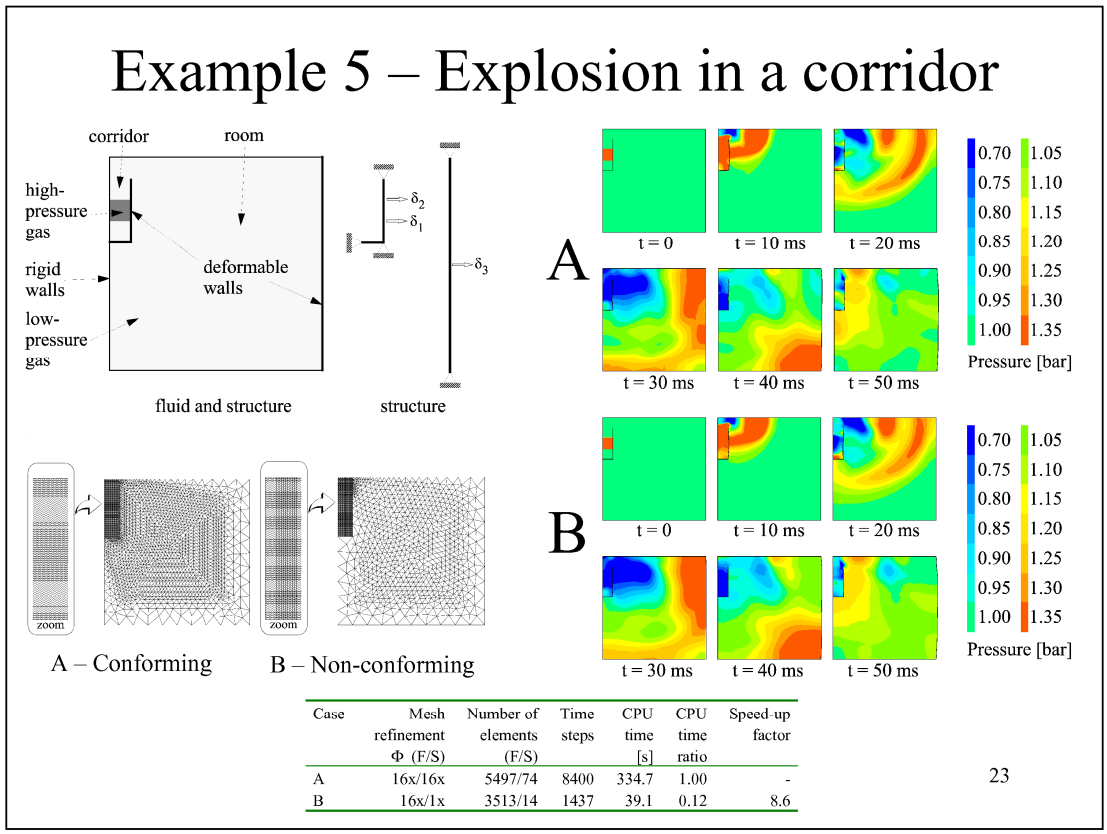


Case	Mesh refinement Φ (F/S)	Number of elements (F/S)	Time steps	CPU time [s]	CPU time ratio	Speed-up factor
A	16x/16x	5497/74	8400	334.7	1.00	-
B	16x/1x	3513/14	1437	39.1	0.12	8.6

Geometric data and materials:

The domain is 10 units wide and 10 units high. The bubble is square in shape and has unit sides. The walls are rigid except the corridor and the rightmost wall.

The fluids are perfect gases. The structure is steel with an elasto-plastic law.

Numerical Solutions

DENS01

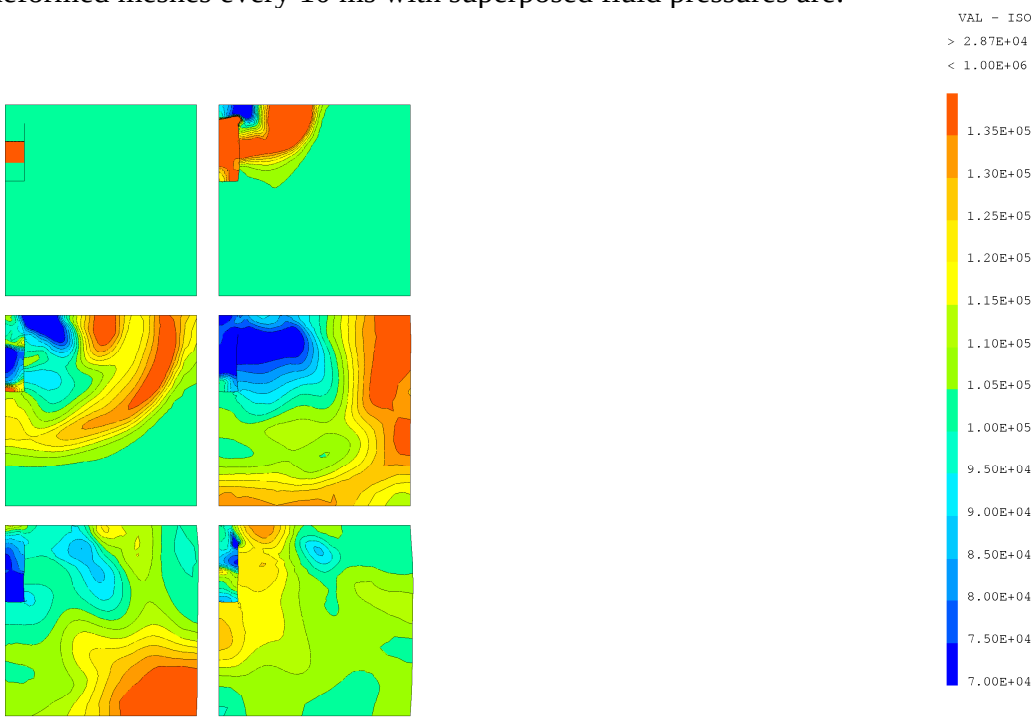
This model uses conforming FSI. The mesh generation file is:

```
*%siz 4000
opti echo 1;
opti titr 'DENS - 01';
opti sauv form 'dens01.msh';
opti dime 2 elem tri3;
opti trac psc ftra 'dens01_mesh.ps';
tol = 0.0001;
dmax = 1.0;
dmin = 1.0 / 16.0;
p1 = 0 0;
p2 = 10 0;
p3 = 10 10;
p4 = 0 10;
p5 = 0 6;
p6 = 1 6;
p7 = 0 9;
p8 = 1 9;
p9 = 1 10;
p10 = 0 8;
p11 = 1 8;
p12 = 0 7;
p13 = 1 7;
c1 = p1 d 10 p2;
c2 = p2 d 10 p3;
fsan = c2;
c3 = p3 d p9 dini dmax dfin dmin;
c4a = p9 d p8 dini dmin dfin dmin;
c4b = p8 d p6 dini dmin dfin dmin;
fsan = fsan et c4b;
c4c = p6 d p5 dini dmin dfin dmin;
fsan = fsan et c4c;
c4 = c4a et c4b et c4c;
c5 = p5 d p1 dini dmin dfin dmax;
s1 = surf (c1 et c2 et c3 et c4 et c5) plan;
p5b = p5 plus p1;
p6b = p6 plus p1;
c1 = p5b d p6b dini dmin dfin dmin;
fsan = fsan et c1;
c2 = p6b d p13 dini dmin dfin dmin;
fsan = fsan et c2;
c3 = p13 d p12 dini dmin dfin dmin;
c4 = p12 d p5b dini dmin dfin dmin;
s2 = dall c1 c2 c3 c4 plan;
c1 = p12 d p13 dini dmin dfin dmin;
c2 = p13 d p11 dini dmin dfin dmin;
fsan = fsan et c2;
c3 = p11 d p10 dini dmin dfin dmin;
c4 = p10 d p12 dini dmin dfin dmin;
s3 = dall c1 c2 c3 c4 plan;
elim tol (s2 et s3);
c1 = p10 d p11 dini dmin dfin dmin;
c2 = p11 d p8 dini dmin dfin dmin;
fsan = fsan et c2;
c3 = p8 d p7 dini dmin dfin dmin;
c4 = p7 d p10 dini dmin dfin dmin;
s4 = dall c1 c2 c3 c4 plan;
elim tol (s3 et s4);
c1 = p7 d p8 dini dmin dfin dmin;
c2 = p8 d p9 dini dmin dfin dmin;
c3 = p9 d p4 dini dmin dfin dmin;
c4 = p4 d p7 dini dmin dfin dmin;
s5 = dall c1 c2 c3 c4 plan;
elim tol (s4 et s5);
elim tol (s5 et s1);
flui = s1 et s2 et s3 et s4 et s5;
p5s = p5 plus p1;
p6s = p6 plus p1;
p8s = p8 plus p1;
p2s = p2 plus p1;
p3s = p3 plus p1;
stru1 = p5s d p6s dini dmin dfin dmin;
stru2 = p6s d p8s dini dmin dfin dmin;
stru3 = p2s d 10 p3s;
stru = stru1 et stru2 et stru3;
bloc = p5s et p6s et p8s et p2s et p3s;
fsrn = flui poin droi p1 p4 tol;
fsrn = fsrn et (flui poin droi p1 p2 tol);
fsrn = fsrn et (flui poin droi p4 p3 tol);
fsrn = chan poi1 fsrn;
fsan = chan poi1 fsan;
fsan = fsan diff (fsan inte fsrn);
d1 = stru poin proc p13;
d2 = stru poin proc p11;
d3 = stru poin proc (10 5);
tpln = d1 et d2 et d3;
e1 = s2 elem cont p5b;
e2 = s5 elem cont p4;
e3 = s1 elem cont p3;
e4 = s1 elem cont p2;
e5 = s1 elem cont p1;
tple = e1 et e2 et e3 et e4 et e5;

mesh = flui et stru et fsan et fsrn et tple et tpln et bloc;
tass mesh;
trac flui;
trac stru;
trac fsrn;
trac fsan;
coco = cont flui;
trac qual (coco et tpln et tple);
sauv form mesh;
list (nbno flui);
list (nbno stru);
list (nbno fsan);
list (nbno fsrn);
list (nbel flui);
list (nbel stru);
opti trac mif;
trac s1;
trac (s2 et s3 et s4 et s5);
trac flui;
trac stru;
trac fsrn;
trac fsan;
trac qual (coco et tpln et tple);
fin;
```

The input file is:

```
DENS01
ECHO
!CONV win
CAST mesh
DPLA ALE
DIME
  NALE 54 NBLE 1
  BLOQ 1200
  FSA 136 IFSA 534
  LIAI 833
  ndvc 16172
TERM
GEOM FL23 flui ED01 stru TERM
COMP EPAI 0.01 LECT stru TERM
GRIL LAGR LECT stru TERM
     EULE LECT fsrn fsan TERM
     MEAN AUTR
OPTI REZO MVRE MODU LIAI
MATE VM23 RO 8000 YOUNG 2.E11 NU 0.3 ELAS 4.E8
          TRAC 3 4.E8 2.E-3 2.4E9 1.002E0 2.4E9 10.
          LECT stru TERM
     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
          pref 1.e5
          LECT s3 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
          pref 1.e5
          LECT s1 s2 s4 s5 TERM
LIAI freq 1
     BLOQ 123 LECT bloc TERM
     FSR LECT fsrn TERM
     FSA LECT fsan TERM
ECRI DEPL VITE ECRO TFRE 10.E-3
     POIN LECT tpln TERM
     ELEM LECT tple TERM
     TRAC TPLO DESC 'DENS01' TFRE 51.E-6
               POIN LECT tpln TERM
               ELEM LECT tple TERM
     fich alic temp TFRE 51.E-6
               POIN LECT tpln TERM
               ELEM LECT tple TERM
     FICH FORM K200 TFRE 2.E-3
          POIN TOUS
          VARI DEPL VITE ECRO ECRC LECT 1 3 TERM
OPTI NOTE
  CSTA 0.6D0
* MOMT 2
  FSCR
  DTML
  LOG 1
CALCUL TINI 0. TEND 50.E-3
*
SUIT
Post-treatment
ECHO
*
RESU ALIC TEMP GARD PSCR
*
SORT GRAP
*
AXTE 1.0 'Time [s]'
*
COUR  1 'dx_1'  DEPL COMP 1 POIN LECT d1 TERM
COUR  2 'dx_2'  DEPL COMP 1 POIN LECT d2 TERM
COUR  3 'dx_3'  DEPL COMP 1 POIN LECT d3 TERM
COUR  4 'p_e1'  ECRO COMP 1 ELEM LECT e1 TERM
COUR  5 'p_e2'  ECRO COMP 1 ELEM LECT e2 TERM
COUR  6 'p_e3'  ECRO COMP 1 ELEM LECT e3 TERM
COUR  7 'p_e4'  ECRO COMP 1 ELEM LECT e4 TERM
COUR  8 'p_e5'  ECRO COMP 1 ELEM LECT e5 TERM
*
trac 1 2 3 axes 1.0 'D [M]'
trac 4 5 6 7 8 axes 1.0 'P [PA]'
list 1 2 3 axes 1.0 'D [M]'
list 4 5 6 7 8 axes 1.0 'P [PA]'
*
*QUAL VITE comp 1 lect 51 term REFE 8.25539E+2 TOLE 5.E-3
*     ECRO comp 1 lect 50 term REFE 3.41392E+5 TOLE 5.E-3
FIN
```

The deformed meshes every 10 ms with superposed fluid pressures are:



DENS01

DENS02

We use a sixteen times coarser structural mesh. The F-S interface is non-conforming. The mesh generation file is:

```
*%siz 4000
opti echo 1;
opti titr 'DENS - 02';
opti sauv form 'dens02.msh';
opti dime 2 elem tri3;
opti trac psc ftra 'dens02_mesh.ps';
tol = 0.0001;
dmax = 1.0;
dmin = 1.0 / 16.0;
p1 = 0 0;
p2 = 10 0;
p3 = 10 10;
p4 = 0 10;
p5 = 0 6;
p6 = 1 6;
p7 = 0 9;
p8 = 1 9;
p9 = 1 10;
p10 = 0 8;
p11 = 1 8;
p12 = 0 7;
p13 = 1 7;
c1 = p1 d 10 p2;
c2 = p2 d 10 p3;
fsan = c2;
c3 = p3 d p9 dini dmax dfin dmin;
c4a = p9 d p8 dini dmin dfin dmin;
c4b = p8 d p6 dini dmin dfin dmax;
fsan = fsan et c4b;
c4c = p6 d p5 dini dmax dfin dmax;
fsan = fsan et c4c;
c4 = c4a et c4b et c4c;
c5 = p5 d p1 dini dmax dfin dmax;
s1 = surf (c1 et c2 et c3 et c4 et c5) plan;
p5b = p5 plus p1;
p6b = p6 plus p1;
c1 = p5b d p6b dini dmin dfin dmin;
fsan = fsan et c1;
c2 = p6b d p13 dini dmin dfin dmin;
fsan = fsan et c2;
c3 = p13 d p12 dini dmin dfin dmin;
c4 = p12 d p5b dini dmin dfin dmin;
s2 = dall c1 c2 c3 c4 plan;
c1 = p12 d p13 dini dmin dfin dmin;
c2 = p13 d p11 dini dmin dfin dmin;
fsan = fsan et c2;
c3 = p11 d p10 dini dmin dfin dmin;
c4 = p10 d p12 dini dmin dfin dmin;
s3 = dall c1 c2 c3 c4 plan;
elim tol (s2 et s3);
c1 = p10 d p11 dini dmin dfin dmin;
c2 = p11 d p8 dini dmin dfin dmin;
```

```
fsan = fsan et c2;
c3 = p8 d p7 dini dmin dfin dmin;
c4 = p7 d p10 dini dmin dfin dmin;
s4 = dall c1 c2 c3 c4 plan;
elim tol (s3 et s4);
c1 = p7 d p8 dini dmin dfin dmin;
c2 = p8 d p9 dini dmin dfin dmin;
c3 = p9 d p4 dini dmin dfin dmin;
c4 = p4 d p7 dini dmin dfin dmin;
s5 = dall c1 c2 c3 c4 plan;
elim tol (s4 et s5);
elim tol (s5 et s1);
flui = s1 et s2 et s3 et s4 et s5;
p5s = p5 plus p1;
p6s = p6 plus p1;
p8s = p8 plus p1;
p2s = p2 plus p1;
p3s = p3 plus p1;
stru1 = p5s d p6s dini dmax dfin dmax;
stru2 = p6s d p8s dini dmax dfin dmax;
stru3 = p2s d 10 p3s;
stru = stru1 et stru2 et stru3;
bloc = p5s et p6s et p8s et p2s et p3s;
fsrn = flui poin droi p1 p4 tol;
fsrn = fsrn et (flui poin droi p1 p2 tol);
fsrn = fsrn et (flui poin droi p4 p3 tol);
fsrn = chan poi1 fsrn;
fsan = chan poi1 fsan;
fsan = fsan diff (fsan inte fsrn);
d1 = stru poin proc p13;
d2 = stru poin proc p11;
d3 = stru poin proc (10 5);
```

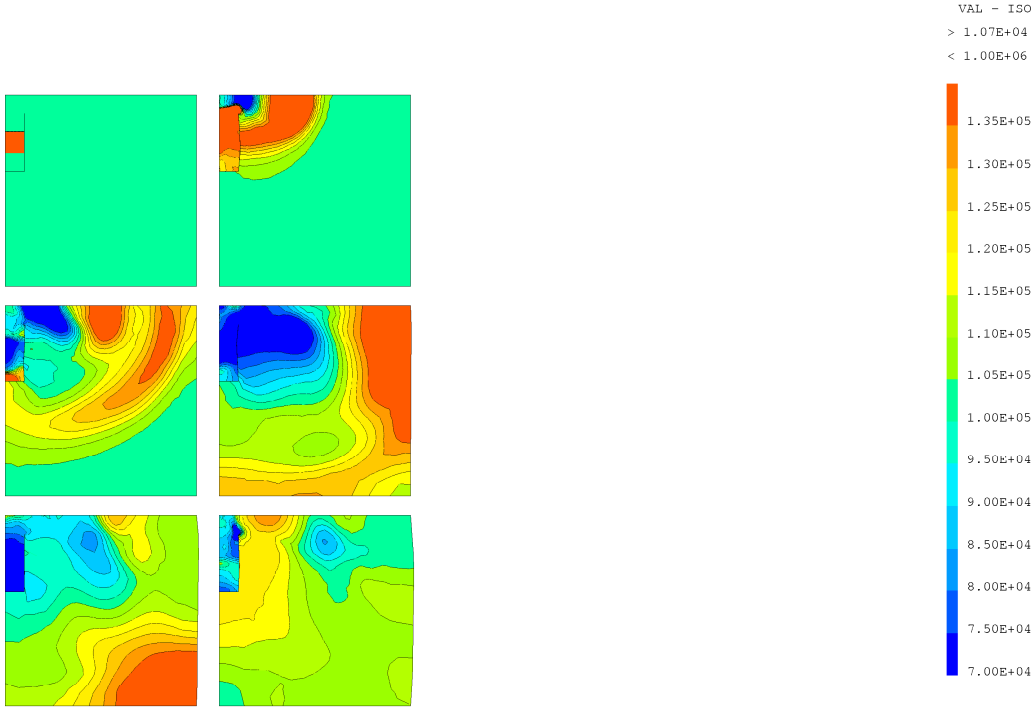
```
tpln = d1 et d2 et d3;
e1 = s2 elem cont p5b;
e2 = s5 elem cont p4;
e3 = s1 elem cont p3;
e4 = s1 elem cont p2;
e5 = s1 elem cont p1;
tple = e1 et e2 et e3 et e4 et e5;

mesh = flui et stru et fsan et fsrn et tple et tpln et bloc;
tass mesh;
trac flui;
trac stru;
trac fsrn;
trac fsan;
coco = cont flui;
trac qual (coco et tpln et tple);
sauv form mesh;
list (nbno flui);
list (nbno stru);
list (nbno fsan);
list (nbno fsrn);
list (nbel flui);
list (nbel stru);
opti trac mif;
trac s1;
trac (s2 et s3 et s4 et s5);
trac flui;
trac stru;
trac fsrn;
trac fsan;
trac qual (coco et tpln et tple);
fin;
```

The input file:

```
DENS02
ECHO
!CONV win
CAST mesh
DPLA ALE
DIME
  NALE 46 NBLE 1
  BLOQ 1200
  FSA 85 IFSA 316
  LIAI 729
  ndvc 9913
TERM
GEOM FL23 flui ED01 stru TERM
COMP EPAI 0.01 LECT stru TERM
GRIL LAGR LECT stru TERM
     EULE LECT fsrn fsan TERM
     MEAN AUTR
OPTI REZO MVRE MODU LIAI
MATE VM23 RO 8000 YOUNG 2.E11 NU 0.3 ELAS 4.E8
          TRAC 3 4.E8 2.E-3 2.4E9 1.002E0 2.4E9 10.
          LECT stru TERM
     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
          pref 1.e5
          LECT s3 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
          pref 1.e5
          LECT s1 s2 s4 s5 TERM
LIAI freq 1
     BLOQ 123 LECT bloc TERM
     FSR LECT fsrn TERM
     FSA NCFS LECT fsan TERM
ECRI DEPL VITE ECRO TFRE 10.E-3
     POIN LECT tpln TERM
     ELEM LECT tple TERM
     TRAC TPLO DESC 'DENS02' TFRE 51.E-6
               POIN LECT tpln TERM
               ELEM LECT tple TERM
     fich alic temp TFRE 51.E-6
               POIN LECT tpln TERM
               ELEM LECT tple TERM
     FICH FORM K200 TFRE 2.E-3
          POIN TOUS
          VARI DEPL VITE ECRO ECRC LECT 1 3 TERM
```

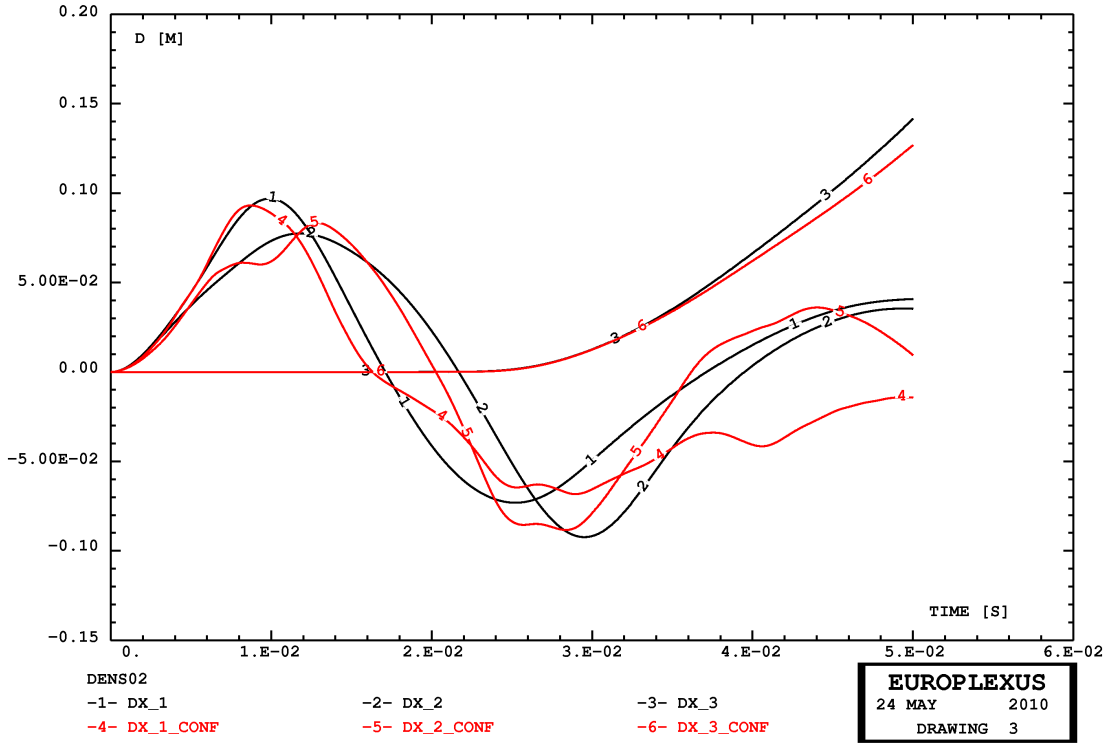
```
OPTI NOTE
  CSTA 0.60D0
* MOMT 2
  FSCR
  DTML
  LOG 1
CALCUL TINI 0. TEND 50.E-3
*
SUIT
Post-treatment
ECHO
*
RESU ALIC TEMP GARD PSCR
*
SORT GRAP
*
AXTE 1.0 'Time [s]'
*
COUR  1 'dx_1'  DEPL COMP 1 POIN LECT d1 TERM
COUR  2 'dx_2'  DEPL COMP 1 POIN LECT d2 TERM
COUR  3 'dx_3'  DEPL COMP 1 POIN LECT d3 TERM
COUR  4 'p_e1'  ECRO COMP 1 ELEM LECT e1 TERM
COUR  5 'p_e2'  ECRO COMP 1 ELEM LECT e2 TERM
COUR  6 'p_e3'  ECRO COMP 1 ELEM LECT e3 TERM
COUR  7 'p_e4'  ECRO COMP 1 ELEM LECT e4 TERM
COUR  8 'p_e5'  ECRO COMP 1 ELEM LECT e5 TERM
RCOU 11 'dx_1'  FICH 'dens01.pun' RENA 'dx_1_conf'
RCOU 12 'dx_2'  FICH 'dens01.pun' RENA 'dx_2_conf'
RCOU 13 'dx_3'  FICH 'dens01.pun' RENA 'dx_3_conf'
RCOU 14 'p_e1'  FICH 'dens01.pun' RENA 'p_e1_conf'
RCOU 15 'p_e2'  FICH 'dens01.pun' RENA 'p_e2_conf'
RCOU 16 'p_e3'  FICH 'dens01.pun' RENA 'p_e3_conf'
RCOU 17 'p_e4'  FICH 'dens01.pun' RENA 'p_e4_conf'
RCOU 18 'p_e5'  FICH 'dens01.pun' RENA 'p_e5_conf'
*
trac 1 2 3 axes 1.0 'D [M]'
trac 4 5 6 7 8 axes 1.0 'P [PA]'
trac 1 2 3 11 12 13 axes 1.0 'D [M]'
     COLO noir noir noir roug roug roug
trac 4 5 6 7 8 14 15 16 17 18 axes 1.0 'P [PA]'
     COLO noir noir noir noir noir roug roug roug roug roug
*
*QUAL VITE comp 1 lect 51 term REFE 8.25539E+2 TOLE 5.E-3
*     ECRO comp 1 lect 50 term REFE 3.41392E+5 TOLE 5.E-3
FIN
```

The deformed meshes every 10 ms with superposed fluid pressures are:



DENS02

Comparison of structural displacements in the conforming (in red) and non-conforming (in black) solutions:



Comparison of fluid pressures in the conforming (in red) and non-conforming (in black) solutions: