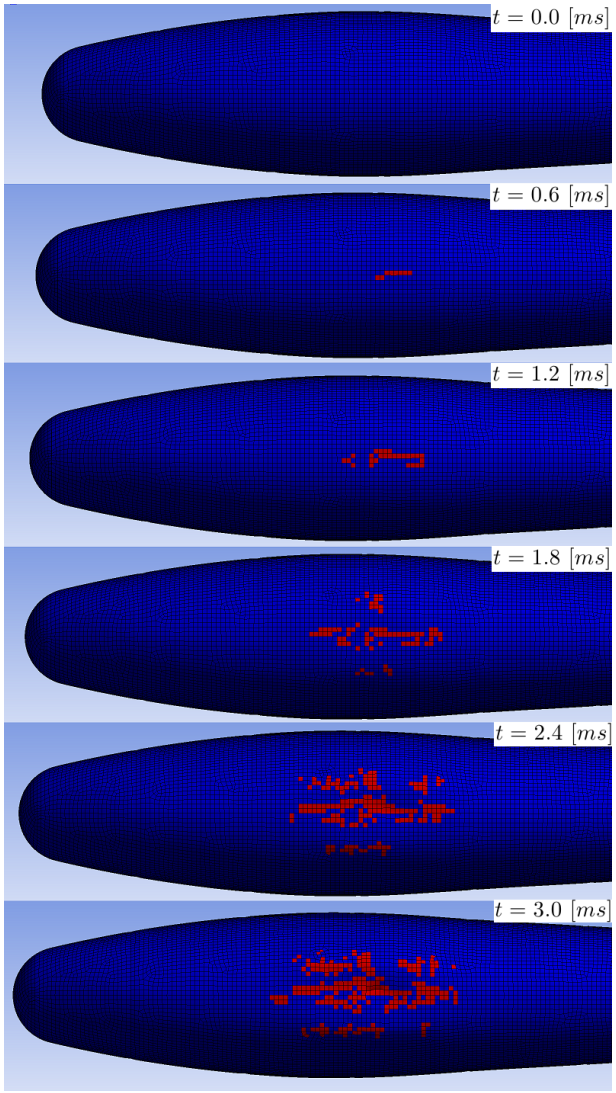
Pressure Contour



 © 2014 ANSYS, Inc.

Impact of a Composite Covered UAV





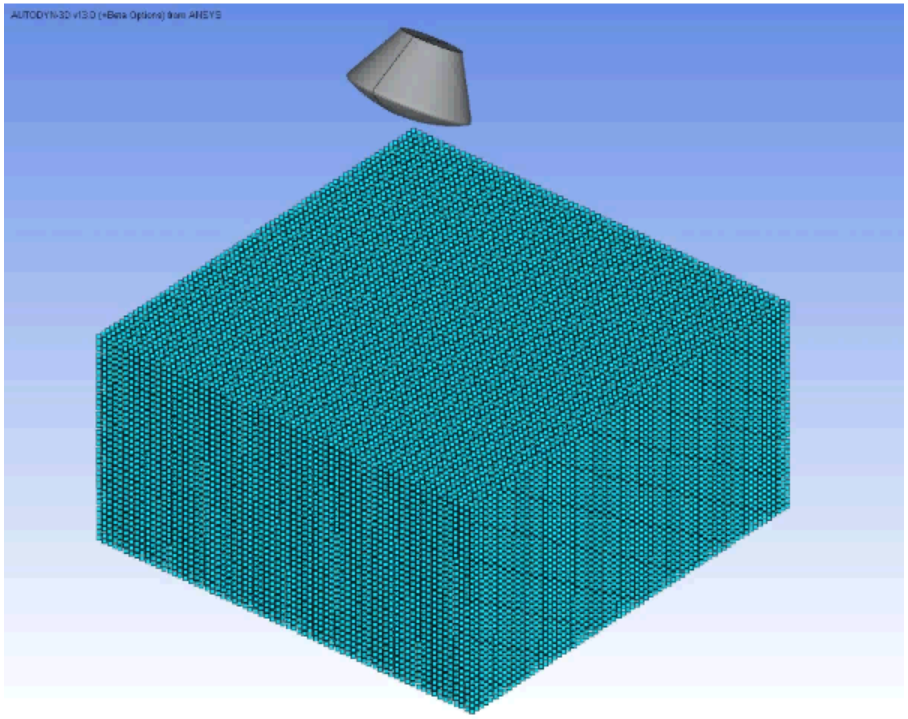
Belly Landing of the LocalHawk UAV

Failure of composite skin from landing

Master's thesis by **Hans Magnus Thorsen**

Chalmers University Of Technology Sweden

Simulation of Capsule Splashdown





http://youtu.be/GM7bIYHIMtY

 © 2014 ANSYS, Inc.

The Best Approach to Explicit Dynamics

- Use simple material models
- Start with a simple problem (Use 2D if possible)
- Simplify geometry
- Create uniform hex mesh if possible
- Select appropriate solution methods (Material response based)
- Cheat if necessary (Erosion and mass scaling)
- Look at results after a few hundred cycles
- Correlate with experiment or publication
- Use HPC (parallel processing) to reduce run times
- Add complexity one step at a time
- Seek insight not numbers

 © 2014 ANSYS, Inc.

Material Modeling

Materials have a complex response to dynamic loading

The following phenomena may need to be modelled

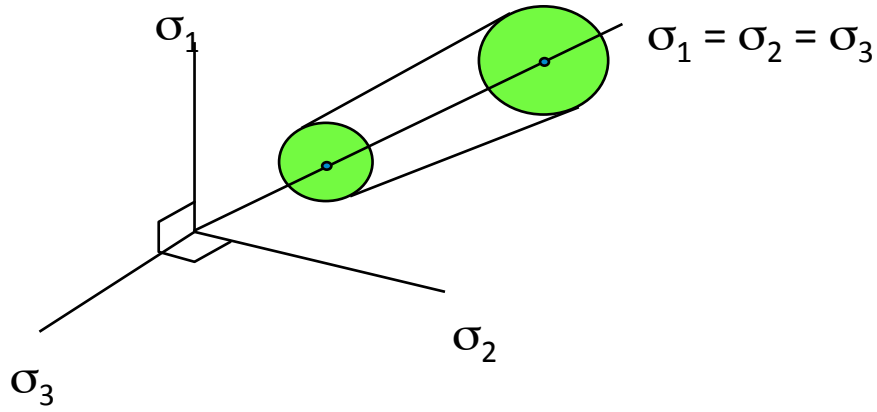
- **Non-linear pressure response**
- **Strain and strain rate hardening**
- **Thermal softening**
- **Directional material properties (composites etc.)**
- **Damage due to crushing (ceramics, glasses etc.)**
- **Tensile failure**

No single material model can incorporate all of these effects

Use different models, based on the problem model

 © 2014 ANSYS, Inc.

Material Modeling Implementation



Material modeling method

EOS:

1) **Calculate Pressure**

Strength:

2) **Calculate Trial Elastic Deviatoric Stresses**

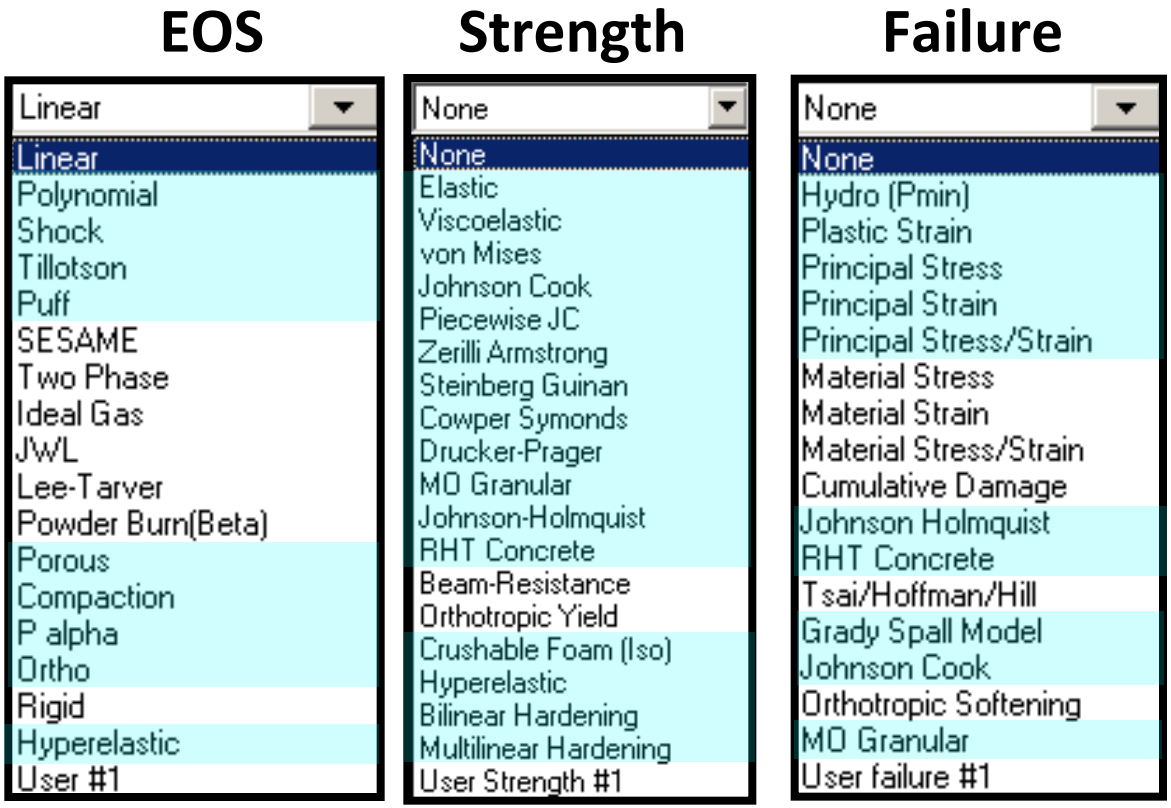
3) **Compare to Yield Surface**
   - **Scale back to yield surface if exceeded**
   - **Update Effective plastic strain**

Failure:

4. **Evaluate Failure Model**

 © 2014 ANSYS, Inc.

Material Models



EOS, Strength and Failure models can be independent

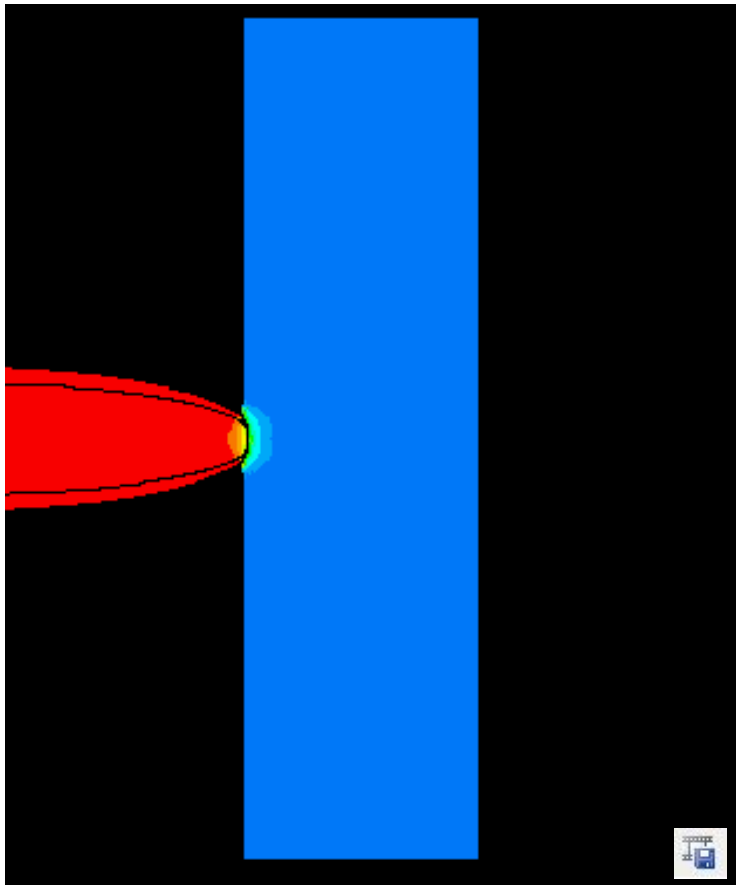
 © 2014 ANSYS, Inc.

How to choose material models

- It is relatively easy to identify the basic category that a material lies in
  - Liquid or Solid?
  - Isotropic or Anisotropic/Orthotropic ?
  - Inert or Reactive?
  - Porous or Not ?
  - Ductile or Brittle ?
  - Pressure Dependant Strength (cohesive) or not ?
- The actual set of models used however are highly dependant on the application and the available material data
- Start with simple models and progress, as required, to more complex models
  - Lets you understand how parameters influence response and which parameters are critical for good results

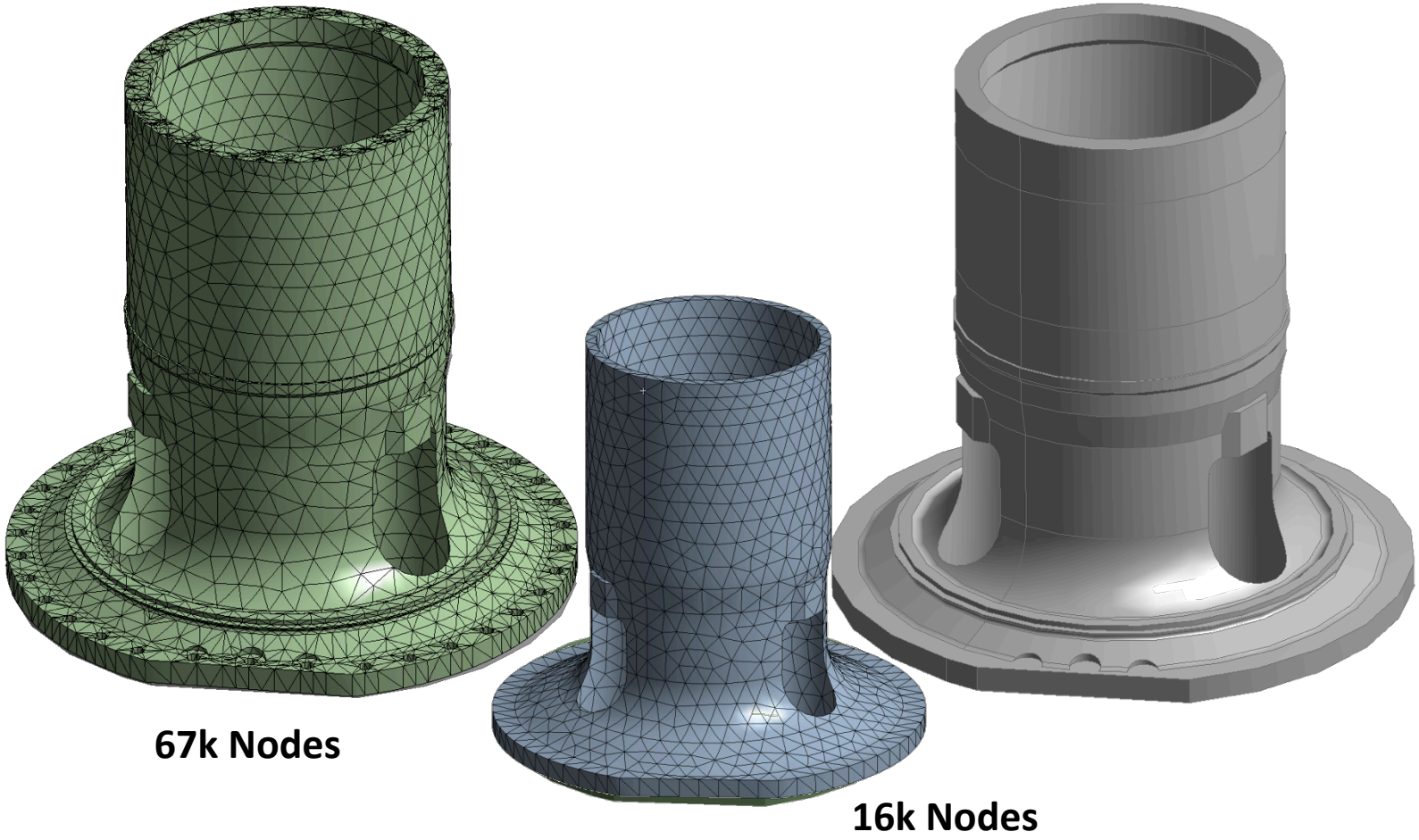
Start with a simple model (2D if possible)

Copper jacket bullet penetration into mild steel at 842 m/s



Courtesy Sandia National Laboratory

Simplify Geometry



67k Nodes

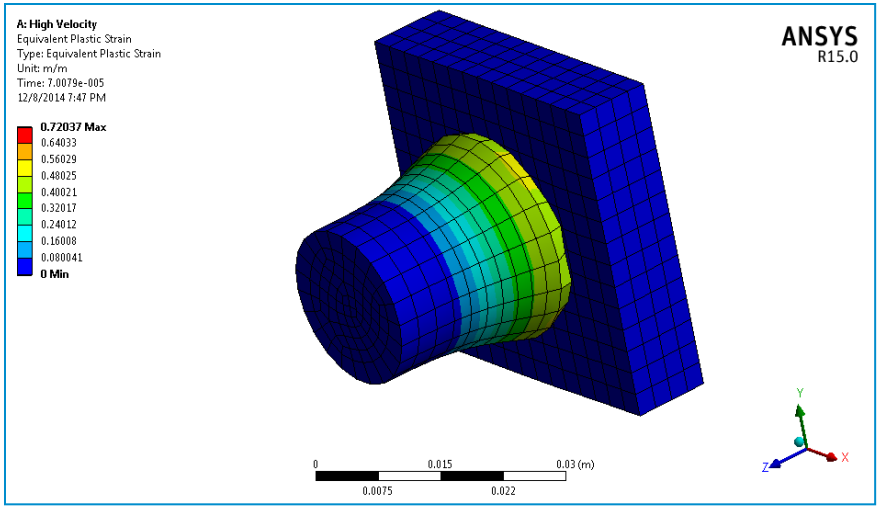
16k Nodes

Defeaturing removes small, unimportant features and reduces element count

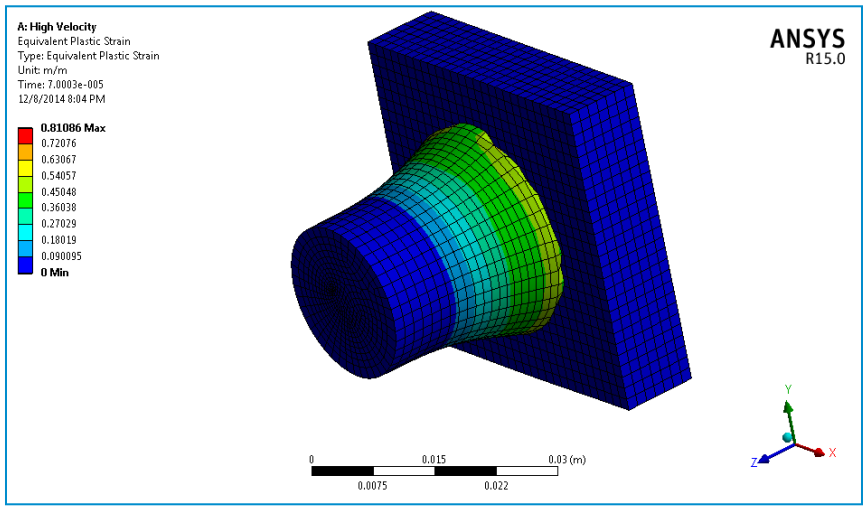
 © 2014 ANSYS, Inc.

Meshing: Size Matters a Lot

- **To resolve peak pressures accurately, the element size must be small relative to the wave frequency**
- **Impulses are often computed accurately, even if peak pressures are low**
- **Practical limits on the total number of elements often determines the element size**



Element size = 0.003
Number of elements = 1,730
ELAPSED RUN TIME = 0.111 min
Time step = 1.247E-07s

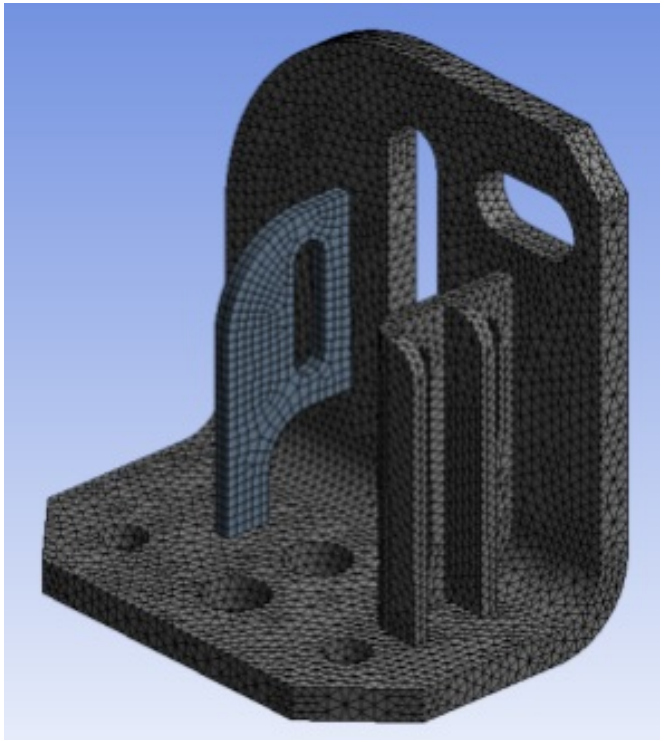


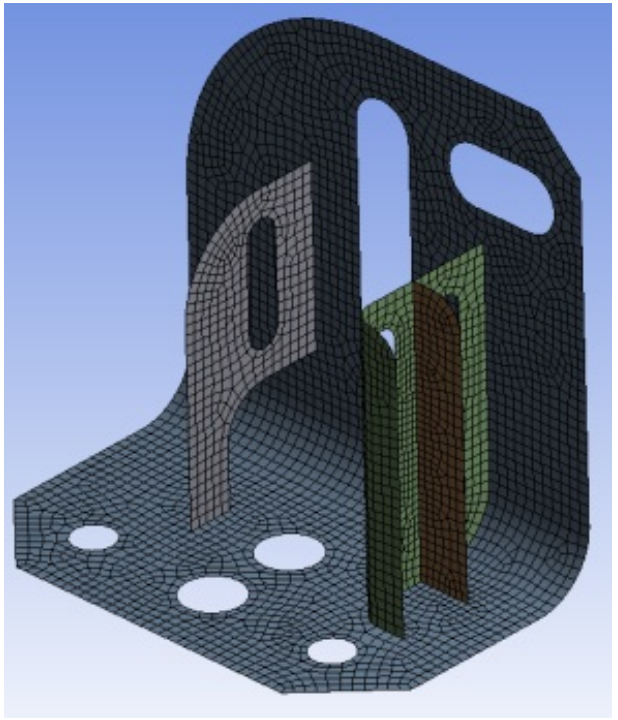
Element size = 0.0015 (0.5X)
Number of elements = 14,175 (8.2X)
ELAPSED RUN TIME = 5.835 min (53.0X)
Time step = 6.295E-09s (0.0198X)

 © 2014 ANSYS, Inc.

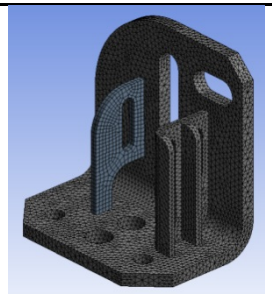
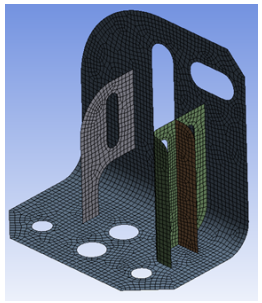
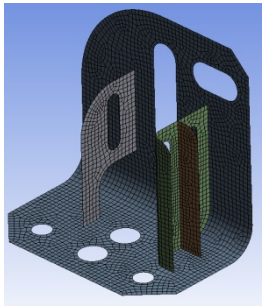
Meshing: Create Uniform Hex Mesh

- **Mid-Surface** thin solids and use shells





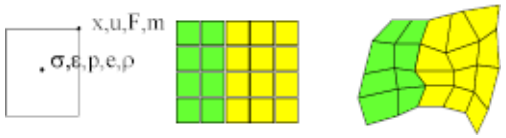
Meshing: Run Time of Solid and Shell Parts

Method		Nodes	Elements	Time Step	Run Time (min)	Ratio
Solid (all tets)		28,785	139,414	1.063E-8	10.517	16.3
Mid-Surfaced Bonded		4,137	3,768	1.056E-8	0.805	1.25
Mid-Surfaced Single Part		4,251	4,040	1.397E-8	0.643	1.00

Element Size: 0.66 mm for all meshes

Assign the Best Solution to Each Part

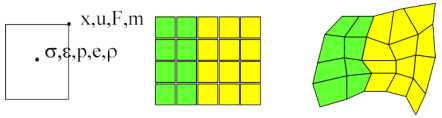
Lagrange (structures)



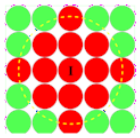
Euler (fluids)



ALE (auto remesh)



SPH (hypervelocity & brittle)



 © 2014 ANSYS, Inc.

Stability Time Step and Mass Scaling

The maximum time step is inversely proportional to the sound speed of the material and directionally proportional to the square root of the mass of material in an element

$$\Delta t \propto \frac{1}{c} = \frac{1}{\sqrt{C_{ii}/\rho}} = \sqrt{\frac{m}{VC_{ii}}}$$

where C_{ij} is the material stiffness (*i=1,2,3*), ρ is the material density, m is the material mass and V is the element volume

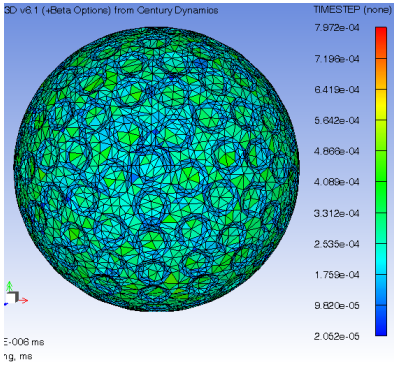
Increasing the mass of an element can increase the time step

If a model contains a few small elements, mass scaling can be used to reduce run time

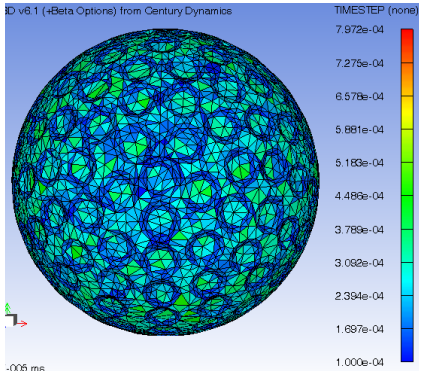
Mass scaling does change the inertial properties of the scaled elements

 © 2014 ANSYS, Inc.

Mass Scaling Example



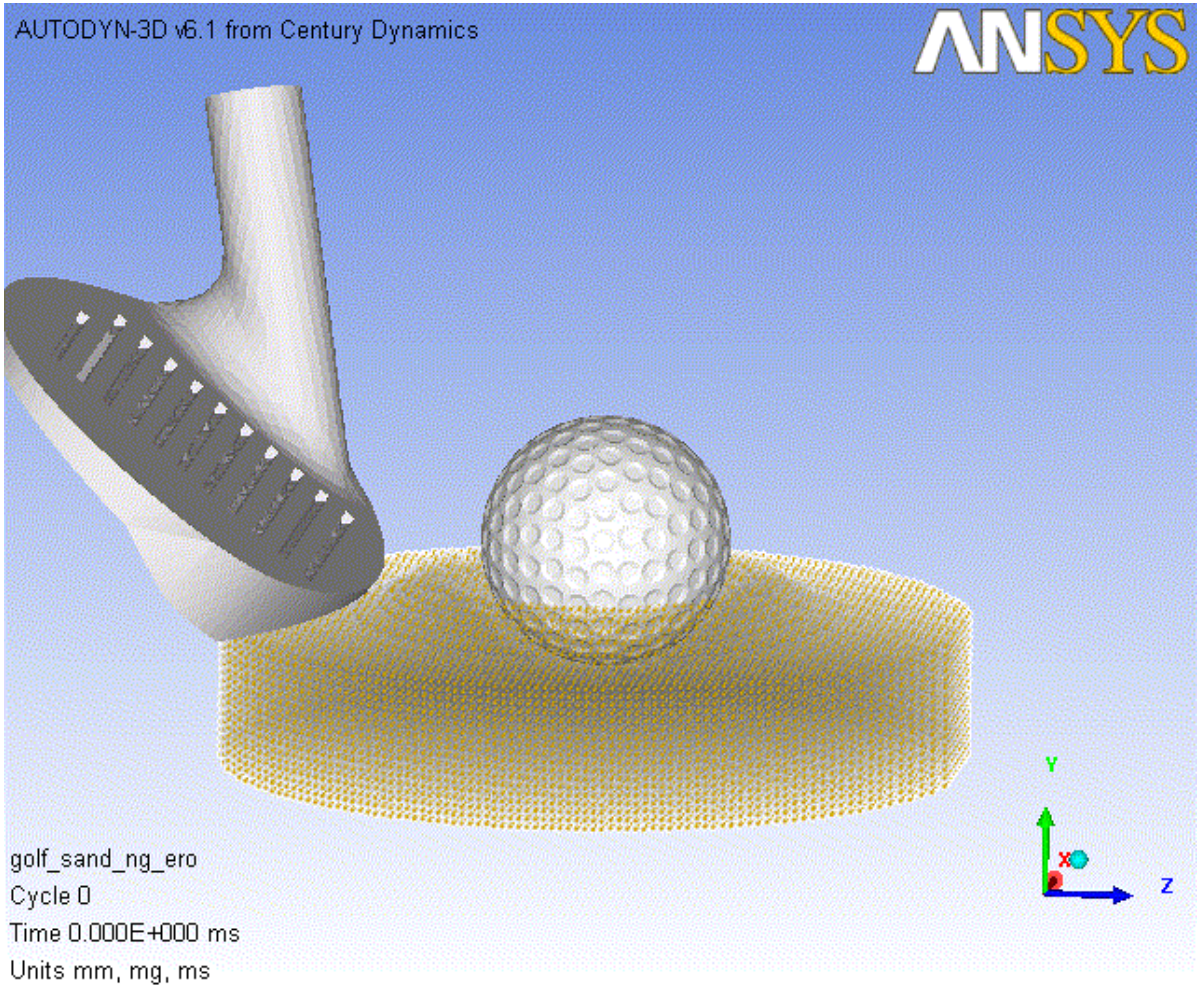
Standard Timestep 2.0e-5



Mass scaled timestep 1.0e-4

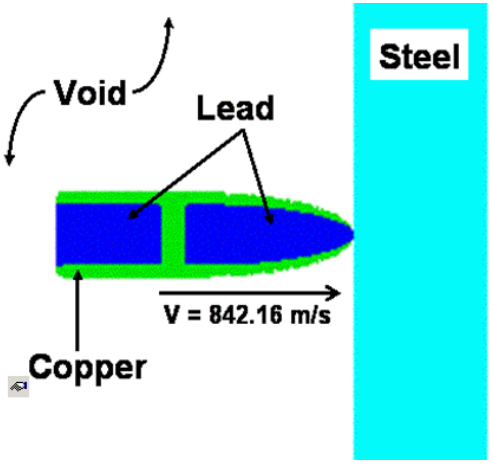
5x Increase in DT

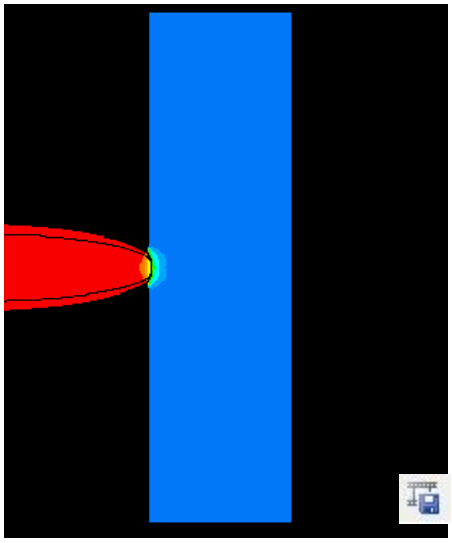
0.02% Increase in mass



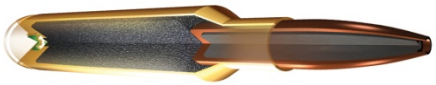
 © 2014 ANSYS, Inc.

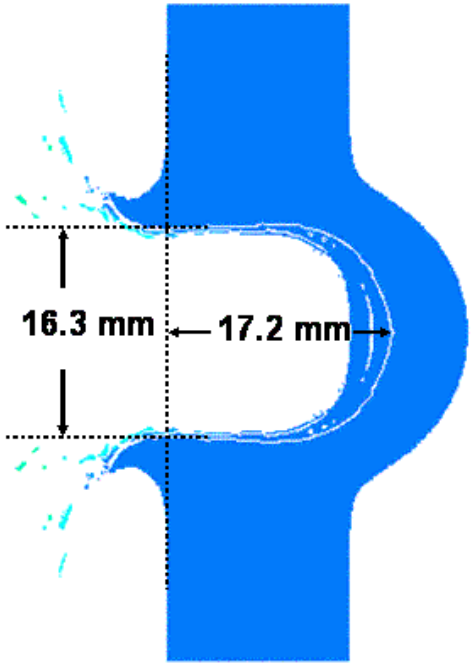
Correlation: Bullet Penetration



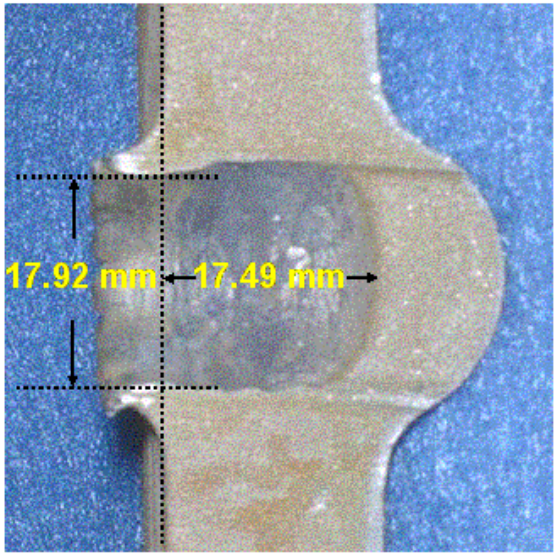


Bullet Penetration of Mild Steel
(338 Winchester Magnum)





a. AUTODYN Simulation

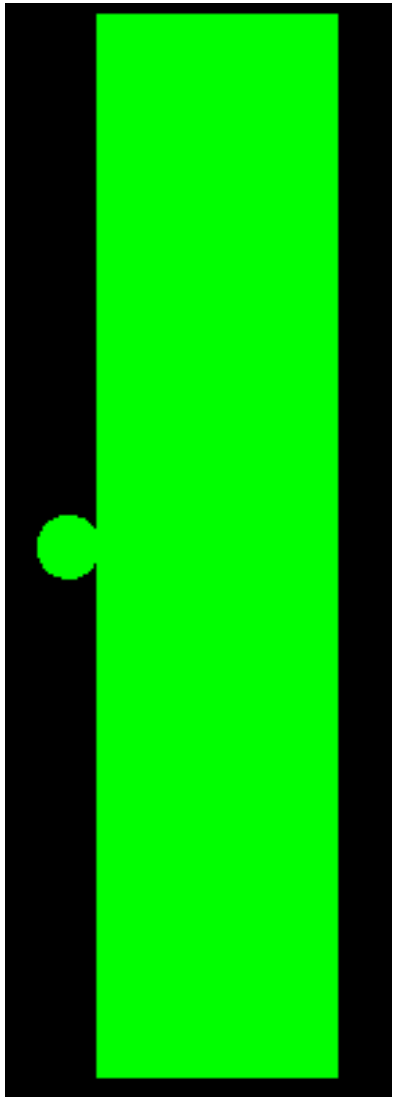


b. Shot 9 Cross-Section

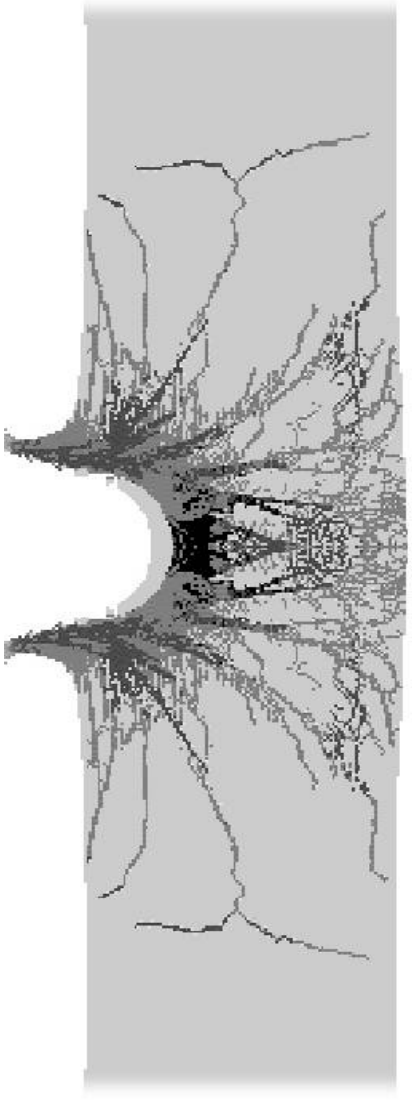
Courtesy Sandia National Laboratory

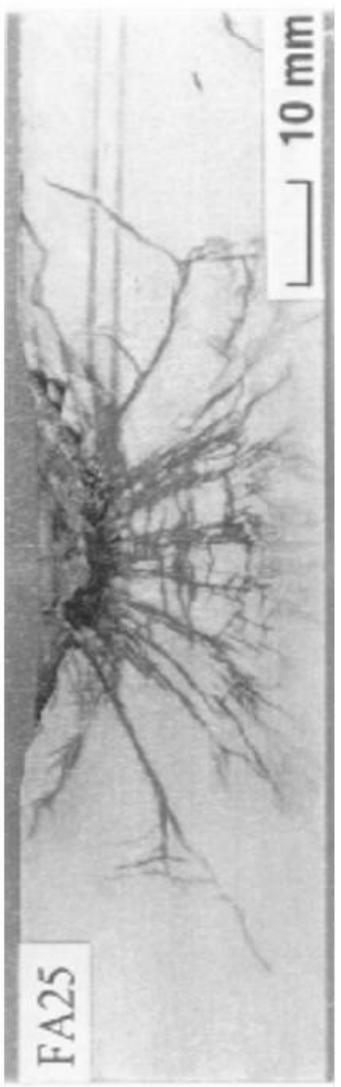
 © 2014 ANSYS, Inc.

Correlation: Impact on Ceramic



Simulation

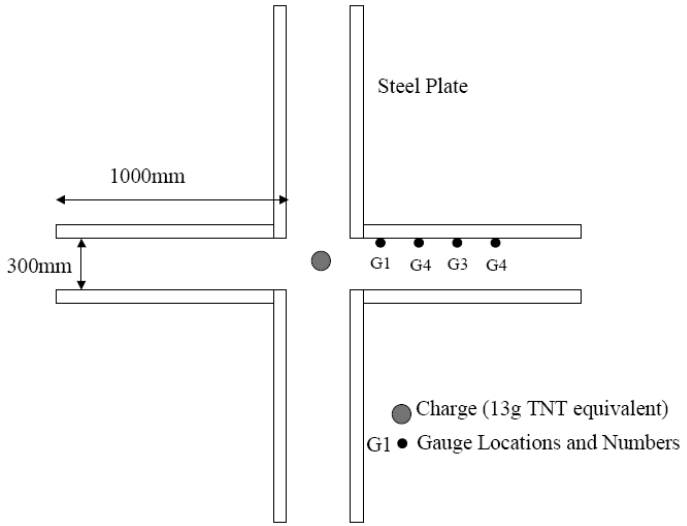


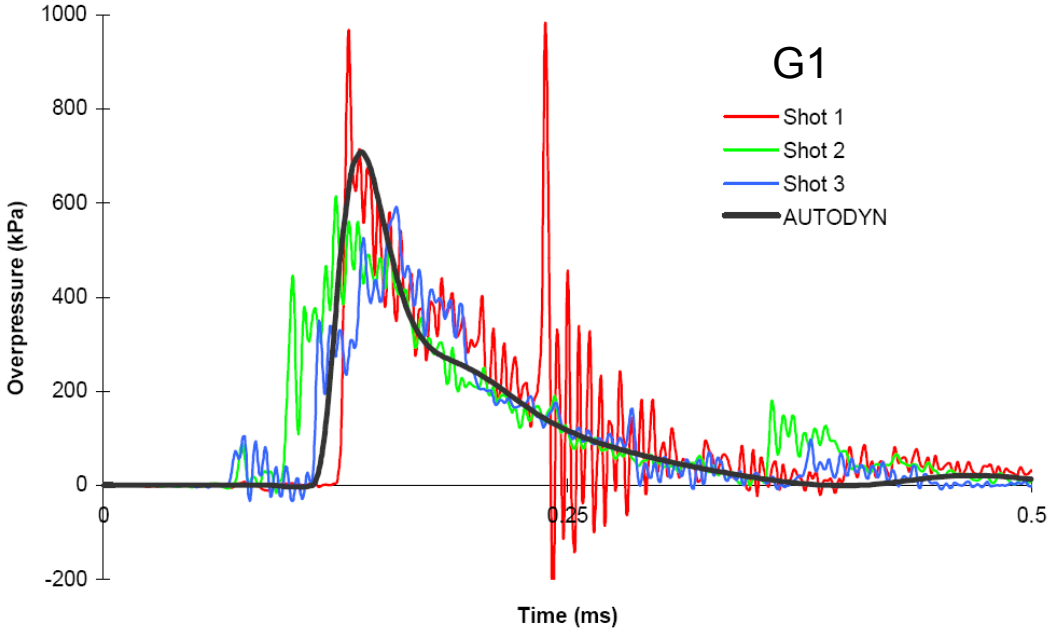


Experiment

 © 2014 ANSYS, Inc.

Correlation: Constrained explosive pressure profile

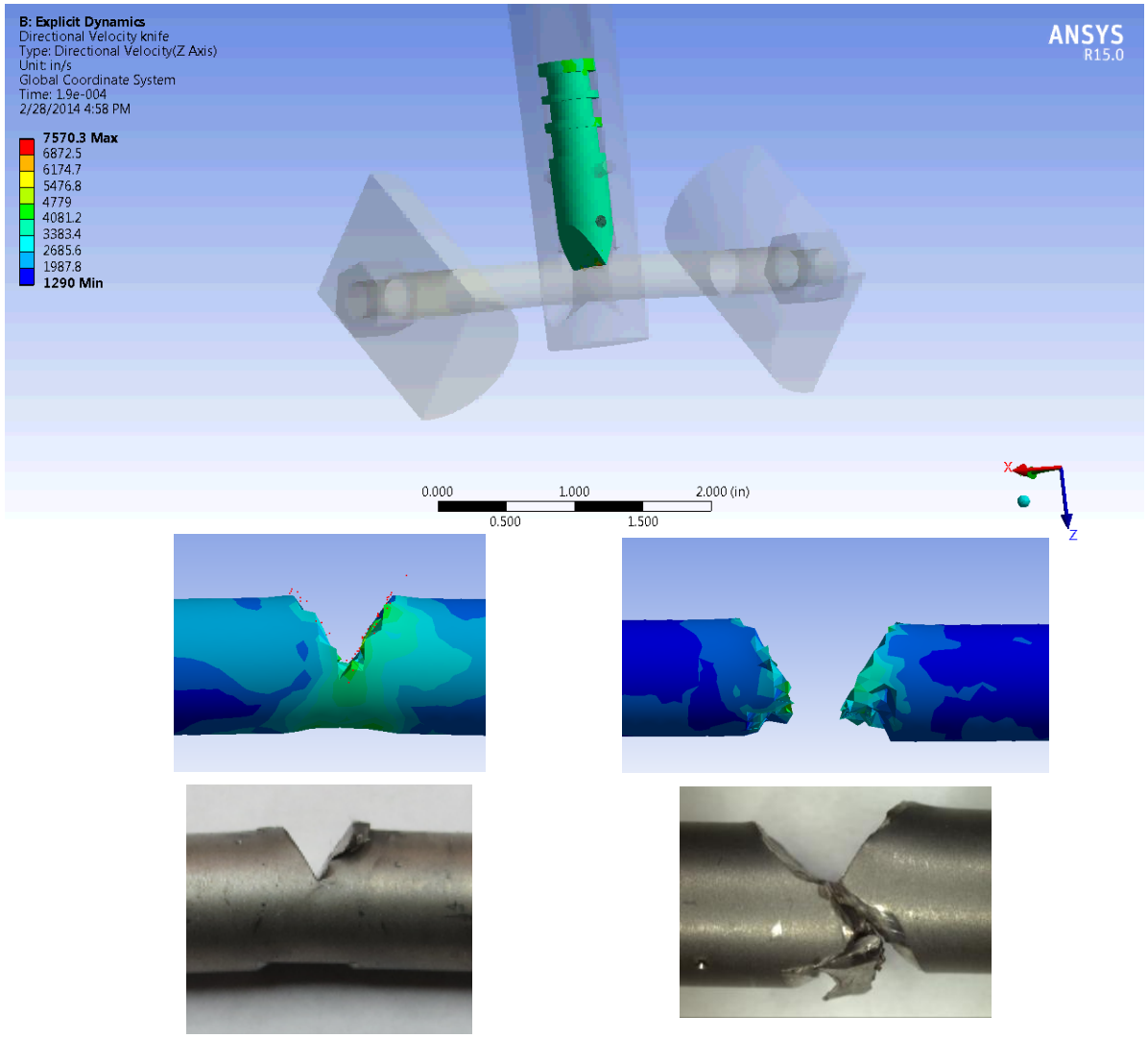




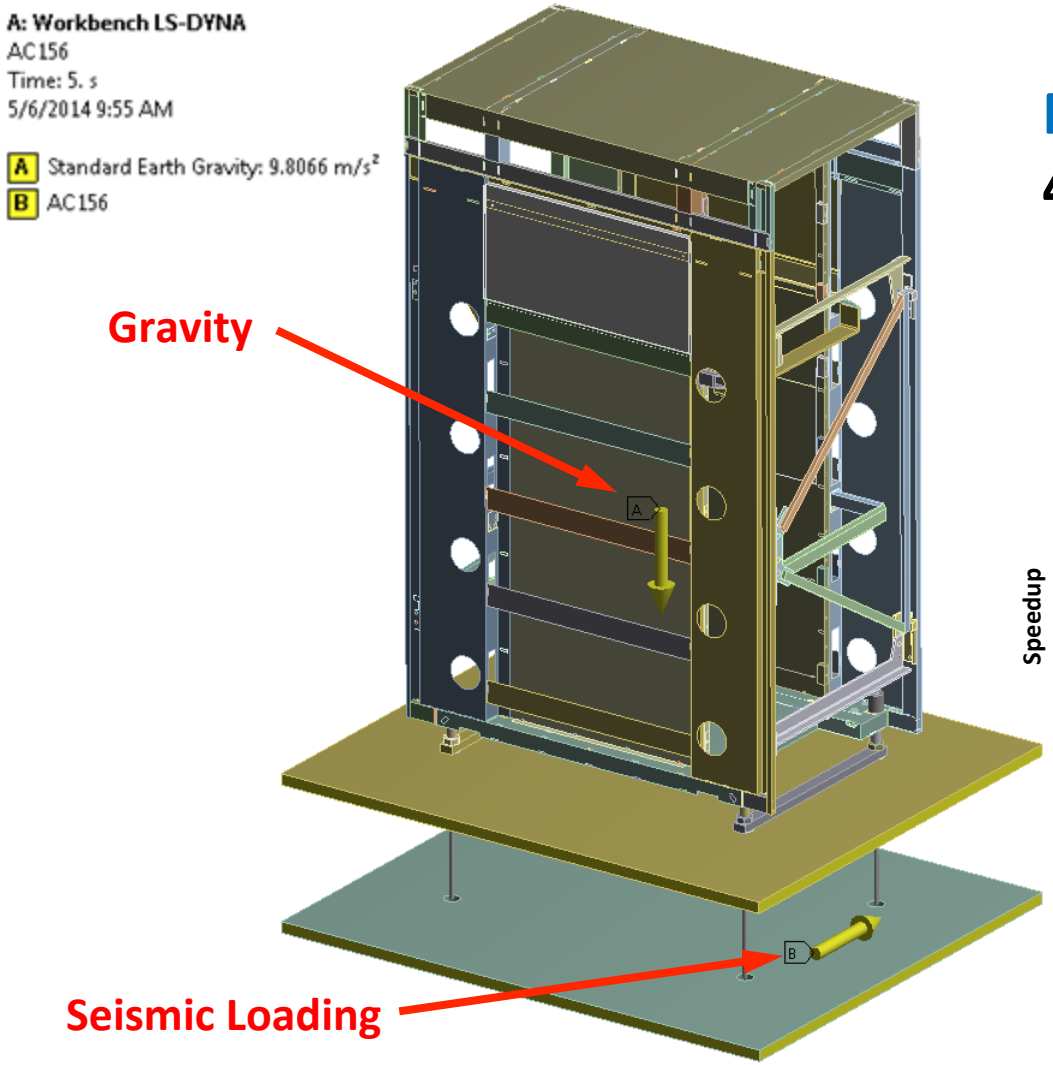
	Peak Overpressure (kPa)				Peak Impulse (kPa ms)			
Gauge	1	2	3	4	1	2	3	4
Shot 1	1898	982.4	384.0	244.0	73.86	57.45	42.68	40.26
Shot 2	3341	613.6	364.0	272.0	81.54	58.99	47.11	43.29
Shot 3	1606	591.2	188.0	157.6	77.24	50.21	39.67	38.06
Average	2282	729.1	312.0	224.5	77.55	55.55	43.15	40.20
AUTODYN-3D	2567	708.9	304.0	169.5	89.57	50.22	40.26	37.85

 © 2014 ANSYS, Inc.

Correlation: Explosively driven bolt cutter



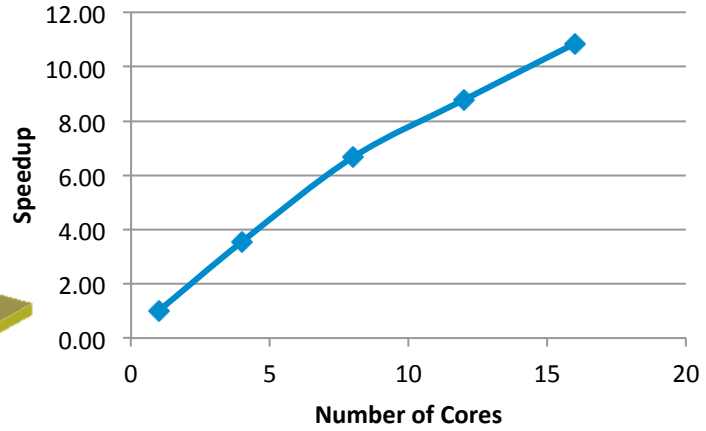
Explicit Dynamics Is Efficient with HPC



Model Courtesy of IBM

440,000 elements

Parallel Speed-up Using MPP



Hardware:
Dual Xeon E5-2690 2.9GHz, 16 cores

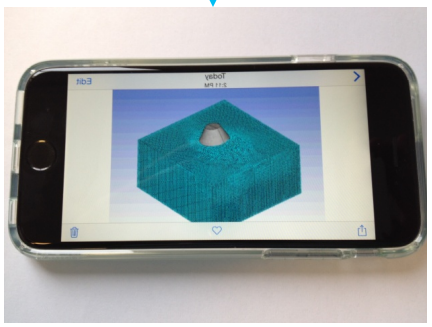
 © 2014 ANSYS, Inc.

Looking Into the Future

How can we improve explicit dynamic tools?

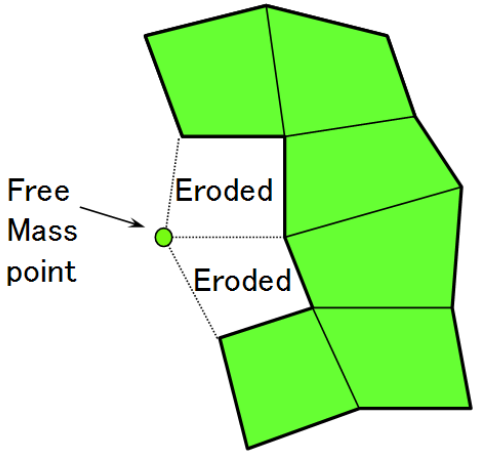
- Encapsulate experience and knowledge
- Remove “numerics”
- Use physics terminology
- Use modern user interfaces
  - Convenient access to cloud computing
  - High bandwidth access to results
  - Voice recognition





Erosion

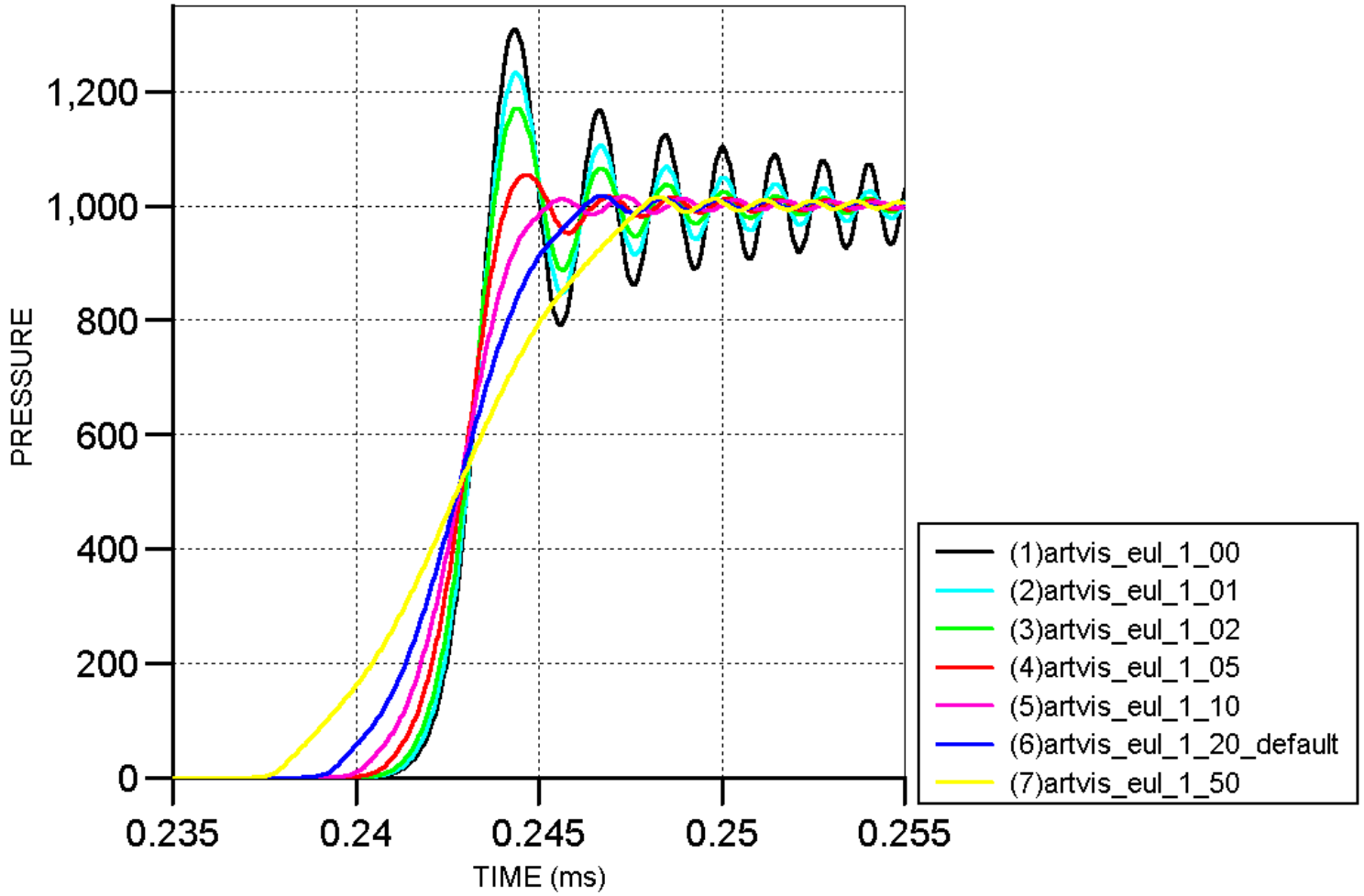
- Erosion is a numerical technique for combating element distortions in Lagrange meshes
  - Has no physical foundation
  - Erosion strains should be much larger than physical failure strains
- When the deformation of an element reaches a point where either the time step is significantly reduced or the element becomes degenerate (i.e. it inverts), the element is removed (eroded) from the analysis.
- When an elements erodes
  - Its internal energy is always discarded
  - Its inertia can be retained as free mass points (not recommended for 2D axial symmetric impact)



 © 2014 ANSYS, Inc.

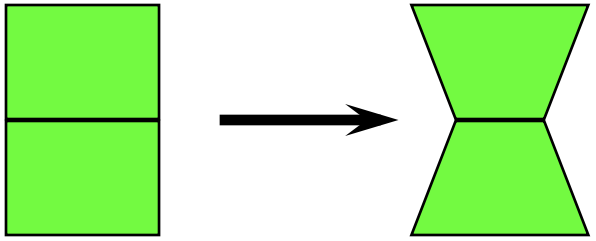
Damping: Artificial Viscosity

Linear Viscosity (reduces noise) - Euler

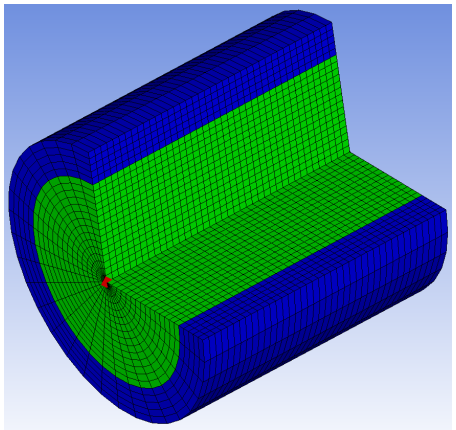


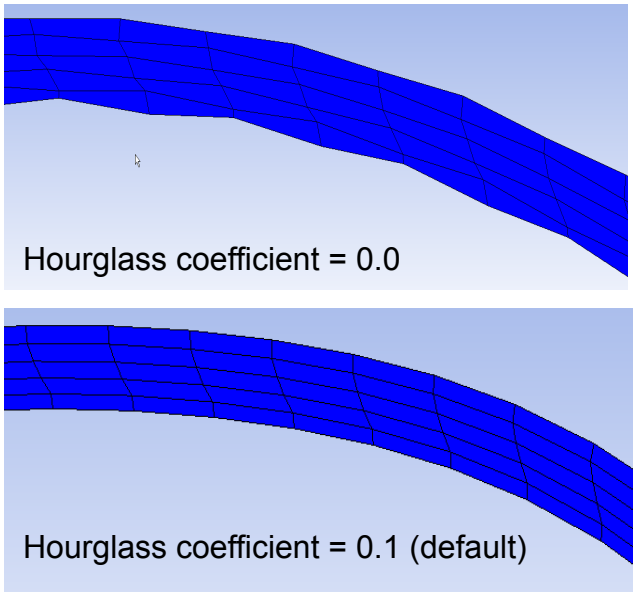
 © 2014 ANSYS, Inc.

Damping: Hourglass control



- "Hourglassing" is a deformation that produces no volume or strain change in hex / quad meshes
  - The numerical equations only involve differences in velocities and coordinates of diagonally opposite corners. If these differences remain constant, there is no change in the element volume / strain
- A damping term is applied to resist this type of distortion





HE Detonation in Aluminum Cylinder

 © 2014 ANSYS, Inc.

The Best Approach to Explicit Dynamics

- Use simple material models
- Start with a simple problem (Use 2D if possible)
- Simplify geometry
- Create uniform hex mesh if possible
- Select appropriate solution methods (Material response based)
- Cheat if necessary (Erosion and mass scaling)
- Look at results after a few hundred cycles
- Correlate with experiment or publication
- Use HPC (parallel processing) to reduce run times
- Add complexity one step at a time
- Seek insight not numbers

 © 2014 ANSYS, Inc.

Thank You for Your Attention

Questions?

bence.gerber@ansys.com
LinkedIn bencegerber
Twitter @bence_g
Facebook bence gerber