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Code_Saturne version 1.3.2 tutorial

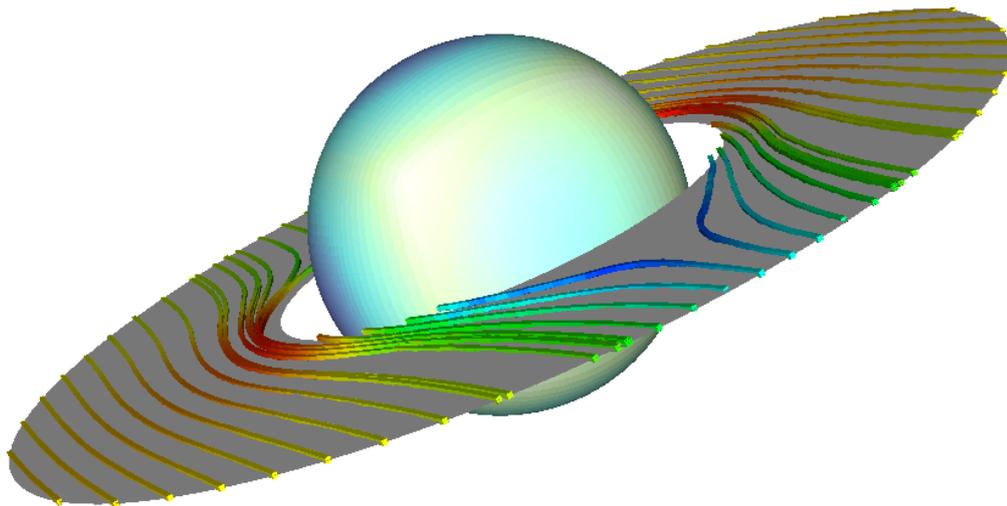


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Part I

STRATIFIED JUNCTION

1 Introduction

Code_Saturne is a system designed to solve the Navier-Stokes equations in the cases of 2D, 2D axisymmetric or 3D flows. Its main module is designed for the simulation of flows which may be steady or unsteady, laminar or turbulent, incompressible or potentially dilatible, isothermal or not. Scalars and turbulent fluctuations of scalars can be taken into account. The code includes specific modules, referred to as “specific physics”, for the treatment of Lagrangian particle tracking, semi-transparent radiative transfer, gas, pulverized coal and heavy fuel oil combustion, electricity effects (Joule effect and electric arcs) and compressible flows. The code also includes an engineering module, Matisse, for the simulation of nuclear waste surface storage.

Code_Saturne relies on a finite volume discretization and allows the use of various mesh types which may be hybrid (containing several kinds of elements) and may have structural non-conformities (hanging nodes).

The present document is a tutorial for *Code_Saturne* version 1.3.2. It presents one simple test case and guides the future *Code_Saturne* user step by step into the preparation and the computation of the case.

The test case directories, containing the necessary meshes and data are available in the *Code_Saturne* Kernel directory:

```
$CS_HOME/doc/TUTORIAL/TEST_CASES/STRATIFIED_PIPE
```

This tutorial focuses on the procedure and the preparation of the *Code_Saturne* computations. For more elements on the structure of the code and the definition of the different variables, it is highly recommended to refer to the user manual (type `info_cs user` at the prompt).

This tutorial is divided in two parts. First a brief description of the test case is done and in the second part, a step by step solution using the Graphical Interface is done.

In this tutorial, the open source post-processing program *ParaView* is used as well as a 2D plotting software *Grace*. See their websites for more info. (<http://www.paraview.org> and <http://plasma-gate.weizmann.ac.il/Grace/>)

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2 General Description

2.1 Objective

The aim of this case is to train the user of *Code_Saturne* on a simplified but real 3D computation. It corresponds to a stratified flow in a T-junction.

2.2 Description of the configuration

The configuration is based on a real mock-up designed to characterize thermal stratification phenomena and associated fluctuations. The geometry is shown on figure I.1.

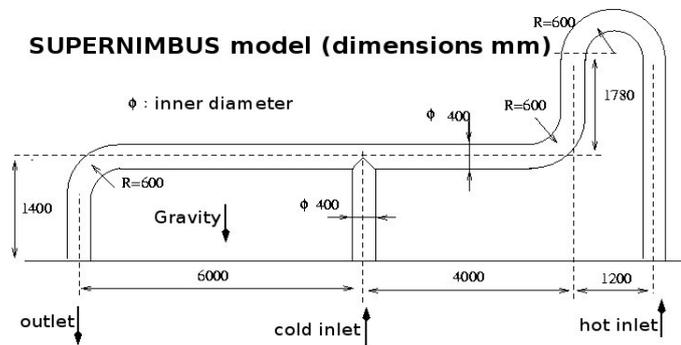


Figure I.1: Geometry of the case

There are two inlets, a hot one in the main pipe and a cold one in the vertical nozzle. The volumic flow rate is identical in both inlets. It is chosen small enough so that gravity effects are important with respect to inertia forces. Therefore cold water creeps backwards from the nozzle towards the elbow until the flow reaches a stable stratified state.

2.3 Characteristics

Characteristics of the geometry:

Diameter of the pipe	$D_b = 0.40 \text{ m}$
----------------------	------------------------

Characteristics of flow:

Cold branch volume flow rate	$Dv_{cb} = 4 \text{ l.m}^{-1}$
Hot branch volume flow rate	$Dv_{hb} = 4 \text{ l.m}^{-1}$
Cold branch temperature	$T_{cb} = 18.26^\circ\text{C}$
Hot branch temperature	$T_{hb} = 38.5^\circ\text{C}$

The initial water temperature in the domain is equal to 38.5°C.

Water specific heat and thermal conductivity are considered constant and calculated at 18.26°C and 10^5 Pa:

- heat capacity: $C_p = 4,182.88 \text{ J.kg}^{-1}.\text{°C}^{-1}$
- thermal conductivity: $\lambda = 0.601498 \text{ W.m}^{-1}.\text{°C}^{-1}$

The water density and dynamic viscosity are variable with the temperature. The functions are given below.

2.4 Mesh characteristics

The mesh used in the actual study had 125 000 elements. It has been coarsened for this example in order for calculations to run faster. The mesh used here contains 16 320 elements.

Type: unstructured mesh

Coordinates system: cartesian, origin on the middle of the horizontal pipe at the intersection with the nozzle.

Mesh generator used: SIMAIL

Color definition: see figure I.2.

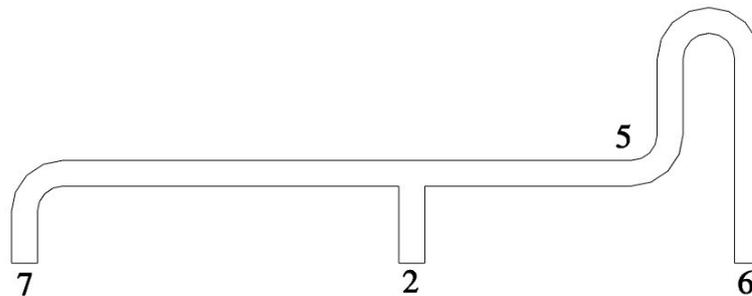


Figure I.2: Colors of the boundary faces

2.5 Calculation options

The following options are considered for the case:

- Flow type: unsteady flow
- Time step: variable in time and uniform in space
- Turbulence model: $k - \epsilon$

Colors	Conditions
2	Cold inlet
6	Hot inlet
7	Outlet
5	Wall

Table I.1: Boundary faces colors and associated references

- Scalar(s): temperature
- Physical properties: uniform and constant for specific heat and thermal conductivity and variable for density and dynamic viscosity
- Specific treatment of hydrostatic pressure: activated
- Time step limitation by gravity effects

2.6 Initial and boundary conditions

- Initialization: temperature initialization at 38.5°C

The boundary conditions are defined as follows:

- **Flow inlet:** Dirichlet condition
 - velocity of 0.03183 $m.s^{-1}$ for both inlets
 - temperature of 38.5°C for the hot inlet
 - temperature of 18.6°C for the cold inlet
- **Outlet:** default value
- **Walls:** default value

Figure I.2 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.

2.7 Parameters

All the parameter necessary to this study can be defined through the Graphical Interface, except the variable fluid characteristics that have to be specified in user routines.

Parameters of calculation control	
Number of iterations	100
Reference time step	1 s
Maximal CFL number	20
Maximal Fourier number	60
Minimal time step	0.01 s
Maximal time step	70 s
Time step maximal variation	0.1
Period of output chronological files	10

2.8 Output management

The standard options for output management will be used. Four monitoring points will be created at the following coordinates:

Points	X(m)	Y(m)	Z(m)
1	0.010025	0.01534	-0.011765
2	1.625	0.01534	-0.031652
3	3.225	0.01534	-0.031652
4	3.8726	0.047481	7.25

2.9 User routines

The following routines have to be copied from the folder FORT/USER/base into the folder FORT¹:

- **usphyv.F**

This routine allows to specify variable physical properties, density and viscosity in particular. In this case, the following variation laws are specified:

$$\rho = T.(A.T + B) + C \quad (\text{I.1})$$

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1000.9$

For the dynamic viscosity, the variation law is:

$$\mu = T.(T.(AM.T + BM) + CM) + DM \quad (\text{I.2})$$

where μ is the dynamic viscosity, T is the temperature, $AM = -3.4016 \times 10^{-9}$, $BM = 6.2332 \times 10^{-7}$, $CM = -4.5577 \times 10^{-5}$ and $DM = 1.6935 \times 10^{-3}$

¹only when they appear in the FORT directory will they be taken into account by the code

Note: in the user routines, the examples are protected by a test to prevent any undesired use. Do not forget to deactivate them.

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.

2.10 Results

Figure I.3 shows the evolution of the temperature in the domain at different time steps. The evolution of the stratification is clearly visible.

Figure I.4 shows the cells where the temperature is lower than 21°C. It is not an isosurface created from the full domain, but a visualization of the full sub-domain created through the post-processing routines.

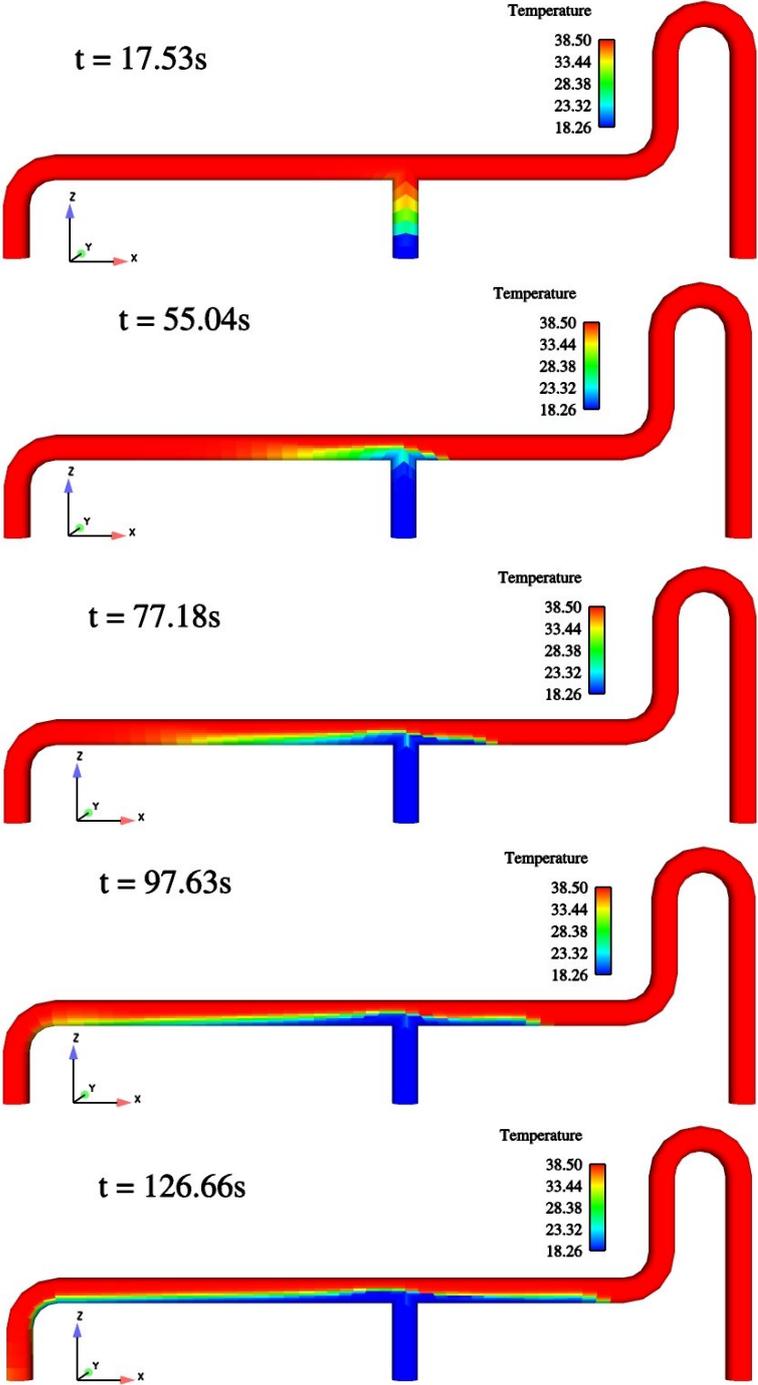


Figure I.3: Evolution of temperature

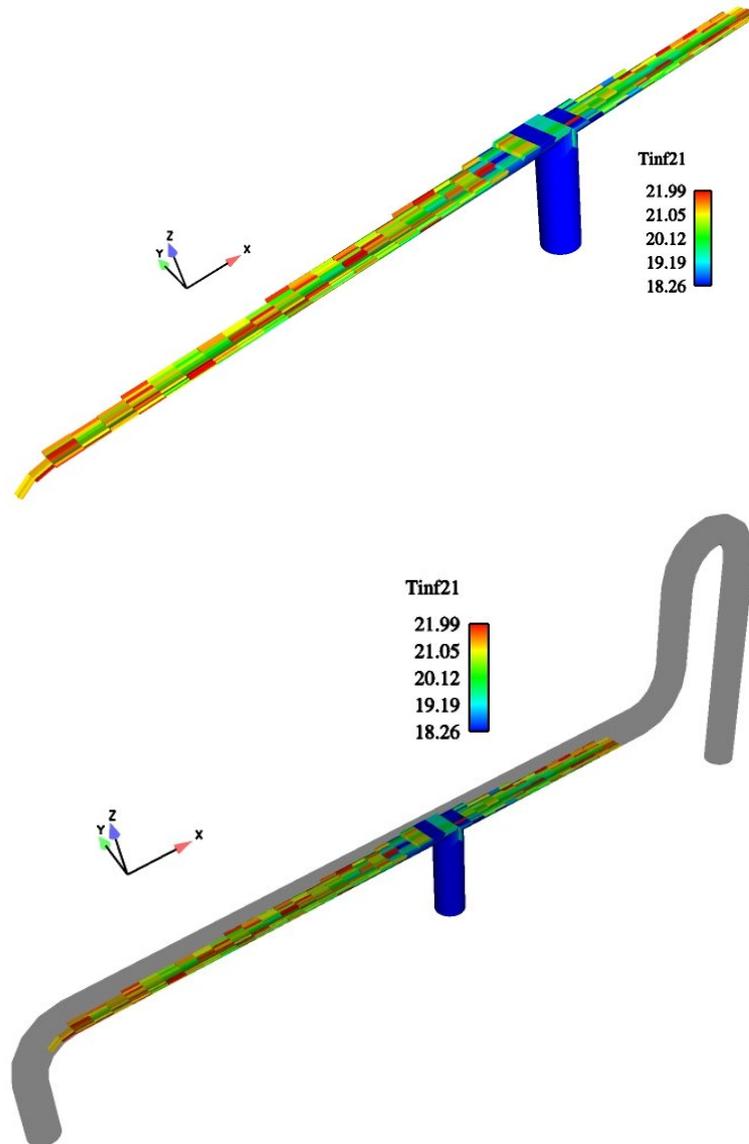


Figure I.4: Sub-domain where the temperature is lower than 21°C (upper figure) and localization in the full domain (lower figure)

3 Step by step solution

Before starting the Graphical Interface on *Code_Saturne*, it is necessary to create the appropriate file structure for the code to work.

In order to allow all the scripts of *Code_Saturne* to work properly, you will need to execute a script to load all the environmental variables needed. Open a console and type:

(**Note:** [bash:\$] in this document represents the prompt. It might be different depending on your GNU-Linux installation and your profile file. There is no need to type this)

```
[bash:$] . /usr/local/Code_Saturne_1.3.2/Noyau/ncs-1.3.2/bin/cs_profile
```

This will load all the variables required (Note the dot (.) at the beginning of the command line).

If everything went ok, you will now have an environmental variable called `CS_HOME`. To see the value of this variable, type:

```
[bash:$] echo $CS_HOME
```

The output should be the path where the *Code_Saturne* installation is located.

Now that you have your `PATH` updated, you can use the case creator script. Go to the desired location on your directory and type:

```
[bash:$] cree_sat -etude STRATIFIED_JUNCTION K_EPS
```

This command will create a study called `STRATIFIED_JUNCTION` and a case called `K_EPS`. The file structure can be seen in figure [I.5](#)

The details of the structure are:

- `K_EPS`: This is the case file, a study can have several cases, for example different turbulence models, different boundary conditions etc.
 - `DATA`: This is where the restarting files need to be copied, it also contains the script to launch the Graphical Interface `SaturneGUI`.
 - `FORT`: This is where the user subroutines are going to be saved. During the compilation stage, the code will re-compile all the subroutines that are in this directory. In the `USERS` directory all the user-defined subroutines are stored. For a specific case you will only need a few of them depending on the changes that you want to implement on the code. The `base` directory contains the basic flow solver subroutines, the other directories contain the subroutines needed by other modules such

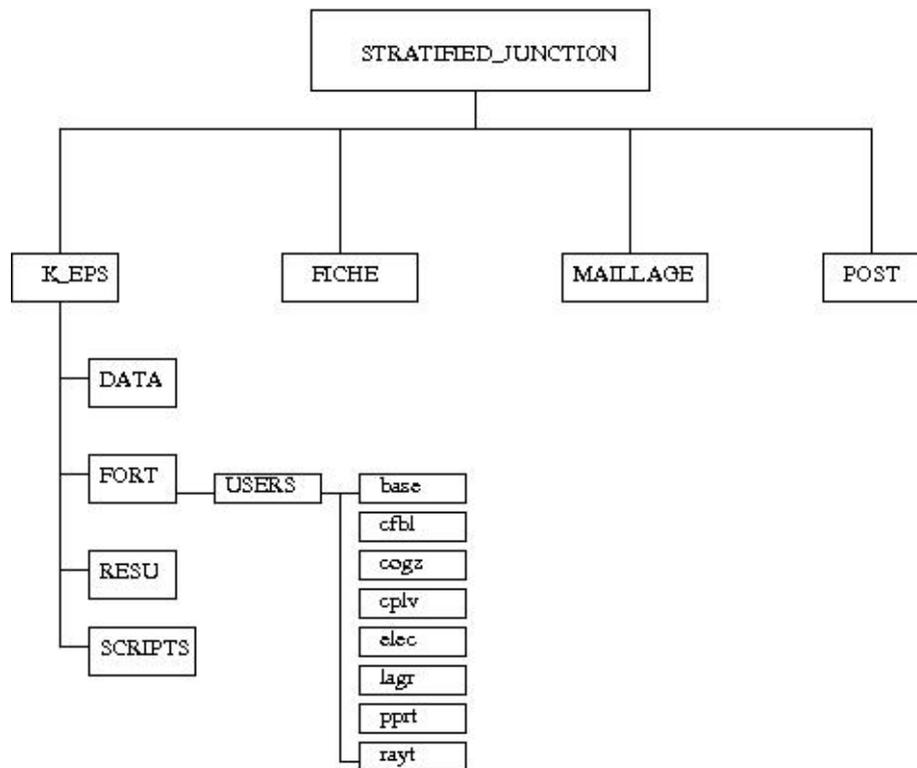


Figure I.5: File structure created by *Code_Saturne*

as the Lagrangian, the combustion or the electric modules. For more information on the other modules please see the "Practical user guide to *Code_Saturne*" (you can get it by typing `info_cs user`).

- RESU: Directory where the results will be exported once the calculation has finished.
- SCRIPTS: Here is were the launching scripts are copied. You will need to run the executable file *lance* to start the calculation.
- MAILLAGE: The program will read the mesh from this directory. The mesh formats that can be read are I-DEAS, CGNS, Gambit Neutral files (neu), Ensigth, prostar/STAR4 (ngeom), Gmsh, NUMECA Hex, MED, Simail and Meta-mesh files.
- POST: This is an empty directory designed to contain post-processing macros (xmgrace, experimental etc.)

You will need to copy the mesh into the MAILLAGE directory. The mesh can be found in the installation of *Code_Saturne*. At the prompt of the console type:

```
[bash:$] cd STRATIFIED_JUNCTION/MAILLAGE
[bash:$] cp $CS_HOME/doc/TUTORIAL/TEST_CASES/STRATIFIED_JUNCTION/MAILLAGE/sn_total.des .
```

(Note the dot (.) at the end of the line).

Now, you can use the graphical interface of *Code_Saturne* to complete the case set up. To launch the graphical interface go to the DATA directory and launch the *SaturneGUI* script by typing:

```
[bash:$] cd ../K_EPS/DATA
```

```
[bash:$] ./SaturneGUI &
```

Once the Graphical Interface is up and running, create a new case (File - Open New) and the values of *Identity and paths* should be filled automatically. Click on the Solution Domain and the mesh should appear selected as *sn_total.des*.

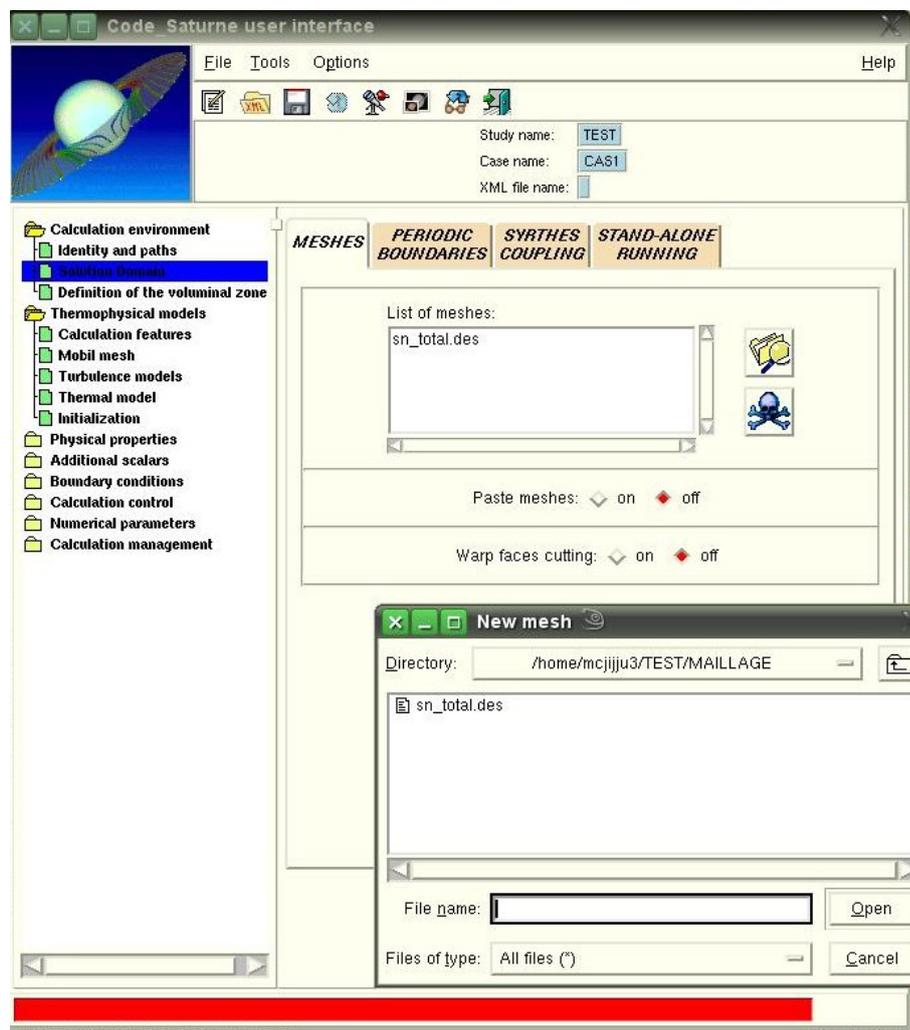


Figure I.6: Mesh Selection

All the default parameters under *Calculation environment* are correct for this case so there is no need to change them. Next go to *Thermophysical models* and under *Turbulence models* select $k - \varepsilon$

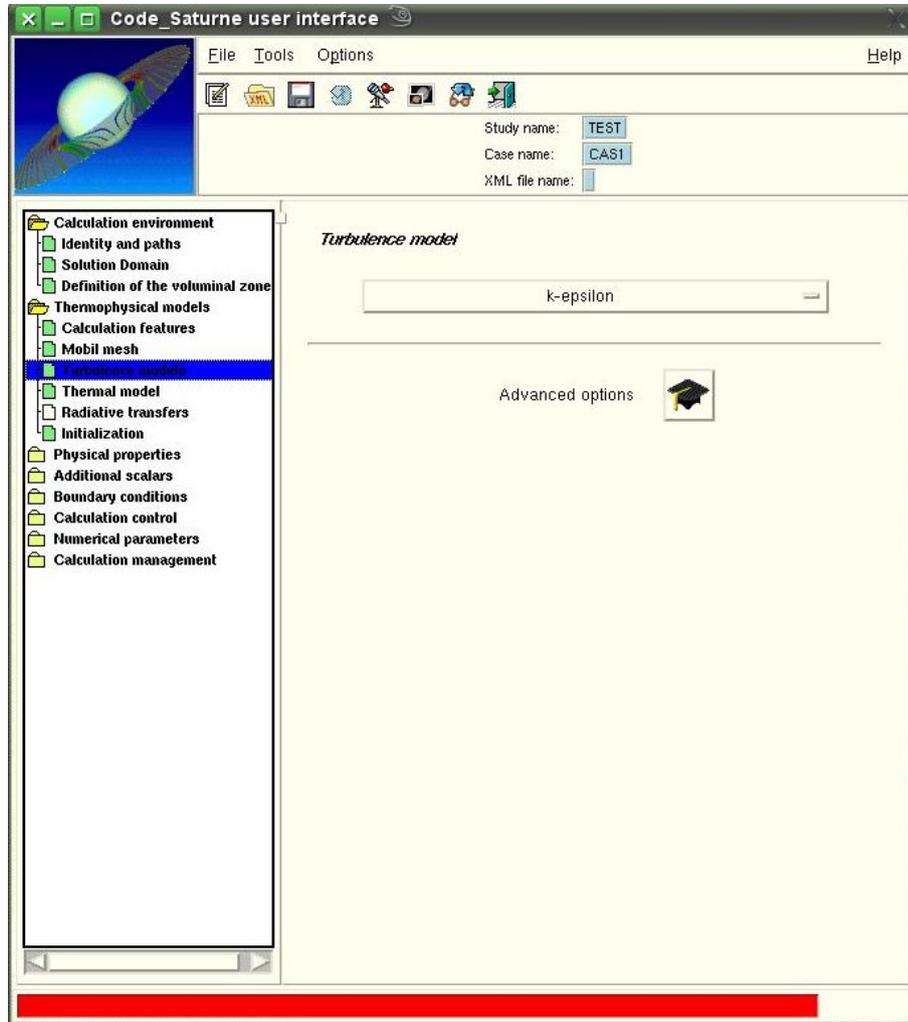


Figure I.7: Turbulence model selection

Since the density and viscosity vary with the temperature, we need to activate the temperature computation. Go to *Thermal model* and select *Temperature (Celsius degrees)*.

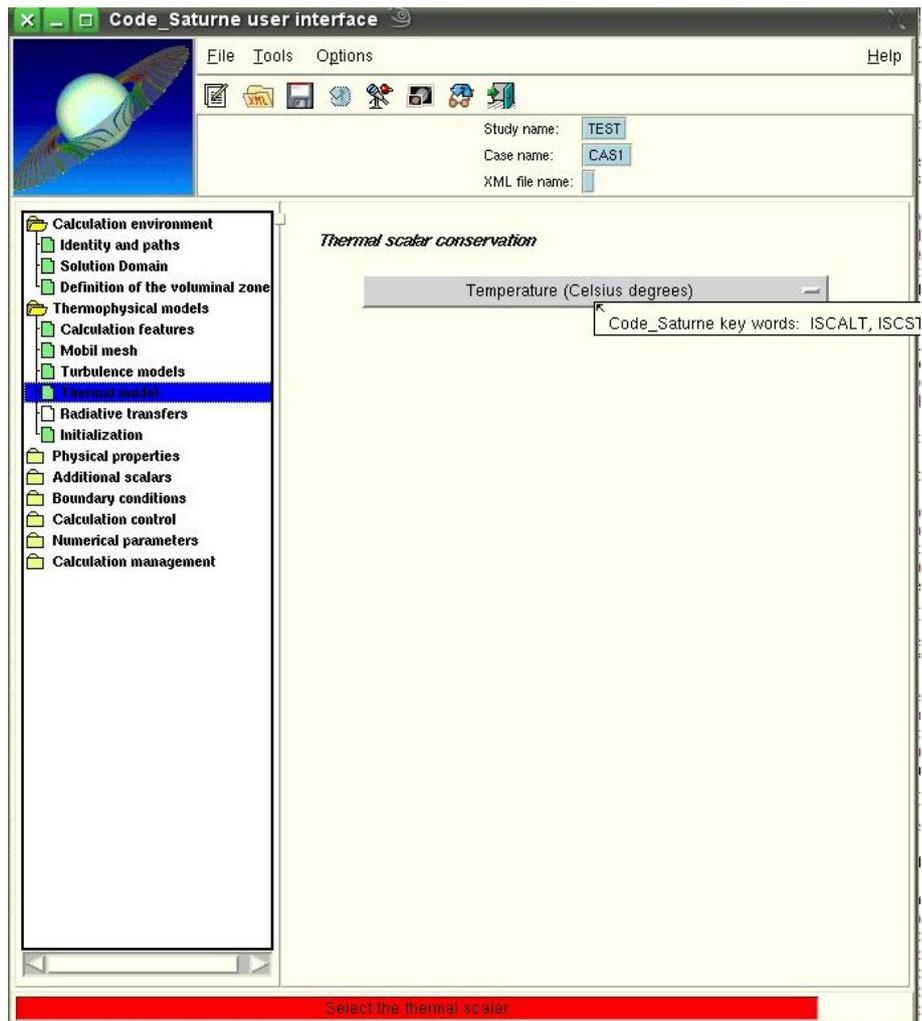


Figure I.8: Temperature activation.

In the item *Initialization*, set the initial value of the temperature in the domain to 38.5°C . Initialize the turbulence with the reference velocity $0.03183 \text{ m}\cdot\text{s}^{-1}$.

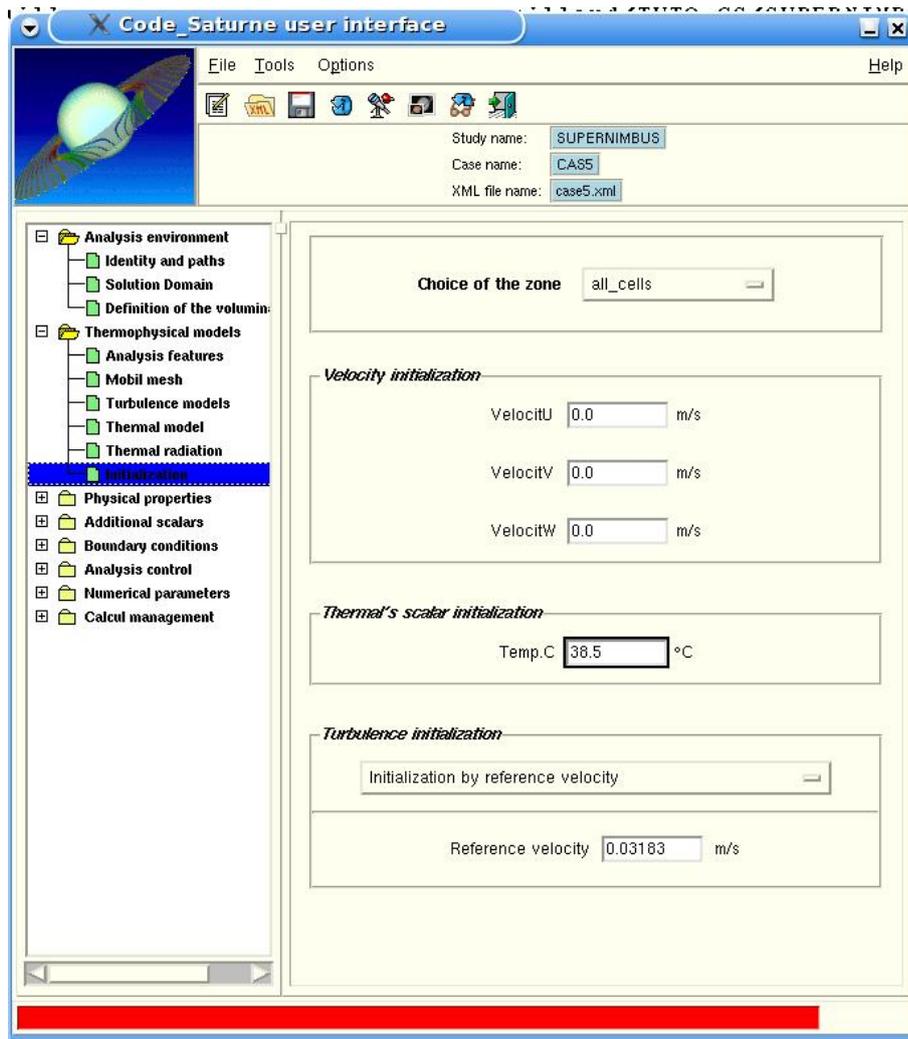


Figure I.9: Thermophysical models - Initialization

In the item *Fluid properties*, under the heading *Physical properties*, enter the following information:

Variable	Type	Value
Density	Variable	$998.671 \text{ kg.m}^{-3}$
Viscosity	Variable	$0.445 \times 10^{-4} \text{ kg.m}^{-1}.s^{-1}$
Specific Heat	Constant	$4182.88 \text{ J.kg}^{-1}.\text{°C}^{-1}$
Thermal Conductivity	Constant	$0.601498 \text{ W.m}^{-1}.K^{-1}$

For density and viscosity, the value given here will serve as a reference value (see user manual for details). Make sure that the density and viscosity are set as **variable** so that they are dependant on the temperature.

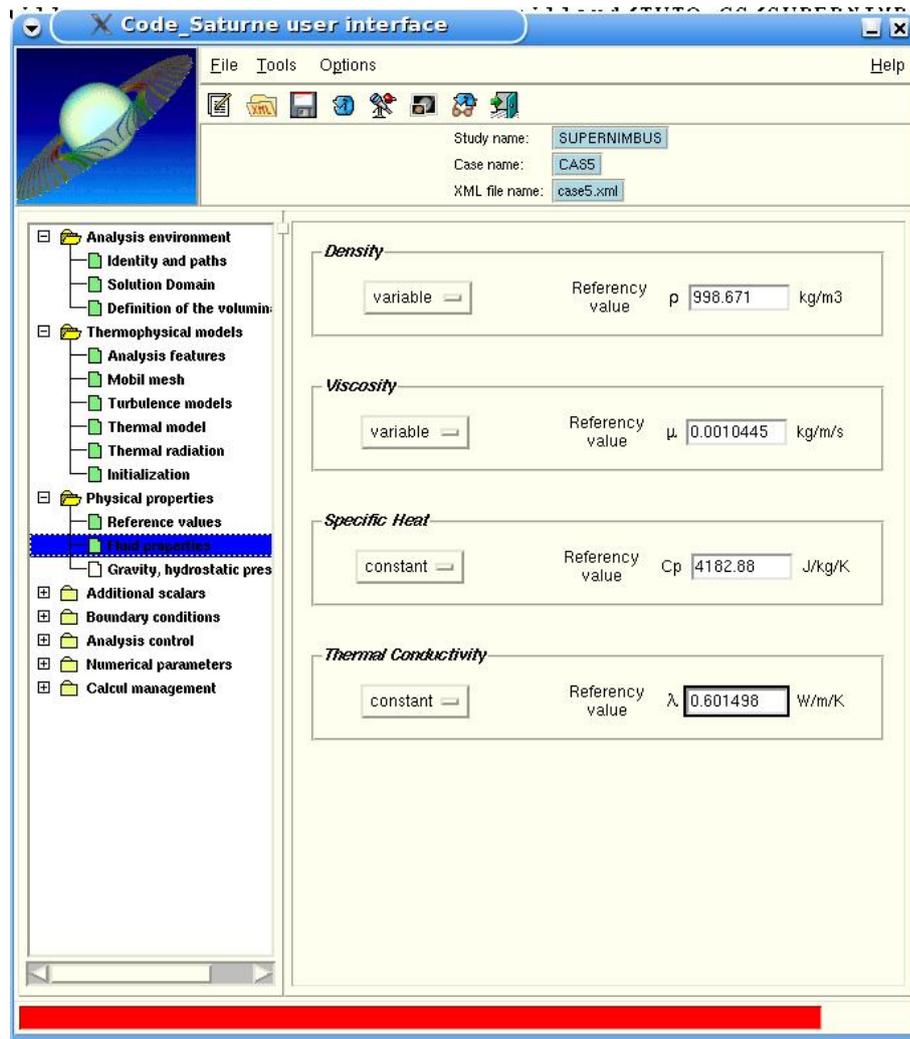


Figure I.10: Physical properties: fluid properties

The aim of the calculation is to simulate a stratified flow. It is therefore necessary to have gravity. Set it to the right value in the item *Gravity, hydrostatic pressure*. In order to have a sharper stratification, the pressure interpolation method will be set to *improved*.

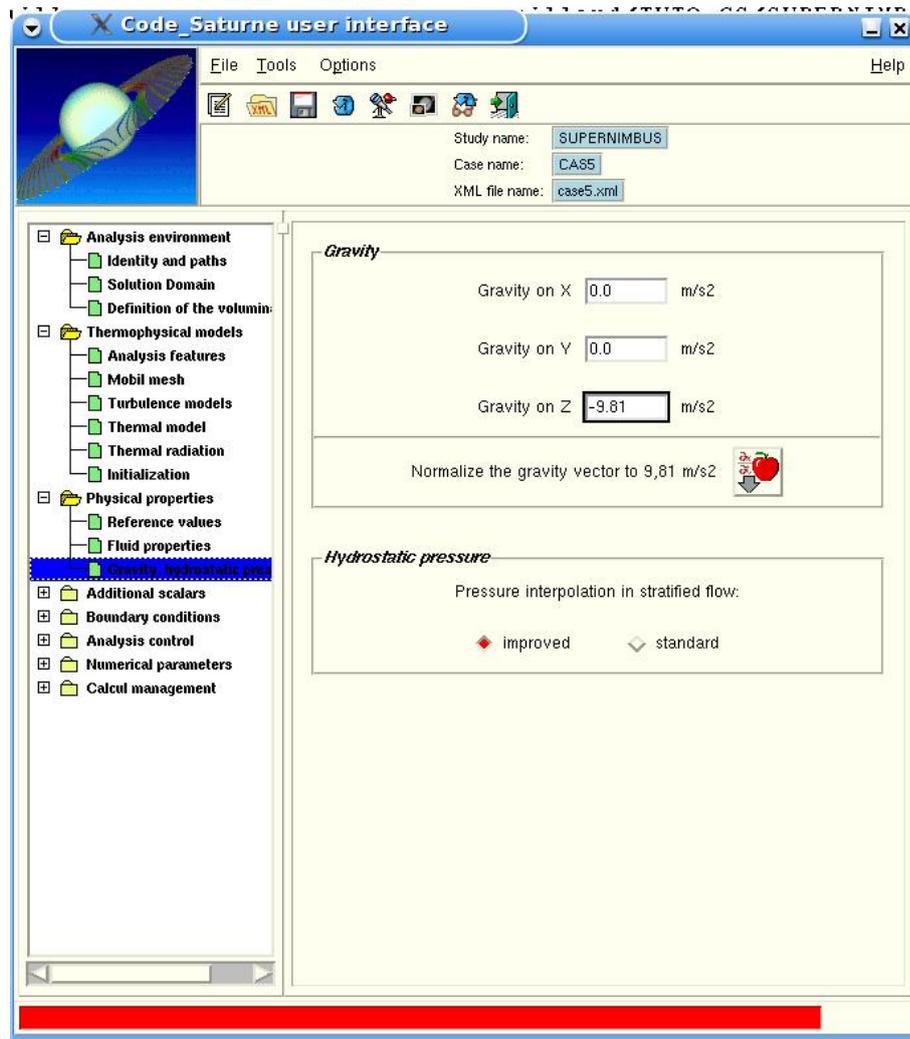


Figure I.11: Fluid properties - Gravity

Go to the item *Definition and initialization* under the heading *Additional scalars* to specify the minimal and maximal values for the temperature: 18.26°C and 38.5°C. Note that the initial value of 38.5°C set earlier is properly taken into account.

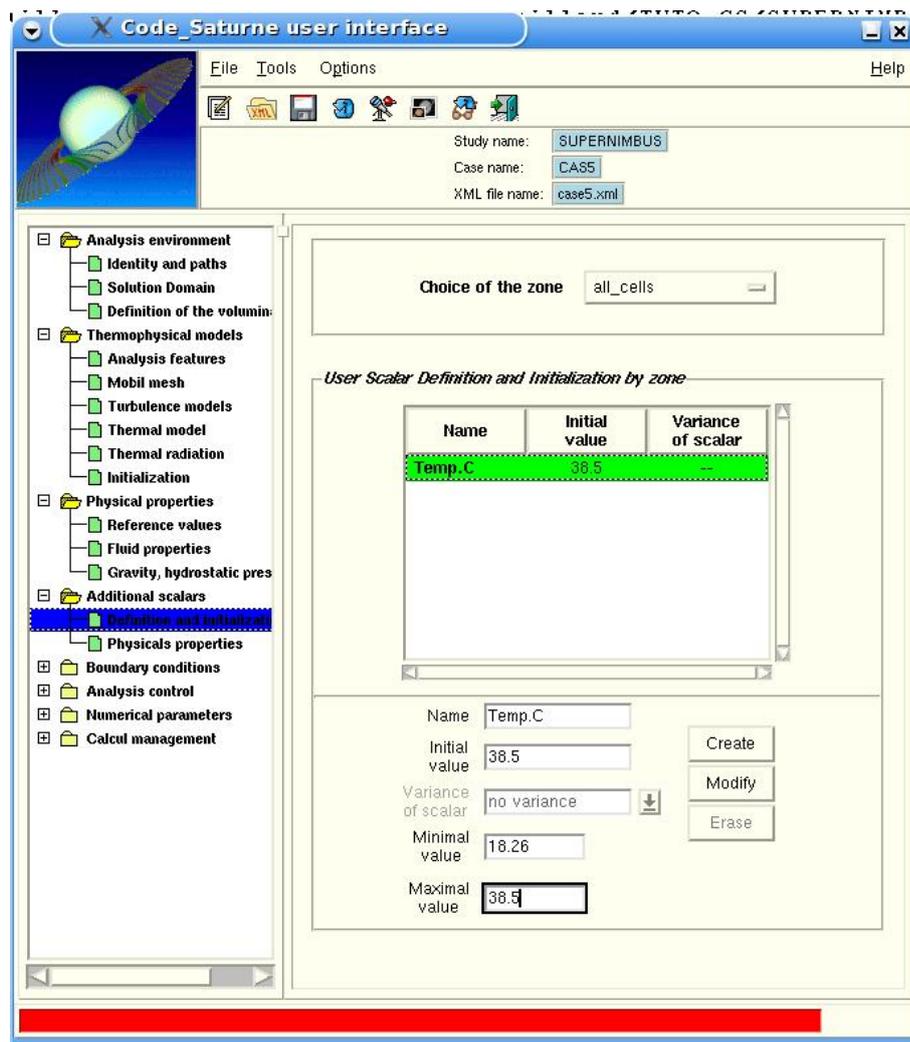


Figure I.12: Scalar initialization

Create the boundary regions.

Colors	Conditions
2	inlet
6	inlet
7	outlet
5	wall

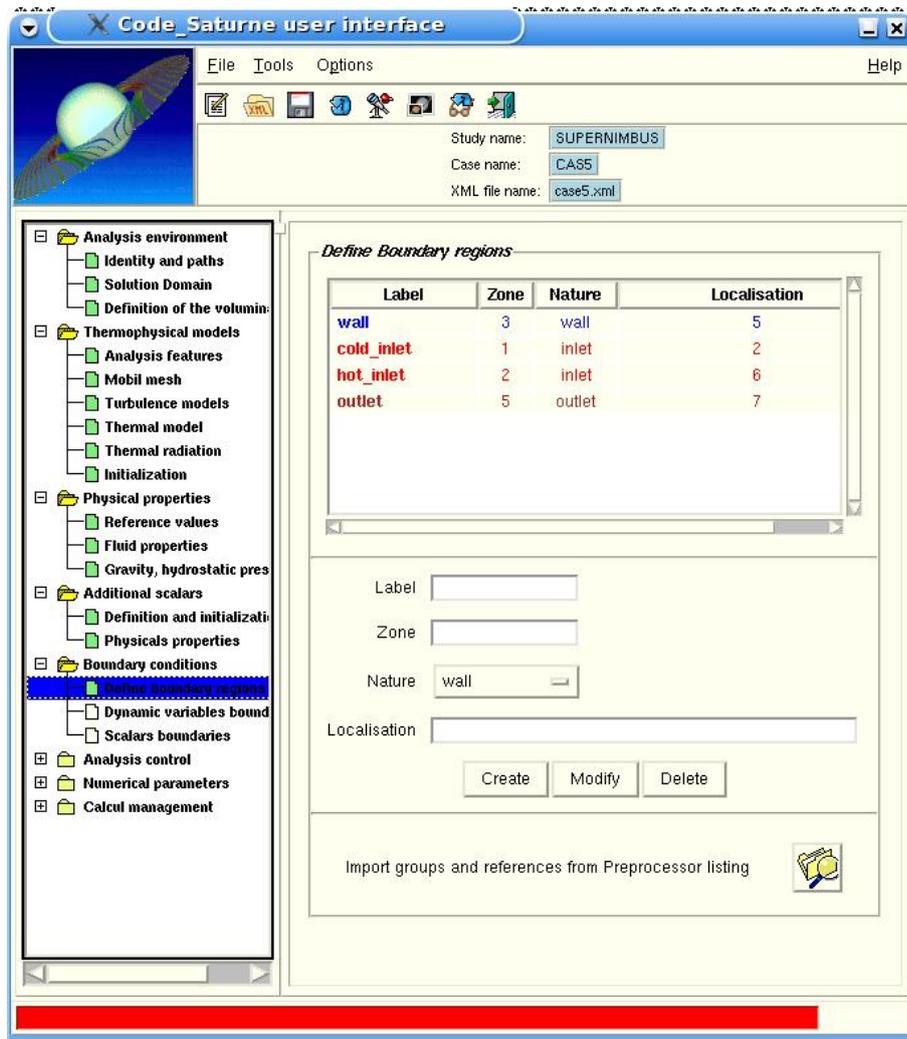


Figure I.13: Boundary regions

For the dynamic boundary conditions, the velocity is 0.03183 m.s^{-1} in the z direction and the hydraulic diameter 0.4 m for both inlets.

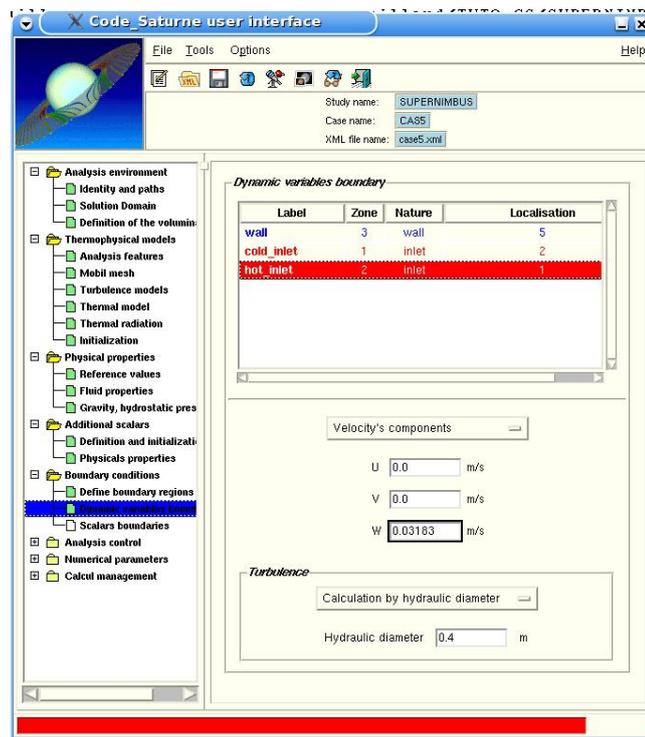
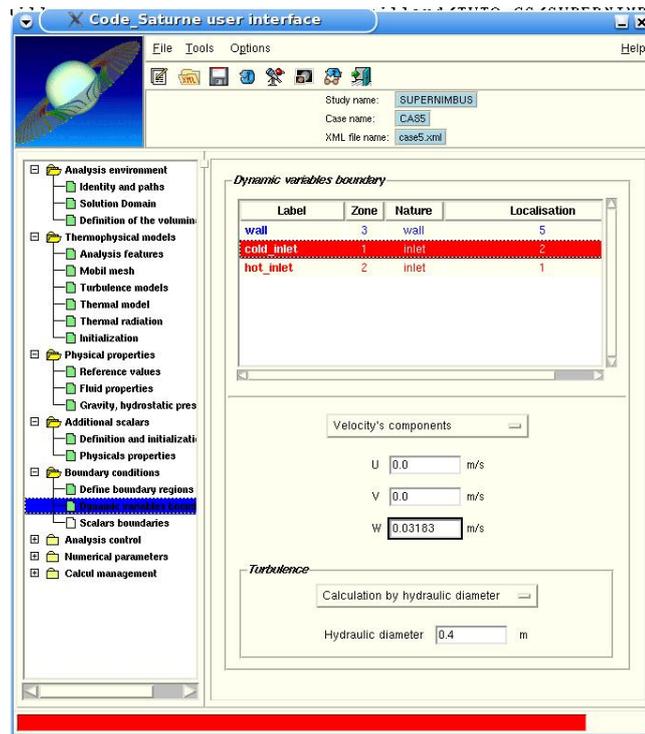


Figure I.14: Dynamic boundary conditions

For the scalar boundary conditions, the temperature of the cold inlet is 18.6°C and that of the hot inlet is 38.5°C.

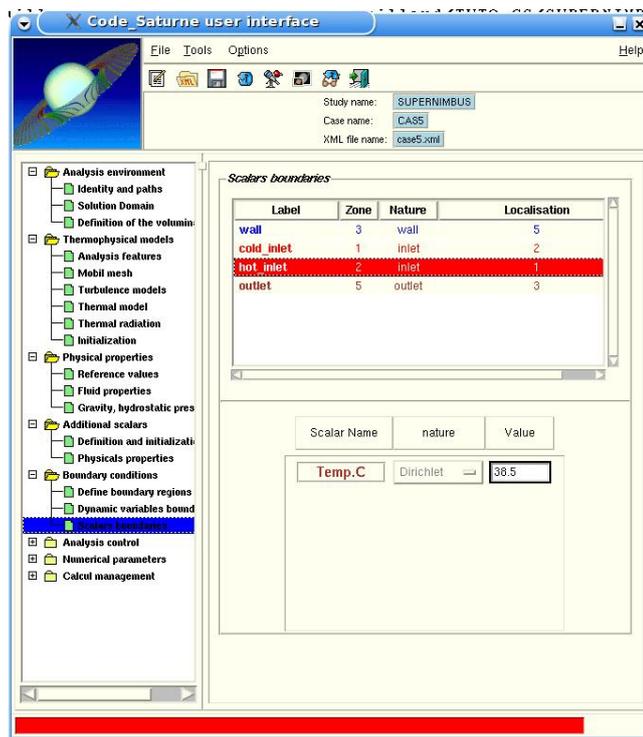
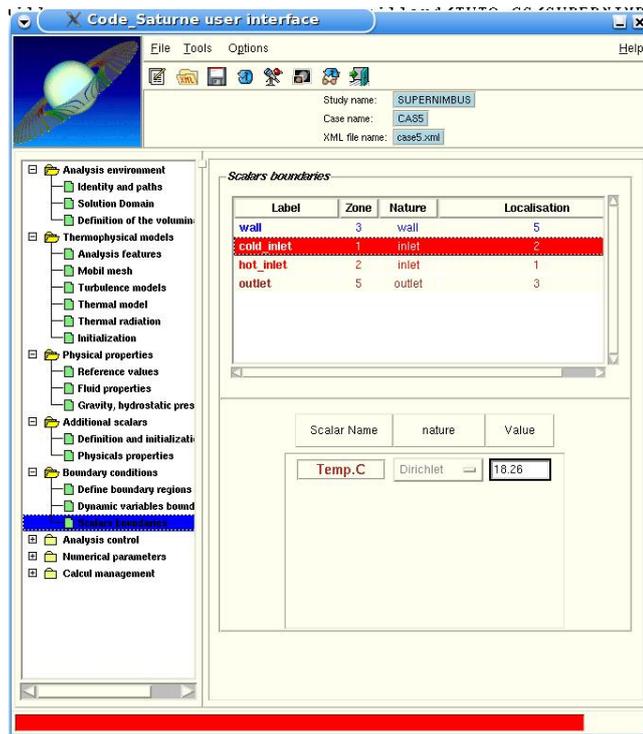


Figure I.15: Temperature boundary conditions

Tick the appropriate box for the time step to be variable in time and uniform in space. In the boxes below, enter the following parameters:

Parameters of calculation control	
Reference time step	1 s
Number of iterations	100
Maximal CFL number	20
Maximal Fourier number	60
Minimal time step	0.01 s
Maximal time step	70 s
Time step maximal variation	0.1

And activate the option *Time step limitation with the local thermal time step*

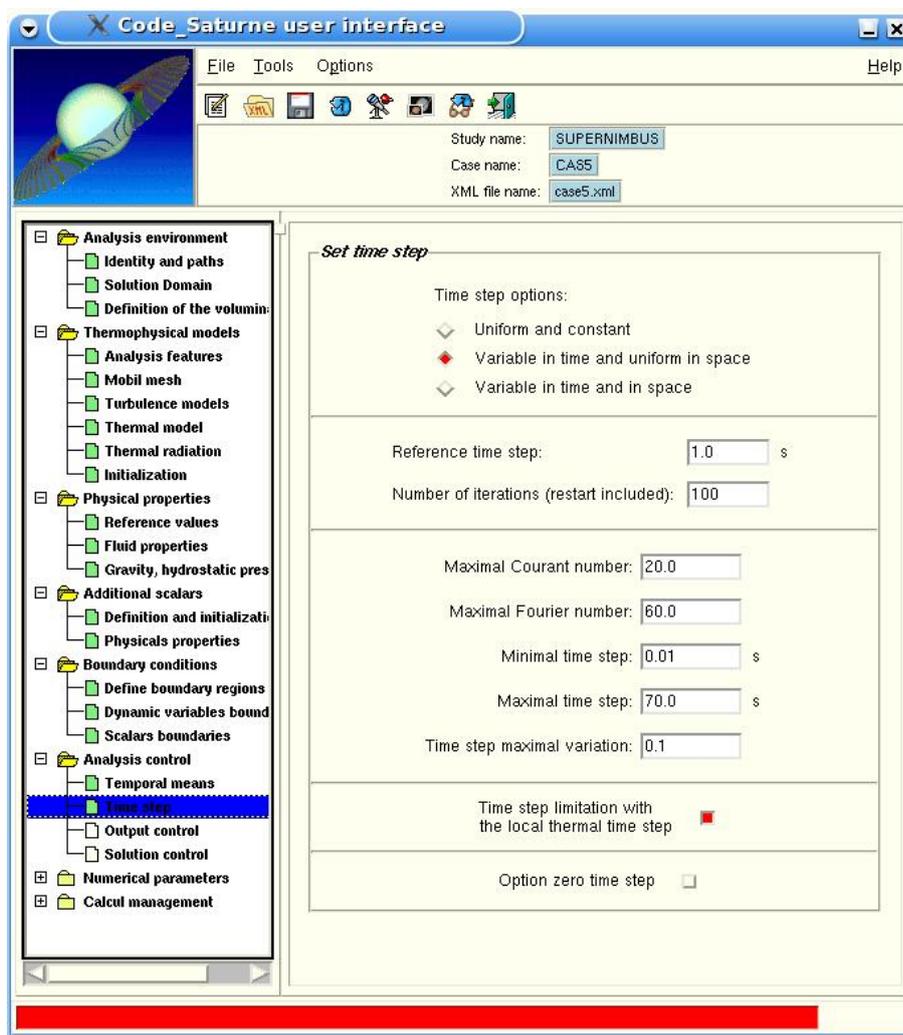


Figure I.16: Time step

Set the frequency of post-processing files to 10.

Create four monitoring probes at the following coordinates:

Points	X(m)	Y(m)	Z(m)
1	0.010025	0.01534	-0.011765
2	1.625	0.01534	-0.031652
3	3.225	0.01534	-0.031652
4	3.8726	0.047481	7.25

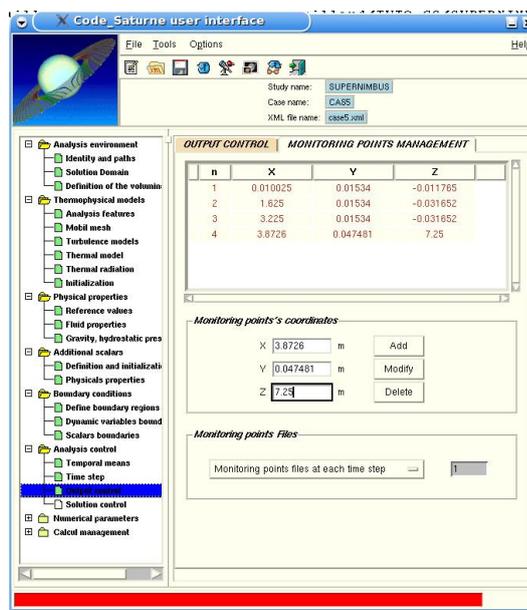
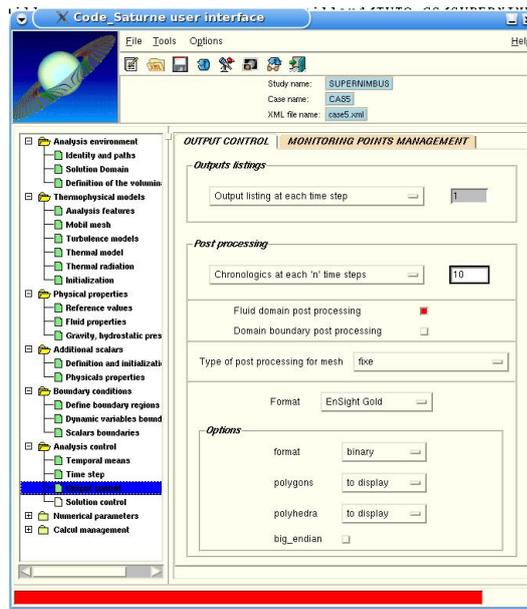


Figure I.17: Output management and monitoring points

Important: Save the file before continuing.

Before running the calculation, fill the *usphyv.F* file to specify the variation of the density and the viscosity with the temperature. Refer to the other cases or the example in the TEST_CASES directory for more information.

3.1 User Subroutine

- `usphyv.F`

In order to allow for temperature dependant changes in density and viscosity, it is necessary to use the user subroutine `usphy.F`.

In general, the user subroutines have to be copied from the folder `FORT/USER/base` into the folder `FORT`². For this case, an already modified subroutine should be copied into the `FORT` directory. To do so, open a console and go to the `FORT` directory using the Unix command `cd`. Then copy the subroutine by typing:

```
[bash:$] cp $CS_HOME/doc/TUTORIAL/TEST_CASES/STRATIFIED_JUNCTION/CASE5/FORT/usphyv.F .
```

(Note the dot (`.`) at the end of the line).

Once you copied, you can open the file with your editor of choice (`gedit`, `emacs`, `vi` ...etc), but you don't need to change anything at this stage.

This routine allows to specify variable physical properties, density and viscosity in particular. In this case, the following variation laws are specified:

$$\rho = T.(A.T + B) + C \quad (\text{I.3})$$

where ρ is the density, T is the temperature, $A = -4.0668 \times 10^{-3}$, $B = -5.0754 \times 10^{-2}$ and $C = 1\,000.9$ Inside the subroutine this is done by altering the density (given by `PROPCE(IEL, IPCROM)`) inside a loop on all cells (with a counter `IEL`). The temperature at each cell is given by `RTP(IEL, ISCA(1))`.

For the dynamic viscosity, the variation law is:

$$\mu = T.(T.(AM.T + BM) + CM) + DM \quad (\text{I.4})$$

where μ is the dynamic viscosity, T is the temperature, $AM = -3.4016 \times 10^{-9}$, $BM = 6.2332 \times 10^{-7}$, $CM = -4.5577 \times 10^{-5}$ and $DM = 1.6935 \times 10^{-3}$

The dynamic viscosity is given by `PROPCE(IEL, IPCVIS)` for each cell `IEL`.

Note that this subroutine has been modified for this specific test case. In general, all user subroutines are in `FORT/USERS` and they have examples for more general cases. **Note:** in the user subroutines, the examples are protected by a test to prevent any undesired use. Do not forget to deactivate them.

²only when they appear in the `FORT` directory will they be taken into account by the code

3.2 Run the case

Once all the user subroutines are in place, the calculation can be launched from the Graphical Interface. Open the 'calculation management' folder and click on 'Prepare batch calculation'. Click on the button labelled as 'Select the batch script file' and select the 'lance' file. This will open new dialogues and give you the button to run the case labelled 'Code_Saturne batch running'.

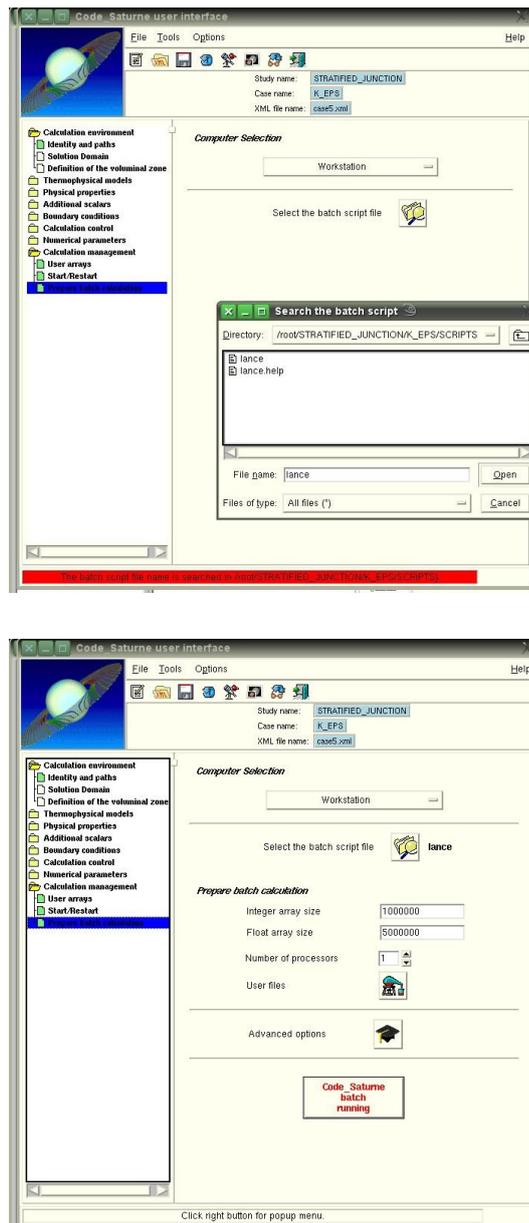


Figure I.18: Run calculation

Click on the button and watch the output on the console screen. It tells you where the temporary directory is located. The temporary directory is useful to see the progress of

the calculation. The calculation should take about ten minutes on a Intel at 2.1 GHz. If everything is correct, you should see the following message:

```
*****
          Fin normale du calcul
*****
```

Once the calculation is finished, close the Graphical Interface and continue with the post processing.

4 Postprocessing

Once the calculation of *Code_Saturne* is finished, the results are copied in the RESU directory with the date appended. The *listenv* file contains the output of the pre-processor which reads the mesh and passes the information to the kernel. The *listing* file has information about all the parameters of the calculation and useful data about the convergence at each time-step. The HIST directory contains ASCII files with the history values of the monitoring points for each variable. The CHR.ENSIGHT directory has the result files in EnSight format. These files can be viewed with *paraview* directly. Additionally, a copy of the FORT directory and the lance script used for the calculation are saved.

In order to visualise the results, go into the CHR.ENSIGHT directory and then type:

```
[bash:$] paraview --data=CHR.case &
```

This will bring the *paraview* interface with the case data ready to be loaded.

Please note that if you are running *paraview* on a desktop you will need to change the **Byte Order** option from BigEndian to LittleEndian. Once this has been changed, click apply to load the data.

In order to view the X-Z plane click on the direction button +Y (see figure I.20). Then you can colour the domain by any variable. Select the Temperature from the box (see 2 in figure I.20). This are the time dependat results, if you want to see the evolution, click on the play button (3 in the figure I.20).

At the end you should have something similar to the figure I.22

It is also possible to colour the domain by the density or viscosity since their values depend on the temperature. It is also possible to create streamlines or vectors (glyphs), but to do so it is necessary to interpolate the cell data to the points. This can be done by using clicking on the menu **Filter --> Alphabetical --> Cell data to point data**. Once you have finished with *paraview* you can close it and continue.

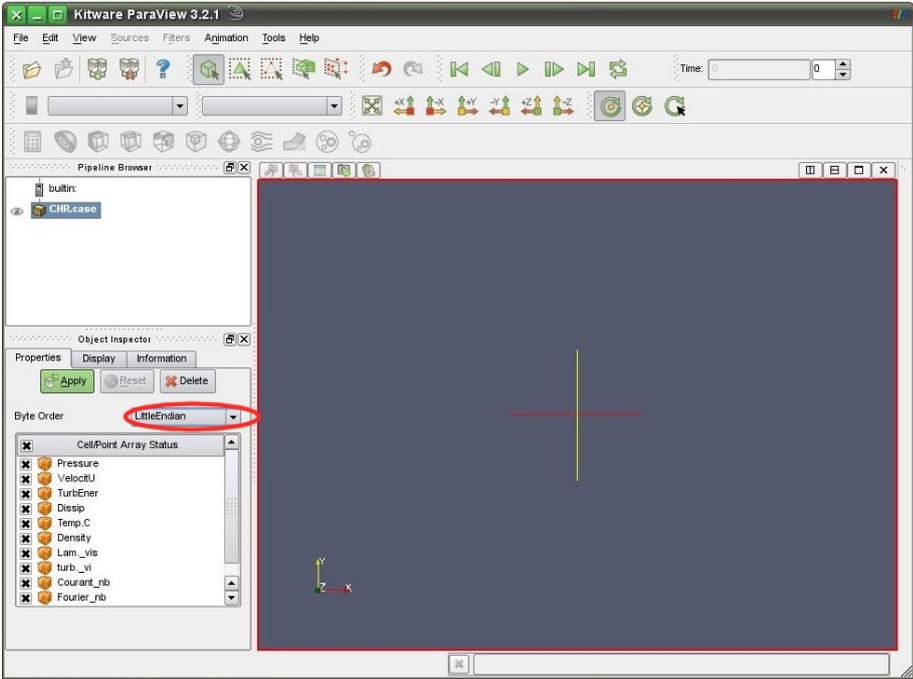


Figure I.19: Paraview initial window

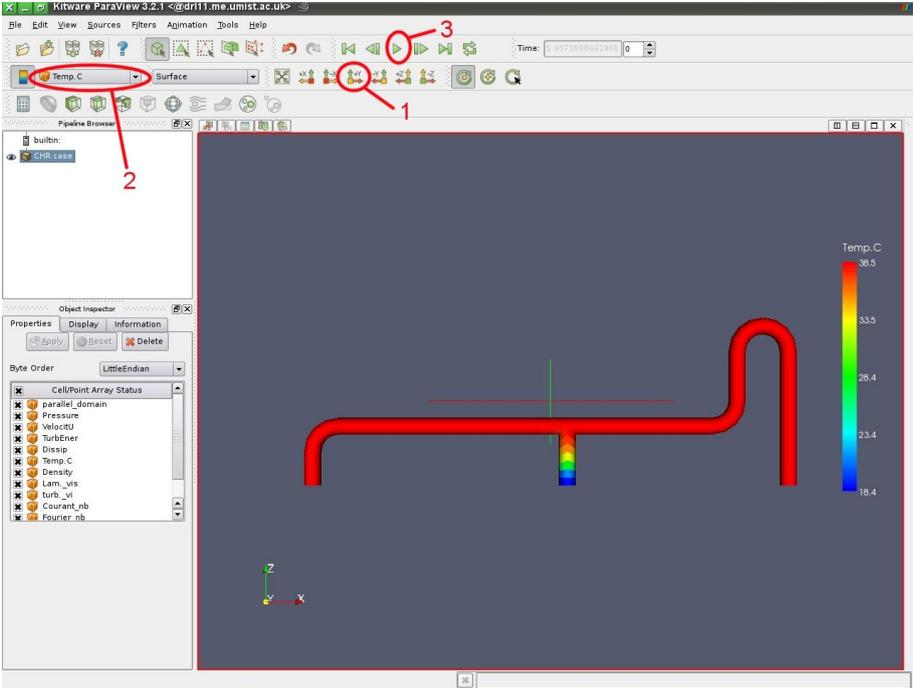


Figure I.20: Temperature contours at 5.93s

The history files of all variables at the monitoring points can be seen in the HIST directory under RESU. Go there and type

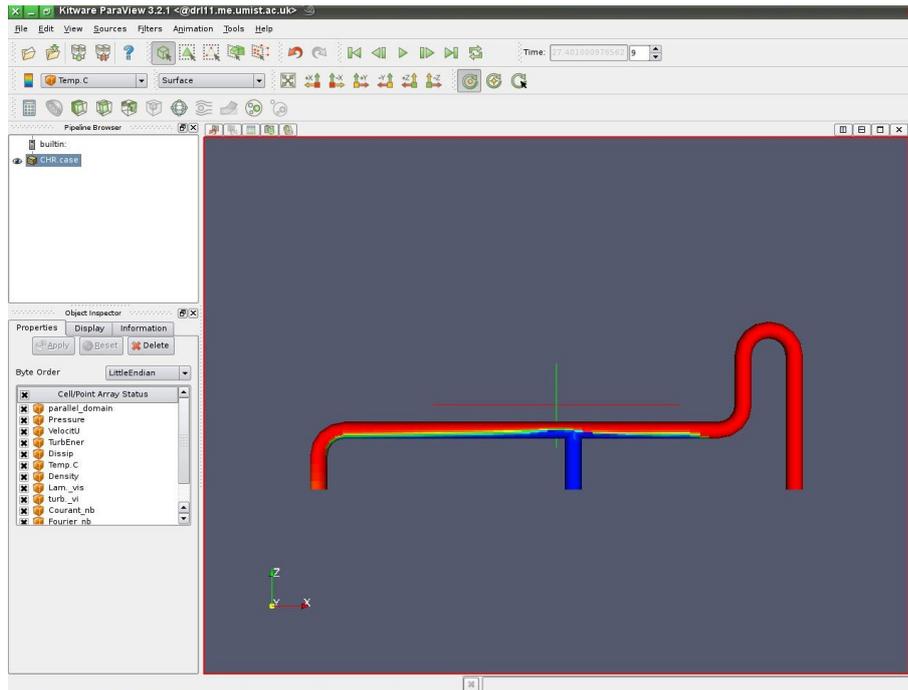


Figure I.21: Temperature contours at 27.4s

```
[bash:$] gracehst Temp.C.hst
```

This script will start a 2D graphical program called grace (or xmgrace) and load the evolution of the temperature over time at the chosen monitoring points. You should obtain something like figure I.6

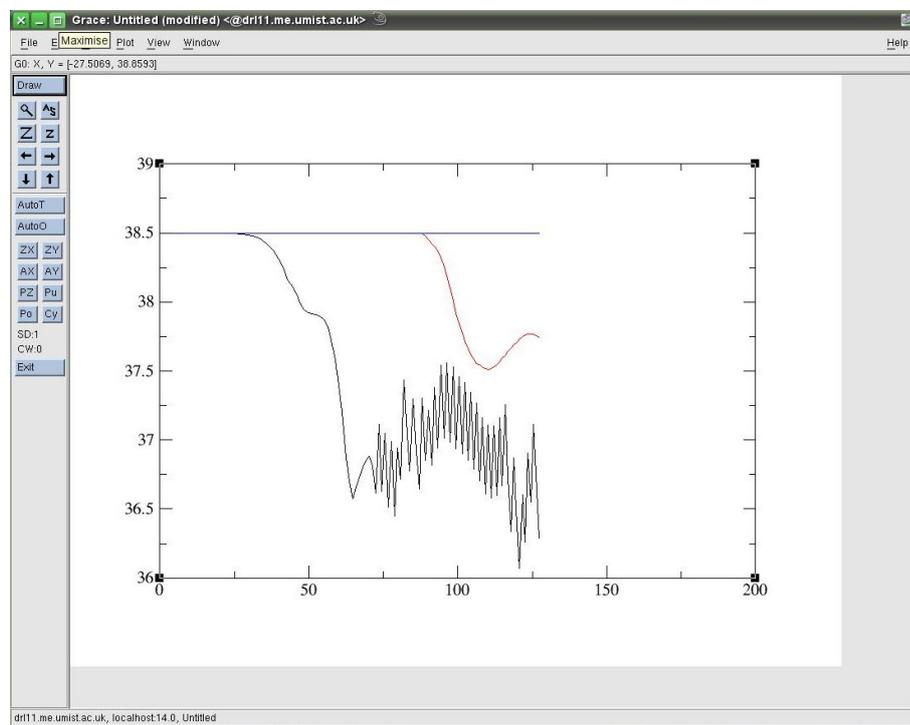


Figure I.22: Temperature evolution at four monitoring points.