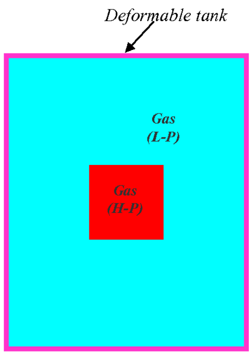
# Exercise 2 – Explosions in simple deformable containers

Add a deformable structure to the case studied in exercise 2 of Part II (air-filled tank).

- Try out ALE solution with FSA

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Geometric data:

For the fluid domain, same as exercise 2 of Part II. The structure is a thin shell of 0.01 units thickness

Materials

For the fluid domain, same as exercise 2 of Part II.

The structure material is a steel with the following characteristics: density 7800, Young's modulus $1.6\times10^{11}$, Poisson's coefficient 1/3, elastic limit $1.05\times10^{8}$, and a bilinear elasto-plastic traction curve characterized by the following points $(\sigma,\varepsilon)$:$1.05\times10^{8}$, $0.65626\times10^{-3}$, $1.6105\times10^{10}$, $1.00066$.

Numerical Solution

**TANK04**

We use the FSA directive to prescribe the fluid-structure interaction along the external edge of the fluid domain. The mesh generation file is:

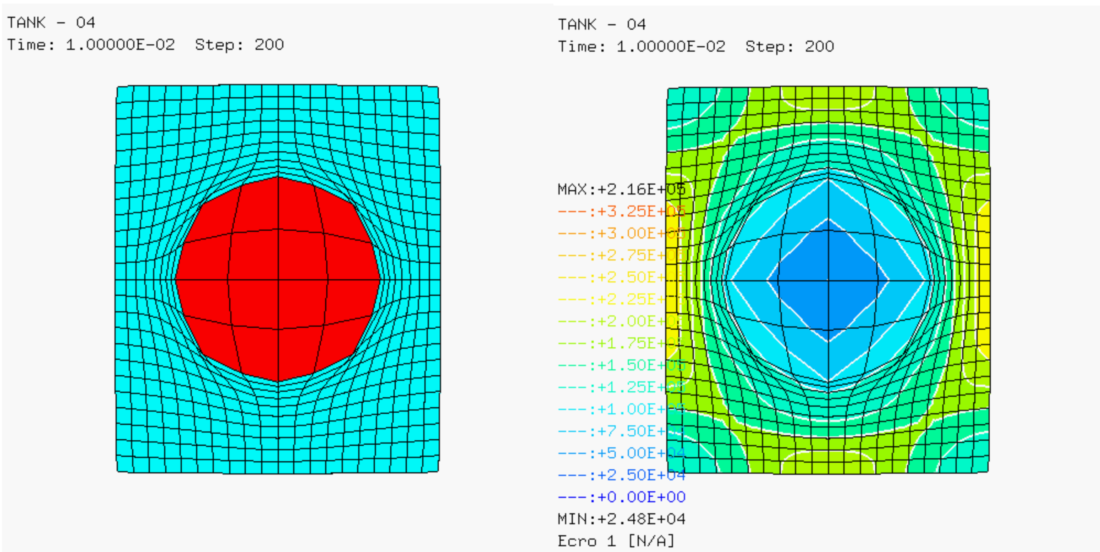
```
*%siz 100
opti echo 1;
opti dime 2 elem qua4;
p0 = 0 0;
p1 = 5 0;
p2 = 5 6;
p3 = 0 6;
p4 = 1 0;
p5 = 1 1;
p6 = 0 1;
p7 = 5 1;
p8 = 1 6;
tol = 0.01;
n1 = 2;
n2 = 8;
n3 = 10;
c1 = p0 d n1 p4;
c2 = p4 d n1 p5;
c3 = p5 d n1 p6;
c4 = p6 d n1 p0;
bull = (dall c1 c2 c3 c4 plan) coul roug;
lag = c2 et c3;
c1 = p4 d n2 p1;
c2 = p1 d n1 p7;
c3 = p7 d n2 p5;
c4 = p5 d n1 p4;
gaz1 = (dall c1 c2 c3 c4 plan) coul turq;
c1 = p5 d n2 p7;
c2 = p7 d n3 p2;
c3 = p2 d n2 p8;
c4 = p8 d n3 p5;
gaz2 = (dall c1 c2 c3 c4 plan) coul turq;
```

```
c1 = p6 d n1 p5;
c2 = p5 d n3 p8;
c3 = p8 d n1 p3;
c4 = p3 d n3 p6;
gaz3 = (dall c1 c2 c3 c4 plan) coul turq;
gaz = (gaz1 et gaz2 et gaz3) coul turq;
flui = bull et gaz;
elim tol flui;
p1p = p1 plus p0;
p2p = p2 plus p0;
p3p = p3 plus p0;
str1 = (p1p d (n1 + n3) p2p) coul rose;
str2 = (p2p d (n1 + n2) p3p) coul rose;
stru = (str1 et str2) coul rose;
lag = lag et stru;
symx = (flui poin droi p0 p3 tol) et p3p;
fsan = flui poin droi p1 p2 tol;
symy = (flui poin droi p0 p1 tol) et p1p;
fsan = fsan et (flui poin droi p3 p2 tol);
e1 = bull elem cont p0;
e2 = gaz  elem cont p2;
mesh = flui et stru et symx et symy et fsan et e1 et e2 et lag;
tass mesh;
opti sauv form 'tank04.msh';
sauv form mesh;
opti trac psc;
trac qual mesh;
list (nbel flui);
list (nbno flui);
fin;
```

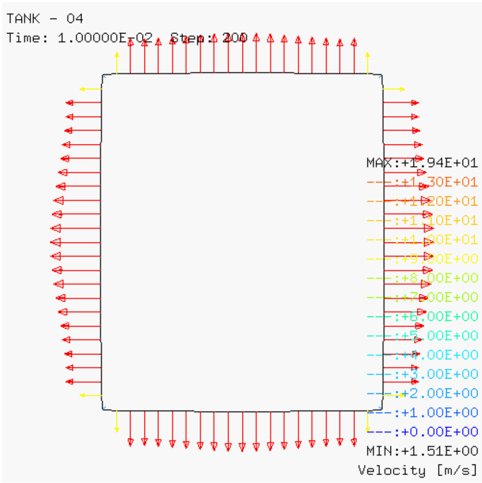
The input file is:

```
TANK - 04
*-----------------------------------------------------------------------
 ECHO
*CONV win
CAST mesh
*-----------------------------------------------------------Problem type
DPLA NONL ALE
*-----------------------------------------------------------Dimensioning
DIME
 PT3L 23 PT2L 143 FL24 145 ED01 22 ZONE 2
 NALE 150 NBLE 150
TERM
*---------------------------------------------------------------Geometry
GEOM FL24 flui ED01 stru TERM
*------------------------------------------------Geometric complements
COMP EPAI 0.01 LECT stru TERM
*------------------------------------------------------------Grid motion
GRIL LAGR LECT lag  TERM
     ALE  LECT flui TERM
     AUTO AUTR
*----------------------------------------------------------Material data
MATE FLUT RO 10  EINT 2.5E5 GAMM 1.4 PB 0 ITER 1 ALF0 1 BET0 1 KINT 1
          AHGF 0 CL 0.5 CQ 2.56 PMIN 0 NUM 1 LECT bull TERM
     FLUT RO 1   EINT 2.5E5 GAMM 1.4 PB 0 ITER 1 ALF0 1 BET0 1 KINT 1
          AHGF 0 CL 0.5 CQ 2.56 PMIN 0 NUM 1 LECT gaz  TERM
     VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT stru TERM
*----------------------------------------------------Boundary conditions
LINK COUP
     CONT SPLA NX 1 NY 0 LECT symx TERM
     CONT SPLA NX 0 NY 1 LECT symy TERM
     FSA LECT fsan TERM
*----------------------------------------------------------------Outputs
ECRI COOR DEPL VITE CONT ECRO TFRE 1.E-3
     FICH ALIC TEMP FREQ 1
               POIN LECT p1 p3 TERM
               ELEM LECT e1 e2 TERM
*----------------------------------------------------------------Options
OPTI NOTE
     CSTA 0.5
     LOG 1
     REZO GAM0 0.5
*-------------------------------------------------Transient calculation
CALCUL TINI 0 TEND 10.E-3
*==================================================================
PLAY

CAME   1 EYE   0.00000E+00  0.00000E+00  3.90512E+01
!        Q     1.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
         VIEW  0.00000E+00  0.00000E+00 -1.00000E+00
         RIGH  1.00000E+00  0.00000E+00  0.00000E+00
         UP    0.00000E+00  1.00000E+00  0.00000E+00
         FOV   2.48819E+01

scen geom navi free
     !vect scco scal user prog 0 pas 25 325 term
     !text vsca
     !iso  fili fiel ecro 1 scal user prog 0.e0 pas 0.25e5 3.25e5 term
     !text isca
     !vect scco scal user prog 0.e0 pas 1.e0 1.3e1 term
     !text vsca
      colo pape

freq 1

sler cam1 1        nfra 1
trac offs fich avi      nocl nfto 161 fps 10 kfre 10 comp -1
                                             !obje lect flui term
                                             !obje lect stru term
                                                  symx symy rend
gotr loop 159 offs fich avi cont nocl
                                             !obje lect flui term
                                             !obje lect stru term
                                                  symx symy rend
go
trac offs fich avi cont
                                             !obje lect flui term
                                             !obje lect stru term
                                                  symx symy rend

ENDPLAY
*==========================================================POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1000.0 'Time [ms]'
*-------------------------------------------------------Curve definitions
COUR 1 'dx_1'     DEPL COMP 1 NOEU LECT p1 TERM
COUR 2 'dy_3'     DEPL COMP 2 NOEU LECT p3 TERM
COUR 3 'pr_1'     ECRO COMP 1 ELEM LECT e1 TERM
COUR 4 'pr_2'     ECRO COMP 1 ELEM LECT e2 TERM
*-------------------------------------------------------------------Plots
trac 1 2 axes 1.0 'DISPL. [M]' yzer
trac 3 4 axes 1.0 'PRESS. [PA]'
*--------------------------------------------------Results qualification
QUAL DEPL COMP 1 LECT  p1 TERM REFE 7.70209E-02  TOLE 1.E-2
     DEPL COMP 2 LECT  p3 TERM REFE 6.65486E-02  TOLE 1.E-2
     CONT COMP 1 LECT  e1 TERM REFE 2.47742E+04  TOLE 1.E-2
     CONT COMP 1 LECT  e2 TERM REFE 1.05241E+05  TOLE 1.E-2
*=======================================================================
FIN
```

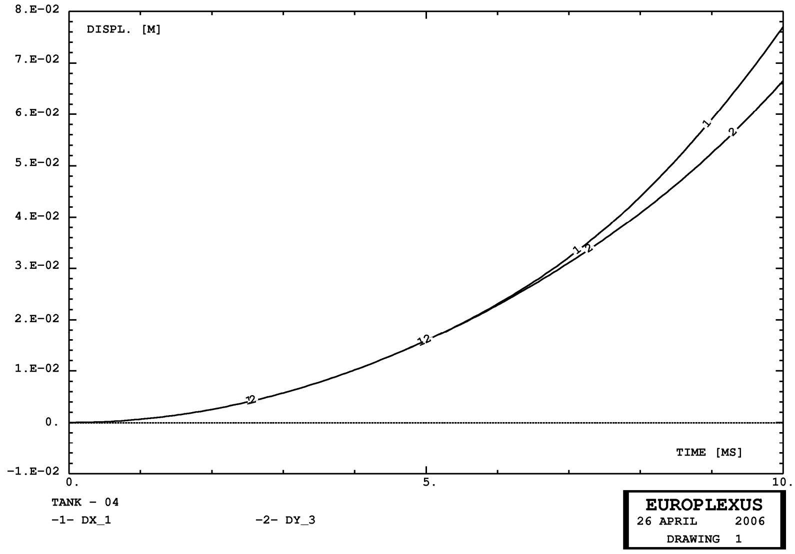
The resulting final deformed mesh with superposed velocity field and the final pressure field is:



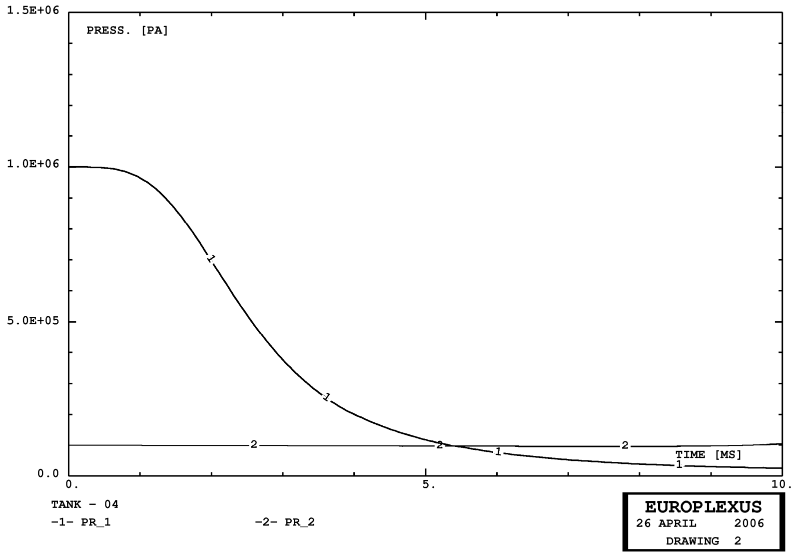

The final structure velocities:




The displacements of the horizontal and vertical mid-points are:



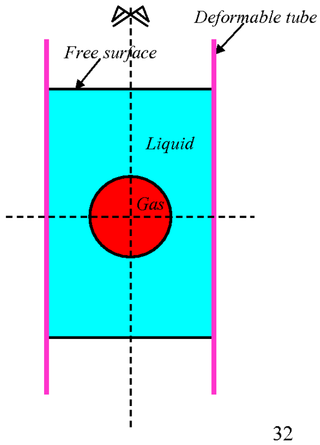

and the fluid pressure histories:



# Exercise 2 – Explosions in simple deformable containers (3)

Treat as deformable the tube of the case studied in exercise 3 of Part II.

- Can one try out ALE solution with FSA?
- Alternative 1: use Lagrangian sliding
- Alternative 2: use FSA with multi-phase multi-component fluid model

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ALE solution with FSA: it is <u>not</u> possible (with a single-component fluid material model), because the F-S contact in this case is <u>non-permanent</u> due to the fact that the liquid free surface (Lagrangian) slides along the tube wall (Lagrangian).

<u>Alternative 1</u>

Use Lagrangian sliding between the liquid and the tube.

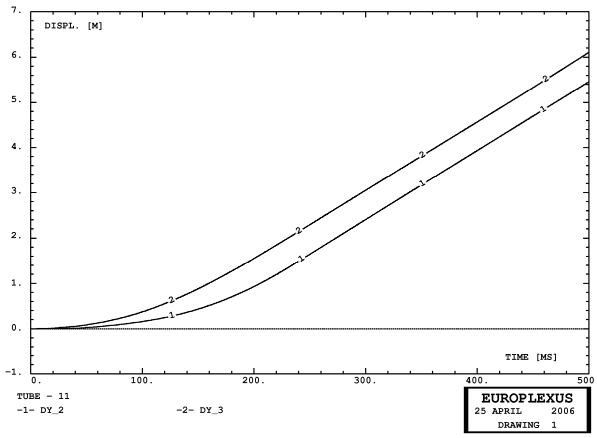
**TUBE11**

The input file is:

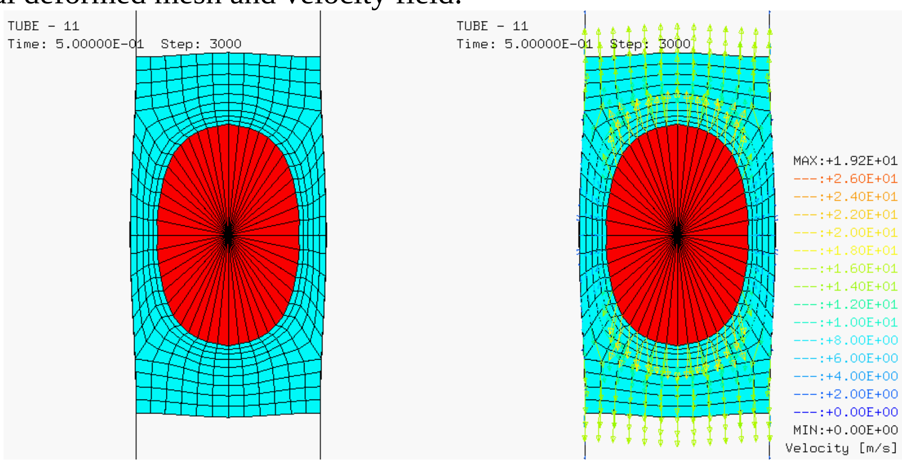
```
TUBE - 11
*----------------------------------------------------------------------
 ECHO
 CONV win
*----------------------------------------------------------Problem type
AXIS NONL ALE
*----------------------------------------------------------Dimensioning
DIME
 PT3L 38 PT2L 107 FL23 12 FL24 84 ED41 18 ZONE 3
 NALE 1 NBLE 98
 FSSL 100
TERM
*--------------------------------------------------------------Geometry
GEOM LIBR POIN 145 FL23 12 FL24 84 ED41 18 TERM
 0.00000E+00 0.00000E+00 3.14500E+00 0.00000E+00 3.11810E+00
 4.10500E-01 3.03780E+00 8.13990E-01 2.90560E+00 1.20350E+00
 2.72360E+00 1.57250E+00 2.49510E+00 1.91460E+00 2.22390E+00
 2.22390E+00 1.91460E+00 2.49510E+00 1.57250E+00 2.72360E+00
 1.20350E+00 2.90560E+00 8.13990E-01 3.03780E+00 4.10500E-01
 3.11810E+00 0.00000E+00 3.14500E+00 5.15600E+00 0.00000E+00
 5.09970E+00 7.30510E-01 5.00880E+00 1.45180E+00 4.86420E+00
 2.15130E+00 4.64850E+00 2.81320E+00 4.34360E+00 3.41610E+00
 3.93350E+00 3.93350E+00 3.41610E+00 4.34360E+00 2.81320E+00
 4.64850E+00 2.15130E+00 4.86420E+00 1.45180E+00 5.00880E+00
 7.30510E-01 5.09970E+00 0.00000E+00 5.15600E+00 7.16700E+00
 0.00000E+00 7.11050E+00 1.06860E+00 7.02640E+00 2.12620E+00
 6.88680E+00 3.15600E+00 6.65900E+00 4.13330E+00 6.30030E+00
 5.02060E+00 5.76190E+00 5.76190E+00 5.02060E+00 6.30030E+00
 4.13330E+00 6.65900E+00 3.15600E+00 6.88680E+00 2.12620E+00
 7.02640E+00 1.06860E+00 7.11050E+00 0.00000E+00 7.16700E+00
 9.17800E+00 0.00000E+00 9.13620E+00 1.42630E+00 9.07480E+00
 2.84270E+00 8.96560E+00 4.23180E+00 8.76610E+00 5.56250E+00
 8.40820E+00 6.78060E+00 7.78260E+00 7.78260E+00 6.78060E+00
 8.40820E+00 5.56250E+00 8.76610E+00 4.23180E+00 8.96560E+00
 2.84270E+00 9.07480E+00 1.42630E+00 9.13620E+00 0.00000E+00
 9.17800E+00 1.11890E+01 0.00000E+00 1.11680E+01 1.80470E+00
 1.11370E+01 3.60290E+00 1.10790E+01 5.38310E+00 1.09600E+01
 7.11960E+00 1.07060E+01 8.75410E+00 1.01290E+01 1.01290E+01
 8.75410E+00 1.07060E+01 7.11960E+00 1.09600E+01 5.38310E+00
 1.10790E+01 3.60290E+00 1.11370E+01 1.80470E+00 1.11680E+01
 0.00000E+00 1.11890E+01 1.32000E+01 0.00000E+00 1.32000E+01
 2.20000E+00 1.32000E+01 4.40000E+00 1.32000E+01 6.60000E+00
 1.32000E+01 8.80000E+00 1.32000E+01 1.10000E+01 1.32000E+01
 1.32000E+01 1.10000E+01 1.32000E+01 8.80000E+00 1.32000E+01
 6.60000E+00 1.32000E+01 4.40000E+00 1.32000E+01 2.20000E+00
 1.32000E+01 6.29420E-06 1.32000E+01 1.32000E+01 1.49000E+01
 1.10000E+01 1.49000E+01 8.80000E+00 1.49000E+01 6.60000E+00
 1.49000E+01 4.40000E+00 1.49000E+01 2.20000E+00 1.49000E+01
 6.29420E-06 1.49000E+01 1.32000E+01 1.66000E+01 1.10000E+01
 1.66000E+01 8.80000E+00 1.66000E+01 6.60000E+00 1.66000E+01
 4.40000E+00 1.66000E+01 2.20000E+00 1.66000E+01 6.29420E-06
1.66000E+01 1.32000E+01 1.83000E+01 1.10000E+01 1.83000E+01
8.80000E+00 1.83000E+01 6.60000E+00 1.83000E+01 4.40000E+00
1.83000E+01 2.20000E+00 1.83000E+01 6.29420E-06 1.83000E+01
1.32000E+01 2.00000E+01 1.10000E+01 2.00000E+01 8.80000E+00
2.00000E+01 6.60000E+00 2.00000E+01 4.40000E+00 2.00000E+01
2.20000E+00 2.00000E+01 6.29420E-06 2.00000E+01
13.2 0 13.2 2.2 13.2 4.4 13.2 6.6 13.2 8.8 13.2 11
13.2 13.2 13.2 14.9 13.2 16.6 13.2 18.3 13.2 20 13.2 22
13.2 24 13.2 26 13.2 28 13.2 30 13.2 32 13.2 34 13.2 36
13.22 0 13.22 2.2 13.22 4.4 13.22 6.6 13.22 8.8 13.22 11
13.22 13.2 13.22 14.9 13.22 16.6 13.22 18.3 13.22 20 13.22 22
13.22 24 13.22 26 13.22 28 13.22 30 13.22 32 13.22 34 13.22 36
     2     3     1           3     4     1           4     5
     1           5     6     1           6     7     1
     7     8     1           8     9     1           9    10
     1          10    11     1          11    12     1
    12    13     1          13    14     1           2    15
    16     3     3    16    17     4     4    17    18     5
     5    18    19     6     6    19    20     7     7    20
    21     8     8    21    22     9     9    22    23    10
    10    23    24    11    11    24    25    12    12    25
    26    13    13    26    27    14    15    28    29    16
    16    29    30    17    17    30    31    18    18    31
    32    19    19    32    33    20    20    33    34    21
    21    34    35    22    22    35    36    23    23    36
    37    24    24    37    38    25    25    38    39    26
    26    39    40    27    28    41    42    29    29    42
    43    30    30    43    44    31    31    44    45    32
    32    45    46    33    33    46    47    34    34    47
    48    35    35    48    49    36    36    49    50    37
    37    50    51    38    38    51    52    39    39    52
    53    40    41    54    55    42    42    55    56    43
    43    56    57    44    44    57    58    45    45    58
    59    46    46    59    60    47    47    60    61    48
    48    61    62    49    49    62    63    50    50    63
    64    51    51    64    65    52    52    65    66    53
    54    67    68    55    55    68    69    56    56    69
    70    57    57    70    71    58    58    71    72    59
    59    72    73    60    60    73    74    61    61    74
    75    62    62    75    76    63    63    76    77    64
    64    77    78    65    65    78    79    66    73    80
    81    74    74    81    82    75    75    82    83    76
    76    83    84    77    77    84    85    78    78    85
    86    79    80    87    88    81    81    88    89    82
    82    89    90    83    83    90    91    84    84    91
    92    85    85    92    93    86    87    94    95    88
    88    95    96    89    89    96    97    90    90    97
    98    91    91    98    99    92    92    99   100    93
    94   101   102    95    95   102   103    96    96   103
   104    97    97   104   105    98    98   105   106    99
    99   106   107   100
```

```
 109 108 127 128
 110 109 128 129
 111 110 129 130
 112 111 130 131
 113 112 131 132
 114 113 132 133
 115 114 133 134
 116 115 134 135
 117 116 135 136
 118 117 136 137
 119 118 137 138
 120 119 138 139
 121 120 139 140
 122 121 140 141
 123 122 141 142
 124 123 142 143
 125 124 143 144
 126 125 144 145
*---------------------------------------------------Geometric Complements
COMP GROU 3 'expl' LECT 1 PAS 1 12 TERM
            'liq'  LECT 13 PAS 1 96 TERM
            'stru' LECT 97 PAS 1 114 TERM
     COUL roug LECT expl TERM
          turq LECT liq  TERM
          rose LECT stru TERM
     EPAIS 0.02 LECT stru TERM
*-------------------------------------------------------------Grid Motion
GRIL LAGR LECT 1 PAS 1 14 67 PAS 1 73 PAS 7 101 PAS 1 107 PAS 1 145 TERM
     ALE TOUS
     AUTO AUTR
*-----------------------------------------------------------Material data
MATE FLUT RO 1.E3 EINT 0 GAMM 2.E9 PB 0 ITER 1 ALF0 1 BET0 1 KINT 0
          AHGF 0 CL 0.5 CQ 2.56 PMIN 0 NUM 9 LECT 13 PAS 1 96 TERM
     FLUT RO 1.E2 EINT 2.5E5 GAMM 1.4 PB 0 ITER 1 ALF0 1 BET0 1 KINT 0
          AHGF 0 CL 0.5 CQ 2.56 PMIN 0 NUM 1 LECT 1 PAS 1 12 TERM
     VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT stru TERM
*-----------------------------------------------------Boundary conditions
LINK COUP
     BLOQ 1 LECT 1 14 PAS 13
                 79 PAS 7 107 TERM
     BLOQ 2 LECT 1 67 2 15 28 41 54 108 127 TERM
     BLOQ 3 LECT 108 127 TERM
LINK DECO
     FSS LAGR NCT1 10
              LECT 61 67 68 TERM
              LECT 62 68 69 TERM
              LECT 63 69 70 TERM
              LECT 64 70 71 TERM
              LECT 65 71 72 TERM
              LECT 66 72 73 TERM
              LECT 73 73 80 TERM
              LECT 79 80 87 TERM
              LECT 85 87 94 TERM
              LECT 91 94 101 TERM
          NPOI 11
          NCT2 18
              LECT 97 108 109 TERM
              LECT 98 109 110 TERM
              LECT 99 110 111 TERM
              LECT 100 111 112 TERM
              LECT 101 112 113 TERM
              LECT 102 113 114 TERM
              LECT 103 114 115 TERM
              LECT 104 115 116 TERM
              LECT 105 116 117 TERM
              LECT 106 117 118 TERM
              LECT 107 118 119 TERM
              LECT 108 119 120 TERM
              LECT 109 120 121 TERM
              LECT 110 121 122 TERM
              LECT 111 122 123 TERM
              LECT 112 123 124 TERM
              LECT 113 124 125 TERM
              LECT 114 125 126 TERM
          NPOI 19
*----------------------------------------------------------------Outputs
ECRI COOR DEPL VITE CONT ECRO TFRE 100.E-3
     FICH ALIC TEMP FREQ 1
               POIN LECT 101 107 TERM
               ELEM LECT 1 91 TERM
*----------------------------------------------------------------Options
OPTI NOTE
 csta 0.5
 log 1
 rezo gam0 0.5
*---------------------------------------------------Transient calculation
CALCUL TINI 0 TEND 500.E-3
*==============================================================ANIMATION
PLAY

CAME   1 EYE   0.00000E+00  0.00000E+00  1.19817E+02
!        Q     1.00000E+00  0.00000E+00  0.00000E+00  0.00000E+00
         VIEW  0.00000E+00  0.00000E+00 -1.00000E+00
         RIGH  1.00000E+00  0.00000E+00  0.00000E+00
         UP    0.00000E+00  1.00000E+00  0.00000E+00
         FOV   3.00000E+01

scen geom navi free
     !vect scco scal user prog 0.e0 pas 2.e0 2.6e1 term
     !text vsca
      colo pape

freq 0 tfre 2.e-3

sler cam1 1        nfra 1
trac offs fich avi      nocl nfto 251 fps 10 kfre 10 comp -1
                                                   symx symy rend
gotr loop 249 offs fich avi cont nocl
                                                   symx symy rend
go
trac offs fich avi cont
                                                   symx symy rend

ENDPLAY
*==========================================================POST-TREATMENT
SUIT
Post-treatment
ECHO
RESU ALIC TEMP GARD PSCR
SORT GRAP
AXTE 1000.0 'Time [ms]'
*-----------------------------------------------------Curve definitions
COUR 1 'dy_2'     DEPL COMP 2 NOEU LECT 101 TERM
COUR 2 'dy_3'     DEPL COMP 2 NOEU LECT 107 TERM
COUR 3 'pr_1'     ECRO COMP 1 ELEM LECT 1   TERM
COUR 4 'pr_2'     ECRO COMP 1 ELEM LECT 91  TERM
*-------------------------------------------------------------------Plots
trac 1 2 axes 1.0 'DISPL. [M]' yzer
trac 3 4 axes 1.0 'PRESS. [PA]'
*--------------------------------------------------Results qualification
QUAL DEPL COMP 2 LECT 101 TERM REFE 5.43306E+00  TOLE 1.E-2
     DEPL COMP 2 LECT 107 TERM REFE 6.07702E+00  TOLE 1.E-2
     ECRO COMP 1 LECT   1 TERM REFE 3.80273E+04  TOLE 1.E-2
     ECRO COMP 1 LECT  91 TERM REFE 0.00000E+00  TOLE 1.E-2
*=======================================================================
FIN
```

The surface displacements are:




The final deformed mesh and velocity field:

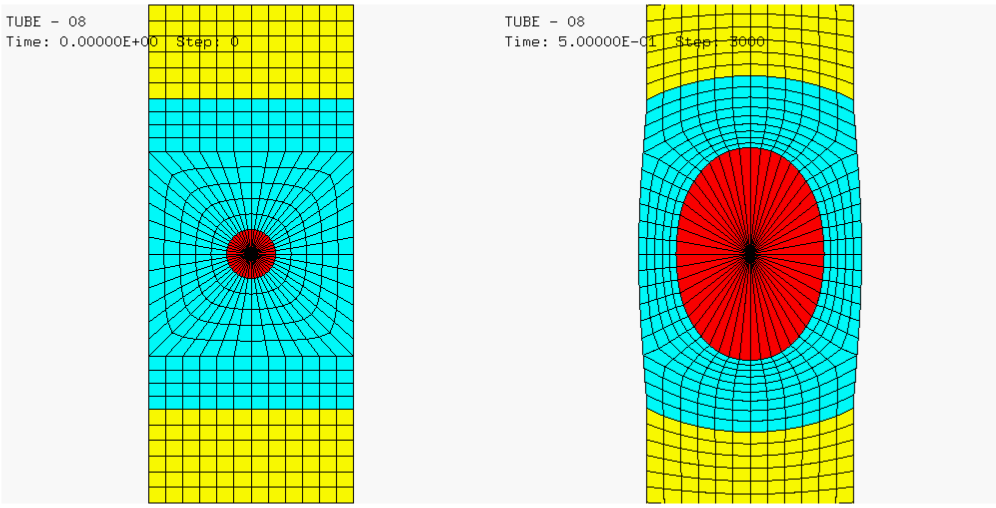


Alternative 2

Use multi-phase multi-component fluid model to get rid of Lagrangian fluid/structure interfaces, and standard FSA model for fluid-structure interaction.

**TUBE08**

To make this type of simulation possible, we model an additional fluid region (in itially filled by air at atmospheric pressure) above the liquid free surface. This region (in yellow in the following drawings) will be filled by the rising liquid during the transient. The initial mesh and the final mesh are (note that the red zone indicates the bubble, whose surface is Lagrangian, but the other two zones are not representative of materials, since the liquid-air interface is ALE):




The final velocities and liquid mass fractions: