Real world study with

Code Saturne

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Introduction

For a long time I've wanted to try and use CFD for a practical purpose and compare it to real-world results, and now during my internship, I have the chance to try it out. For all intent and purposes, I'm far from an expert on CFD nor fluid dynamics, but I have done a few experiments and have a good general idea of how things come together in fluid dynamics/CFD. What this sums up to, is 'nothing is written in stone here' – There may be errors and the setup is probably far from optimal, there is always room for improvement.

Here is a hands on case with Code Saturne without getting too technical.

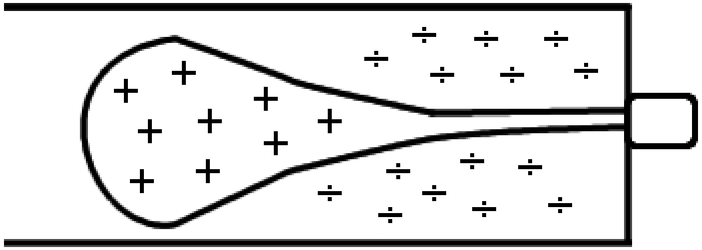
/Claus Andersen, April 20th '09

Goal

To create a computer model that corresponds to real world – with the goal of further development of burner tube. This is an initial simulation to make sure I can make Code_Saturne emulate real world conditions. The goal is however, not to be 100% physically correct, nor does time permit me to set up the experiment to a laboratory grade.

Scenario

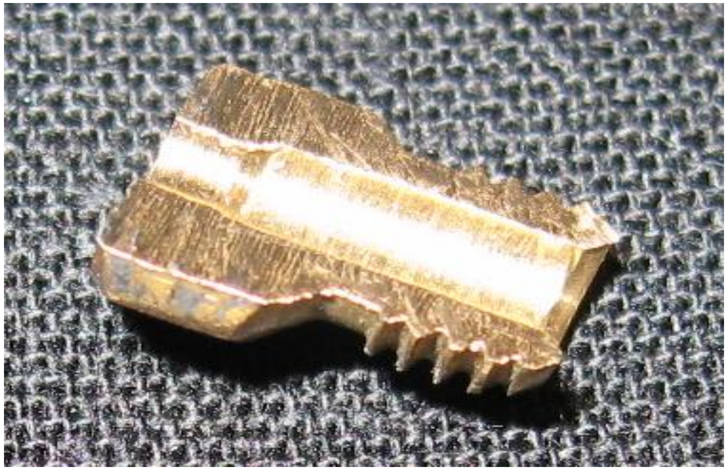
In a gas fire a burner tube is used to mix the fuel (in this case natural gas) with oxygen using the Venturi effect. The pressurized fuel is sent from the high pressure bottle, through a regulator and from the regulator through a nozzle into the burner tube. The gas jet from the nozzle creates a low pressure zone around the base of the jet which sucks in air through the aeration port and mixes it in the burner tube before it is sent into the burner1.



Scenario

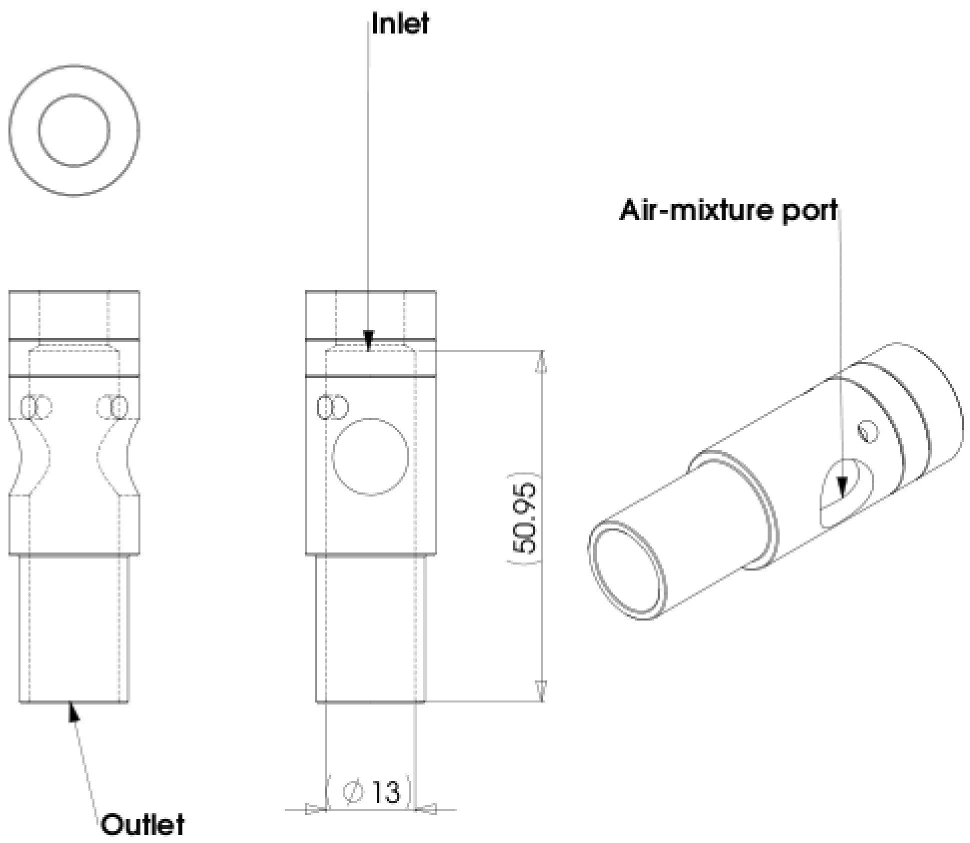
Among other things, the geometry of the nozzle and the velocity of the fluid determines the shape of the jet and the magnitude of the low pressure zone. In this case I've guestimated a discharge coefficient of 0.5, based on the geometry of the nozzle and calculated the exit velocity accordingly.

The exit orifice has a diameter of ~1.9mm



In this study I wont simulate what happens inside the nozzle, nor will I concern myself too much whether the shape of the gas jet is physically correct at the exit – That will be discussed a bit more later on.

Scenario



Mathematical approach

Collecting data

For my simulation I need to input some data into the model, this was done in the following manner:

- Measure volumetric flow rate of the gas going into the burner tube using a flow-meter on the actual gas fire and compare it to the technical documents specified by the test lab
- Guestimate a discharge coefficient for the nozzle using empirical numbers from a table
- Acquiring physical properties for natural gas (using pure methane)
- Measure pressure differential on the regulator
- Calculate exit velocity of gas jet using above values

Result

Calculating the exit velocity at the nozzle has been done in two ways – using the flow rate and using a theoretical approach. Both results equals ~38m/s but since I know that that is a bit high considering the setup and the values used, I back it down a bit to ~33m/s for the simulation.

See Media:*Mathcad-dyse.xmcd.pdf* MathCAD PDF for calculation.

Simulation approach

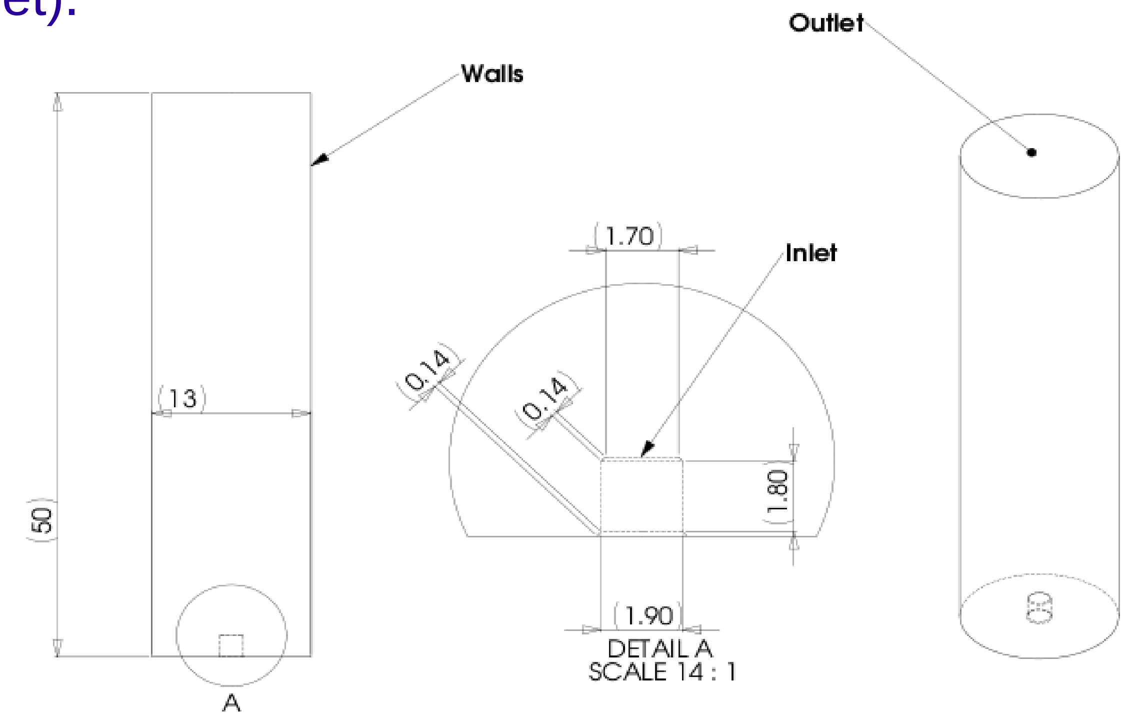
- **Software**
  - SolidWorks for modeling the flow domain
  - Salomé 4.1.4 for preparing geometry and meshing flow domain
  - Code Saturne 1.4b for solving the simulation
  - Paraview 3.4.0 for Post processing

Everything besides SolidWorks is run on Ubuntu 8.10 Linux – SolidWorks could easily be replaced by Salomé but laziness dictated I did it in SW at work.

The computer used is my trusty Zepto Znote 6014W, 1.7ghz Celeron, 1GB RAM

Model description and preparation

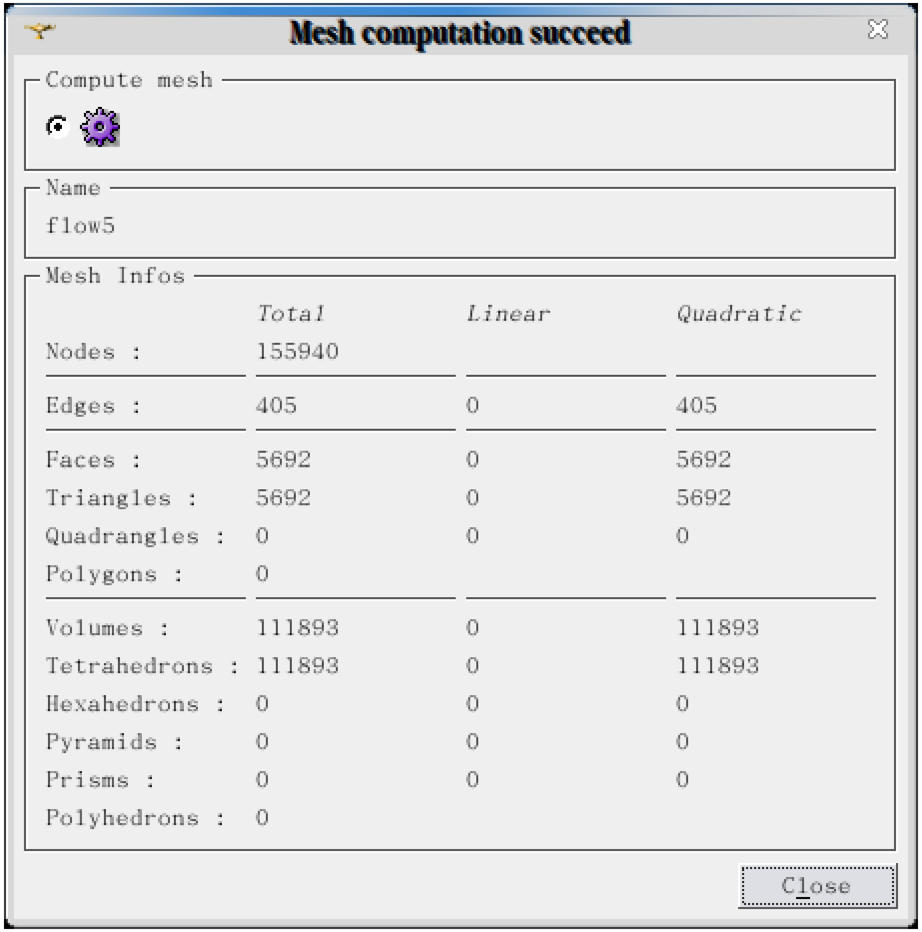
The simplified flow domain consists of a cylinder (Ø13mm, h 50mm) with a simplified inlet (remember, I don't care too much about what happens near and around the inlet).



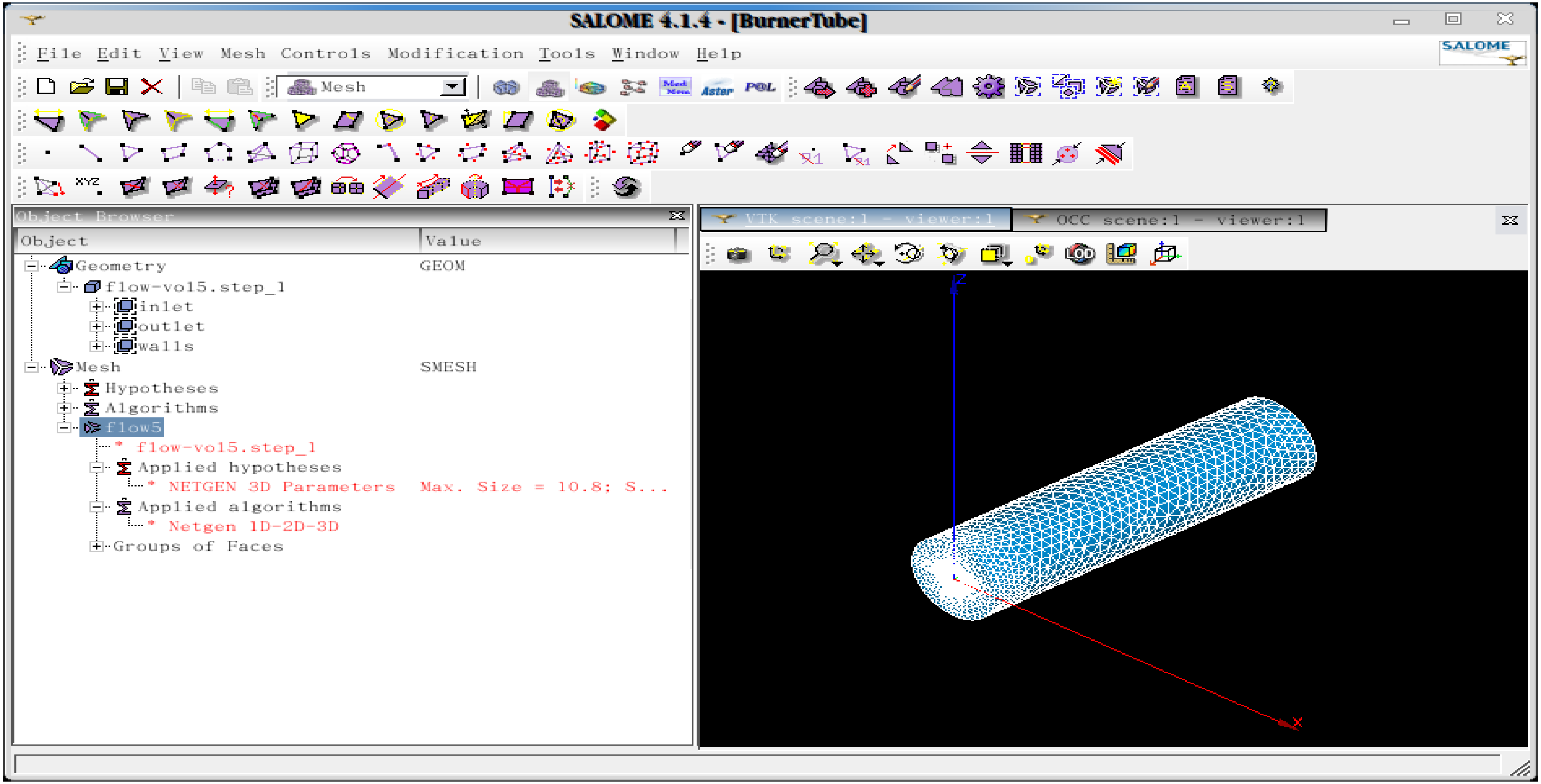
This is exported from SolidWorks in STEP file format and assigned groups in Salomé geometry module, before it is meshed in the meshing module using the following parameters

Model description and preparation

NetGen 1D-2D-3D using the setting 'very fine' and 'quadratic' (2nd order) – the NetGen algorithm and geometry makes sure that the mesh is refined around the inlet and coarsens further up the flow domain. This yields the following mesh:



Model description and preparation



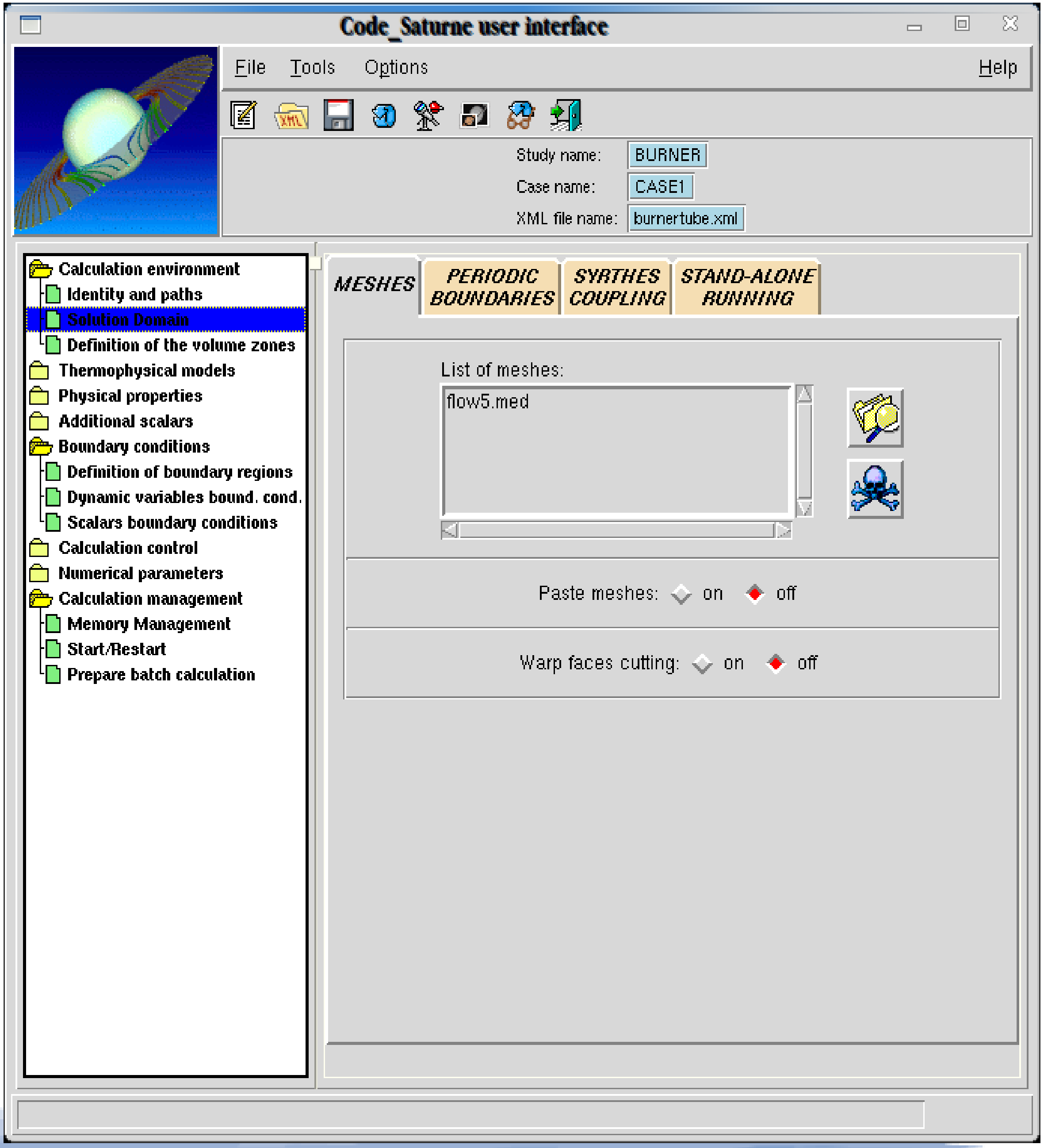
Again, without getting too technical, a way to make sure your mesh is optimized for the simulation, you can calculate the Courant number and adjust your mesh accordingly.
((u*deltat)/deltax)<C

Preparing and running simulation

The mesh is exported in MED file format to the folder ~/Study/MESH/ and the Saturne GUI is started from ~/Study/CASE1/DATA/ using ./SaturneGUI

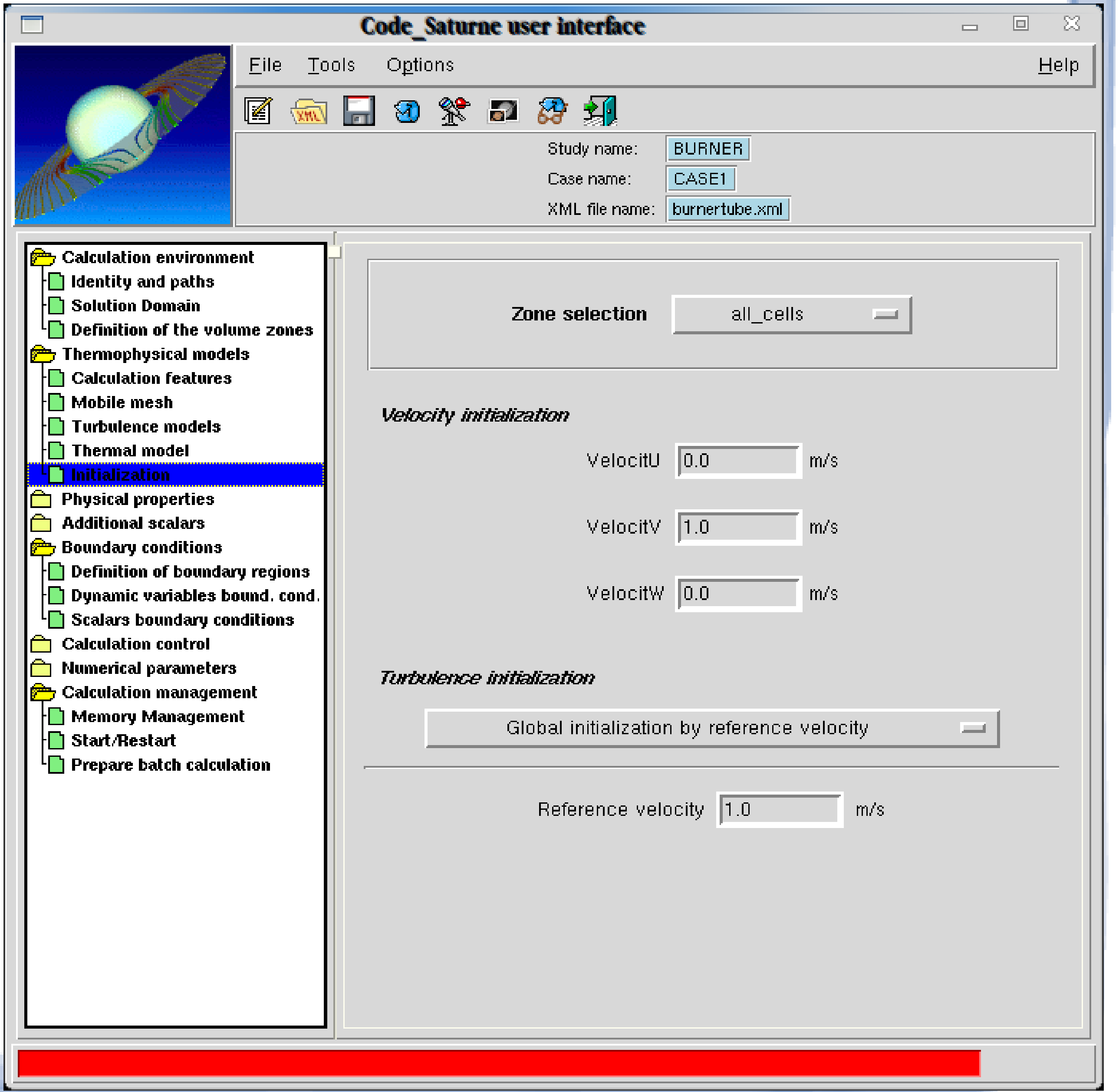
Code Saturne GUI ...

Once the GUI has loaded, it is time to enter the values (the options/tabs not mentioned is left at default if nothing is stated).
Under Solution domain load the mesh file exported from Salomé :



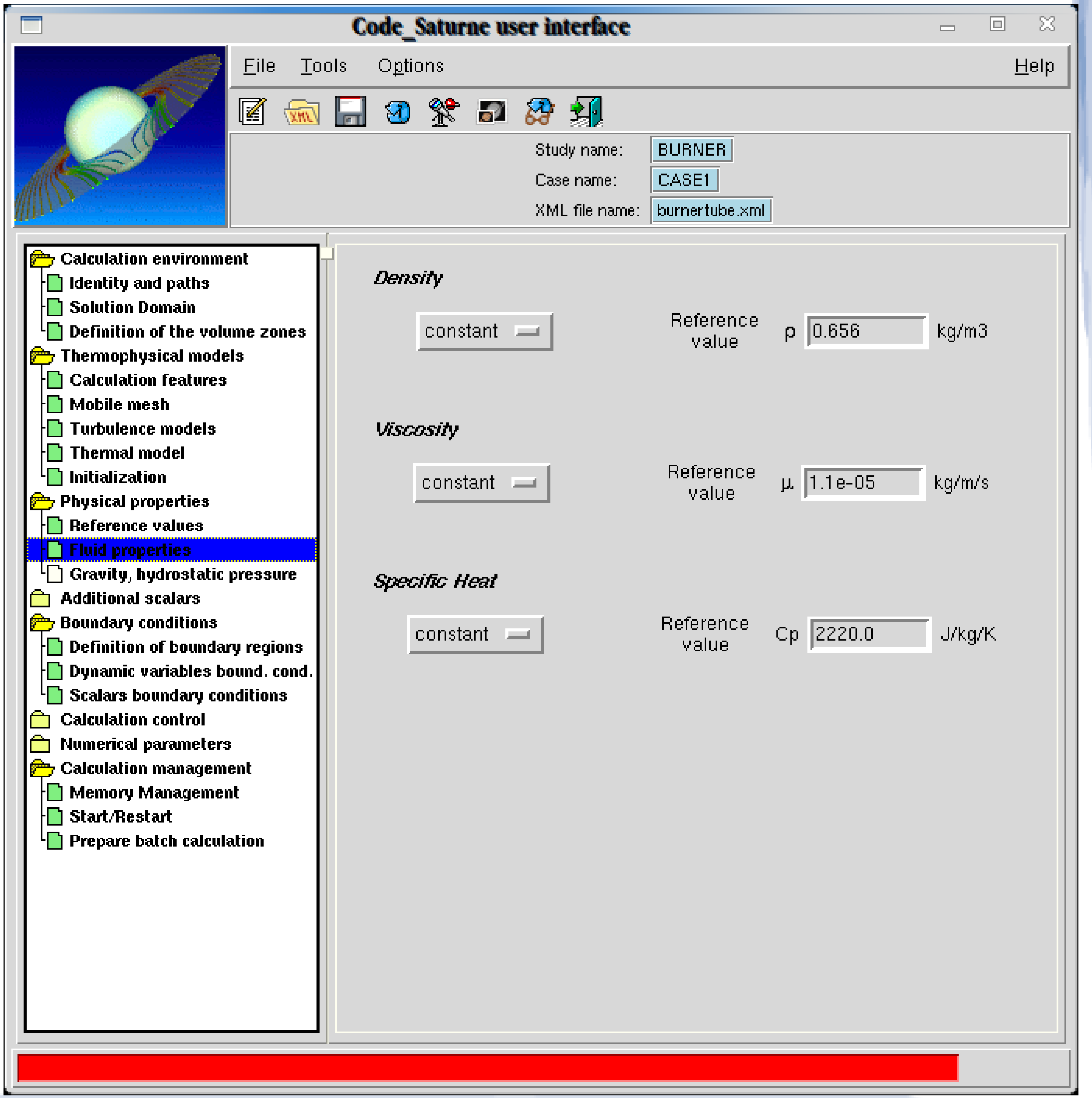
Code Saturne GUI ...

Next go into Thermophysical models and set the turbulence model to k-epsilon – This is a high Renolds number model since that's what I have here. Initialization is set as seen here:



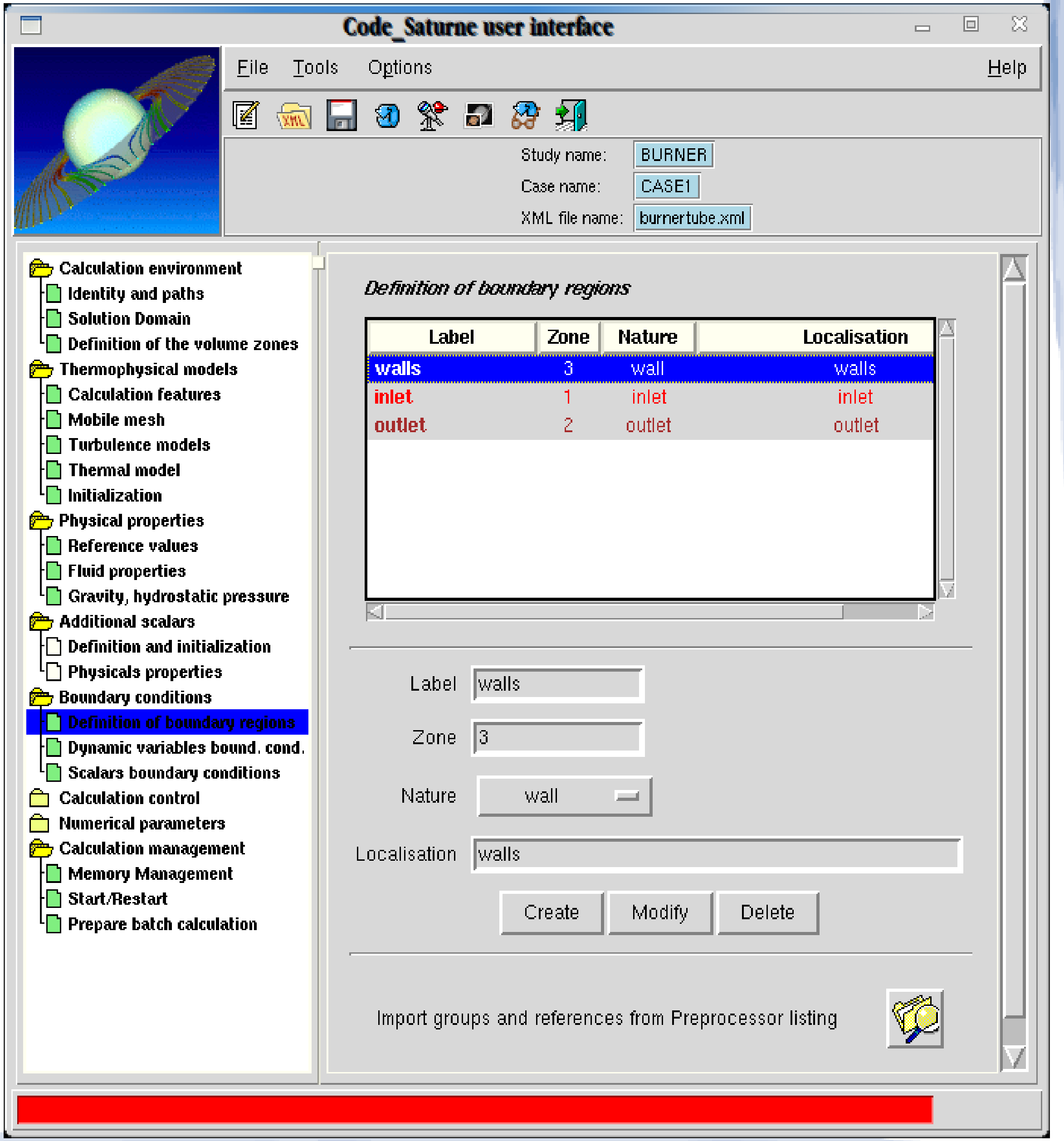
Code Saturne GUI ...

Next the physical properties of the fluid needs to be set:



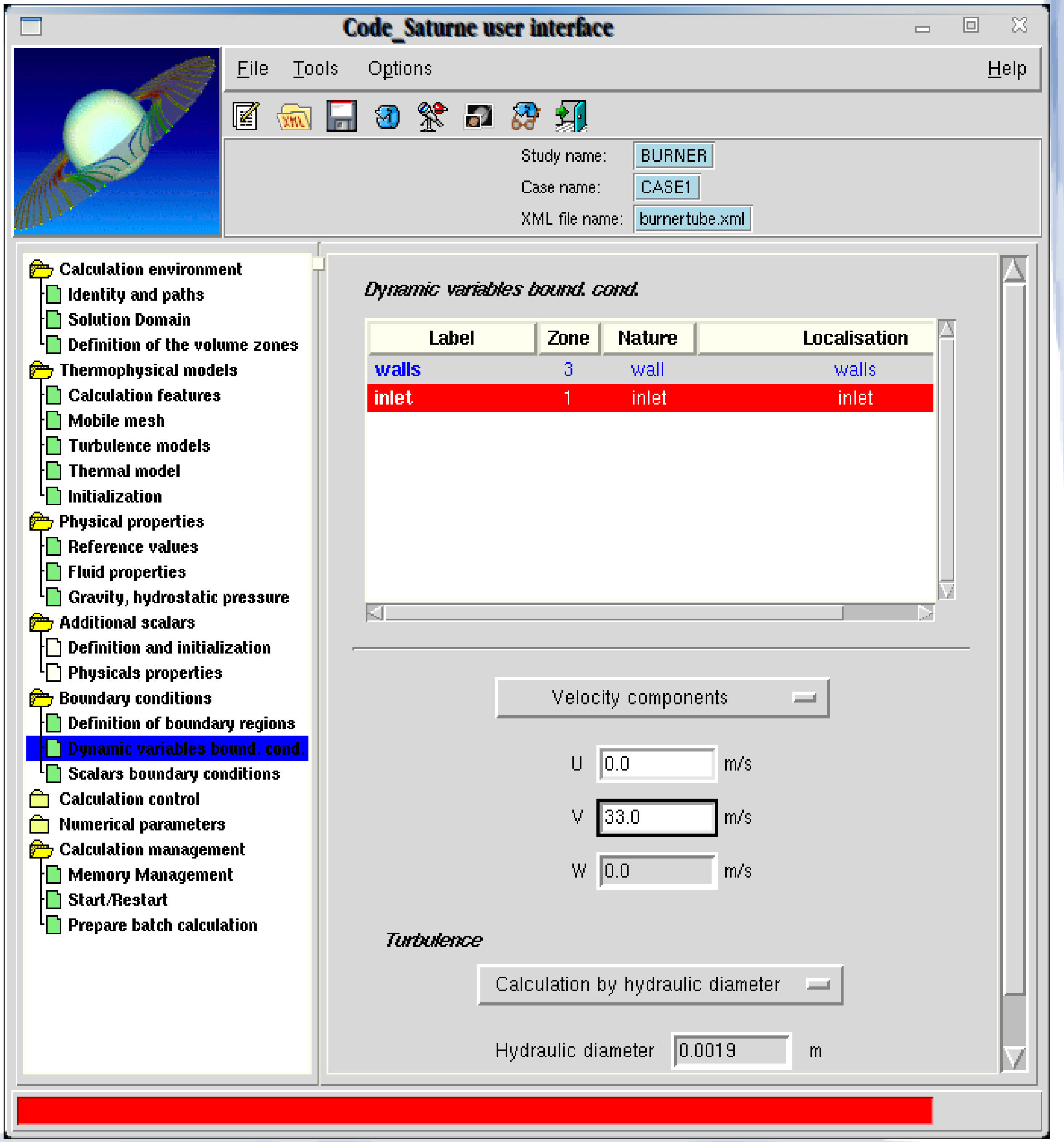
Code Saturne GUI ...

Definition of boundary regions are set next – the names of the boundary regions corresponds to the group names assigned in Salomé.



Code Saturne GUI ...

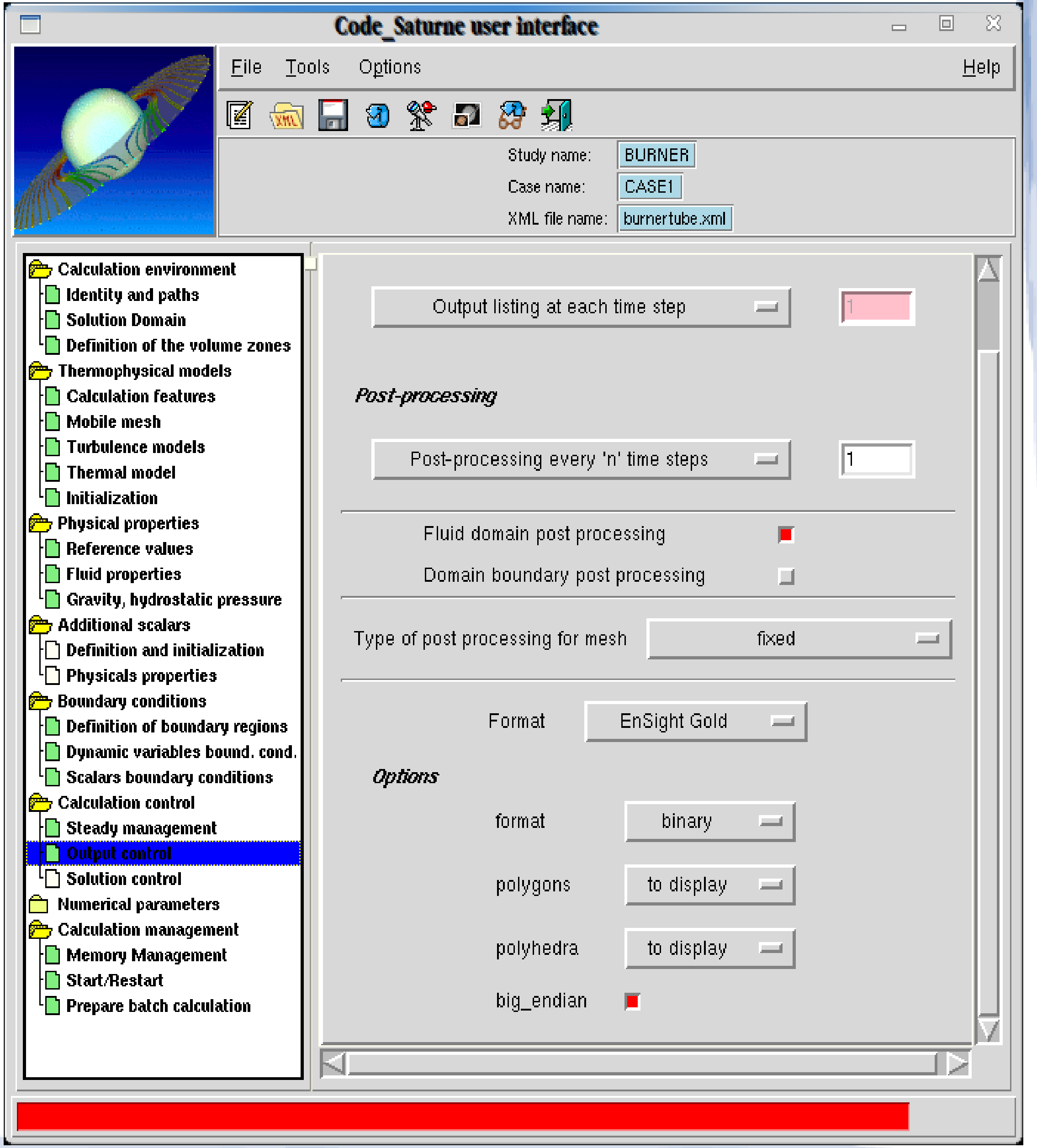
Entering the calculated velocity in the positive Y-direction in Dynamic variables bound. cond.



Code Saturne GUI ...

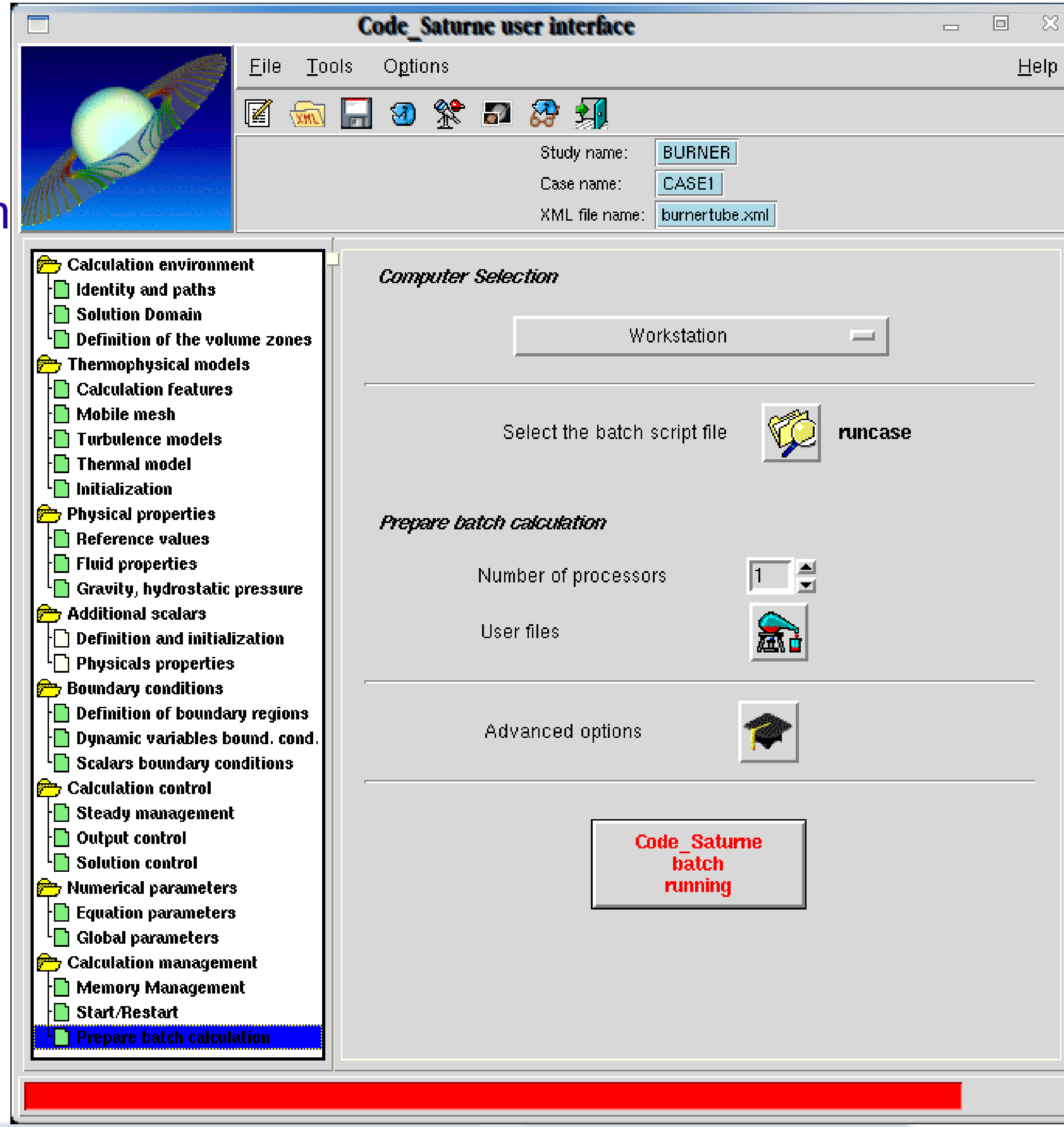
Since this is a steady state condition, this is what I left it at in Steady Management.

Under Output control I set it to Post-processing every 'n' time step to 1 and select Ensight Gold as the output format (This is so ParaView can post-process the result):



Code Saturne GUI ...

Once everything is set up, theres only one thing left: Load the 'runcase' file under Prepare batch calculation and press Code Saturne batch running:



Code Saturne GUI ...

This launches the calculation and outputs the temporary results in ~/tmp_saturne and the finished results in ~/Study/CASE1/RESU
As the calculation runs, issueing the terminal command
tail -qf ~/tmp_saturne/Study.CASE1.date/listing
will give info on the progress and convergence of the calculation:

If everything went smoothly, Code_Saturne rewards you with a **“Normal Simulation Finished”** and one can move on to...

Post processing . . .

Fire up ParaView and select

File → open → Study/CASE1/RESU/CHR.ENSIGHT.date/chr.case

Click *'apply'*

and select

Filters → Alphabetical → Cell data to point data

and

Filters → Common → Slice and de-select show plane select Z Normal –

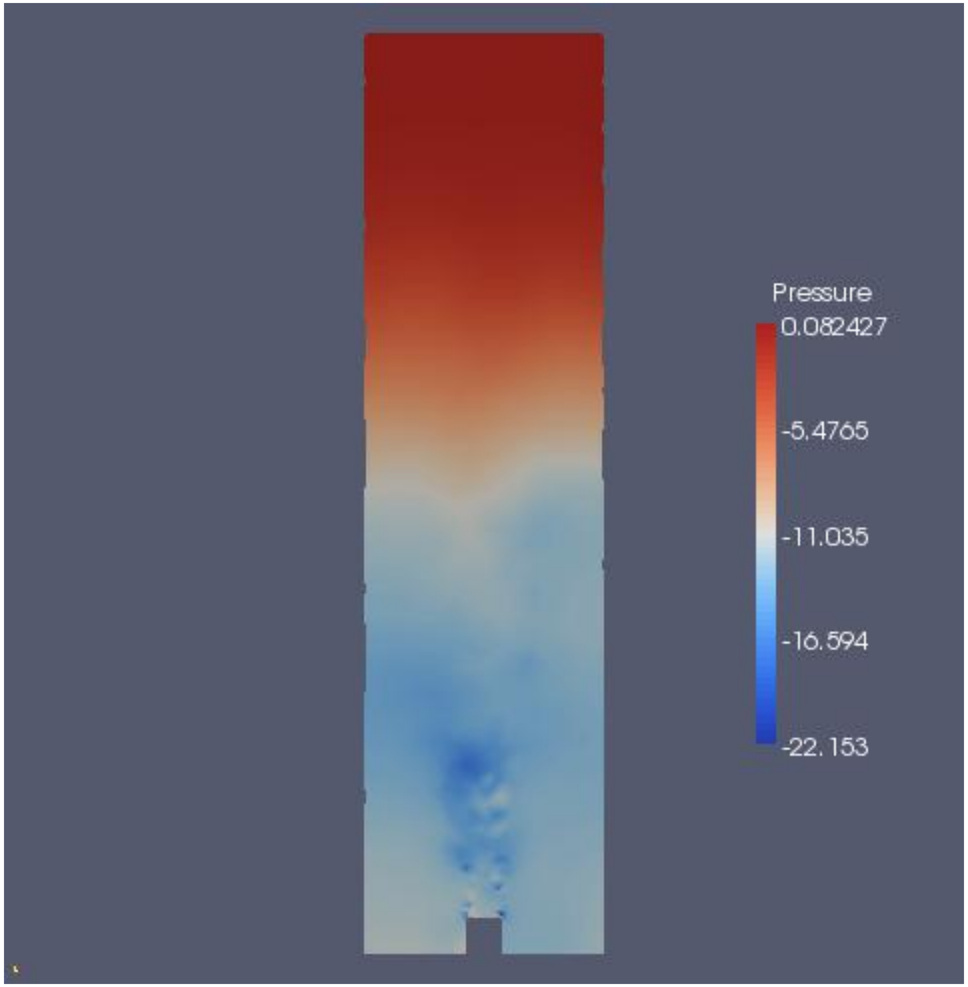
click *apply*

Cell data to point data will give a much more smooth representation of the fields and allow showing the velocity field as streamlines.

Post processing . . .

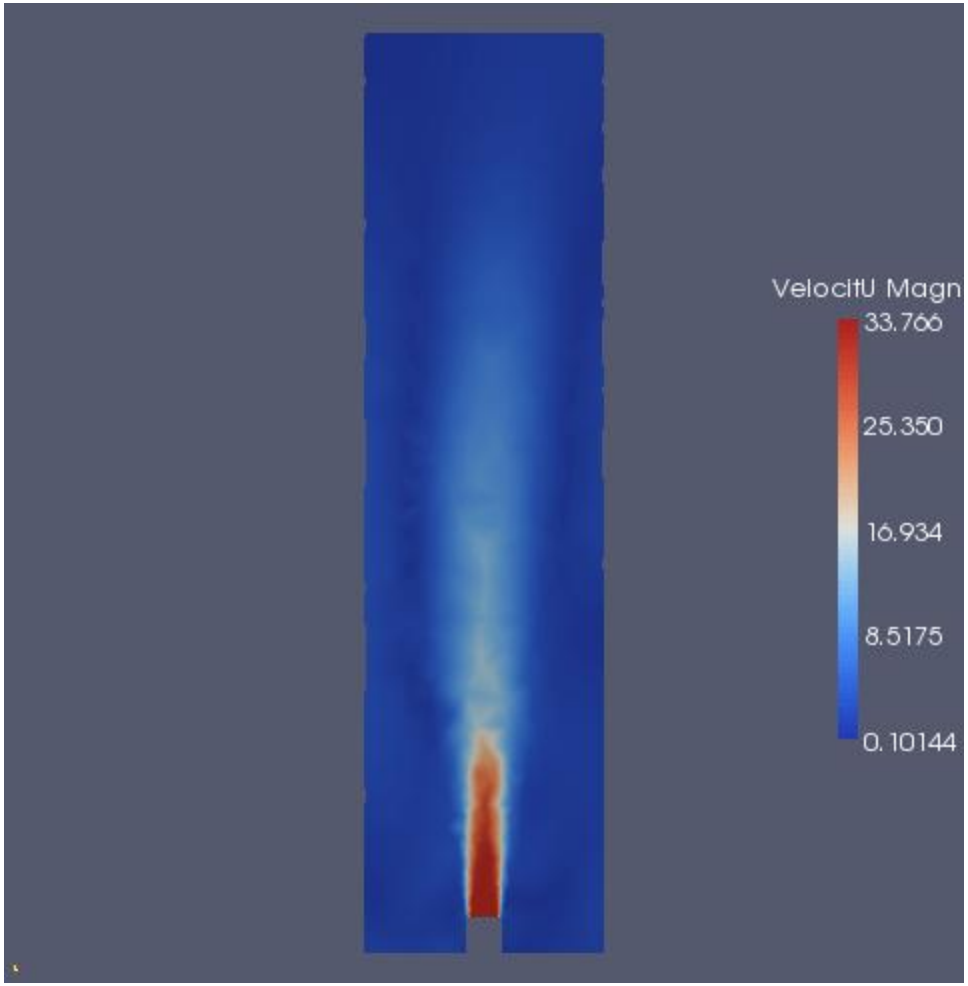
Images are captured at timestep 200 where we have a reasonably steady state:

Pressure
:



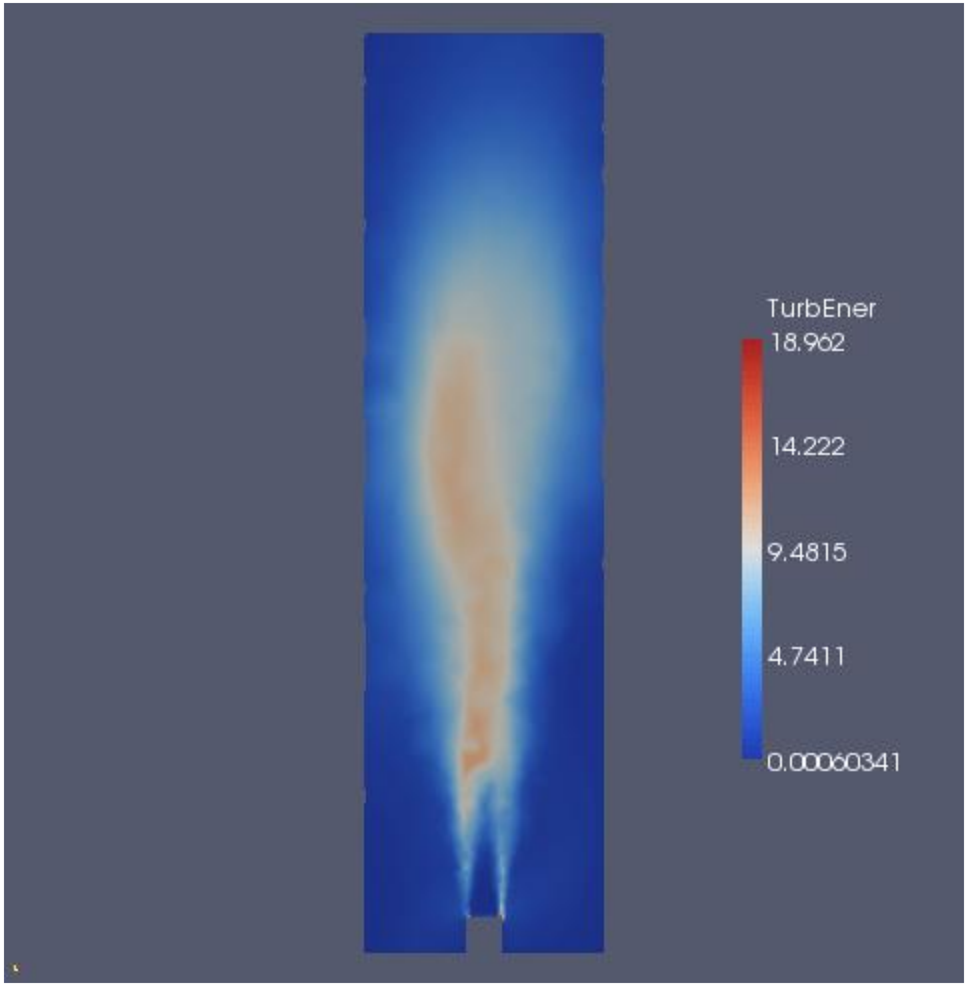
Post processing . . .

Velocity
:



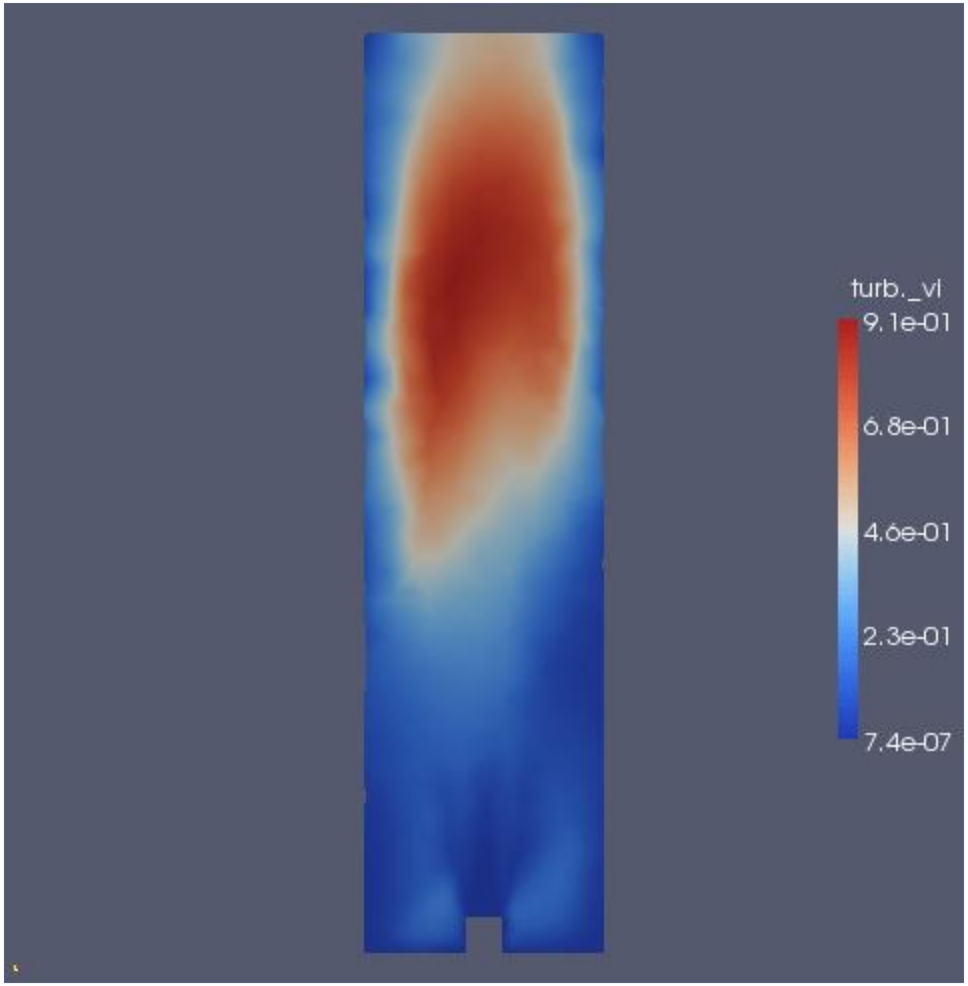
Post processing . . .

Turbulent energy



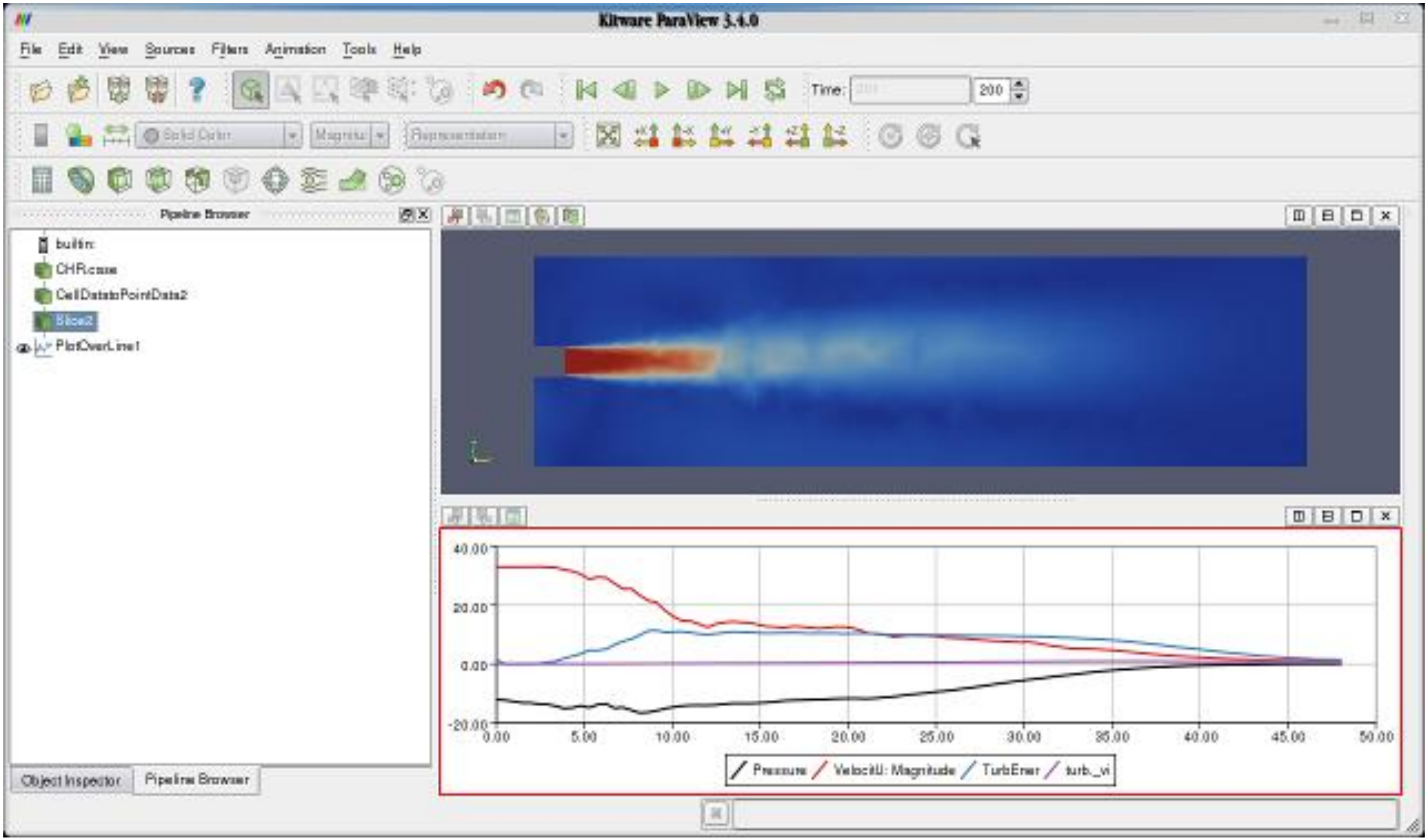
Post processing . . .

Turbulence – magnitude



Post processing . . .

ParaView set up with Plot over line to show values along the X axis:



Post processing . . .

So after post processing the simulation, what conclusions can be drawn?
Velocity is indeed 33m/s as was the initial condition. The low pressure zone around the base of the jet is ~-22Pa, this is what I'm interested in, since this is what I plan to measure later on in the practical approach. The zones for turbulence and turbulent energy isn't that surprising at all – I'll keep that in mind for when I have to modify the burner tube later on.

Practical approach . . .

So now I've gotten the simulation to finish and have reasonable derivatives(?), I proceed to do a practical test on the burner tube. First I want to measure the gas flowing into the burner tube; this is done with a flow meter connected between the gas bottle and the regulator. The results of the measurement is used in the MathCAD document both to hold up against the technical document on the gas burner and to control my theoretical calculation.

In this image the middle flowmeter is used and if you squint, you can see the ball hovering at around 6[l/min].

Practical approach . . .

Practical approach . . .

During the run of the flow measurement, I attach a manometer to the low pressure side of the regulator to make sure it has the proper inlet pressure: 1[kPa]

Practical approach . . .

Next up is the actual measurement of the burner tube. I have attached a small fitting to the aeration port and sealed the ports with electrical tape. This should hopefully emulate the simulation setup.

Turning on the gas and letting it flow free through the burner tube with a micro-manometer attached, gave the following reading:

Conclusion

Goal archived, I have a model on which I can build further on.
Code_Saturne can be a harsh mistress. I've have spent many many hours tweaking the shape of the mesh for a seemingly simple numerical analysis. Especially the inlet takes much care to model – the initial 'backlash' of the fluid as it enters the tube (as seen in the animations) has given me much grievance. The trick in this case since I was only interested in low pressures zone in the steady state, was to let the inlet protrude into the chamber to allow for the 'backlashing' – otherwise I got wildly inaccurate if any, results.
CFD requires you to know exactly what you want to retrieve from the simulation and under what conditions. It simply does not converge if you don't have some idea of what mesh size, inlet velocity etc. etc. to apply. This takes much experimentation, at least for me since I don't have a formal background in fluid dynamics.
Don't do CFD on a 1.7ghz celeron if you have the choice – it will wear you out.