Simulations versus in situ measurements analysis for detecting, characterizing and localizing flow perturbations

MONTERO Ivan[a], DJERIDI Henda[b], IOANA Cornel[c], BALLESTER Jean Louis[d]

[a]Laboratoire des Écoulements Géophysiques et Industriels (LEGI), ST-MARTIN D'Hères, France.
[b]Laboratoire des Écoulements Géophysiques et Industriels (LEGI), ST-MARTIN D'Hères, France.
[c]University Grenoble Alpes, GIPSA-LAB, ST-MARTIN D'Hères, France.
[d]MOTRHYS, Grenoble, France.

Abstract

Flow perturbation is an important issue that can only be addressed by knowing its origin and characteristics. For long pipes such as those in penstocks, identifying its origin and even its characteristics is challenging. Simulations and data analysis from in situ measurements are both the main methods currently discussed for a quick solution to this issue. The effectiveness of both methods lays down in the amount of data provided and the accuracy of it. For simulations, such data and accuracy are tightly related to the amount of data brought to the model from the real site. In situ measurements analysis does not requires specific information from the site to obtain sufficient and accurate data. Even with only raw data, the use of in situ analysis provide a powerful and fast tool to identify the origin and characteristics of flow perturbations when compared to simulations.

Specific objectives

1-To determine the effectiveness of simulations and local measurements for characterizing flow perturbations.

2-To determine the usable data provided by simulations and local measurements for localizing the origin of flow perturbations.

Keywords: Non-destructive testing, ultrasonic flow meter, matched filter, time-of-flight, CFD analysis

1. **Introduction**

Flows in different applications are eventually changing their behavior due the evolution of the conditons inside the pipes, pumps and external factors. These changes may produce disturbance in the flow that are not desirable and may have little or no clue of its origin. In maintenance, tracking a change in the conditions of the flow due installing a new equipement such as a pump, may be an easy solution, but when no change has been done in the infrastructure, it is clear that the flow disturbance may be produced by variety of causes which may result in a difficult task to locate.

Characterizing the fluid disturbance is one of the main steps before trying to localize and identify the causes of such disturbance. Nowadays, simulations are starting to been used as a method to directly find the location of the disturbance while having a clue about its origin. However, simulations demand accurate and big amount of data in order to modeled a convincing model of the system to be simulated, any detail missed out may convey to the loss of hours performing a wrong simulation.

In situ measurements analysis also provides useful data to characterize, identify and localize flow disturbance without having to worry about getting enough data from the system.

The objective of this study is to compare these two potential methods for detecting and localizing (pin-pointing) a variety of flow perturbations in a pipe. The paper is organized as follows. In Section 2, the reduced-scale Test facility is described, which is used to perform experiments described herein. Section 3 includes the description of the models employed for simulating the reduced-scale test facility in Simulink and the characteristics of the models. Simulation details and results are presented in Section 4. Section 5 provides discussion and concluding remarks.

2. Reduced-scale Test facility

The test facility is "Hydro-Signal platform" (shown in figure 1) of GIPSA-lab, St Martin D'Hères. It is used for recreating transient pressure and flow rate signals, such as, water column separation, water hammer, cavitation among others.

This facility uses a water reservoir (up to 200 liters) capable to be pressurized up to 8 bar. This setup offers the best recreation of the free water surface body, as those seen in dams and lagoons.

50 meters of pipe length are used for recreating and measuring different transient phenomena. The facility also includes several control valves for ensuring a proper regulation of the experiment.

The sensors deployed for these tests are a pressure sensor and ultrasonic transducers (1 emitter and 1 receiver). The sampling frequency for the pressure sensor and ultrasonic transducer is 2Mhz with a resolution of 14 bits. This ensures high speed and fidelity sampling which allows high accuracy transient analysis.

Fig. 1 Reduced-scale Test facility at GIPSA-Lab

2.1 **Setup for obstruction experiment**

We employ control valve V2 indicated by a yellow circle in figure 2, opened at 45° permanently, this generates an obstruction in the flow rate. In order to start the flow we use the valve V1, which is close the output of the upstream reservoir, encircled in blue at figure 3. Figure 4 depicts the used pressure sensor (signalled with a yellow arrow) placed upstream valve V2.

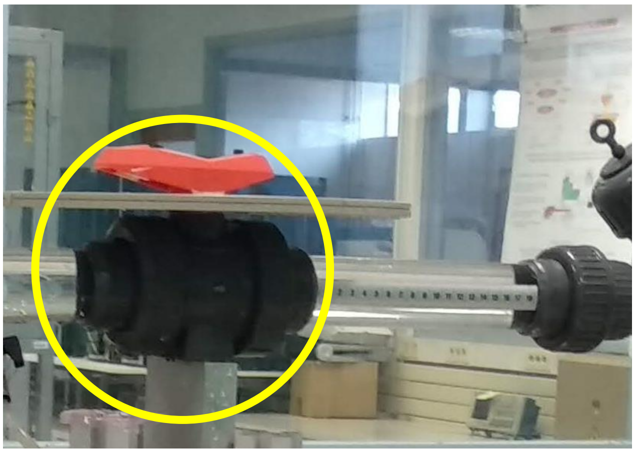

Fig. 2 shows V2 valve, which is a spherical valve used to produce the obstruction by being opened at 45°.

Fig. 3 shows V1 valve, which is a spherical valve used to start the flow in the circuit. It is installed at the output of the upstream reservoir.

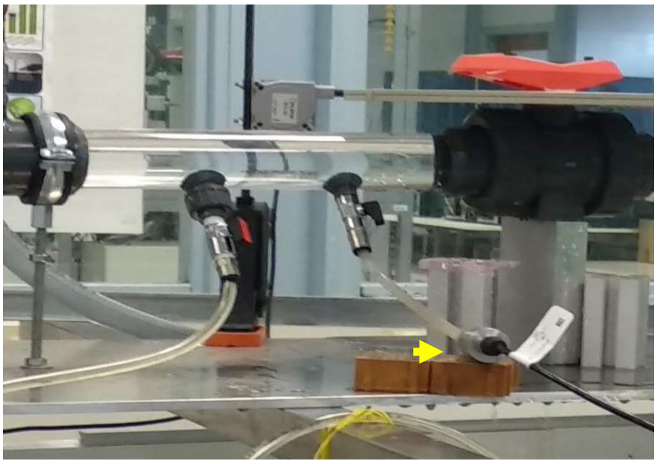

Fig. 4 depicts the pressure sensor (signalled by the yellow arrow) which is installed 10 cm before valve V2;

In addition to the pressure sensor, two ultrasonic transducers where placed downstream V2 in a "Z" configuration, this setup is shown in figure 5. Emitter is facing downstream while receiver is facing upstream.

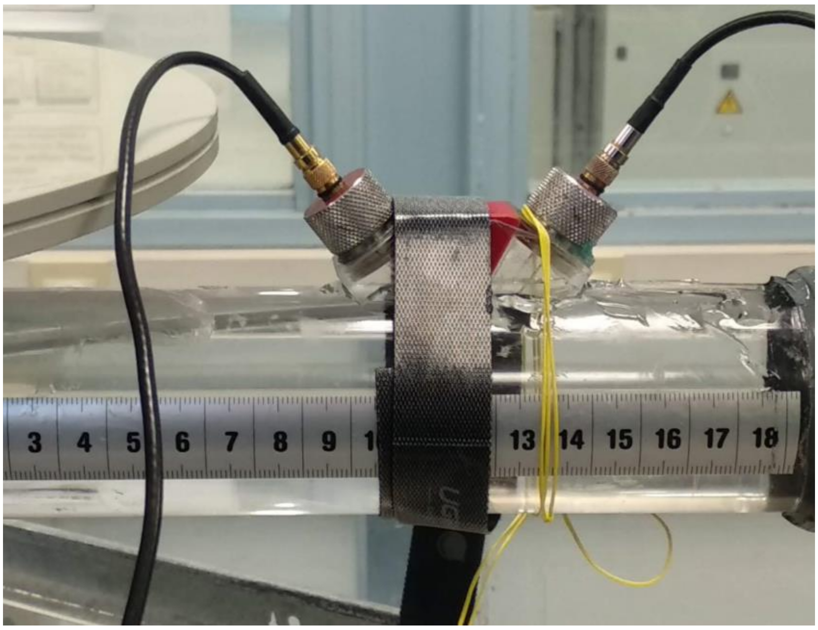

Fig. 5 shows the ultrasonic transducers installed downstream the valve V2. They are installed in a "V" configuration, which means the ultrasonic beam bounces off from the inner wall of the pipe to the ultrasonic receiver performing a "V" trajectory.

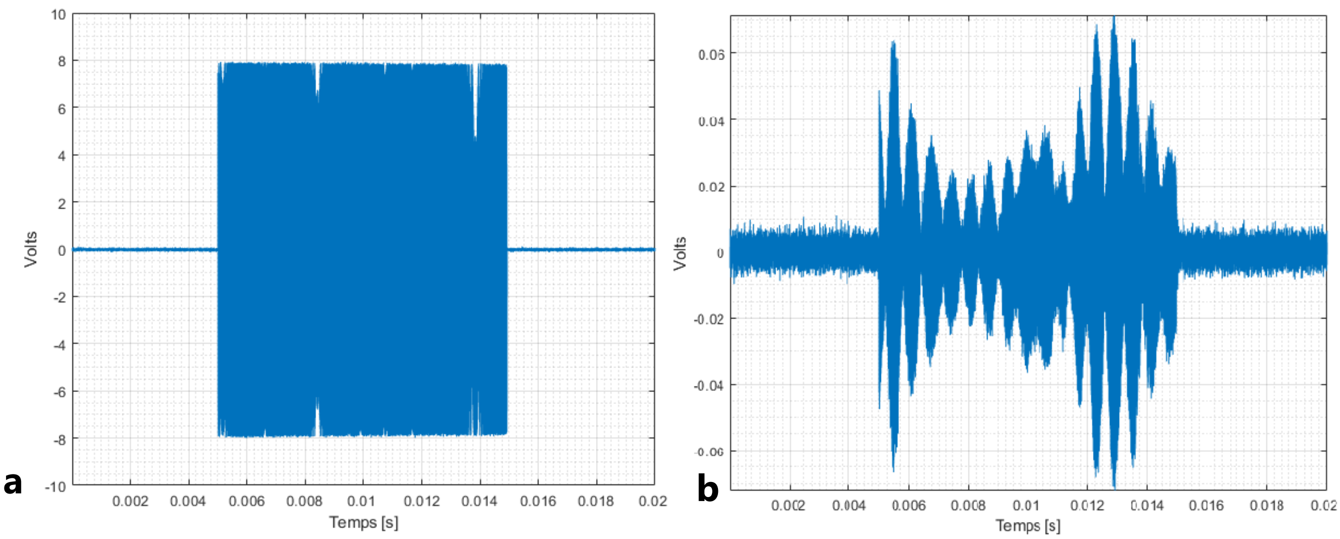

Fig. 6a depicts the ultrasonic signal emitted while Fig. 6b shows the received signal, which has been attenuated by the flow, such attenuation is related to the flow intrinsic characteristics.

3. **Computer model**

The model is fully based on Hydrosignal test facility and was developed using SIMULINK from MATLAB. The solver chosen was ode23t(mod. stiff/Trapezoidal) with a variable-step configuration. Furthermore, the simulation includes real conditions of the test model, such as pressure change on upstream reservoir, flow rate, fitting loses, among others.

Simulation lasts 120 seconds, the same time of each physical test in the experimental setup. 50 simulations were performed for each case, in each simulation we iterated the location of obstruction, this methodology allows spatial discretization of the simulation in order to “pin point” the phenomena (obstruction) by moving it along the pipe and them comparing it to local measures in situ. The longer the pipe the more simulations are required for an acceptable pin pointing of the phenomena. Pressure measure is taken in the same point where the pressure sensor is installed in the test facility, 10 cm upstream valve V2.

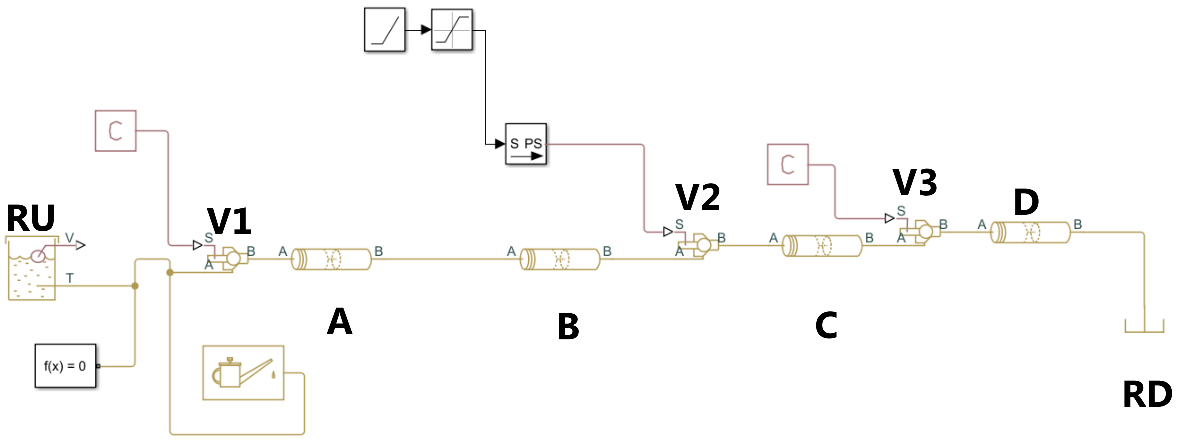

Diagram 1 shows the model built in Simulink, this model does not have any obstruction modelled on it, it serves as benchmark when comparing its behaviour versus the real test facility

The elements in the model are:
RU Reservoir upstream, pressurized and filled with 200 liters of water.
V1 Spherical valve, normally opened in leak model, regulated in obstruction model.
A Pipe segment A, initial length is 49.9 meters, length is reduced as the iterating simulation increases, final length is 0.1 meter.
B Pipe segment B, initial length is 0.1 meter, length is increased as the iterating simulation increases, final length is 49.9 meters.
C & D pipe segments C & D have fixed length and their purpose is to keep the pressure and flow rate close to the ones in the test facility, such segments also exists in the test facility.
V2 Spherical valve, normally closed in obstruction model, regulated in leak model.
V3 Spherical valve, partially closed in both models model, it keeps the maximum flowrate as the one in the test facility.
RD Reservoir downstream at atmospheric pressure.

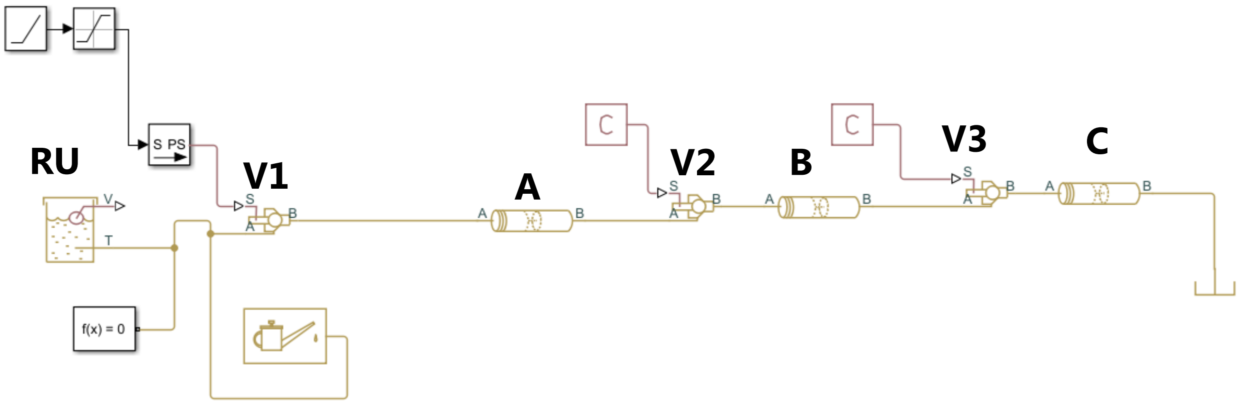

Diagram 2 depicts the model with an obstruction at V2 between to segments of pipes, A and B, such obstruction is the valve V2 partially closed at 45°. The length of segments A and B varies in each simulation, A reduces its length as B increases the same length lost by A. By doing this we effectively test the obstruction (V2), in several locations in order to find the simulation results that better resembles to the measurement in situ. After finding the best matching results we can determine approximation of the obstruction in the real site, the test facility in this case.

4. **Results**

The following figure show the pressure behavior in the test facility with an obstruction. Figure 7a depicts the results from the simulation 1 (1 from 50), where the pressure probe is at is a 0.1 m from the valve V2 (obstruction) and 49.9 m from the upstream valve V1. Figure 7b depicts the results from the in situ measures at the test facility, the location of the obstruction location is fixed at the valve V2 (partially closed at 45°) and is the pressure sensor same as the one in the computer model 1. Furthermore, 2 ultrasonic transducers were placed in "V" configuration downstream valve "V2". Sampling frequency was set to 2Mhz

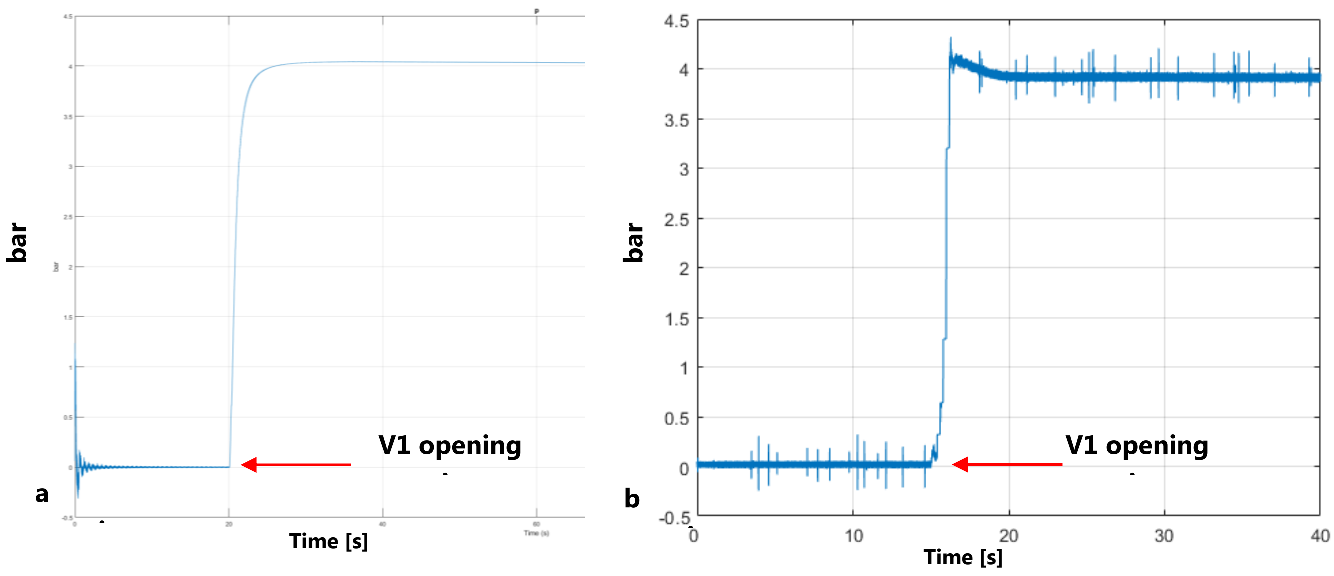

Fig. 7a-b: Pressure behavior computed from simulations (7a) and from in situ measurements (7b).

As shown in both charts, pressure starts from 4.12 bar when valve V1 is still closed, pressure in chart 1 shows a small disturbance as the water in the simulation is moving in small scale before the opening, this is due pressure waves bouncing off the pipe walls and due the long length it is highly amplificated.

Behavior of pressure in the simulation is close to those measured in the test facility, however the fluctuation of the pressure after the opening of the valve V1 (from time 20 s) is less accurate and shows a smoother curve than in reality. There is no peak pressure and no significant reflection of shockwaves as those detected in the test facility (as shown in detail in figure 8). These peaks are caused by shockwaves coming back after encountering valve “V3” which has a fixed opening to keep the same discharge, as the fluid flows more shockwaves travels back and forth, the simulation shows an almost instantaneous stable fluid. It is evident the lack of important information in the simulation results.

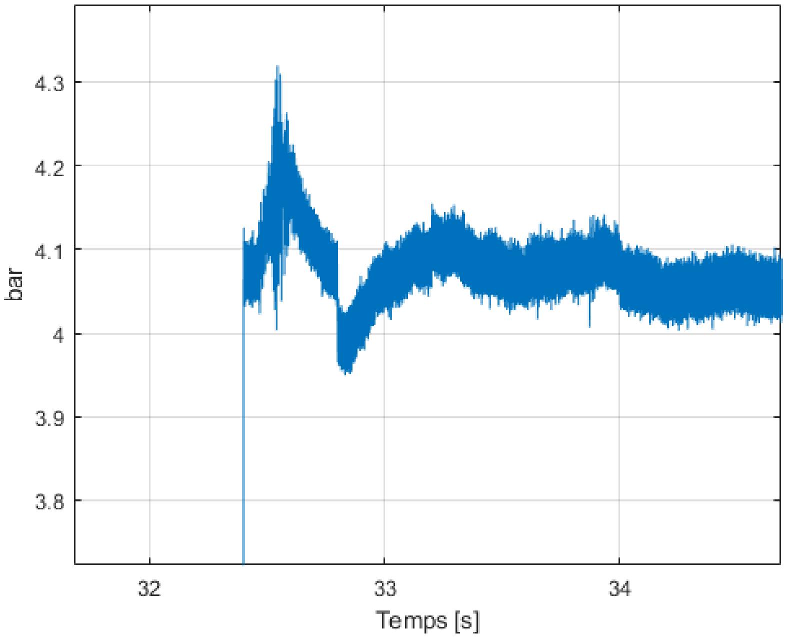

Fig. 8 shows a detailed view of the pressure peak and pressure fluctuation after the opening of V1

Taking a look into the data provided by the ultrasonic receiver (figure 9), we can see there is a change of regime after opening the valve. We also observe improvement in the reception of the ultrasonic signal as it is dragged by the flow, the emitter is facing the flow upstream, this means the signals are "blown off" by the flow. Since ultrasonic transducers where installed with an active flow this is was expected.

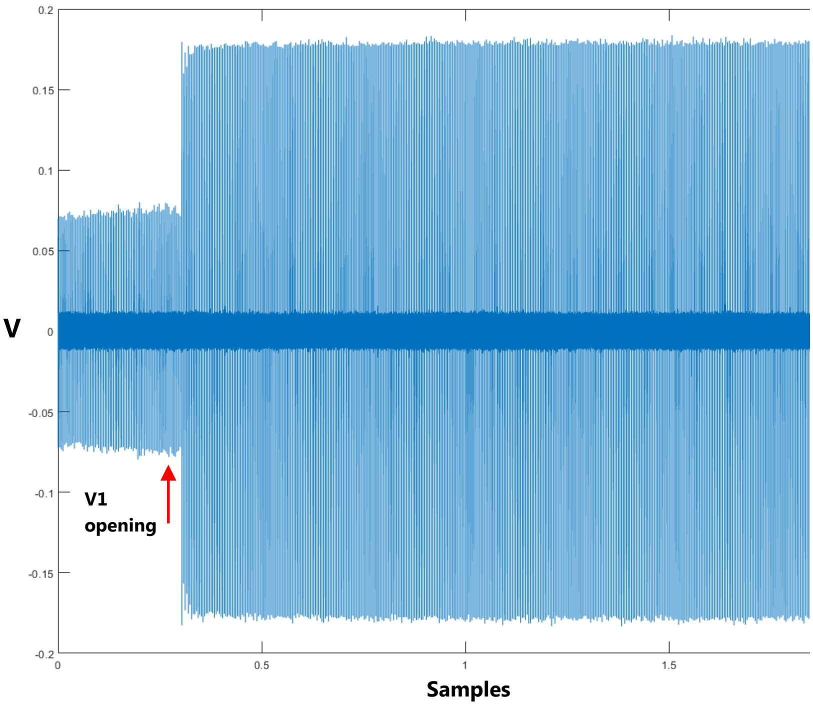

Fig. 9 depicts the development of the ultrasonic signal received before, during and after the opening of valve V1

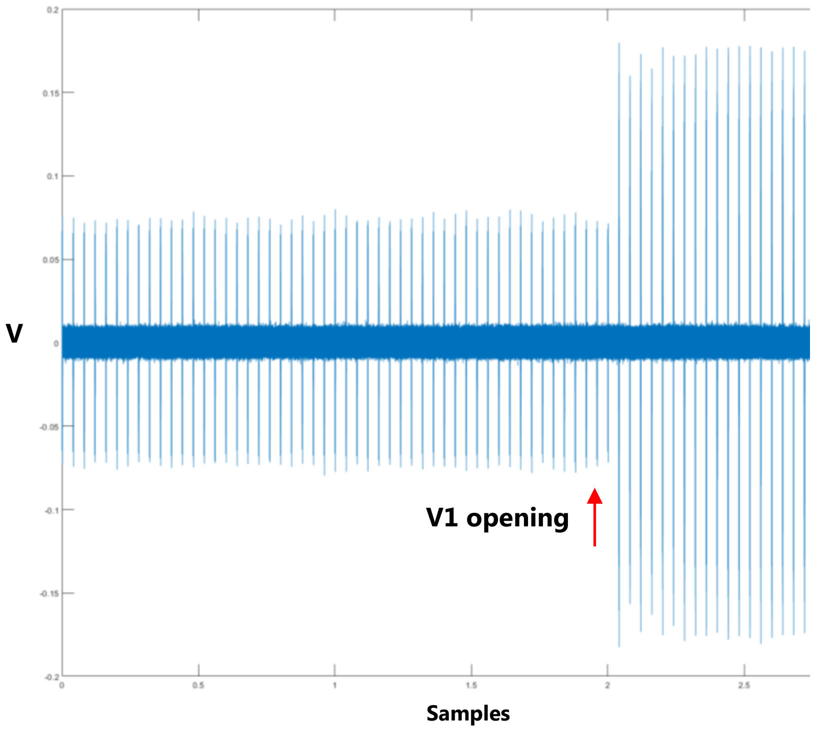

Fig. 10 zoomed-in the region when the valve is opened, it shows no important attenuation after the valve is opened since there is no vapour present due valve V1 cavitating, because cavitation bubbles already collapsed upstream

The next figures (11 and 12) depicts the result of several simulations iterating the location of the obstruction in the model. Charts depict the development of the pressure signal as the obstruction is moved close to the upstream valve V1, where L is the distance from the obstruction point (valve V2) to pressure sensor. A total of 50 simulations were performed (only 4 results are shown per figure, not the total 50 simulations).

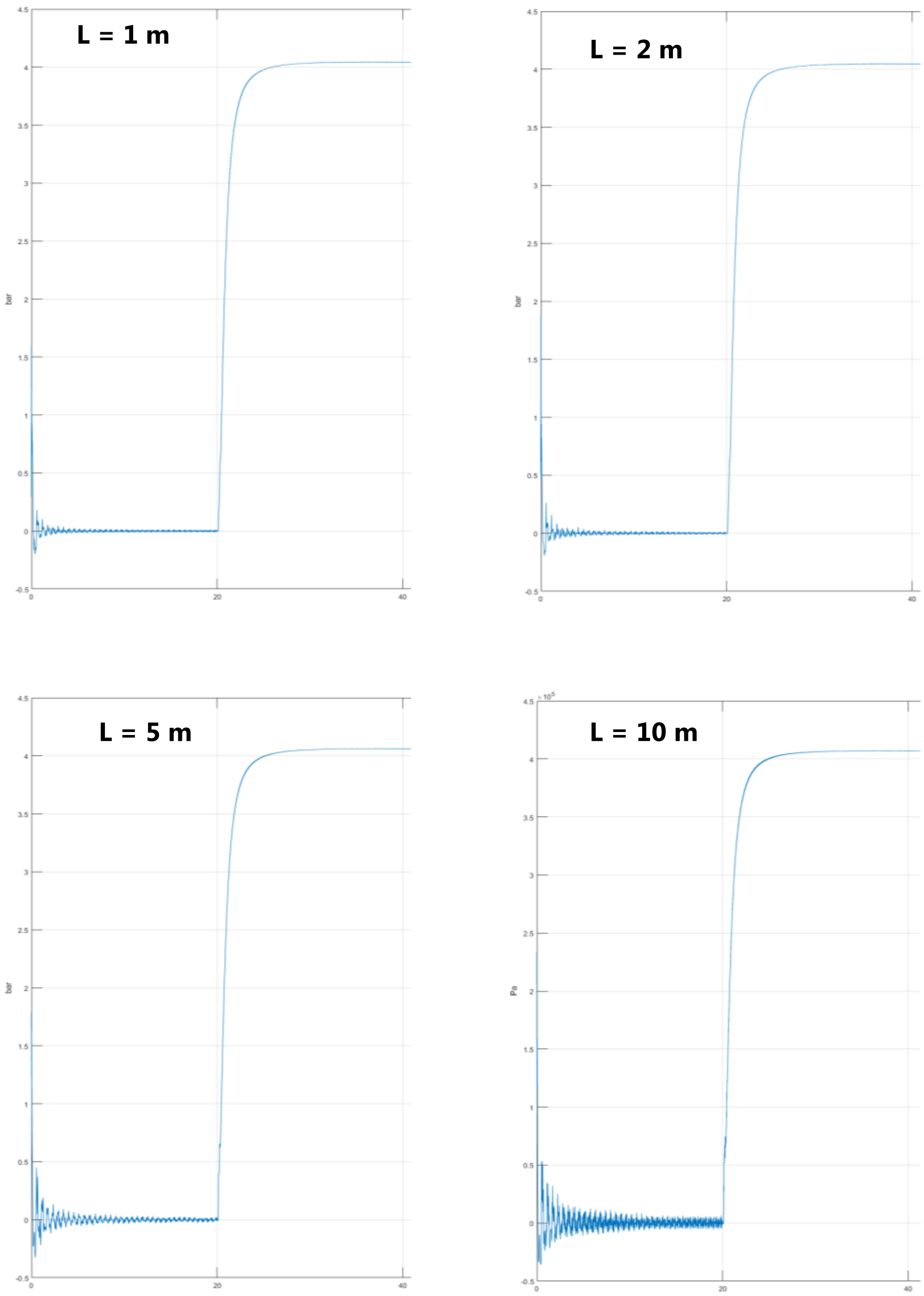

Fig. 11 shows different results of pressure behavior of iterations ranging from 1m to 10m regarding the location of the flow disturbance (valve V2).

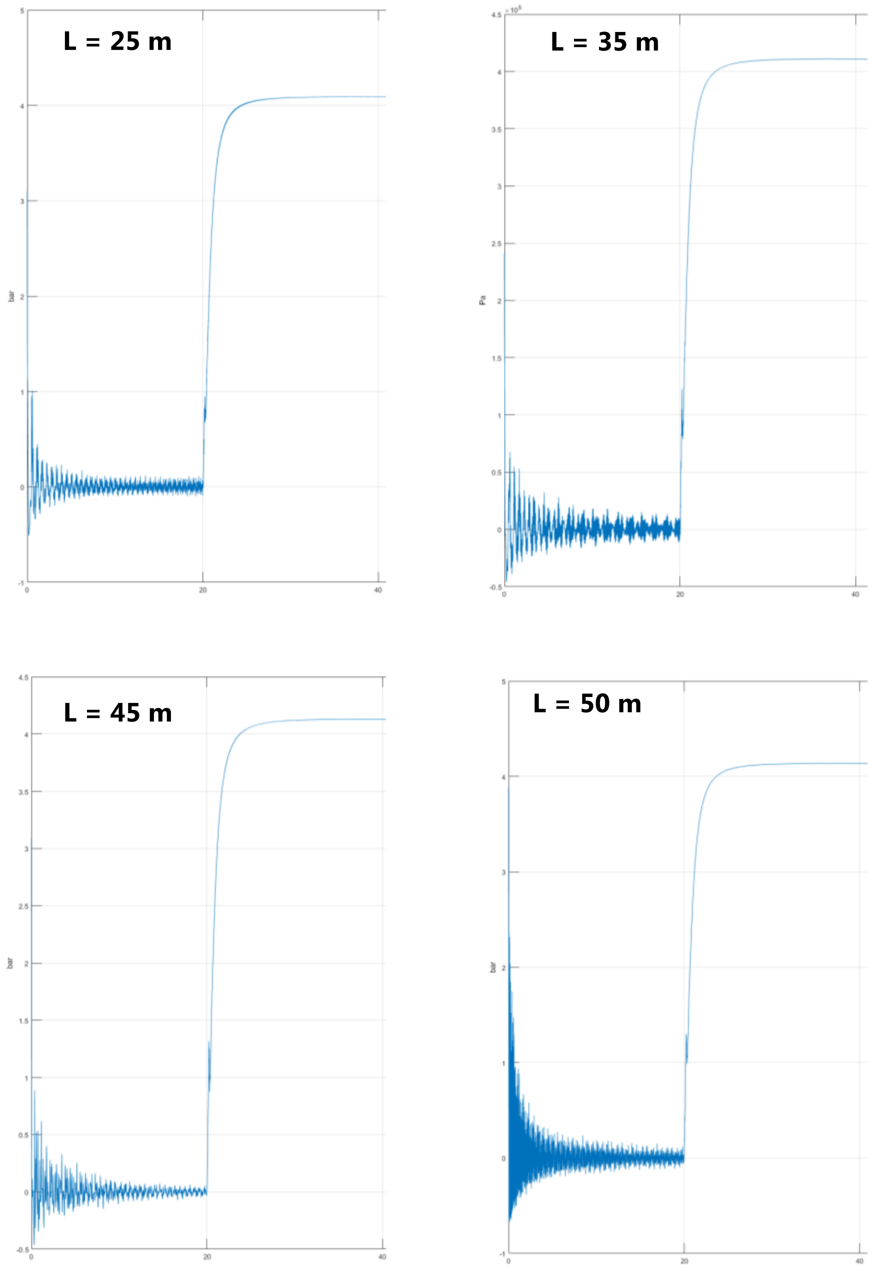

Fig. 12 shows different results of pressure behavior of iterations ranging from 25m to 50m regarding the location of the flow disturbance (valve V2).

In both figures (11 and 12) We observe pressure fluctuation before valve V1 is opened, which corresponds to irrelevant flow displacement filling up gaps and seals in the valves and fittings. Pressure fluctuation increases as the perturbation get closer to the upstream valve V1, since the perturbation is originated even before fluid is flowing through valve "V2" we can confirm these oscillations are negligible. We also found that the smooth curve persists during and after the opening of the valve V1, which does not correspond to reality and does not provide enough data to pin-point and characterize the flow perturbation.

5. **Conclusions**

1-Results from simulations lacks data that could be used to determine the characteristics and type of flow perturbation. Nevertheless, data from simulations did not show convincing presence of any flow disturbance in the system modeled. By contrary, in situ measurements provide enormous amounts of data from the flow. Raw data was useful enough to show the presence of flow disturbance even downstream the pressure sensor, this data can be subsequently analyzed in order to obtain more information from the flow properties, flow disturbances characteristics and behavior of transients.

2- Simulation did not provide any hint of the existence of a flow perturbation and the results did not shown anything important after the flow was opened in all the iterations. In situ measurements, provided enough data to be treated for getting and an acceptable approximation of the location of flow disturbance. Such treatments include some already known in the art, such as power spectral density analysis, which can be applied to benchmark results, the leak/obstruction experiment and data from extra sensors such as the ultrasonic transducers. Simulations even requires in situ measurements in order to get an accurate model and also consume more time than the signal analysis.

We have found that in situ measurements provide more advantages than simulations when dealing with transient flow disturbances and their location in a system.

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