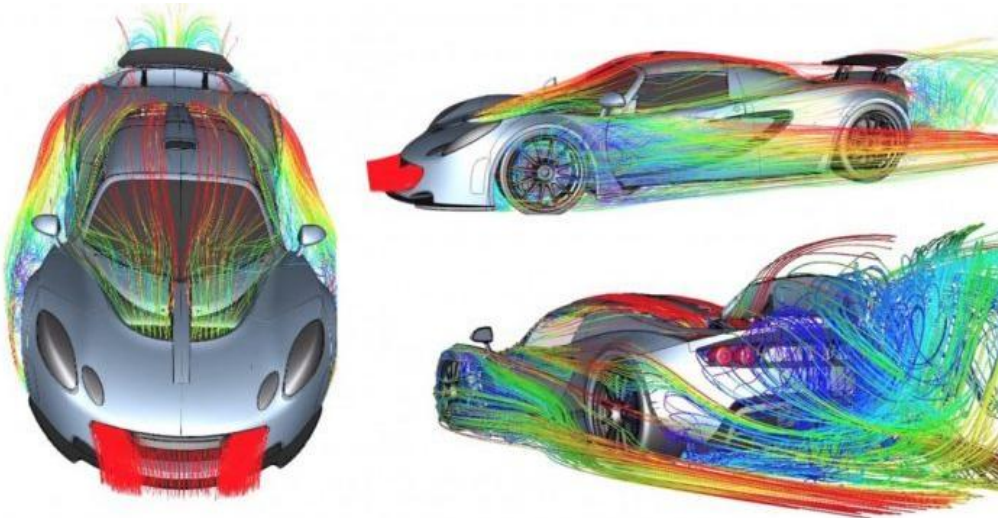*Projet de Physique P6*

STPI/P6/2017 – 11

TECHNIQUES AVANCEES POUR LA VISUALISATION ET L'ANALYSE EN MECANIQUE DES FLUIDES DANS L'APPLICATION D'INGENIERIE

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Intitulé du projet : *Techniques avancées pour la visualisation et l'analyse en mécanique des fluides dans l'application d'ingénierie*

Type de projet : *Bibliographie / Numérique*

Objectif du projet :

L'objectif de ce projet a été de visualiser, grâce à différents outils numériques, le phénomène de turbulence d'un fluide lors d'un écoulement.

Mots-clefs du projet :

- Visualisation scientifique
- Analyse
- Turbulence

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1. INTRODUCTION

Fluid mechanics is a field of physics belonging to mechanic of the continuous areas. It consists of the study of the behaviors of liquids and gases in the balance or in movement, and the study of the interactions of these latter each other or with solids.

The study of fluids began during the prehistoric times when men were searching how to divert the course of rivers, for irrigating crops. The prehistoric men studied fluids when they wanted to optimize the propulsion of boats by the wind.

Nevertheless fluid mechanics, as a physical discipline, started in the 3rd century B.C when Archimede stated the eponym principle.

Today fluid mechanics represents a solid set, that we can consider as the pillar of several disciplines like hydrology or meteorology.

The development of tools of the computing and the digital technology allowed a great step forward in the research and for simulations that we can realise in the fluid mechanics field.

However regarding turbulent fluids, simulations remains limited and tried uncertainties.

Our project's subject is carried towards those numerical tools, in order to learn how to use them and then study the behavior of fluids in particularly conditions. This study was of one any other way that the one seen currently in class. It enabled us to check each theorem in a practical way.

In a first part we will establish a description of several softwares with their advantages and disadvantages, in order to determine the one we could use for the future.

In a second part our framing teacher gave us some data about fluids. The first ones were to learn how to use the several softwares. Then he gave us new data more complicated and by working with it we had to extract some data - like the temperature, the pressure, the velocity according to the various axis or the probability density and many more.

2. METHODOLOGY AND REPARTITION OF THE WORK

In a first part before making of the visualization and the analysis we made researches about the different softwares that exist to observe some phenomena a fluid is undergoing during its flow. To be effective in our searches each of us was looking for five different softwares to see the advantages and disadvantages of them and then we selected some of these softwares that we could work with. But to the end of the project we didn't choose the software we wanted because of the data M. SADFARI SHADLOO and M. SHARMA were giving to us, to exploit them.

To work on our project we divided our group in two small groups. Chloée and Adel worked on the software ParaView, to visualize the flow of the studied fluid, and Elise and Amine concentrated on Matlab.

Before starting to visualize physical phenomena and analyze them our teacher M. SADFARI SHADLOO first gave us simple data to discover how the different softwares - TecPlot, VisIt, ParaView and MatLab - are working and to know which functions are important in the engineering domain. Then he gave us the real data to visualize and analyze with ParaView and Tecplot.

First the work on Paraview consisted in visualizing the flow regime, and observe the turbulent phenomena the fluid is undergoing. To this end we plotted several parameters and observed them through different points of view, i.e. when the fluid was propagating along the x-, y- or z-axis. Thanks to this we could assert in which direction was the turbulence. With ParaView several parameters are at arrangement, so that we then could confirm our first hypothesis by visualizing the phenomena in another way, for instance we observed the turbulence with the velocity and the vorticity in the fluid during the flow regime. Moreover after finding the direction of propagation of the turbulence, to well understand what is happening during a turbulence, we made some different cuts, along the x-axis for our study, and thus we remarked that this physical phenomena is not immediate but it gradually appears during the flow.

Then thanks to the MatLab software we could confirm what was observed with ParaView using many different ways of calculation. Through the several plotted functions we remark that some of them were very helpful to understand what is evolving in the fluid during the turbulence, for example the velocity along different axis, the temperature of this fluid.

However MatLab is a very complex software that can be used in many different domains and it took us time to become familiar with it and well know how to use each of the several functions available and useful for our project.
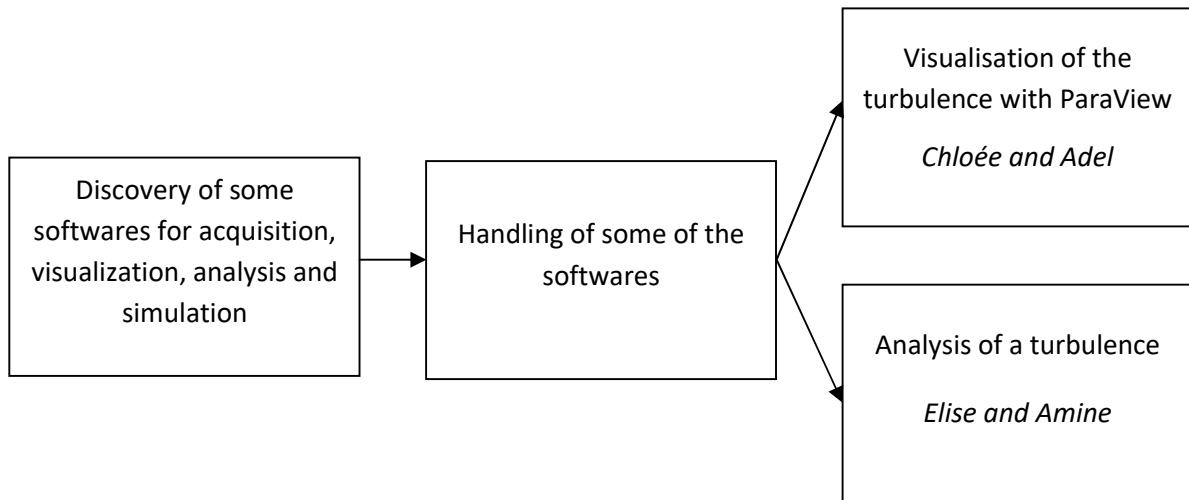
Evolution of our work during the semester

3. REALIZED WORK AND RESULTS

3.1. Some softwares useful for visualization, simulation, analysis and resolution

Before we start to work on some softwares for visualization and analysis, we looked for some of those softwares. It allowed us to know which one are free or paying, what we can do on it, and what are the advantages and disadvantages.

3.1.1. Acquisition

3.1.1.1. FileIView

The software FieldView was originally developed for oil and gas production. It provides a end-to-end solution to know where and when to use oil and gas. It's mainly used by industries.

The range of applications is large ; it includes for instance ''tank and silo monitoring''.

The benefits of such a software are the gratuity and the independance to internet. We can access to our project from anywhere and we don't need internet connection. The improvement of performances, productivity, quality and safety is an advantage of the software.

3.1.2. Visualization

3.1.2.1. TecPlot

Tecplot is used for graphical visualization, particularly in fluid mechanics. From structured or not meshing, we can easily visualize in 1D, 2D or 3D complex data, thanks to the simple use of the software.

It exists 4 different licenses for TecPlot, each intended for different uses ; but for each version we can work on Windows, Linux or Mac OS.

The advantage of this software is that it is very simple to use. Nevertheless, it is only used to plot data and we can't then analyze it.

3.1.2.2. ParaView

ParaView is a free software to create visualization data and then to analyze them. It is developed to analyze very important data, specially designed for fluids dynamics area. It is so practical for qualitative as for quantitatives analysis. Besides there is a large library for the different functions existing and it is very simple to use it.

Thanks to this software we pass during our project to visualize the turbulence of the fluid flow. In fact we can plot several parameters, like the velocity or the vorticity for instance, along the three axis x, y and z. Moreover, we can make some cut to see the phenomena a different instants of the flow.

3.1.2.3. VisIt

VisIt is a 2D and 3D visualization software for structured and not structured meshing. Data from other format (Fluent for example) can be exported to VisIt so that we can visualize them.

The first advantage of this software is that wa can work with data availabled on distant server on the condition of having the simiar version of VisIt. Moreover we can create animation films from these data, to well visualize what we are working on and what is undergoing the structure.

Nevertheless if our version of the software is different to the one of the data the opening of the file is complicated, long and sometimes doesn't work.

3.1.2.4.   OpenDX

Formerly the old version of OpenDX was DataExplorer which became an open source in 1999. The toolbox enables to visualize data fields in 2D or 3D, that they are structured or not. To visualize those fields, we need to construct the viewing program. Data don't have to be structured and it can be of different types : scalar, integer, vector.

The strong points are the flexibility - we can create a viewing program like we want, thanks to all different varieties of functions - useful for visualization - , high capacities - , the interface is simple and it is thus simple to learn how to use the software. Moreover since it's an opensource this software is free

The weak points are in a first time the time needed to load data. Then we note the evolution and the improvement of such a software. Since it's an open source, the evolution is possible only if some voluntary users want to develop it.

OpenDX is a powerful tool for visualization and is mainly used by scientists and engineers, to analyze a maximum of informations from data.

3.1.2.5.   Amira

This software is written in C^{++} and is available for Windows, Linux and Mac OS. It's created and developped by two french and german groups in 1999. This platform is used for 3D and 4D visualization, processing and analysis.

Researchers and engineers use it a lot, all over the world ; the tool is universal for analysis and the interface is flexible.

One of the most important point of Amir ais that data can exceed the available main memory, and standard modules are extendable.

However we can't get this software for free - we need a license – but we can download a full-featured free version for a given time to test it before to buy the complete version.

3.1.3. Analysis

3.1.3.1.   MatLab

MatLab was developed for scientists and engineers in data analysis, design of algorithms and models. It is present in a lot of areas like signal processing (electrical devices, medical supervision), design of controller, robotics or visualization. The latest is the one in which we're particularly interested in during our project.

For our project we focused with MatLab on the visualization part of the software. Indeed, through several functions that we plotted we observed the turbulent phenomena, and how we can interpret each functions.

There is a big variety of sources and formats, it contains an important number of mathematical functions to treat any scientific problem. Moreover we have to possibility to visualize in 2D or 3D and we can integrate codes in different informatical languages (Java, Python, C++).

But this software is not free and it costs a lot to buy the license. Nevertheless other similar free softwares today exist, for instance Scilab.

3.1.3.2. Zoho

Zoho is a used software to visually analyze big data, by creating reports, tables, graphs and we can mix our data.

It's an online software. Thanks to that we can communicate with other people using Zoho too. The problem with it is that it is mostly used in the business area and not a lot for scientists.

3.1.4. Simulation

3.1.4.1. Fluent

The software ANSYS Fluent allows us to realize simulation about fluid mechanics. This solver is today mostly used in industry or in research and development.

Moreover it's the most powerful software in fluid mechanics. Indeed it offers a large range of functionalities.

The benefits of this software are the timeless to make computation for simple data in 2D and the facility to recover and modify these data.

Although the graphical user interface is very efficient – since the software is very complete – it is not easy to adapt to it.

3.1.4.2. Bentley LumenRT

It allows us to create and simulate several environments of the daily life. It is intuitive and easy to use.

Moreover many structures are available - like roads, buildings, vegetation - and we have the possibility to act on a big number of parameters (day/night, season, car traffic, population). Some animations enable to see the evolution of a created model.

The main disadvantage is that it is limited to the evolution model of the created environment. It doesn't care about what already exists.

3.1.4.3. RFEM

RFEM is a useful software in the civil engineering to compute internal efforts of many structures, using the finite elements method.

This intuitive and easy to use software, that we can find in different languages, owns a lot of material are available (steel, wood) and we have the possibility to pattern several elements (beam, solid)

Nevertheless the standards of construction are not integrated in the software.

3.2. The attainment of the utilization of some of these softwares, used for the project

First to learn how to use new softwares for analysis and visualization, we began with very simple data to discover what is a turbulence.

Therefore, we saw thanks to Tecplot, VisIt and Paraview what is a turbulence and how we can notice it. To clearly understand this phenomena, we plot several data which are the pressure P, the temperature T, the mach number, the density R and the velocities U, V, W respectively following axis x, y, z.

For each parameter we can see that its value is not not same at each coordinate. The value does not vary a lot for increasing z but when we are near to z=0 the value is not the sam, and that is because of the turbulence phenomena.
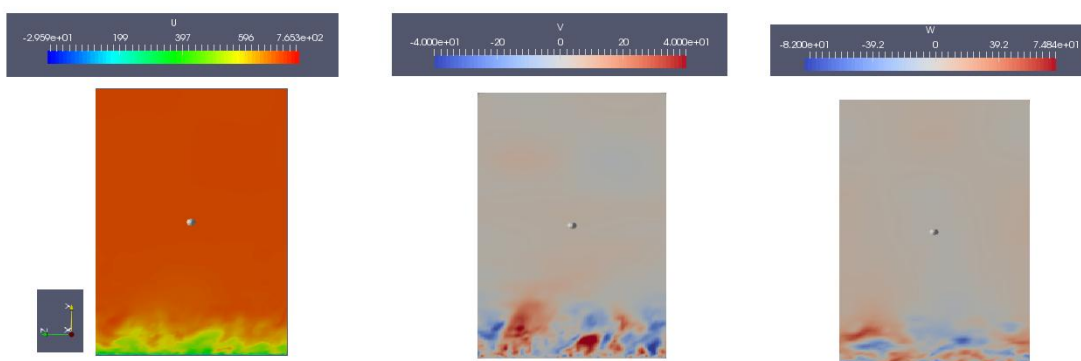

Behaviour of u,v and w component on the x axis (in m/s)
Made with ParaView

We remark the velocity along the x-axis, called parameter U, grows when y increases and goes to 0 when y decreases. We can thus suppose this flow follows Couette flow.

Similarly U is not homogeneous on x and it is probably because of the turbulent phenomena of the flow.

V is almost non existing when y increase, but when y is near zero, there is more contrast on this value, certainly caused by the turbulence of the flow.

W is almost non existing everywhere. This is probably due to the direction of the flow (according to x axis).

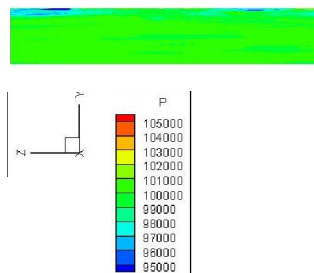*Behavior of the temperature in the (y,z) plane (in K)*
Made with ParaView
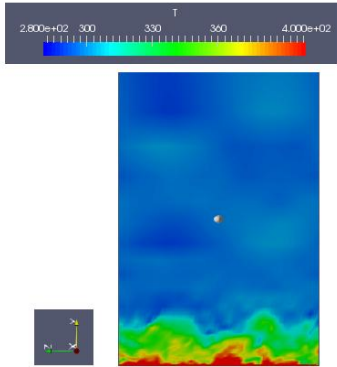
We notice that the fluid is hotter when y decreases, which corresponds to the concentration of the fluid : more there is fluid, more the temperature increases.

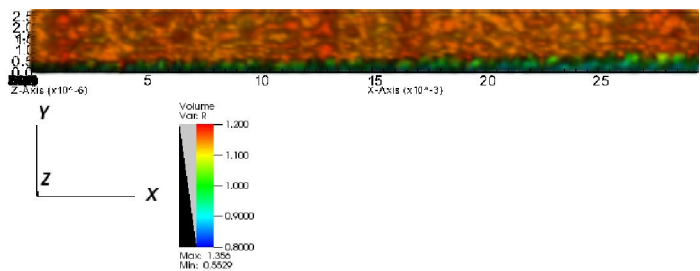*Behavior of the Mach number in the (y,z) plane*
Made with TecPlot
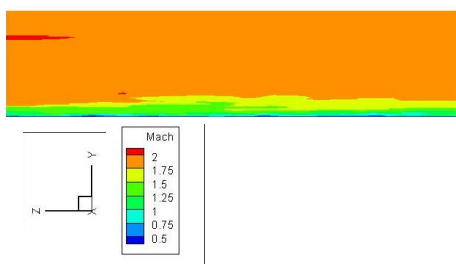
For the Mach number, we have a graph very similar to the one of the u component, since the Mach number is the ratio of the velocity and the speed of the sound. Only the figures change.

Behavior of the pressure in the (y,z) plane
Made with TecPlot

Behavior of the viscosity coefficient R in the (y,z) plane
Made with VisIt

Such a flow can be assimilated to a flow in a pipe and its study could enable for instance to optimize the pipes forms, knowing the fluid characteristics like the viscosity.

For the rest of our project we only use the softwares ParaView and MatLab and we study all the behaviour of the flow : laminar, transition and turbulence.

3.3.   The observation of a turbulence thanks to different ways of visualization

We say a fluid, liquid or gas is in a laminar flow regime when the flow is regular, which means that all the flows are in parallel layers and there is no disruption between them. The set of fluid flows is more or less in the same direction, but if there are local differences, they are not mutually contradictory.

The laminar flow regime is mainly the kind of flow we are looking for when we want to make a fluid circulate in a pipe or to make fly a plane.

The transition state is between the laminar one and the turbulence. During this state scientists and engineers today don't have any theoretical model to efficiently predict the behavior of the studied fluid.

In opposition to the laminar flow regime there is the turbulence. A turbulence is a flow state, of a liquid, gas or fluid, in which the velocity has a whirling character. The size, location and orientation of these vortex constantly vary, so that we can't predict the behavior and simulate it for example with mathematical formula. Turbulent flows are recognizable thanks to a very messy appearance, with difficulty predictable behavior, and the existence of a lot of spatial and temporal scales.

Such flows appear when there is a very intensive source of kinetic energy to set the fluid in motion, in front of the strength of viscosity that the fluid objects to move.

The main characters of this flow regime are a change in pressure, and temperature, and ne in flow velocity.
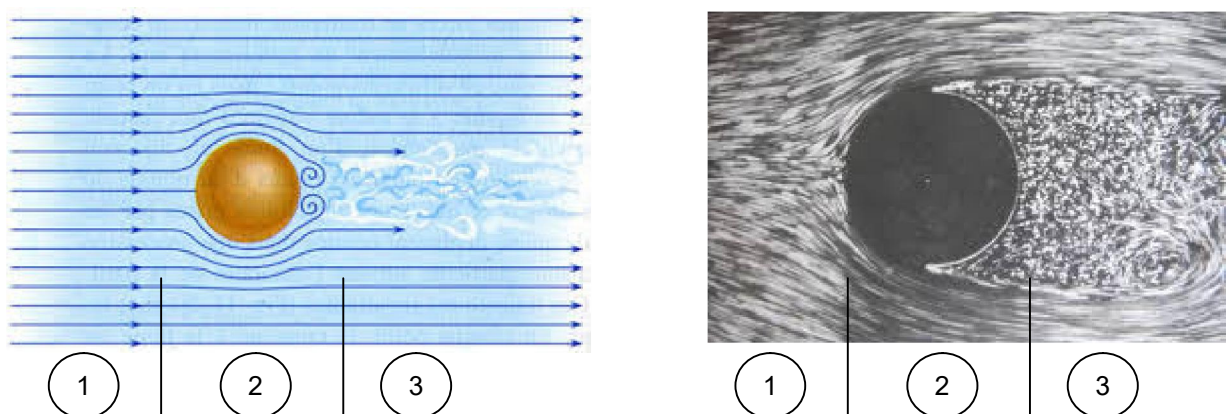

Behavior of a fluid during a turbulent flow

We can on both pictures distinguish the three different phases a fluid is undergoing duting a turbulent flow. Indee during the first phase we well observe the parallel layers, then in a second time layers start to distort and finally vortex appear so that we can't distinguish the layers and define mathematically their behavior.

(1 : the laminar phase ; 2 : the transition state ; 3 : the turbulence)
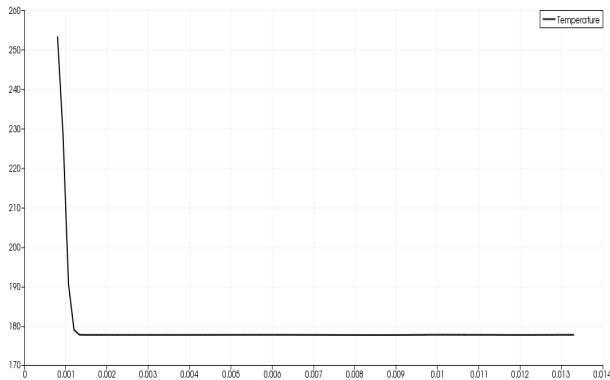
3.3.1. The temperature
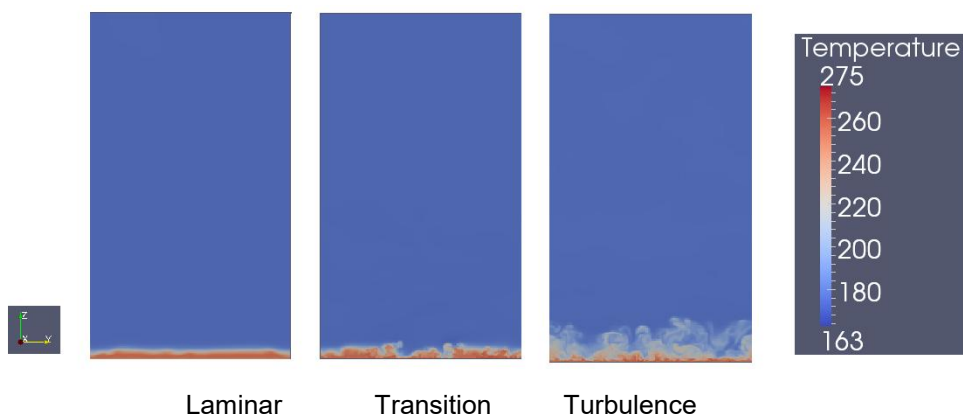
The evolution of the temperature during the flow (in K)

In the laminar regime the temperature is generally constant in the same plane. This can be explained by the lack of abrupt moves in the laminar regime. The moves of the fluid are similar to homogeneous moves of layers of the fluid : all the layers behave in the same way.

We begin to notice differents fields of temperature in the fluid during the transition state. Indeed the layers of the fluid no longer moves in an homogeneous way.

The temperature varies more in y-direction than before, in addition to vary in x-direction. We are gradually going into the turbulence regime.

Through the turbulent flow differences of temperature are very marked within the fluid. During the turbulence, moves within the fluid acquire some random feature and become hard to predict. Those features are responsible for huge variations and the noticed instability, which cause heat waste.

Curve showing the evolution of the temperature in laminar regime (in K)
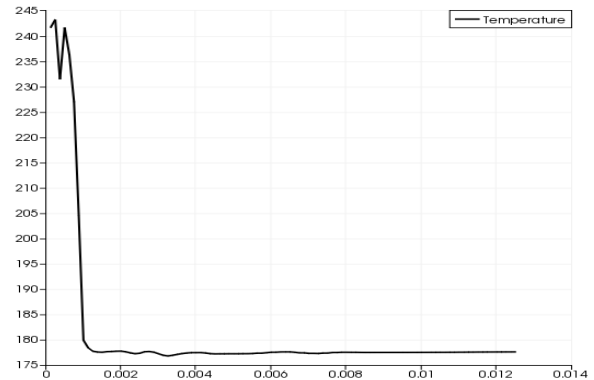
Curve showing the evolution of the temperature in transition regime (in K)

Curve showing the evolution of the temperature in turbulent regime (in K)

Those curves show the evolution of the temperature between to points of the cut of the pictures above. The first point is the one on the most hot part of the fluid, that is why the curves drop.

In laminar regime, we can see that there is no abrupt variation of the temperature like said previously.

In transition regime, we can note some begin of turbulence in the begin of the curve, where the flow is the most abundant.

In turbulence regime, the curve shows variation of the temperature until there is almost no fluid, for high values of y.

3.3.2. The velocity

After visualizing the turbulence thank to the different parameters available concerning the data, we can first analyze and compute the total speed.

The general formula for the velocity is :

$$V = \sqrt{\overline{u^2 + v^2 + w^2}}$$

We can notice that in 3 Dimensions the velocity is decomposed into three components; one for each direction of propagation.

It means that in the formula $V = \sqrt{\overline{u^2 + v^2 + w^2}}$, U is called the velocity component along the x-axis, V the one along the y-axis and W along the z-axis.

Before computing the total speed of the fluid in his motion, we first observe the different components of the speed. Thanks to them we already can determinate along which axis is propagating the turbulence.

We made these calculations and analysis with the software Paraview to visualize where the velocity is the highest and where it is the lowest.

| Laminar | Transition | Turbulence |
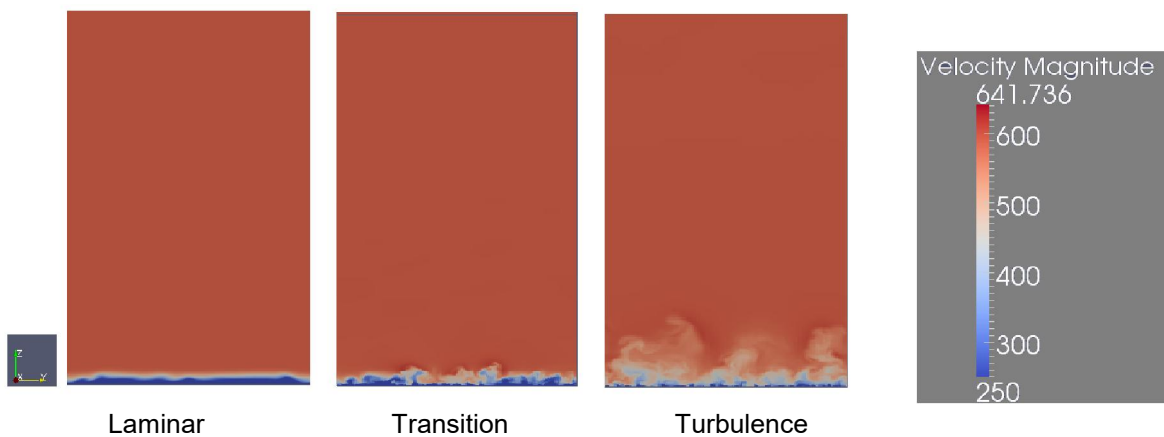
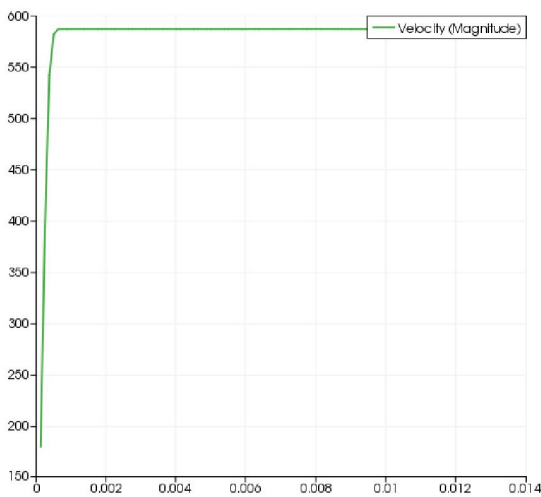*The evolution of the velocity magnitude (in m/s) during the flow*

The velocity is almost constant through the flow. Nevertheless to observe the turbulent phenomena we made three cuts at different values of x. We can thus remark that this velocity does stay constant and it varies a lot on the y- and z-axis.

The velocity seems to be globally constant on a same plan during the laminar state. It can be explicated with the absence of abrupt and sudden movements in laminar regime, where the fluid motions are comparable to homogeneous and uniform motions of layers of fluid.

When the fluid enters the transition state we start to observe some differences of values for the velocity of the fluid. The isovelocities start to be troubled. Indeed the layers of fluid don't move anymore in an homogeneous way and we progressively enter the turbulent regime. The velocities along the y- and z- axis vary; we remark the layers of fluid move at different speeds. The viscosity of the fluid is taken into account, which means there is a resistance of layers some with regard to the others. This phenomena is characterized by the apparition of vortex in the fluid.

During the turbulence the differences of velocity are very marked through the fluid. These speeds suddenly vary along the y- and z-axis and we notice the apparition of waves in the fluid. During the turbulent flow the motions of fluid acquire an unpredictable and random character, which is responsible of these big variations and the observed instability.
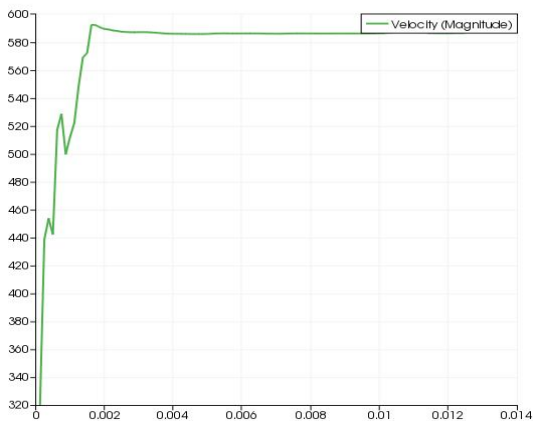
The viscous nature is growing, causing a loss of kinetic energy. Similarly to the transition regime we observe vortex bigger and bigger and outnumbered.

Curve showing the evolution of the velocity in laminar regime (in m/s)
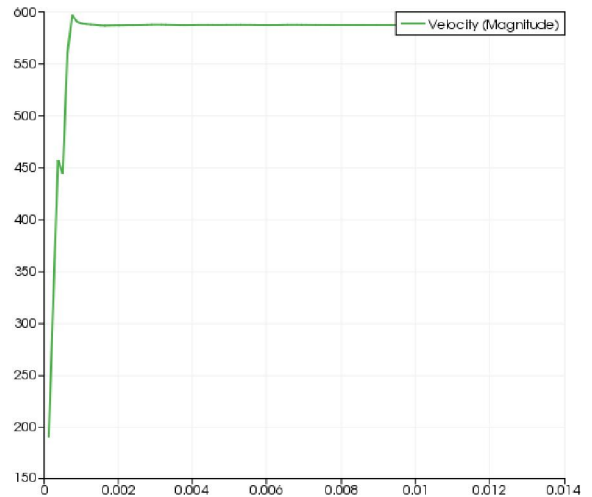
Curve showing the evolution of the velocity in transition regime (in m/s)

Curve showing the evolution of the velocity in turbulent regime (in m/s)

The laminar regime of the velocity is quite similar to the one of the temperature.

Compared at the temperature evolution, this graphs show that the transition takes place when y is more high. This can be explained by the fact that the viscosity concern the external layers of the fluid.

The turbulence regime affect all the fluid like for the temperature.

3.3.3. The vorticity

The vorticity is in fluid mechanics a pseudovector field to represent the spinning motion of a fluid at a given point. In other words it means it is the observation of the relative displacements of the fluid at a point in a small neighborhood.

In mathematics and for a 3 dimensional flow the vorticity is defined as the curl or rotational of the velocity field to describe a continuous motion. The vorticity is usually denoted by :

$$\vec{\omega} = \nabla \times \vec{v} = \left(\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z} \right) \times (v_x, v_y, v_z)$$
$$= \left(\frac{\partial v_z}{\partial y} - \frac{\partial v_y}{\partial z}, \frac{\partial v_x}{\partial z} - \frac{\partial v_z}{\partial x}, \frac{\partial v_y}{\partial x} - \frac{\partial v_x}{\partial y} \right)$$

To summarize what the vorticity means, we can say that it represents the changements of the velocity vector when it moves by an infinitesimal distance and that these changements in motion are perpendicular to the vector.
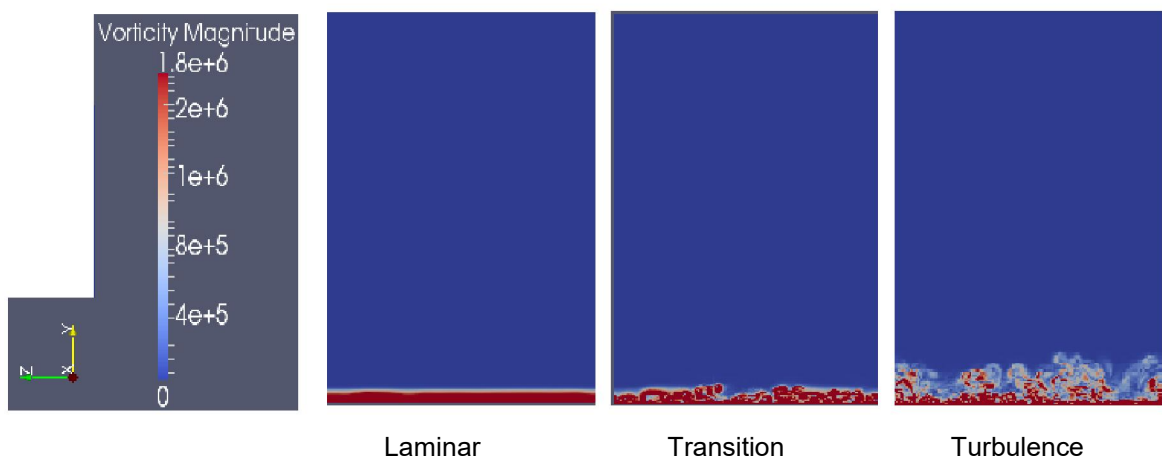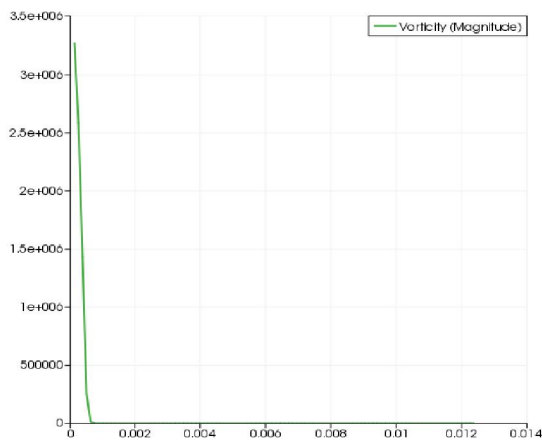

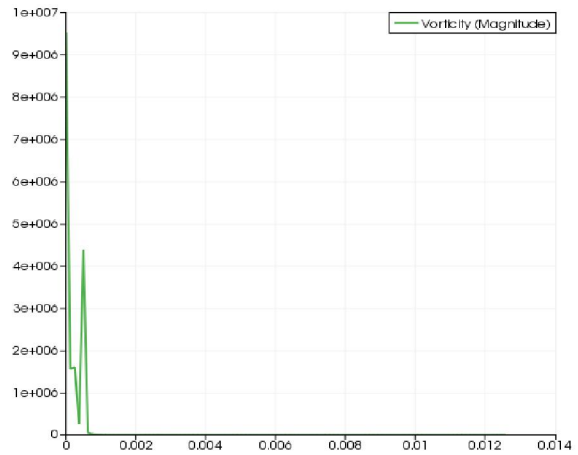*Evolution of the vorticity (s⁻¹) during the flow*

The vorticity is first homogeneous in the fluid during the laminar phase, because of the homogeneous motions of the studied fluid in this regime.

Through the transition regime the vorticity starts to vary. It appears on the pictures like the apparition and the propagation of small vortex. Indeed a beginning of perturbation is observed on the (y, z) plane. The fluid begins to turn, causing an agitation and a variation of velocity of the fluid. Actually the transition regime precedes the arrival of the turbulent regime.

Through the turbulence the vorticity is variable and heterogeneous within the fluid, which appears on the image like clear differences of values in the whole fluid and by the presence of vortices everywhere. This is due to the instabilities and unpredictabilities characterizing the turbulent regime. The behavior of the fluid is thus not mathematically characterizable.

Curve showing the evolution of the vorticity in laminar regime (in s^{-1})

Curve showing the evolution of the vorticity in transition regime (in s^{-1})

Curve showing the evolution of the vorticity in turbulent regime (in s^{-1})

In opposition to the temperature and the velocity, the vorticity reach the zero when y is high. Indeed, in laminar regime, there is no rotation move so the curve goes directly to zero.

In the transition regime, the whirl begin to appear, so the curve shows huge variations of the vorticity when y is low.

In the turbulence regime, the movements of rotation are more present, the curve shows variations until there is no longer fluide.

3.3.4. Calculation of the average of parameters

We can observe this turbulence by plotting graphs of a parameter as a function of time and plot at the same time the mean value of the chosen parameter.

Thanks to this method we can see if the values are close to the mean value, or conversely if they are scattered.
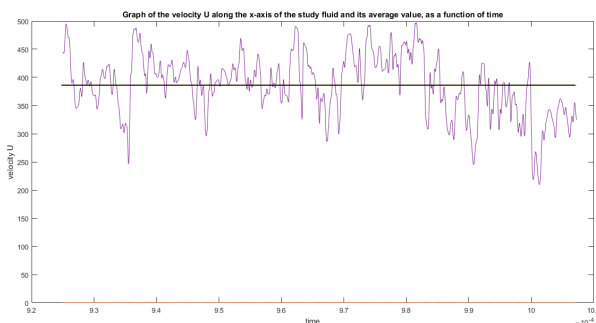
Graph of the U velocity (in m/s) along the x-axis, and its average value, as a function of time (in s)
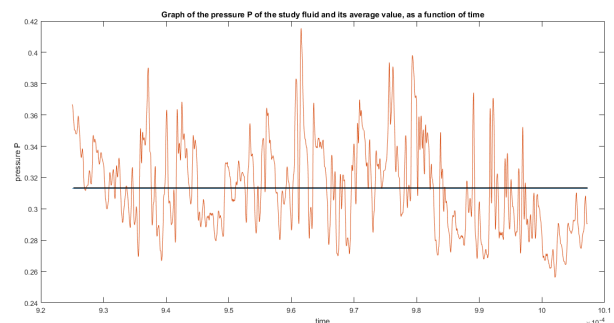
Graph of the pressure P (in Pa), and its average value, as a function of time (in s)

First we compute with matlab the mean value of the parameter U and we obtained U(mean)= 385.9470 m/s.

Then we plot on the same graph U as a function of time and we compared the difference with the mean.

We see values of U vary between 200 and 500 m/s and are not so close to the average.

Then we plot the graph for the pressure P. The obtained medium for P is P(mean)= 0,3130 Pa.

As for parameter U, we observe that the values of the pressure at different time is not close to the average. It varies a lot between 0.26 and 0.42 Pa.

With our data we observed, on each graph we plotted, that there is a difference between the different values of the parameter and its average value.

It thus means we are in the case of a turbulence. However we can't deduce with this method which intervals belong to the laminar state, the transition and the turbulent one.

We need other methods of analysis to determine it.

3.3.5. Fast Fourier Transform and Welch's method

3.3.5.1.   Fast Fourier Transformation

FFT is the most widely used method today to convert a signal from its original domain to its frequency domain

It is used a lot in engineering, science and mathematic areas.

It enables us to compute the magnitude of a signal. It is an infinite sum of trigonometric functions of all the present frequencies where the signal can be written as a sum of cosine and sine functions. The computation of the magnitude of the signal is thus easier.
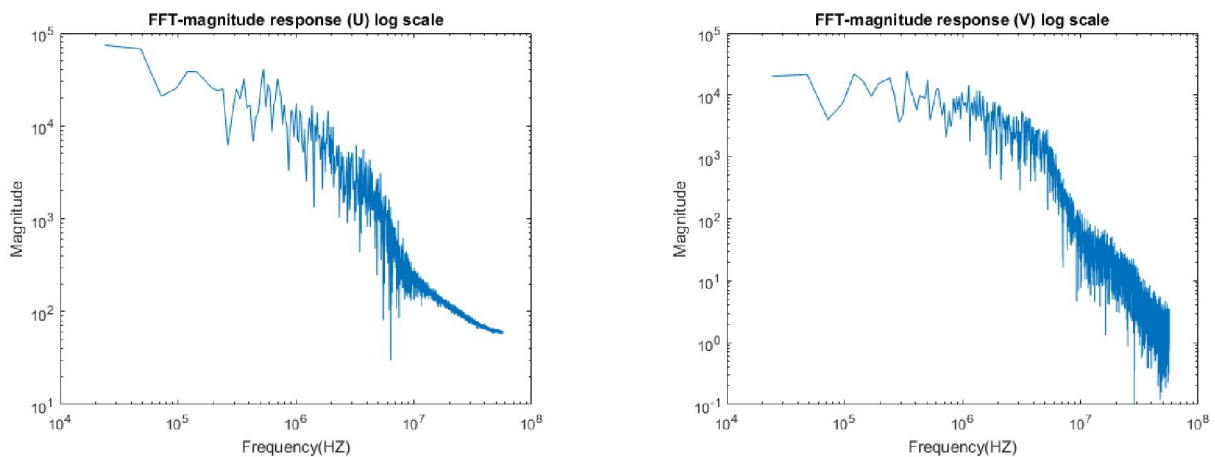
Evolution of the FFT-Magnitude for U and V velocities in high frequencies

The study of the FFT functions for velocities U and V is made for high frequencies.

When we plotted the FFT magnitude of the velocity U, we observe that the magnitude stays almost constant up to 10^6 Hz and the magnitude is about 10^4. After this frequency the magnitude begins to decrease up to a magnitude of 10^2 and we notice a lot of oscillations. More the frequency is big and more the oscillations are numerous and their amplitude increases.

Then we plot the FFT magnitude for the velocity V. Like for the one about the U-velocity we see that there is a lot of oscillations from 10^6 Hz and the amplitude is bigger than for lower frequencies.

The difference between the plot of U and V velocities is the value of the magnitude. It is due to the fact that U and V are not the same at a given time, through the flow and it explains why the magnitude is not identical for both graphs.

3.3.5.2.   Welch's method

This method applies in physics, mathematics and engineering. We can estimate the power of a signal at different frequencies. We can move closer to the spectral density estimation approach.

The goal of this method is to detect the period of the signal and then use its periodicity to see, with graphs, at which frequency the signal occurs.
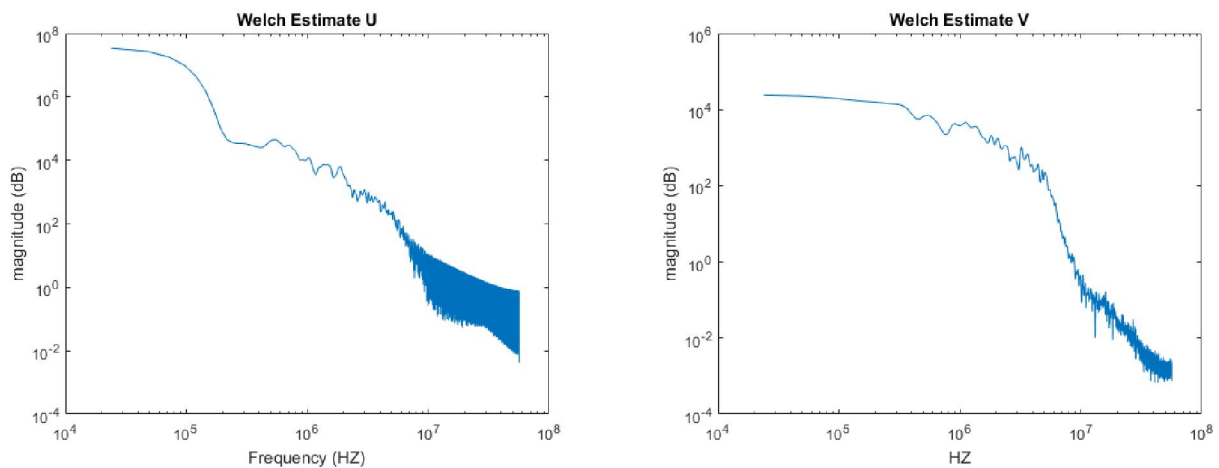
Evolution of the P-Welch for the U and V velocities in high frequencies

First we plotted the P-Welch function for the U velocity. In high frequencies up to 10^5 Hz the magnitude decreases from about 10^8 to 10^4 dB without any oscillations of this magnitude. Then between 10^5 and 10^7 Hz while the magnitude decreases up to 10^2 dB we begin to observe some oscillations but the amplitudes is weak. However after 10^7 Hz the frequency of these oscillations and their amplitude increase.

For the P-Welch function for the V velocity the appearance of the curve is the same as for the P-Welch function for the U velocity. Indeed the magnitude doesn't oscillate up to 10^5 Hz, then the oscillations begin between 10^5 and 10^7 Hz and for higher frequencies the oscillations are numerous and their amplitude is bigger.

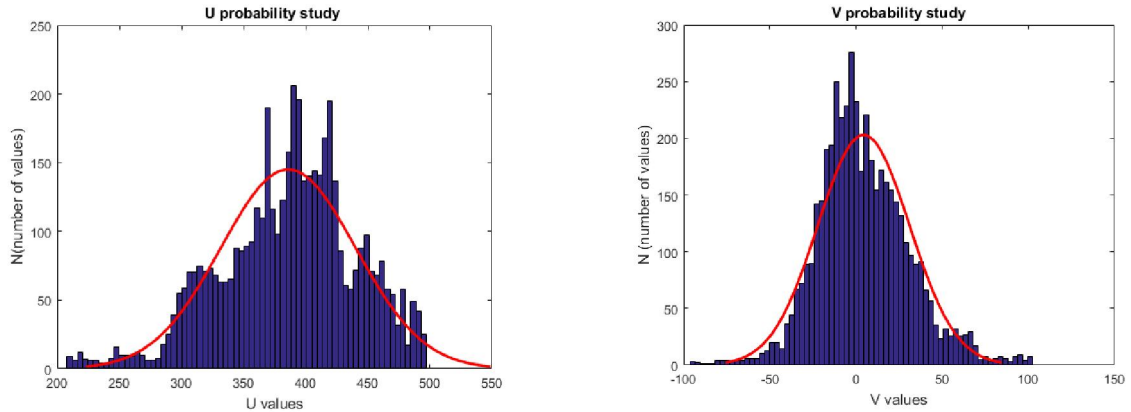### 3.3.6. Probability Density Function

When we plot the probability density function of a variable it gives us the number of time we have a given value. In our case these values are U and V velocities.

Thanks to this method we can see which values are the most present through the fluid. Moreover we also can see if the values are dispersed or closes with regard to the others.

It means we could have a lot of time a same number and not a lot of other values, or we could have a lot of different values and each of them being reached about the same number of times.

In both cases we can then plot the curve of the probability density.

Probability Density Functions for the U and V velocities during the flow regime

The values of U are concentrated between 300 and 450 m/s. We can see on the graph that there are a lot of U velocities around 400 m/s. Moreover we know that the average of the U velocity is 386 m/s. Quite a lot of values are around this average, even if the range is large. It shows this velocity varies during the flow and it justify the turbulent phenomena the fluid is undergoing.

Most of the V values are between -40 and 40 m/s. The range is here smaller than for the U velocity. However it is not constant and is justified because of the turbulence.

By plotting the Probability Density function for U and V we already can say there is a turbulence and we know it will go along the x-axis and the y-axis, because the velocity isn't constant.

Moreover it is another way observe the turbulent phenomena. Indeed we can find the average value of a parameter and see how the values evolve and are dispersed around this value.

For these parameters we see the value are not constant or in a small range. It means that the fluid undergoes a turbulence during its flow.

3.3.7. Joint Probability Density Function

The Joint Probability Density Function fx,y(x,y) applies for continuous variables and is given by the formula :

$$f_{X,Y}(x,y) = f_{Y|X}(y \mid x)f_X(x) = f_{X|Y}(x \mid y)f_Y(y)$$

$f_{Y|X}(y \mid x)$,

$f_{X|Y}(x \mid y)$ The conditional distributions of respectively Y given X=x and X given Y=y

$f_X(x)$

$f_Y(y)$ The marginal distributions for X and Y.

It gives un the probability that each of the U and V parameters in particular ar in a given set of values. We thus can see how is steamed the velocity with respect to the average, i.e. if the values are dispersed around the mean value or so on the contrary they are closed to this value.

It thus informs us about how the velocity components are distributed during the flow.
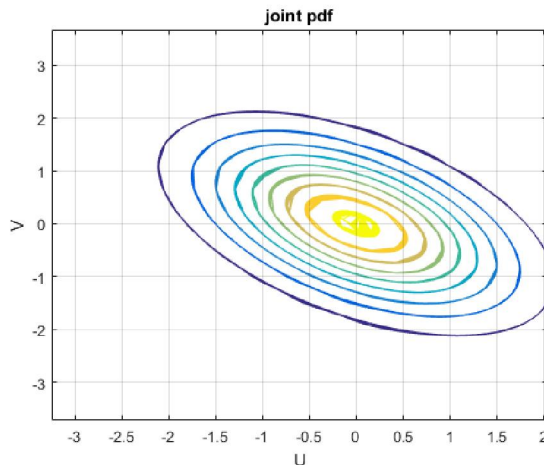
*Joint Probability Density Function for the U
and V velocities through the flow regime*

In our case we see nine different ellipses for the different dispersions.

The centered one is for U=0 and V=0. This ellipse represents the values concentrated around the average of the two components U and V that we chose to analyze.

The other ellipses move away from (0, 0). It means that these values are not constant through the flow and thus we can deduce that the fluid is undergoing a turbulent regime.

3.3.8.   The ios-Q criterion

Through the iso-Q representation of the studied fluid we can observe the magnitude of the velocity at each point of the structure. It means we can see in which part of the structure the turbulence is the biggest.

Moreover the structure can be seen in 3 dimensions to well represent it and then study what could be improved during the flow.

The lambda-ci parameter, used to determine the previously quoted Q criterion, consists in measuring the ratio between the rotational component and the non rotational component of the fluid movement.

Knowing this, we can say that the lambda-ci is minimal during the laminar regime; it is stable and there is not almost of rotational movement due to low vorticity; and this criterion is maximal during the turbulent regime, which is unstable with a rotational movement due to high vorticity.
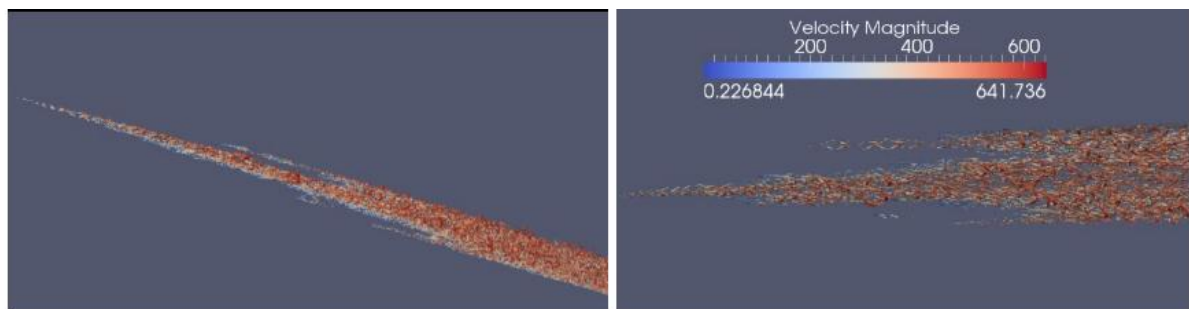
Transition of the iso-Q criteria (vorticity in s^{-1})

4. CONCLUSION AND PERSPECTIVES

To conclude we can say that as we were able to recognize throughout our project there exists a lot of different way to observe the turbulent flow of a fluid. Moreover some functions are more precise to study this phenomena.

This project enabled us to work in group about a complex subject. We learned that it's impossible to focus on each tasks our teachers were asking us to realize. That's why we had to work in small groups of two. For that we had to agree from the beginning of the study, otherwise we couldn't go further.

Moreover we discovered through this project another way to study a natural phenomena and we can know better understand what's happening during a turbulence and justify the change of behavior of the surrounding. For example we now can explain what's happening when we are in a plane and that pilot-in-command tells us to fasten our seat belt. This is because there is a change in pressure, temperature and velocity of the atmosphere and that is why we feel shocks when we cross the turbulence.

Thanks to this project we acquired new methods of work, in particular for the works of group. Starting now we can apply what we learned and it thus will be useful and helpful to be more effective in our future studies and projects.

Moreover as engineer students, it will be brought to us to work as a team with colleagues that we don't necessarily know. We learned during the semester how to organize our work according to the different tasks to be realized and of the time which is given to us.

Among the different possible perspectives of evolution, it could be interessant to have some detailed and comprehensive tutorials about how to use the softwares needed and necessary. Indeed we spent this semester a long time to read and watch a lot of different tutorials to learn how to use them, but there are in these tutorials a lot of things that were not interesting for our work, and it would have been very helpful to have available and simple tutorials to start working more rapidly. Moreover techniques of visualization are today in full development and such softwares will be brought the future engineers to use.

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6. ANNEXES

1. Annexe 1 : Calculation of the average with MatLab (for the U velocity)

```
moy = mean (E8)
u = ones(4708,1)
U = moy*u

plot (E03,U)
hold on
plot (E03,E8)

E03 : column 1, the time
```

2. Annexe 2 : Fast Fourier Transformation with MatLab (for the U velocity)

FFT U
```
fu = fft(u);
ffu = fu(1:length(fu)/2);
```

magnitude U
```
mag_u = abs(ffu);
N = length (mag_u);
F =((0:N-1)*Fe/N)';
loglog(F, mag_u)
title('FFT-magnitude response (U) log scale');
xlabel('Frequency(HZ)');
ylabel('Magnitude');
```

3. Annexe 3 : P-Welch function with MatLab (for the U velocity)

Pwelch U
```
pwu = pwelch(u,[],[],length(u));
N = length (pwu);
F =((0:N-1)*Fe/N)';
loglog(F,pwu)
title('Welch Estimate U');
xlabel('Frequency (HZ)')
ylabel('magnitude (dB)')
```

4. Annexe 4 : Probability Density Function with LatLab (for the U velocity)

PDF U %

```
histfit(u)
title('U probability study ');
xlabel('U values')
ylabel('N(number of values)')
```

5. Annexe 5 : Joint Probability Dencity Function with MatLab (for the U and V velocities)

```
flucu= (u - (mean(u) * ones(4708,1)))/std(u);
flucv= (v - (mean(v) * ones(4708,1)))/std(v);
[U V] = meshgrid(flucu,flucv); %// all combinations of x, y
y = [flucu flucv];
mu = mean(y);
sigma= cov(y);
Z = mvnpdf([U(:) V(:)],mu,sigma);
Z = reshape(Z,size(U));
contour(U,V,Z)
grid on
title('joint pdf');
xlabel('U')
ylabel('V')
```