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documentation

version 3.0 tutorial - Simplified nuclear vessel

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Part I

Simple Junction testcase

1 General description

The first thing to do before running *Code_Saturne* is to prepare the computation directories. In this first example, the study directory `T_junction/` will be created, containing a single calculation sub-directory `case1`. This is done by typing the command:

```
$ code_saturne create -s T_junction -c case1
```

The mesh files should be copied in the directory `MESH/` as below:

```
$ cd T_junction/MESH/
$ cp ITECH_CS_training_2012/meshes/1-simple_junction/downcomer.des .
```

The *Code_Saturne* Graphic User Interface (GUI) is launched by typing the following command lines:

```
$ cd T_junction/case1/DATA
$ ./SaturneGUI &
```

1.1 Objective

The aim of this case is to train the user of *Code_Saturne* on an oversimplified 2D junction including an inlet, an outlet, walls and symmetries.

1.2 Description of the configuration

The configuration is two-dimensional.
It consists of a simple junction as shown on figure I.1. The flow enters through a hot inlet into a cold environment and exits as indicated on the same figure. This geometry can be considered as a very rough approximation of the cold branch and the downcomer of the vessel in a nuclear pressurized water reactor. The effect of temperature on the fluid density is not taken into account in this first example.

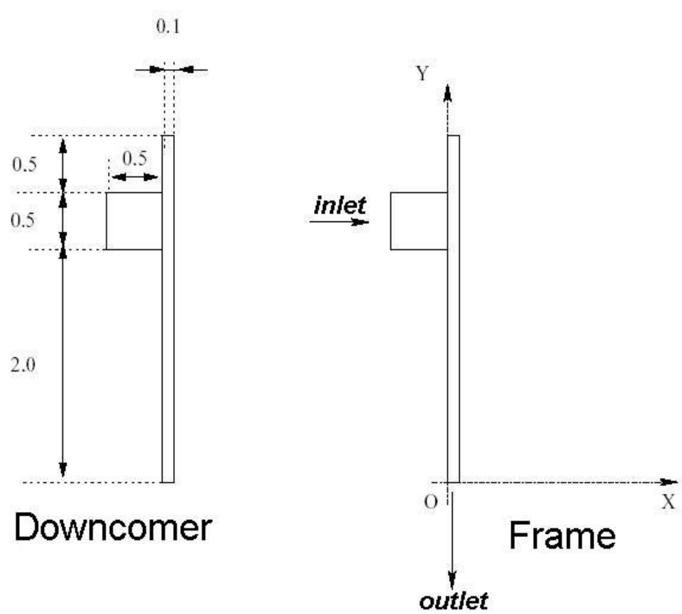


Figure I.1: Geometry of the downcomer

1.3 Characteristics

Characteristics of the geometry and the flow:

Height of downcomer	$H = 3.00\ m$
Thickness of downcomer	$E_d = 0.10\ m$
Diameter of the cold branch	$D_b = 0.50\ m$
Inlet velocity of fluid	$V = 1\ m.s^{-1}$

Physical characteristics of fluid:
The initial water temperature in the domain is equal to 20°C. The inlet temperature of water in the cold branch is 300°C. Water characteristics are considered constant and their values taken at 300°C and $150 \times 10^5\ Pa$:

- density: $\rho = 725.735\ kg.m^{-3}$
- dynamic viscosity: $\mu = 0.895 \times 10^{-4}\ kg.m^{-1}.s^{-1} = 8.951 \times 10^{-5}\ Pa.s$
- specific heat: $C_p = 5\,483\ J.kg^{-1}.°\mathrm{C}^{-1}$
- Thermal Conductivity $= 0.02495\ W.m^{-1}.K^{-1}$

1.4 Mesh characteristics

Figure I.2 shows a global view of the downcomer mesh. This two-dimensional mesh is composed of 700 cells, which is very small compared to those used in real studies. This is a deliberate choice so that tutorial calculations run fast.

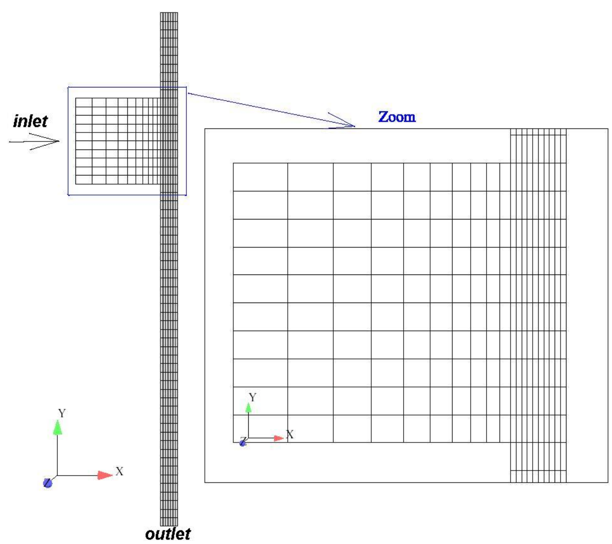


Figure I.2: Geometry of the downcomer

Note that here the case is two-dimensional but *Code_Saturne* always operates on three-dimensional mesh elements (cells). The present mesh is composed of a layer of hexahedrons created from the 2D mesh shown on figure I.2 by extrusion (elevation) in the z direction. The virtual planes parallel to Oxy will have “sliding” (“symmetry”) conditions to account for the two-dimensional character of the configuration.

Type: structured mesh

Coordinates system: cartesian, origin on the edge of the main pipe at the outlet level, on the nozzle side (figure I.1)

Mesh generator used: SIMAIL

Color definition: see figure I.3. To specifiy boundary conditions on the boundary faces of the mesh, the latter have to be identified. It is commonly done by assigning an integer to each of them, characteristic of the boundary region they belong to. This integer is refered to as "color" or "reference".

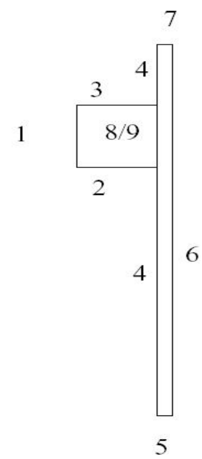


Figure I.3: Colors of the boundary faces

2 CASE 1: Basic calculation

2.1 Calculation options

Most of the options used in this calculation are default options of *Code_Saturne*.

→ Flow type: steady flow

→ Turbulence model: $k - \epsilon$

→ Scalar(s): 1 - temperature

→ Physical properties: uniform and constant

2.2 Initial and boundary conditions

→ Initialization: none (default values)

The boundary conditions are defined as follows:

- **Flow inlet**: Dirichlet condition, an inlet velocity of 1 $m.s^{-1}$ and an inlet temperature of 300°C are imposed
- **Outlet**: default values
- **Walls**: default values

Figure I.3 shows the colors used for boundary conditions and table I.1 defines the correspondance between the colors and the type of boundary condition to use.

Do not forget to enter the value of the hydraulic diameter, adapted to the current inlet (used for turbulence entry conditions).

Colors	Conditions
1	Inlet
5	Outlet
2 3 4 6 7	Wall
8 9	Symmetry

Table I.1: Boundary conditions and associated references

2.3 Parameters and User routines

All parameters necessary to this study can be defined through the Graphical Interface without using any user Fortran files.

Calculation control parameters	
Pressure-Velocity coupling	SIMPLE algorithm
Number of iterations	30
Relaxation coefficient	0.9
Output period for post-processing files	1

2.4 Results

Figure I.4 presents the results obtained at different iterations in the calculation. They were plotted from the post-processing files, with EnSight.

Note: since the "steady flow" option has been chosen, the evolution of the flow iteration after iteration has no physical meaning. It is merely an indication of the rapidity of convergence towards the (physical) steady state.

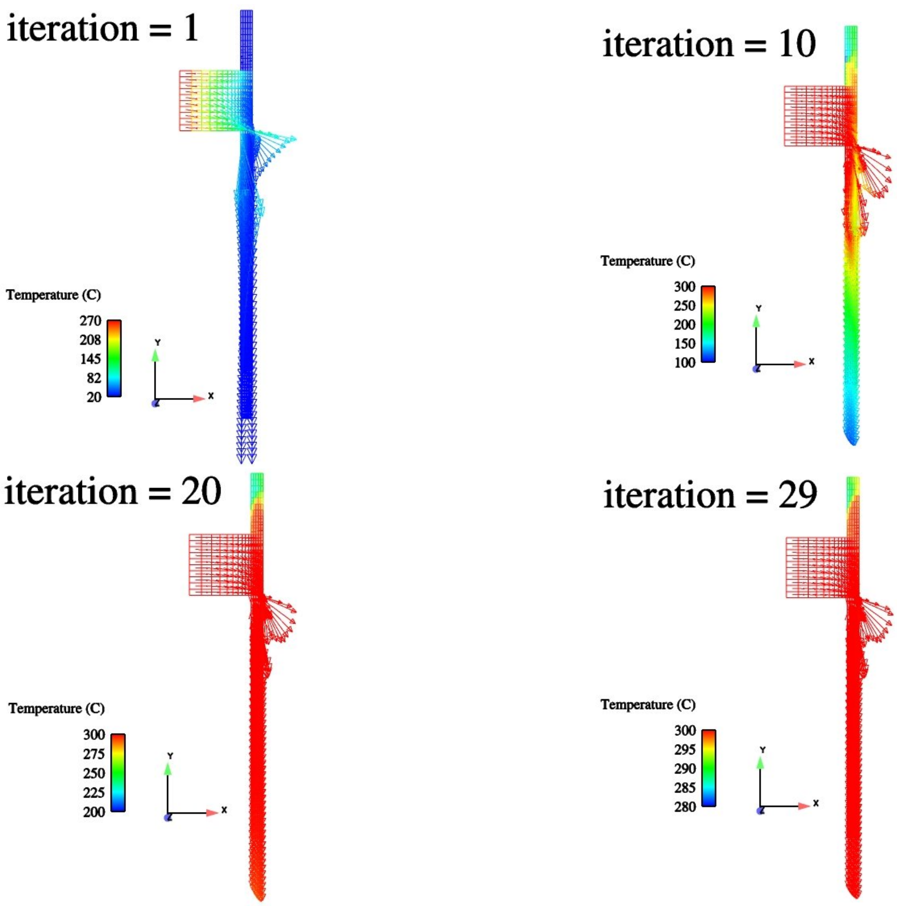


Figure I.4: Water velocity field colored by temperature at different time steps

Part II

Full domain

1 General description

1.1 Objective

This aim of this case is to tackle the merging of initially separate meshes into a single fluid domain. The questions of mesh joining and hanging nodes will be addressed. The test case will then be used to present more complex calculations, with time dependent variables and Fortran user routines.

1.2 Description of the configuration

The fluid domain is composed of three separate meshes, very roughly representing elements of a nuclear pressurized water reactor vessel:

- the downcomer
- the vessel's bottom
- the lower core plate and core

Figure II.1 represents the complete domain. The flow circulates from the top left horizontal junction to the right vertical outlet.

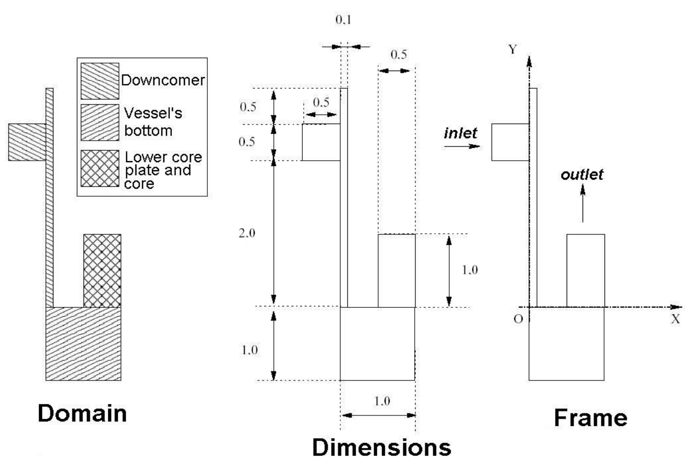


Figure II.1: Geometry of the complete domain

1.3 Characteristics

The characteristics of the geometry and the flow are:

Height of downcomer	$H = 3.00\ m$
Thickness of downcomer	$E_d = 0.10\ m$
Diameter of the inlet cold branch	$D_b = 0.50\ m$
Height of vessel's bottom	$H_{fc} = 1.00\ m$
Width of vessel's bottom	$l_{fc} = 1.00\ m$
Height of core above the lower core plate	$H_{pic} = 1.00\ m$
Width of core above the lower core plate	$l_{pic} = 0.50\ m$
Inlet velocity of fluid	$V = 1\ m.s^{-1}$

Physical characteristics of fluid:
The initial water temperature in the domain is equal to 20°C. The inlet temperature of water in the cold branch is 300°C. Water characteristics are considered constant[1] and their values taken at 300°C and $150 \times 10^5\ Pa$, except density which is considered variable in cases 3 and 4:

- density: $\rho = 725.735\ kg.m^{-3}$
- dynamic viscosity: $\mu = 0.895 \times 10^{-4}\ kg.m^{-1}.s^{-1} = 8.951 \times 10^{-5}\ Pa.s$
- heat capacity: $C_p = 5\,483\ J.kg^{-1}.°\mathrm{C}^{-1}$
- Thermal Conductivity $= 0.02495\ W.m^{-1}.K^{-1}$

1.4 Mesh characteristics

Figure II.2 shows a global view of the mesh and some details of the joining zones, to show that *Code_Saturne* can deal with hanging nodes. This mesh is composed of 1 650 cells, which is very small compared to those used in real studies. This is a deliberate choice so that tutorial calculations run fast.

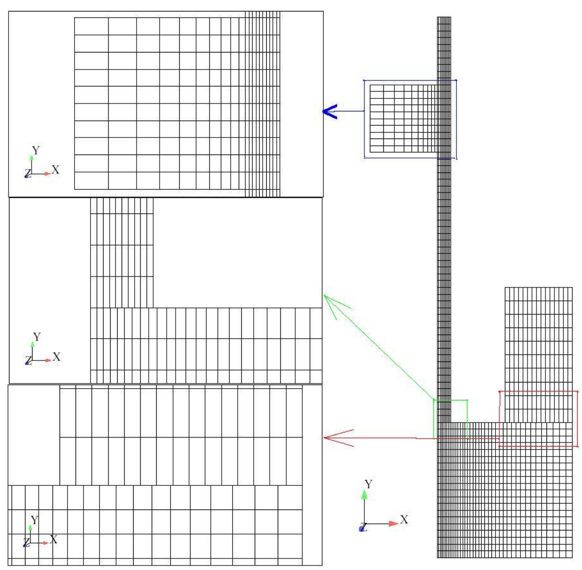


Figure II.2: View of the full domain mesh with zoom on the joining regions

Type: block structured mesh

Coordinates system: cartesian, origin on the edge of the main pipe at the outlet level, on the nozzle side (figure II.2)

Mesh generator used: SIMAIL and mesh joining with the Preprocessor of *Code_Saturne* (in order to deal with hanging nodes)

Color definition: see figure II.3

1.5 Summary of the different calculations

Three cases will be studied with this geometry. The following table gives a summary of their different characteristics.

[1] which makes temperature a passive scalar ... but it is only for simplification purposes

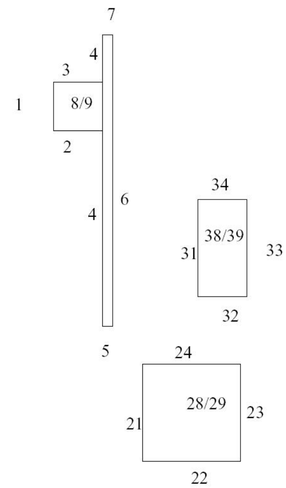


Figure II.3: Colors of the boundary faces

CASE	characteristics
CASE 2	unsteady flow, additionnal passive scalar, output management
CASE 3	same as case 2 with time dependent boundary conditions, fluid density depending on the temperature and calculation restart
CASE 4	same as case 3 with head losses, parallelism and spatial average

Remark: In this case, you must add three meshes which have to be joined. In order to join the three meshes, you must add a selection criteria in the box *Selection criteria*. In this case, only faces of colors 5, 24 and 32 are liable to be joined (different colors can be entered on a single line, separated by comma).
You can verify the quality of your mesh in *Mesh quality criteria*.

2 CASE 2: Passive scalar with various boundary conditions and output management

2.1 Calculation options

Some options are similar to case 1:

→ Turbulence model: $k - \epsilon$

→ Scalar(s): 1 - temperature

→ Physical properties: uniform and constant

The new options are:

→ Flow type: unsteady flow

→ Time step: uniform and constant

→ Scalar(s): 2 - passive scalar[2]

→ Management of monitoring points

[2] could correspond to a tracer concentration for instance

2.2 Initial and boundary conditions

→ Initialization: 20°C for temperature (default value)
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone.

- **Flow inlet**: Dirichlet condition, an inlet velocity of 1 $m.s^{-1}$, an inlet temperature of 300°C and an inlet value of 200 for the passive scalar are imposed
- **Outlet**: default value
- **Walls**: velocity, pressure and thermal scalar: default value
  passive scalar: different conditions depending on the color and geometric parameters

In order to test the ability to specify boundary condition regions in the Graphical Interface, various conditions will be imposed for the passive scalar, as specified in the following table:

Wall	Nature	Value
wall_1	Dirichlet	0
wall_2	Dirichlet	5
wall_3	Dirichlet	0
wall_4	Dirichlet	25
wall_5	Dirichlet	320
wall_6	Dirichlet	40

The "wall_1" to "wall_6" regions are defined as follows, through color references and geometric localization:

Label	Color and geometric parameters
wall_1	24 and $0.1 \leqslant x$ and $x \leqslant 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leqslant 1$
wall_6	31 or 33

Figure II.3 shows the colors used for boundary conditions and table II.1 defines the correspondance between the colors and the type of boundary condition to use.

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 24 31 33	Wall
8 9 28 29 38 39	Symmetry

Table II.1: Boundary faces colors and associated references

2.3 Parameters and User routines

All parameters necessary to this study can be defined through the Graphical Interface without using any user Fortran files.

Calculation control parameters	
Pressure-Velocity coupling	SIMPLEC algorithm
Number of iterations	300
Reference time step	0.05
Output period for post-processing files	2

2.4 Output management

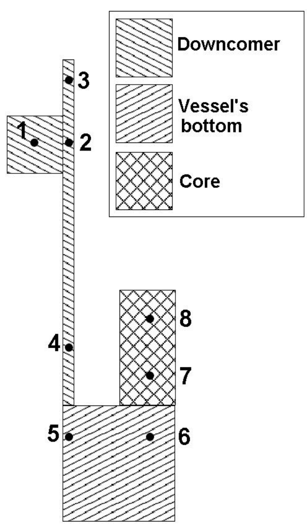
In this case, different aspects of output management will be addressed.

By default in the Graphical Interface, all variables are set to appear in the listing, the post-processing and the chronological records. This default choice can be modified by the user.

In this case, the *Pressure*, the *Tubulent energy* and the *Dissipation* will be removed from the listing file.

The *Courant number* (CFL) and *Fourier number* will be removed from the post-processing results[3].

Eventually, probes will be defined for chronological records, following the data given in figure II.4. Then the *total pressure* will be deactivated for all probes and the *Velocity U* will only be activated on probes 1, 2, 6, 7 and 8.



Probe n^o.	x (m)	y (m)	z (m)
1	-0.25	2.25	0
2	0.05	2.25	0
3	0.05	2.75	0
4	0.05	0.5	0
5	0.05	-0.25	0
6	0.75	-0.25	0
7	0.75	0.25	0
8	0.75	0.75	0

Figure II.4: Position and coordinates of probes in the full domain

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the passive scalar.

2.5 Results

Figure II.5 shows the boundary domain colored by the passive scalar boundary conditions. The different regions of boundary conditions defined earlier can be checked.

Figure II.6 presents results obtained at different times of the calculation. They were plotted from the post-processing files, with EnSight.

[3]this can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large

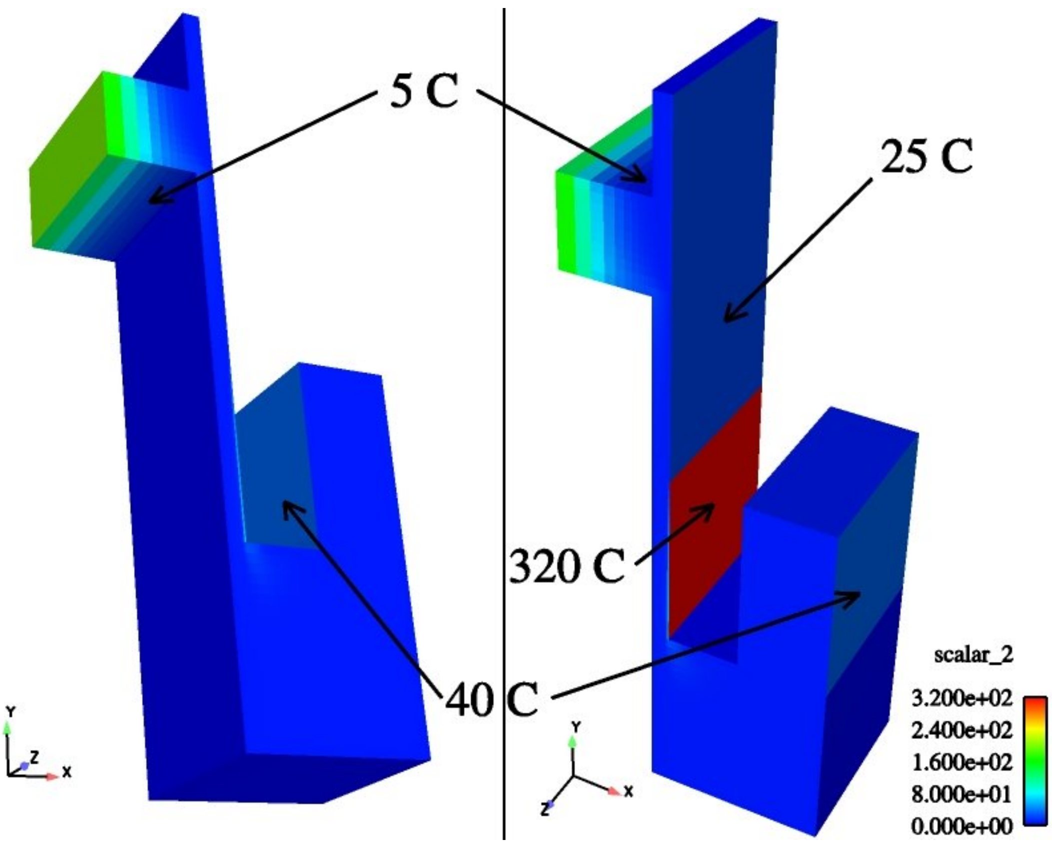


Figure II.5: View of the boundary domain colored by the scalar_2 variable - Case 2

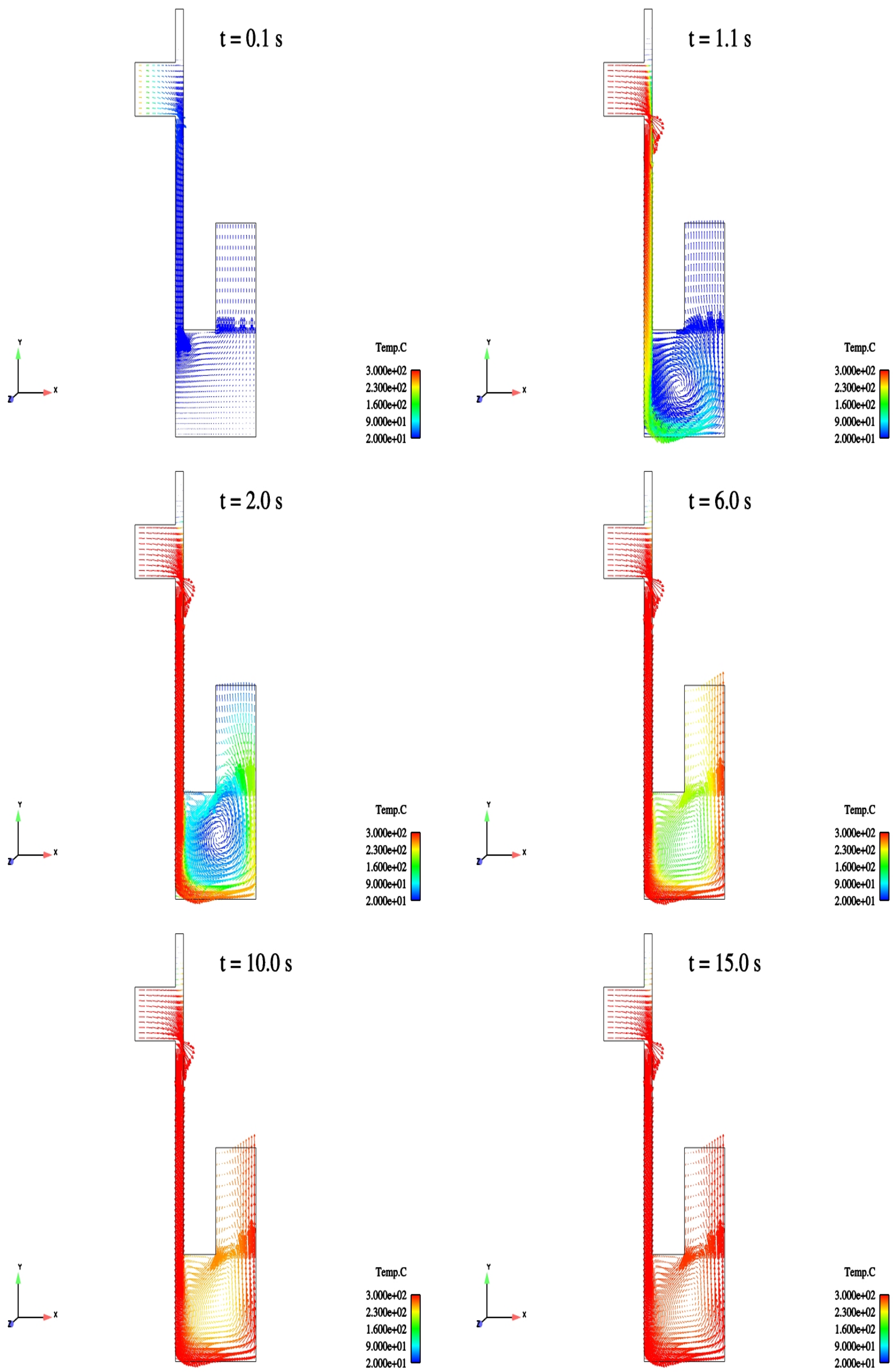


Figure II.6: Water velocity field colored by temperature at different time steps - Case 2

3 CASE 3: Time dependent boundary conditions and variable fluid density

In this case some boundary conditions will be time dependent and some physical characteristics of the fluid will be dependent on the temperature.

Remark: You can copy your `case2` in order to make the `case3`:

```
$ code_saturne create --copy-from case2 case3
```

3.1 Calculation options

The options for this case are the same as in `case2`, except for the variable fluid density:

→ Flow type: unsteady flow

→ Time step: uniform and constant

→ Turbulence model: $k - \epsilon$

→ Scalar(s): 1 - temperature
2 - passive scalar

→ Physical properties: uniform and constant (except density)

→ Management of monitoring points

3.2 Initial and boundary conditions

→ Initialization: 20°C for temperature (default value)
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone. The time dependence of the temperature boundary condition implies the use of a Fortran user routine (see below).

- **Flow inlet**: Dirichlet condition, an inlet velocity of 1 $m.s^{-1}$, a time dependent inlet temperature and a value of 200 for the passive scalar are imposed
- **Outlet**: default value
- **Walls**: velocity, pressure and thermal scalar: default value
passive scalar: different conditions depending on the color and geometric parameters

The boundary conditions for the passive scalar are identical as in case 2, as specified in the following table:

Wall	Nature	Value
wall_1	Dirichlet	0
wall_2	Dirichlet	5
wall_3	Dirichlet	0
wall_4	Dirichlet	25
wall_5	Dirichlet	320
wall_6	Dirichlet	40

The "wall_1" to "wall_6" regions are defined as follows, through color references and geometric localization:

Label	Color and geometric parameters
wall_1	24 and $0.1 \leqslant x$ and $x \leqslant 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leqslant 1$
wall_6	31 or 33

Figure II.3 shows the colors used for boundary conditions and table II.2 defines the correspondance between the colors and the type of boundary condition to use.

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 31 33	Wall
24 for $0.1 \leq x \leq 0.5$	Wall
8 9 28 29 38 39	Symmetry

Table II.2: Boundary faces colors and associated references

3.3 Variable Density

In this case the density is a function of temperature, the variation law is defined in the Graphical User Interface although it can also be defined in a Fortran user routine. The expression is:

$$\rho = T.(A.T + B) + C \tag{II.1}$$

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1\,000.9$

In order for the variable density to have an effect on the flow, gravity must be set to a non-zero value. $\underline{g} = -9.81\underline{e}_y$ will be specified in the Graphical Interface.

Remark:
The temperature is "TempC" is the user expression if the temperature is in Celsius. Don't forget **";"** at the end of the expression.

3.4 Parameters

All the parameters necessary to this study can be defined through the Graphical Interface, except the time dependent boundary conditions that have to be specified in user routines.

Parameters of calculation control	
Number of iterations	300
Reference time step	0.05
Output period for post-processing files	2

In order to join the separate meshes into a single domain, colors 5, 24 and 32 will have to be joined through the Graphical Interface.

3.5 User routine

The following routine has to be copied from the folder SRC/REFERENCE/base into the folder SRC[4]: `cs_user_boundary_conditions.f90`.

cs_user_boundary_conditions.f90
This routine allows to define advanced boundary conditions on the boundary faces.
Even if `cs_user_boundary_conditions.f90` is used, all boundary conditions have to be defined in the Graphical User Interface. Only the conditions that differ from this first definition need to appear in `cs_user_boundary_conditions.f90`. The boundary conditions defined in `cs_user_boundary_conditions.f90` will replace those specified in the Graphical Interface.

In this case, the temperature at entry is supposed variable in time, following the law:

$$\begin{cases} T = 20 + 100t & \text{for } 0 \leqslant t \leqslant 3.8 \\ T = 400 & \text{for } t > 3.8 \end{cases} \tag{II.2}$$

where T is the temperature in °C and t is the time in second (s).

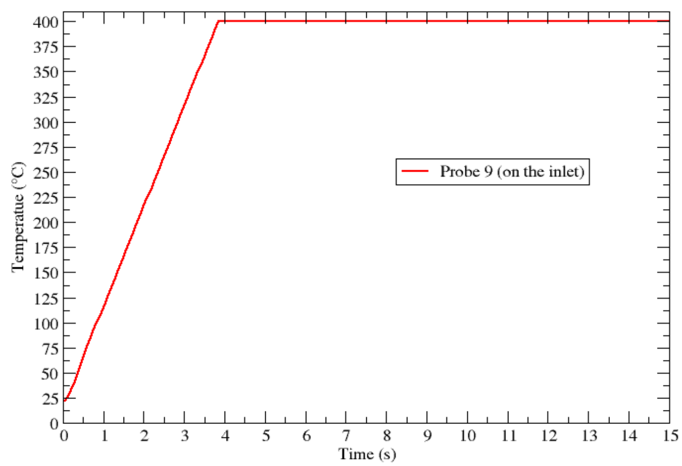


Figure II.7: Time evolution of the temperature at inlet.

Remark:
`ttcabs` is the current physical time. See the example file in the subdirectory `SRC/EXAMPLES` for the complete `cs_user_boundary_conditions.f90` file.

3.6 Output management

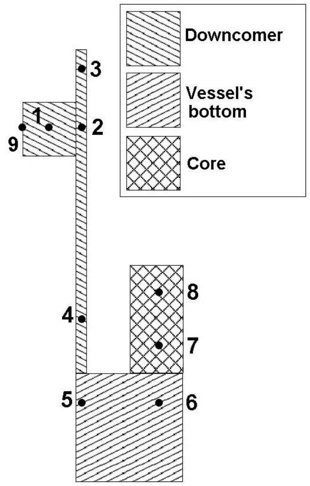
The output management is the same as in `case2`, except that a nineth monitoring point will be added, just at the entry, to monitor the temperature evolution at inlet.

In this case, the *Pressure*, the *Tubulent Energy* and the *Dissipation* will be removed from the listing file.

The *Courant number* (CFL) and *Fourier number* will be removed from the post-processing results[5].

Eventually, probes will be defined for chronological records, following the data given in figure II.4. Then the *total_pressure* will be deactivated from all probes and the *Velocity U* will be only activated on probes 1, 2, 6, 7 and 8.

[4]only when it appears in the SRC directory will it be taken into account by the code
[5]this can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large



Probe n^o.	x (m)	y (m)	z (m)
1	-0.25	2.25	0
2	0.05	2.25	0
3	0.05	2.75	0
4	0.05	0.50	0
5	0.05	-0.25	0
6	0.75	-0.25	0
7	0.75	0.25	0
8	0.75	0.75	0
9	-0.5	2.25	0

Figure II.8: Position and coordinates of probes in the full domain

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the temperature and passive scalar.

3.7 Calculation restart

After the first run, the calculation will be continued for another 400 time steps. The calculation restart is managed through the Graphical Interface.

3.8 Results

Figure II.9 shows the time evolution of temperature recorded on each monitoring probe. Figure II.10

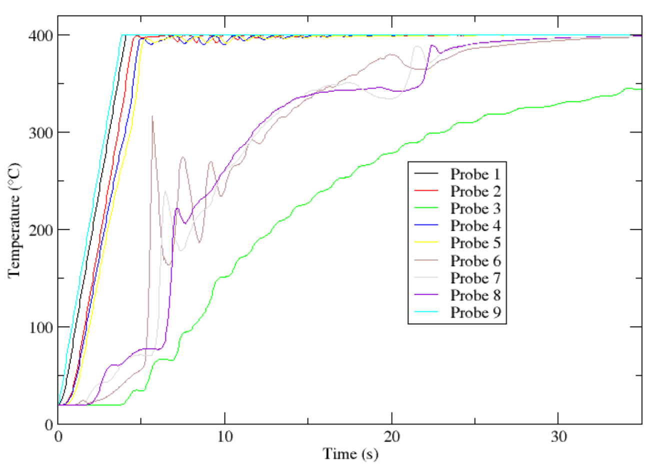


Figure II.9: Time evolution of temperature at monitoring probes for case 3

shows the velocity fields colored by temperature in the first run of calculation. Figure II.11 shows the velocity fields in the second calculation (restart of the first one).

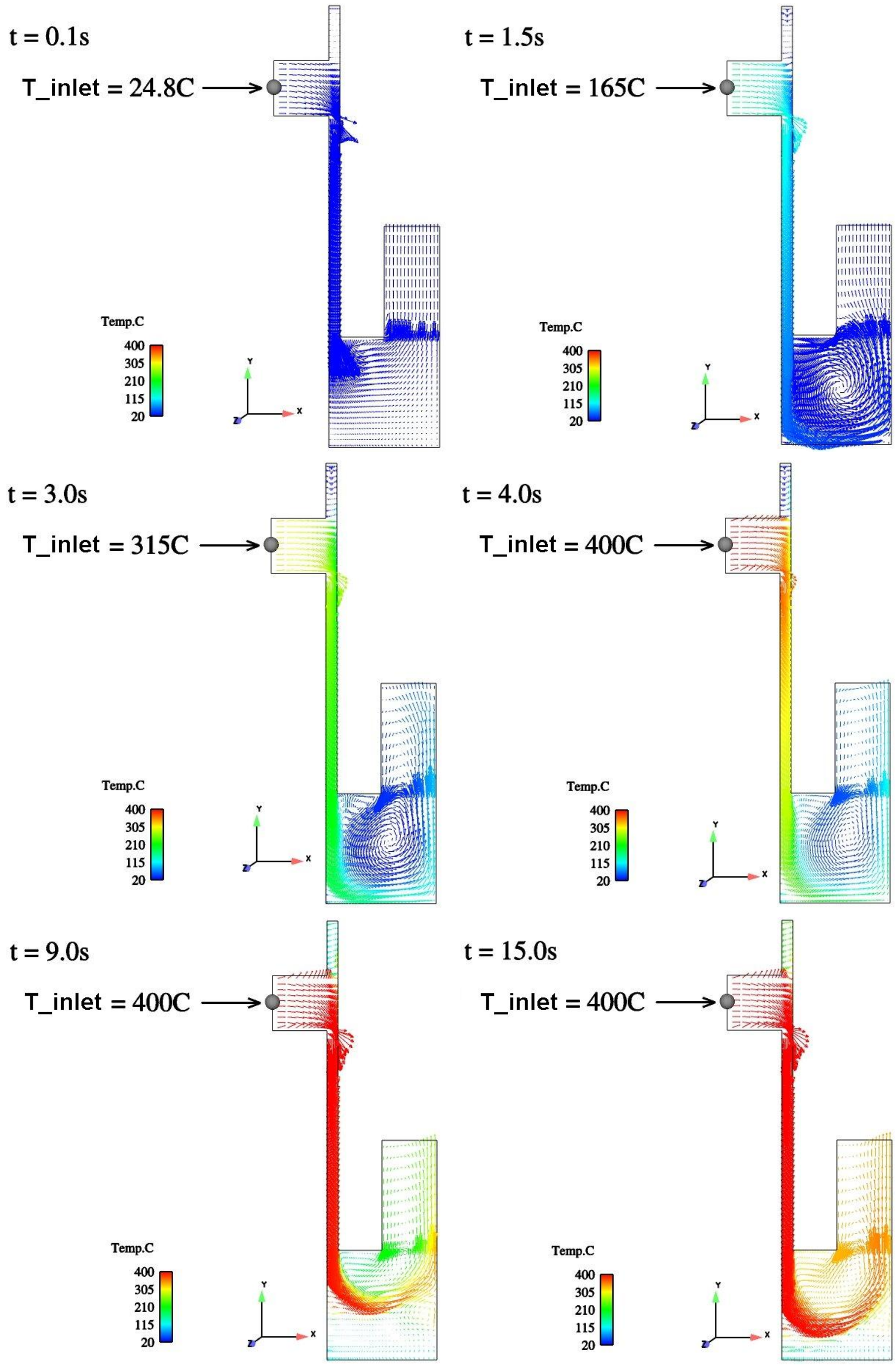


Figure II.10: Water velocity field colored by temperature and inlet temperature value at different time steps (first calculation)

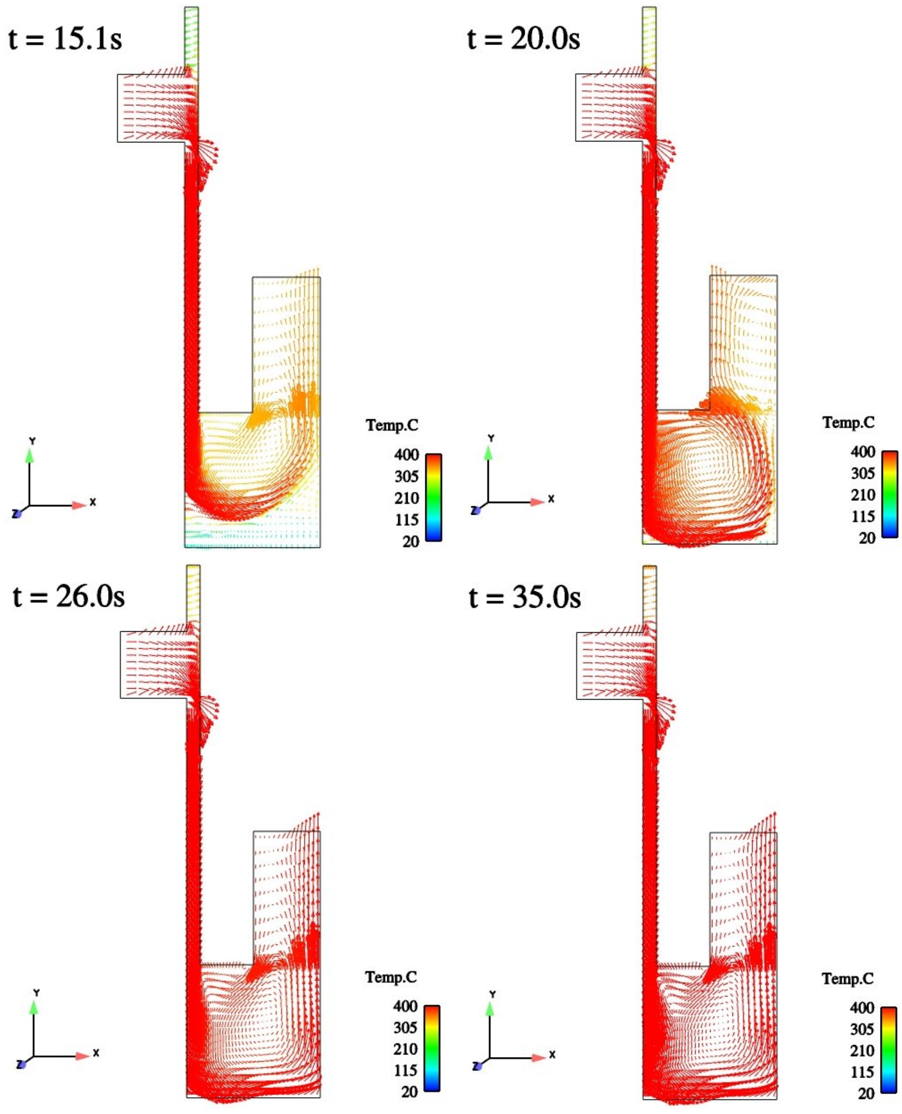


Figure II.11: Water velocity field colored by temperature and inlet temperature value at different time steps (second calculation)

4 CASE 4: Head losses, parallelism and spatial average

This case will be run in parallel on two processors. Head losses will be used to simulate the presence of an obstacle in the flow and the spatial average of the temperature will be calculated at each time step.

4.1 Calculation options

The options for this case are the same as in case 3:

→ Flow type: unsteady flow

→ Time step: uniform and constant

→ Turbulence model: $k - \epsilon$

→ Scalar(s): 1 - temperature
2 - passive scalar

→ Physical properties: uniform and constant (except density)

→ Management of monitoring points

4.2 Initial and boundary conditions

→ Initialization: 20°C for temperature (default value)
10 for the passive scalar

The boundary conditions are defined in the user interface and depend on the boundary zone.

- **Flow inlet**: Dirichlet condition, an inlet velocity of 1 $m.s^{-1}$ and a time dependent inlet temperature are imposed
- **Outlet**: default value
- **Walls**: velocity, pressure and thermal scalar: default value
  passive scalar: different conditions depending on the color and geometric parameters

The boundary conditions for the passive scalar are identical as in case 2, as specified in the following table:

Wall	Nature	Value
wall_1	Dirichlet	0
wall_2	Dirichlet	5
wall_3	Dirichlet	0
wall_4	Dirichlet	25
wall_5	Dirichlet	320
wall_6	Dirichlet	40

The "wall_1" to "wall_6" regions are defined as follows, through color references and geometric localization:

Label	Color and geometric parameters
wall_1	24 and $0.1 \leqslant x$ and $x \leqslant 0.5$
wall_2	2 or 3
wall_3	4 or 7 or 21 or 22 or 23
wall_4	6 and $y > 1$
wall_5	6 and $y \leqslant 1$
wall_6	31 or 33

Figure II.3 shows the colors used for boundary conditions and table II.3 defines the correspondance between the colors and the type of boundary condition to use.

Colors	Conditions
1	Inlet
34	Outlet
2 3 4 6 7 21 22 23 31 33	Wall
24 for $0.1 \leq x \leq 0.5$	Wall
8 9 28 29 38 39	Symmetry

Table II.3: Boundary faces colors and associated references

4.3 Variable Density

In this case the density is a function of temperature, the variation law is defined in the Graphical User Interface although it can also be defined in a Fortran user routine. The expression is:

$$\rho = T.(A.T + B) + C \tag{II.3}$$

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1\,000.9$

In order for the variable density to have an effect on the flow, gravity must be set to a non-zero value. $\underline{g} = -9.81\underline{e}_y$ will be specified in the Graphical Interface.

4.4 Head losses

To simulate the presence of an obstacle 0.20 (m) large and 0.5 (m) high in the vessel, a zone of head losses will be created in the domain (fig II.12).

The head losses zone is located between the coordinates $x = 0.2$ (m) and $x = 0.4$ (m), and $y = -0.75$ (m) and $y = -0.25$ (m).

The head losses coefficient to apply is $K_{ii} = 10^4 = \frac{1}{2}\ \alpha_{ii}$ and is isotropic.

4.5 Parameters

All the parameters necessary to this study can be defined through the Graphical Interface. However, the calculation of the spatial average is defined by a user routine.

Parameters of calculation control	
Number of iterations	300
Reference time step	0.05
Output period for post-processing files	2
The calculation will be run in parallel	2 procs.

In order to join the separate meshes into a single domain, colors 5, 24 and 32 will have to be joined through the Graphical Interface.

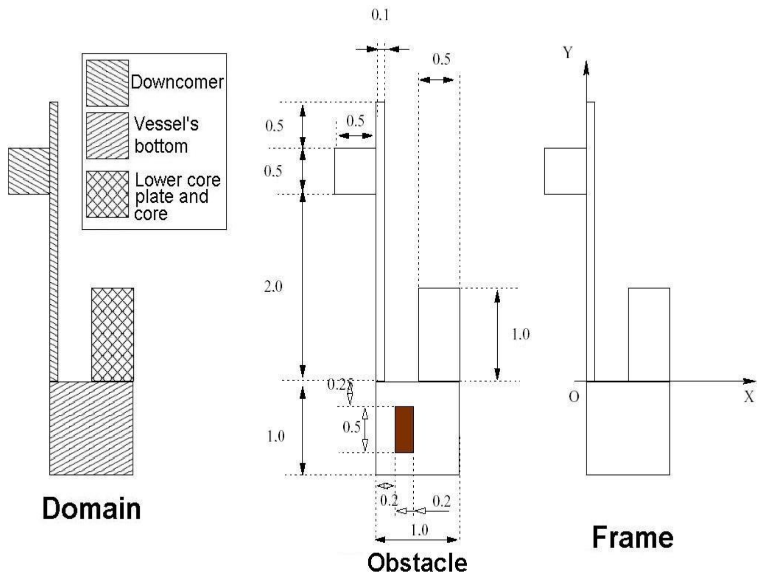


Figure II.12: Full domain geometry with the obstacle

4.6 User routines

The following routines have to be copied from the folder **SRC/REFERENCE/** into the folder **SRC/**[6]: `cs_user_boundary_conditions.f90` and `cs_user_extra_operations.f90`. We can find and copy some basic and specific boundary conditions examples in the folder **SRC/EXAMPLES/** to correctly impose the *Code_Saturne* boundary conditions.

• **cs_user_boundary_conditions.f90**
This routine allows to define advanced boundary conditions on the boundary faces.

Even if cs_user_boundary_conditions.f90 is used, all boundary conditions have to be defined in the Graphical User Interface (GUI). Only the conditions that differ from this first definition need to appear in cs_user_boundary_conditions.f90. The boundary conditions defined in cs_user_boundary_conditions.f90 will replace those specified in the Graphical Interface.

In this case, the temperature at entry is supposed variable in time, following the law:

$$\begin{cases} T = 20 + 100t & \text{for } 0 \leqslant t \leqslant 3.8 \\ T = 400 & \text{for } t > 3.8 \end{cases} \tag{II.4}$$

where T is the temperature in °C and t is the time in s.

• **cs_user_extra_operations.f90**
This routine is called at the end of each time step and has access to the whole set of variables of the code. It is therefore useful for many user-specific post-processing, including the calculation of a spatial average in the present case.
The spatial average of the temperature will be calculated at each time step and the result wrote in a file named `‘‘moy.dat’’`. The values are saved in order to draw the time evolution of the average temperature.

Beware when calculating the average. Since the calculation is running in parallel, computing the sum of the temperatures on “all the cells” will only yield for each processor the sum on the cells managed by this processor. In order to obtain the full sum, the parallelism routine `parsom` must be used (see example in the cs_user_extra_operations-parallel_operations.f90 routine).

[6]only when they appear in the SRC directory will they be taken into account by the code.

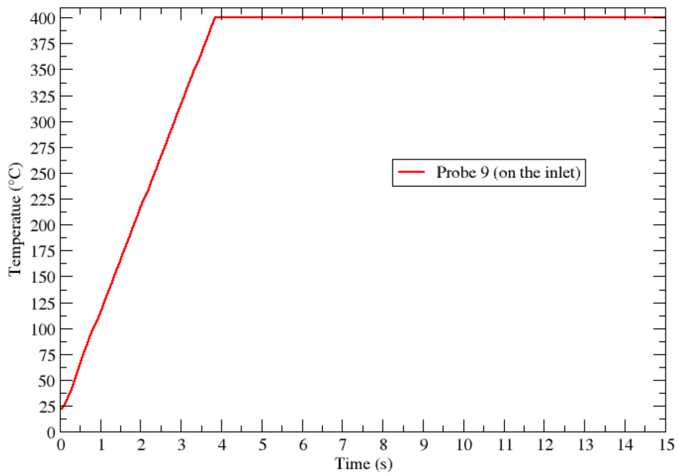
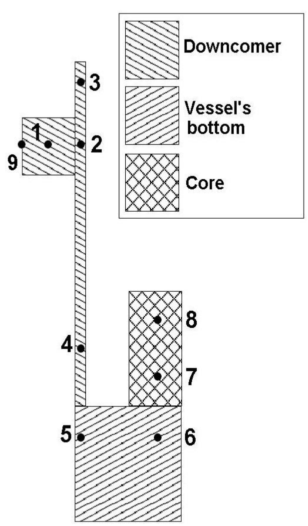


Figure II.13: Time evolution of the temperature at inlet

Remark: `cs_user_extra_operations-xxx.f90` are different example routines present in the subdirectory `SRC/EXAMPLES`. They should be removed from the `SRC/` before running the case.

4.7 Output management

The output management is the same as in case 3.



Points	X(m)	Y(m)	Z(m)
1	-0.25	2.25	0
2	0.05	2.25	0
3	0.05	2.75	0
4	0.05	0.5	0
5	0.05	-0.25	0
6	0.75	-0.25	0
7	0.75	0.25	0
8	0.75	0.75	0
9	-0.5	2.25	0

Figure II.14: Position and coordinates of probes in the full domain

In this case, the *Pressure*, the *Tubulent Energy* and the *Dissipation* will be removed from the listing file.

The *Courant number* (CFL) and *Fourier number* will be removed from the post-processing results[7].

Eventually, probes will be defined for chronological records, following the data given in figure II.4. Then the *total pressure* will be deactivated from all probes and the *Velocity U* will be only activated on probes 1, 2, 6, 7 and 8.

[7]this can be very useful to save some disk space if some variables are of no interest, as post-processing files can be large

In addition the domain boundary will be post-processed. This allows to check the boundary conditions, and especially that of the temperature and passive scalar.

4.8 Results

Figure II.15 shows the evolution of the spatial average of the temperature.

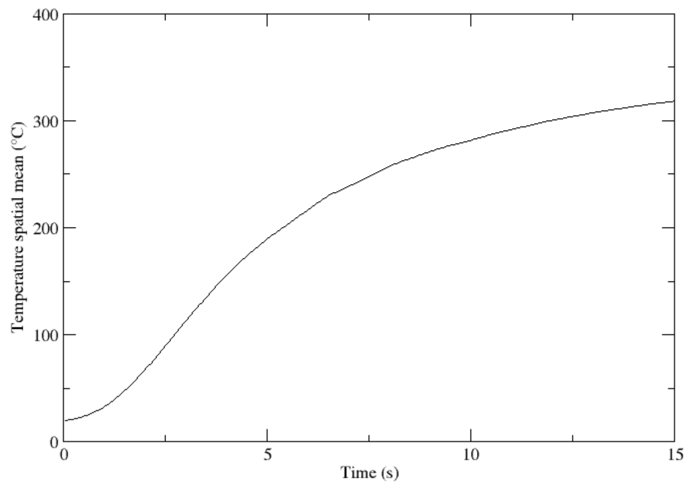


Figure II.15: Evolution of spatial average of the temperature as a function of time

Figure II.16 shows velocity fields colored by temperature. The effect of the head loss modeling the obstacle is clearly visible.

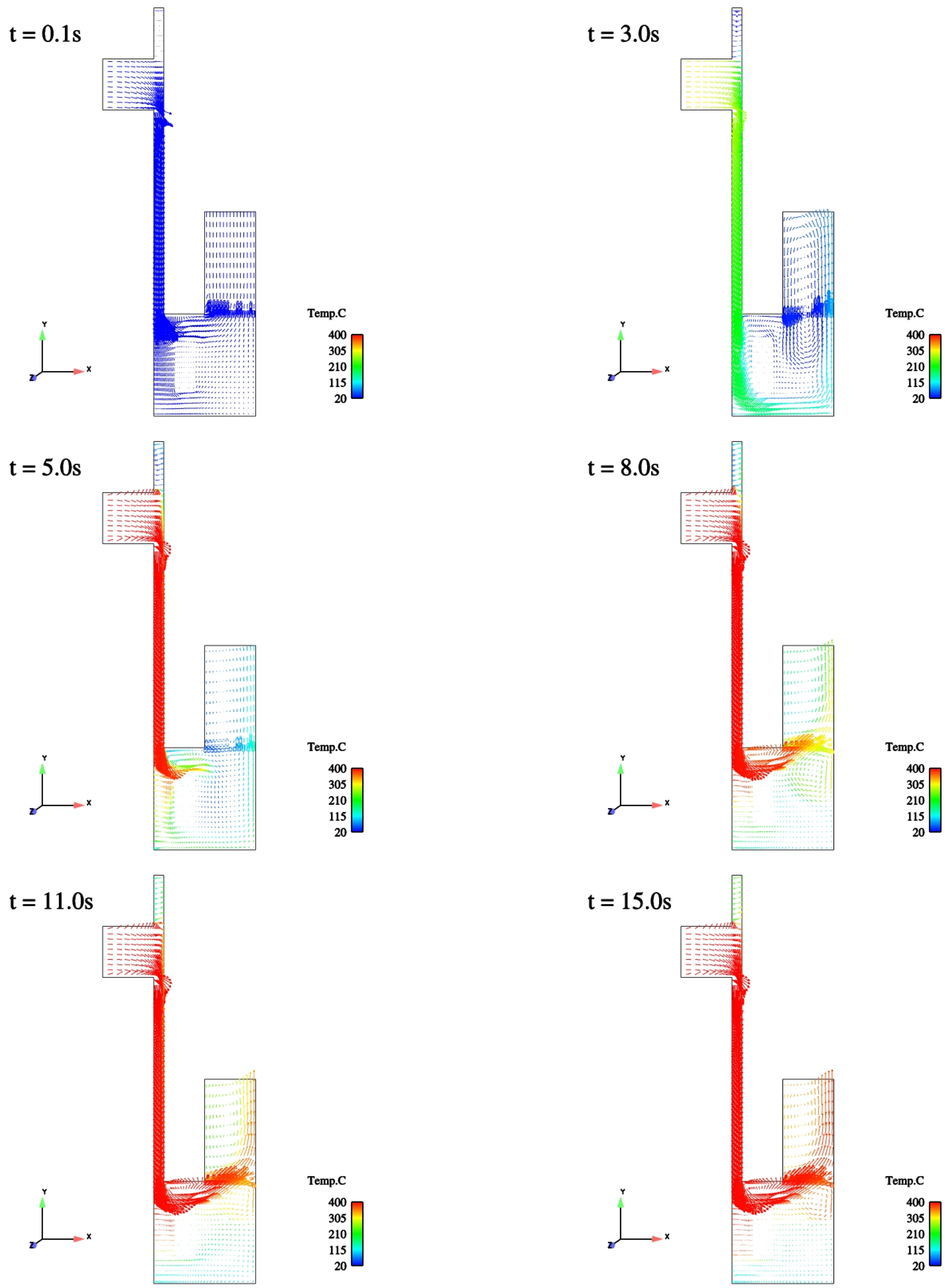


Figure II.16: Water velocity field colored by temperature

Part III

Step by step solution

1 Solution for case1

The first thing to do before running *Code_Saturne* is to prepare the computation directories. In this first example, the study directory "simple_junction" will be created, containing a single calculation directory `case1`. This is done by typing the command:

```
$ code_saturne create -s simple_junction -c case1
```

The mesh files should be copied in the directory `MESH/`, as follow:

```
$ cd simple_junction/MESH/
$ cp ITECH_CS_training_2012/meshes/1-simple_junction/downcomer.des .
```

The *Code_Saturne* Graphical User Interface (GUI) is launched by typing the command lines as below:

```
$ cd simple_junction/case1/DATA
$ ./SaturneGUI &
```

And the following graphic window opens (fig III.1).

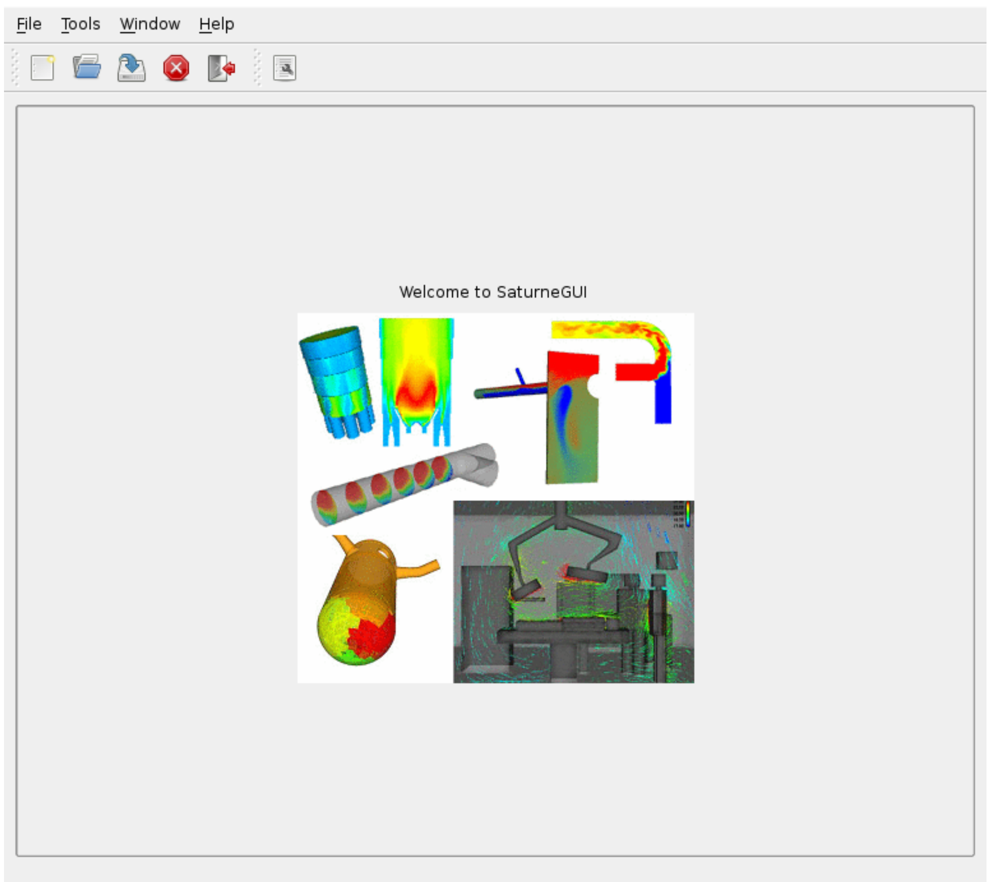


Figure III.1: *Code_Saturne* (GUI) graphic window

Go to the *File* menu and click on *New file* to open a new calculation data file. The interface automatically updates the following information:

- Study name
- Case name
- Directory of the case
- Associated sub-directories of the case

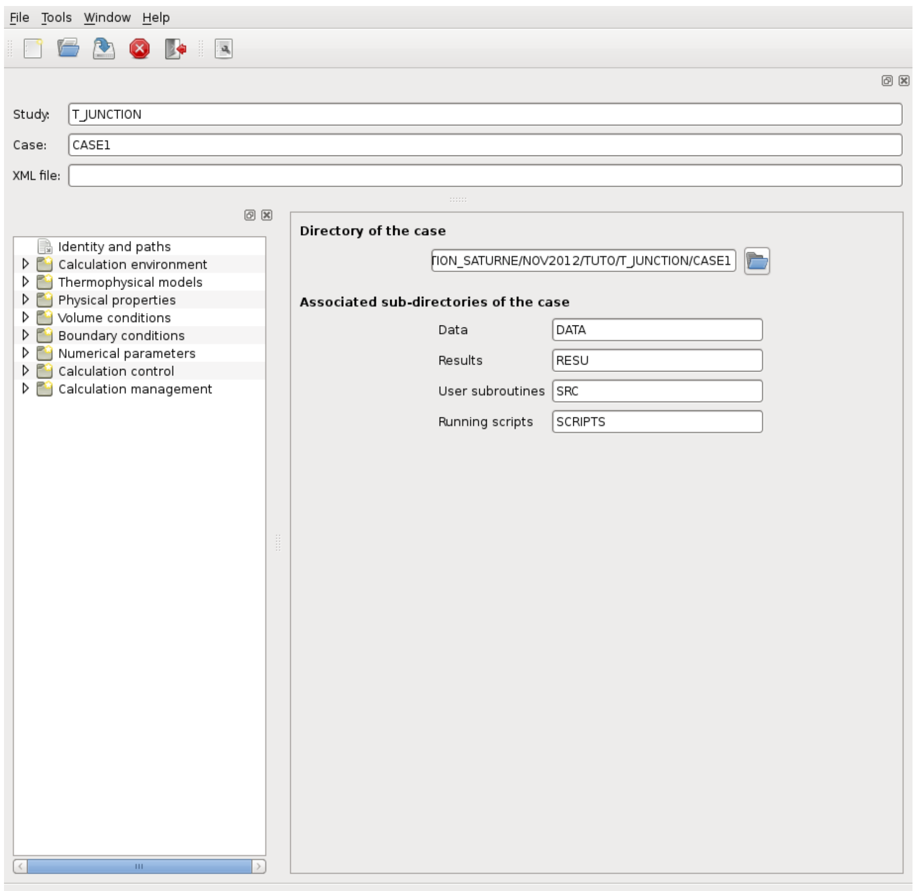


Figure III.2: Identity and paths

Save the case to give a name to the new `xml` file (such as `case1.xml`) by opening the *File* menu and clicking on *Save as...*.

A new window will appear, enter the name of the case in *File Name* then click on *Save*.

Remember to save the case regularly throughout the preparation of the calculation.

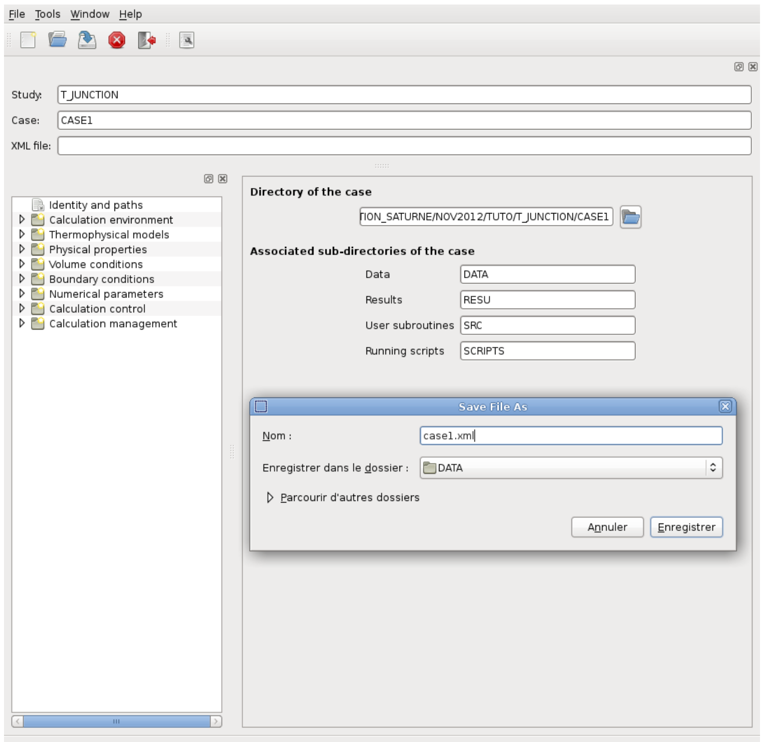


Figure III.3: Saving the `xml` file

The next step is to specify the mesh(es) to be used for the calculation. Click on the *Mesh selection* item under the heading *Calculation environment*. Click to "+" to add meshes.

The list of meshes in the folder *Meshes* appears in the window *List of meshes*. In this case only the mesh `downcomer.des` is needed.

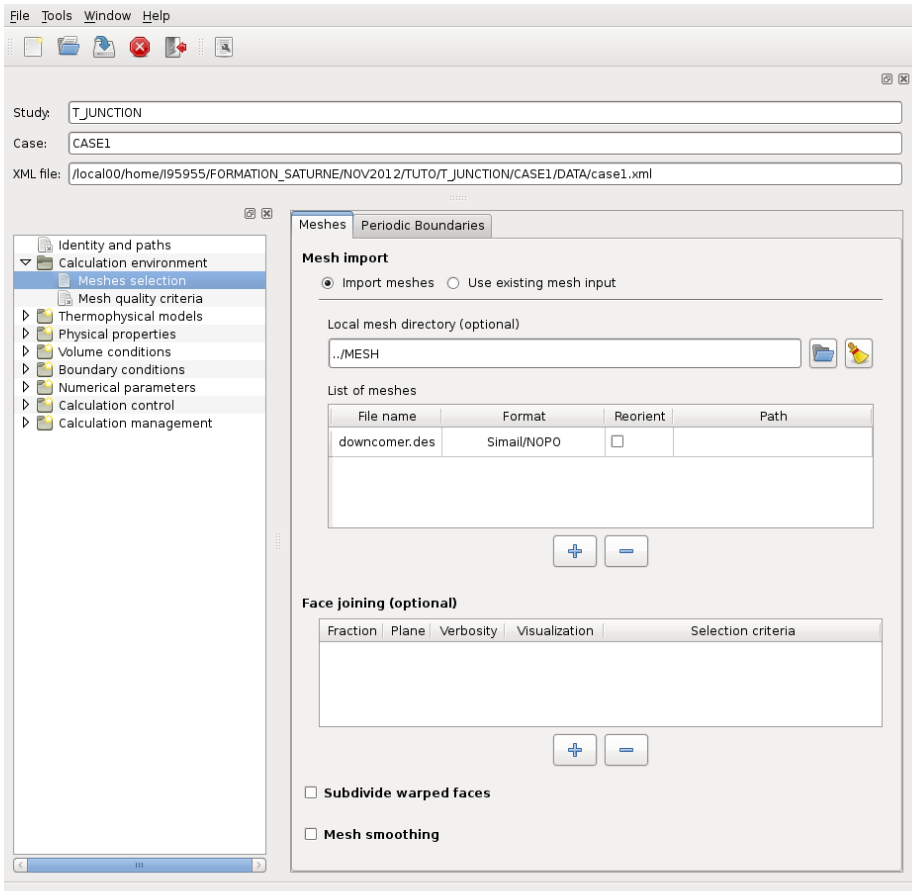


Figure III.4: Meshes: list of meshes

The *Periodic Boundaries* is not used in this case. Keep the default values.

The *Calculation features* item under the heading *Thermophysical models* allows to define the type of flow to be simulated. In this case, a steady flow will be chosen.

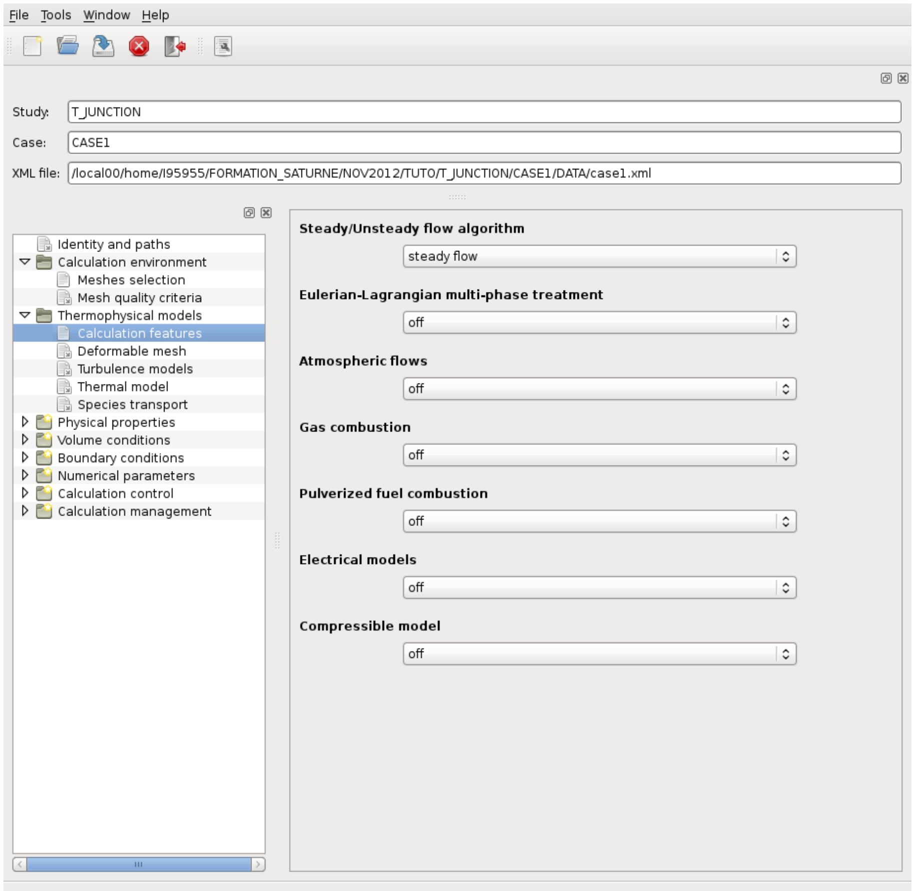


Figure III.5: Flow type

The turbulence model is selected in the following list:

- laminar flow (no model)
- mixing length
- k-ε
- k-ε Linear Production
- Rij-ε LLR
- Rij-ε SSG
- v2f (φ model)
- k-ω SST
- Spalart-Allmaras
- LES (Smagorinsky)
- LES (classical dynamic model)
- LES (WALE)

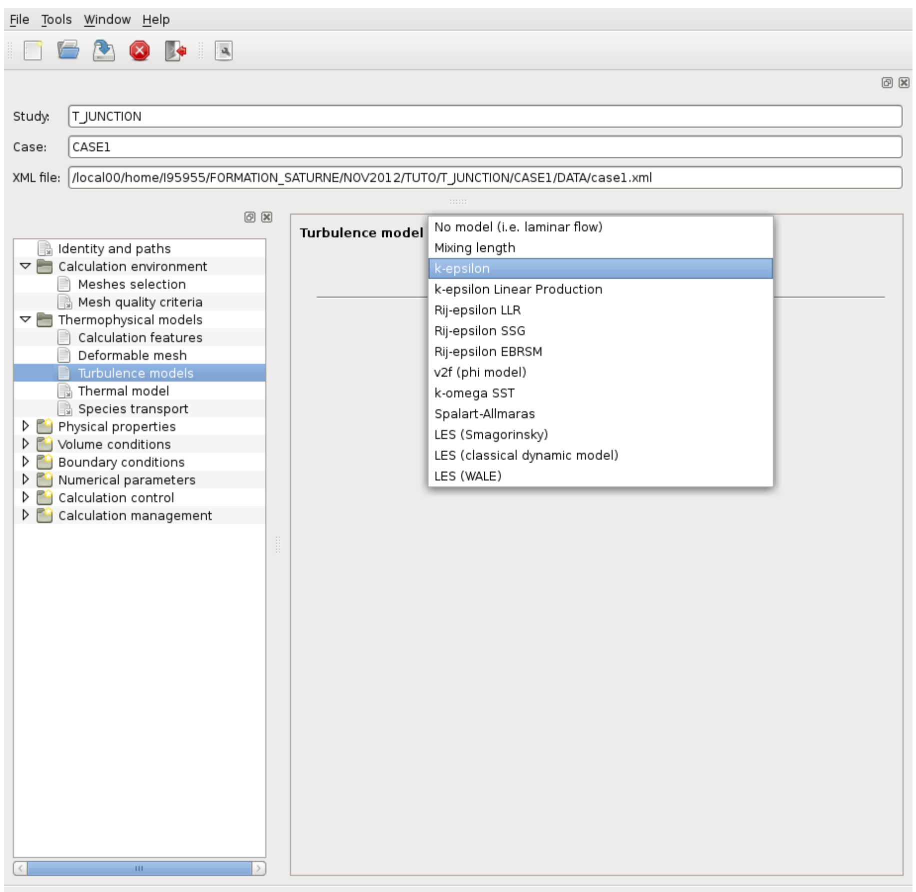


Figure III.6: Turbulence model: list of models

In this case, the k-ε model is used.

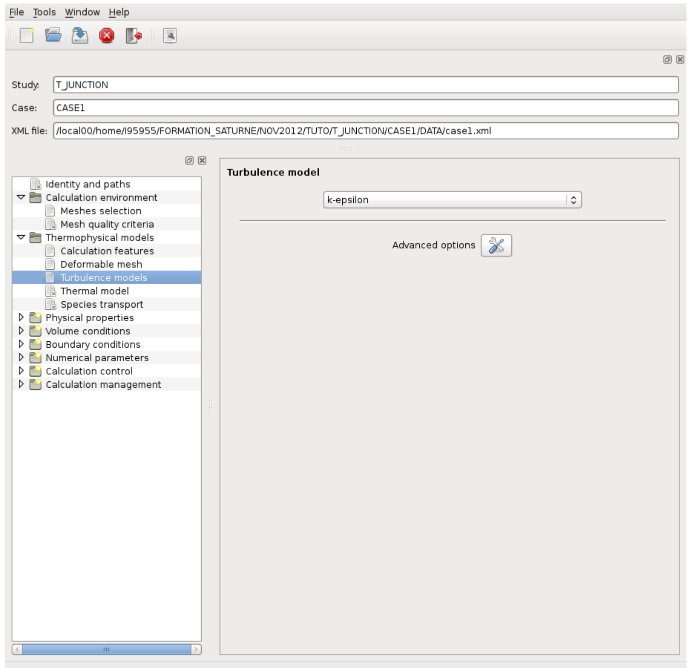


Figure III.7: Turbulence model: choice of a model

For this study the equation for temperature must be solved. Click on the *Thermal model* item to choose between:

- No thermal scalar
- Temperature (Celsius degrees)
- Temperature (Kelvin)
- Enthalpy

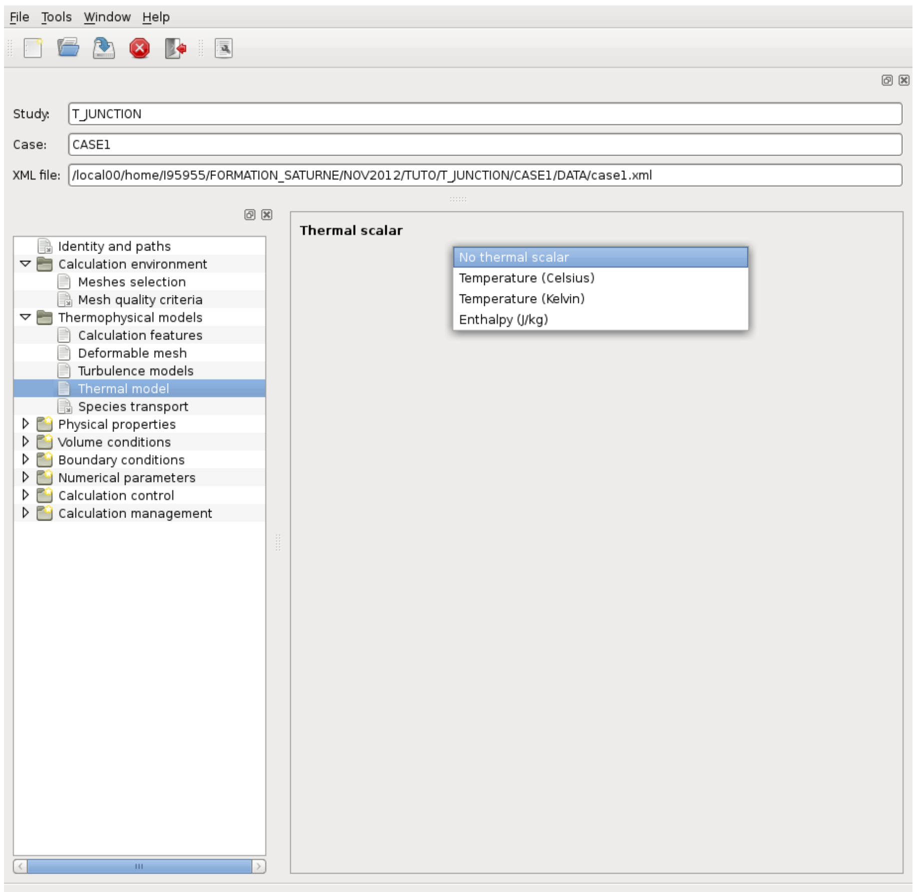


Figure III.8: Thermal scalar conservation: list of models

In the present case, select *Temperature (Celsius)*.

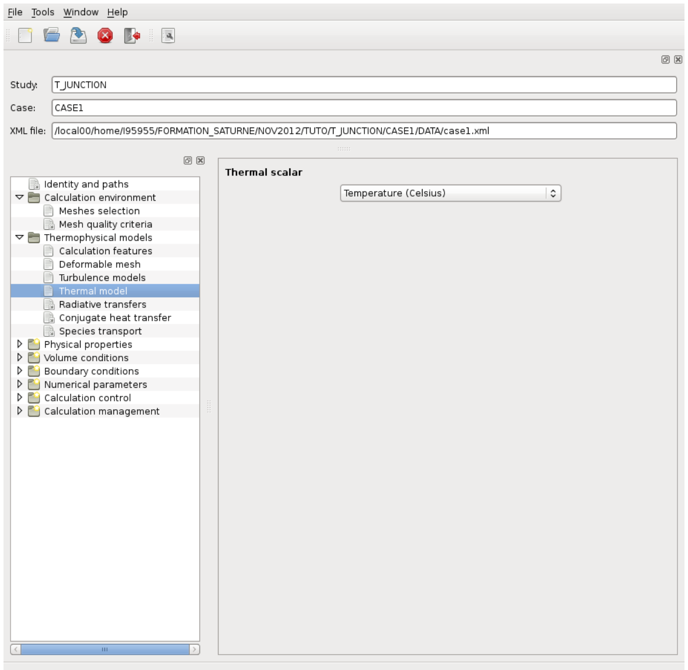


Figure III.9: Thermal scalar conservation: choice of a model

Once the thermal scalar selected, additional items appear. There are no radiative transfers in our case, so this item can be ignored.

Initialization:

To initialize variables at the instant $t = 0$ (s), go to the *Initialization* item under the heading *Volume conditions*. Here the velocity, the thermal scalar and the turbulence can be initialized.

In this case, the default values can be kept: zero velocity, an initial temperature of **20**°C and a turbulence level based on a reference velocity of **1** $(m.s^{-1})$. Specific zones can be defined with different initializations. In this case, only the default "all cells" is used.

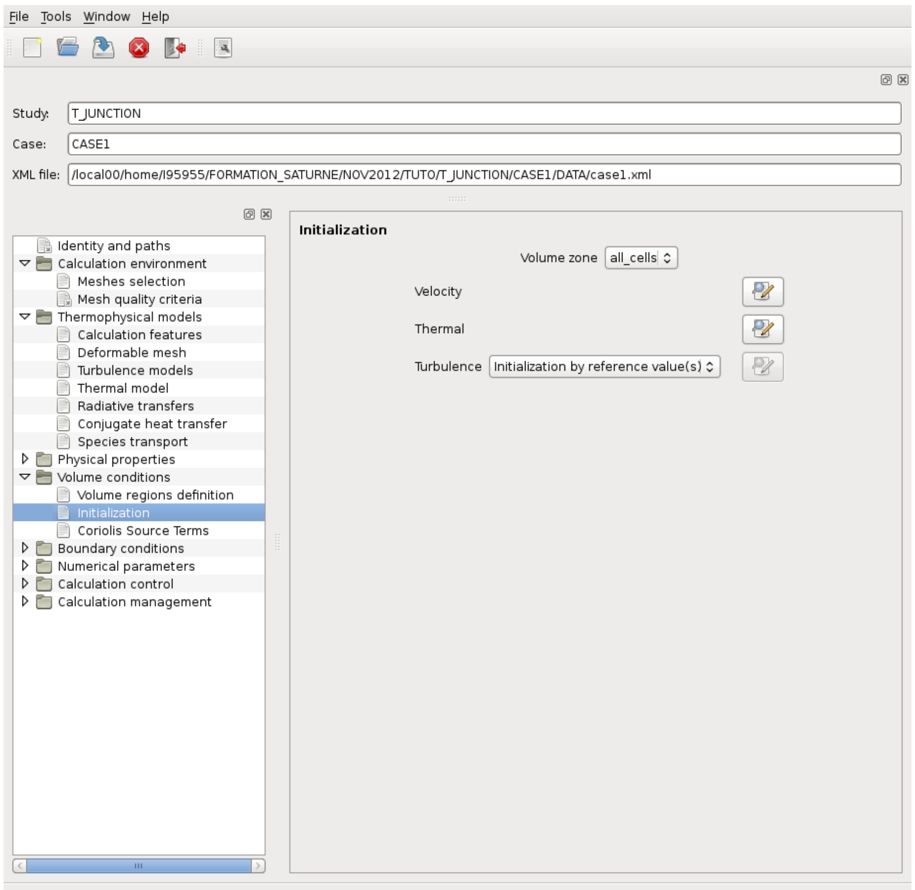


Figure III.10: Initialization of the scalar, velocity and turbulence

- Click on the icon near *"Thermal"* in order to specify the initial value of the thermal scalar. It can be a value or a user expression.

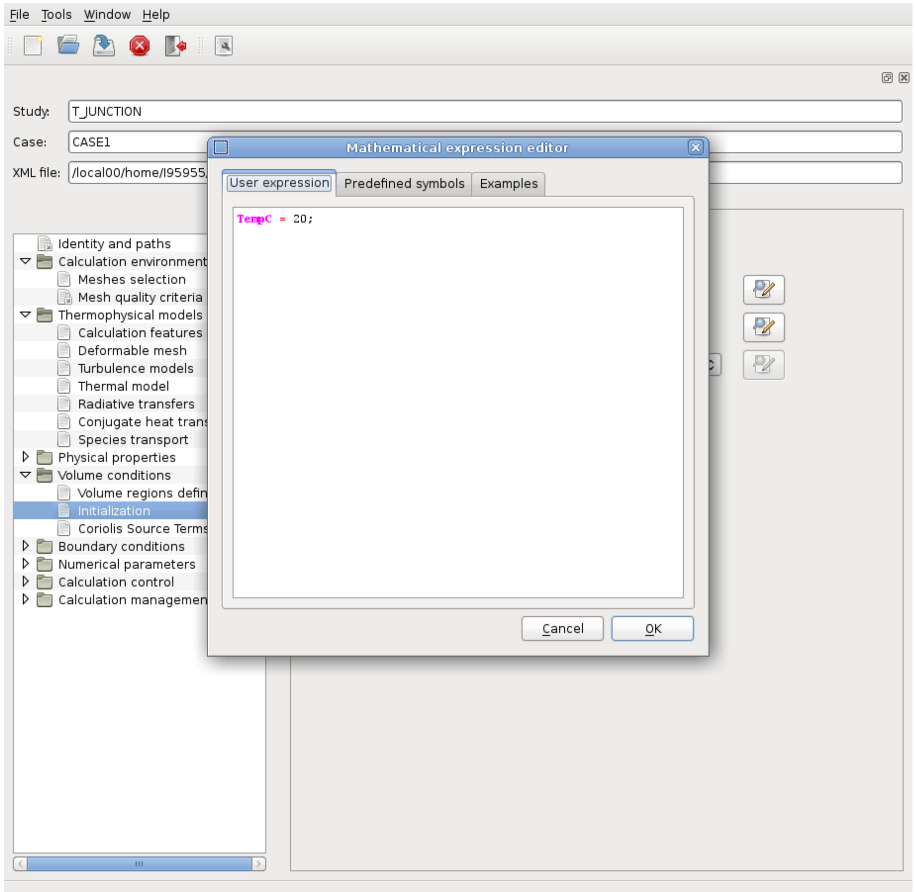


Figure III.11: Initialization of the scalar

- To initialize the velocity, click also on the icon near *"Velocity"*.

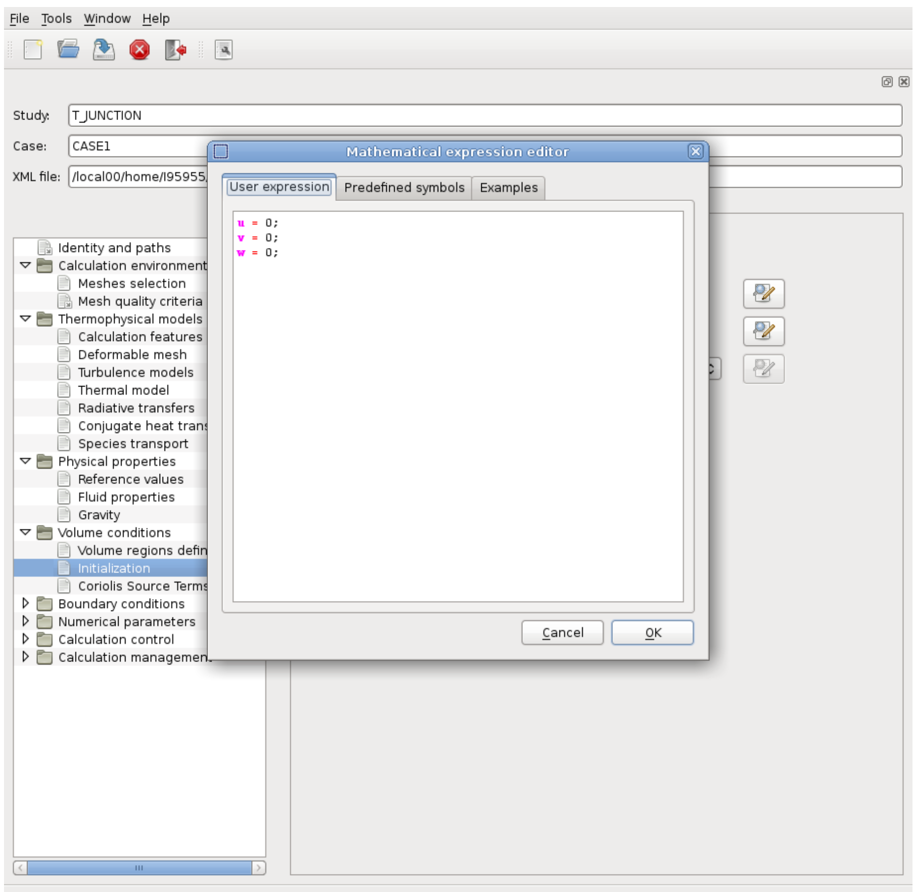


Figure III.12: Initialization of the velocity

Under the heading *Physical properties* in the main list, the *Reference values* item allows to set the reference pressure, the reference velocity and the reference length.

Use the default value of **101 325** (Pa) for the pressure and **1** (m/s) for the velocity.

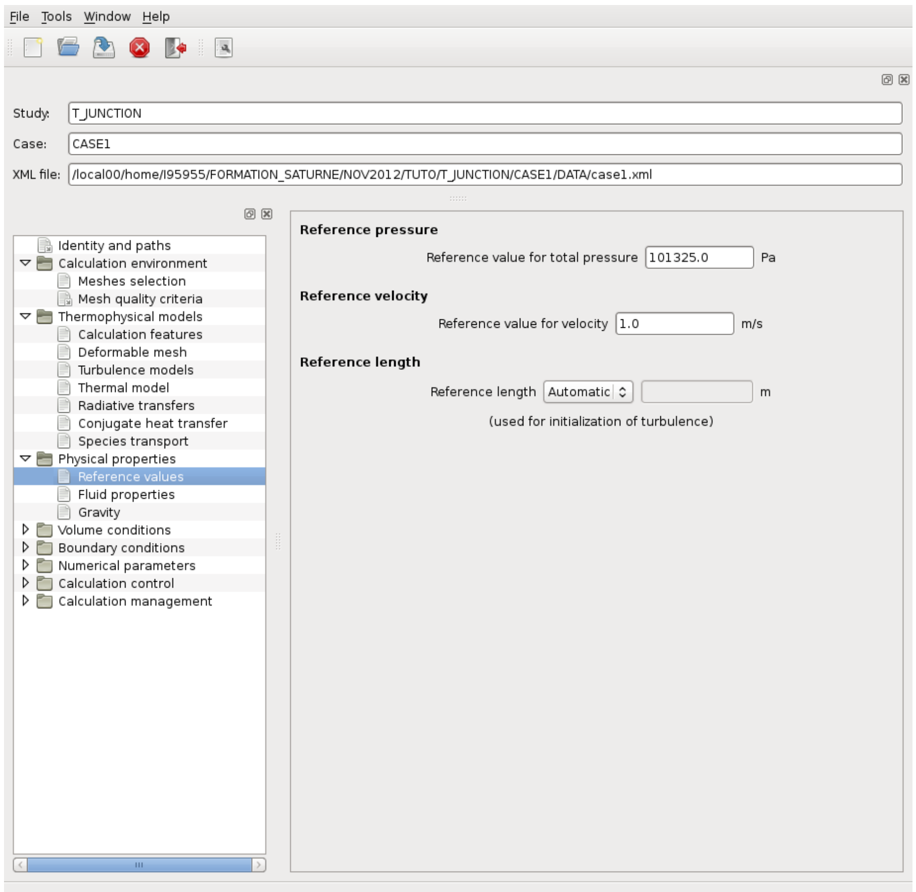


Figure III.13: Physical properties: reference pressure

Specify the fluid physical characteristics in the *Fluid properties* item:

- Density
- Viscosity
- Specific Heat
- Thermal Conductivity

In this case they are all constant.

- $\rho \quad = 725.735\ kg.m^{-3}$
- $\mu \quad = 0.895 \times 10^{-4}\ kg.m^{-1}.s^{-1}$
- $C_p \quad = 5\,483\ J.kg^{-1}.°\mathrm{C}^{-1}$
- $(\lambda/C_p) = 0.02495\ W.m^{-1}.K^{-1}$

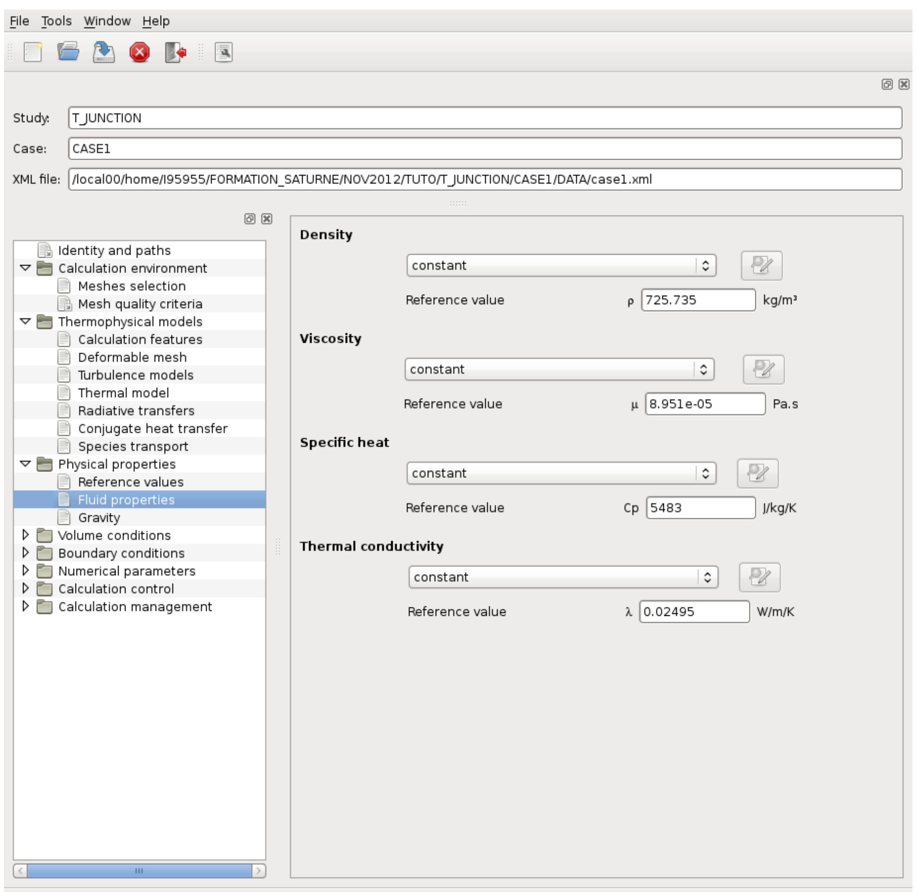


Figure III.14: Physical properties: fluid properties

Set the three components of gravity in the *Gravity* item. In this case, since the gravity doesn't have any influence on the flow, gravity can be set to **0**.

As for the pressure interpolation, the interpolation method keeps the standard default value.

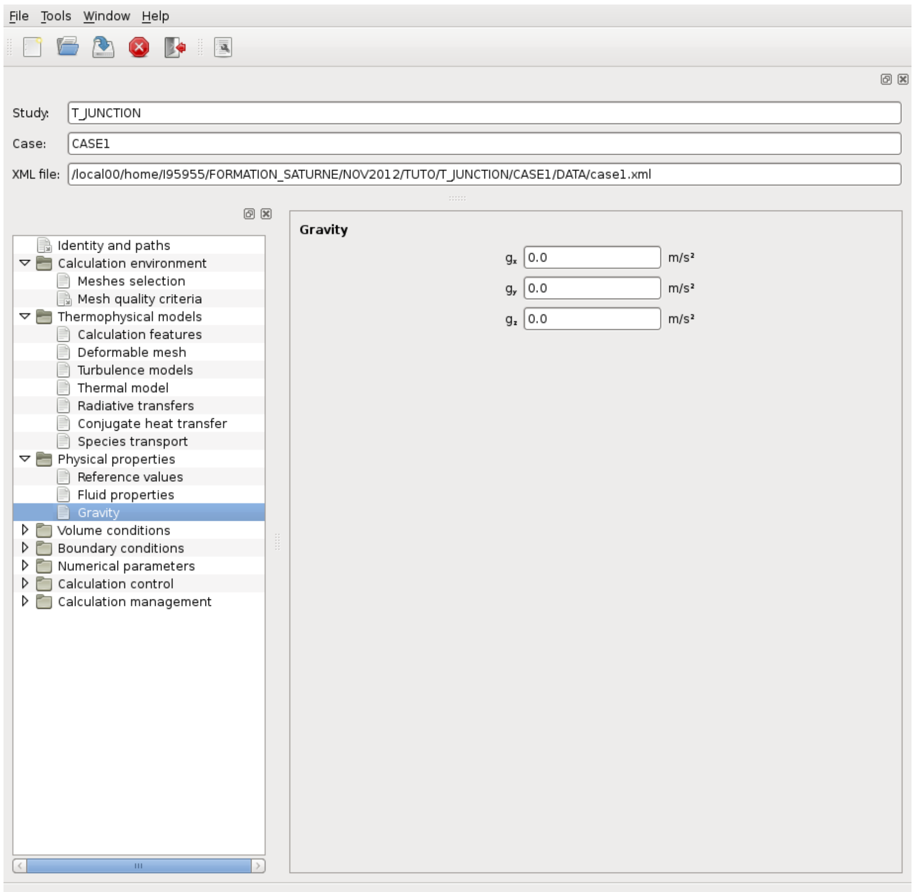


Figure III.15: Physical properties: gravity and hydrostatic pressure

Boundary conditions now need to be defined. Go to the *Define boundary regions* item under the heading *Boundary conditions*. The following window opens (fig III.18).

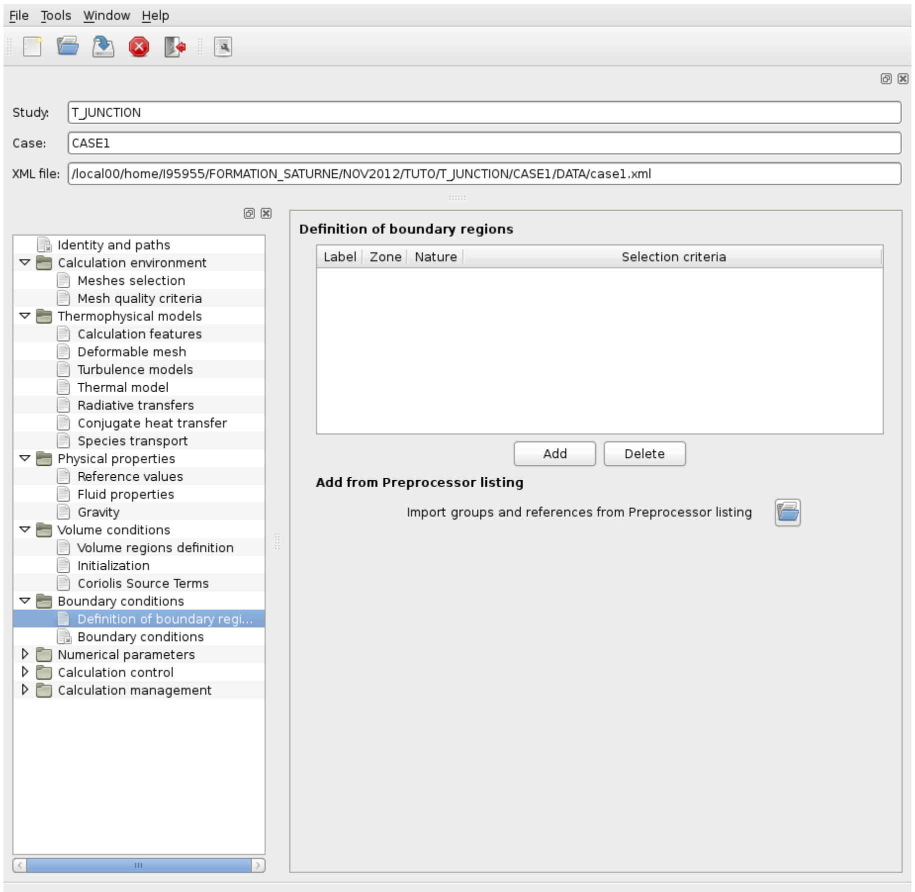


Figure III.16: Creation of a boundary region

Each boundary must be defined. Click on *Add* to edit a new boundary. The boundary faces will be grouped in user-defined zones, based on their color or on geometrical conditions. For each zone, a reference number, a label, a nature and a selection criteria must be assigned. The different natures that can be assigned are:

```
- wall
- inlet
- symmetry
- outlet
```

The *Label* can be any character string. It is used to identify the zone more easily. It usually corresponds to the nature of the zone.

The *Zone* number can be any integer. It will be used by the code to identify the zone. No specific order or continuity in the numbering is needed.

The *Selection criteria* is used to define the faces that belong to the zone. It can be a color number, a group reference, geometrical conditions, on a combination of them, related by `‘‘or’’` or `‘‘and’’` keywords.

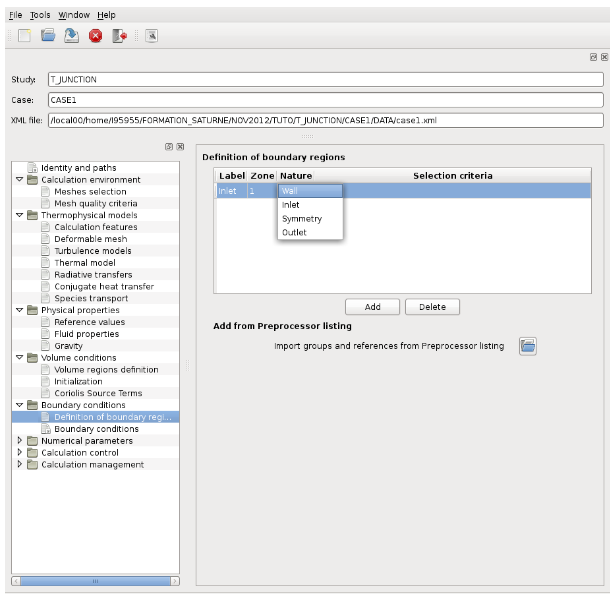


Figure III.17: Creation of a boundary region

The specification of the inlet condition is detailled in the following pages. The settings will be as follows:

```
Label:  inlet,
Zone:  1,
Nature:  inlet,
Selection criteria:  1
```

Type all the information in the fields, the result diplays as figure III.18

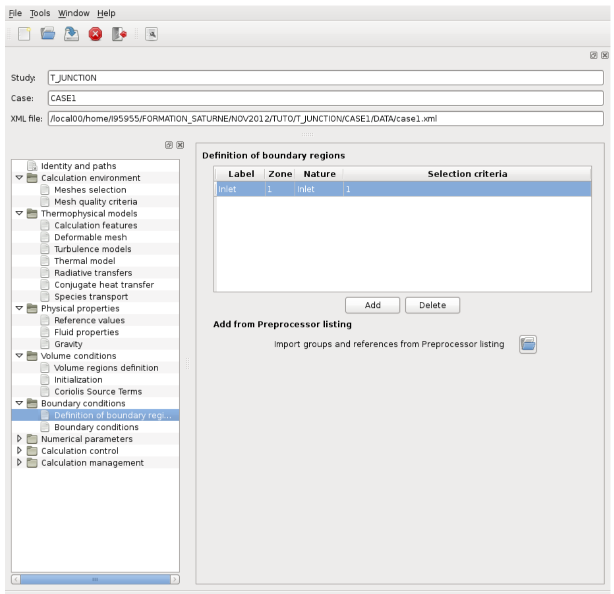


Figure III.18: Creation of a boundary region

Remember to save the `xml` file regularly!

Do the same thing for the other boundaries.

In our case, colors 8 and 9 are symmetry boundaries. One option can be to define a separate zone for each color, as follows:

Label	symmetry_1	symmetry_2
Zone	3	4
Nature	symmetry	symmetry
Localization	8	9

But it is usually faster to regroup the different colors in one single zone, as shown on figure III.19. In our case, the localization for this zone is the string `‘‘8 or 9’’`.

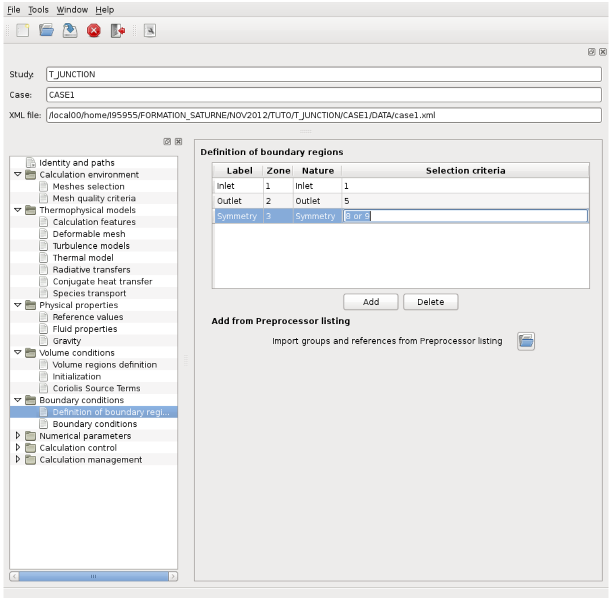


Figure III.19: Creation of boundary regions: symmetry region

The same treatment must be done for the wall conditions. All colors 2, 3, 4, 6 and 7 can be grouped in a single boundary zone.

After defining all the boundary zones, the Interface window will look as in figure III.20.

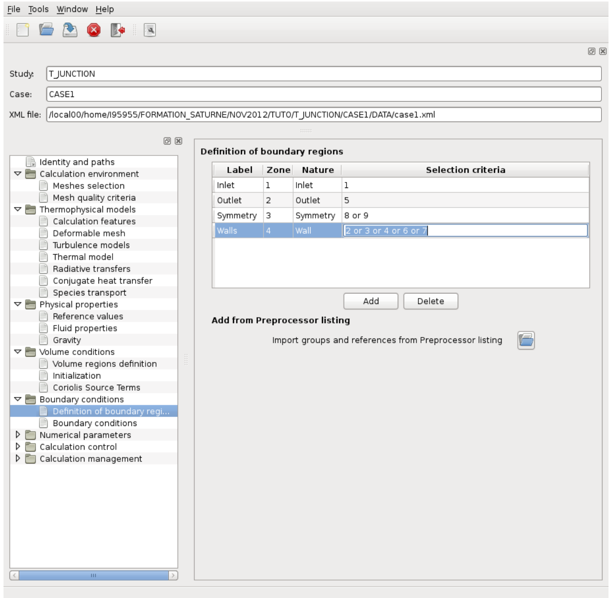


Figure III.20: Creation of boundary regions

Now that the boundary zones are defined, the boundary conditions assigned to them will be specified. Click on the *Boundary conditions* item to set the inlet boundary conditions for velocity, turbulence and themal scalar.

As shown on figure III.23, outlet and wall boundary zones also appear in the window.

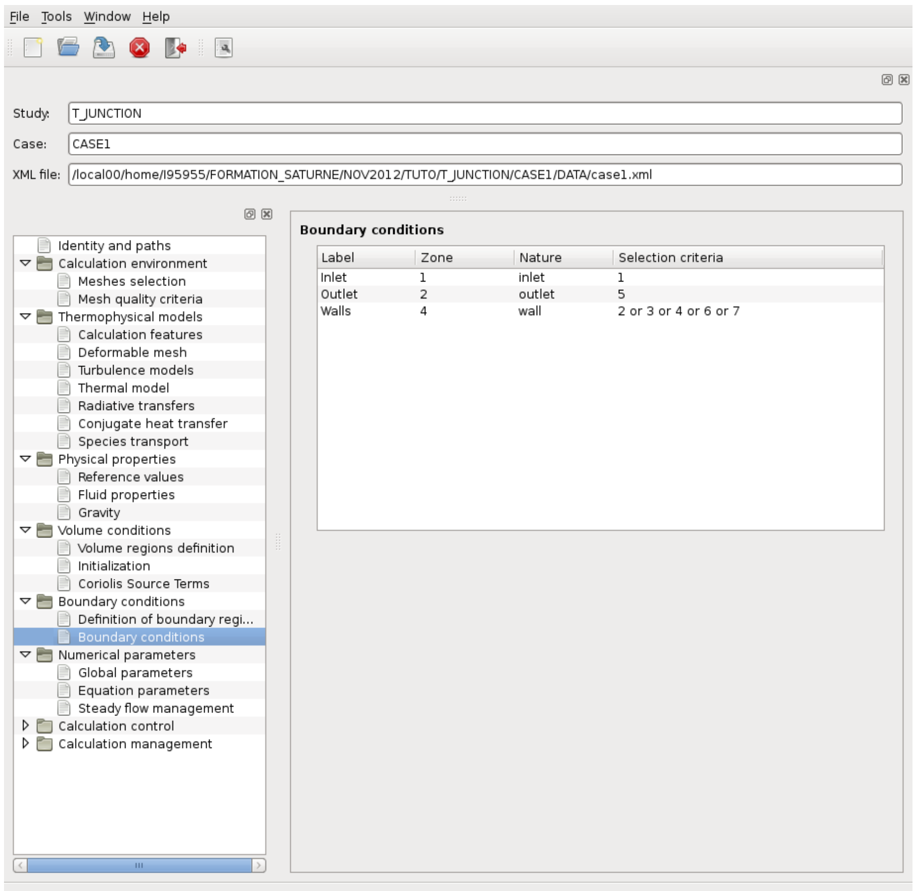


Figure III.21: Dynamic variables boundary conditions

Click on the label *inlet*. In the section *Velocity*, select *norm*, then in the sub-section *Direction* choose *specified coordinates* and enter the normal vector components of the inlet velocity.

For the turbulence, choose the inlet condition based on a hydraulic diameter and specify it as below:

```
x = 1.0 (m) ; y = 0.0 (m) ; z = 0.0 (m)
hydraulic diameter = 0.5 (m)
```

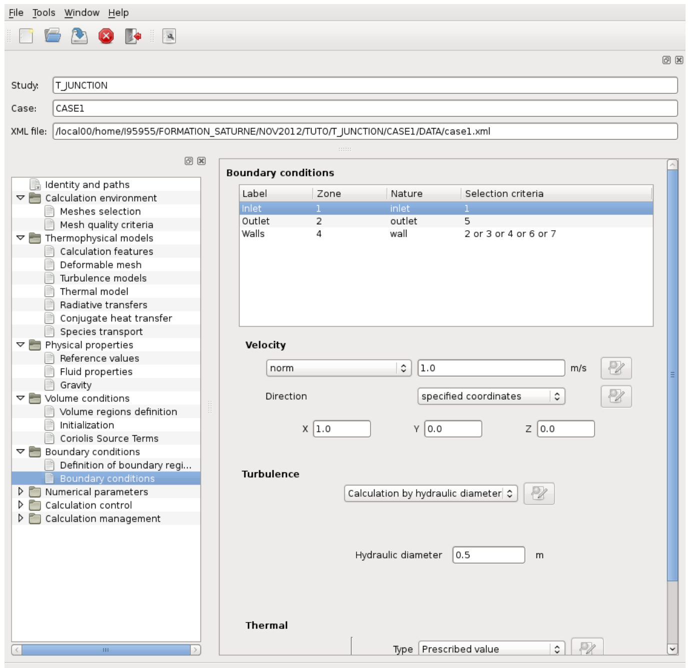


Figure III.22: Dynamic variables boundary conditions: inlet

Click on *inlet* to choose the temperature inlet value. Here this value is **300**°C.

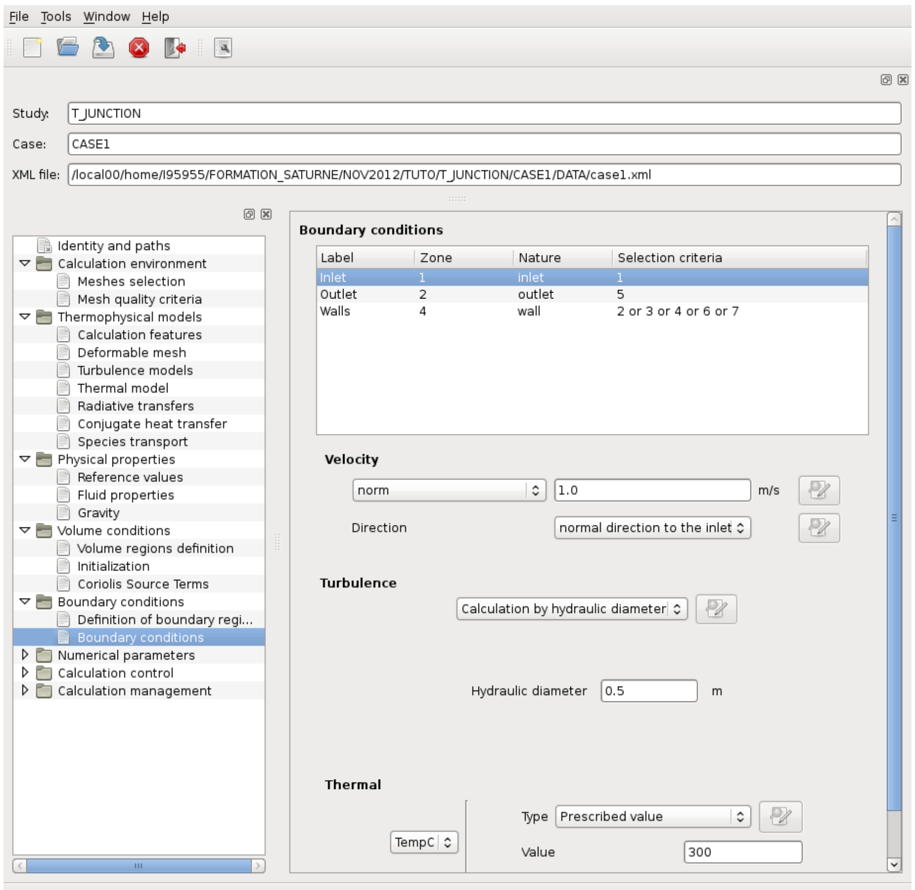


Figure III.23: Dynamic variables boundary conditions: inlet

As for the wall boundary zone, the specifications the user might have to give is when the wall is sliding, and if the wall is "smooth" or "rough". In this case, the walls are fixed so the option is not selected, and the wall is considered as "smooth".

Note that if one of the walls had been sliding, it would have been necessary to isolate the corresponding boundary faces in a specific boundary region.

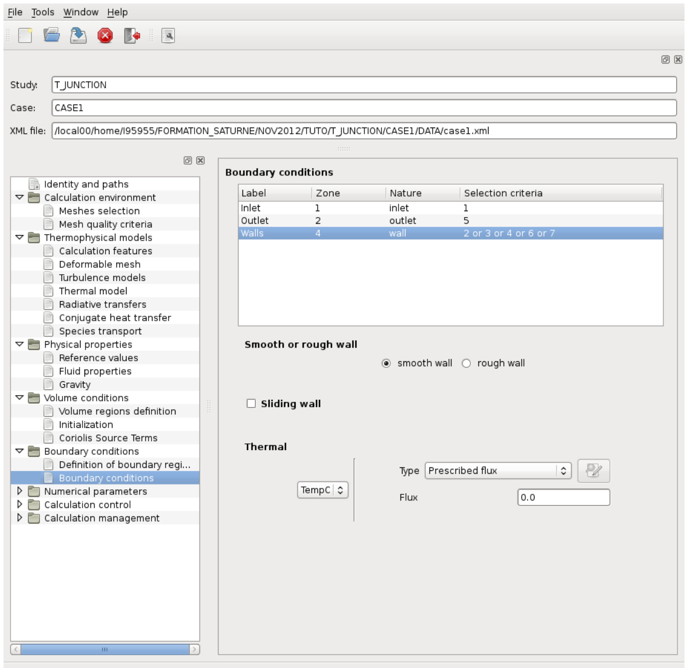


Figure III.24: Dynamic variables boundary: walls

The boundary conditions on the temperature are only applied on inlets, outlets and walls.

For the walls, three conditions are available:

```
- Prescribed value
- Prescribed flux
- Exchange Coefficient
```

For the outlet, only *Prescribed value* and *Prescribed flux* are available, but they are taken into account only when the flow re-enters from the outlet. Otherwise, homogeneous *Prescribed flux* is considered by *Code_Saturne*.

For the inlets, only *Prescribed value* is available.

In this case all walls are adiabatic. So the boundary condition for the temperature will be a *Prescribed flux* set to **0**.

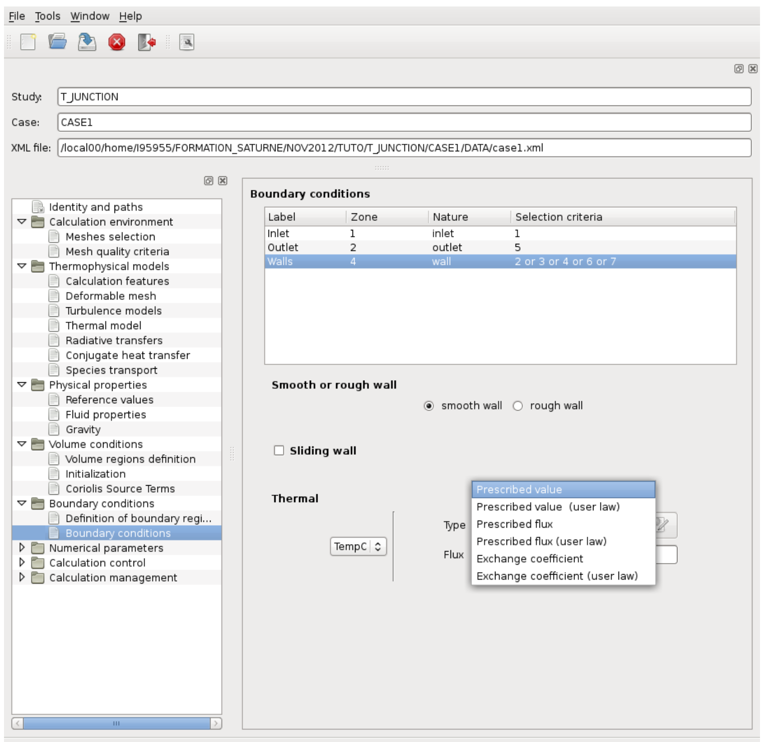


Figure III.25: Scalars boundaries: walls

The Global parameters need then to be specified, under the header *Numerical parameters*. In this case, the SIMPLE algorithm must be chosen

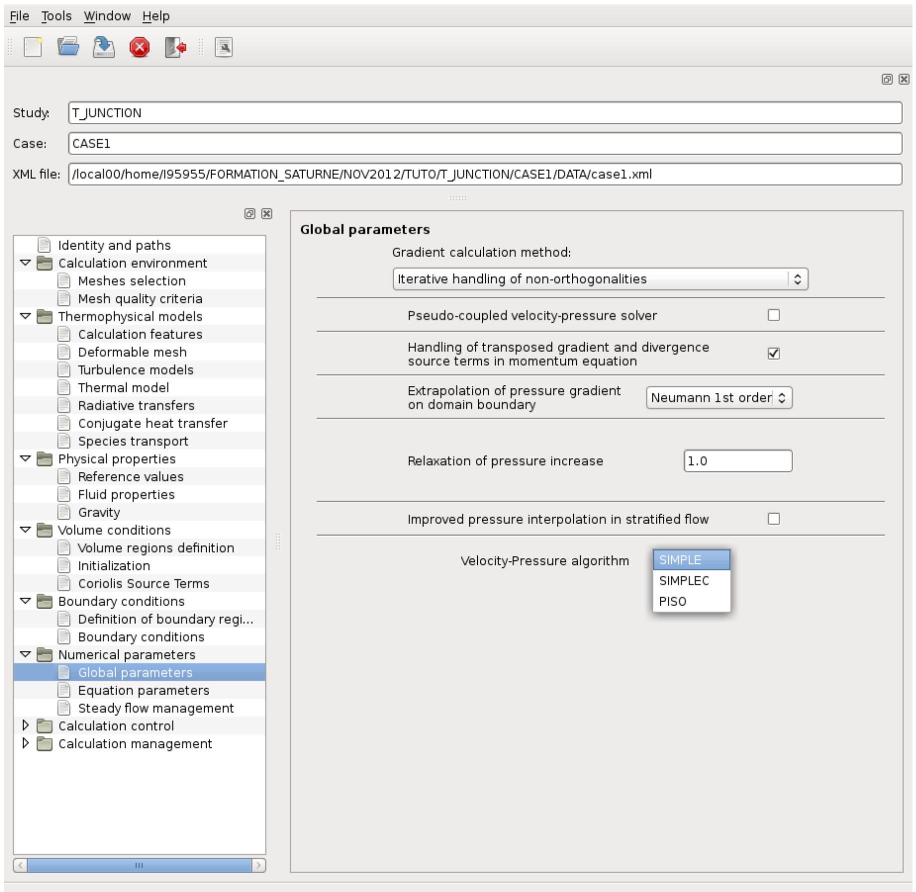


Figure III.26: Steady flow management

After selecting the *Equation parameters* item, the tab *Scheme* allows to change different more advanced numerical parameters.

In this case none of them should be changed from their default value.

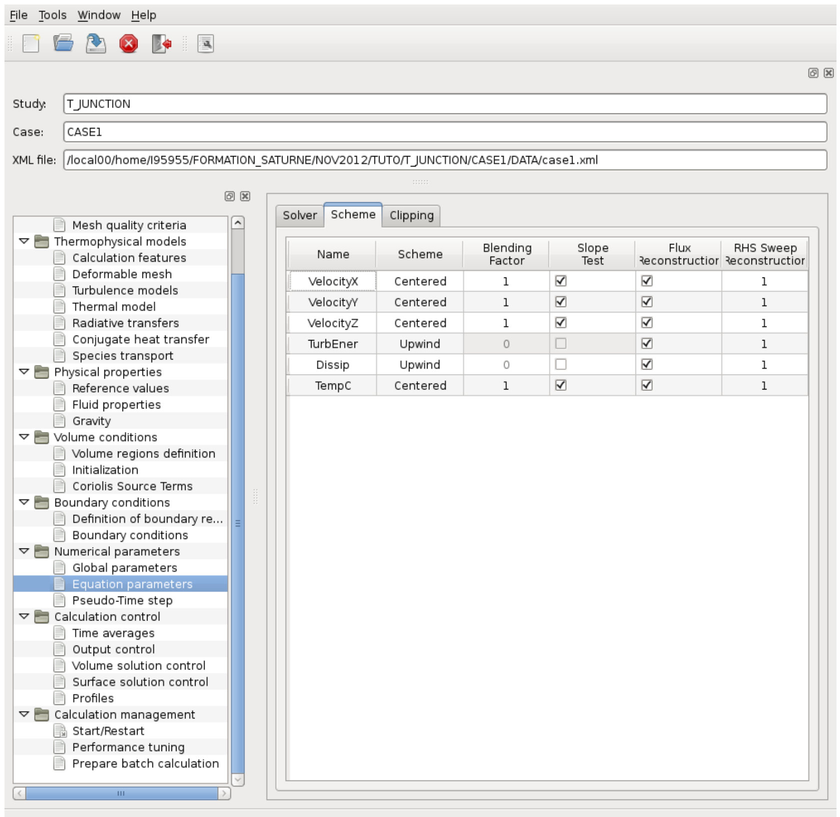


Figure III.27: Numerical parameters

The tab *Clipping* in the *Equation parameters* item permits to vanish the too small or too big value.

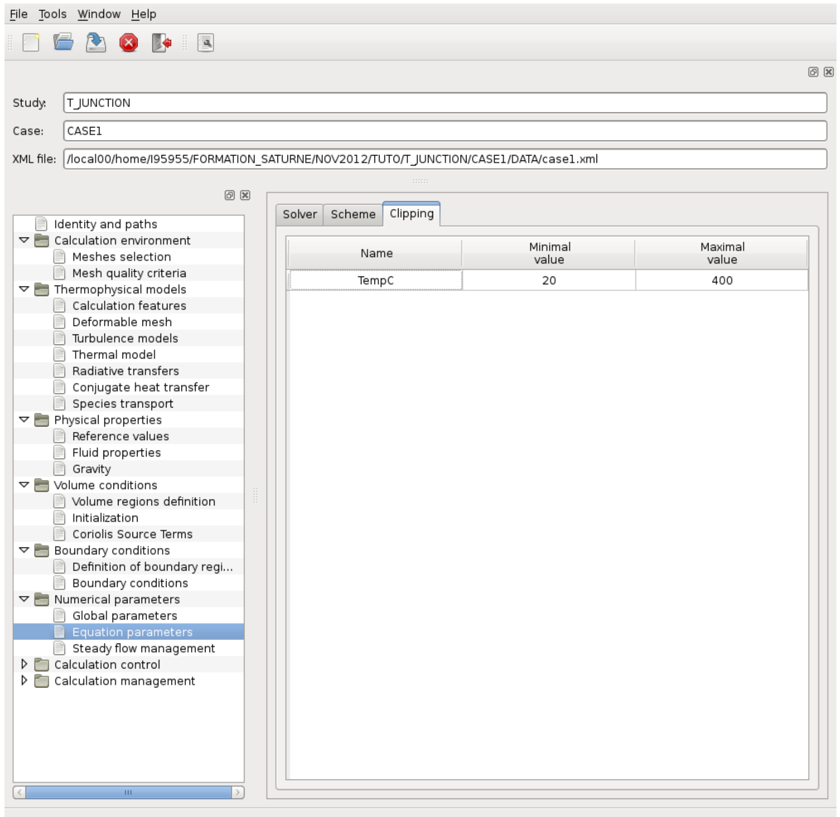


Figure III.28: Clipping

Go to the *Steady flow management* item to specify the number of iterations, **300** in this case. The relaxation coefficient is equal to **0.9** and the *Zero iteration option* will not be activated.

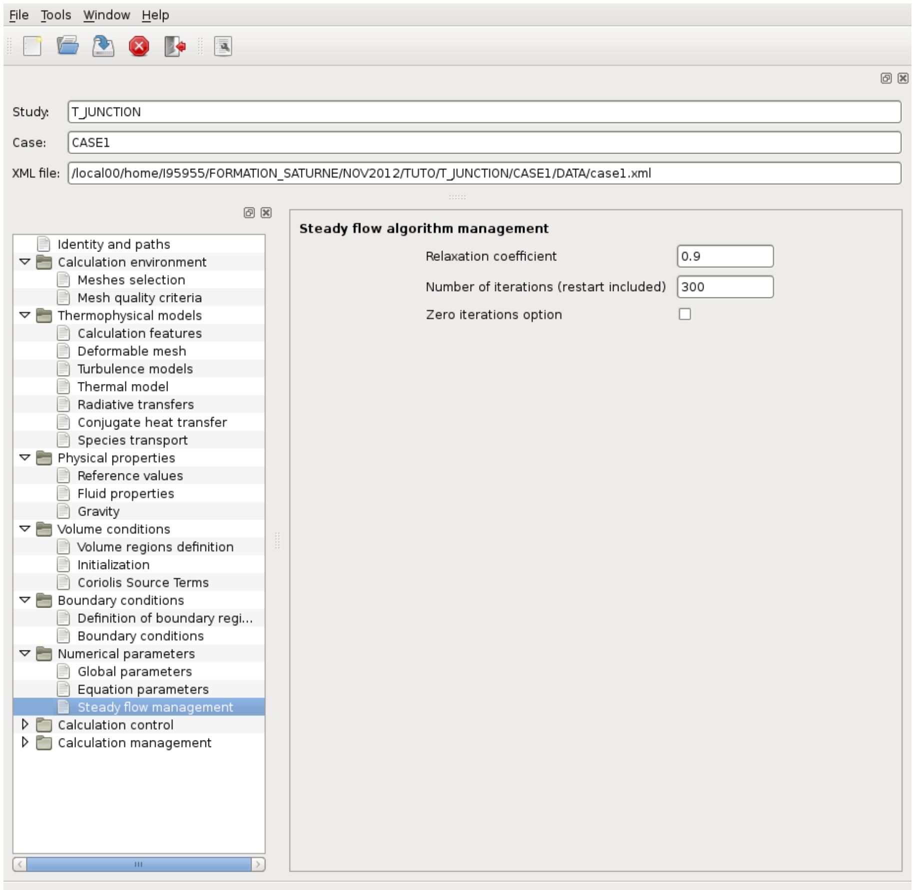


Figure III.29: Steady flow management

Under the heading *Calculation control*, click on the *Output control* item to change the frequency for the printing of information in the output listing.

The options are:

```
- No output
- Output listing at each time step
- Output at each 'n' time step (the value of 'n' must then be specified)
```

Here and in most cases, the second option should be chosen.

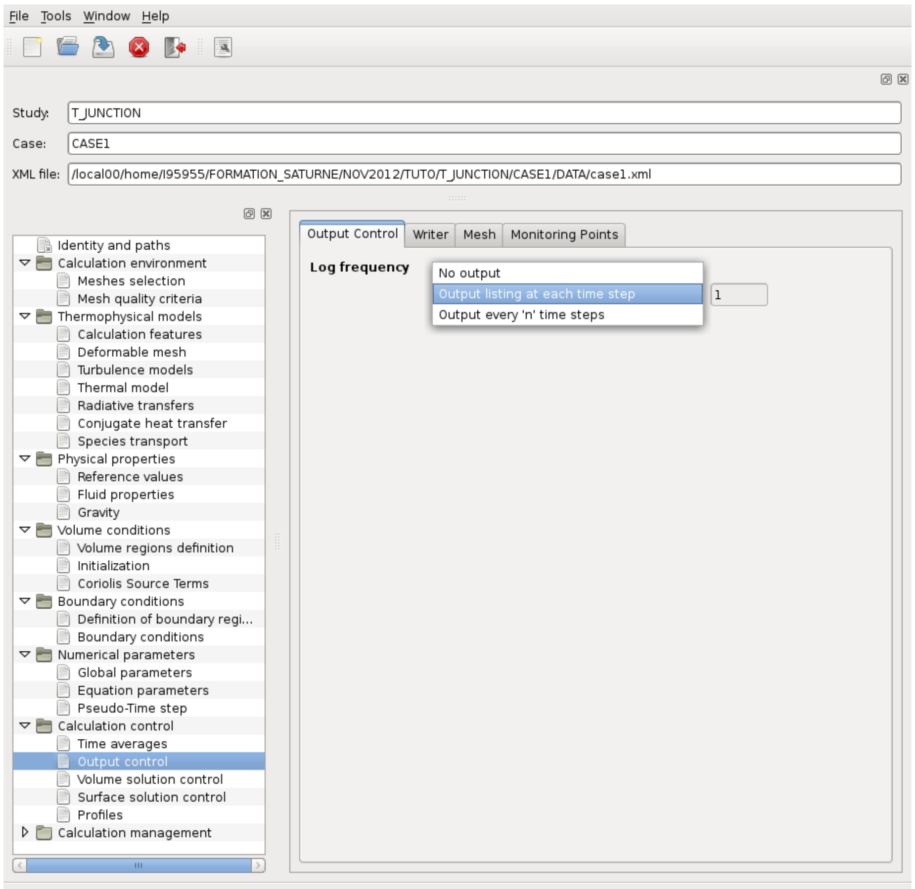


Figure III.30: Output control: output listing

For the post-processing (by default EnSight format files), there are three options:

```
- Only at the end of calculation
- At each time step
- Post-processing every 'n' time steps
```

In this case, we are interested in the evolution of the variables during the calculation, so the second option is chosen.

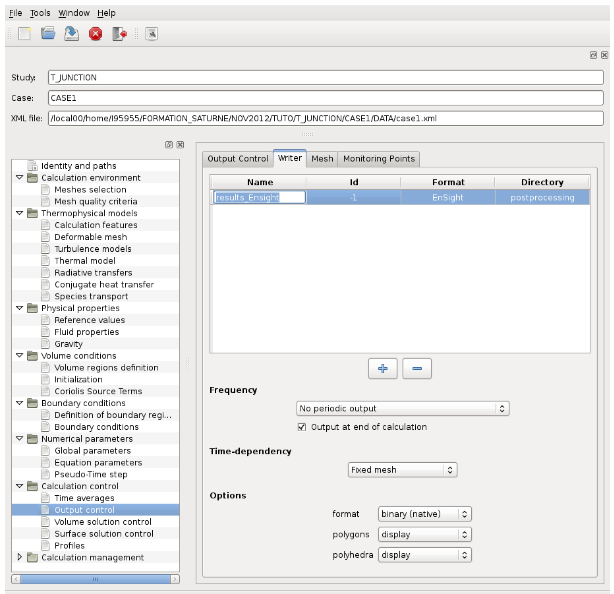


Figure III.31: Output control: post-processing

The other options are kept to their default value.

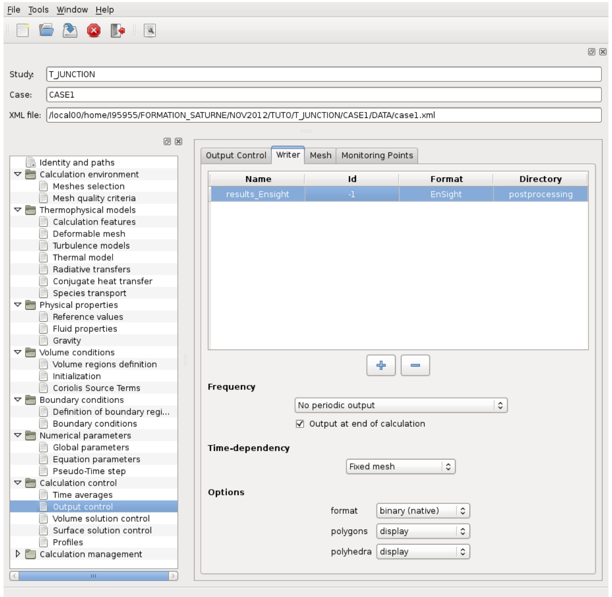


Figure III.32: Output control

The *Monitoring Points* tab allows to define specific points in the domain (monitoring probes) where the time evolution of the different variables will be stored in historic files. In this case no monitoring points are defined.

The *Volume solution control* item allows to specify which variable will appear in the output listing, in the post-processing files or on the monitoring probes. In this case, the default value is kept, where every variable is activated.

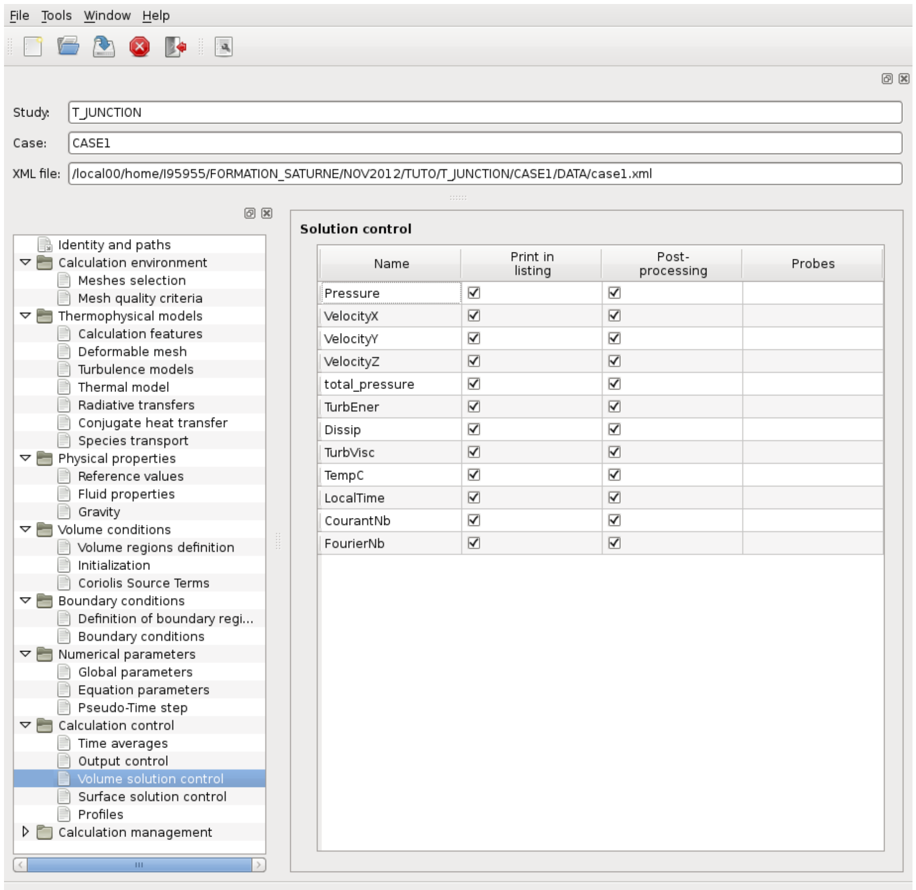


Figure III.33: Solution control

The *Start/Restart* item allows to start a new calculation from the results of a former one. It is not the case in the present calculation so nothing has to be modified.

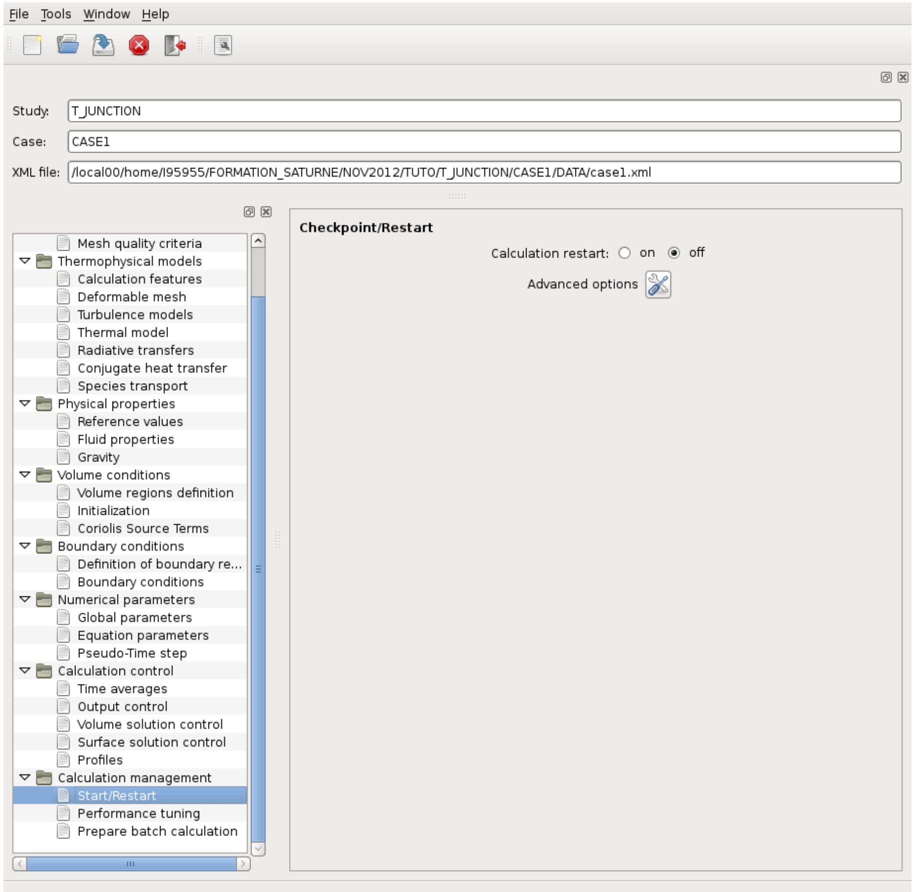


Figure III.34: Start/Restart

The final item, *Prepare batch calculation*, is used to prepare the launch script and, on certain architectures, launch the calculation.

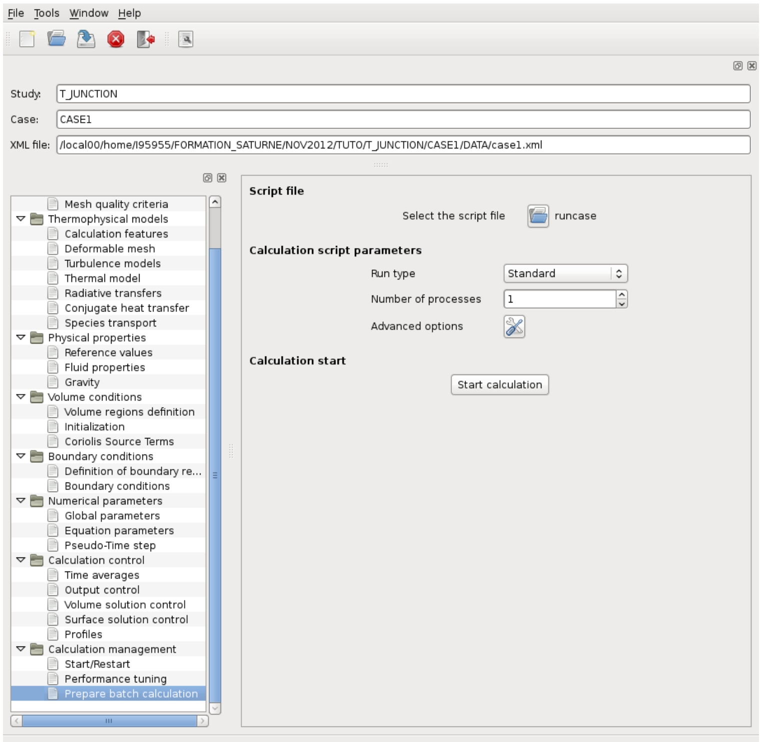


Figure III.35: Prepare batch analysis: Computer selection

Click on the icon to *Select the batch script file* to select the launch script. The default launch script is named `runcase` and is located in the `SCRIPTS/` directory. Select it and click on *Open*.

Remember to save the `xml` file before opening the launch script.

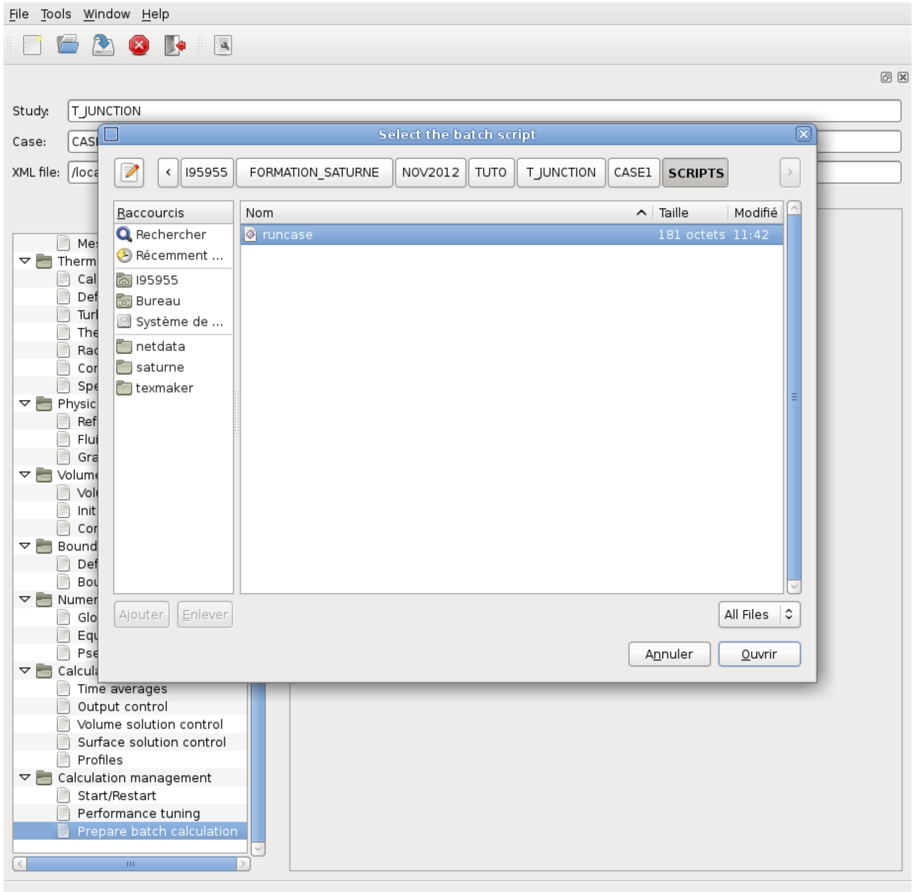


Figure III.36: Prepare batch analysis: batch script file selection

When the script is selected, new options will appear. On this calculation, the number of processors used will be left to 1.

Finally, the *Advanced options* icon allows to change some more advanced parameters that will not be needed in this simple case.

Eventually, save the `xml` file and execute it by clicking on *start calculation*. The results will be copied in the `RESU/` directory.

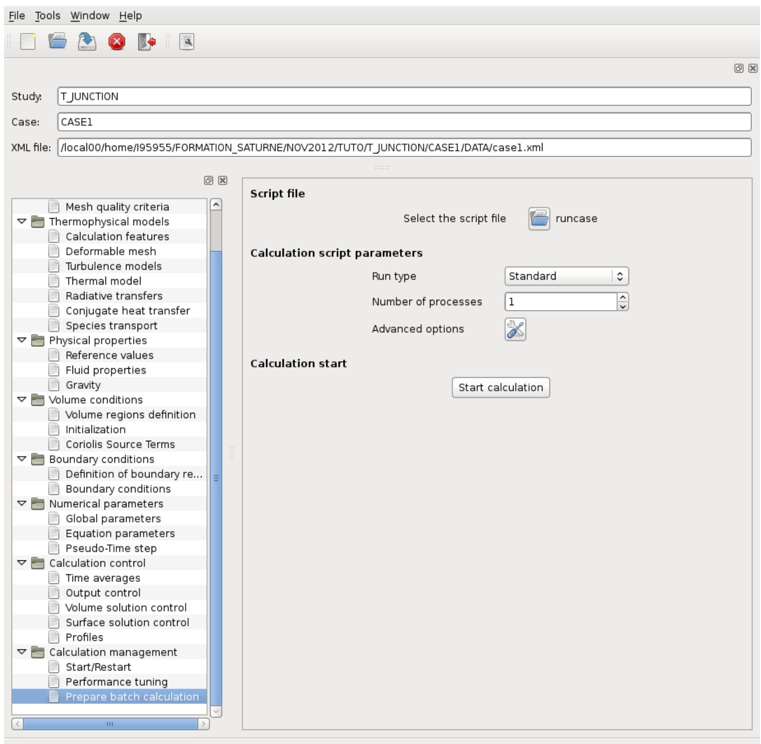


Figure III.37: Prepare batch analysis: Execution

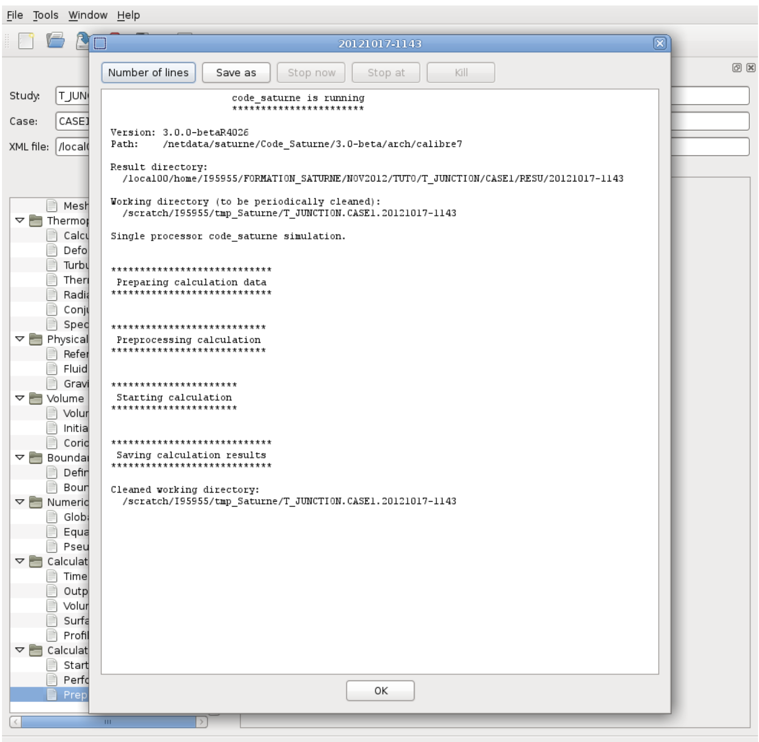


Figure III.38: Run

2 Solution for case2

This case corresponds to a new study, in which there will be three calculation cases (cases 2, 3 and 4). We can create one case in a single `code_saturne create` command and additional cases can be added later. To test this functionality, first create the study directory, with case subdirectory `case2`, as below:

```
$ code_saturne create -s full_domain -c case2
$ cd full_domain
```

Go to the `DATA` directory in `case2`, open a new case and select the meshes to use.

Click on the heading *Calculation environment* then on the *Meshes selection* item. In this case, you must add three meshes which have to be joined.

In order to join the three meshes, you must add a selection criteria in the box *Selection criteria*. In this case, only faces of colors 5, 24 and 32 are liable to be joined (different colors can be entered on a single line, separated by comma).

Click on the + icon to enter the list of colors to be joined in the *Face joining (optional)* item.

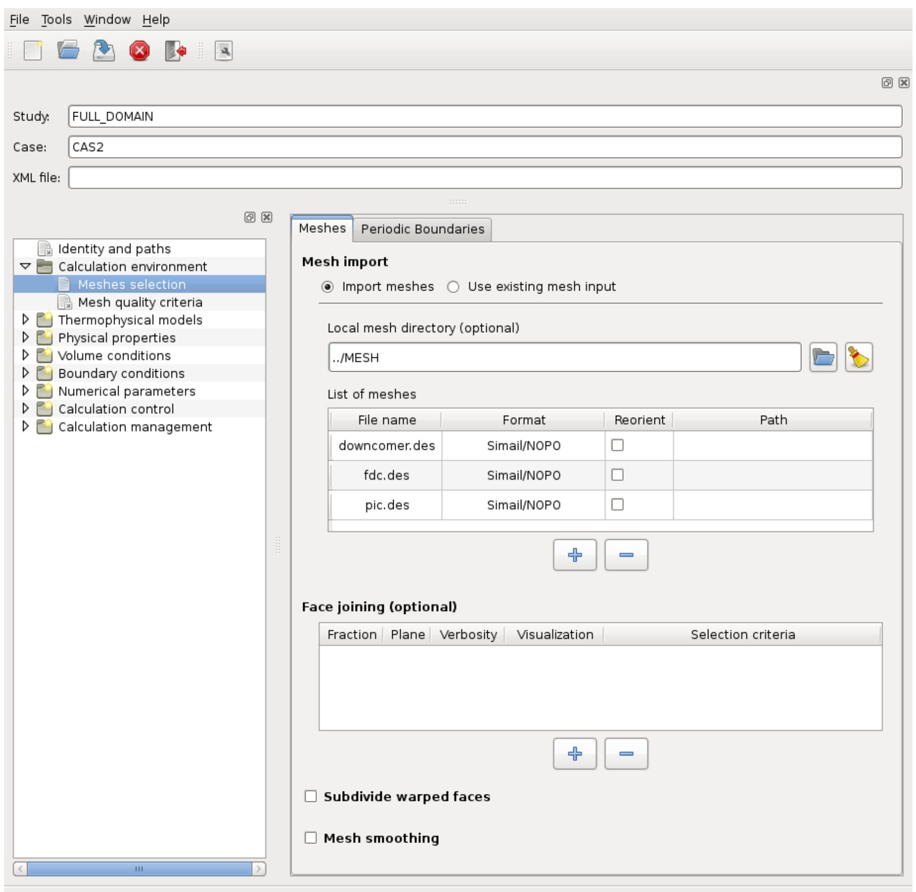


Figure III.39: Meshes: list of meshes

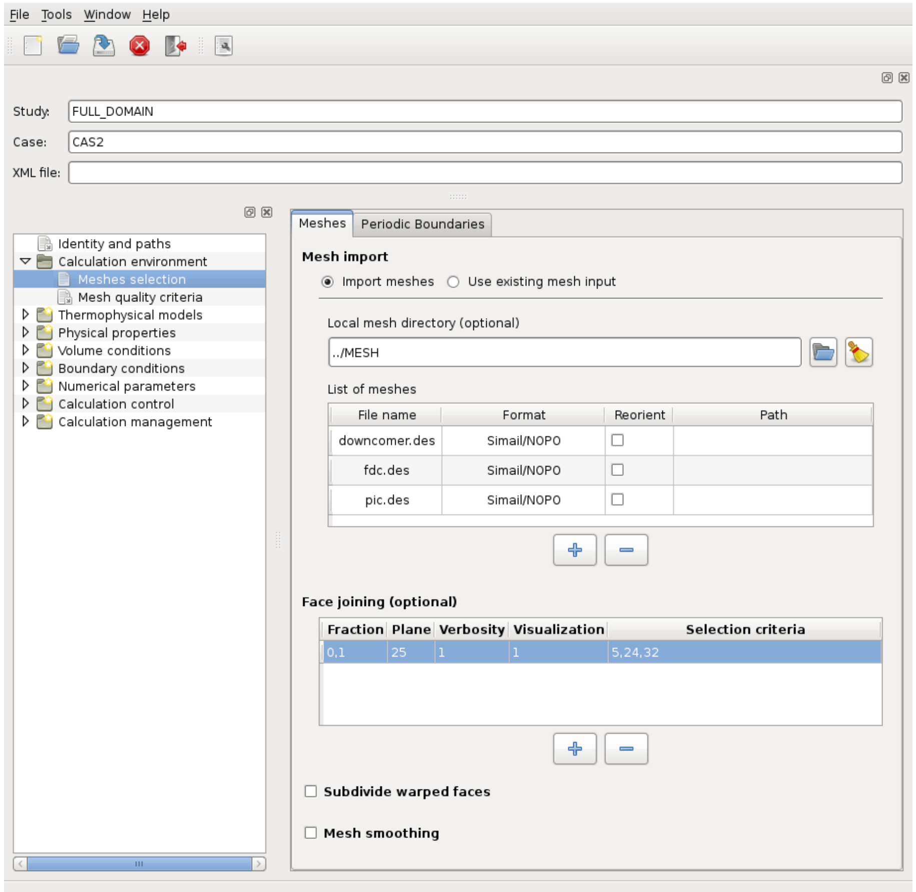


Figure III.40: Join a Mesh

You can now verify the quality of your mesh.

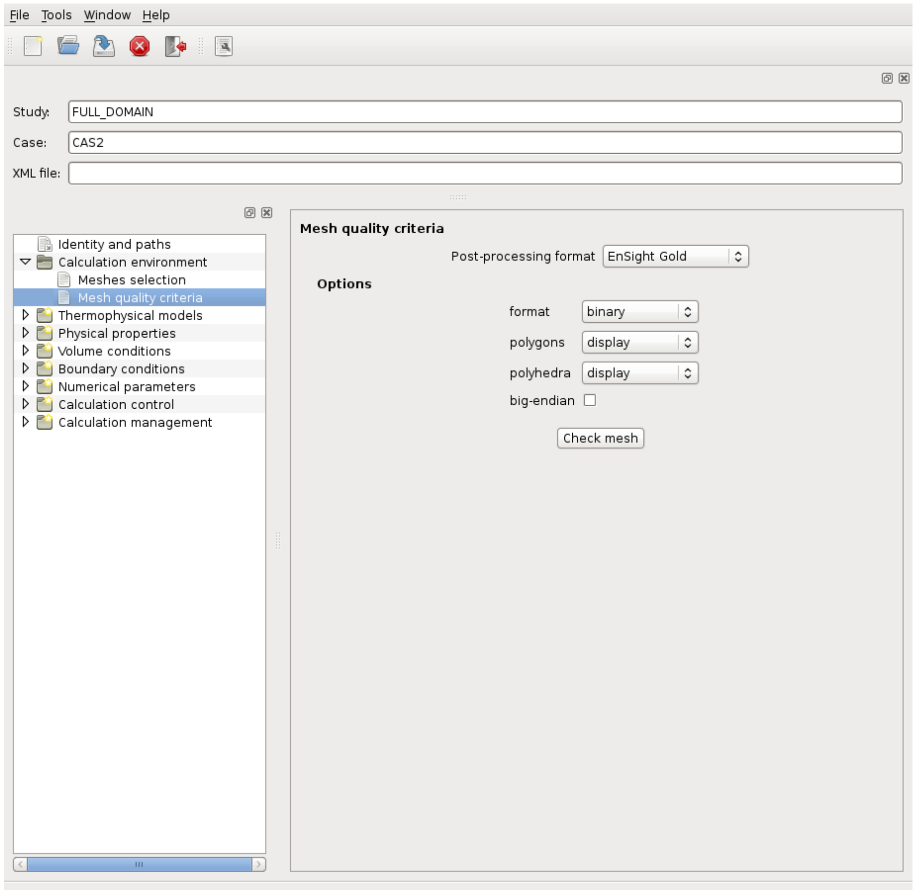


Figure III.41: Mesh quality criteria

In this case “Unsteady flow” must be selected in the *Calculation features* item.

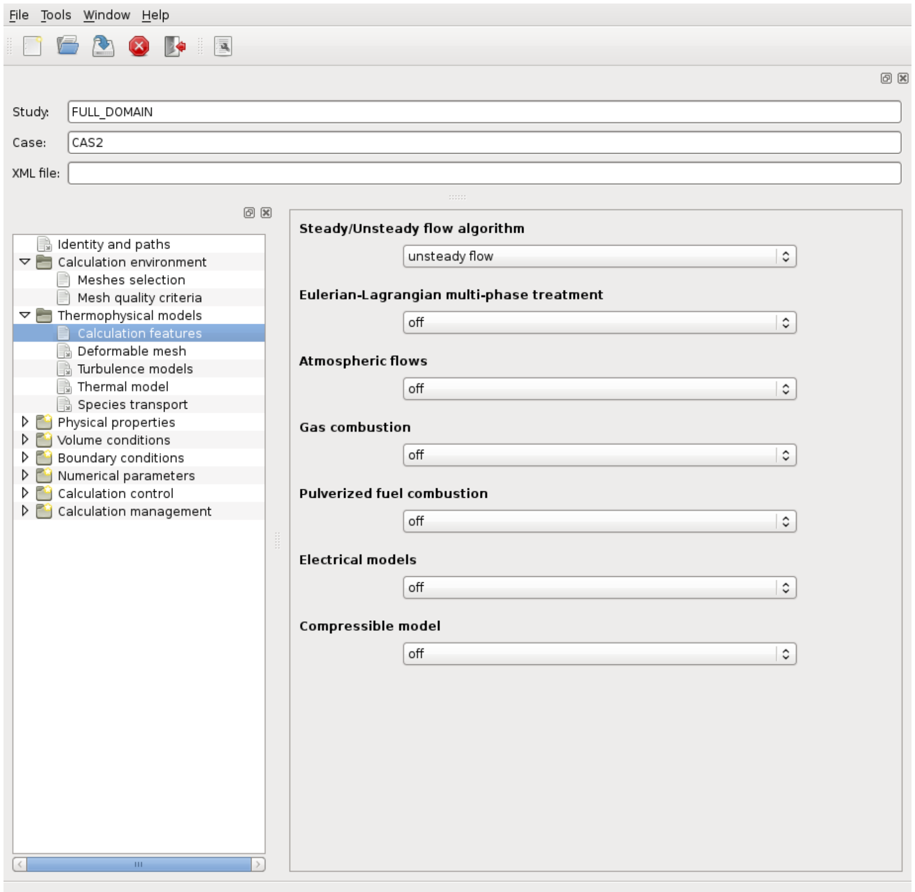


Figure III.42: Thermophysical models - Analysis features - Unsteady flow

The rest of the heading *Thermophysical models* is identical to `case1`.

To add an additional scalar, click on the *Species transport* item under the *Thermophysical models* heading.

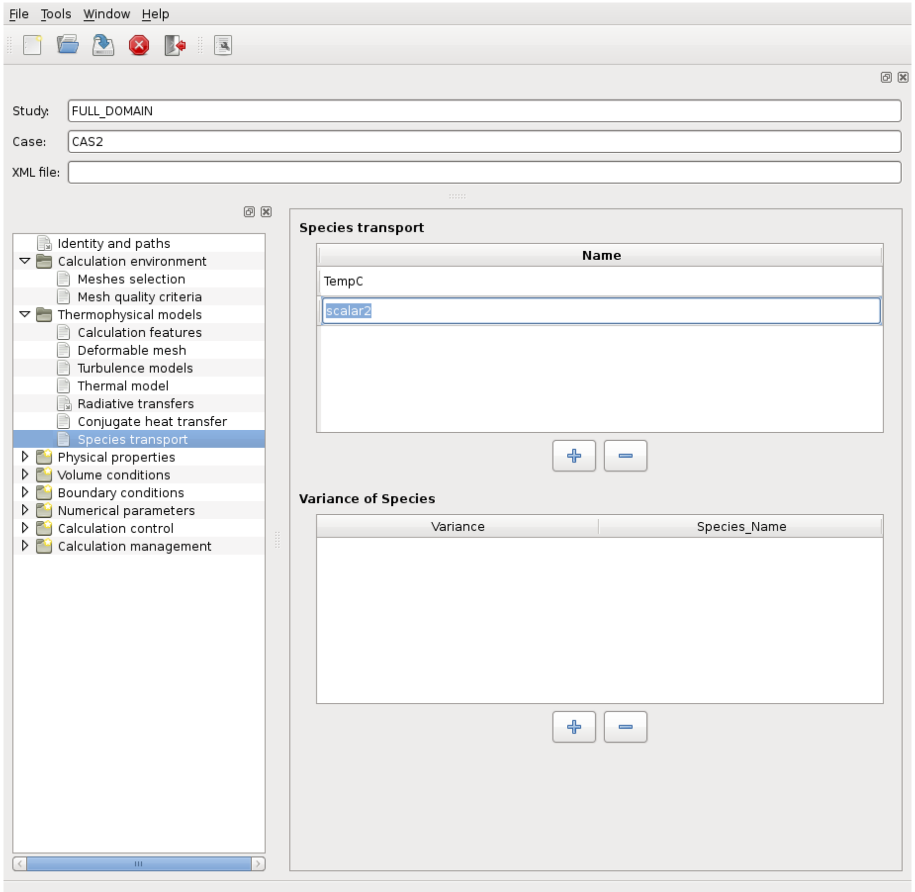


Figure III.43: Additional scalar

The heading of *Physical properties* is identical to `case1`.
In the *Fluid properties* item, still under the heading *Physical properties*, specify the diffusion coefficient of this new scalar.

Click on the scalar name to highlight it, then enter the value in the box. In this case, the species diffusion coefficient value is **0.855** ($\times 10^{-5}$ $m^2.s^{-1}$) for the `scalar2` scalar to solve.

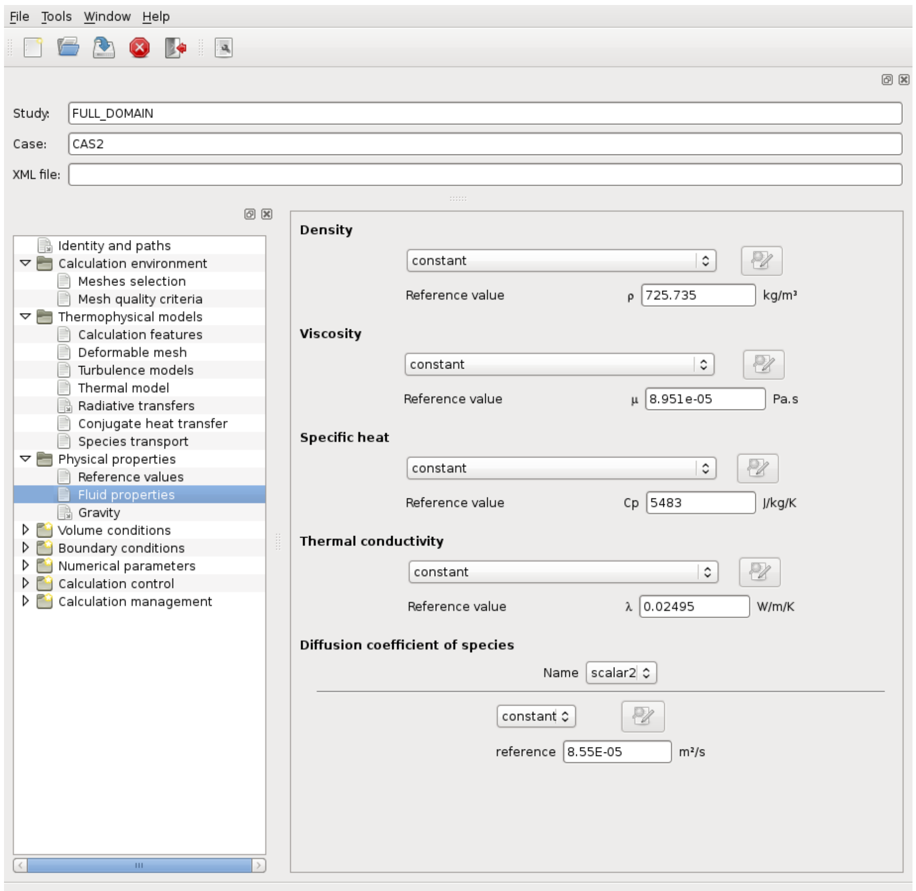


Figure III.44: Fluid properties

Initialization:
To initialize variables at the instant $t = 0$ s, go to the *Initialization* item under the heading *Volume conditions*.

Here the velocity, the thermal scalar and the turbulence can be initialized. In this case, the default values can be kept: zero velocity, an initial temperature of **20**°C and a turbulence level based on a reference velocity of **1** ($m.s^{-1}$). You must also initialize the `scalar2` species at **10**°C.

Specific zones can be defined with different initializations. In this case, only the default "all cells" is used.

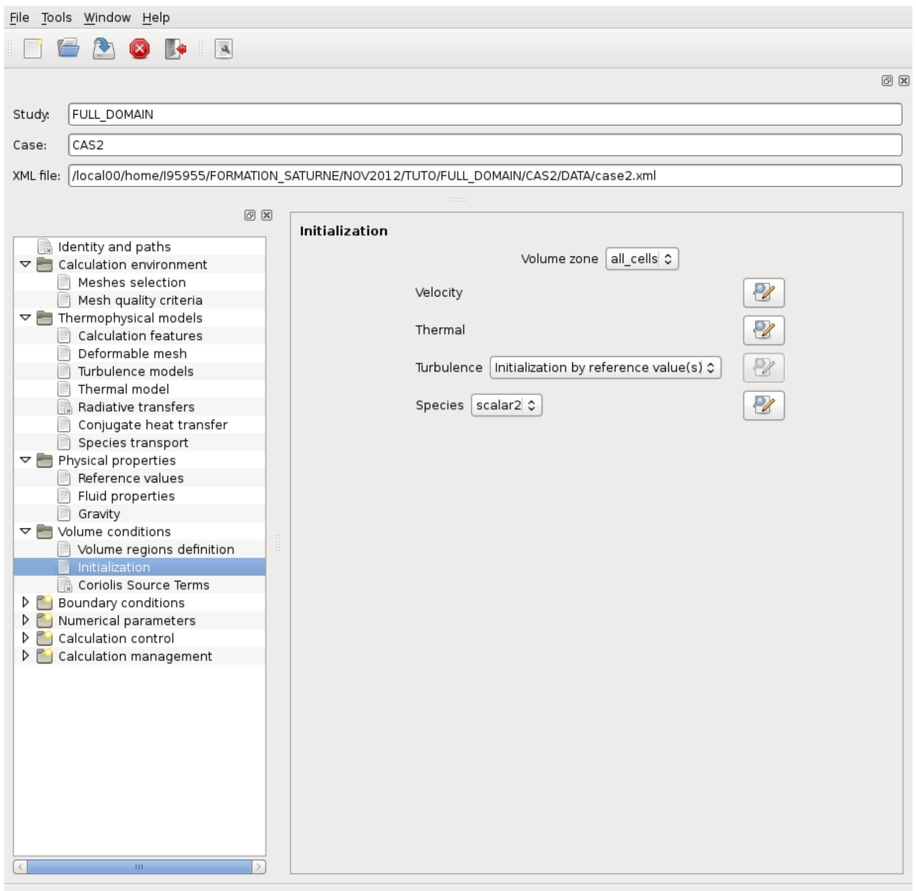


Figure III.45: Initialization

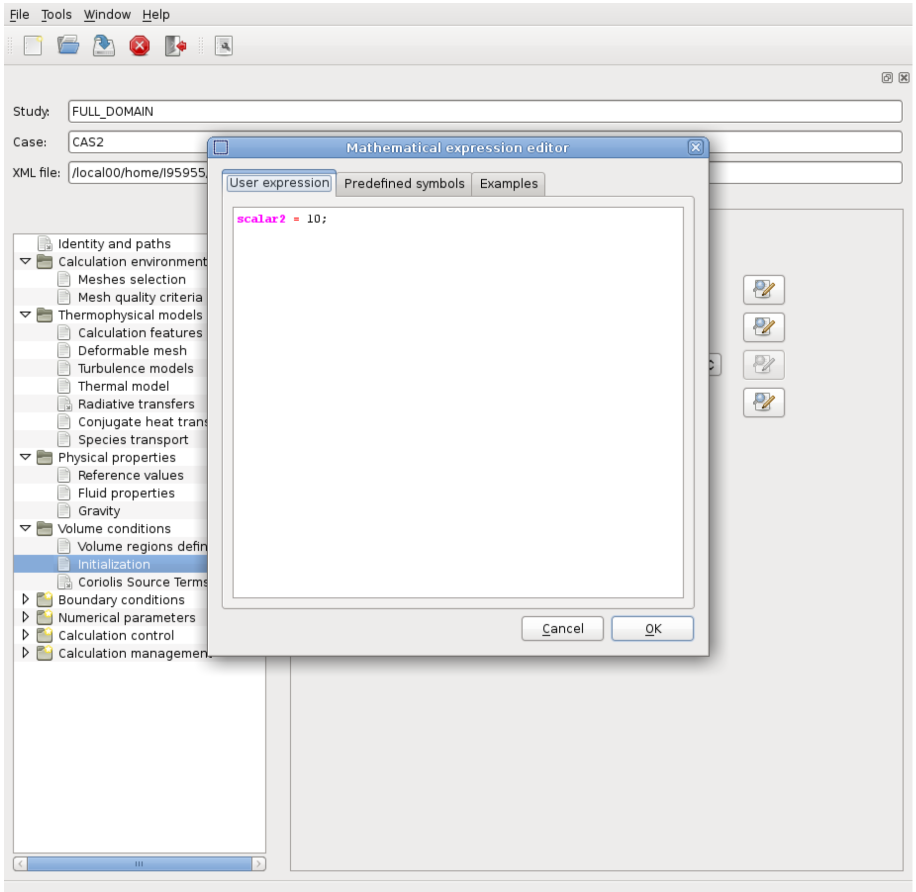


Figure III.46: Initialization- Species

•**Create the boundary zones**:

The procedure is the same as in case 1, but the colors are different. Note that colors 5 and 32 have completely disappeared in the joining process (they are now internal faces and are not considered as boundaries), while some boundary faces of color 24 remain.

Create the inlet, outlet and symmetry boundary zones with the following colors:

```
- inlet    :  ''1''
- outlet   :  ''34''
- symmetry:  ''8 or 9 or 28 or 29 or 38 or 39''
```

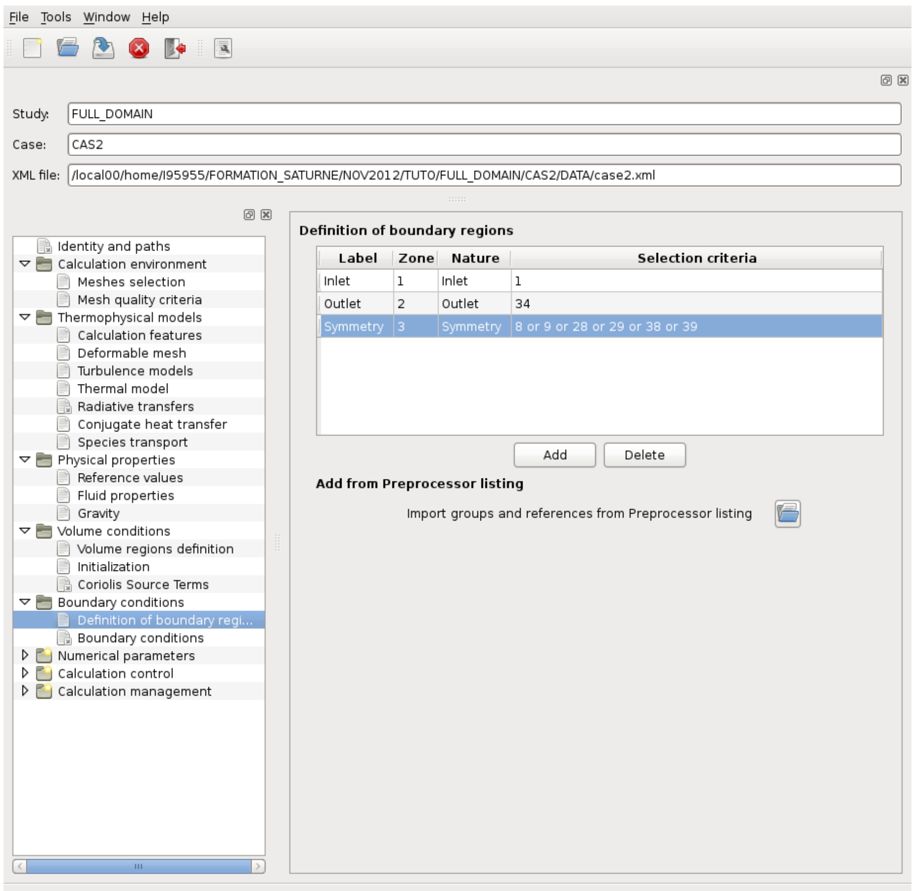


Figure III.47: Creation of the boundary zones

In this case, different conditions are applied for the walls. Separate corresponding wall boundary regions must therefore be created, following the data in the following table.

Label	Zone	Nature	Selection criteria
wall_2	5	wall	2 or 3
wall_3	6	wall	4 or 7 or 21 or 22 or 23
wall_4	7	wall	6 and y>1
wall_5	8	wall	6 and y⩽1
wall_6	9	wall	31 or 33

The "wall_1" region combines color and geometrical criteria. The associated character string to enter in the "Selection criteria" box[1] is as follows:

```
''24 and 0.1 <= x and 0.5 >= x''
```

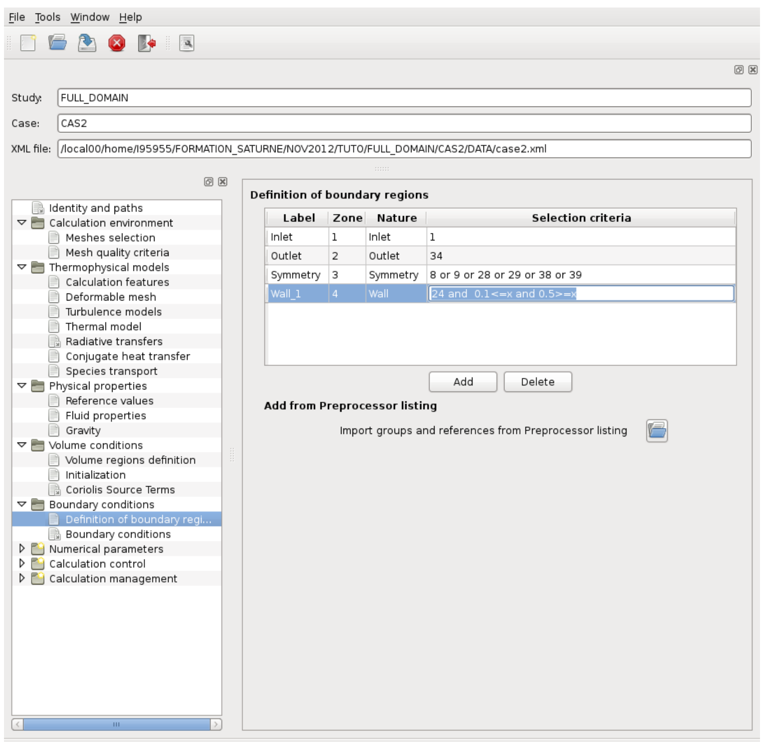


Figure III.48: Creation of a wall boundary region

[1]Note that, due to the joining process, there are in fact no boundary faces of color 24 with x coordinate outside the [0.1;0.5] interval. The geometrical criterium is therefore not necessary. It is presented here to show the capacity of the face selection module.

Define the other wall boundary zones. The faces of color 6 have to be divided in two separate zones, based on a geometrical criterium on y.

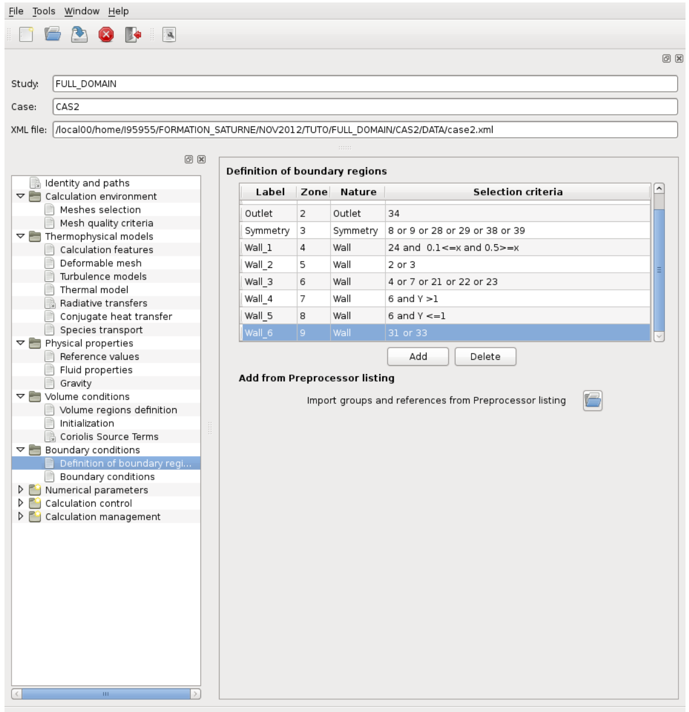


Figure III.49: Creation of wall boundary regions

The dynamic boundary conditions are the same as in case 1 for the inlet, and there are still no sliding walls.

– Inlet:

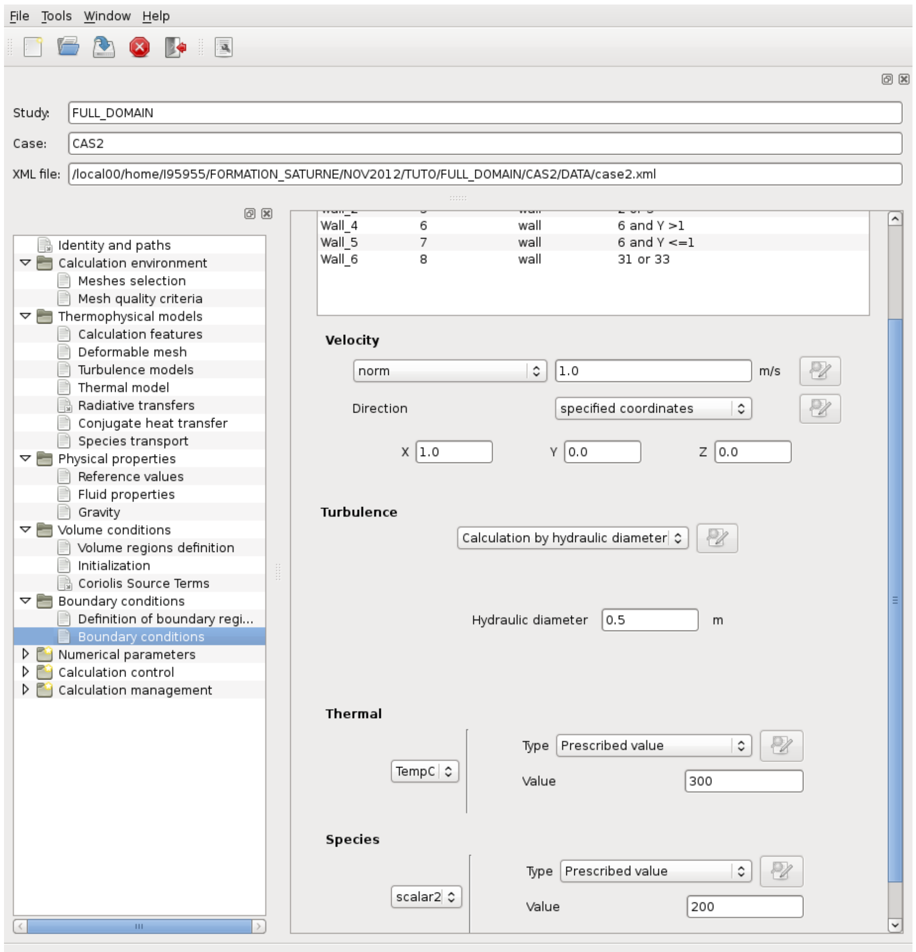


Figure III.50: Dynamic variables boundary: Inlet

– Outlet:

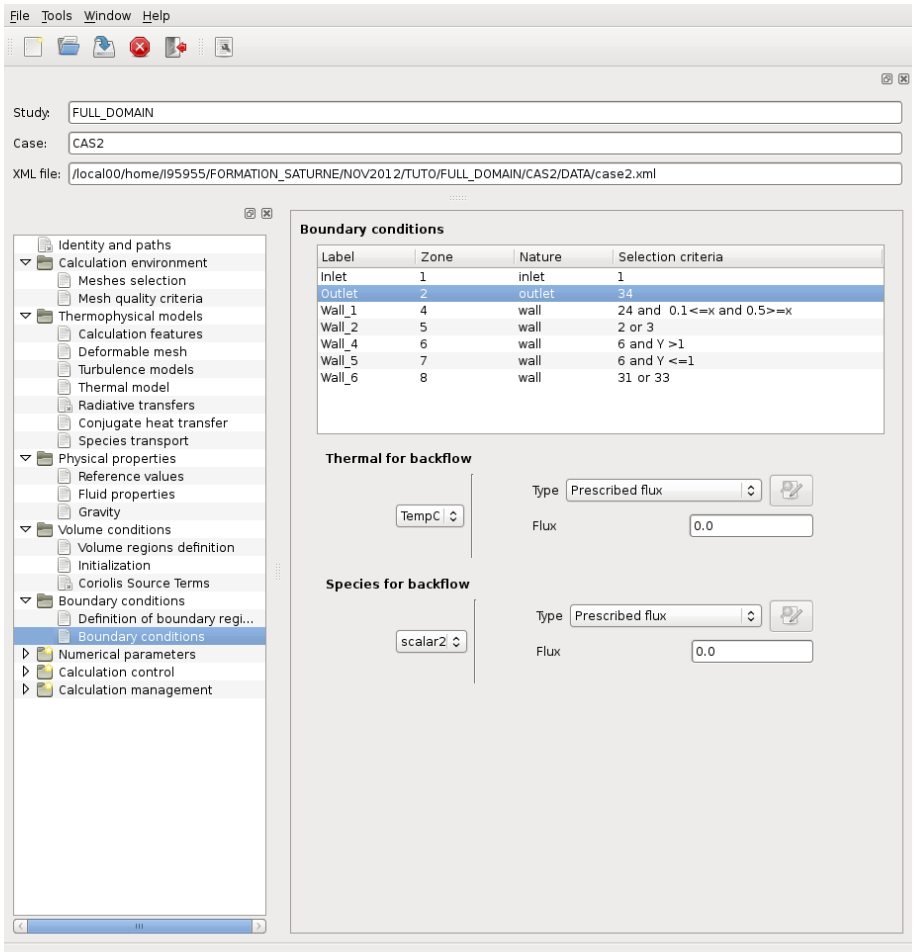


Figure III.51: Dynamic variables boundary: Outlet

To configure the scalar boundary conditions on the walls, select individually each wall in the *Boundary conditions* item.

On all the walls, a default homogeneous `prescribed flux` is set for temperature, and `prescribed values` are specified for the passive scalar, named `scalar2`, according to the following table:

Wall	Nature	`Scalar2` value
wall_1	Prescribed value	0
wall_2	Prescribed value	5
wall_3	Prescribed value	0
wall_4	Prescribed value	25
wall_5	Prescribed value	320
wall_6	Prescribed value	40

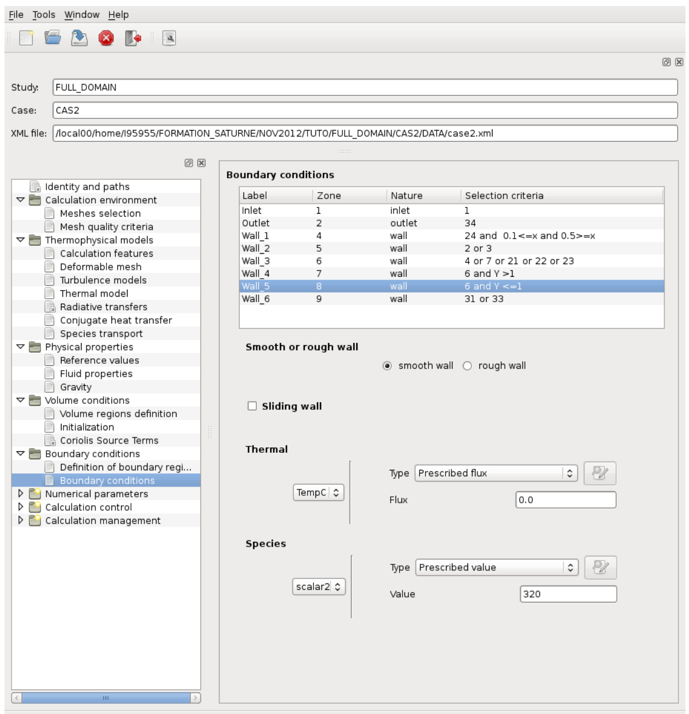


Figure III.52: Scalars boundaries: wall_5

Some calculation parameters now need to be defined. Go to the *Global parameters* item under the heading *Numerical parameters*. In our case the Pressure-Velocity algorithm is *SIMPLEC*.

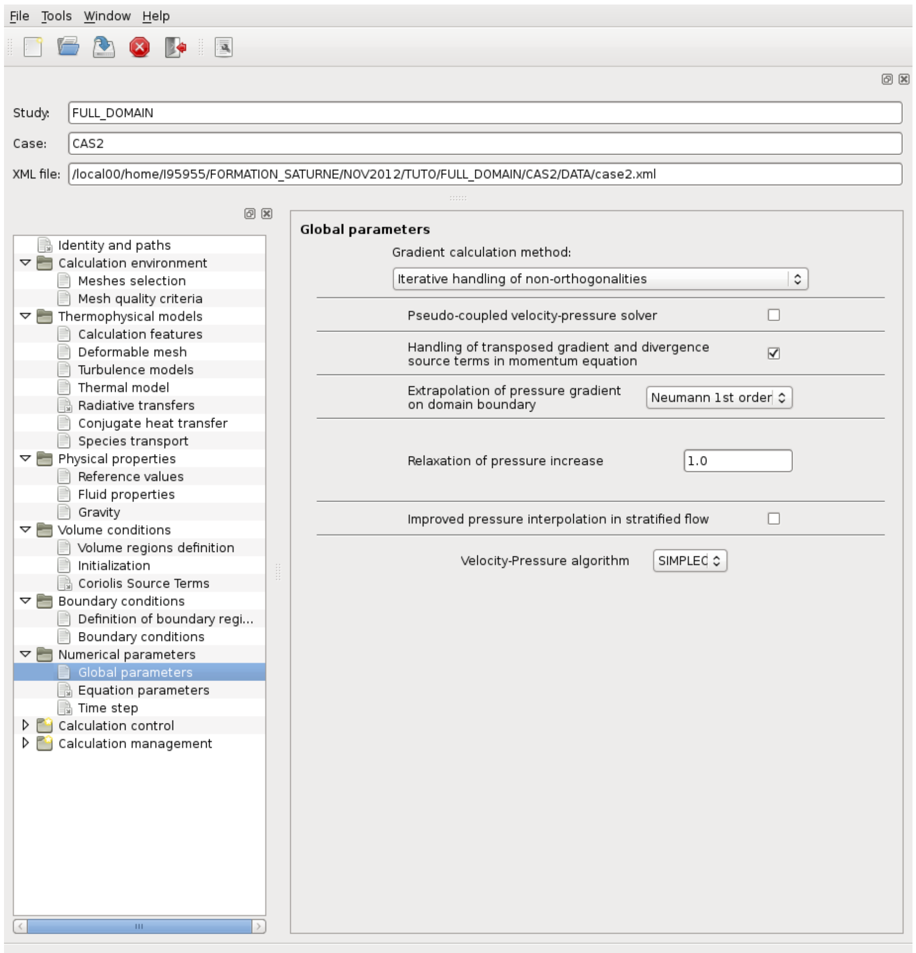


Figure III.53: Time step setting

Go to the *Equations parameters* item under the heading *Numerical parameters*. You can define the maximum and minimun value for the `TempC` and for the `scalar2` scalars.

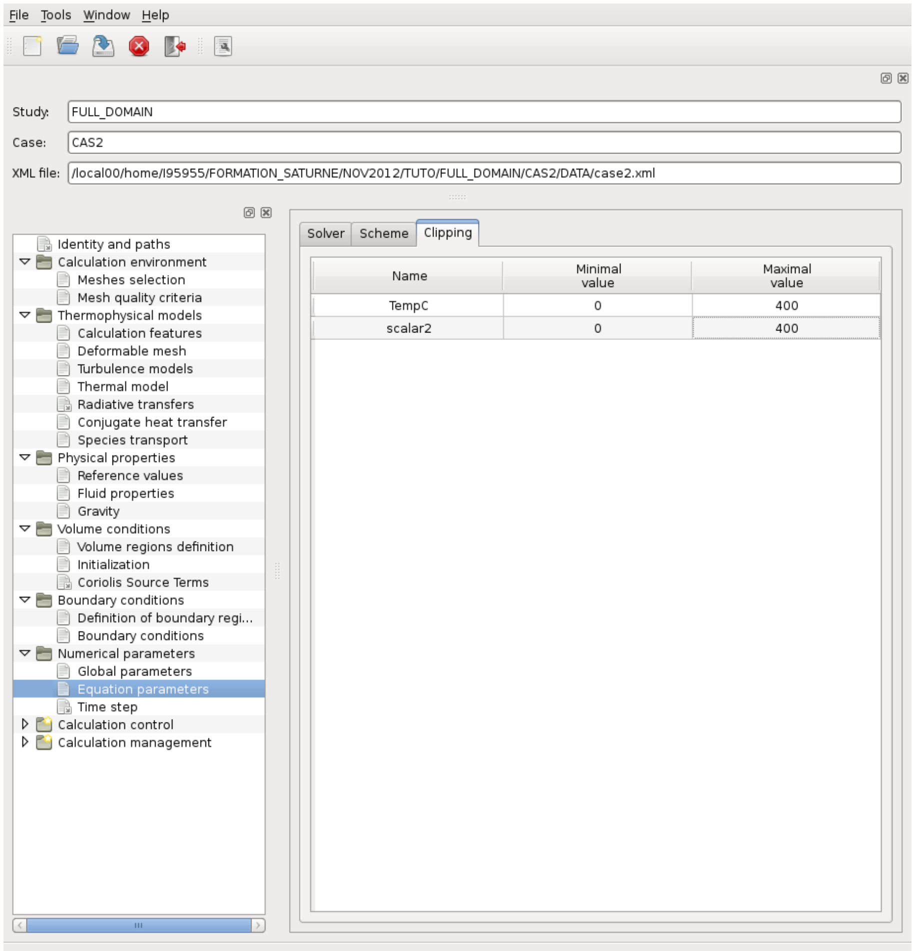


Figure III.54: Clipping

Go to the *Time step* item under the heading *Numerical parameters*. In our case the time step is *Constant*. Set the number of iterations to **300** and the reference time step to **0.05** (s).

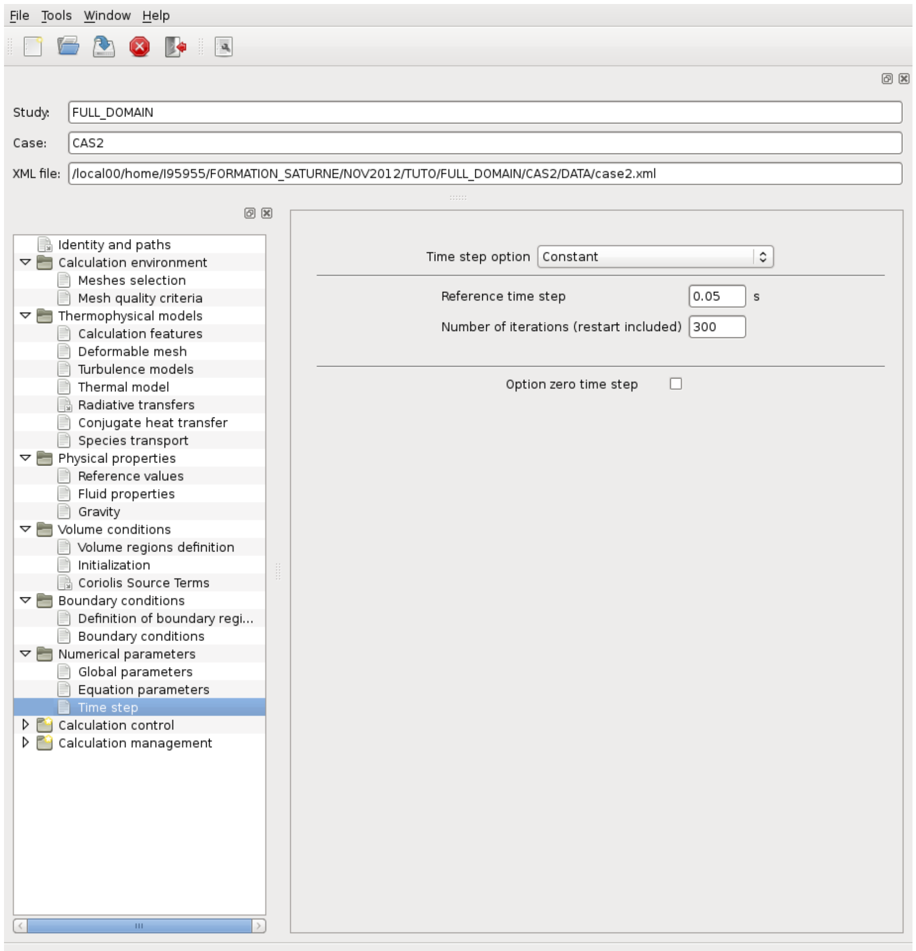


Figure III.55: Time step setting

Go to the *Output control* item under the heading *Calculation control* to set the output parameters. In the *Output control* item, keep the default value for the output listing frequency.

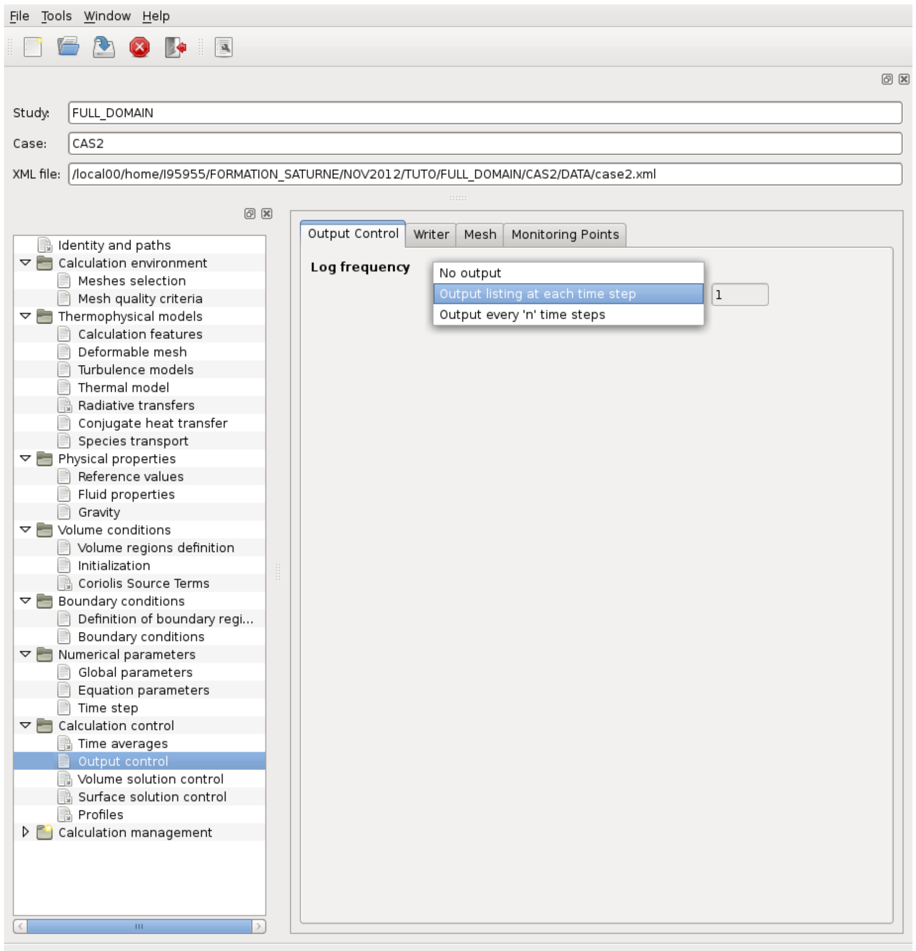


Figure III.56: Output control: log frequency

For the Post-processing, go to the *Writer* item and click on “results“.

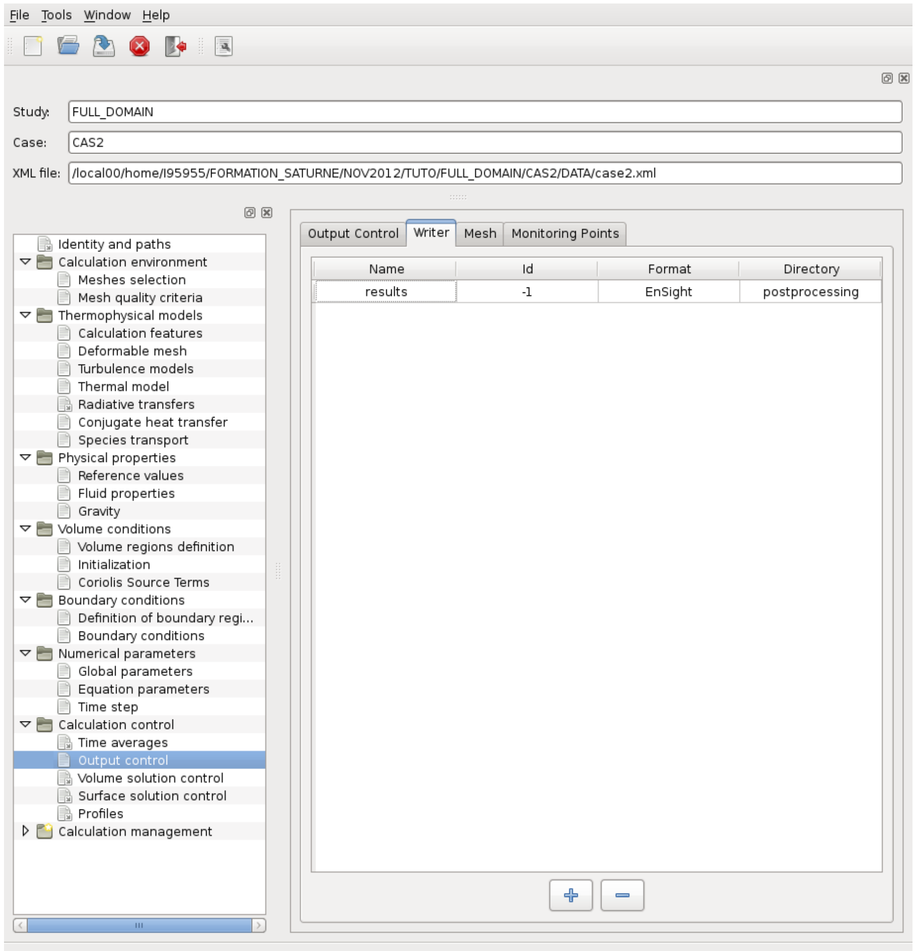


Figure III.57: Output control: Writer

Now you can select the third option in the *Frequency (output every 'n' time steps)* item and set the value of 'n' to **2**. By default, the boundary faces are selected.

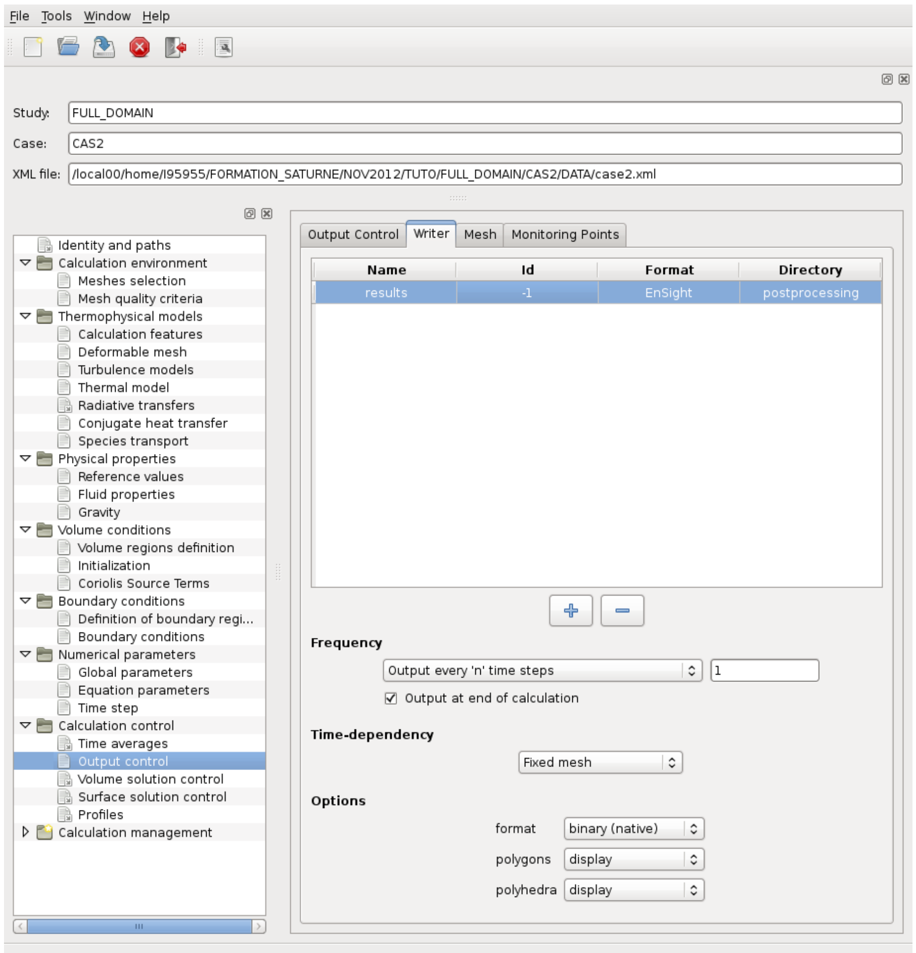


Figure III.58: Output control: results

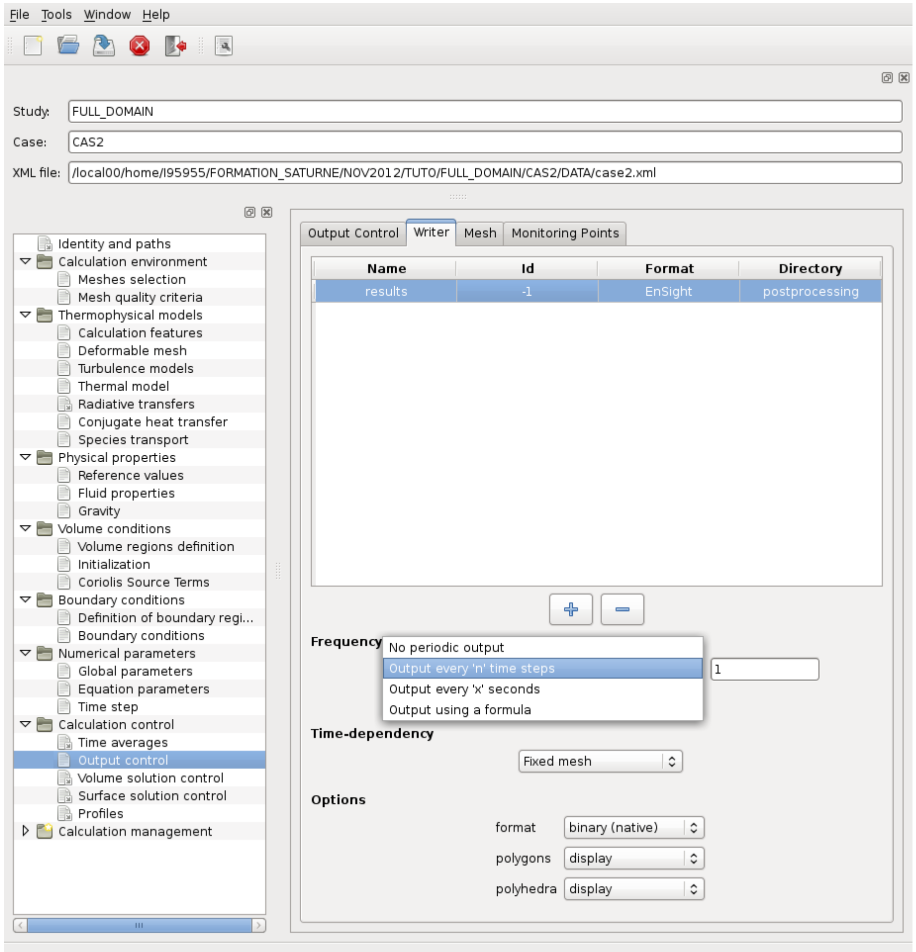


Figure III.59: Output control: frequency

You can also choose the format. In this case, you will choose the EnSight format.

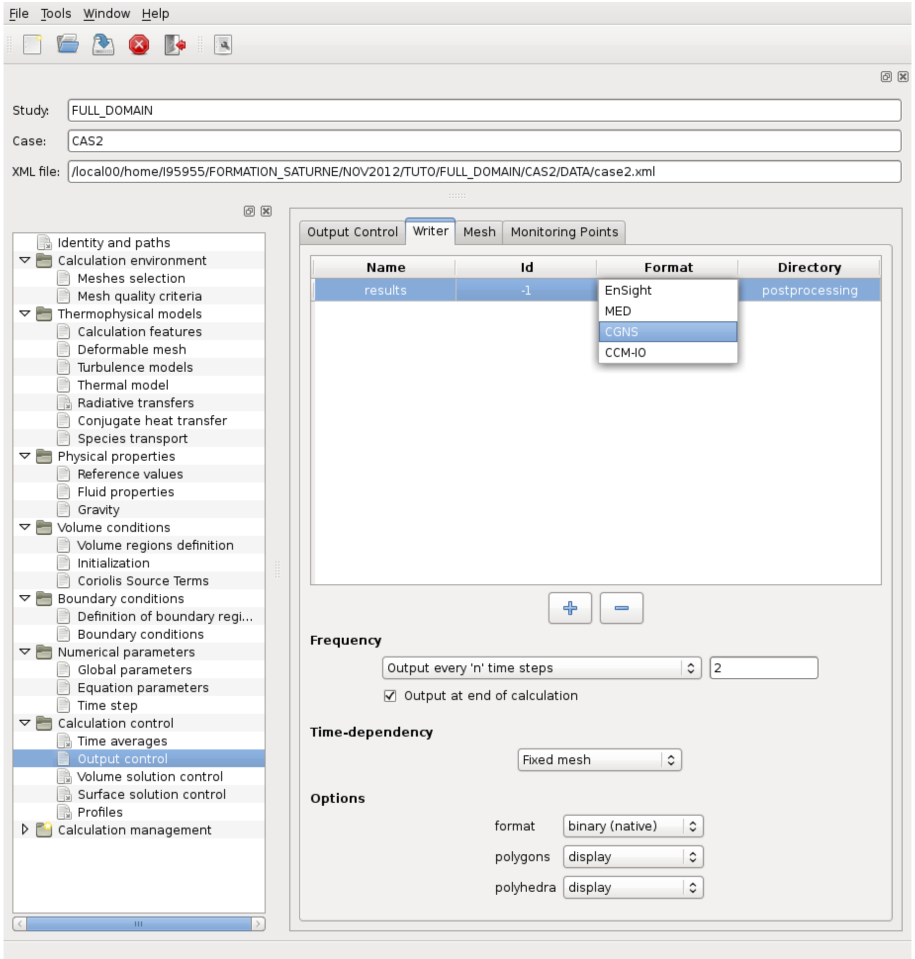


Figure III.60: Output control: format

Go to the *Mesh* item.

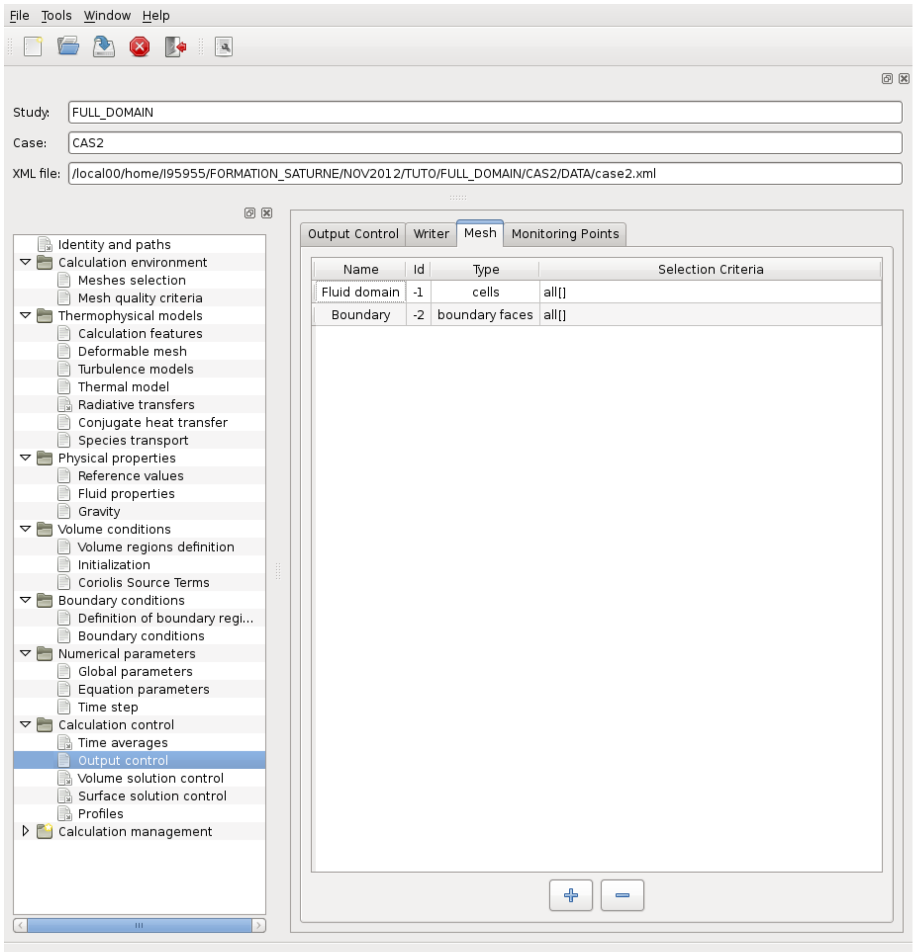


Figure III.61: Output control: mesh

You can click on the *Fluid domain Mesh Name* item and new options will appear.

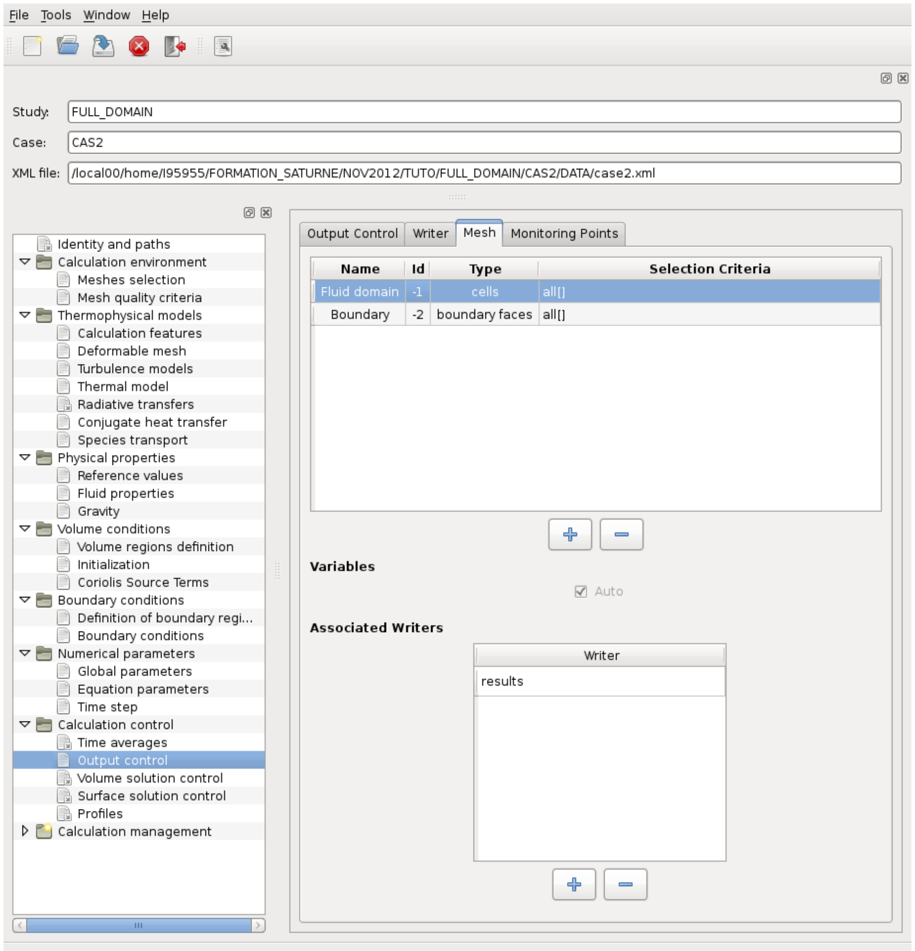


Figure III.62: Output control: post-processing

You can associated a mesh with several writers.

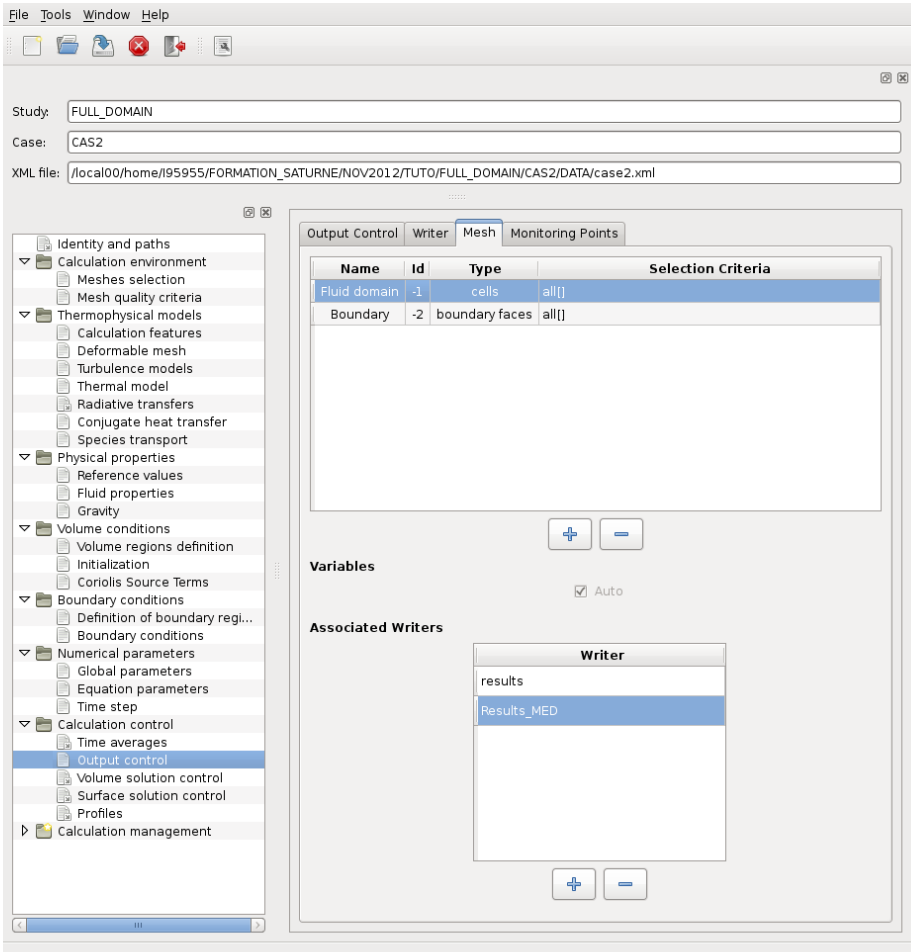


Figure III.63: Output control:associated writers

In this case, chronological records on specified monitoring probes are needed. To define the probes, click on the *Monitoring points Coordinates* tab.

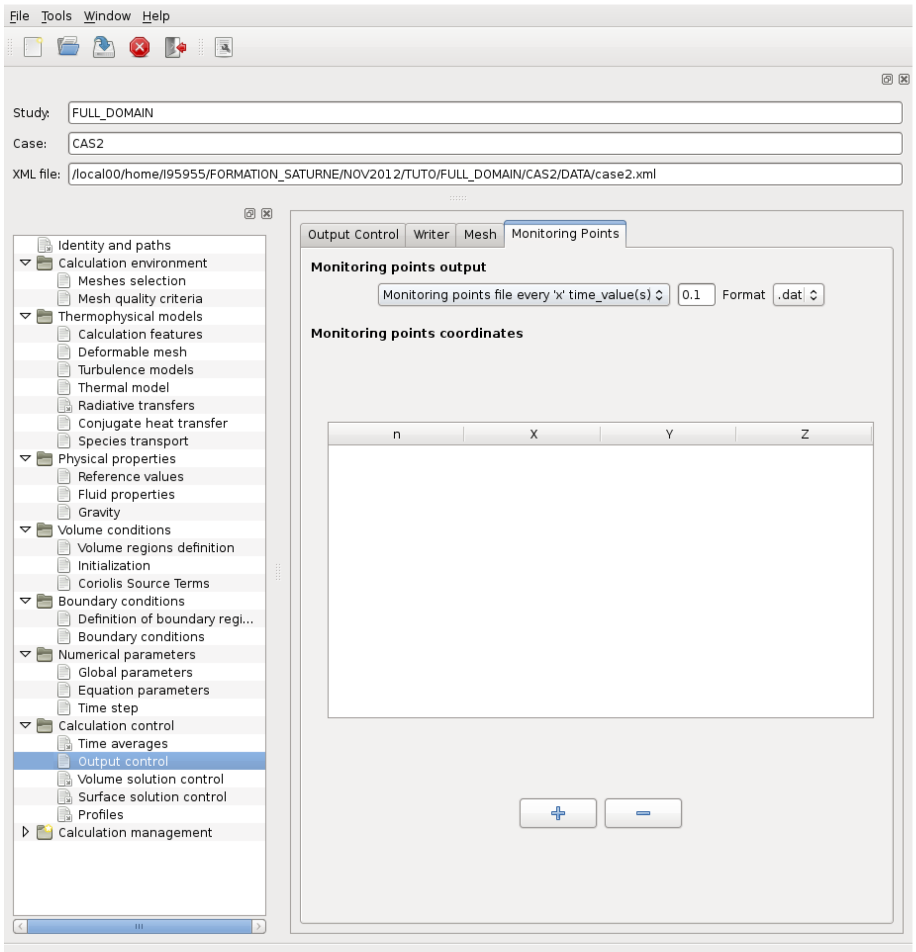


Figure III.64: Output control: monitoring points

Click on **"+"** and enter the coordinates of the monitoring points you want to define.

For the first probe:

```
Probe (1) :  x = -0.25 (m) ; y = 2.25 (m) ; z = 0.0 (m)
```

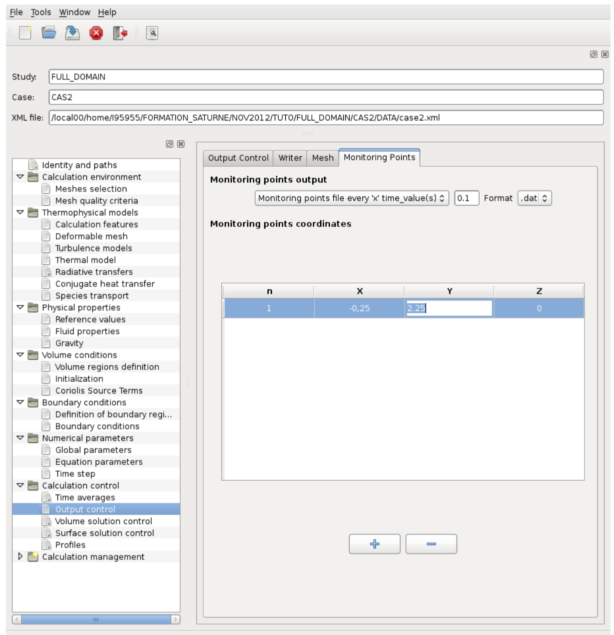


Figure III.65: Output controls: monitoring points - 1st point

Repeat the procedure for the other probes. Their coordinates are indicated in the following table (the z coordinate is always 0).

Probe n^o.	x (m)	y (m)
2	0.05	2.25
3	0.05	2.75
4	0.05	0.50
5	0.05	-0.25
6	0.75	-0.25
7	0.75	0.25
8	0.75	0.75

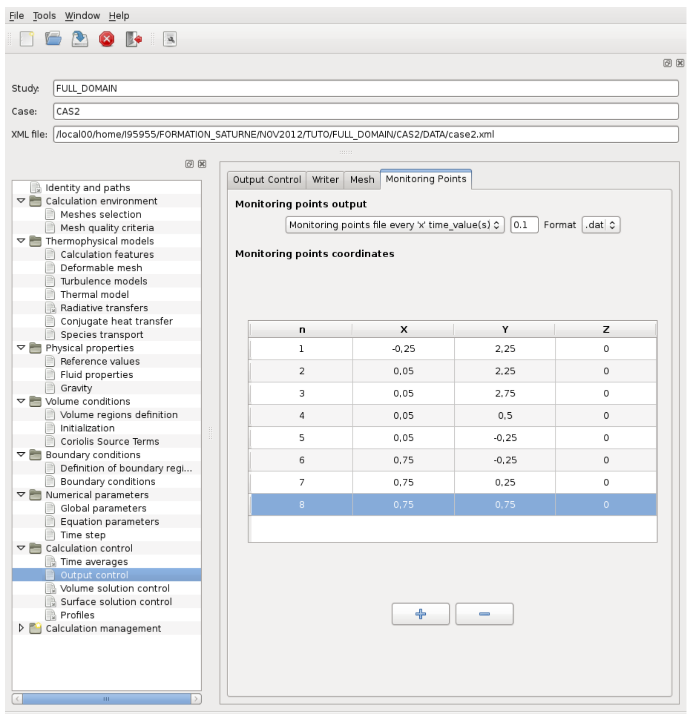


Figure III.66: Output control: monitoring points

Remember to save the `xml` file regularly.

Go to the *Volume solution control* item to define which variables will appear in the listing, the post-processing and the chronological records.

Uncheck the boxes in front of the *Pressure*, *Tubulent Energy* and *Dissipation* variables, in the *Print in listing* column. Information on these three variables will not appear in the output listing anymore.

Uncheck the boxes in front of the *Courant number* and *Fourier number* variables in the *Post-processing* column. These variables will be removed from the post-processing results.

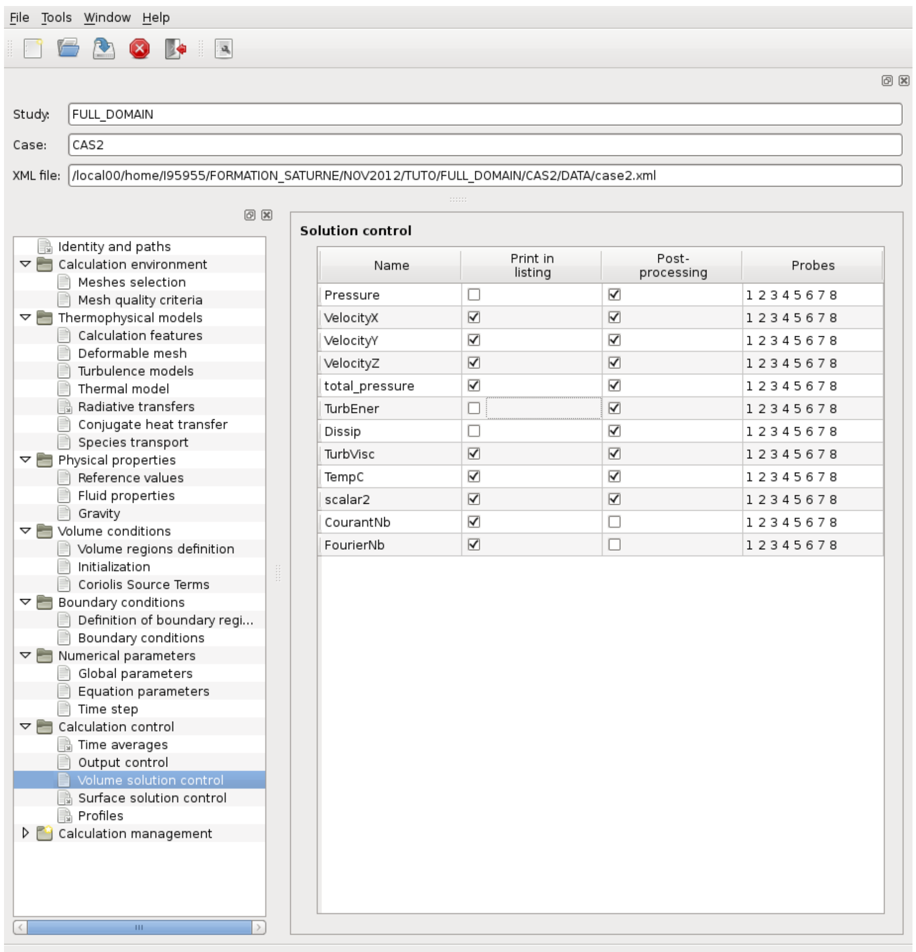


Figure III.67: Solution control - Output configuration

Delete all the probe numbers for the *total_pressure* variable. No chronological record will be created for this variable.

As for the *VelocityX* variable, only select probes 1, 2, 6, 7 and 8. Time evolution on the other probes will not be recorded.

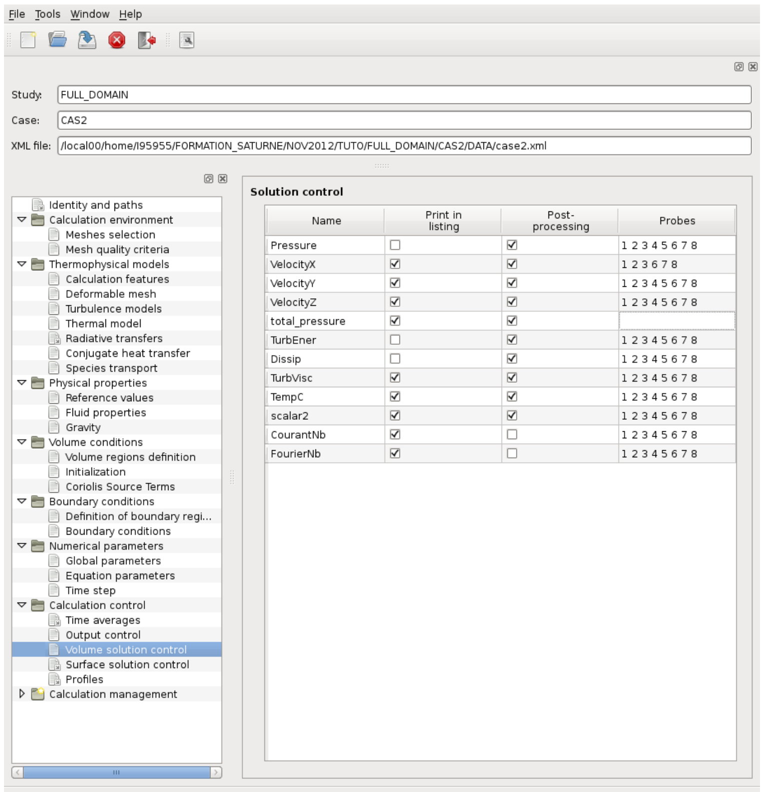


Figure III.68: Solution control - Probes

Switch to the *Calculation management* heading to prepare the launch script and run the calculation.

3 Solution for case3

Only a few elements are different from `case2`.

In this case the density becomes variable. Go to the *Fluid properties* item under the heading, *Physical properties* and change the nature of the density from `constant` to `user law`.

The user law of the density is defined as following in the *Code_Saturne* (GUI):

```
rho = TempC * ( -4.668E-03*TempC - 5.0754E-02 ) + 1000.9 ;
```

Click on the highlighted icon and define the user law in the window that pops up. Follow the format used in the *Examples* tab.

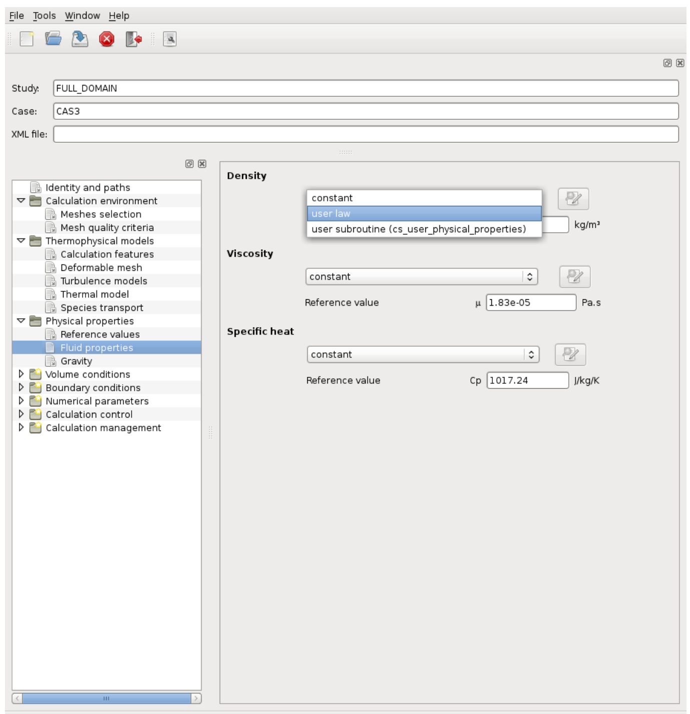


Figure III.69: Fluid properties - Variable density

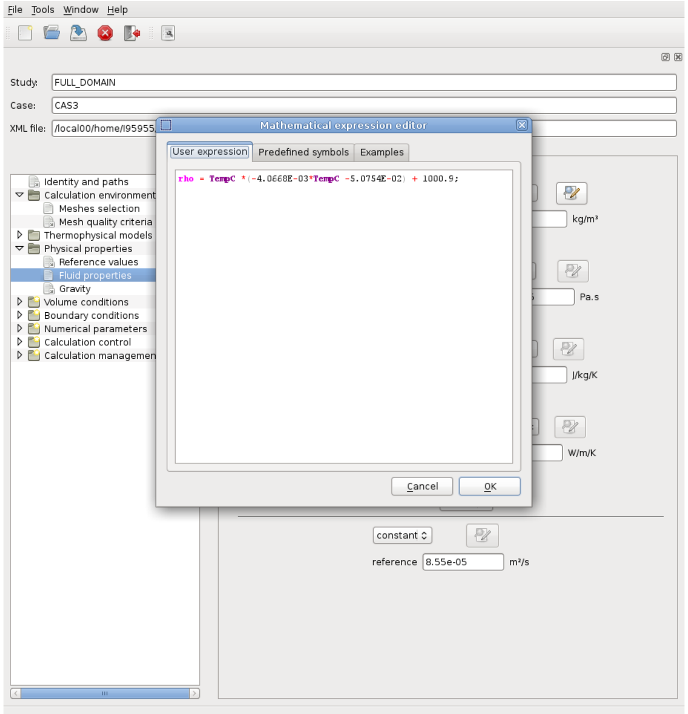


Figure III.70: Fluid properties - Variable density - User expression

As the density is variable, the influence of gravity has to be considered. In the heading *Physical properties* go to *Gravity* and set the value of each component of the gravity vector.

```
g_x = 0.0 ; g_y = -9.81 ; g_z = 0.0
```

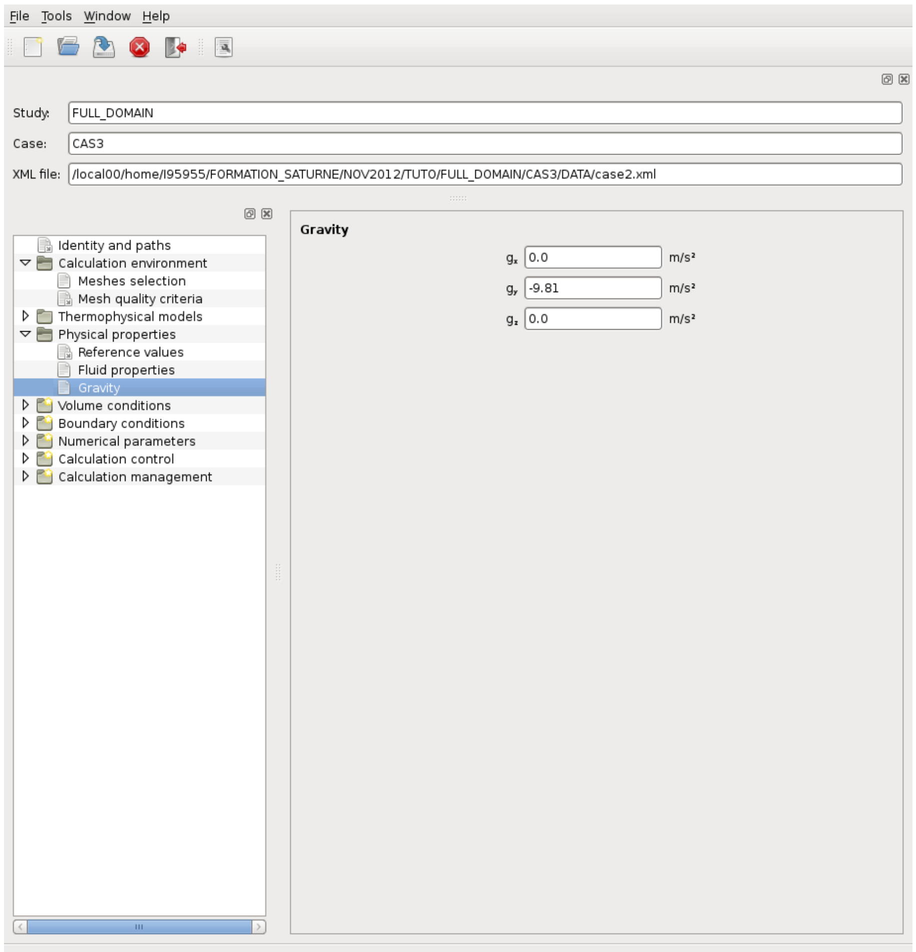


Figure III.71: Fluid properties - Gravity

Add a monitoring point close to the entry boundary condition in the *Output control* item.

Probe	x (m)	y (m)	z (m)
9	-0.5	2.25	0.0

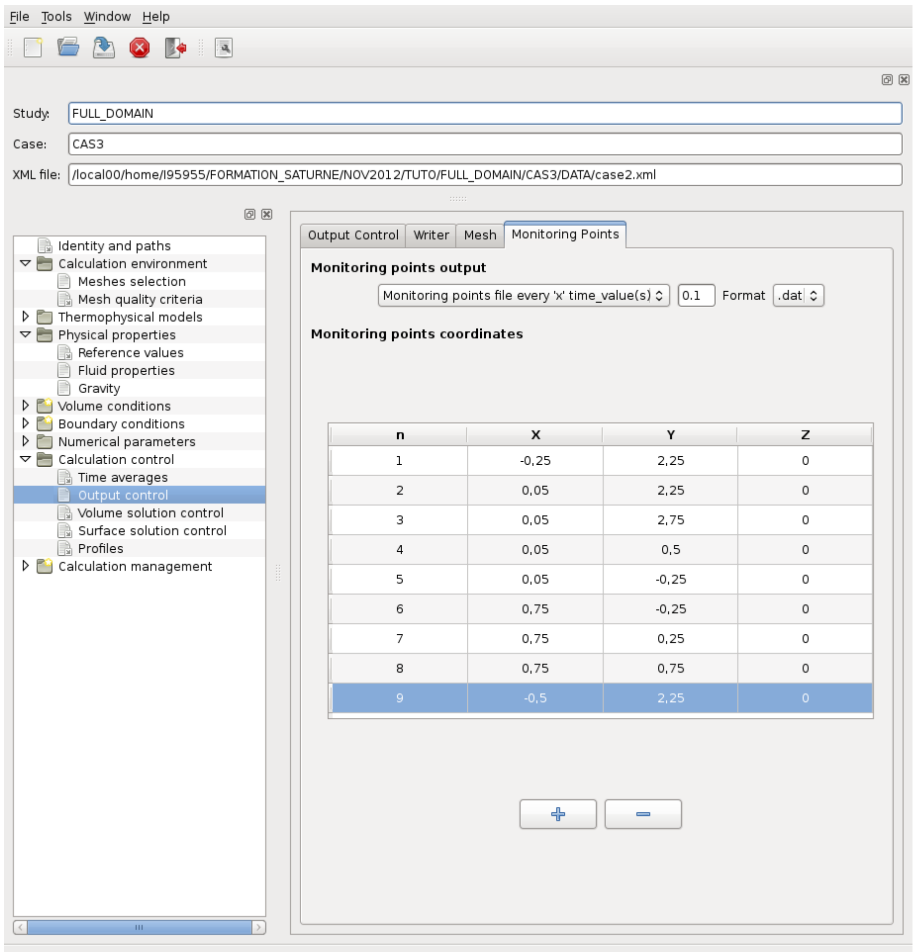


Figure III.72: New monitoring probe

After completing the interface, before running the calculation, some Fortran user routines need to be modified.

Go to the folder SRC/REFERENCE/base and copy cs_user_boundary_conditions.f90 in the SRC directory.

• `cs_user_boundary_conditions.f90`:
In this case, cs_user_boundary_conditions.f90 is used to specify the time dependent boundary condition for the temperature. Refer to the comments in the routine or to the *Code_Saturne* user manual for more information on this routine.

In our case, you need to identify the boundary faces of color **'1'**.
The command `call getfbr('1',nlelt,lstelt)` will return an integer `nlelt`, corresponding to the number of boundary faces of color 1, and an integer array `lstelt` containing the list of the `nlelt` boundary faces of color 1.

• **Remark**: Note that the string '1' **can be more complex and combine different colors, group references or geometrical criteria**, with the same syntax as in the Graphical Interface.

For each boundary face `ifac` in the list, the Dirichlet value is given in the multi-dimension array `rcodcl` as follows:

```
if (ttcabs.lt.3.8d0) then
do ielt = 1, nlelt
ifac = lstelt(ielt)
rcodcl(ifac,isca(1),1) = 20.d0 + 100.d0*ttcabs
enddo
else
do ielt = 1, nlelt
ifac = lstelt(ielt)
rcodcl(ifac,isca(1),1) = 400.d0
enddo
endif
```

`isca(1)` refers to the first scalar and ttcabs is the current physical time.

See the example `cs_user_boundary_conditions-base.f90` file in the subdirectory `SRC/EXAMPLES` to complet correctly your boundary conditions for this `case3`.

• Remark: Note that, although the inlet boundary conditions for temperature are specified in the `cs_user_boundary_conditions.f90` file, it is necessary to specify them also in the Graphical Interface.

The value given in the Interface can be anything, it will be overwritten by the Fortran routine.

After updating the Fortran file, run the calculation as explained in `case2`.

When a calculation is finished, *Code_Saturne* stores all the necessary elements to continue the computation in another execution, with total continuity. These elements are stored in several files, grouped in a `yyyymmdd-hhmm/checkpoint` subdirectory, in the `RESU` directory.

In this case, after the first calculation is finished, a second calculation will be run, starting from the results of the first one.

Go directly on the *Start/Restart* item under the heading *Calculation management*. Activate the *Calculation restart* by clicking the **"on"** box.

Then click on the folder icon next to it to specify the restart files to use.

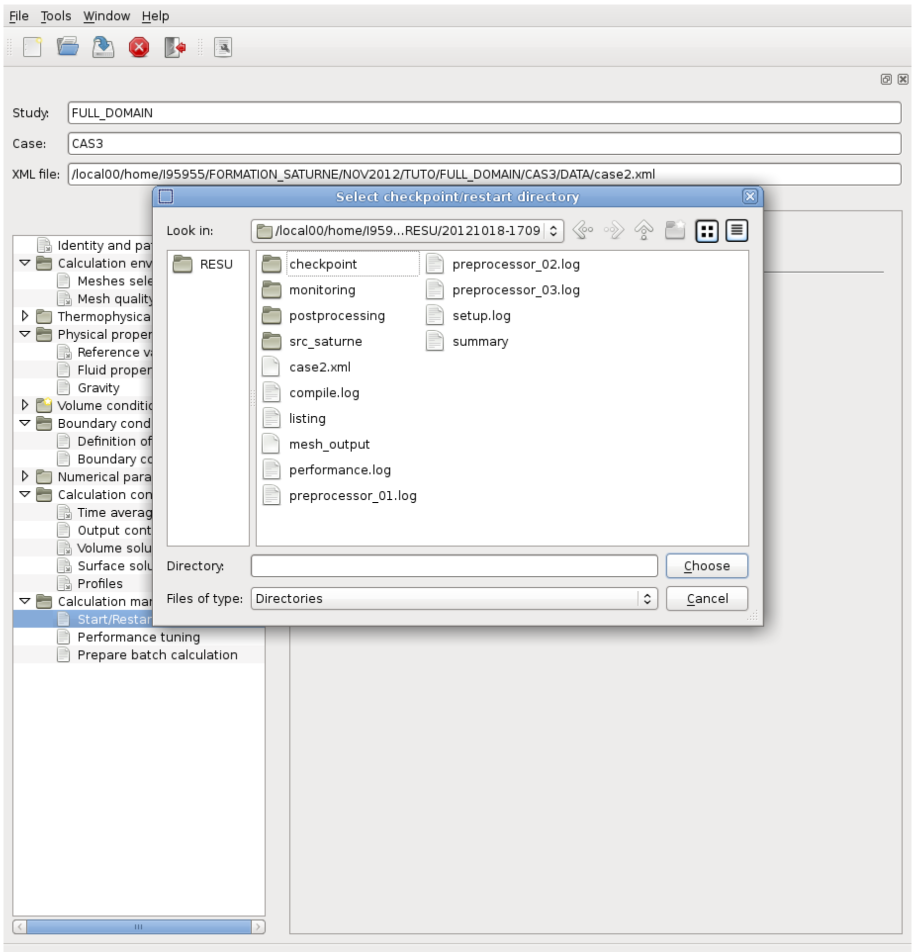


Figure III.73: Start / Restart

A window opens, with the architecture of the study sub-directories. Open the `RESU` folder and click on the folder `yyyymmdd-hhmm/checkpoint` (where `yyyymmdd-hhmm` corresponds to the reference of the first calculation results). Then click on *Validate*.

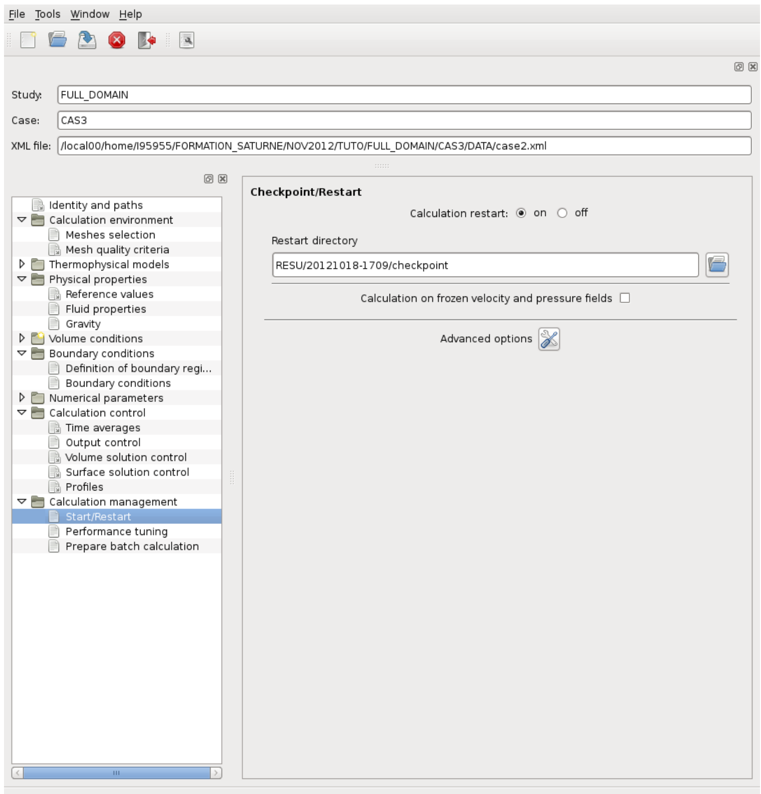


Figure III.74: Start / Restart - Selection of the restart directory

Go to the *Time step* item under the heading *Numerical parameters* and change the number of iterations. It must be the total number of iterations, from the beginning of the first calculation.

The first calculation was done with 300 iterations and another 400 iterations are needed for the present case. Therefore the value 700 must be entered.

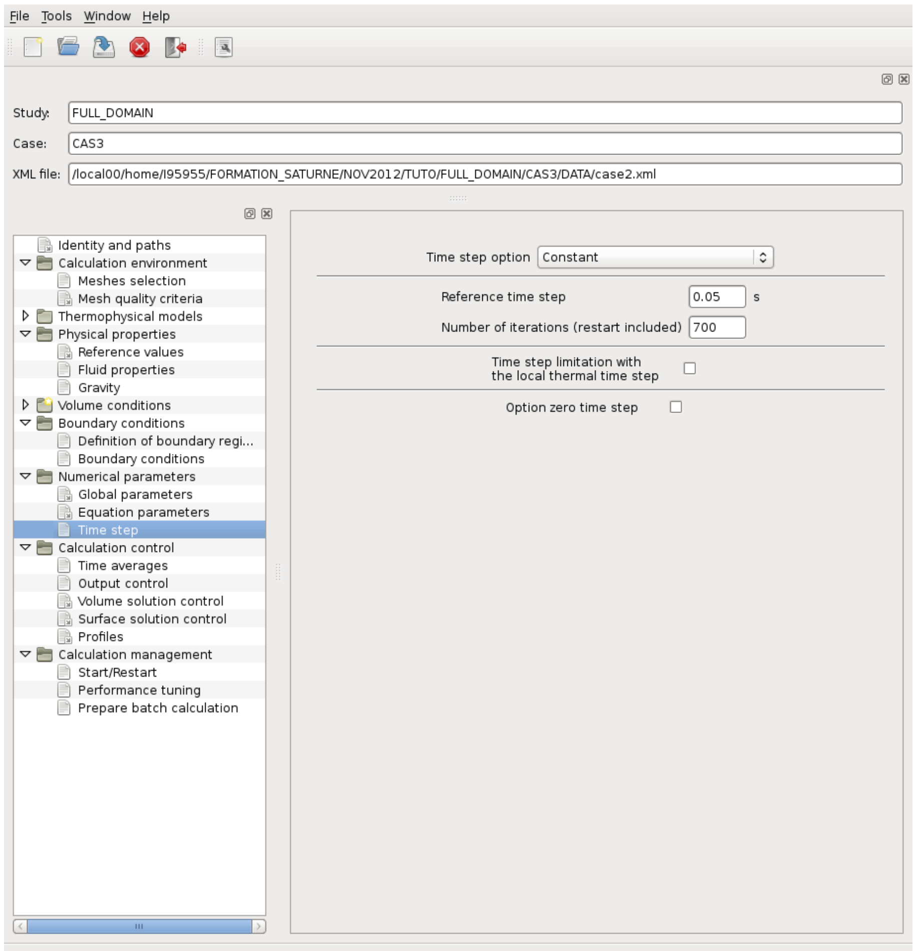


Figure III.75: Time step

Eventually, run the calculation.

4 Solution for case4

This case is similar to `case3`, with the following differences:

- **Step 1**: define head losses in the fluid domain,
- **Step 2**: compute the spatial average of temperature scalar,
- **Step 3**: parallel computation on 2 processors,
- **Step 4**: dealing with a user results file.

• **Step 1-1**: Define the head losses in the Graphical User Interface (GUI).
Go to *Volume regions definition* under the heading *Volume conditions*. Click on **"Add"**, unselect "Initialization" and select **"Head losses"** in the box named *Nature*. In the box named *Label*, name the head losses region.
Define the limits of the head losses region in *Selection criteria*. The associated character string to enter is as below:

``$0.2 <= x$ `and` $0.4 >= x$ `and` $-0.75 <= y$ `and` $-0.25 >= y$''

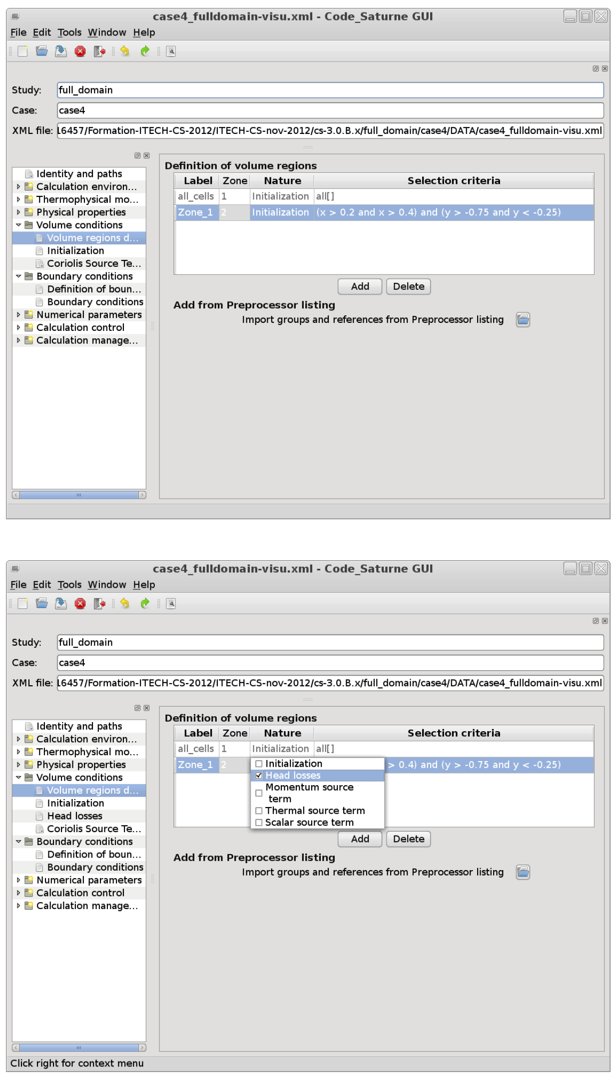


Figure III.76: Creation of head losses region

• **Step 1-2**: Specify the head losses coefficients α_{ii}.
To specify the head losses coefficients go to the *Head losses* item and select the name of the head losses volume region. In this example, the coefficient is isotropic so that we use the same value for each α_{ii}. Please note that $\alpha_{ii} = 2 \times K_{ii}$, therefore if $K_{ii} = 10^4$, $\alpha_{ii} = 2\ 10^4$.

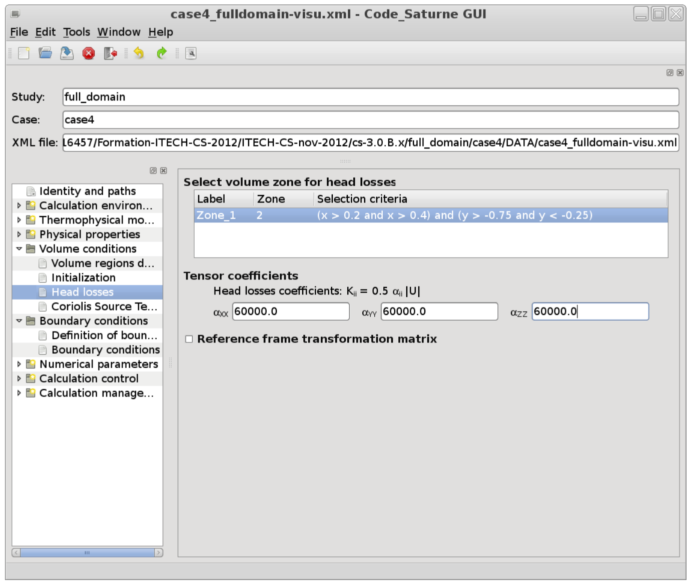


Figure III.77: Head losses coefficients

• **Step 2**: compute the spatial average of temperature **TempC**
The computation of the spatial average is done in the `cs_user_extra_operations.f90` routine.

• Remark: Refer to the example files in the subdirectory `SRC/EXAMPLES` which names are:

```
cs_user_extra_operations-energy_balance.f90
cs_user_extra_operations-extract_1d_profile.f90
cs_user_extra_operations-force_temperature.f90
cs_user_extra_operations-global_efforts.f90
cs_user_extra_operations-parallel_operations.f90
cs_user_extra_operations-print_statistical_moment.f90
```

To correctly complet your `cs_user_extra_operations.f90` routine (copied in the `SRC` directory), you can use mainly these examples files: `cs_user_extra_operations-print_statistical_moment.f90` and `cs_user_extra_operations-extract_1d_profile.f90`.

• **Step 3**: choose a computation with 2 processors
This modification will be done in the *Prepare batch analysis* item.
To run the calculation on two processors, simply change the number of processors indicator to 2. The launch script will automatically deal with the rest.

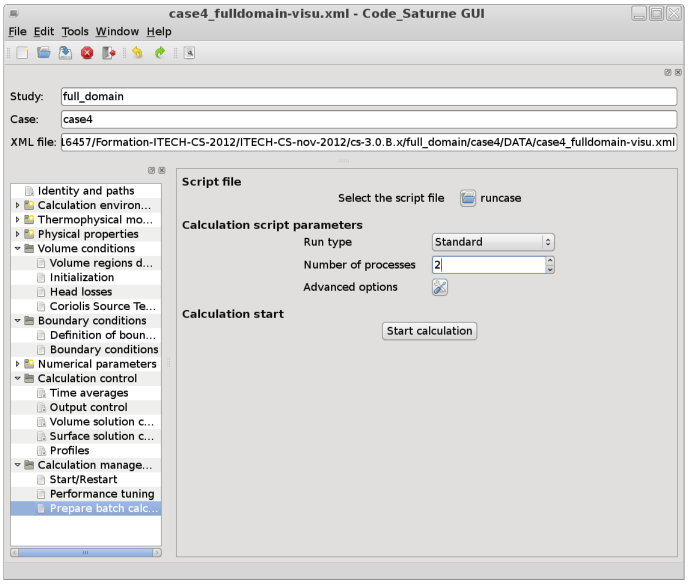


Figure III.78: Number of processors

• **Step 4**: dealing with a user results file **"moy.dat"**
The new user file "moy.dat" created by `cs_user_extra_operations.f90` will be written directly in the `yyyymmdd-hhmm` results subdirectory created at the end of the computation in the `RESU` directory.

• Remark : We do not have to specify the name of the new user file in the Graphical User Interface (GUI), like in previous *Code_Saturne* versions.
The name of the new user file had to be identified in the launch script in order to be automatically copied in the `RESU` directory, this is not requested.

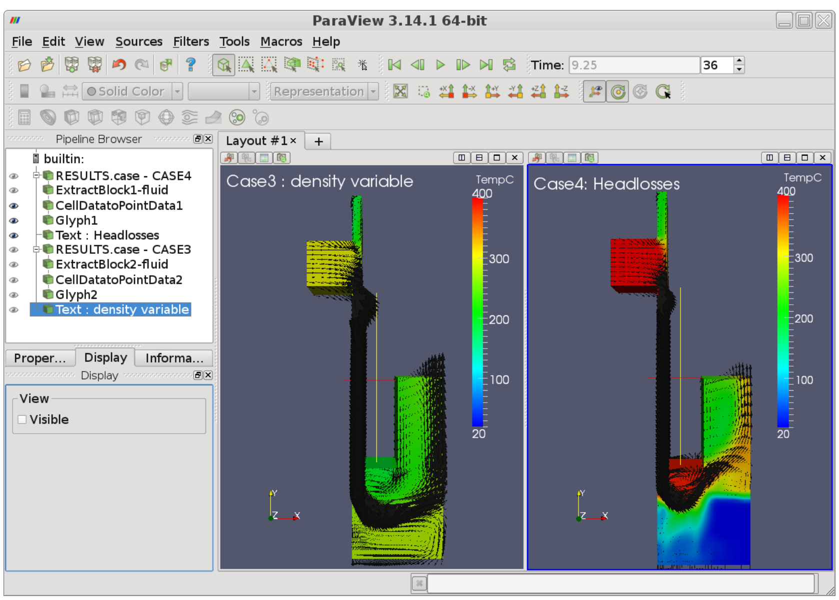


Figure III.79: User results files