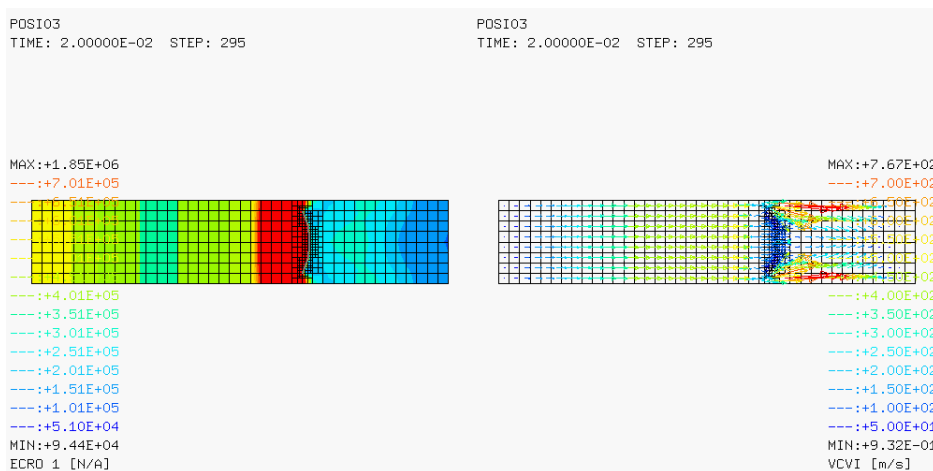


# On the interpretation and post-processing of mesh-adaptive numerical results in EUROPLEXUS

Folco Casadei  
Georgios Valsamos  
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2015

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European Commission  
Joint Research Centre  
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of mesh-adaptive numerical results  
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2 June 2015

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# 1. Introduction

This report is a sequel to reports and publications [1-16] on mesh adaptivity in fast transient dynamics and focuses on the post-treatment and interpretation of numerical results in calculations involving mesh adaptivity. The algorithms mentioned here are implemented in the EUROPLEXUS code.

EUROPLEXUS [17] is a computer code for fast explicit transient dynamic analysis of fluid-structure systems jointly developed by the French Commissariat à l’Energie Atomique et aux Energies Alternatives (CEA Saclay) and by the Joint Research Centre of the European Commission (JRC Ispra).

Reference [1] presented the first implementation in EUROPLEXUS of an adaptive mesh refinement and un-refinement procedure, in two space dimensions (element shape QUA4) for solid mechanics. The procedure was extended to fluid mechanics (FE formulation) in 2D in reference [2]. Then, reference [3] applied a similar refinement and un-refinement procedure in three space dimensions to the CUB8 element shape, both in solids mechanics and in fluid mechanics (FE formulation).

All numerical examples presented in references [1-3] with a variable mesh used a so-called “manual” mesh adaptation directive, the WAVE directive (see the code manual in reference [17]), first introduced in reference [1]. This directive refines the mesh along “wavefronts” that are specified by the user, e.g. according to a known analytical solution to the problem considered. This technique was used with success to simulate a bar problem (in solid mechanics) and a shock tube problem (in fluid mechanics) both in 2D and in 3D [1-3].

However, those solutions cannot be qualified as “true” adaptive solutions, because in (true) adaptivity mesh refinement and un-refinement should be completely automatic, based upon suitable *error estimators* or *error indicators*. The formulation of error estimators in fast transient dynamics is challenging and is still a subject of research. The use of so-called error indicators, however, is much simpler. For this reason, subsequent work in EUROPLEXUS focused on error indicators. References [4] and [5] document a first prototype implementation of adaptivity based upon error indicators in EUROPLEXUS, limited to 2D problems in continuum and fluid mechanics. An extension of the indicator technique to 3D is under development but has not been completed and documented yet.

Publications [6-7] focus on the natural quantities of interest in goal-oriented error assessment and adaptivity, but limited to the case of linear elasto-dynamics.

The adaptive technique was then applied to Cell-Centred Finite Volumes (CCFV) for the description of the fluid domain, first in 2D (see [8]) and then also in 3D [9]. More recently, the technique has also been extended for use with the CDEM combustion model which makes use of the CCFV formulation [10]. A complete description of the element refinement and un-refinement techniques used in mesh adaptation has been published in a paper [11].

A first contribution towards combination of mesh adaptivity with Fluid-Structure Interaction (FSI) was given in reference [12], in which a model is described that automatically refines the fluid mesh in the vicinity of an embedded structure which can move and deform until and beyond rupture (but without being itself subjected to adaptivity).

In [13] adaptivity was activated for simplex elements (triangles in 2D and tetrahedra in 3D). The report [14] extends adaptivity to CEA's family of fluid elements. Reference [15] extends adaptivity to shell, beam and bar structural elements. It becomes therefore possible to have mesh adaptivity both in a fluid and at the same time in a structure (typically made of shells) embedded in the fluid.

Finally, reference [16] extends the automatic fluid mesh adaptation of reference [12] to the case where adaptation of the structure according to the techniques described in [15] occurs simultaneously. This technique is particularly useful in conjunction with FSI algorithms of the *embedded* or *immersed* type, such as the FLSR or FLSW algorithms available in EUROPLEXUS.

The present work addresses the post-processing and the correct interpretation of results obtained in numerical simulations using mesh adaptivity.

This document is organized as follows:

- Section 2 discusses the potential problems related to the interpretation of mesh-adaptive results, and then proposes a methodology to deal with them.
- Section 3 presents some numerical examples for the verification of the proposed methodology.
- Section 4 presents a new syntax for the production of time curves for element- or node-related quantities, which allows to extract the values to be plotted at a chosen spatial position rather than at a given node or element. This can be very useful in mesh-adaptive computations but can be used also in normal (non-adaptive) computations.

The Appendix contains a listing of all the input files mentioned in the present report.

## 2. Interpretation of results

The interpretation and post-processing of numerical results in a mesh-adaptive numerical simulation is somewhat different from the standard case in which the mesh connectivity is fixed in time, and raises some problems. Therefore, a standard and well-defined procedure for dealing with such results is needed, in order to avoid possible mis-interpretation of results by the code users.

### 2.1 Example 1 : “static” mesh adaptation

Consider as a first example the simple mesh-adaptive model presented in Figure 1. A square rigid box contains a gas at normal pressure (blue region in the left picture). Near a corner an explosion takes place, represented by high-pressure gas (red region). The base mesh is shown in the central picture and consist of 4 (base) elements and 9 (base) nodes. Let us assume for simplicity that the user wants to refine the mesh locally at the beginning of the calculation but then keeps it constant during the whole transient (the case of a fully “dynamic” connectivity will be considered next).

If element 1 is refined once, we obtain the adapted mesh shown in the right picture. As a consequence of refinement:

- Element 1 becomes inactive. It generates four “children”, elements 5, 6, 7 and 8, which become active.
- Five new nodes are generated: nodes 10, 11, 12, 13 and 14.

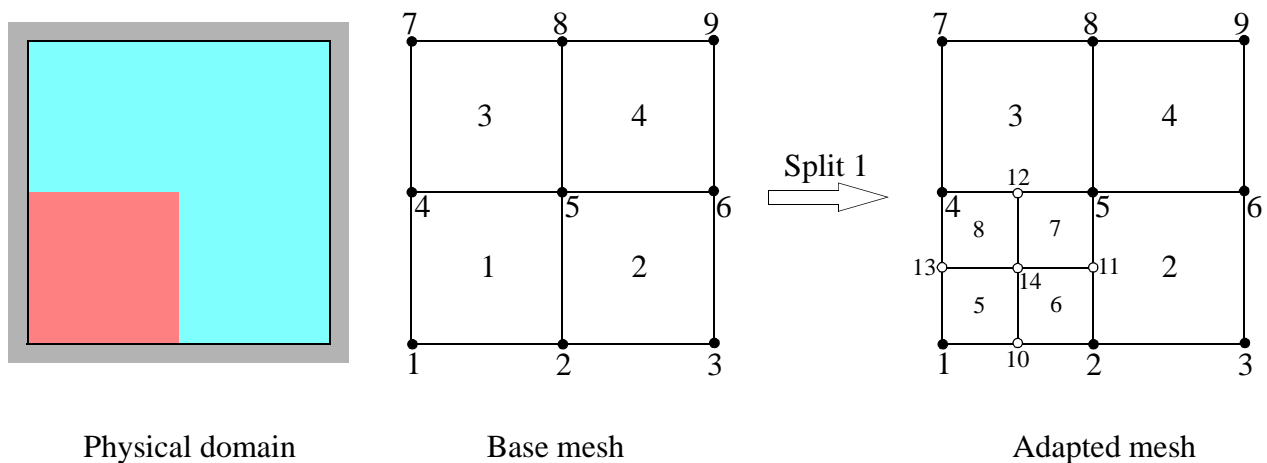


Figure 1 - A simple mesh-adaptive calculation

The calculation is performed, say just 5 time steps, and then the user wants to post-process the results. A typical set of required results could be:

1. Maps of some scalar quantity on the modelled domain at selected time instants in the form of iso-values, e.g. pressure maps. The quantity may be defined either at the elements or at the nodes.
2. Maps of some vector quantity on the modelled domain at selected time instants in the form of arrows, e.g. velocity maps. The quantity may be defined either at the elements or at the nodes.
3. Time curves showing the variation in time of a chosen scalar quantity at a chosen location in space. The quantity may be defined either at an element or at a node. For example, the pressure time history at a certain location (typically at an element center), or the velocity norm time history at a certain location (typically a node, but possibly an element center).
4. “Space” curves representing the variation of a scalar quantity along a curvilinear abscissa defined by an ordered sequence of nodes.

These results are usually presented in the form of graphs, images or animations built from a set of images. However, to complete the picture, one should also consider the possibility of having the results printed in the listing file, or listed in tabular form in an output file (e.g. the .PUN file).

Ideally, all such representations of results should be consistent among them, and “transparent” to the user as concerns their interpretation. This is indeed the case in standard (non-adaptive) calculations, but in the adaptive case some problems can arise.

### **2.1.1 Node-related curve results**

Let us first consider the case of the processing of node-related adaptive results in the form of time or space curves (points 3 and 4 above). In the simple adaptive case of Figure 1 this poses no problem, since:

- Base nodes never become inactive during an adaptive calculation (unlike base elements).
- In the particular example chosen, the (adapted) mesh stays constant during the whole transient, so the “descendant” nodes are also always active and each of them stays constantly attached to the same spatial position, since an Eulerian formulation is adopted for this problem. If the formulation would be Lagrangian, again no problem would occur and the descendant node would constantly remain attached to the same material particle.

Therefore, this type of processing can be done “normally”, like in a non-adaptive case, for this particularly simple adaptive problem. For example, the user may time-plot the velocity norm at node 2 (a base node) and at node 10 (a descendant node) in exactly the same manner.

We tentatively propose the following rule:

**Rule 1 : In an adaptive calculation, a node-related quantity:**

- I represents the value belonging to the node itself, if the node is currently used;*
- II is undefined (and should not be used) if the node is currently not used. Typically, the value is set to 0.0 in this case.*

**2.1.2 Element-based curve results**

The case of curves (in time or in space) based on element-related results is slightly more complex. Suppose for example that the user wants to follow in time the pressure in the “explosion” zone (left-bottom corner of the domain).

One possibility would be that of tracking the pressure in element 1. Although this element is inactive during the whole transient in this particular example, it represents a well-defined region of space, so its use seems legitimate.

Another possibility would be tracking the pressure in a more localized zone, e.g. in one of the descendants of element 1, say in element 5. Again, this makes sense since the descendants are active all the time and they are “static” in this particular example: each descendant always occupies the same region of space.

A precise definition is needed in order to avoid any confusion about the interpretation of results. We tentatively propose the following rule:

**Rule 2 : In an adaptive calculation, an element-related quantity:**

- I represents the value belonging to the element itself, if the element is currently active;*
- II represents the weighted average value of all its current active descendants, if the element is currently used but inactive;*
- III is undefined (and should not be used) if the element is currently not used. Typically, the value is set to 0.0 in this case.*

**2.1.3 Other types of results**

We consider now the other type of results (not in the form of time or space curves), i.e. those related to cases 1 and 2 in Section 2.1. These are maps in space, either in the form of iso-values or in the form of vectors.

Assume for example that the user wants to visualize the distribution of fluid pressure on the domain at a selected time. What he or she would probably expect is to see the current state of the mesh, i.e. only the currently active elements (elements 2 to 8 in this example) with superposed their pressure values. Since element 1 is always inactive, it should not be visible in this type of representation: its active “children” should be visible instead.

However, it may be difficult for a user to keep track of mesh adaptation. So, assuming that the pressure map must be visualized only on a part of the model, say, in the explosive region, it seems natural for the user to refer to this as “element 1” in this particular example.

More generally, the user normally should only know the base mesh of his model, and use parts of it, identified by lists of (typically) base element indexes, or object names, to visualize results only in some selected regions of the model.

Therefore, the following tentative rule is proposed:

**Rule 3 : In an adaptive calculation, a list of elements or the name of an object made by elements:**

- I represents the elements listed, if such elements are currently active;*
- II represents the set of all current active descendants of the elements listed, if such elements are currently used but inactive;*
- III is illegal if the elements listed are currently unused.*

The third (illegal) case may occur only if one uses a list of element indexes. In fact, if an object name or an element group name is used, this stays for a set of base elements which, by definition, are always used (although they can be inactive).

## **2.2 Example 2 : “dynamic” mesh adaptation**

Let us now consider the most general adaptive case, i.e. full “dynamic” mesh adaptation during the transient calculation. For example let us assume that the user wants to unsplit element 1 at step 3 of the calculation, and then wants to split element 4 at step 4, see Figure 2.

### **2.2.1 Node-related curve results**

In this case, curve-plotting of quantities related to base nodes can be done as usual, but when it comes to descendant nodes the situation changes, since a descendant node may be active only during part of the transient, and even when it’s active it may be attached to different spatial positions in time (if an Eulerian description is used), or to different material particles in time (if a Lagrangian description is used).

For example, this is the case for node 10. At steps 0 to 2 it represents a certain location. At step 3 it becomes unused (since the mesh is un-refined). Then, from step 4 on it represents another (different) spatial location.

The user must be aware of this when post-processing and interpreting adaptive results.

### 2.2.2 Element-based curve results

The case of curves (in time or in space) based on element-related results (for a descendant element) is similar to the case of nodal quantities already discussed in Section 2.2.1. A descendant element, say element 5 in Figure 2, represents a certain region of space at steps 0, 1 and 2, is undefined at step 3, and represents another region of space at steps 4 and 5.

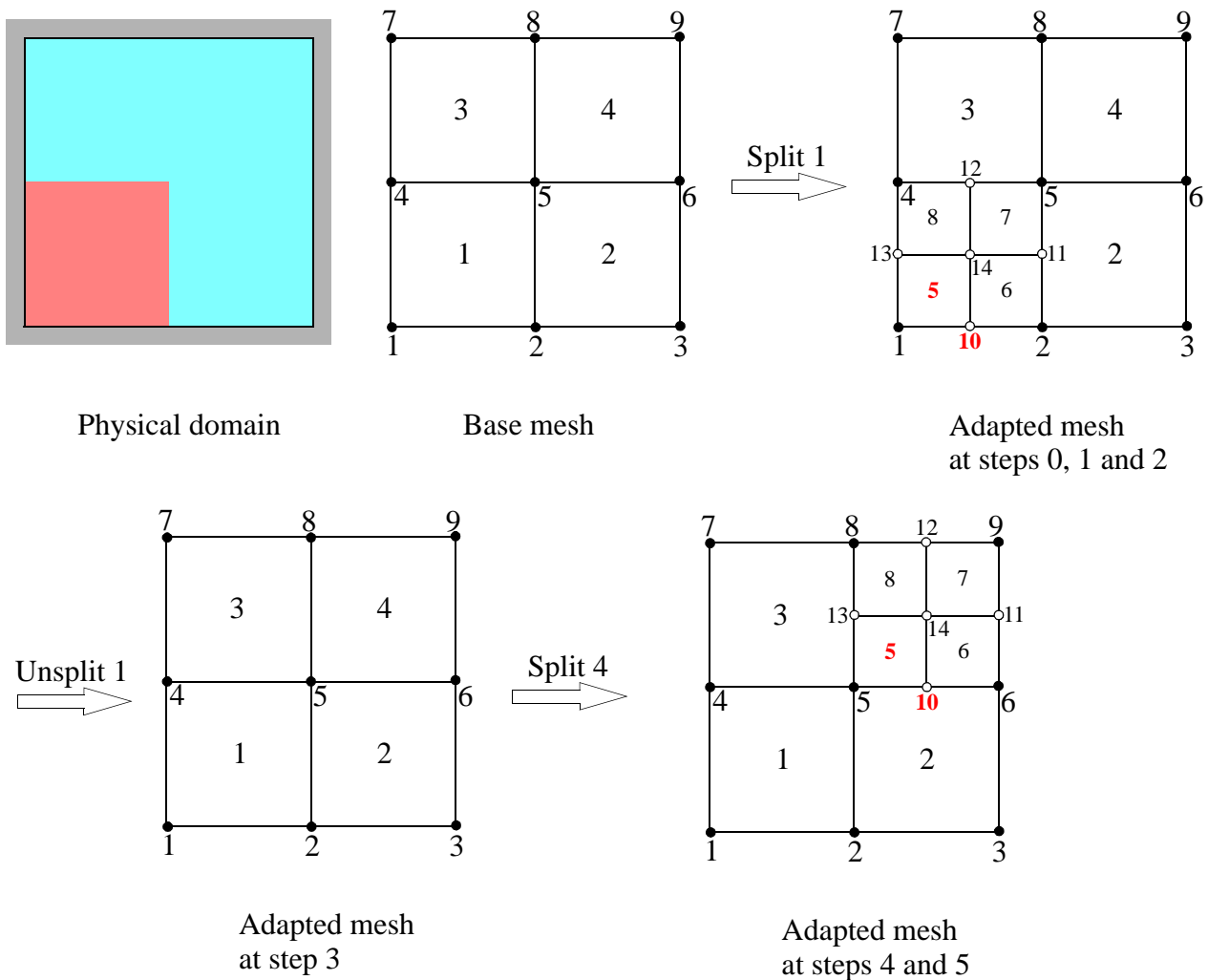


Figure 2 - Another example of mesh-adaptive calculation

### 2.2.3 Other types of results

The other type of results (not in the form of time or space curves), i.e. those related to cases 1 and 2 in Section 2.1, do not present any additional particularities in the present case of fully dynamic mesh adaptivity. They behave as discussed in Section 2.1.3.

## 2.3 Implementation notes

The “rules” 1, 2 and 3 listed in the previous Sections had been already partially implemented in the code in previous developments. However, it has been decided to do some modifications in order to render the implementation cleaner and more consistent.

### 2.3.1 Previous situation

Rule 3, which deals mainly with the processing of results in the form of maps, had been already implemented in the code.

Whenever an object name (or an explicit list of elements) is used in a directive that generates a map type of output (e.g. a TRAC directive) the list is transformed according to Rule 3, before passing it to the graphic output routines.

Rule 1 does not seem to need any specific development in the code. The user must be simply aware of it.

Rule 2 was only partially implemented. The implementation was limited to ALIC or ALIC TEMP results files, and to the SIG (stress), ECR (internal variables) and EPST (total strains) element fields. Other element-based quantities (such as the fluid velocity at element centres used by Cell-Centred Finite Volumes, or VFCCs) were not taken into account.

Furthermore, the implementation of Rule 2 was made only in some data-storing routines: routine ALICET for the “full” version of the Alice file and routine ALITPT for the “reduced” version. Just before writing the data on the results file, if an adaptive calculation was present, the global tables (SIG, ECR, EPST) were copied to a temporary array (ADA), to which Rule 2 was applied (thus filling up the values for the used but inactive elements) by calling the routine ADAP\_FILL\_INAC\_ELEM of module M\_ADAPTIVITY. Then the temporary array was written on the file, and finally destroyed. This strategy left the global tables untouched.

Upon reading back of the results from the ALIC or ALIC TEMP files, the “right” data were directly in place for all elements (including the used but inactive ones) so that curve-based post-processing could be done without any special treatments.

This implementation has a few drawbacks:

- The implementation of Rule 2 was faulty, in the sense that only an arithmetic average of the descendants’ values was computed, instead of a weighted average using as weight the area or volume of the descendant as it should be. This could produce slightly wrong results in case of multiple adaptive refinement.

- The treatment of data would have to be implemented separately for each type of possible results file (not only the Alice files).
- There is a discrepancy between the plotted values and the values printed on the listing. The latter, for an inactive but used element, are 0 or some fixed huge number. The former, are those resulting from Rule 2.

One possible advantage of this implementation was in the calculation of global quantities. For example, the total mass of the elements can be computed as a single (unconditional) summation of all element values, if the mass of inactive elements is set to 0. But, if the mass of inactive elements is set to the sum of the masses of their active descendants, then one must take care of skipping the inactive elements when computing the total value. This is just an example, but there may be many similar cases in the code.

### **2.3.2 New implementation**

The new implementation corrects (of course) the problem of the faulty implementation in the `ADAP_FILL_INAC_ELEM` routine. It also tries to be more consistent.

The idea is to consistently set the element-related values of inactive elements to the weighted average (for intensive quantities such as a pressure) or to the sum (for extensive quantities such as the mass) of the values of their currently active descendants. For this we use the same algorithm and the same routines that serve to un-split an element, in order to be as consistent as possible with the adaptive algorithm.

In this way, all values printed on the listing, stored on results files (of any type), etc., are consistent (also for the inactive elements) with what a user obtains by plotting time or space curves of such quantities.

The drawback is, as mentioned in the previous Section, that some care is needed when computing global values: the values of inactive (as well as of unused) elements in adaptivity should not be considered in summations. It also becomes essential that, upon unsplitting of an element, the parent's quantities be recomputed exclusively from the children's values. That is, the old value in the parent must have no effect on the calculation.

The new implementation is based on a modified version of routine `ADAP_FILL_INAC_ELEM`, which is now called at every time step at the beginning of the `IMPSOR` routine (which produces all types of outputs), and not directly from the storage-specific routines. This will cause a (hopefully slight) overhead in CPU time, but it ensures a much better consistency of code results interpretation.

### 3. Numerical examples

We now present some numerical examples in order to check the models and procedures described in the previous Section.

#### 3.1 Static adaptivity

We solve the problem described in Section 2.1, Figure 1. The simulations performed are summarized in Table 1.

Case	Fluid	Structure	FSI	Notes
TPOS01	VFCC	—	—	Refine to level 2
TPOS05	VFCC	—	—	Refine to level 3

**Table 1 - Test cases with “static” adaptivity**

##### *TPOS01*

The solution is advanced for 5 time steps. Figure 3 shows the computed pressure maps. The computed fluid velocities (at the cell centres for the VFCC) are presented in Figure 4. In such types of representations (maps, not curves) only the active elements appear. Therefore, elements 5, 6, 7 and 8 are visible instead of their parent, element 1. This process is completely automatic and transparent to the user.

Figure 5 shows the pressure time curves recorded in three “elements”: the first one is element “expl” which coincides with base element 1. Since this element is split from the beginning of the calculation, giving rise to elements 5, 6, 7 and 8, this result corresponds to the weighted average pressure in elements 5, 6, 7 and 8. The second curve is the pressure in element 4, which is a base element and stays unadapted during the whole transient. The third one is the pressure in element 5. This is a child of element 1 and stays constant during the calculation. Note that a descendant element like this one can only be selected by explicitly giving its index (5 in this case). In fact, the operators in EPX allowing for the identification of parts of the mesh (such as the GROU operator used to define the object expl already mentioned above) always operate on the base elements in the mesh.

Finally, Figure 6 shows the velocity time curves in the same three elements. Again, the result for the “expl” element is a weighted average of its children but, unlike the case of pressures and in order to be consistent with the conserved variables in the VFCC formulation, it is not obtained by direct averaging of the children’s velocities.

In fact, in the case of fluid pressures the value  $p_1$  in the parent volume 1 is obtained from:

$$p_1 = \frac{p_5 V_5 + p_6 V_6 + p_7 V_7 + p_8 V_8}{V_5 + V_6 + V_7 + V_8} = \frac{p_5 V_5 + p_6 V_6 + p_7 V_7 + p_8 V_8}{V_1} \quad (1)$$

where  $V$  are the volumes. But, since:

$$V_I = \frac{1}{4} V_1 \quad I = 5, 6, 7, 8 \quad (2)$$

equation (1) simplifies to:

$$p_1 = \frac{1}{4}(p_5 + p_6 + p_7 + p_8) \quad (3)$$

i.e., in this specific example the pressure in the parent is the arithmetic mean of the pressures in the children.

However, in the case of fluid velocity, of components  $u, v, w$ , what is conserved is the momentum  $\rho u, \rho v, \rho w$  so that the equivalent of (1) becomes:

$$\rho_1 u_1 = \frac{\rho_5 u_5 V_5 + \rho_6 u_6 V_6 + \rho_7 u_7 V_7 + \rho_8 u_8 V_8}{V_5 + V_6 + V_7 + V_8} = \frac{\rho_5 u_5 V_5 + \rho_6 u_6 V_6 + \rho_7 u_7 V_7 + \rho_8 u_8 V_8}{V_1} \quad (4)$$

which, by exploiting (2), reduces to (considering for example the  $x$ -component):

$$\rho_1 u_1 = \frac{1}{4}(\rho_5 u_5 + \rho_6 u_6 + \rho_7 u_7 + \rho_8 u_8) \quad (5)$$

From (2) and from conservation of the mass  $M = \rho V$  one has:

$$\rho_1 = \frac{1}{4}(\rho_5 + \rho_6 + \rho_7 + \rho_8) \quad (6)$$

so that from (5) we obtain:

$$u_1 = \frac{1(\rho_5 u_5 + \rho_6 u_6 + \rho_7 u_7 + \rho_8 u_8)}{4 \rho_1} = \frac{\rho_5 u_5 + \rho_6 u_6 + \rho_7 u_7 + \rho_8 u_8}{\rho_5 + \rho_6 + \rho_7 + \rho_8} \quad (7)$$

Note therefore that, in general:

$$u_1 \neq \frac{1}{4}(u_5 + u_6 + u_7 + u_8) \quad (8)$$

In other words, a simple arithmetic averaging relation such as (3) for the pressures or (6) for the densities does not hold, in general, for the velocities (it holds, in fact, for the linear momenta, see eq. 5).

This is confirmed by Figure 7, which compares the equivalent velocity in volume 1, which is computed according to (7) (black curve), with the arithmetic average computed by (8) (red curve). Figure 8 shows the velocity curves in the four children.

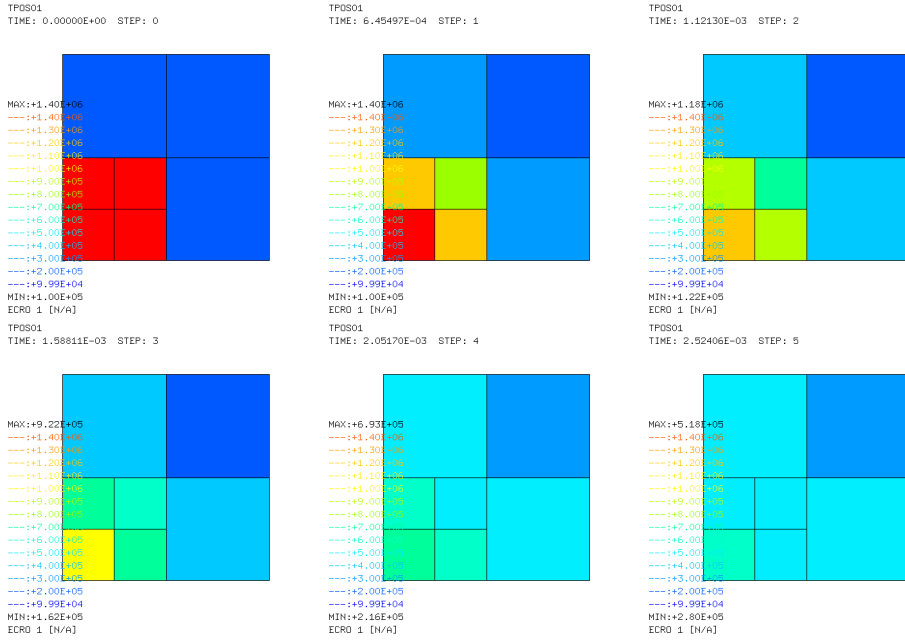


Figure 3 - Pressure maps in test TPOS01

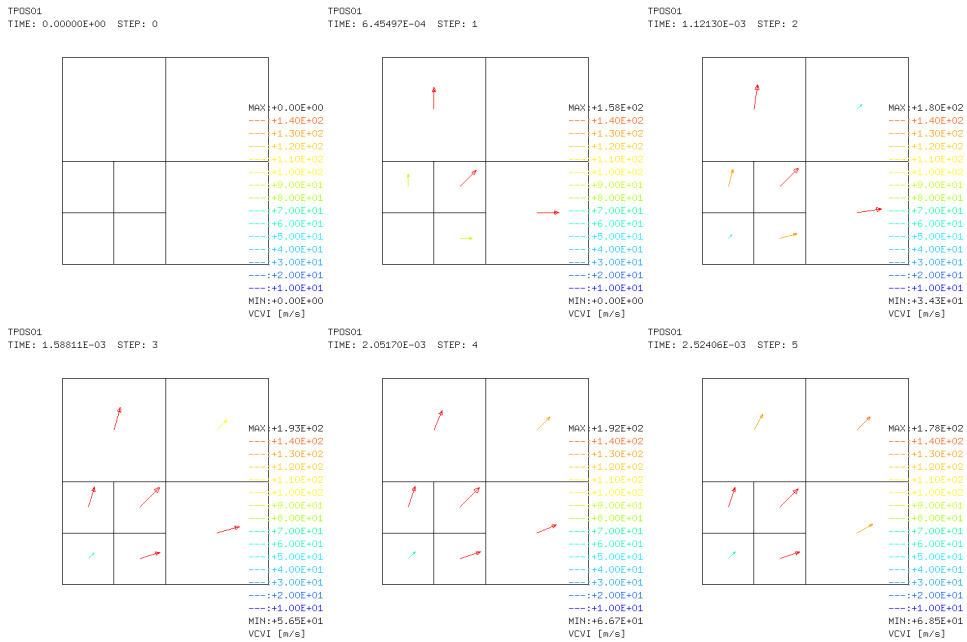


Figure 4 - Velocity maps in test TPOS01

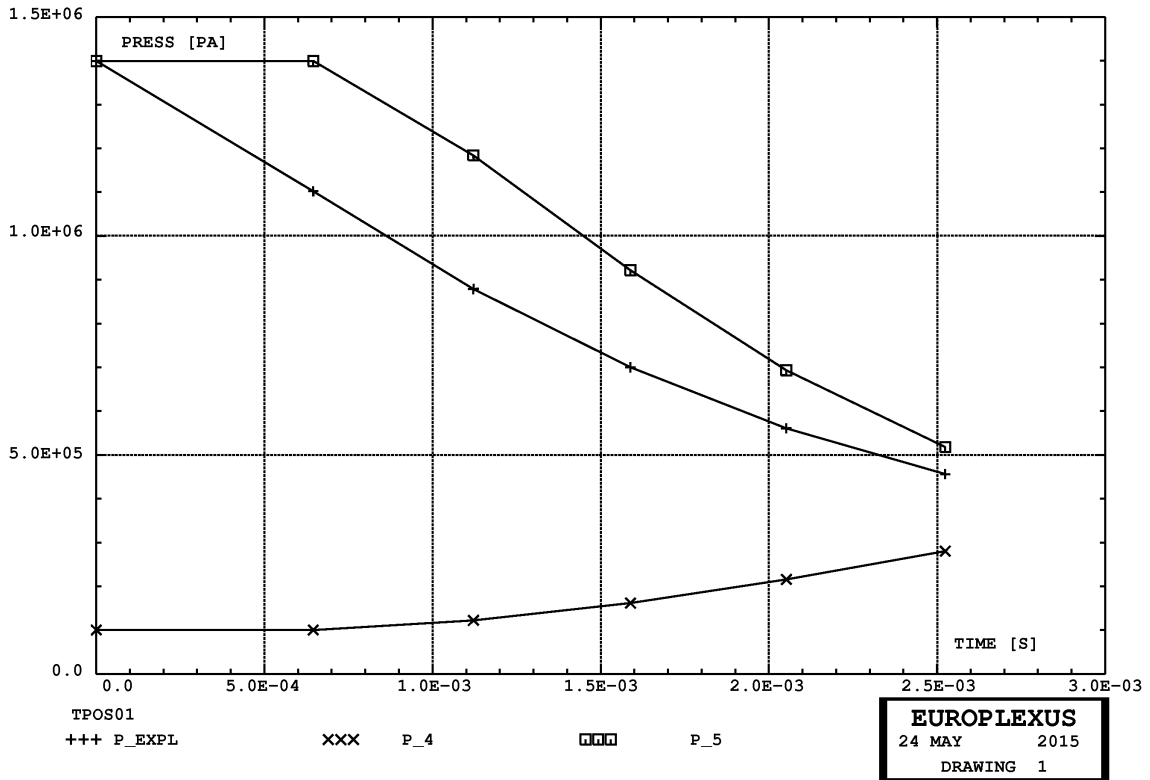


Figure 5 - Pressure time curves in test TPOS01

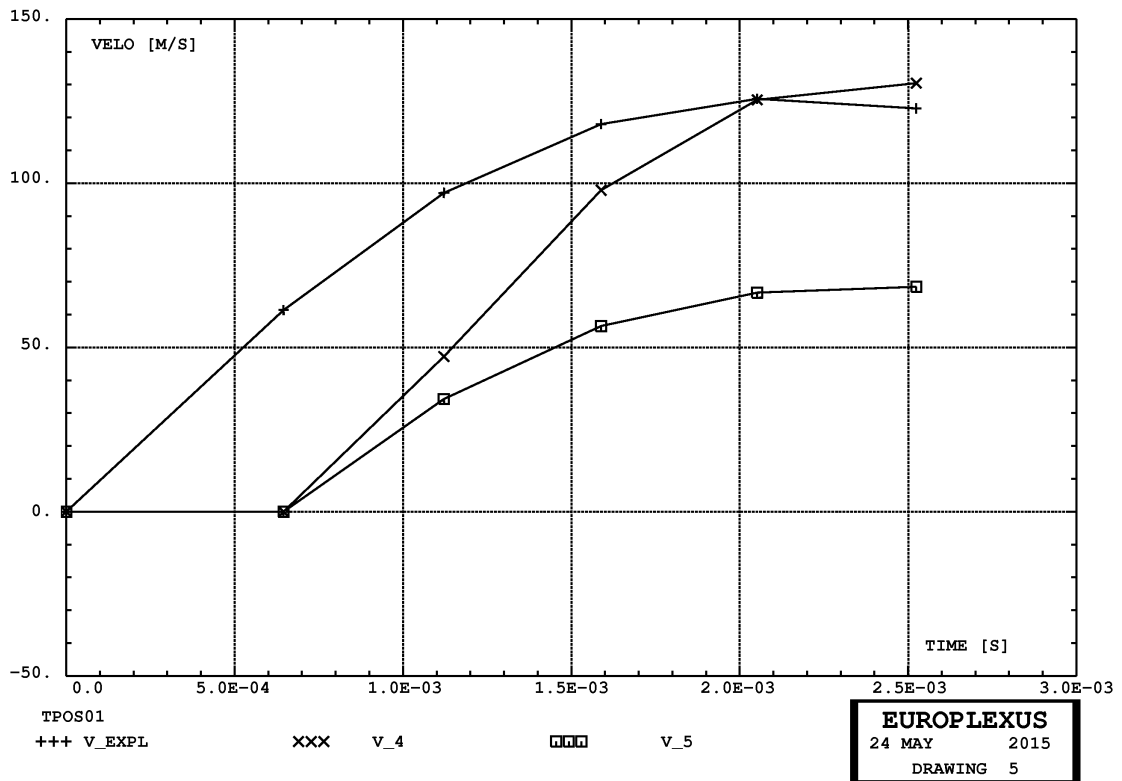


Figure 6 - Velocity time curves in test TPOS01

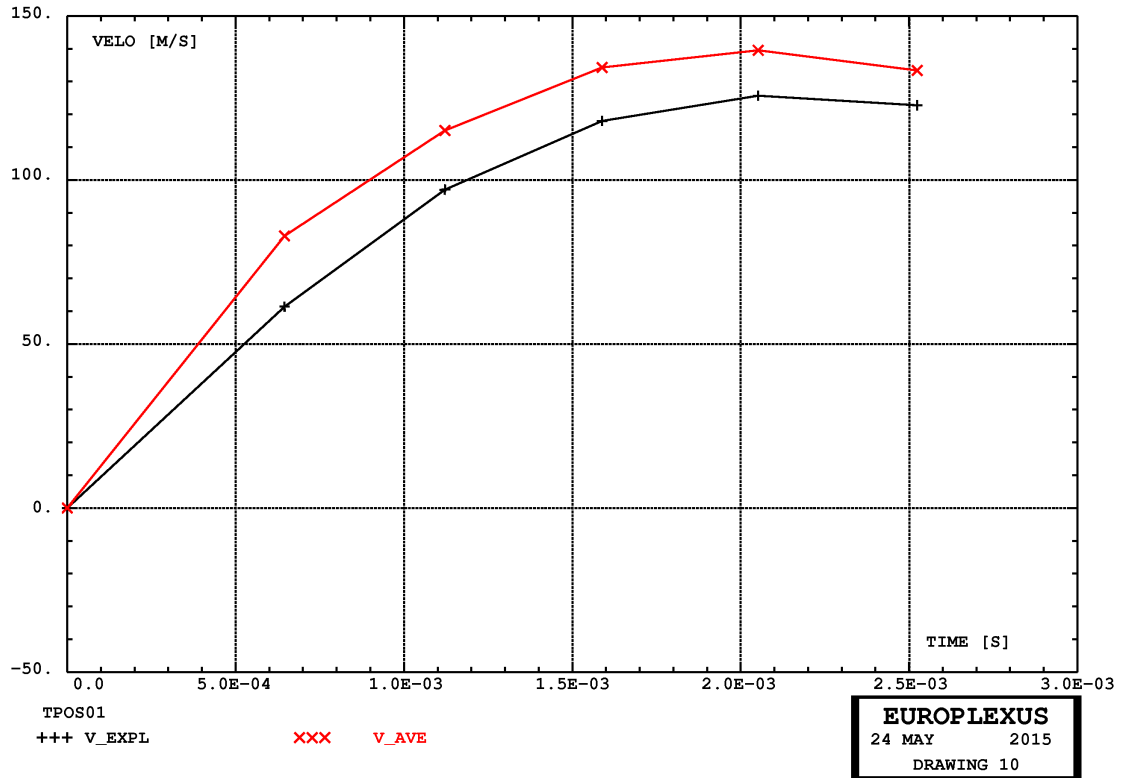


Figure 7 - Velocity time curves in volume 1 in test TPOS01

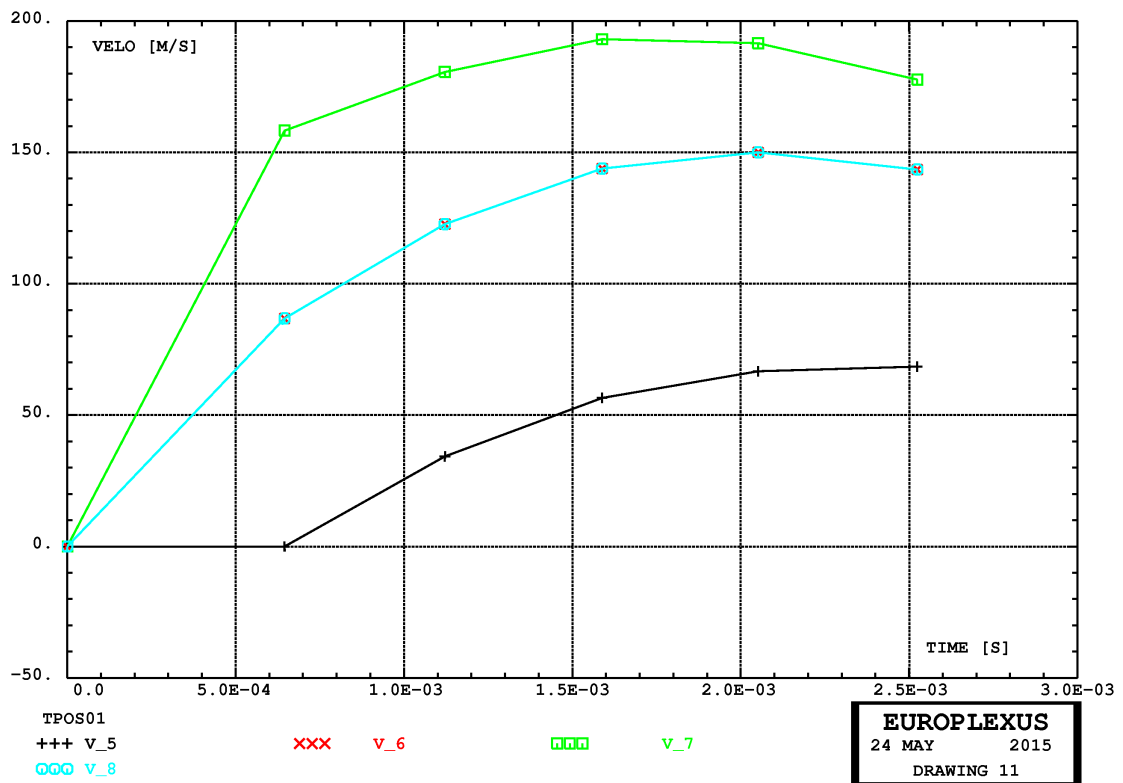


Figure 8 - Velocity time curves in volumes 5 to 8 test TPOS01

### TPOS05

This test is similar to TPOS01 but we further refine the mesh up to level 3 by splitting at the initial time element 7 as shown in Figure 9 (which generates elements 9, 10, 11 and 12 and nodes 15, 16, 17, 18 and 19), and keeping the mesh constant throughout the transient.

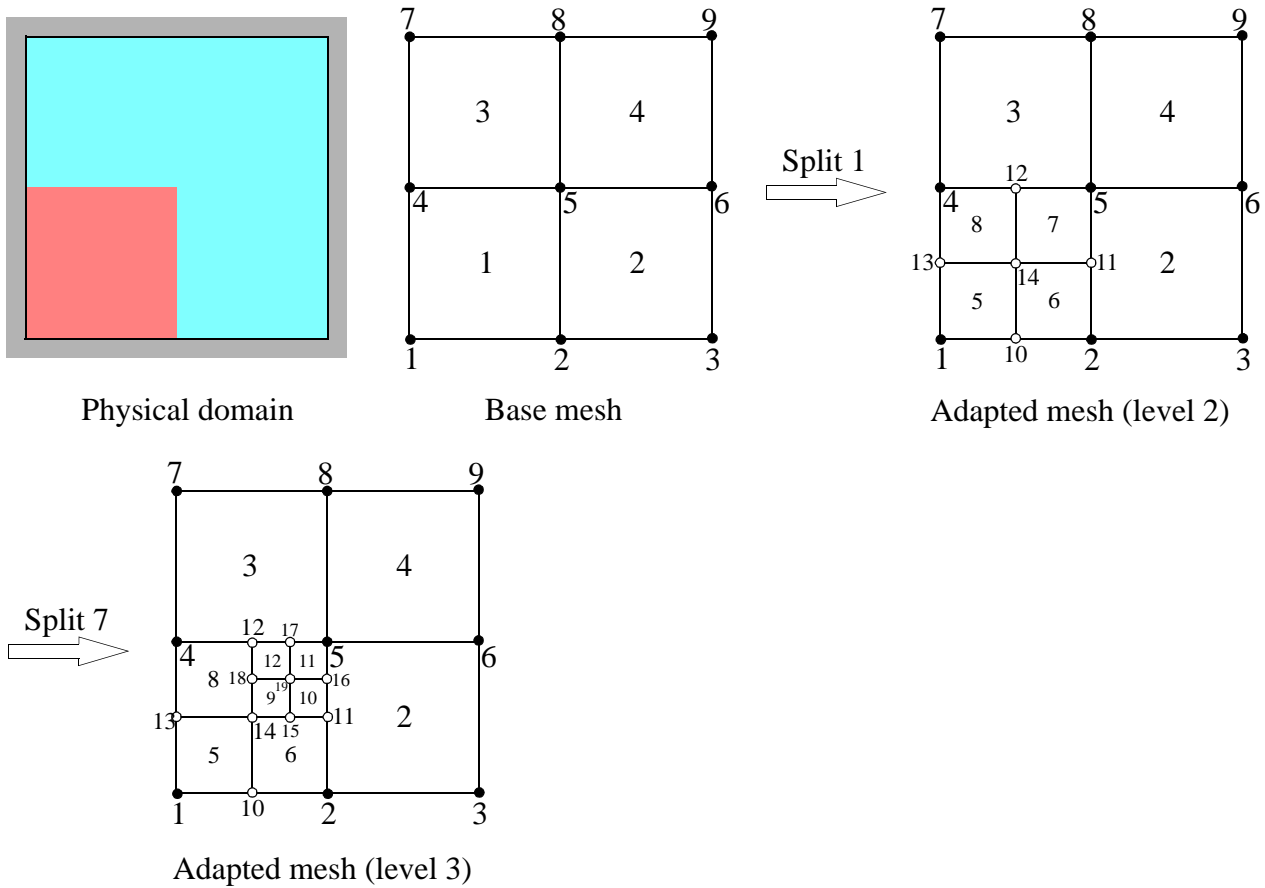


Figure 9 - Mesh adaptation in test TPOS05

The computed pressure and velocity maps for the first 5 steps are shown in Figures 10 and 11, respectively.

The averaging process to obtain pressure time curves is shown in Figure 12 for element 7 and in Figure 13 for element 1.

The averaging process to obtain velocity time curves is shown in Figure 14 for element 7 and in Figure 15 for element 1.

Finally, Figures 16 and 17 show graphical checks of the pressure averaging process for elements 7 and 1, respectively.

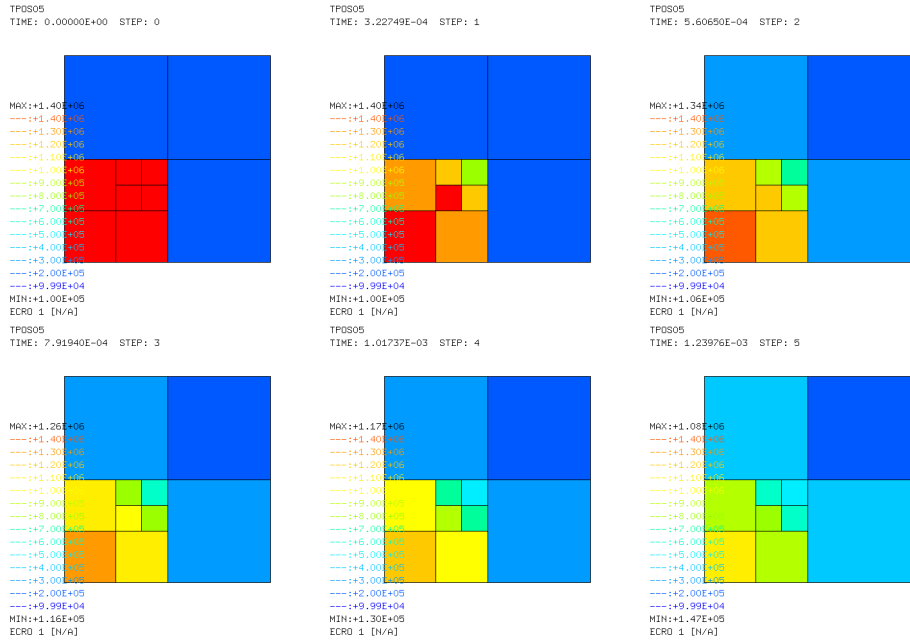


Figure 10 - Pressure maps in test TPOS05

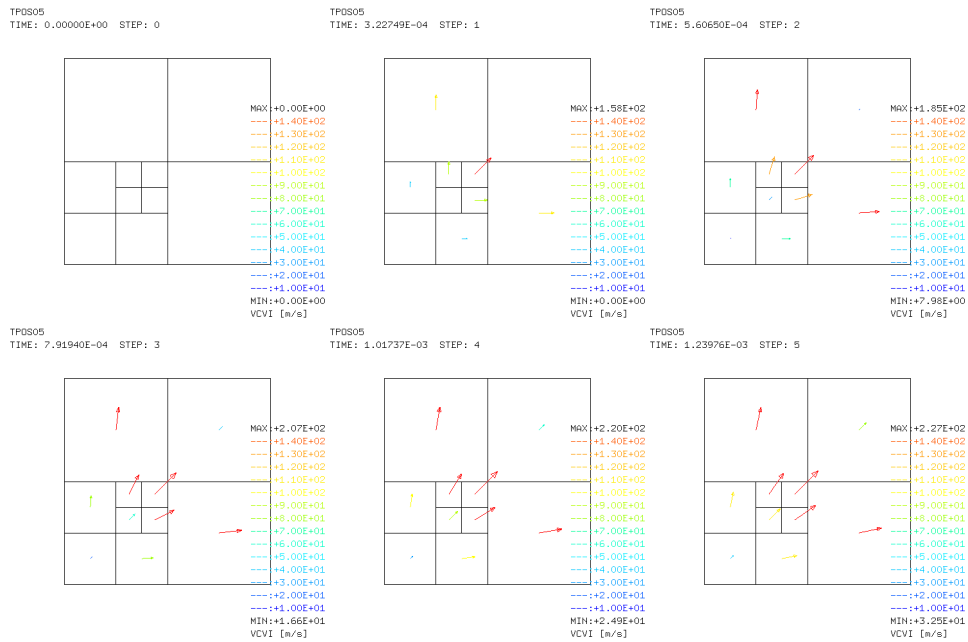


Figure 11 - Velocity maps in test TPOS05

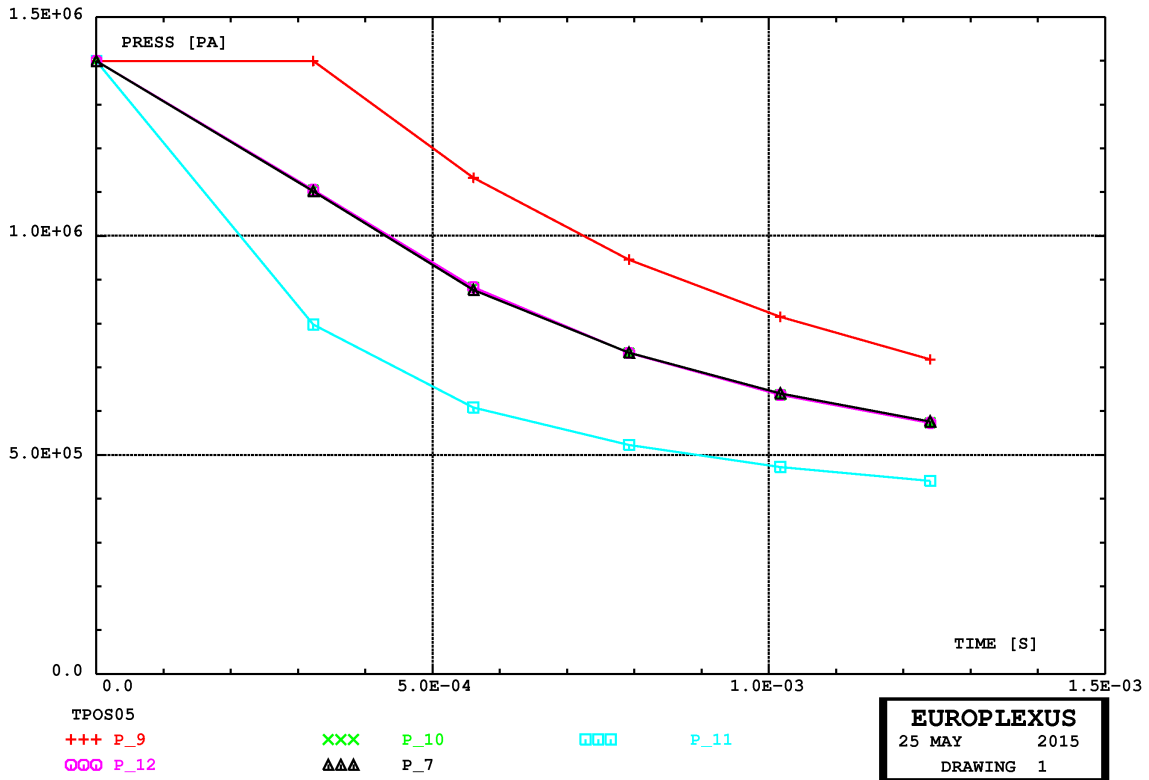


Figure 12 - Pressure time curves in volume 7 in test TPOS05

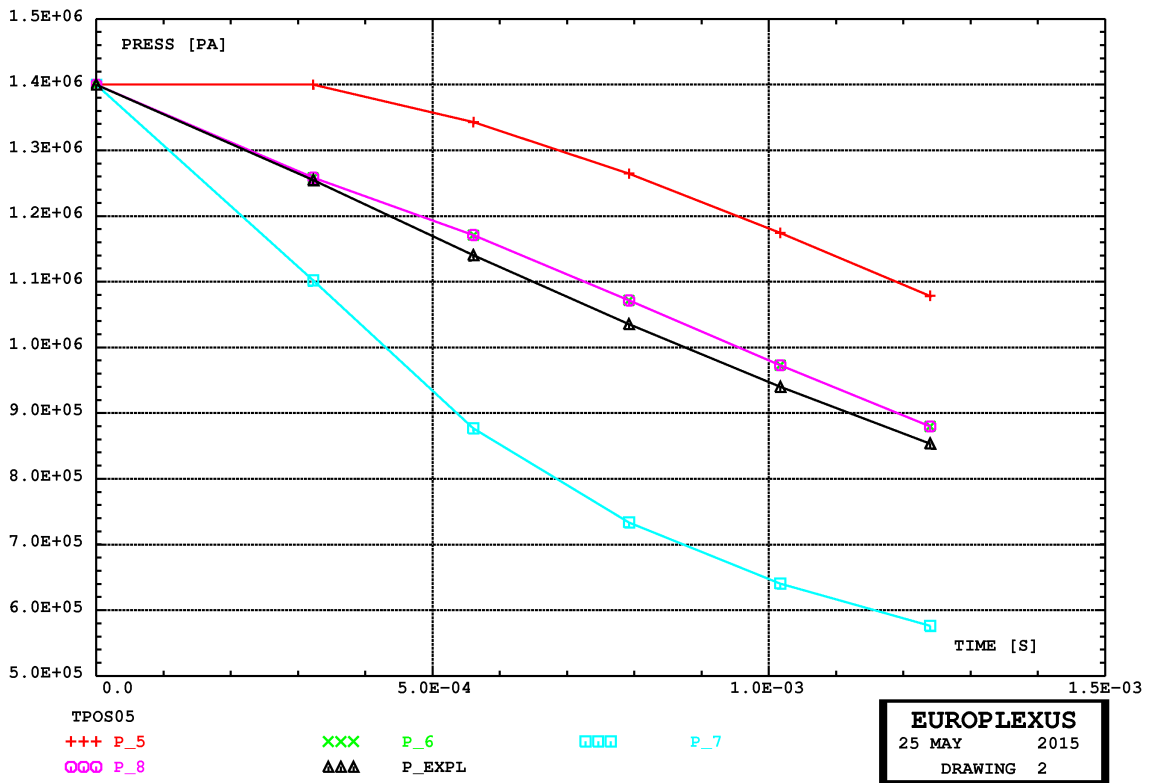


Figure 13 - Pressure time curves in volume 1 in test TPOS05

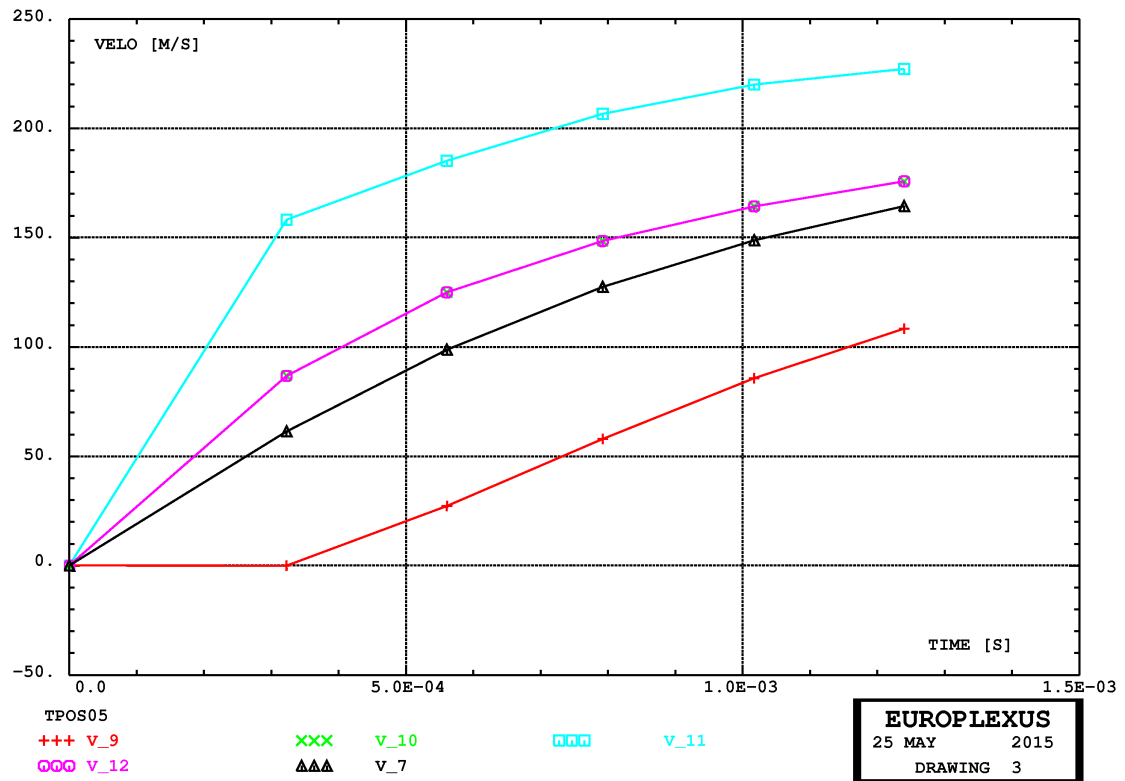


Figure 14 - Velocity time curves in volume 7 in test TPOS05

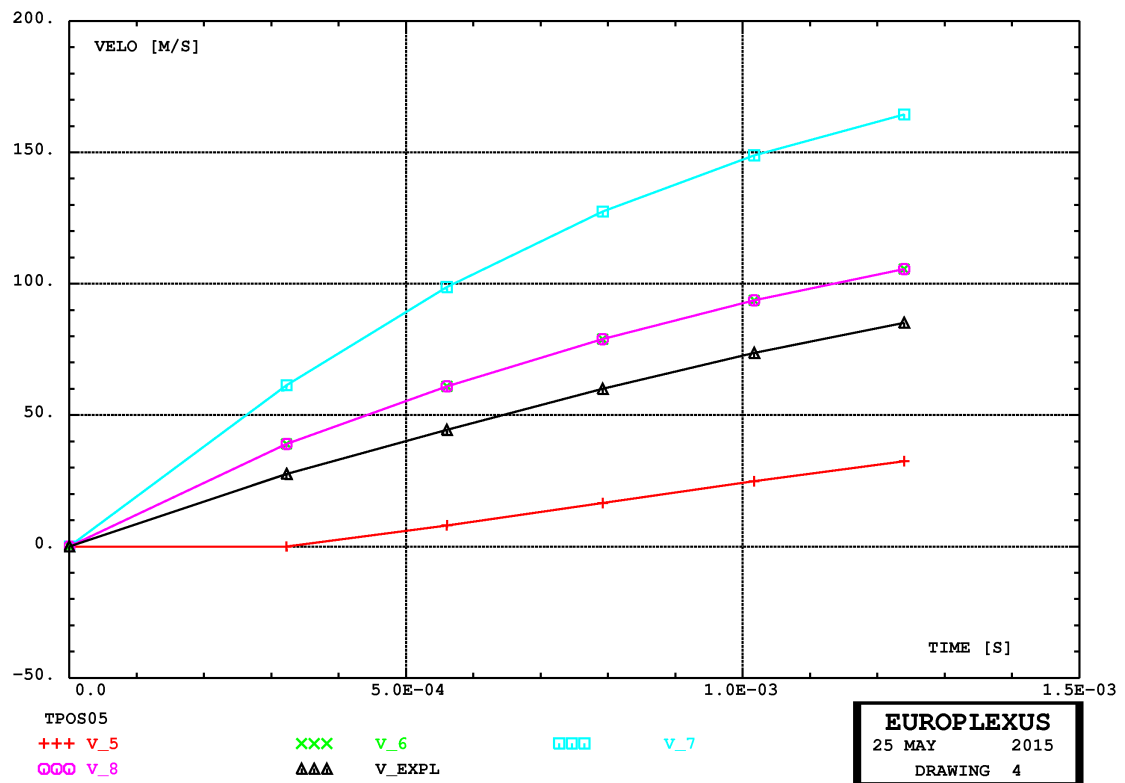


Figure 15 - Velocity time curves in volume 1 in test TPOS05

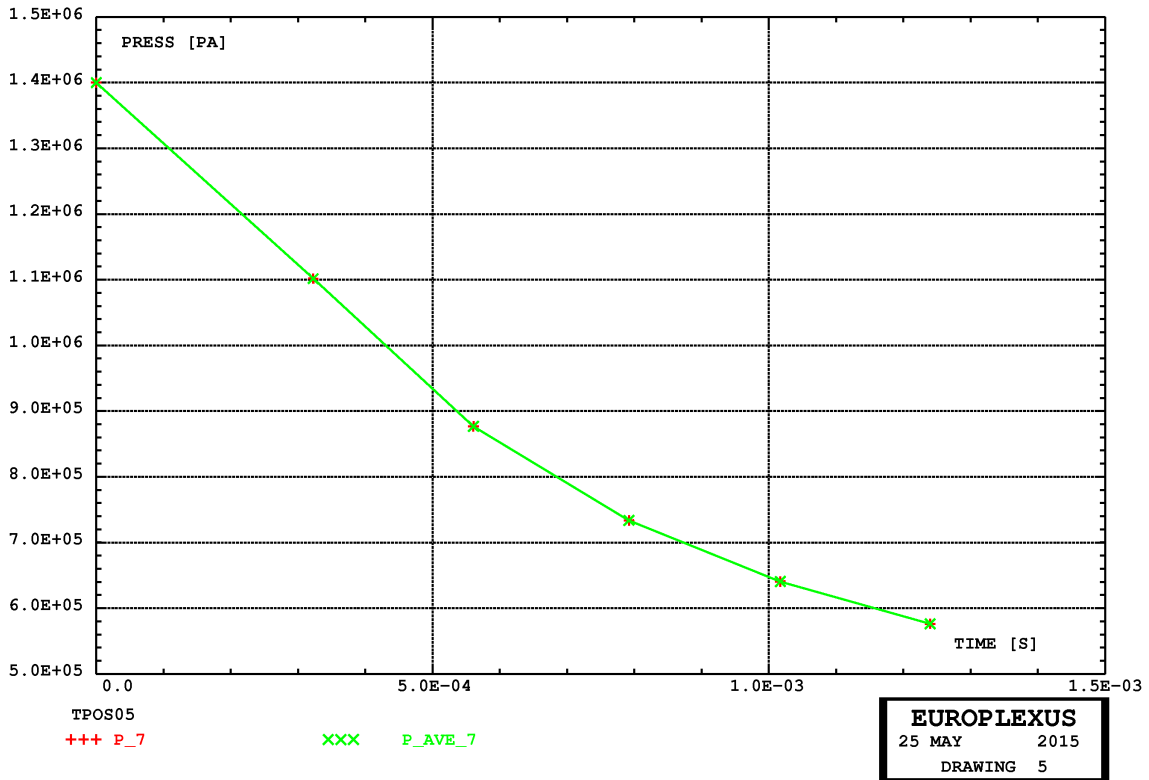


Figure 16 - Graphical check of pressure time curve in volume 7 in test TPOS05

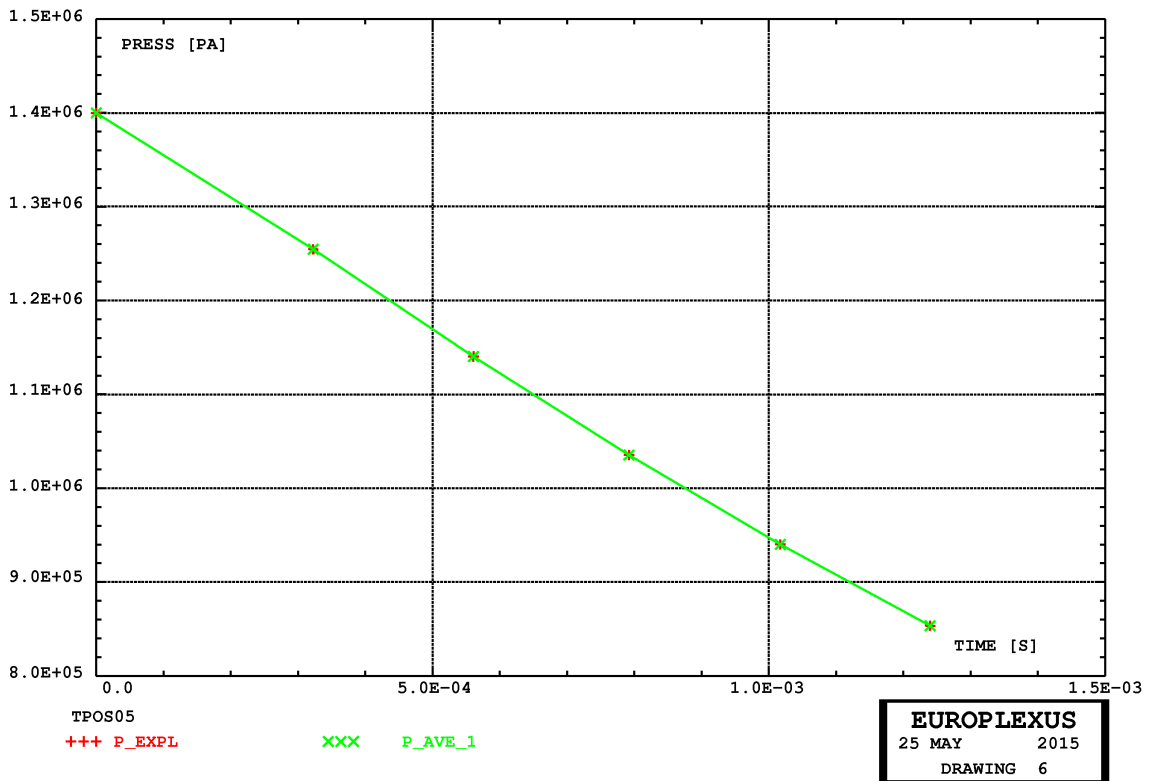


Figure 17 - Graphical check of pressure time curve in volume 1 in test TPOS05

### 3.2 Dynamic adaptivity

We solve the problem described in Section 2.2, Figure 2. The simulations performed are summarized in Table 1.

Case	Fluid	Structure	FSI	Notes
TPOS06	VFCC	—	—	Dynamically refine to level 2

**Table 2 - Test cases with “dynamic” adaptivity**

#### *TPOS06*

The solution is advanced for 5 time steps. Figure 18 shows the computed pressure maps. The computed fluid velocities (at the cell centres for the VFCC) are presented in Figure 19.

Figure 20 shows the pressure time curves and Figure 21 the velocity time curves in elements 1, 4, 5, 6, 7 and 8.

In the first Figure, relative to pressures, we see that the only “continuous” or “smooth” curves are those relative to element 1 (black curve) and to element 4 (red curve). These two are base elements and therefore they are always used, although at some time instants they are active and at others they are inactive. When they are active, the recorded pressure is the pressure in the element itself. When they are inactive, the recorded pressure is the average of the pressures of their active descendants, as already shown in the previous examples.

Consider now the elements 5, 6, 7 and 8 (green, cyan, magenta and blue curves, respectively): these are descendant elements. By symmetry of the problem, the cyan and blue curves (elements 6 and 8) are always superposed. At steps 0, 1 and 2 these elements are the children of element 1, and in fact one sees that the black curve lies between their curves. At step 3, these elements are unused, and in fact all their values drop to 0. Finally, at steps 4 and 5 these elements are the children of element 4, and in fact one sees that now the red curve lies between their curves.

Similar considerations can be made on the curves of Figure 21 which represents the fluid velocities.

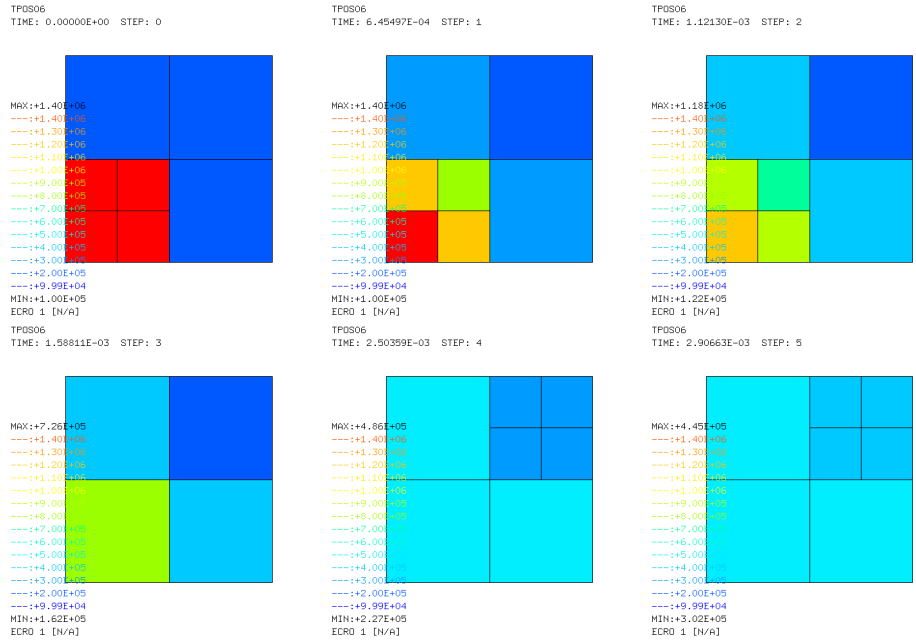


Figure 18 - Pressure maps in test TPOS06

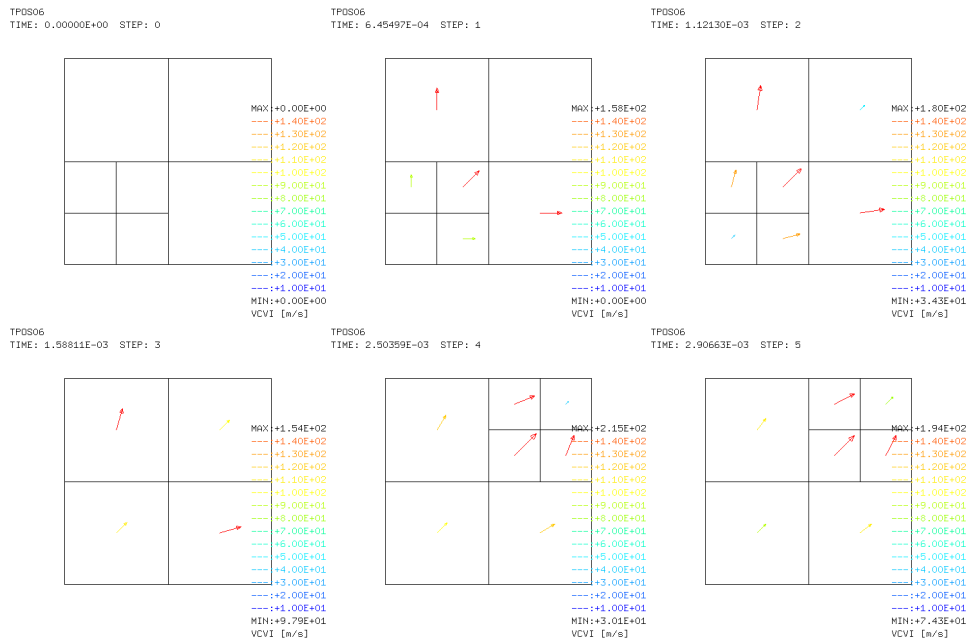
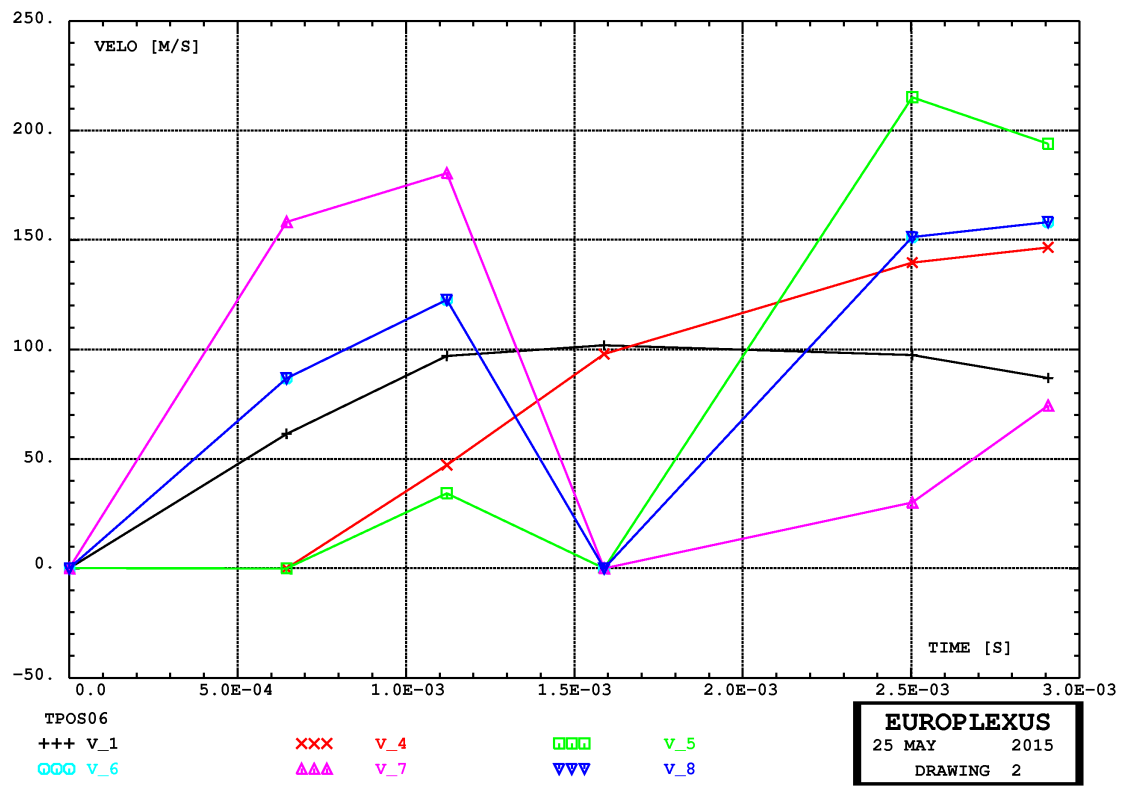
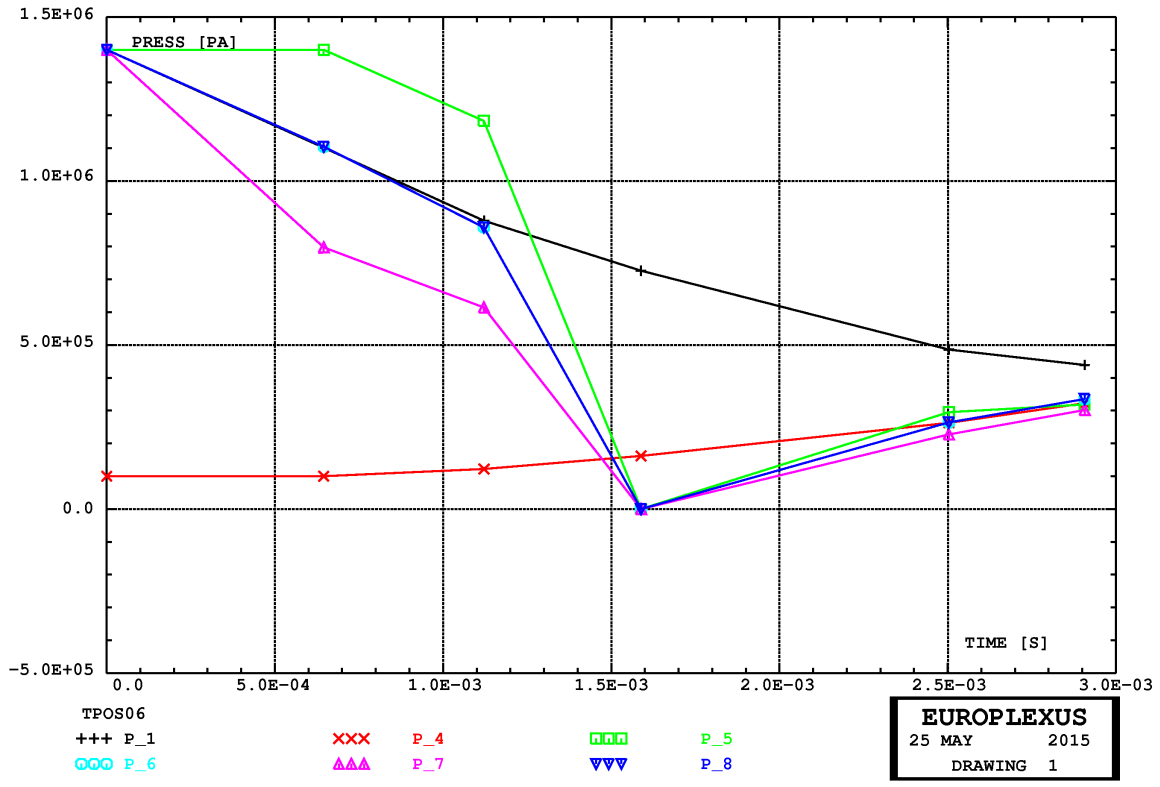


Figure 19 - Velocity maps in test TPOS06



## 4. New syntax for time curves

Besides the revision of the post-processing directives in adaptivity described in the previous Sections, a new possibility has been added for the production of node- or element-based time curves. Instead of referring the value to be plotted to a node or an element, it could be sometimes more convenient referring it to a position in space, either fixed or relative, as it will be shown below.

### 4.1 Position-based time curves of nodal quantities

The syntax of the COUR directive for the production of time curves related to nodal quantities (see User's Manual [17], logical page ED.70) is enhanced as follows (in red below):

```
"COURBE" nuco < 'nomcourbe' >
    | [ "COOR" ; "DEPL" ; "VITE" ; "ACCE" ; "FINT" ; "FEXT" ;
        "FLIA" ; "ADFT" ; "MCPR" ; "MCRO" ; "MCTE" ; "MCMF" ;
        "MCUX" ; "MCUY" ; "MCUZ" ; "SIGN" ; "ECRN" ; "LFNO" ;
        "LFNV" ; "ILNO" ; "DTNO" ; "VITG" ; "NTLE" ; "MASN" ;
        "FDEC" ; "PFSI" ; "PFMI" ; "PFMA" ] |
    | [ "COMP" icomp ; "NORME" ] |
    $ [ "NOEU" /LECTURE/ ;
        "ZONE" /LECTURE/ ;
        "POSI" $[ x y <z> ;
            "FOLL" dx dy <dz> /LECT1/ ] $
        "OBJE" /LECT2/ ] $
```

The directive already allowed to draw the quantity related either to a single node (NOEU keyword) or to a set of nodes (ZONE keyword: the values are then added up together).

The new POSI keyword allows to define a position in space at which the quantity to be plotted has to be extracted. Then, the convention is that, at each time instant, the value of the quantity at the nearest node to the specified position is extracted to produce the time curve. Therefore, the plotted quantity refers to different nodes in time, in general.

The spatial position can either be specified directly by its coordinates  $x$ ,  $y$  and  $z$  (in 3D), and in that case it is a fixed position in time, or it can be specified relative to a chosen node, see Figure 22 left drawing. In the latter case the FOLL directive specifies that the position should “follow” the motion of the node listed in the /LECT1/ directive, with a (constant) offset of  $dx$ ,  $dy$ ,  $dz$  (in 3D) along the global axes, see Figure 22 right drawings.

Finally, the mandatory OBJE directive lists (in /LECT2/) the set of nodes among which the nearest node has to be sought. This can be useful in order to limit the search to fluid nodes, or to structure nodes, for example.

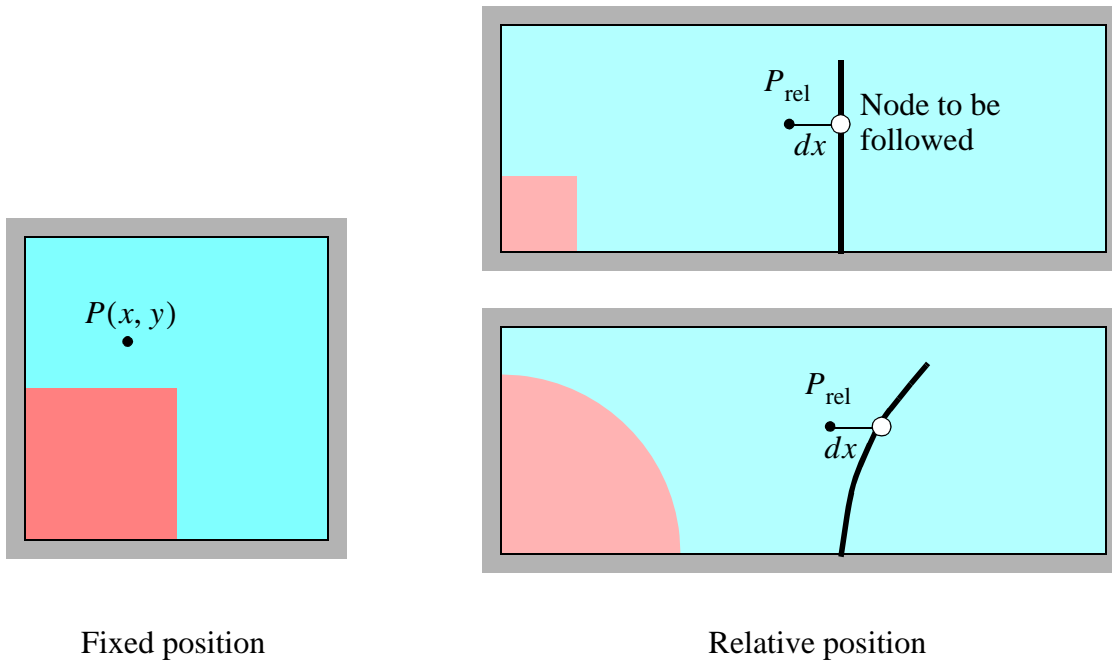


Figure 22 - Position-based nodal quantity

## 4.2 Position-based time curves of element quantities

The syntax of the COUR directive for the production of time curves related to element quantities (see User's Manual [17], logical page ED.80) is enhanced as follows (in red below):

```
"COURBE" nuco < 'nomcourbe' >

| [
  | [ "CONT" ; "ECRO" ; "EPST" ; "ENEL" ; "WAUX" ; "LFEL" ;
      "LFEV" ; "DTEL" ; "ELCE" ; "FAIL" ; "RISK" ; "CERR" ;
      "MAXC" ; "ERRI" ; "CLEN" ; "ILEN" ; "ETLE" ; "MASE" ] |
  "COMP" icomp $[ "GAUS" igaus ; "GAUZ" igauz ]$ ;
  "VCVI" |[ "COMP" icomp ; "NORM" ]|
] |

$[ "ELEM" /LECTURE/ ;
  "ZONE" /LECTURE/ ;
  "POSI" $[ x y <z> ;
    "FOLL" dx dy <dz> /LECT1/ ]$
  "OBJE" /LECT2/ ]$
```

The added POSI syntax is perfectly analogous to the one already described in Section 4.1 for the case of nodal quantities. The only difference is that now the closest element (rather than node) to the specified position is sought. For search operations, an element is supposed to coincide with its centroid.

### 4.3 Implementation notes

The implementation of the new syntax for time curves is made in module M\_GRAPHE. The derived type COURBE receives some additional fields (in red below):

```
TYPE COURBE
  CHARACTER(16) :: CO_NOM
  INTEGER :: CO_NBR, CO_ITY, CO_CMP, CO_GSS, CO_TYP, CO_NER, CO_NCB
  INTEGER :: CO_FTY
  INTEGER, POINTER :: CMB_K(:, :)
  REAL(8), POINTER :: CMB_V(:)
  INTEGER :: CO_NPT
  REAL, POINTER :: CO_POINT(:, :)
  INTEGER :: CO_FON
  INTEGER, POINTER :: CO_NODE(:)
  REAL :: CO_TIME
  INTEGER :: CO_NPAS
  INTEGER :: CO_NSTO
  INTEGER :: IS_SCOU
  REAL(8) :: CO_SCOE
  CHARACTER(16) :: CO_NOM_SAXE
  LOGICAL :: CO_INIT
  INTEGER :: CO_NEL
  INTEGER, POINTER :: CO_ELEM(:)
  INTEGER :: CO_NZO
  INTEGER, POINTER :: CO_ZONE(:)
  REAL(8) :: POSI_X(3) ! position or offset
  INTEGER :: POSI_TYPE ! position, offset or none
  INTEGER :: POSI_NELE ! n of elems to be sought for nearest to position
  INTEGER, POINTER :: POSI_ELEM(:) ! list of (base) elements in the object
  TYPE(COURBE), POINTER :: PERE
  TYPE(COURBE), POINTER :: FILS
END TYPE COURBE
```

Some modifications in routine LIT\_COURBE allow to read the new syntax. Finally, in routine GR\_LEC we add the following code:

```
      POSI_X(1:3) = CRB(ICO)%POSI_X(1:3)
      POSI_TYPE = CRB(ICO)%POSI_TYPE
      POSI_NELE = CRB(ICO)%POSI_NELE
      POSI_ELEM => CRB(ICO)%POSI_ELEM
*
* if posi (position) has been specified for the curve, then the
* node or element (ipe) is the currently nearest node or element
* to the specified position
*
      SELECT CASE (POSI_TYPE)
      CASE (-1, 1) ! fixed position or follow node
        SELECT CASE (TYP)
        CASE (1) ! nodal variable
          CALL FIND_NEAREST_NODE (X, INDOX, NUMN, POSI_X, POSI_TYPE,
>                                POSI_NELE, POSI_ELEM, IPE)
        CASE (2) ! element variable
          CALL FIND_NEAREST_ELEM (X, POSI_X, POSI_TYPE, POSI_NELE,
>                                POSI_ELEM, IPE)
        >
        END SELECT
      CASE DEFAULT
      END SELECT
```

Two new routines `FIND_NEAREST_NODE` and `FIND_NEAREST_ELEM` are added in the module to search the nearest node or element.

## 4.4 Numerical examples

The simulations performed are summarized in Table 3.

Case	Fluid	Structure	FSI	Notes
POSI01	VFCC	—	—	Refine to level 2
POSI02	FE	—	BLOQ	Refine to level 3
POSI03	VFCC	ED01	—	FSI-driven adaptivity

**Table 3 - Test cases with “static” adaptivity**

### *POSI01*

The problem considered is again the one depicted in Figure 1 of Section 2.1. The present solution is identical to case TPOS01 presented in Section 3.1, but in the post-processing we test the new syntax for curve production (in red below):

```

Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_pt' ECRO COMP 1 POSI 0.25 0.75 OBJE LECT expl air TERM
COUR 11 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 2 'v_pt' VCVI NORM POSI 0.25 0.75 OBJE LECT expl air TERM
COUR 12 'v_8' VCVI NORM ELEM LECT 8 TERM
COUR 3 'p_nd' ECRO COMP 1 POSI FOLL -0.1 -0.2 LECT 6 TERM
OBJE LECT expl air TERM
COUR 13 'p_2' ECRO COMP 1 ELEM LECT 2 TERM
COUR 4 'v_nd' VCVI NORM POSI FOLL -0.1 -0.2 LECT 6 TERM
OBJE LECT expl air TERM
COUR 14 'v_2' VCVI NORM ELEM LECT 2 TERM
TRAC 1 11 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 2 12 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 3 13 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 4 14 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
FIN

```

Assume that we want to track the fluid pressure near a point of coordinates (0.25, 0.75). From Figure 1 of Section 2.1 and from the fact that the mesh is adapted only at the initial time in this example, we see that the “closest” element to this point is element 8, and this during the entire transient.

Figure 23 compares the pressure computed according to position with the one obtained by tracking explicitly element 8, showing that they are identical, indeed. Figure 24 does the same for the fluid velocity and, again, the agreement is perfect.

Next, we check the “follow” directive. Curve number 3 contains the pressure of the fluid element “closest” to the position of node 6 with an offset of (-0.1, -0.2). We see that this is element 2, during the whole transient. Figures 25 and 26 check the pressure and velocity results, respectively.

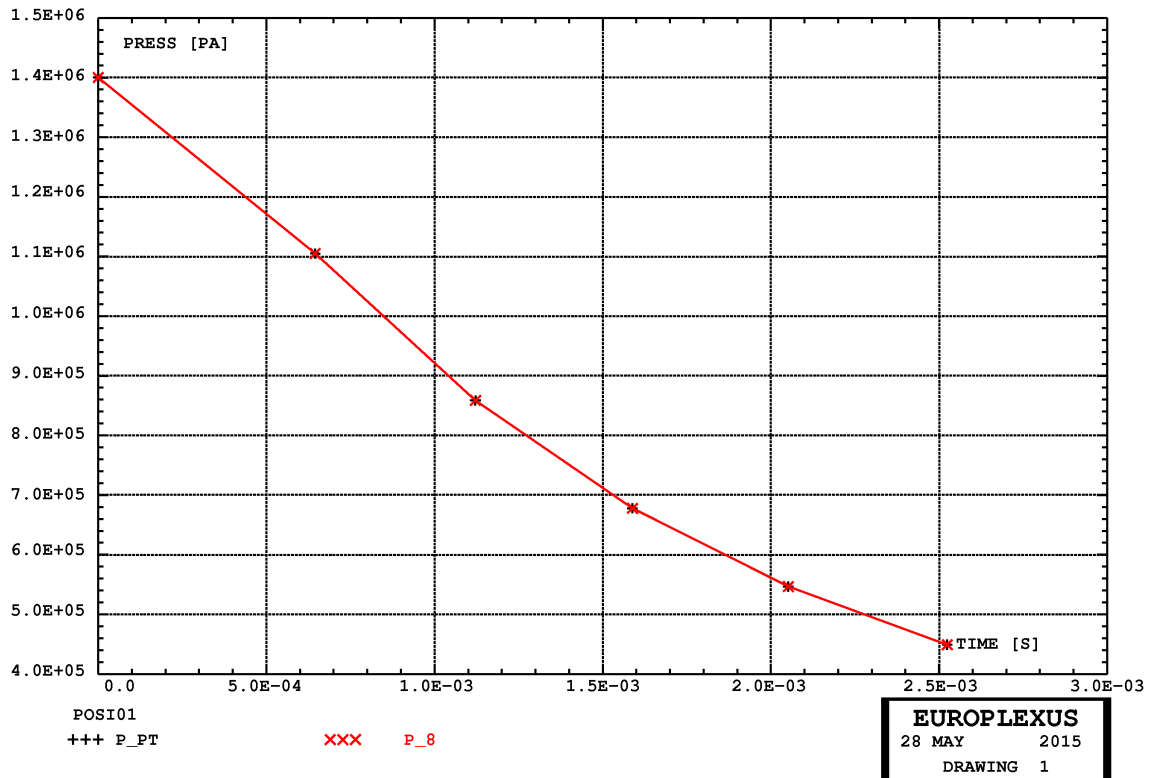


Figure 23 - Fluid pressures in case POSI01

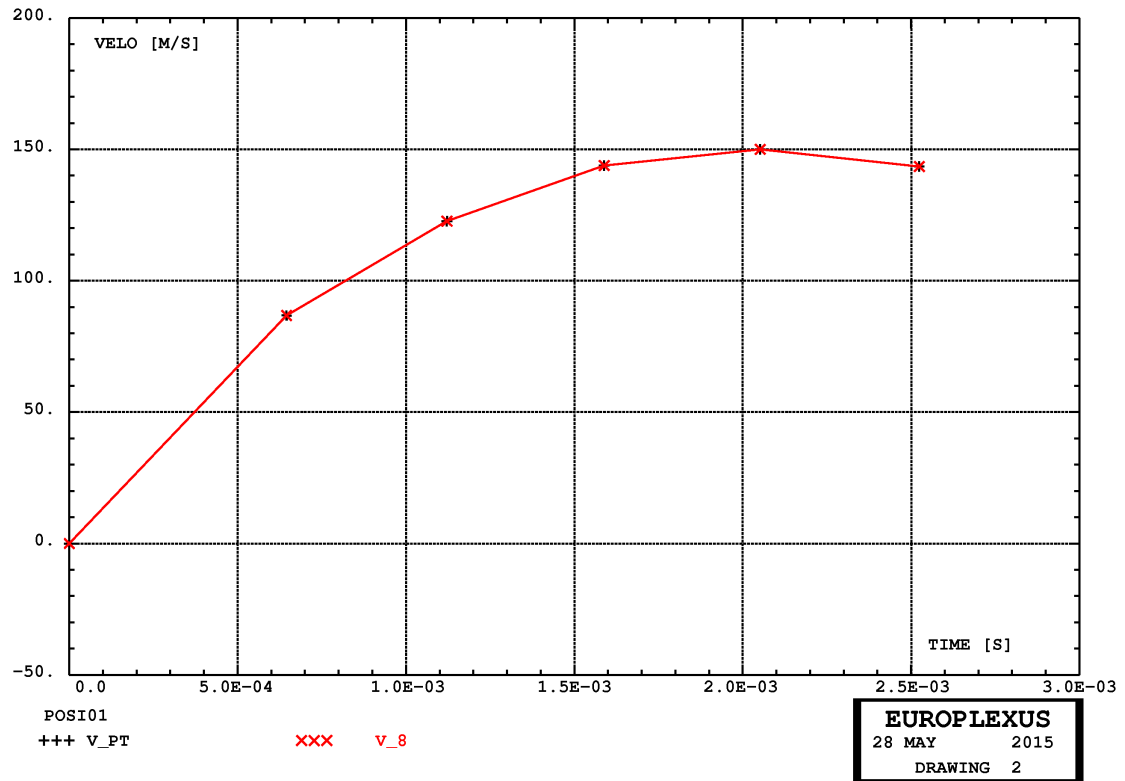


Figure 24 - Fluid velocities in case POSI01

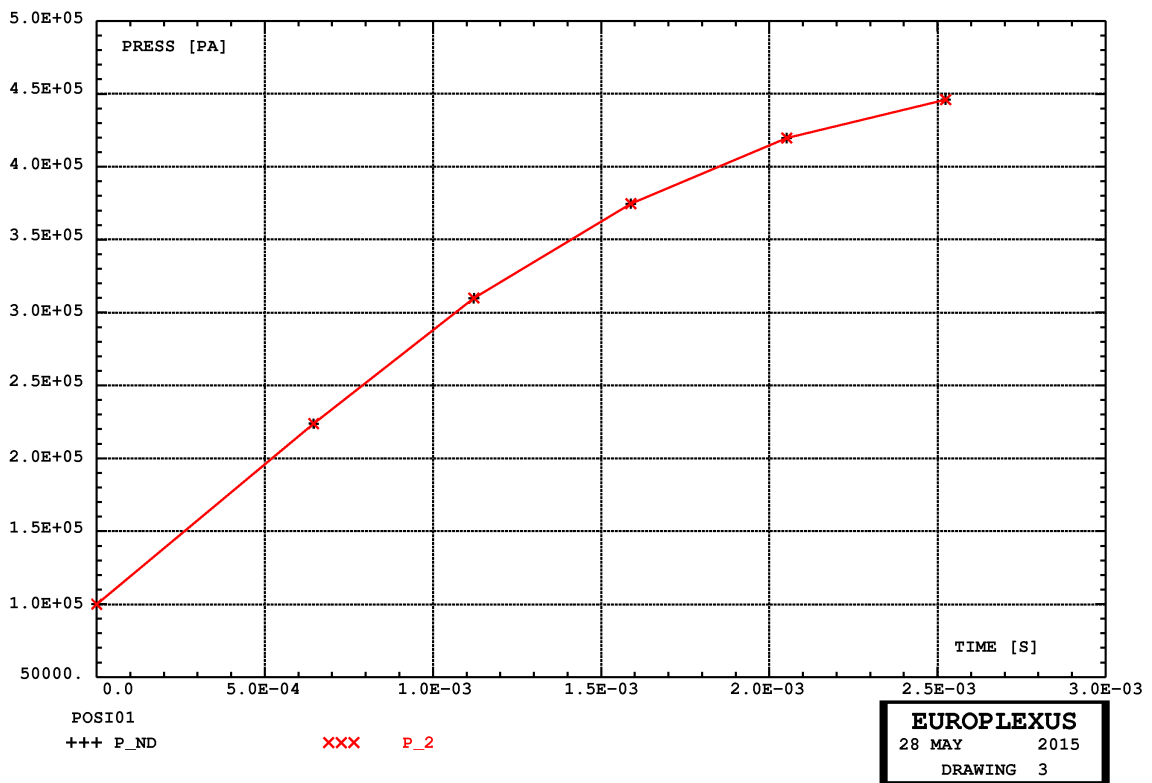


Figure 25 - Fluid pressures (with "follow") in case POSI01

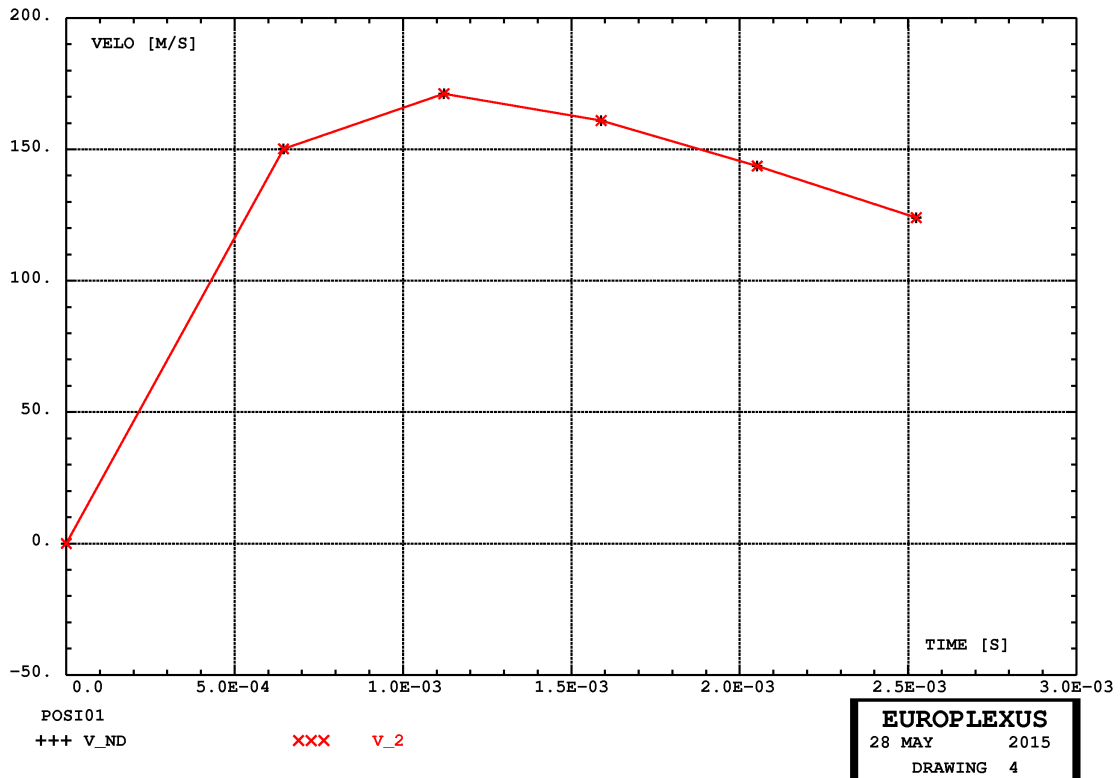


Figure 26 - Fluid velocities (with “follow”) in case POSI01

## POSI02

This solution is similar to the previous one but uses Finite Elements instead of Finite Volumes in the fluid domain. The scope is to have some nodal variables (e.g. velocities) to plot with the new syntax:

```

Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_pt' ECRO COMP 1 POSI 0.26 0.76 OBJE LECT expl air TERM
COUR 11 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 2 'v_pt' VITE NORM POSI 0.26 0.76 OBJE LECT expl air TERM
COUR 12 'v_12' VITE NORM NOEU LECT 12 TERM
COUR 3 'p_nd' ECRO COMP 1 POSI FOLL -0.1 -0.2 LECT 6 TERM
                                OBJE LECT expl air TERM
COUR 13 'p_2' ECRO COMP 1 ELEM LECT 2 TERM
COUR 4 'v_nd' VITE NORM POSI FOLL -0.1 -0.2 LECT 6 TERM
                                OBJE LECT expl air TERM
COUR 14 'v_6' VITE NORM NOEU LECT 6 TERM
TRAC 1 11 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 2 12 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 3 13 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 4 14 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
FIN
  
```

The next Figures 27, 28, 29 and 30 show the results for this case, again showing perfect agreement of curves obtained via the position with those obtained using the element or node number explicitly.

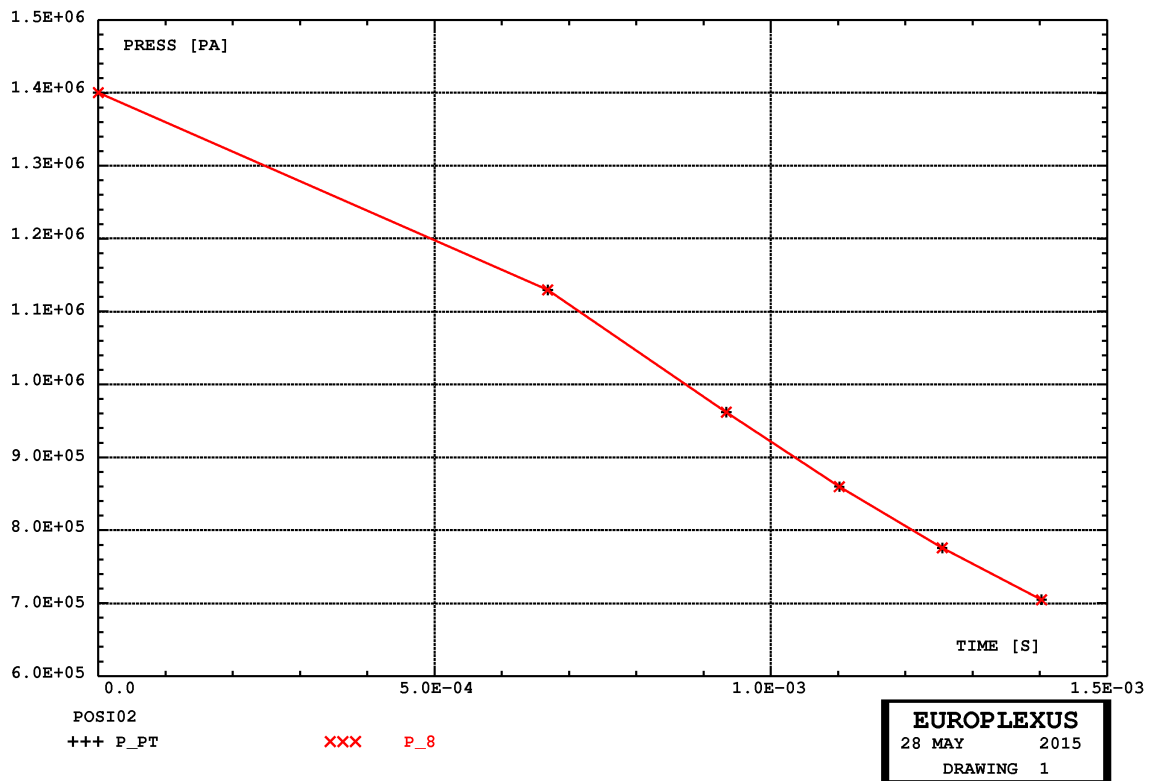


Figure 27 - Fluid pressures in case POSI02

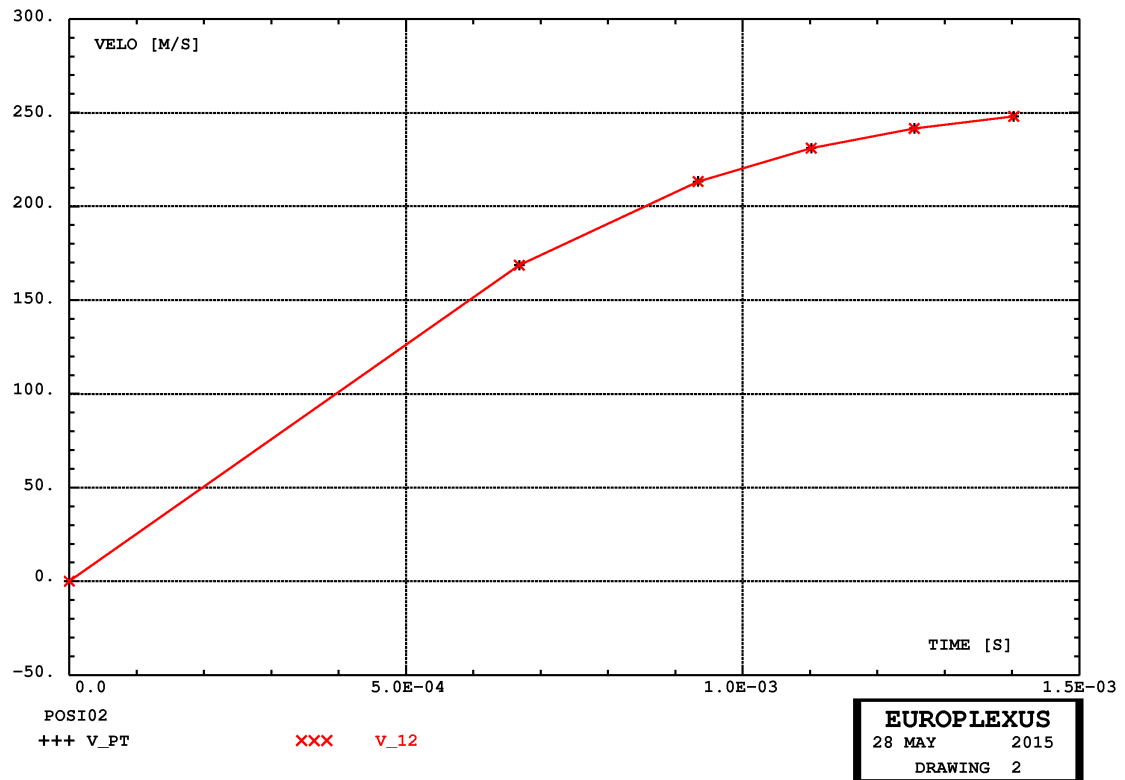


Figure 28 - Fluid velocities in case POSI02

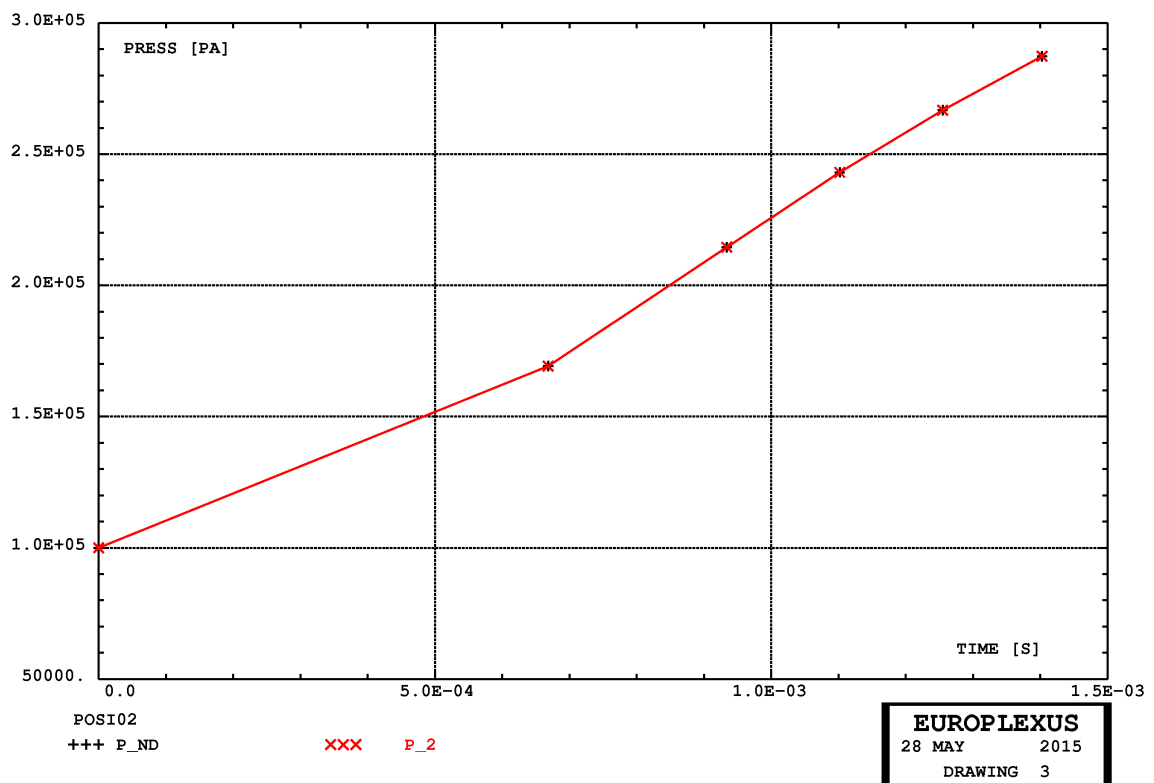


Figure 29 - Fluid pressures (with "follow") in case POSI02

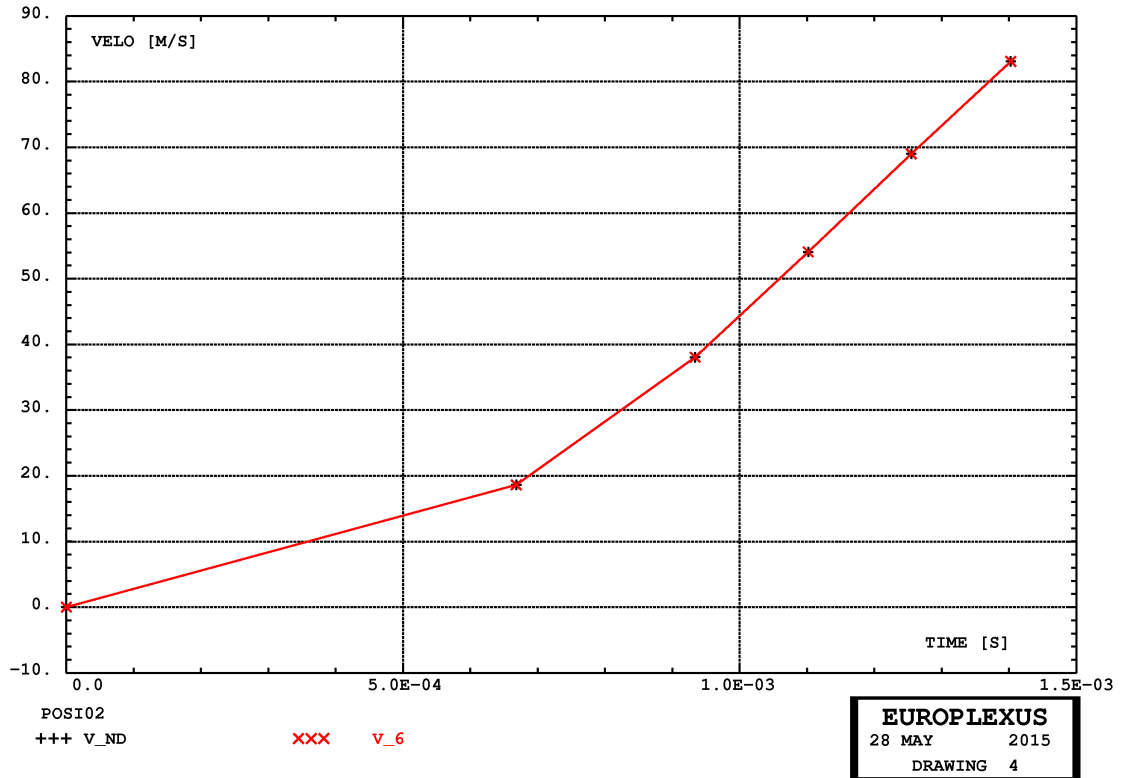


Figure 30 - Fluid velocities (with “follow”) in case POSI02

**POSI03**

This is a slightly more realistic example of the use of the POSI directives. The problem is illustrated in Figure 31. An explosion (red zone) takes place in a closed tube containing a deformable plate, supported at both ends. FSI-driven adaptivity in the fluid mesh is used.

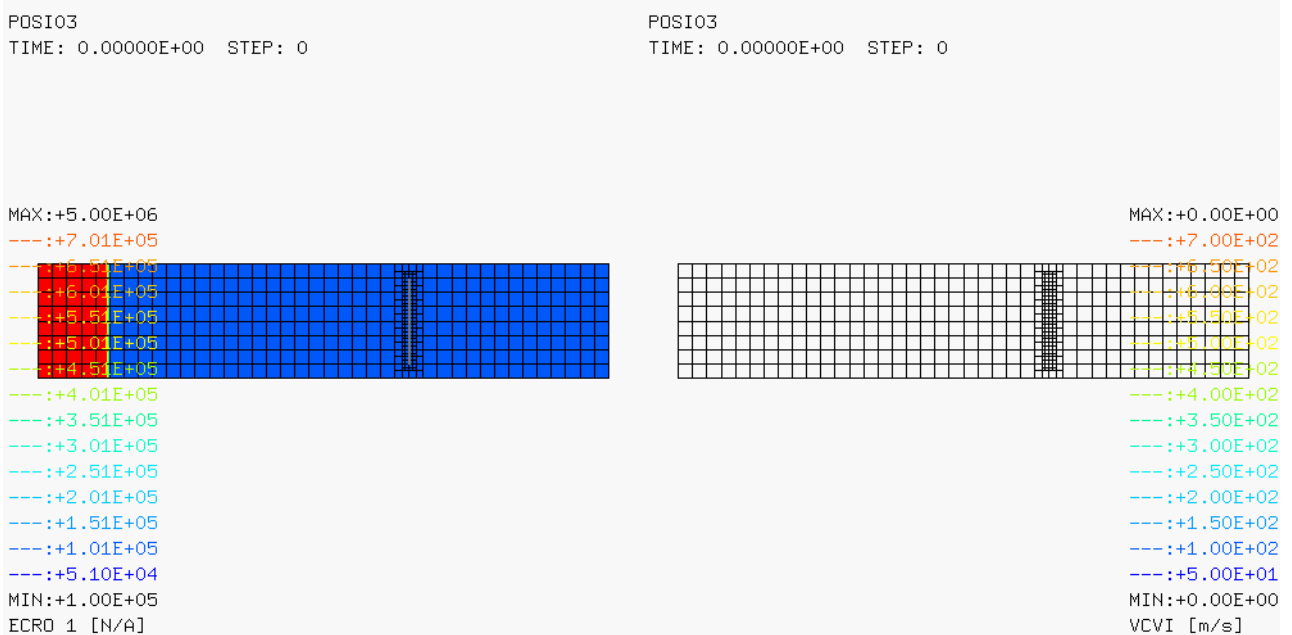


Figure 31 - Geometry of test case POSI03

Some results are shown next in the form of maps: fluid pressures at 20, 40, 60, 80, 100 and 120 ms in Figure 32 and the corresponding fluid velocities in Figure 33. The plate undergoes relatively large displacements and the fluid mesh is continuously adapted to follow the plate motion.

Suppose that the user is interested to have a record of the pressure and fluid velocity “upstream” and “downstream” the plate. Since the plate moves, this is not an easy task with the traditional directives, but it can be done with the new POSI directive.

Figures 34 and 35 show the fluid pressures and velocities at a distance of 0.125 m from the plate: the black curves represent the values “upstream”, i.e. to the left of the plate in this case, the red curves the values “downstream” (to the right of the plate). In the second Figure the green curve is added, which records the horizontal component of the velocity at the center point of the plate (pcs), for comparison.

Figures 36 and 37 show the same results but at an offset of 1.25 m instead of 0.125 m. As it can be seen by comparison, the results are relatively insensitive with respect to the actual offset considered (within reasonable bounds). The fluid base mesh size in this case is 0.5 m so that the maximum refined mesh at the chosen adaptivity level of 3 has a size of 0.125 m.

POSI03  
TIME: 2.00000E-02 STEP: 295

MAX:+1.85E+06  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+9.44E+04  
ECRO 1 [N/A]



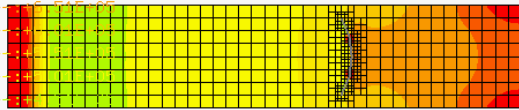
POSI03  
TIME: 4.00000E-02 STEP: 603

MAX:+1.43E+06  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+1.25E+05  
ECRO 1 [N/A]



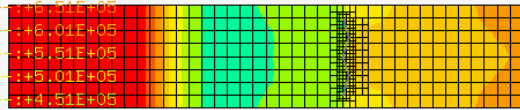
POSI03  
TIME: 6.00000E-02 STEP: 853

MAX:+1.08E+06  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+3.92E+05  
ECRO 1 [N/A]



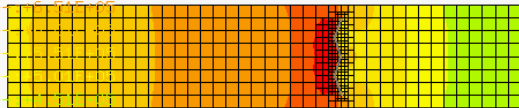
POSI03  
TIME: 8.00000E-02 STEP: 1103

MAX:+8.09E+05  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+2.82E+05  
ECRO 1 [N/A]



POSI03  
TIME: 1.00000E-01 STEP: 1354

MAX:+7.48E+05  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+4.32E+05  
ECRO 1 [N/A]



POSI03  
TIME: 1.20000E-01 STEP: 1604

MAX:+6.78E+05  
---:+7.01E+05  
---:+6.51E+05  
---:+6.01E+05  
---:+5.51E+05  
---:+5.01E+05  
---:+4.51E+05  
---:+4.01E+05  
---:+3.51E+05  
---:+3.01E+05  
---:+2.51E+05  
---:+2.01E+05  
---:+1.51E+05  
---:+1.01E+05  
---:+5.10E+04  
MIN:+4.76E+05  
ECRO 1 [N/A]

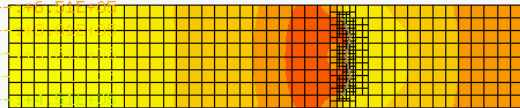


Figure 32 - Fluid pressures in test case POSI03

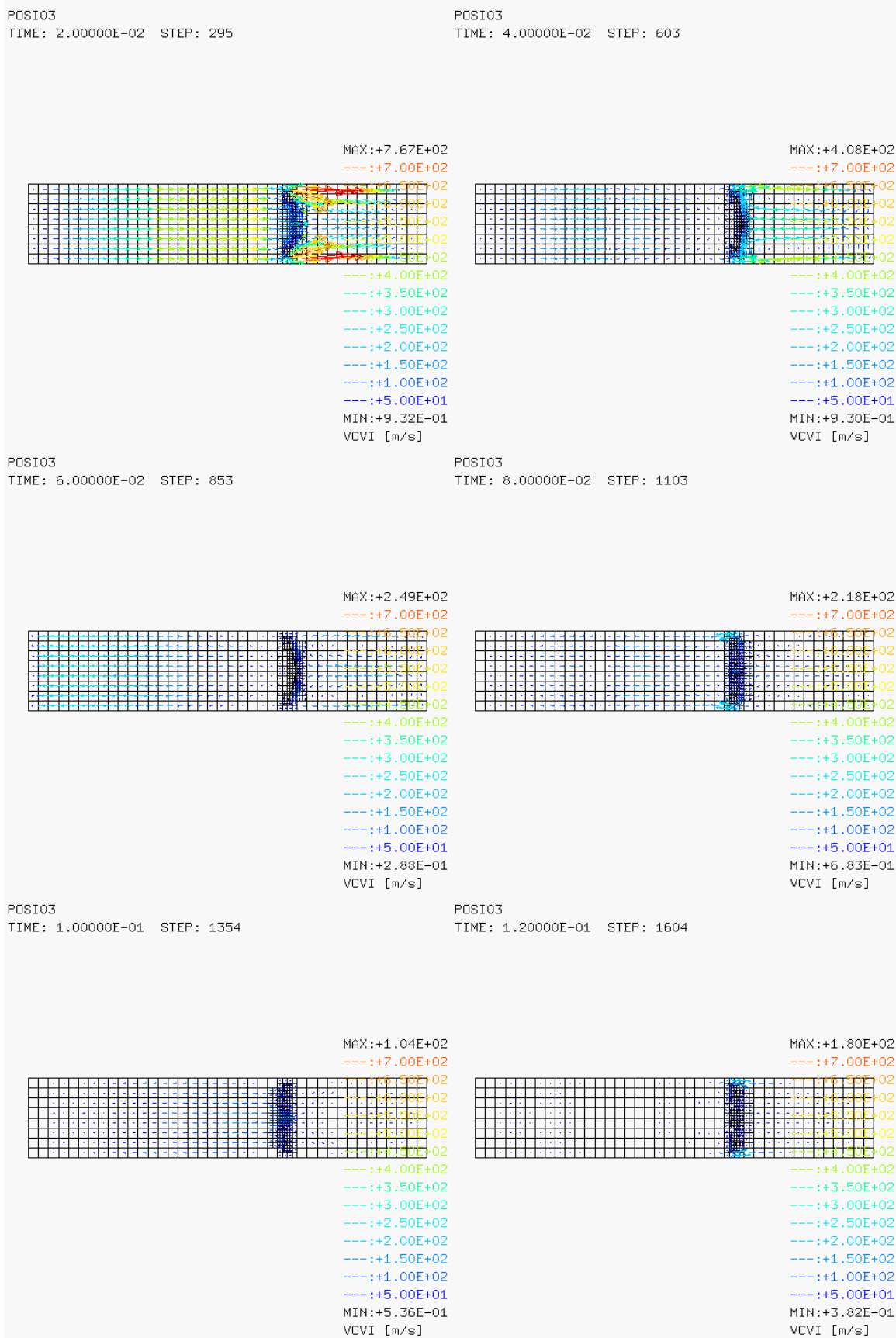


Figure 33 - Fluid velocities in test case POSI03

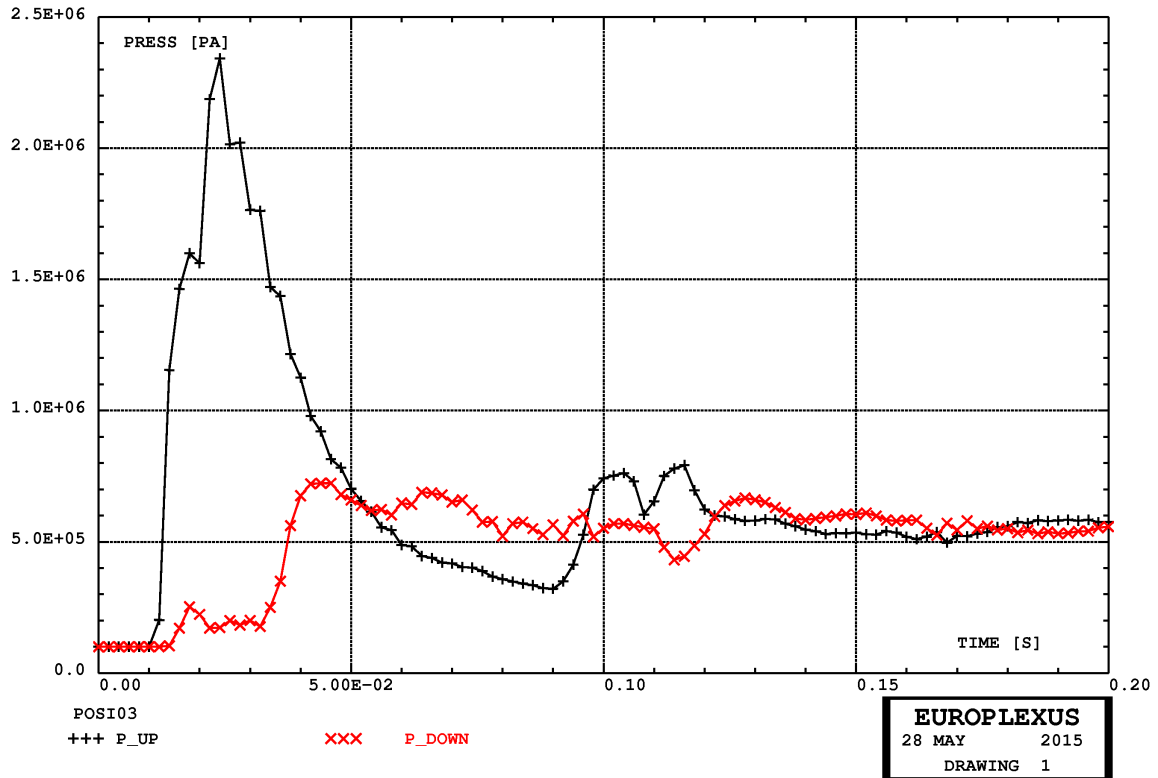


Figure 34 - Fluid pressures 0.125 m upstream and downstream the plate POSI03

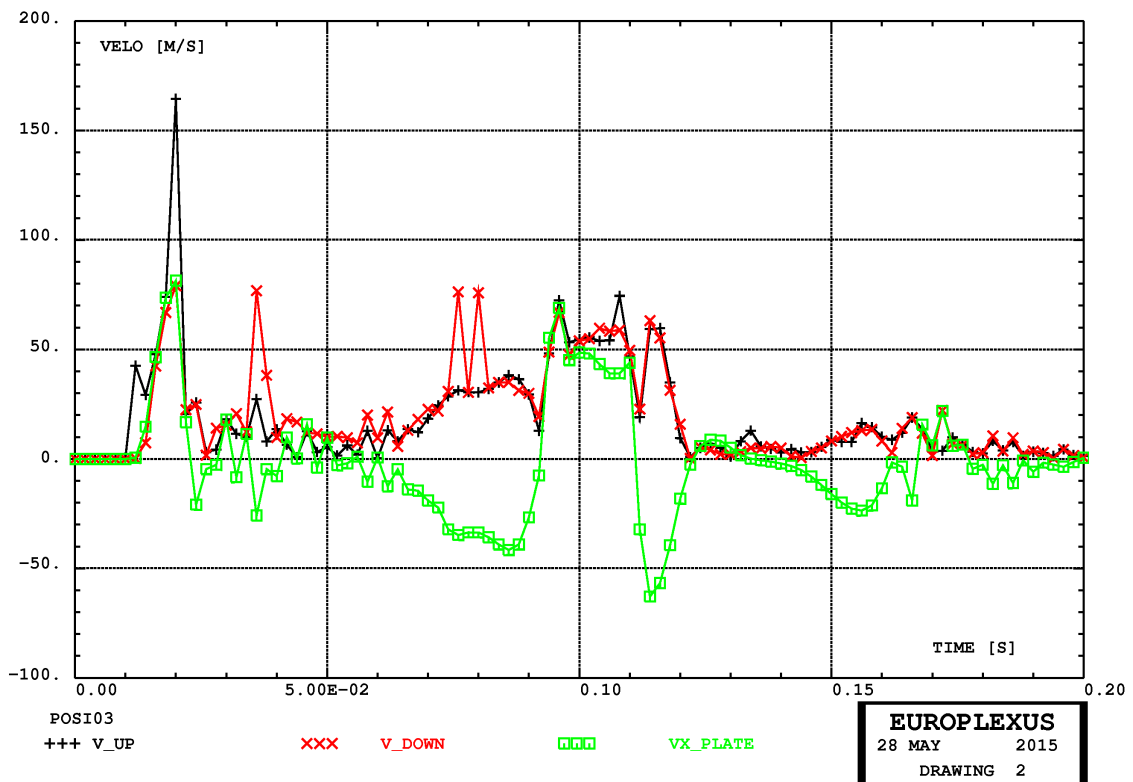


Figure 35 - Fluid velocities 0.125 m upstream and downstream the plate POSI03

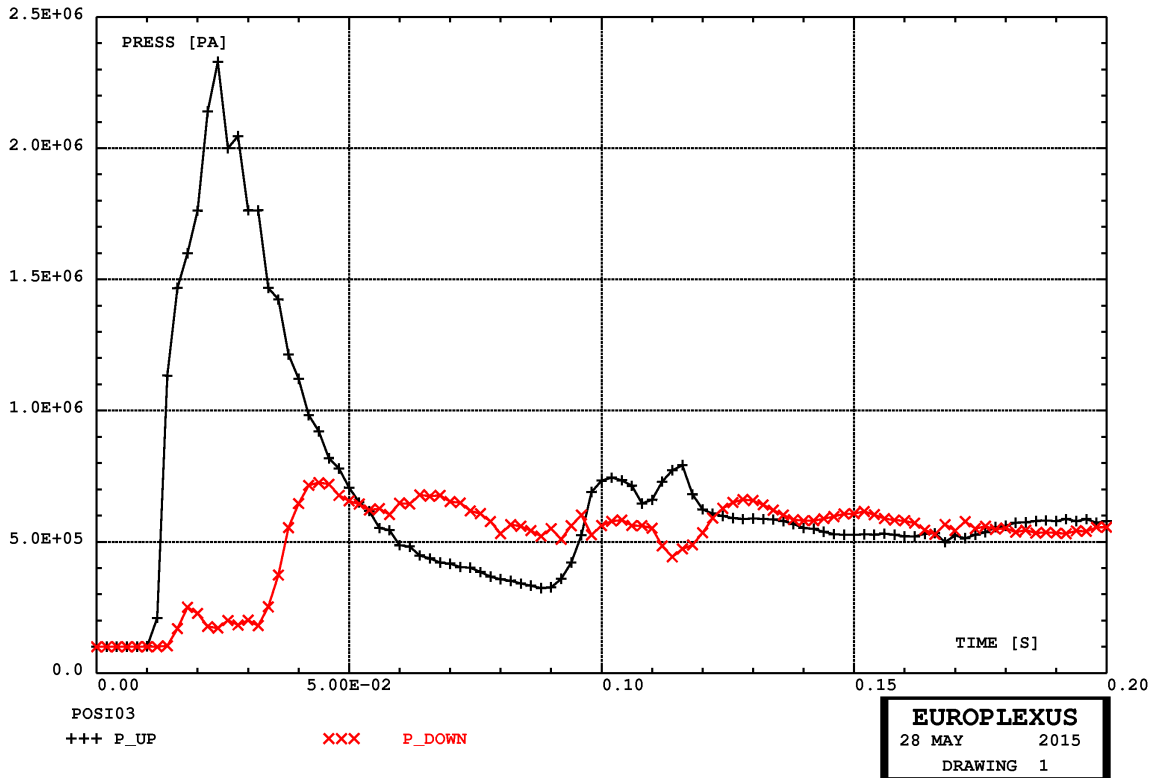


Figure 36 - Fluid pressures 0.25 m upstream and downstream the plate POSI03

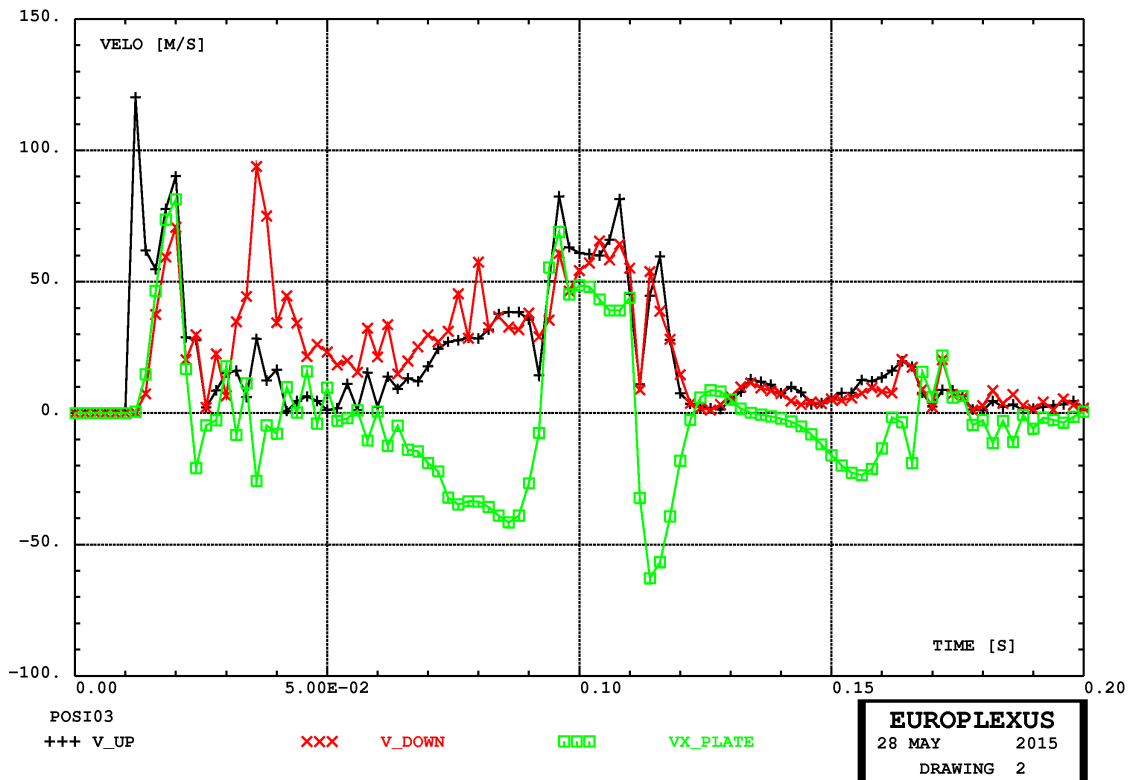


Figure 37 - Fluid velocities 0.25 m upstream and downstream the plate POSI03

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# Appendix

## Sample input files

This Section contains, in alphabetical file order, the listings of all input files related to the examples which were proposed in the previous Sections.

### posi01.epx

```

POSI01
ECHO
!CONV WIN
EULE DPLA
DIME ADAP NPOI 5 Q4VF 4 NVFI 12 ENDA TERM
GEOM LIBR POIN 9 Q4VF 4 TERM
0 0 1 0 2 0
0 1 1 1 2 1
0 2 1 2 2 2
1 2 5 4
2 3 6 5
4 5 8 7
5 6 9 8
COMP GROU 2 'expl' LECT 1 TERM
          'air' LECT 2 3 4 TERM
      COUL ROUG LECT expl TERM
          TURQ LECT air TERM
MATE GAZP RO 14 GAMM 1.5 PINI 14.E5 PREF 1.E5
      LECT expl TERM
      GAZP RO 1 GAMM 1.5 PINI 1.E5 PREF 1.E5
          LECT air q4vf TERM
INIT ADAP SPLI LEVE 2 LECT expl TERM
ECRI ECRO VFCC FREQ 1
      FICH ALIC FREQ 1
OPTI NOTE STEP IO CSTA 0.5 LOG 1
CALC TINI 0. TEND 1.0 NMAX 5
*****
SUIT
Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_pt' ECRO COMP 1 POSI 0.25 0.75 OBJE LECT expl air TERM
COUR 11 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 2 'v_pt' VCVI NORM POSI 0.25 0.75 OBJE LECT expl air TERM
COUR 12 'v_8' VCVI NORM ELEM LECT 8 TERM
COUR 3 'p_nd' ECRO COMP 1 POSI FOLL -0.1 -0.2 LECT 6 TERM
          OBJE LECT expl air TERM
COUR 13 'p_2' ECRO COMP 1 ELEM LECT 2 TERM
COUR 4 'v_nd' VCVI NORM POSI FOLL -0.1 -0.2 LECT 6 TERM
          OBJE LECT expl air TERM
COUR 14 'v_2' VCVI NORM ELEM LECT 2 TERM
TRAC 1 11 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 2 12 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 3 13 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 4 14 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
FIN

```

### posi02.epx

```

POSI02
ECHO
!CONV WIN
EULE DPLA
DIME ADAP NPOI 5 FL24 4 ENDA TERM
GEOM LIBR POIN 9 FL24 4 TERM
0 0 1 0 2 0
0 1 1 1 2 1
0 2 1 2 2 2
1 2 5 4
2 3 6 5
4 5 8 7
5 6 9 8
COMP GROU 2 'expl' LECT 1 TERM
          'air' LECT 2 3 4 TERM
      COUL ROUG LECT expl TERM
          TURQ LECT air TERM
MATE FLUT RO 14 EINT 2.5E5 GAMM 1.4 PB 0 PREF 1.E5
      ITER 1 ALFO 1 BETO 1 KINT 0 AHGF 0 CL 0.5
          CQ 2.56 PMIN 0 NUM 1
          LECT expl TERM
      FLUT RO 1 EINT 2.5E5 GAMM 1.4 PB 0 PREF 1.E5
          ITER 1 ALFO 1 BETO 1 KINT 0 AHGF 0 CL 0.5
          CQ 2.56 PMIN 0 NUM 1
          LECT air fl24 TERM
LINK COUP SPLT NONE
      BLOQ 1 LECT 1 3 4 6 7 9 TERM
      BLOQ 2 LECT 1 2 3 7 8 9 TERM
INIT ADAP SPLI LEVE 2 LECT expl TERM
ECRI VITE ECRO FREQ 1
      FICH ALIC FREQ 1
OPTI NOTE STEP IO CSTA 0.5 LOG 1
CALC TINI 0. TEND 1.0 NMAX 5
*****
SUIT
Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR

```

```

SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_pt' ECRO COMP 1 POSI 0.26 0.76 OBJE LECT expl air TERM
COUR 11 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 2 'v_pt' VITE NORM POSI 0.26 0.76 OBJE LECT expl air TERM
COUR 12 'v_12' VITE NORM NOEU LECT 12 TERM
COUR 3 'p_nd' ECRO COMP 1 POSI FOLL -0.1 -0.2 LECT 6 TERM
          OBJE LECT expl air TERM
COUR 13 'p_2' ECRO COMP 1 ELEM LECT 2 TERM
COUR 4 'v_nd' VITE NORM POSI FOLL -0.1 -0.2 LECT 6 TERM
          OBJE LECT expl air TERM
COUR 14 'v_6' VITE NORM NOEU LECT 6 TERM
TRAC 1 11 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 2 12 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 3 13 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 4 14 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
FIN

```

### posi03.dgibi

```

opti echo 1;
opti dime 2 elem qua4;
opti sauv form 'posi03.msh';
opti trac psc ftra 'posi03_mesh.ps';
p1 = 0 0;
p2 = 20 0;
p3 = 20 4;
p4 = 0 4;
c1 = p1 d 40 p2;
c2 = p2 d 8 p3;
c3 = p3 d 40 p4;
c4 = p4 d 8 p1;
flui = dall c1 c2 c3 c4 plan;
pls = 13 0.5;
pcs = 13 2.0;
p2s = 13 3.5;
stru = pls d 2 pcs d 2 p2s;
mesh = flui et stru;
tass mesh noop;
sauv form mesh;
trac qual mesh;
fin;

```

### posi03.epx

```

POSI03
ECHO
!CONV WIN
CAST mesh
ALE DPLA
DIME ADAP NPOI 1000 Q4VF 1000 NVFI 3000 ENDA
      NALE 1 NBLE 1 TERM
GEOM Q4VF flui ED01 stru TERM
COMP EPAI 0.01 LECT stru TERM
      GROU 2 'expl' LECT flui TERM COND BOX XO 0.0 YO 0.0 DX 2.0 DY 4.0
          'air' LECT flui DIFF expl TERM
      COUL ROUG LECT expl TERM
          TURQ LECT air TERM
          VERT LECT stru TERM
GRIL LAGR LECT stru TERM
      EULE LECT flui TERM
MATE GAZP RO 50 GAMM 1.5 PINI 50.E5 PREF 1.E5
      LECT expl TERM
      GAZP RO 1 GAMM 1.5 PINI 1.E5 PREF 1.E5
          LECT air q4vf 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
LINK COUP BLOQ 12 LECT p1s p2s TERM
LINK DECO
      PLSW STRU LECT stru TERM
      FLUI LECT flui TERM
      R 0.355 ! so that d = 2r = 0.71
      HGRI 0.76
      DGRI
      FACE
      BFLU 1 FSCP 0
      ADAP LMAX 3 SCAL 2
ECRI ECRO VFCC TFRE 10.E-3
      FICH ALIC TFRE 2.E-3
OPTI NOTE STEP IO CSTA 0.5 LOG 1
      ADAP RCON
CALC TINI 0. TEND 200.E-3
FIN

```

### posi03a.epx

```

POSI03A
ECHO
!CONV WIN
OPTI PRIN
RESU ALIC 'posi03.ali' GARD PSCR
SORT VISU NSTO 101
FIN

```

### posi03b.epx

```

POSI03B
ECHO
!CONV WIN
OPTI PRIN
RESU ALIC 'posi03.ali' GARD PSCR
SORT VISU NSTO 1
PLAY
CAME 1 EYE 1.00000E+01 2.00000E+00 5.09902E+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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+01  2.00000E+00  0.00000E+00
!RSPHERE: 1.01980E+01
!RADIUS : 5.09902E+01
!ASPECT : 1.00000E+00
!NEAR : 3.97724E+01
!FAR : 7.13863E+01
SCEN GEOM NAVI FREE
      ISO FILL FIEL ECRO 1 SCAL USER PROG 0.51E5 PAS 0.5E5 7.01E5 TERM
      SUPP LECT flui TERM
      TEXT ISCA
      COLO PAPE
SLER CAM1 1 NFRA 1
FREQ 1
TRAC OFFS FICH AVI NOCL NPTO 101 FPS 15 KPRE 10 COMP -1
      REND
GOTR LOOP 99 OFFS FICH AVI CONT NOCL
      REND
GO
TRAC OFFS FICH AVI CONT
      REND
ENDPLAY
FIN
    
```

posi03c.epx

```

POSIO3C
ECHO
!CONV WIN
OPTI PRIN
RESU ALIC 'posi03.ali' GARD PSCR
SORT VISU NSTO 1
PLAY
CAME 1 EYE 1.00000E+01  2.00000E+00  5.09902E+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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+01  2.00000E+00  0.00000E+00
!RSPHERE: 1.01980E+01
!RADIUS : 5.09902E+01
!ASPECT : 1.00000E+00
!NEAR : 3.97724E+01
!FAR : 7.13863E+01
SCEN GEOM NAVI FREE
      FACE HPRO
      VECT SCCO FIEL VCVI SCAL USER PROG 50 PAS 50 700 TERM
      SUPP LECT flui TERM
      TEXT VSCA
      COLO PAPE
SLER CAM1 1 NFRA 1
FREQ 1
TRAC OFFS FICH AVI NOCL NPTO 101 FPS 15 KPRE 10 COMP -1
      REND
GOTR LOOP 99 OFFS FICH AVI CONT NOCL
      REND
GO
TRAC OFFS FICH AVI CONT
      REND
ENDPLAY
FIN
    
```

posi03d.epx

```

POSIO3D
ECHO
OPTI PRIN
RESU ALIC 'posi03.ali' GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_up' ECRO COMP 1 POSI FOLL -0.125 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 2 'p_down' ECRO COMP 1 POSI FOLL 0.125 0.0 LECT pcs TERM
      OBJE LECT air TERM
TRAC 1 2 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
      COLO NOIR ROUG
COUR 3 'v_up' VCVI NORM POSI FOLL -0.125 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 4 'v_down' VCVI NORM POSI FOLL 0.125 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 5 'vx_plate' VITE COMP 1 NOEU LECT pcs TERM
TRAC 3 4 5 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
      COLO NOIR ROUG VERT
FIN
    
```

posi03d2.epx

```

POSIO3D2
ECHO
OPTI PRIN
RESU ALIC 'posi03.ali' GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_up' ECRO COMP 1 POSI FOLL -0.25 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 2 'p_down' ECRO COMP 1 POSI FOLL 0.25 0.0 LECT pcs TERM
      OBJE LECT air TERM
TRAC 1 2 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
      COLO NOIR ROUG
COUR 3 'v_up' VCVI NORM POSI FOLL -0.25 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 4 'v_down' VCVI NORM POSI FOLL 0.25 0.0 LECT pcs TERM
      OBJE LECT air TERM
COUR 5 'vx_plate' VITE COMP 1 NOEU LECT pcs TERM
    
```

```

TRAC 3 4 5 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
      COLO NOIR ROUG VERT
      FIN
    
```

tpos01.epx

```

TPOS01
ECHO
CONV WIN
EULE DPLA
DIME ADAP NPOI 5 Q4VF 4 NVPI 12 ENDA TERM
GEOM LIBR POIN 9 Q4VF 4 TERM
      0 0 1 0 2 0
      0 1 1 1 2 1
      0 2 1 2 2 2
      1 2 5 4
      2 3 6 5
      4 5 8 7
      5 6 9 8
COMP GROU 2 'expl' LECT 1 TERM
      'air' LECT 2 3 4 TERM
      COUL ROUG LECT expl TERM
      TURQ LECT air TERM
MATE GAZP RO 14 GAMB 1.5 PINI 14.E5 PREF 1.E5
      LECT expl TERM
      GAZP RO 1 GAMB 1.5 PINI 1.E5 PREF 1.E5
      LECT air_q4vf TERM
INIT ADAP SPLI LEVE 2 LECT expl TERM
ECRI ECRO VFCC FREQ 1
      FICH ALIC FREQ 1
OPTI NOTE STEP IO CSTA 0.5 LOG 1
CALC TINI 0. TEND 1.0 NMAX 5
*=====
PLAY
CAME 1 EYE 1.00000E+00  1.00000E+00  7.07107E+00
!      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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00  1.00000E+00  0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
      FELE FIEL ECRO 1 SCAL USER PROG 0.999E5 PAS 1.E5 13.999E5 TERM
      TEXT ISCA
      COLO PAPE
SLER CAM1 1 NFRA 1
TRAC OFFS FICH BMP REND
FREQ 1
GOTR LOOP 5 OFFS FICH BMP REND
ENDPLAY
*=====
SUIT
Post: "animation" of velocities
ECHO
RESU ALIC GARD PSCR
SORT VISU NSTO 1
*=====
PLAY
CAME 1 EYE 1.00000E+00  1.00000E+00  7.07107E+00
!      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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00  1.00000E+00  0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
      FACE HPRO
      VECT SCCO FIEL VCVI SCAL USER PROG 10 PAS 10 140 TERM
      TEXT VSCA
      COLO PAPE
SLER CAM1 1 NFRA 1
TRAC OFFS FICH BMP REND
FREQ 1
GOTR LOOP 5 OFFS FICH BMP REND
ENDPLAY
*=====
SUIT
Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_expl' ECRO COMP 1 ELEM LECT expl TERM
COUR 2 'p_4' ECRO COMP 1 ELEM LECT 4 TERM
COUR 3 'p_5' ECRO COMP 1 ELEM LECT 5 TERM
COUR 4 'v_expl' VCVI NORM ELEM LECT expl TERM
COUR 5 'v_4' VCVI NORM ELEM LECT 4 TERM
COUR 6 'v_5' VCVI NORM ELEM LECT 5 TERM
TRAC 1 2 3 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
TRAC 1 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
TRAC 2 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
TRAC 3 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
TRAC 4 5 6 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
TRAC 4 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
TRAC 5 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
TRAC 6 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COUR 7 'p_6' ECRO COMP 1 ELEM LECT 6 TERM
COUR 8 'p_7' ECRO COMP 1 ELEM LECT 7 TERM
COUR 9 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 10 SOMM 4 3 1.0 7 1.0 8 1.0 9 1.0
COUR 11 'p_ave' DIVC 10 4.0
TRAC 1 11 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
      COLO NOIR ROUG
    
```

```
COUR 12 'v_6' VCVI NORM ELEM LECT 6 TERM
COUR 13 'v_7' VCVI NORM ELEM LECT 7 TERM
COUR 14 'v_8' VCVI NORM ELEM LECT 8 TERM
COUR 15 SOMM 4 6 1.0 12 1.0 13 1.0 14 1.0
COUR 16 'v_ave' DIVC 15 4.0
TRAC 4 16 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
TRAC 6 12 13 14 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG VERT TURQ
COUR 17 'v_1' VCVI NORM ELEM LECT 1 TERM
TRAC 4 17 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG
FIN
```

```
COLO ROUG VERT TURQ ROSE NOIR
TRAC 6 7 5 8 9 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO ROUG VERT TURQ ROSE NOIR
COUR 11 'v_9' VCVI NORM ELEM LECT 9 TERM
COUR 12 'v_10' VCVI NORM ELEM LECT 10 TERM
COUR 13 'v_11' VCVI NORM ELEM LECT 11 TERM
COUR 14 'v_12' VCVI NORM ELEM LECT 12 TERM
COUR 15 'v_7' VCVI NORM ELEM LECT 7 TERM
COUR 16 'v_5' VCVI NORM ELEM LECT 5 TERM
COUR 17 'v_6' VCVI NORM ELEM LECT 6 TERM
COUR 18 'v_8' VCVI NORM ELEM LECT 8 TERM
COUR 19 'v_expl' VCVI NORM ELEM LECT expl TERM
TRAC 11 12 13 14 15 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO ROUG VERT TURQ ROSE NOIR
TRAC 16 17 15 18 19 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO ROUG VERT TURQ ROSE NOIR
COUR 20 SOMM 4 1 1.0 2 1.0 3 1.0 4 1.0
COUR 21 'p_ave_7' DIVC 20 4.0
TRAC 5 21 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO ROUG VERT
COUR 22 SOMM 4 6 1.0 7 1.0 5 1.0 8 1.0
COUR 23 'p_ave_1' DIVC 22 4.0
TRAC 9 23 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO ROUG VERT
FIN
```

tpos05.epx

```
TPOS05
ECHO
!CONV WIN
EULE DPLA
DIME ADAP NPOI 10 Q4VF 8 NVFI 24 ENDA TERM
GEOM LIBR POIN 9 Q4VF 4 TERM
0 0 1 0 2 0
0 1 1 1 2 1
0 2 1 2 2 2
1 2 5 4
2 3 6 5
4 5 8 7
5 6 9 8
COMP GROU 2 'expl' LECT 1 TERM
'air' LECT 2 3 4 TERM
COUL ROUG LECT expl TERM
TURQ LECT air TERM
MATE GAZP RO 14 GAMM 1.5 PINI 14.E5 PREF 1.E5
LECT expl TERM
GAZP RO 1 GAMM 1.5 PINI 1.E5 PREF 1.E5
LECT air q4vf TERM
INIT ADAP SPLI LEVE 2 LECT expl TERM
SPLI LEVE 3 LECT 7 TERM
ECRI ECRO VFCC FREQ 1
FICH ALIC FREQ 1
OPTI NOTE STEP IO CSTA 0.5 LOG 1
CALC TINI 0. TEND 1.0 NMAX 5
*=====
PLAY
CAME 1 EYE 1.00000E+00 1.00000E+00 7.07107E+00
! 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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00 1.00000E+00 0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
ISO FELE FIEL ECRO 1 SCAL USER PROG 0.999E5 PAS 1.E5 13.999E5 TERM
TEXT ISCA
COLO PAPE
SLER CAM1 1 NFRA 1
TRAC OFFS FICH BMP REND
FREQ 1
GOTR LOOP 5 OFFS FICH BMP REND
ENDPLAY
*=====
SUIT
Post: "animation" of velocities
ECHO
RESU ALIC GARD PSCR
SORT VISU NSTO 1
*=====
PLAY
CAME 1 EYE 1.00000E+00 1.00000E+00 7.07107E+00
! 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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00 1.00000E+00 0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
FACE HFR0
VECT SCCO FIEL VCVI SCAL USER PROG 10 PAS 10 140 TERM
TEXT VSCA
COLO PAPE
SLER CAM1 1 NFRA 1
TRAC OFFS FICH BMP REND
FREQ 1
GOTR LOOP 5 OFFS FICH BMP REND
ENDPLAY
*=====
SUIT
Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_9' ECRO COMP 1 ELEM LECT 9 TERM
COUR 2 'p_10' ECRO COMP 1 ELEM LECT 10 TERM
COUR 3 'p_11' ECRO COMP 1 ELEM LECT 11 TERM
COUR 4 'p_12' ECRO COMP 1 ELEM LECT 12 TERM
COUR 5 'p_7' ECRO COMP 1 ELEM LECT 7 TERM
COUR 6 'p_5' ECRO COMP 1 ELEM LECT 5 TERM
COUR 7 'p_6' ECRO COMP 1 ELEM LECT 6 TERM
COUR 8 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
COUR 9 'p_expl' ECRO COMP 1 ELEM LECT expl TERM
TRAC 1 2 3 4 5 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
```

tpos06.epx

```
TPOS06
ECHO
!CONV WIN
EULE DPLA
DIME ADAP NPOI 5 Q4VF 4 NVFI 12 ENDA TERM
GEOM LIBR POIN 9 Q4VF 4 TERM
0 0 1 0 2 0
0 1 1 1 2 1
0 2 1 2 2 2
1 2 5 4
2 3 6 5
4 5 8 7
5 6 9 8
COMP GROU 2 'expl' LECT 1 TERM
'air' LECT 2 3 4 TERM
COUL ROUG LECT expl TERM
TURQ LECT air TERM
MATE GAZP RO 14 GAMM 1.5 PINI 14.E5 PREF 1.E5
LECT expl TERM
GAZP RO 1 GAMM 1.5 PINI 1.E5 PREF 1.E5
LECT air q4vf TERM
INIT ADAP SPLI LEVE 2 LECT expl TERM
ECRI ECRO VFCC FREQ 1
FICH ALIC FREQ 1
OPTI NOTE STEP IO CSTA 0.5 LOG 1
CALC TINI 0. TEND 1.0 NMAX 5
*=====
PLAY
CAME 1 EYE 1.00000E+00 1.00000E+00 7.07107E+00
! 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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00 1.00000E+00 0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
ISO FELE FIEL ECRO 1 SCAL USER PROG 0.999E5 PAS 1.E5 13.999E5 TERM
TEXT ISCA
COLO PAPE
SLER CAM1 1 NFRA 1
TRAC OFFS FICH BMP REND ! step 0
FREQ 1
GO
TRAC OFFS FICH BMP REND ! step 1
GO
TRAC OFFS FICH BMP REND ! step 2
ADAP USPL 1 TERM
GO
TRAC OFFS FICH BMP REND ! step 3
ADAP SPLI 4 TERM
GO
TRAC OFFS FICH BMP REND ! step 4
GO
TRAC OFFS FICH BMP REND ! step 5
ENDPLAY
*=====
SUIT
Post: "animation" of velocities
ECHO
RESU ALIC GARD PSCR
SORT VISU NSTO 1
*=====
PLAY
CAME 1 EYE 1.00000E+00 1.00000E+00 7.07107E+00
! 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
!NAVIGATION MODE: ROTATING CAMERA
!CENTER : 1.00000E+00 1.00000E+00 0.00000E+00
!RSPHERE: 1.41421E+00
!RADIUS : 7.07107E+00
!ASPECT : 1.00000E+00
!NEAR : 5.51543E+00
!FAR : 9.89949E+00
SCEN GEOM NAVI FREE
FACE HFR0
VECT SCCO FIEL VCVI SCAL USER PROG 10 PAS 10 140 TERM
TEXT VSCA
COLO PAPE
SLER CAM1 1 NFRA 1
```

```
TRAC OFFS FICH BMP REND
FREQ 1
GOTR LOOP 5 OFFS FICH BMP REND
ENDPLAY
*-----
SUIT
Post: time curves
ECHO
OPTI PRIN
RESU ALIC GARD PSCR
SORT GRAP
AXTE 1.0 'Time [s]'
COUR 1 'p_1' ECRO COMP 1 ELEM LECT 1 TERM
COUR 2 'p_4' ECRO COMP 1 ELEM LECT 4 TERM
COUR 3 'p_5' ECRO COMP 1 ELEM LECT 5 TERM
COUR 4 'p_6' ECRO COMP 1 ELEM LECT 6 TERM
COUR 5 'p_7' ECRO COMP 1 ELEM LECT 7 TERM
COUR 6 'p_8' ECRO COMP 1 ELEM LECT 8 TERM
TRAC 1 2 3 4 5 6 AXES 1.0 'PRESS [PA]' SYMB XGRD YGRD
COLO NOIR ROUG VERT TURQ ROSE BLEU
COUR 11 'v_1' VCVI NORM ELEM LECT 1 TERM
COUR 12 'v_4' VCVI NORM ELEM LECT 4 TERM
COUR 13 'v_5' VCVI NORM ELEM LECT 5 TERM
COUR 14 'v_6' VCVI NORM ELEM LECT 6 TERM
COUR 15 'v_7' VCVI NORM ELEM LECT 7 TERM
COUR 16 'v_8' VCVI NORM ELEM LECT 8 TERM
TRAC 11 12 13 14 15 16 AXES 1.0 'VELO [M/S]' SYMB XGRD YGRD
COLO NOIR ROUG VERT TURQ ROSE BLEU
FIN
```



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#### **Abstract**

The present work addresses the post-processing and the correct interpretation of results obtained in numerical simulations using mesh adaptivity in the explicit Finite Element code EUROPLEXUS.

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