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Overview of the SALE solver in LS-DYNA for defense applications

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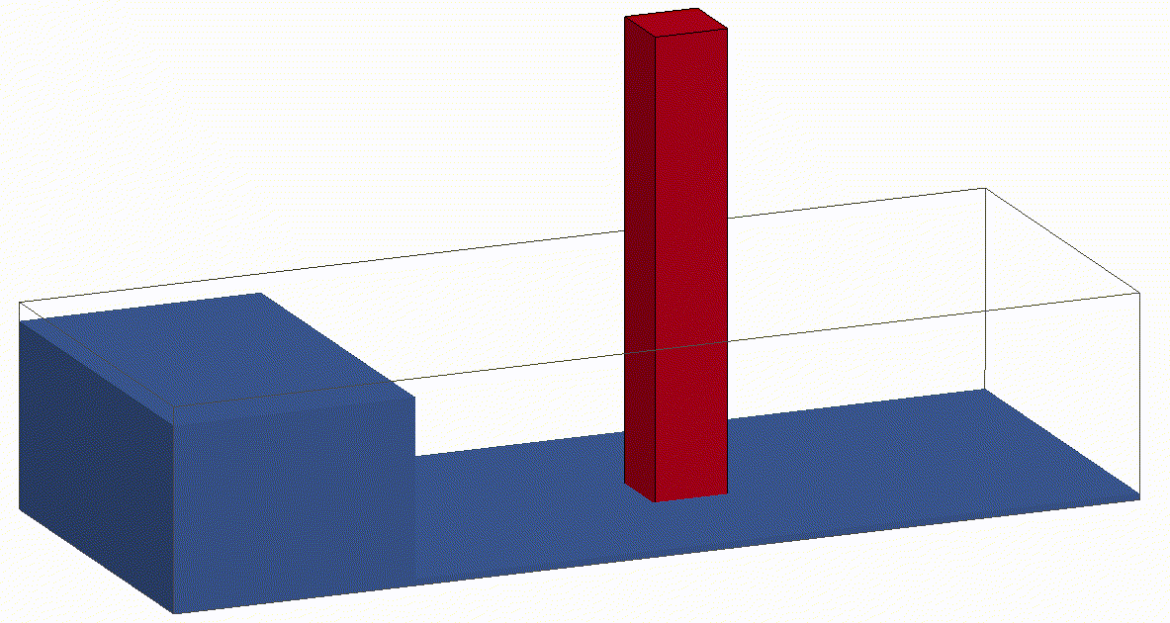
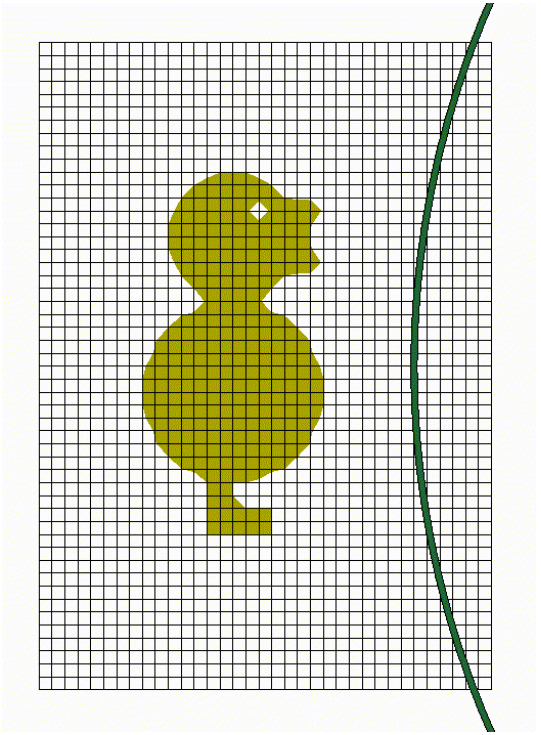
Background SALE

- SALE = Structured ALE
- Based on automatically generated block structured mesh
- Introduced 2017 in LS-DYNA R10
- Supports SMP/MPP in 2D/3D
- Uses the same theory as the regular ALE solver with respect to advection and interface reconstruction, but a separate coding
- This allows...
  - Faster sorting and searching
  - More efficient and cleaner code



Background SALE

- Benefits compared to regular ALE
  - ✓Easier mesh generation
  - ✓Smaller input files
  - ✓Uses less memory
  - ✓Runs faster
  - ✓New user-friendly setup
- Drawbacks compared to regular ALE
  - X More complex fluid geometries can not be automatically meshed
  - X Can not merge fluid elements to Lagrangian structure elements
- Main difference compared to regular ALE
  - The fluid part is either a mesh part or a material part, it can not be both
  - New options to create sets



SALE keyword family

- *ALE_STRUCTURED_FSI → New cleaner card
- *ALE_STRUCTURED_MESH → Generate mesh and invoke the SALE solver
- *ALE_STRUCTURED_MESH_CONTROL_POINTS → Provide mesh spacing information
- *ALE_STRUCTURED_MESH_MOTION
- *ALE_STRUCTURED_MESH_REFINE
- *ALE_STRUCTURED_MESH_TRIM
- *ALE_STRUCTURED_MESH_VOLUME_FILLING
- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP → New user-friendly setup
- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP_AXISYM
- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP_PLNEPS

SALE setup – Step #1 Mesh

```
*ALE_STRUCTURED_MESH
$#    mshid       dpid       nbid       ebid
          1          5     100004     100001
$#    cpidx      cpidy      cpidz       nid0      lcsid
          1          2          3     100001        123
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
          1                                1.0                  0.0
$#                   n                    x
                     1                -555.0
                    75                 555.0
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
          2                                1.0                  0.0
$#                   n                    x
                     1                -555.0
                    75                 555.0
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
          3                                1.0                  0.0
$#                   n                    x
                     1                -555.0
                    38                   0.0
*DEFINE_COORDINATE_NODES
$#      cid         n1         n2         n3       flag        dir
        123     100001     100002     100003         0X
*NODE
$#    nid                x                y                z       tc       rc
  100001              0.0              0.0              0.0        0        0
  100002             10.0              0.0              0.0        0        0
  100003              0.0             10.0              0.0        0        0
```

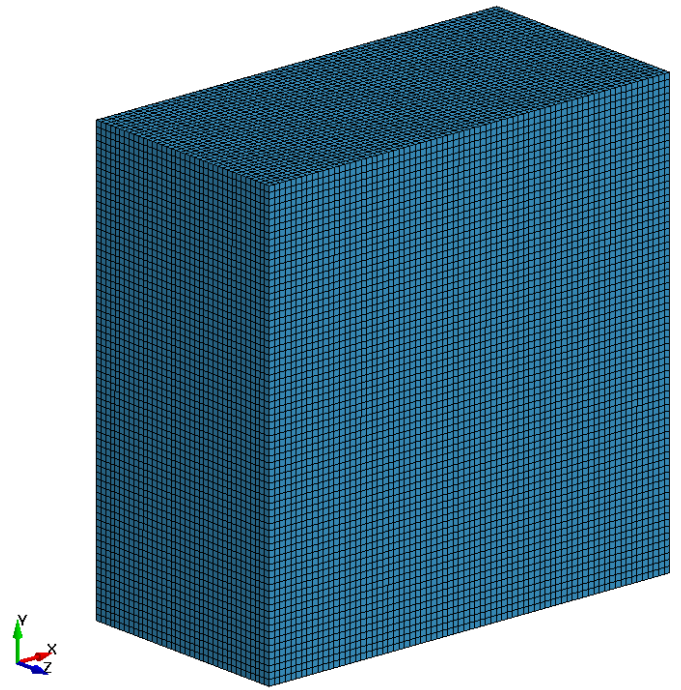
X-direction

Y-direction

Z-direction

Mesh origin

Local coordinate system



SALE setup – Step #2 Multi-materials

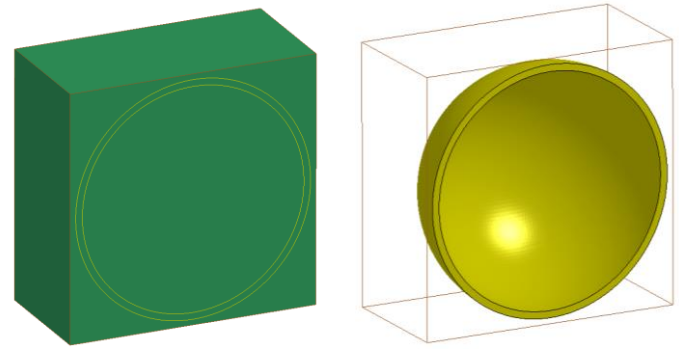
- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP
  - Possible to use names instead of IDs → Names for volume filling and *SET_MULTI-MATERIAL...
  - Specify material and EOS → No need for *PART and *SECTION
  - The ELFORM is set automatically → Therefore different cards for 2D
  - Each multi-material could have its own reference pressure PREF

```
*ALE_STRUCTURED_MULTI-MATERIAL_GROUP
$#ammg_name      mid     eosid    unused    unused    unused    unused      pref
Explosive          1         1                                            0.0
Air_in             2         2                                     1.01325E-4
Air_out            2         2                                     1.01325E-4
```

SALE setup – Step #3 Fill the mesh

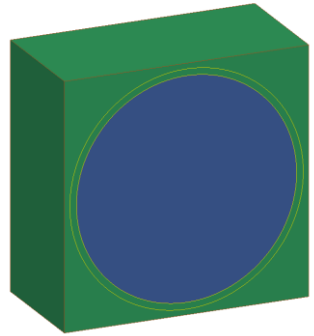
```
*ALE_STRUCTURED_MESH_VOLUME_FILLING
$#    mshid    unused      ammgto    unused    nsample     unused    unused-       vid
         1               Air_out                     3                              0
$#     geom    in/out        e1        e2        e3        e4        e5
ALL               0
```

Air_out



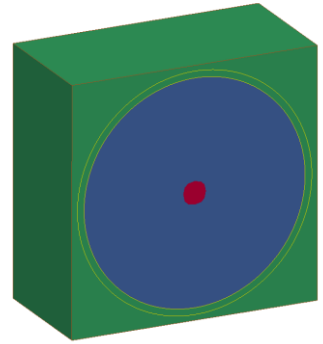
```
*ALE_STRUCTURED_MESH_VOLUME_FILLING
$#    mshid    unused      ammgto    unused    nsample     unused    unused-       vid
         1               Air_in                      3                              0
$#     geom    in/out     segsid        e2        e3        e4        e5
SEGSET            0        100
```

Air_in

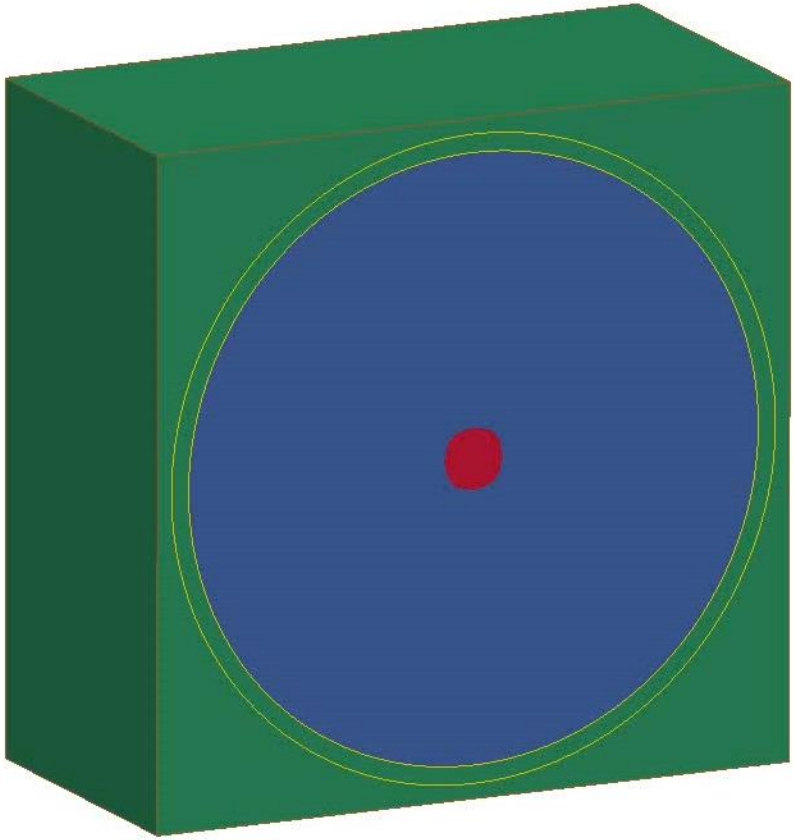


```
*ALE_STRUCTURED_MESH_VOLUME_FILLING
$#    mshid    unused      ammgto    unused    nsample     unused    unused-       vid
         1               Explosive                   3                              0
$#     geom    in/out        nid     radiix     radiiy     radiiz      lcsid
ELLIPSOID         0     100001       52.7
```

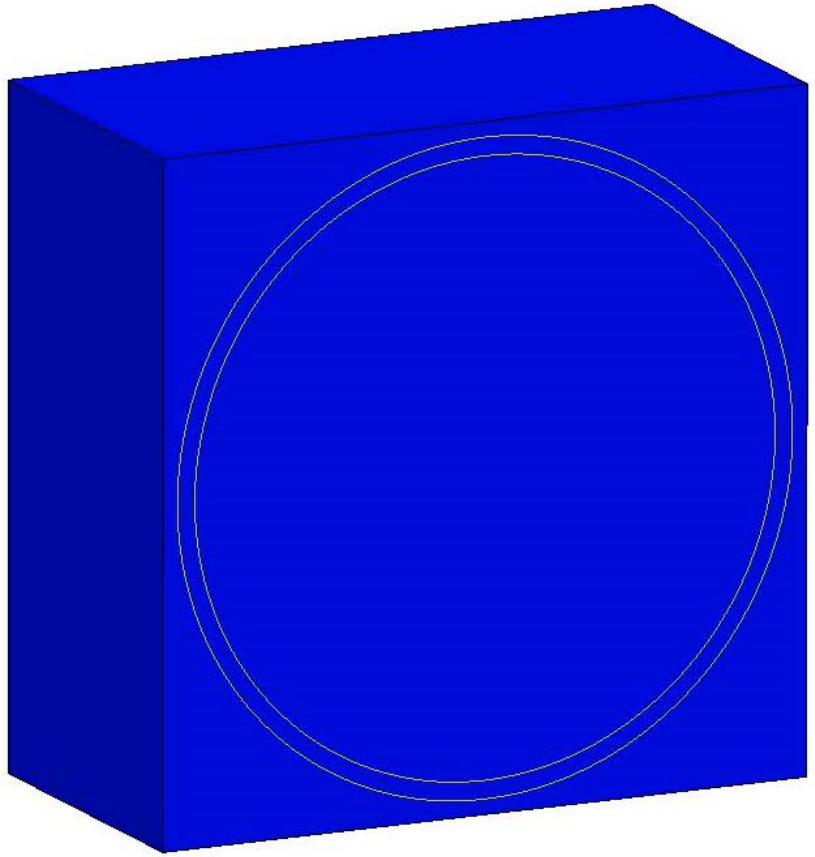
Explosive



Example – Contained detonation



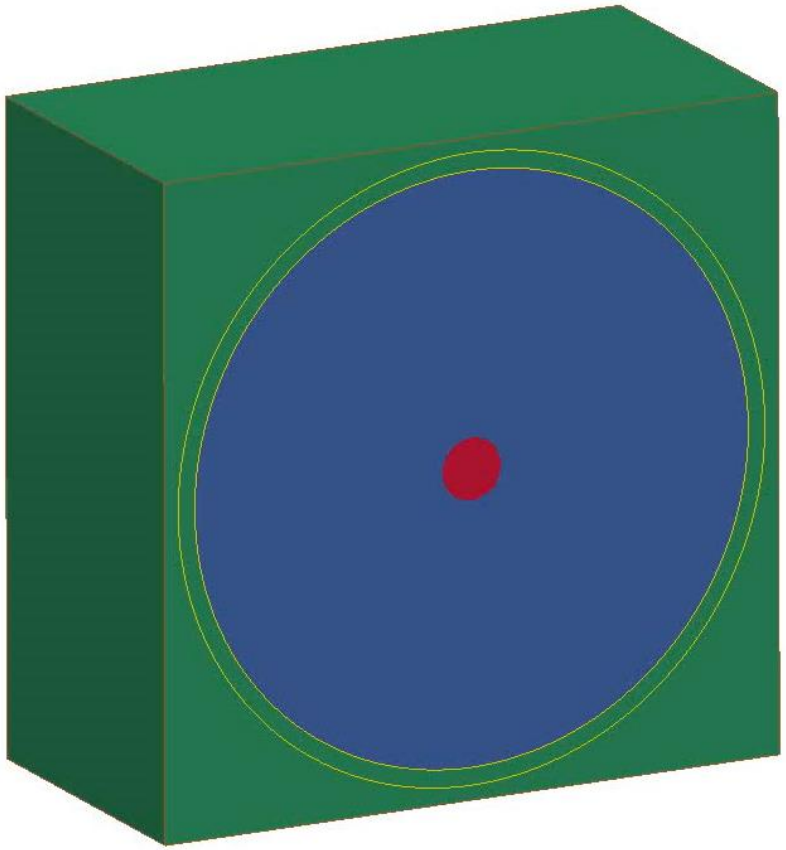
Multi-materials



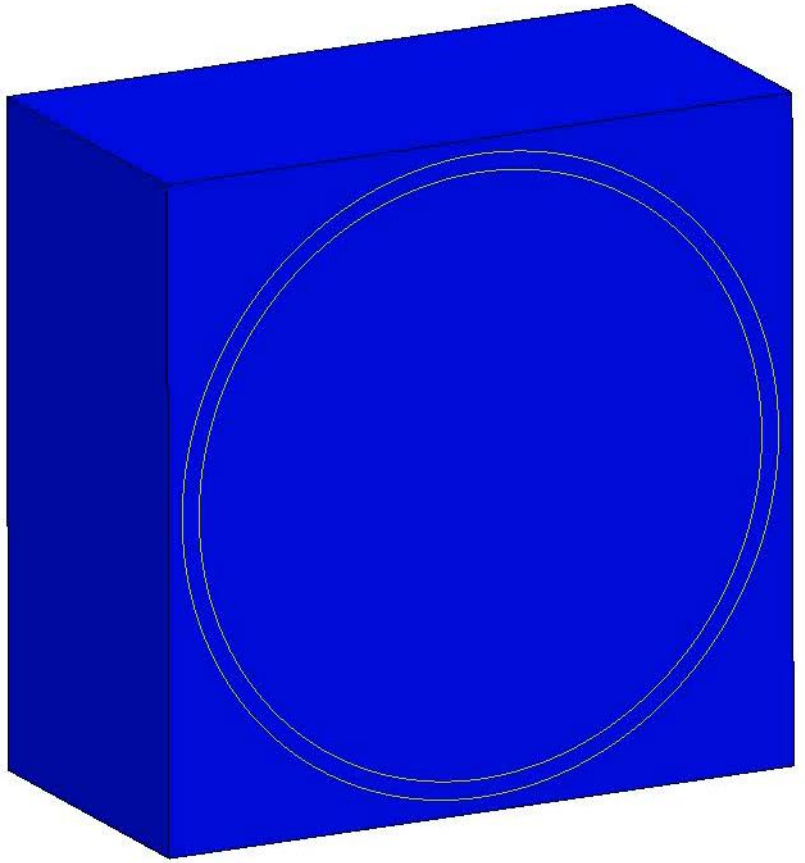
Pressure

Example – Contained detonation refine

```
*ALE_STRUCTURED_MESH_REFINE
$#   mshid      ifx,      ify,      ifz,
         1         2         2         2
```



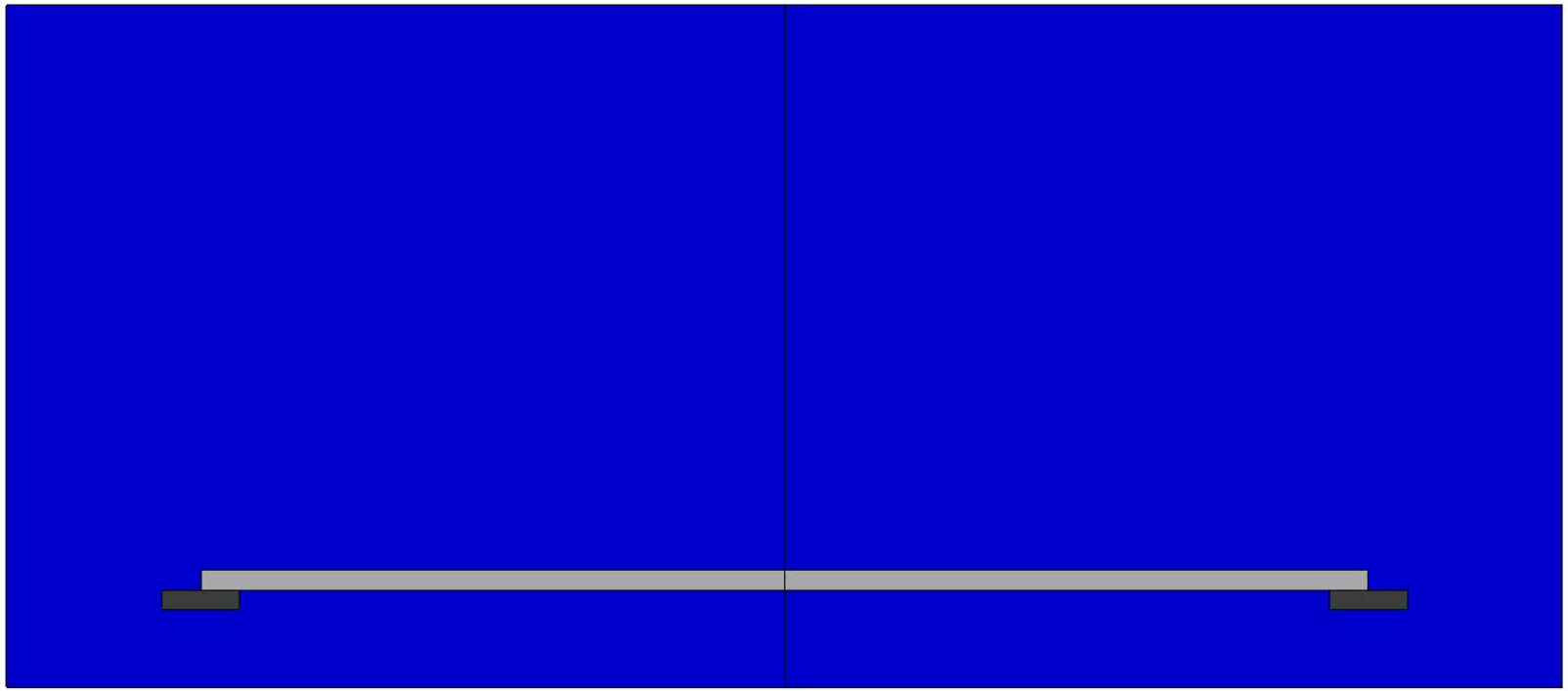
Multi-materials



Pressure

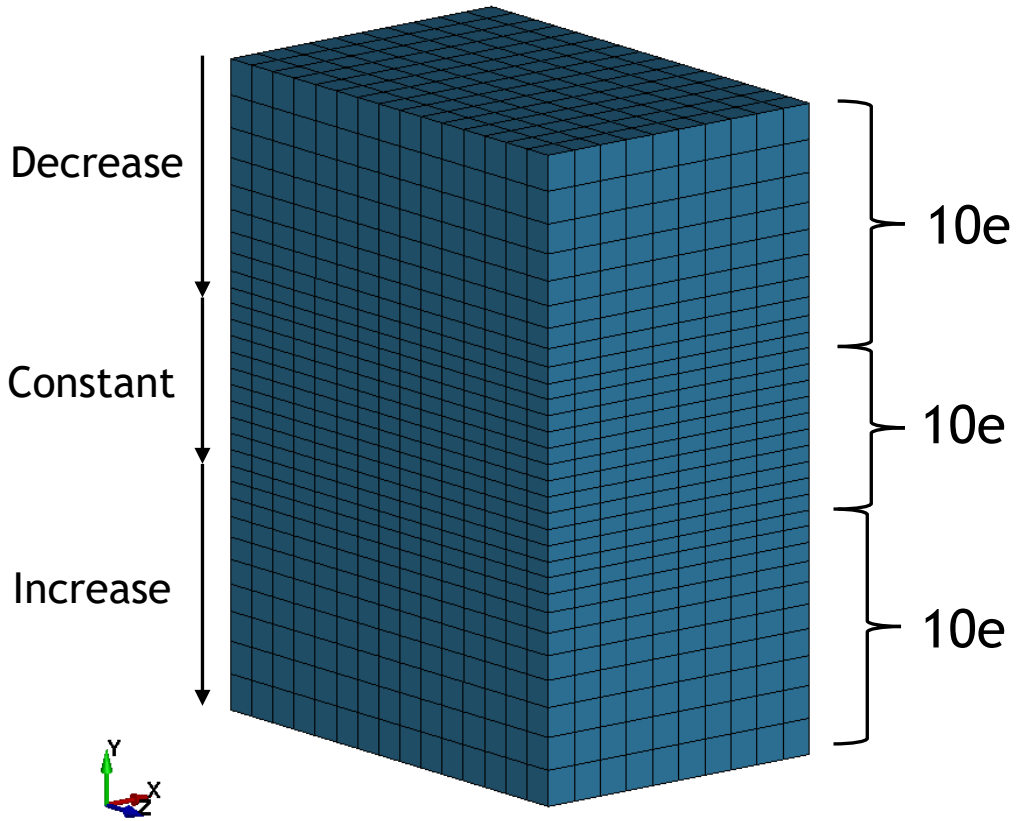
SALE in 2D

- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP_AXISYM
- *ALE_STRUCTURED_MULTI-MATERIAL_GROUP_PLNEPS



SALE progressive mesh spacing

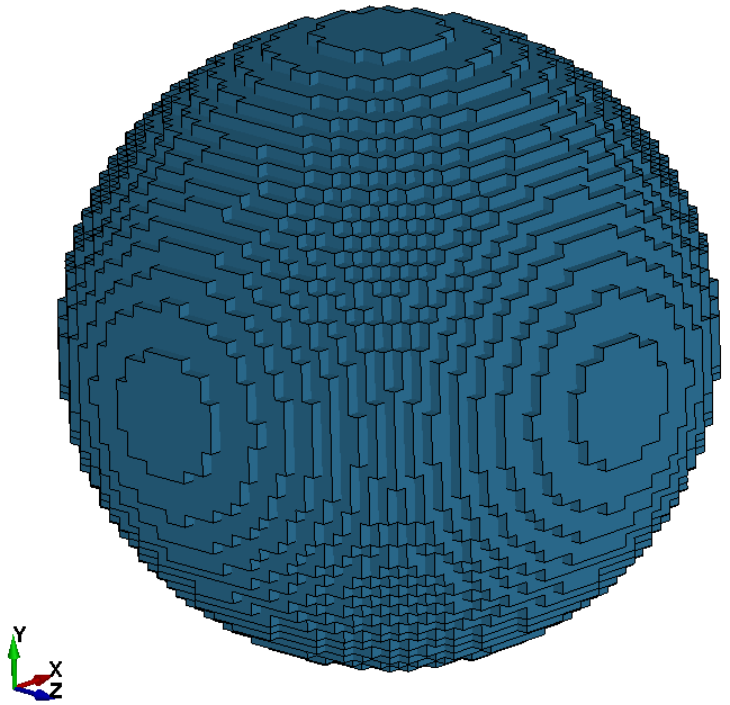
```
*ALE_STRUCTURED_MESH
$#    mshid       dpid       nbid       ebid
          1          2     100000     100000
$#    cpidx      cpidy      cpidz       nid0      lcsid
         10         20         30          1        123
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
         10                             1.0                   0.0
$#                  n                    x
                    1                  0.0
                   11                100.0
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
         20                             1.0                   0.0
$#                  n                    x                  ratio
                    1                  0.0                 -0.1
                   11                 75.0
                   21                125.0                  0.1
                   31                200.0
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
         30                             1.0                   0.0
$#                  n                    x
                    1                  0.0
                   16                150.0
```



SALE mesh trimming

- *ALE_STRUCTURED_MESH_TRIM
  - Option = PARTSET, SEGSET, PLANE, CYLINDER, BOXCOR, BOXCPT, SPHERE

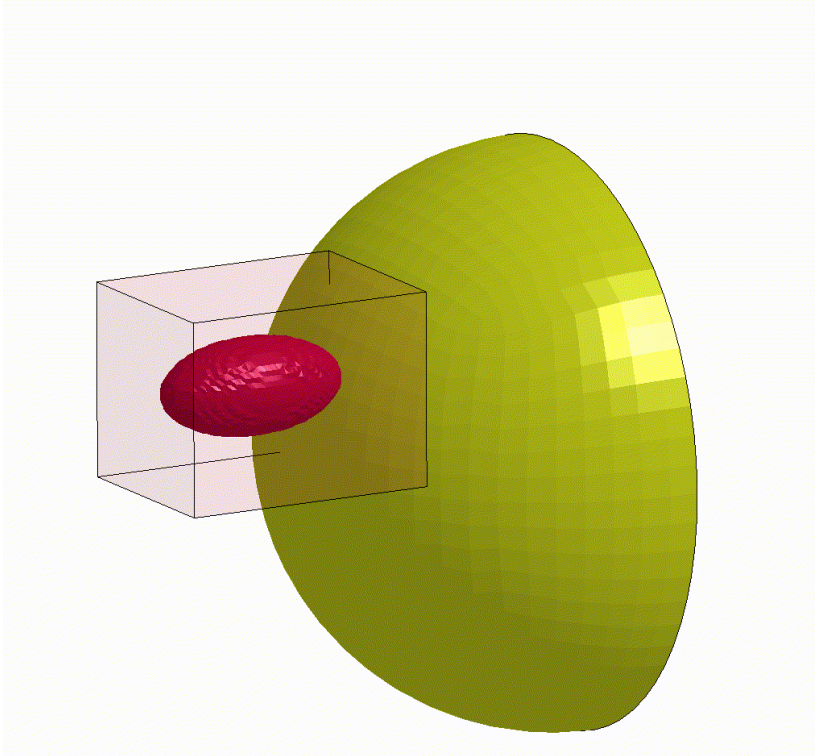
```
*ALE_STRUCTURED_MESH
$#    mshid       dpid       nbid       ebid
          1          2     100000     100000
$#    cpidx      cpidy      cpidz       nid0      lcsid
         10         10         10          1        123
*ALE_STRUCTURED_MESH_CONTROL_POINTS
$#     cpid     unused     unused        sfo     unused       offo
         10                             1.0                   0.0
$#                  n                    x
                    1               -100.0
                  101                100.0
*ALE_STRUCTURED_MESH_TRIM
$#    mshid     option       oper       flip        nid          r         e3         e4
          1SPHERE                0          0          1       50.0        0.0        0.0
*DEFINE_COORDINATE_NODES
$#      cid         n1         n2         n3       flag        dir
        123          1          2          3         0X
*NODE
$#    nid               x                  y                  z       tc       rc
        1             0.0                0.0                0.0        0        0
        2             1.0                0.0                0.0        0        0
        3             0.0                1.0                0.0        0        0
```



SALE mesh motion

- *ALE_STRUCTURED_MESH_MOTION
  - FOLLOW_GC: Mesh follow the mass center of the fluid (bird, projectile)
  - COVER_LAG: Mesh follow the motion of a Lagrangian structure (airbag)

```
*ALE_STRUCTURED_MESH_MOTION
$#    mshid     option    ammgsid     explim
         1FOLLOW_GC            1        2.0
```



SALE create sets

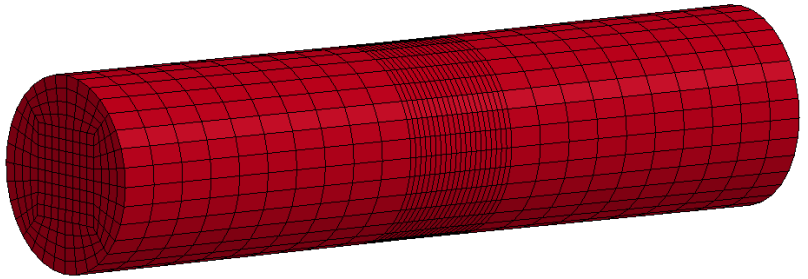
- Two new options available for SALE to create sets
- *SET_NODE_GENERAL, *SET_SEGMENT_GENERAL or *SET_SOLID_GENERAL
  - Option = SALEFAC: select the mesh face
  - Option = SALECPT: select with a box
- Example of a symmetry boundary condition

```
*BOUNDARY_SPC_SET
$#     nsid        cid       dofx       dofy       dofz      dofrx      dofry      dofrz
         1          0          0          0          1          0          0          0
*SET_NODE_GENERAL
$#      sid        da1        da2        da3        da4     solver
         1        0.0        0.0        0.0        0.0MECH
$#   option      mshid         -x         +x         -y         +y         -z         +z
SALEFAC              1          0          0          0          0          0          1
```

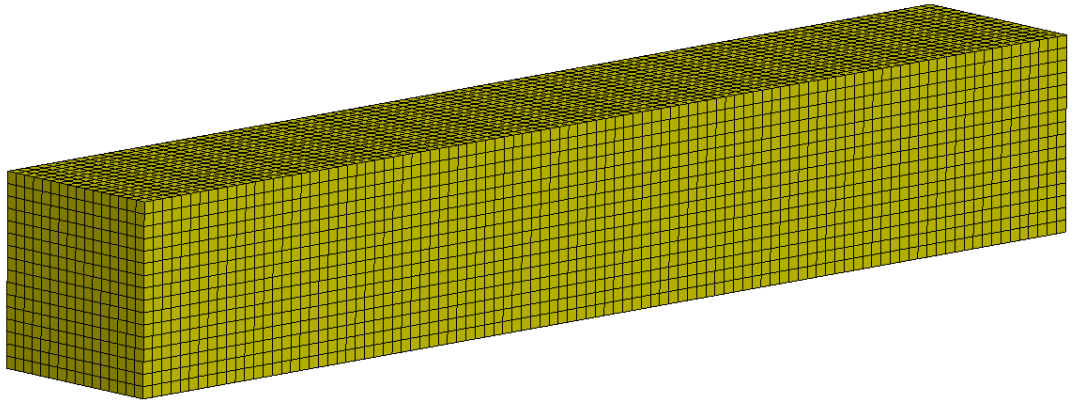
Benchmark – Tensile test

- Near quasistatic tensile test with a slight waist to induce consistent location of the necking
- *MAT_JOHNSON_COOK (015) with an equation of state and fracture model

FEM



SALE



Benchmark – Tensile test

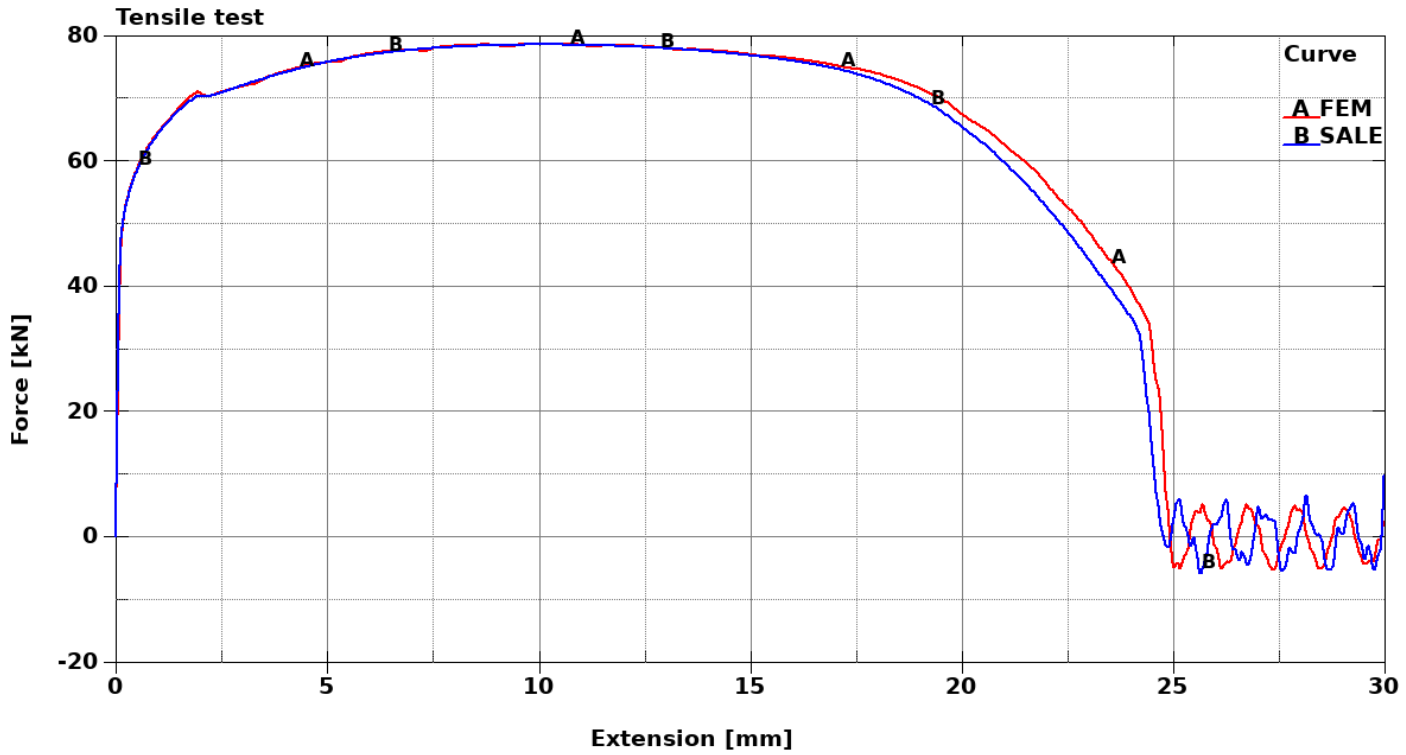
- The output format d3sale is used for higher rendering quality

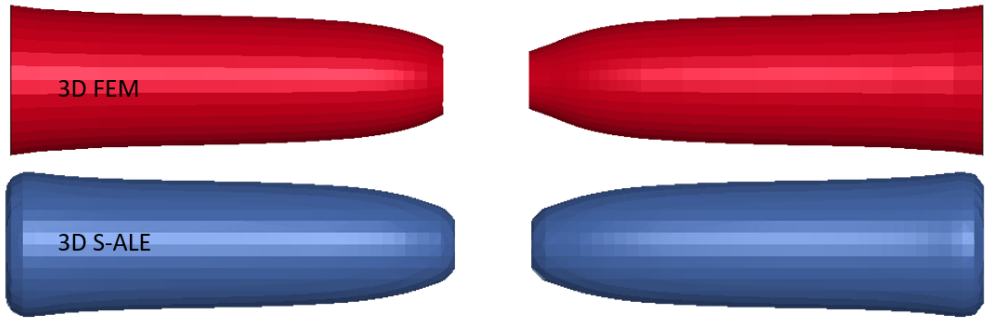
FEM

SALE

Benchmark – Tensile test

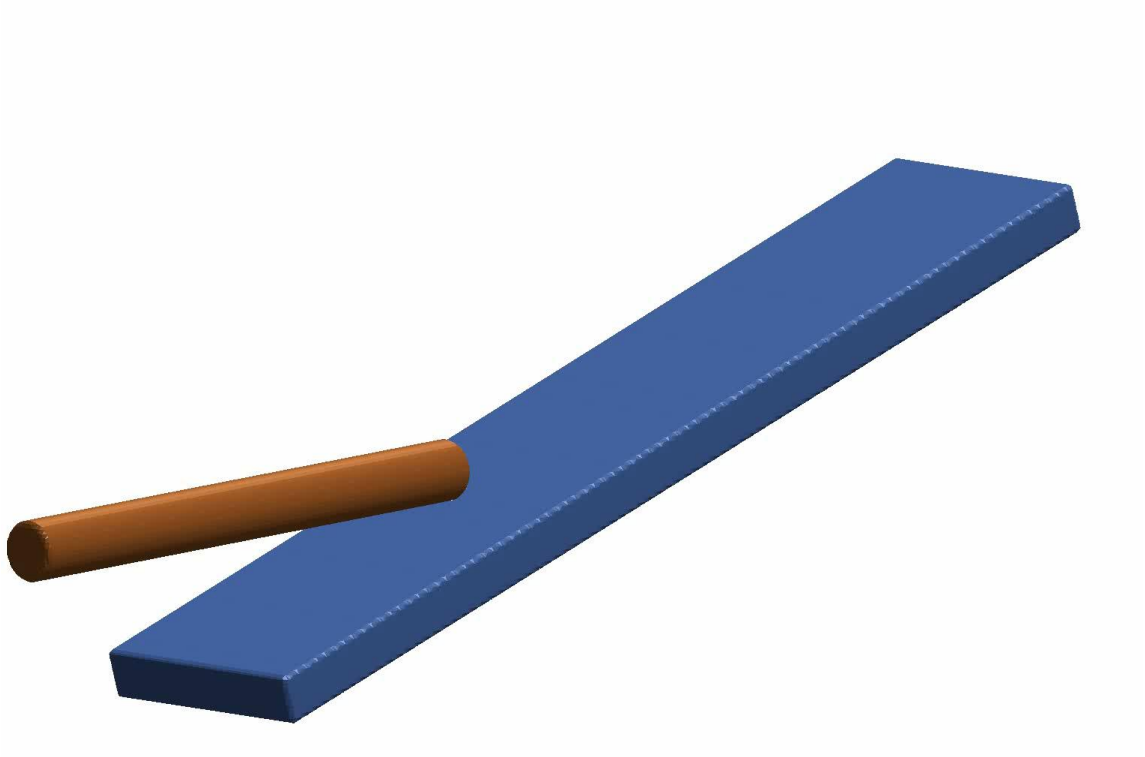
- FEM run time 37 sec on 10 cores
- SALE run time 75 sec on 10 cores
- Force vs Extension comparison – good agreement!

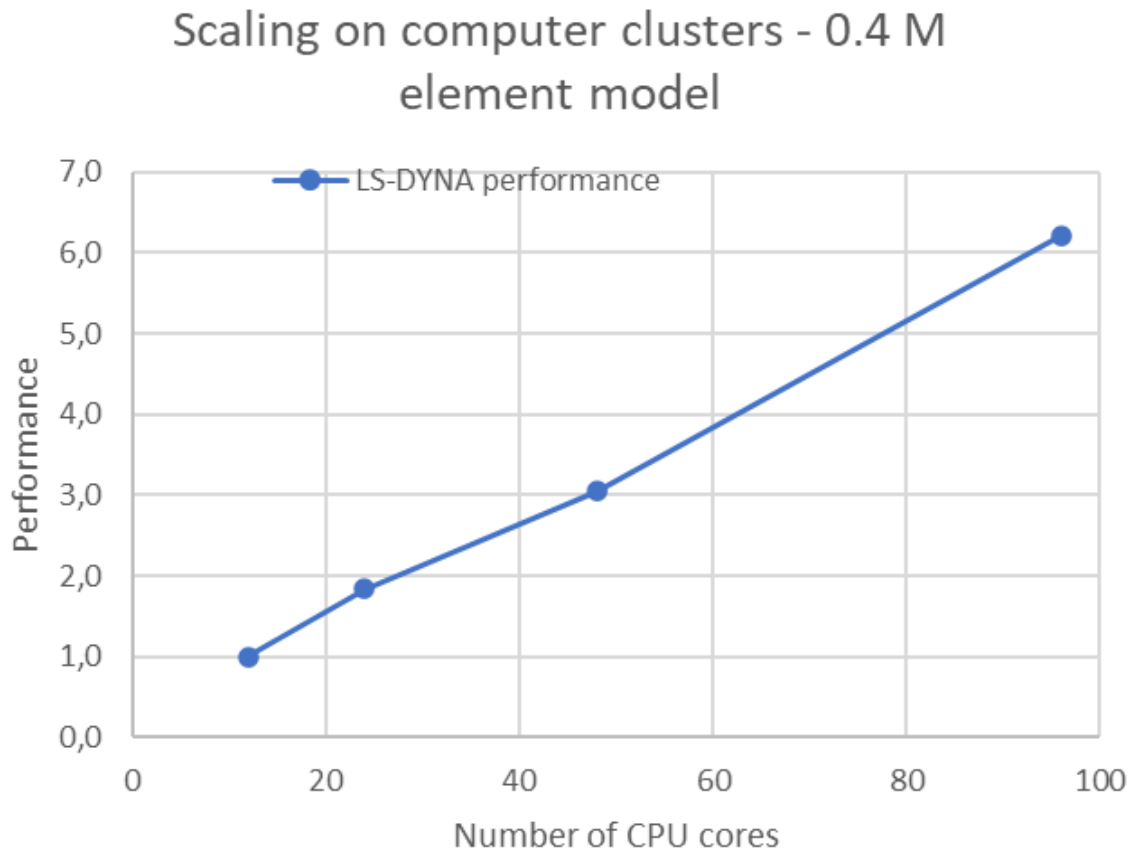




Benchmark – Performance small model

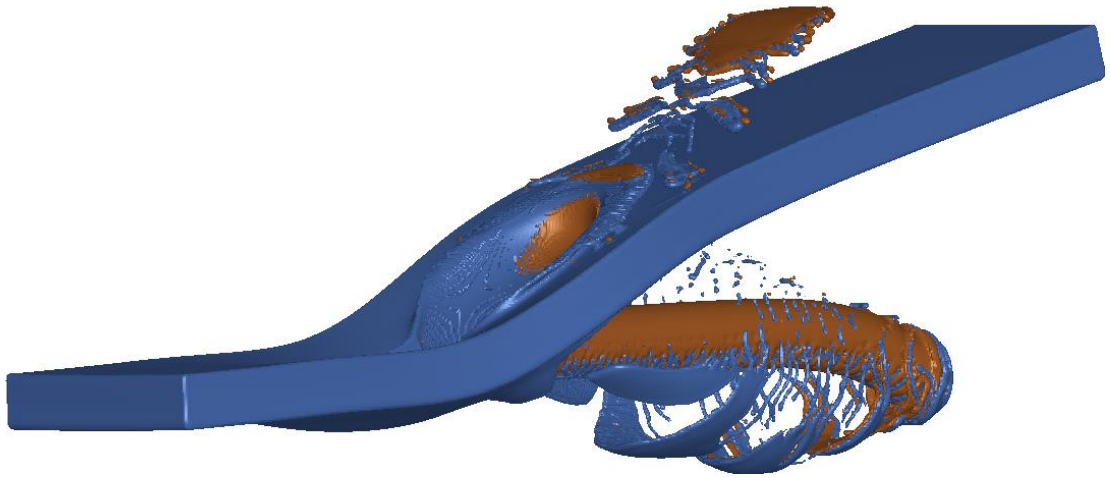
- High velocity flying steel plate
- 0.4 M elements, scaling from 16 to 96 cores

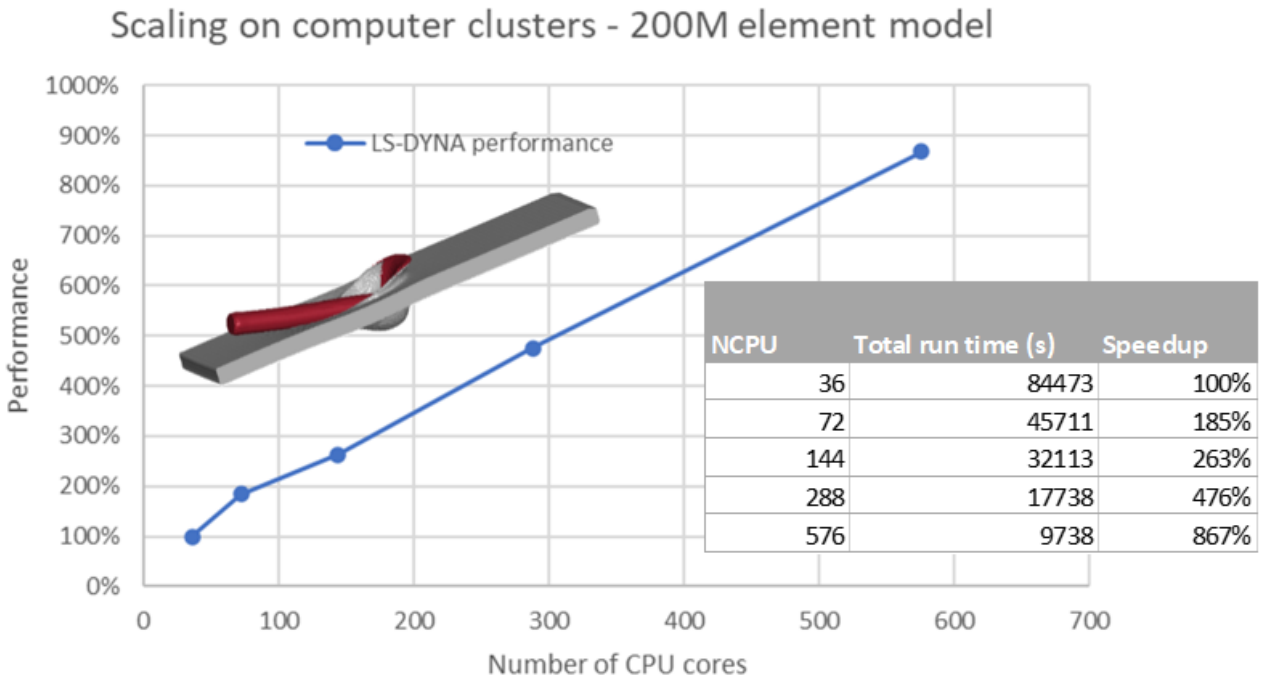




Benchmark – Performance large model

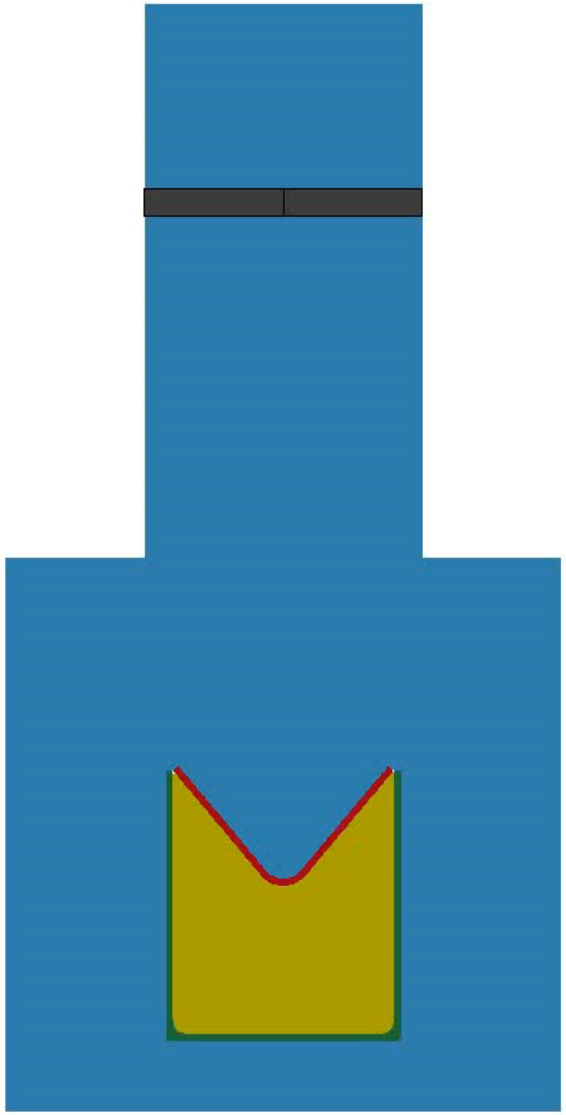
- High velocity flying steel plate
- 200 M elements, scaling from 36 to 576 cores

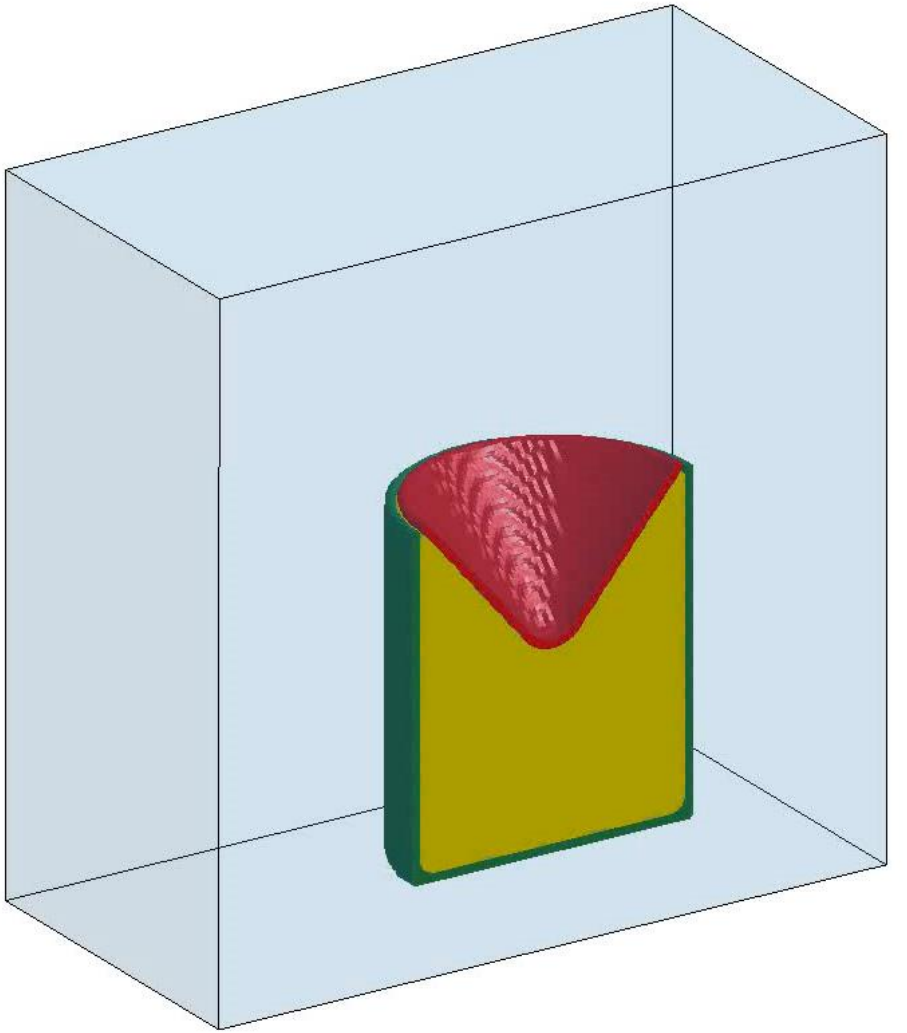




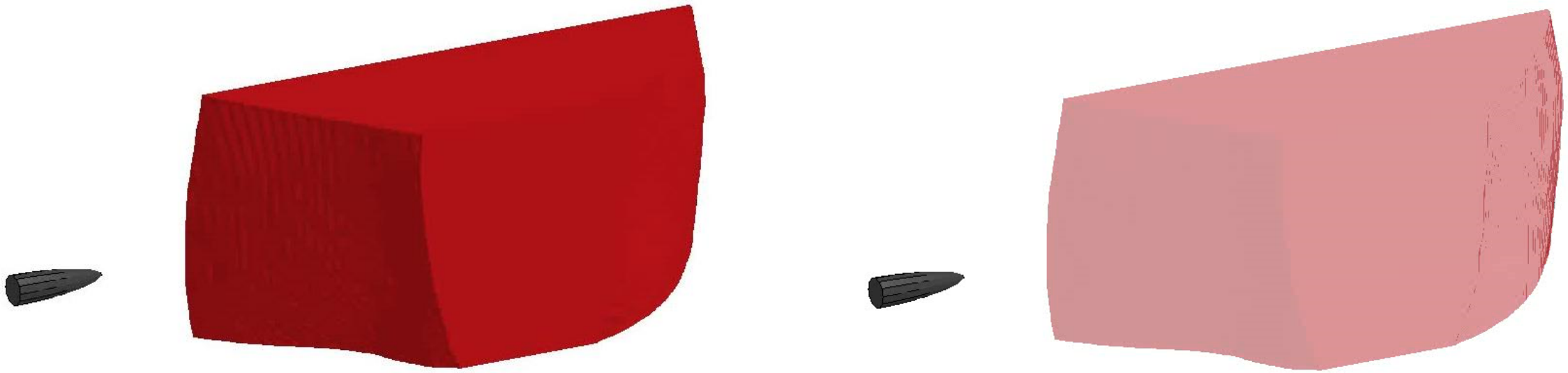
NCPU	Total run time (s)	Speedup
36	84473	100%
72	45711	185%
144	32113	263%
288	17738	476%
576	9738	867%

Application – Shape charge in 2D & 3D

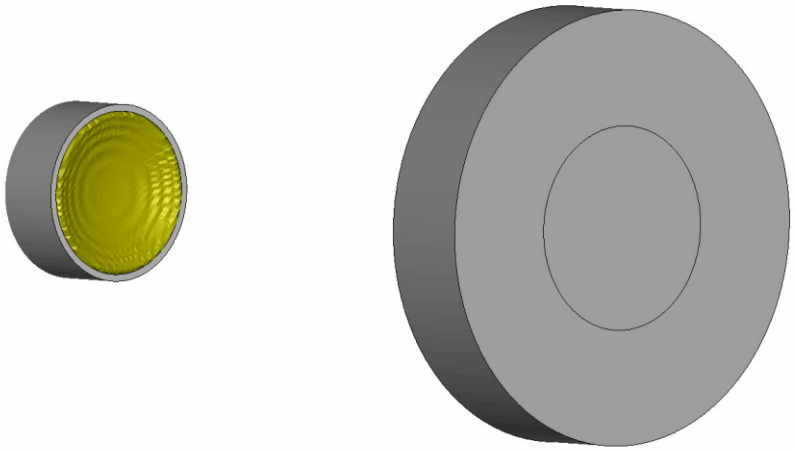


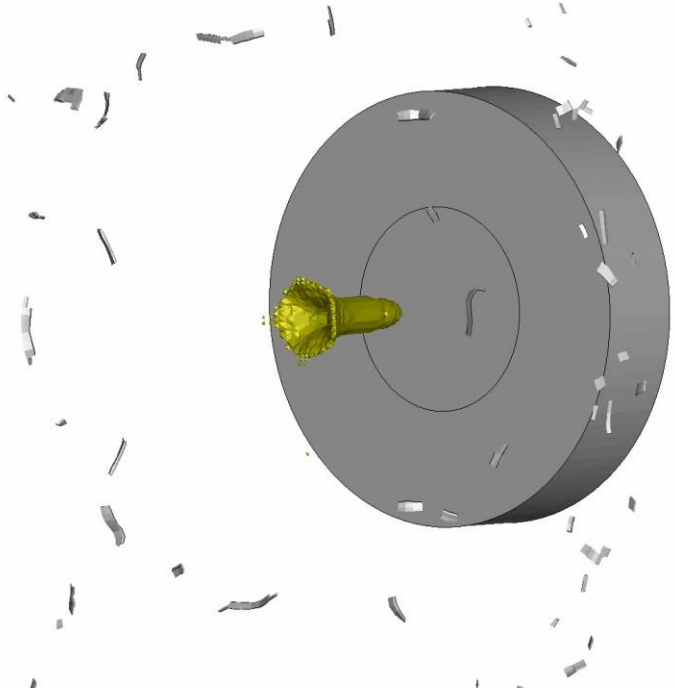


Application – Flying bullet with FSI



Application – Explosively formed penetrator

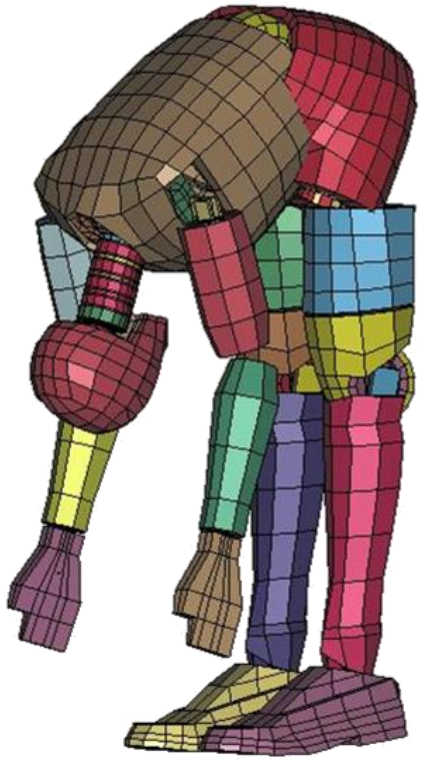




Recent progress

- The *ALE_STRUCTURED_FSI leakage prevention continuously improves – Try the latest version…
- Thermal support implemented for single material
- FSI thermal support implemented to allow heat exchanges between fluids and structure
- Multi-material thermal support under development…
- *CONTROL_EXPLOSIVE_SHADOW has been reimplemented for SALE
- DYNAmores Defense guideline with best practices is being updated…
- It is distributed to customers with reasonable need

Thank You



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