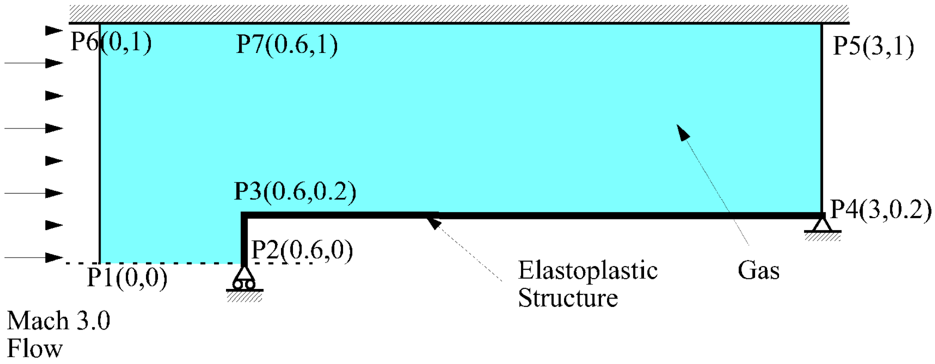
Exercise/Example 6 : Woodward-Colella Test (FV with deformable step)

Set up FV model and treat the step as deformable:



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The well-known Woodward-Colella test in 2D, revisited by using a deformable structure (FSI). Supersonic flow over a forward-facing deformable step.

PROBLEM:

This is the well-known Woodward-Colella problem, a benchmark used to validate CFD codes. A channel is filled by gas flowing at Mach 3, initially in uniform conditions. The channel is 3 m long, 1 m high and 0.4 m wide (but the problem may be considered as 2-D plane). A deformable step is introduced at time 0 at 0.6 m downstream from the channel inlet. The step is 0.2 m high and its thickness and material law are chosen so as to undergo relatively large deformations during the transient solution. An ALE calculation with fluid-structure interaction is performed. Mesh rezoning is done automatically by Giuliani's algorithm.

MESH:

The model is 2D plane deformation and uses 8064 MC34 triangular finite volumes (4193 nodes) for the fluid domain, and 104 beam/shell elements for the step.

MATERIALS:

The step is made of elasto-plastic metallic material (VM23), while the fluid is a mixture of perfect gases (MCGP). A special MCFF material is used to model the inlet and outlet conditions(far field).

BOUNDARY CONDITIONS:

The step is entirely blocked at the outlet, and blocked in thevertical direction only in the front tip. At the inlet and outlet suitable boundary conditions are prescribed in the fluid. The boundary conditions at the channel inlet also correspond to the initial conditions. The same boundary conditionsare assumed at the channel outlet, although they will not be taken into consideration by the numerical scheme, since they correspond to a supersonic outlet where all the characteristic lines leave the computational domain.

LOADING:

The system is initially at rest, but not in equilibrium since the pressure in the fluid will tend to deform the step, which is disturbing the initially uniform flow field.

CALCULATION:

The calculation is performed up to 3.5 ms. At the final time, the shock detached from the step has hit the upper part of the channel being reflected again towards the downstream portion of the step.

RESULTS:

These results have been found in good agreement with those reported in the literature for the case with rigid step.

POST-TREATMENT

Several animations of the computed results from this calculation are available on the EUROPLEXUS Consortium Web site.

REFERENCES:

The original problem is described in:

1) P. Woodward and P. Colella: "The numerical simulation of Two-Dimensional Fluid Flow with Strong Shocks", J. Comp. Phys., 54, pp. 115-173 (1984).

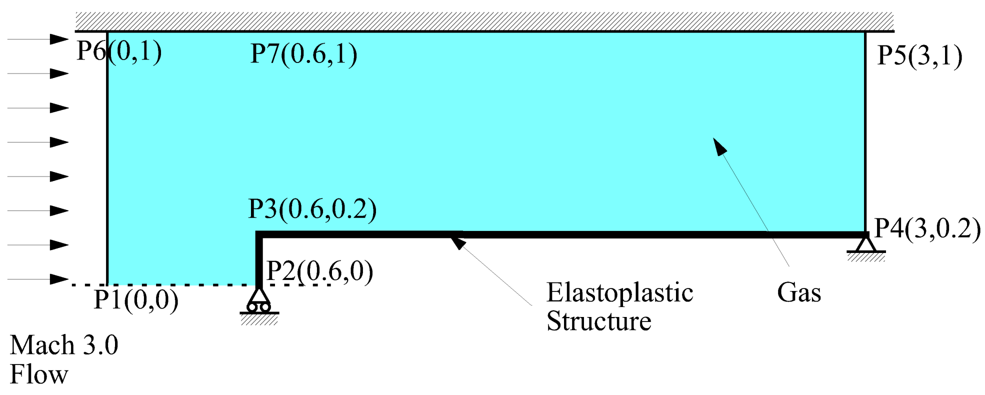
This calculation is detailed in the following two references, both available in the EUROPLEXUS Consortium Web site:

2) A. Soria, F. Casadei: "Modelling of Arbitrary Lagrangian-Eulerian Multicomponent Flow with Fluid-Structure Interaction in PLEXIS-3C." Special Publication N. I.95.01, Jan. 1995.

3) A. Soria, F. Casadei: "Arbitrary Lagrangian-Eulerian Multicomponent Compressible Flow with Fluid-Structure Interaction." International Journal for Numerical Methods in Fluids, Vol. 25, pp. 1263--1284, December 1997.

Numerical Solutions

WOCO2D



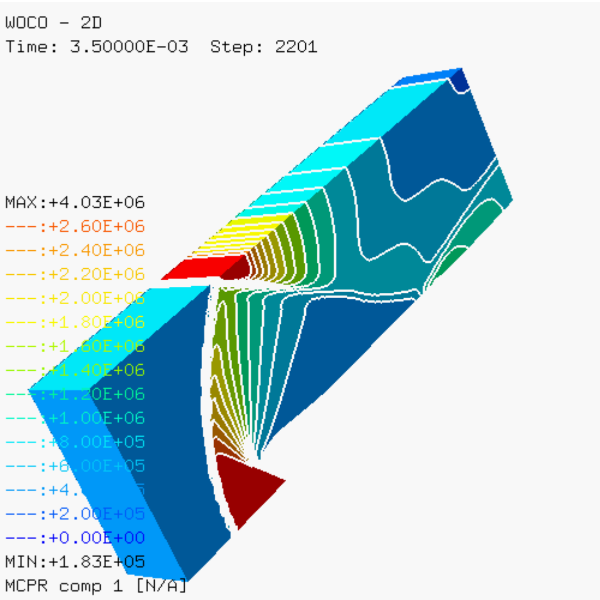
The mesh generation file (K2000) is:

```
*%siz 100
*
opti echo 1 dime 2 elem qua4;
opti titr 'WOCO - 2D';
*
p1 = 0 0;
p2 = 0.6 0;
p3 = 0.6 0.2;
p4 = 3 0.2;
p5 = 3 1;
p6 = 0 1;
p7 = 0.6 1;
tol = 0.001;
*
in = p1 d 40 p6;
s1 = in tran 24 (0.6 0);
s1 = chan s1 tri3;
*
la = p3 d 32 p7;
s2 = la tran 96 (2.4 0);
s2 = chan s2 tri3;
*
lh1 = p1 d 24 p2;
lh2 = p3 d 96 p4;
lh3 = p5 d 120 p6;
lv  = p2 d 8 p3;
out = p4 d 32 p5;
*
lfsa = lh2 et lv;
*
flui = s1 et s2;
mesh = flui et lfsa et in et out et lh1 et lh3;
*
elim tol mesh;
*
p2s = p2 'PLUS' p1;
p3s = p3 'PLUS' p1;
p4s = p4 'PLUS' p1;
strt = p2s d 8 p3s d 96 p4s;
*
mesh = mesh et strt;
*
tass mesh;
*
opti sauv form 'woco2d.msh';
sauv form mesh;
opti trac psc ftra 'woco2d_mesh.ps';
trac mesh;
trac qual mesh;
```

The EUROPLEXUS input file reads:

```
WOCO - 2D
$
 ECHO
!CONV win
CAST MESH
DPLA NONL ALE
$
DIME
 PT2L 4193 PT3l 105 ZONE 3
 ED01 104 CL22 72 MC23 8064
 NDVC 24513
 NALE 42 NBLE 4119
 TABL 1 10
 ELVC 500
 mtpo 10
TERM
$
GEOM
  MC23 flui
  ED01 strt
  CL22 in out
TERM
EPAI 0.020 LECT strt TERM
$
$OPTI DUMP
$
GRIL LAGR LECT strt   TERM
     EULE LECT in out TERM
     ALE  LECT flui   TERM
     AUTO AUTR
$
$ multicomponent material
MATE MCGP NCOM 2 R 8312.
          COMP 'Air' PM 28.96 CV1 20780 CV2 0 CV3 0
          COMP 'Nitrogen' PM 28.96 CV1 20780 CV2 0 CV3 0
          LECT flui TERM
     MCFF BDFO 3 TEMP 400. PRES 300000.
          VEL1 1202.7 VEL2 0. VEL3 0.
          COMP 'Air'       MFRA 1.
          COMP 'Nitrogen'  MFRA 0.
          LECT in out TERM
     VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT strt TERM
$
INIT MCOM COMP 'Air'      MFRA 1.0 LECT TOUS
          COMP 'Nitrogen' MFRA 0.0 LECT TOUS
          PRES 300000.     LECT TOUS
          TEMP 400.        LECT TOUS
          VEL1 1202.7      LECT TOUS
          VEL2 0.00        LECT TOUS
          VEL3 0.00        LECT TOUS
$
LINK COUP
     BLOQ 123 LECT p4s         TERM
     BLOQ 2   LECT p2s lh3 lh1 TERM
     FSA      LECT lfsa        TERM
$
ECRI DEPL VITE MCVA POIN LECT p1 p2 p2s p3 p3s p4 p4s p5 p6 p7 TERM
          TFREQ 0.5E-3
     FICH K200 TFREQ 0.5E-3 POIN TOUS
     FICH ALIC TFRE 1.0E-5
$
OPTI NOTE CSTA 0.5
OPTI MC ORDR 2 NUFL ROE
 rezo gam0 0.5
 log 1
CALCUL TINI 0 TEND 3.5E-3
*================================================================
SUIT
Post-treatment (time curves from alice file)
ECHO
*
RESU ALIC GARD PSCR
*
SORT GRAP
*
AXTE 1000.0 'Time [ms]'
*
COUR  1 'dx_p2'   DEPL COMP 1 NOEU LECT p2 TERM
COUR  2 'dx_p3'   DEPL COMP 1 NOEU LECT p3 TERM
COUR  3 'dy_p3'   DEPL COMP 2 NOEU LECT p3 TERM
COUR  4 'vx_p1'   VITE COMP 1 NOEU LECT p1 TERM
COUR  5 'vx_p4'   VITE COMP 1 NOEU LECT p4 TERM
COUR  6 'pr_p7'   MCPR COMP 1 NOEU LECT p7 TERM
COUR  7 'pr_p2'   MCPR COMP 1 NOEU LECT p2 TERM
COUR  8 'pr_p4'   MCPR COMP 1 NOEU LECT p4 TERM
*
trac 1 2 3  axes 1.0 'DISPL. [M]'
trac 4 5    axes 1.0 'VELOC. [M/S]'
trac 6 7 8  axes 1.0 'PRESS [PA]'
*
QUAL DEPL COMP 1 LECT p2   TERM REFE  1.30900E-1 TOLE 2.E-2
     DEPL COMP 1 LECT p3   TERM REFE  1.18235E-2 TOLE 2.E-2
     DEPL COMP 2 LECT p3   TERM REFE -3.93403E-2 TOLE 2.E-2
     VITE COMP 1 LECT p1   TERM REFE  1.20270E+3 TOLE 2.E-2
     VITE COMP 1 LECT p4   TERM REFE  1.09280E+3 TOLE 2.E-2
     MCPR COMP 1 LECT p7   TERM REFE  3.00000E+5 TOLE 2.E-2
     MCPR COMP 1 LECT p2   TERM REFE  3.23207E+6 TOLE 2.E-2
     MCPR COMP 1 LECT p4   TERM REFE  7.07217E+5 TOLE 2.E-2
*================================================================
FIN
```

Some results: final pressure distribution:



WOCO3D

The mesh generation file (K2000) is:

```
*%siz 100
*
opti echo 1 dime 3 elem cub8;
opti titr 'WOCO - 3D';
*
p1 = 0 0 0;
p2 = 0.6 0 0;
p3 = 0.6 0.2 0;
p4 = 3 0.2 0;
p5 = 3 1 0;
p6 = 0 1 0;
p7 = 0.6 1 0;
vz = 0 0 0.4;
tol = 0.001;
*
in = p1 d 40 p6;
s1 = in tran 24 (0.6 0 0);
s1 = chan s1 tri3;
*
la = p3 d 32 p7;
s2 = la tran 96 (2.4 0 0);
s2 = chan s2 tri3;
*
lh1 = p1 d 24 p2;
lh2 = p3 d 96 p4;
lh3 = p5 d 120 p6;
lv  = p2 d 8 p3;
out = p4 d 32 p5;
*
in  = in  tran 1 vz;
lh1 = lh1 tran 1 vz;
lh2 = lh2 tran 1 vz;
lh3 = lh3 tran 1 vz;
lv  = lv  tran 1 vz;
out = out tran 1 vz;
*
lfsa = lh2 et lv;
*
flui = (s1 et s2) volu tran 1 vz;
mesh = flui et lfsa et in et out et lh1 et lh3;
*
elim tol mesh;
*
p2s = p2 'PLUS' p1;
p3s = p3 'PLUS' p1;
p4s = p4 'PLUS' p1;
strt = p2s d 8 p3s d 96 p4s;
strt = strt tran 1 vz;
p2su = p2s 'PLUS' vz;
p4su = p4s 'PLUS' vz;
elim tol (strt et p2su et p4su);
*
mesh = mesh et strt;
*
tass mesh;
*
opti sauv form 'woco3d.msh';
sauv form mesh;
opti trac psc ftra 'woco3d_mesh.ps';
trac cach mesh;
trac cach qual mesh;
```

The EUROPLEXUS input file reads:

```
WOCO - 3D
$
 ECHO
!CONV win
CAST MESH
TRID NONL ALE
$
DIME
 PT3L 8386 PT6L 210 ZONE 3
 Q4GS 104 CL3Q 72 MC36 8064
 NDVC 57410
 NALE 84 NBLE 8238
 ELVC 500
 mtpo 10
TERM
$
GEOM
  MC36 flui
  Q4GS strt
  CL3Q in out
TERM
EPAI 0.020 LECT strt TERM
$
$OPTI DUMP
$
GRIL LAGR LECT strt   TERM
     EULE LECT in out TERM
     ALE  LECT flui   TERM
     AUTO AUTR
$
$ multicomponent material
MATE MCGP NCOM 2 R 8312.
          COMP 'Air' PM 28.96 CV1 20780 CV2 0 CV3 0
          COMP 'Nitrogen' PM 28.96 CV1 20780 CV2 0 CV3 0
          LECT flui TERM
     MCFF BDFO 3 TEMP 400. PRES 300000.
          VEL1 1202.7 VEL2 0. VEL3 0.
          COMP 'Air'        MFRA 1.
          COMP 'Nitrogen'   MFRA 0.
          LECT in out TERM
     VM23 RO 7800. YOUNG 1.6E11 NU 0.333 ELAS 1.05E8
          TRAC 2 1.05E8 .656256E-3 1.6105E10 1.00066
          LECT strt TERM
$
INIT MCOM COMP 'Air'      MFRA 1.0 LECT TOUS
          COMP 'Nitrogen' MFRA 0.0 LECT TOUS
          PRES 300000.      LECT TOUS
          TEMP 400.         LECT TOUS
          VEL1 1202.7       LECT TOUS
          VEL2 0.00         LECT TOUS
          VEL3 0.00         LECT TOUS
$
LINK COUP
     BLOQ 123456 LECT p4s p4su         TERM
     BLOQ 2      LECT p2s p2su lh3 lh1 TERM
     BLOQ 3      LECT TOUS
     FSA         LECT lfsa             TERM
$
ECRI DEPL VITE MCVA POIN LECT p1 p2 p2s p3 p3s p4 p4s p5 p6 p7 TERM
          TFREQ 0.5E-3
     FICH K200 TFREQ 0.5E-3 POIN TOUS
     FICH ALIC TFRE 1.0E-5
$
OPTI NOTE CSTA 0.5
OPTI MC ORDR 2 NUFL ROE
 rezo gam0 0.5
 log 1
CALCUL TINI 0 TEND 3.5E-3
*=================================================================
SUIT
Post-treatment (time curves from alice file)
ECHO
*
RESU ALIC GARD PSCR
*
SORT GRAP
*
AXTE 1000.0 'Time [ms]'
*
COUR  1 'dx_p2'   DEPL COMP 1 NOEU LECT p2 TERM
COUR  2 'dx_p3'   DEPL COMP 1 NOEU LECT p3 TERM
COUR  3 'dy_p3'   DEPL COMP 2 NOEU LECT p3 TERM
COUR  4 'vx_p1'   VITE COMP 1 NOEU LECT p1 TERM
COUR  5 'vx_p4'   VITE COMP 1 NOEU LECT p4 TERM
COUR  6 'pr_p7'   MCPR COMP 1 NOEU LECT p7 TERM
COUR  7 'pr_p2'   MCPR COMP 1 NOEU LECT p2 TERM
COUR  8 'pr_p4'   MCPR COMP 1 NOEU LECT p4 TERM
*
trac 1 2 3  axes 1.0 'DISPL. [M]'
trac 4 5    axes 1.0 'VELOC. [M/S]'
trac 6 7 8  axes 1.0 'PRESS [PA]'
*
QUAL DEPL COMP 1 LECT p2   TERM REFE  1.25965E-1 TOLE 2.E-2
     DEPL COMP 1 LECT p3   TERM REFE  1.00924E-2 TOLE 2.E-2
     DEPL COMP 2 LECT p3   TERM REFE -3.69872E-2 TOLE 2.E-2
     VITE COMP 1 LECT p1   TERM REFE  1.20270E+3 TOLE 2.E-2
     VITE COMP 1 LECT p4   TERM REFE  0.00000E+0 TOLE 2.E-2
     MCPR COMP 1 LECT p7   TERM REFE  3.00000E+5 TOLE 2.E-2
     MCPR COMP 1 LECT p2   TERM REFE  3.42310E+6 TOLE 2.E-2
     MCPR COMP 1 LECT p4   TERM REFE  4.53681E+5 TOLE 2.E-2
*=================================================================
FIN
```

Some results: final pressure distribution: