INVESTIGATION OF IN-LINE PRESSURE EFFECT ON PITOT TUBE MEASUREMENTS

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Abstract

Pitot tubes are commonly used to measure gas flow in ducts. The integration of the velocity profile which allows the calculation of the gas flow is described in several international standards such as ISO 3966 or ISO 10780.
The common working principle of Pitot tubes is based on the measurement of the differential pressure between the two different pressure taps. The gas velocity is related to this differential pressure through a flow coefficient depending on the Pitot tube type.
In case of stable flow, in a pressurised duct, fluctuations of the in-line pressure, even low, can occur. If the response times of the two pressure lines (static and total) between the Pitot tube head and the differential pressure sensor are not equal, these fluctuations can be seen as fluctuations of the measured differential pressure and then of the calculated velocity.
This phenomenon is investigated for different design of Pitot tubes and the difference in behaviour of the two pressure lines is highlighted.

1. Introduction

In the middle of the past century, significant work was undertaken on Pitot tubes. This research led to recommendations for proper calibration and use to minimize the measurement uncertainty.

Some of these recommendations are summarized in ISO 3966 [1], for L-type Pitot tubes, in which different error sources are listed. When the conditions are fulfilled, an uncertainty of about 2% (k=2) can be achieved on the flow rate when using L-type Pitot tubes.

However, if fluctuations, even small, of the static pressure occur inside the duct, an artificial differential pressure measured by the pressure sensor could be generated if the response time is not the same at the two pressure taps of the Pitot tube. As a consequence, unexpected fluctuations in the velocity (and flow) would be measured.

This has already been observed in industrial applications when measuring an air flow rate of a slightly pressurized flow with a L-type Pitot tube, as shown in Figure 1.

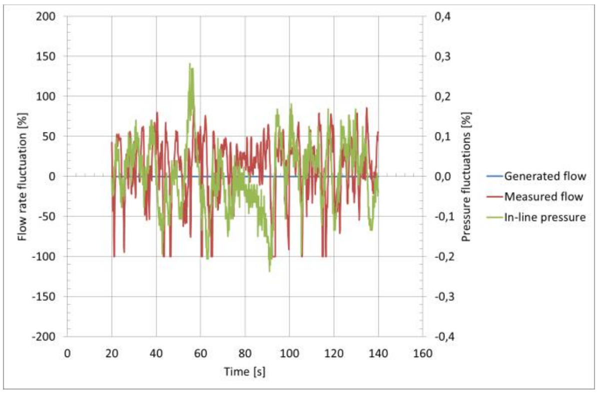

Figure 1: Results of unexpected fluctuating flow rate observed in a pressurized duct

In this application, a flow is generated at a rate of 3.2 m^3/h and an overpressure of 150 mbar in the pipe. This flow rate is measured with a mass flow meter. The observed fluctuations of flow (blue line, left axis) and pressure (green line, right axis) are both less than 0.2% of the flow rate.

When measuring the flow with a Pitot tube inserted in the pipe, the observed fluctuations (red line, left axis) are 60% of the rate.

In order to contribute to the understanding of this phenomenon, this paper presents some analysis for different types of Pitot tube.

2. Preliminary results

2.1 Pitot tubes

In 2018, preliminary results were presented at ISFFM [2] for 8 Pitot tubes of different design. In this paper, 7 of these 8 ones are under investigation:

- 6 are L-type Pitot tubes designed according ISO 3966 [1] and are of different head diameter: 2 are of NPL type, 1 is of AMCA type and 3 are of CETIAT type. They differ by the shape of the nozzle
- 1 is a straight Pitot tube manufactured by TSI Inc.

Table 1: The tested Pitot tubes

Pitot tube type		Designation and head diameter (mm)
NPL		MAG1 (Ø8) MAG2 (Ø4)
AMCA		MAG4 (Ø5)
CETIAT		ANEMO2 (Ø4) MAG3 (Ø3) MAG5 (Ø8)
TSI		ANEMO3

When using a Pitot tube, the relation between the measured differential pressure, ΔP, and the velocity, V_{Pitot}, is given by Equation (1):

$$V_{Pitot} = K \times \sqrt{\frac{2 \times \Delta P}{\rho}} \quad (1)$$

with:

- ρ, the density of air
- K, the coefficient of the Pitot tube, closed to one for the Pitot tubes designed according ISO 3966 [1] or specified by the manufacturer for the others

2.2 Experiment facility and results

In 2018, preliminary results were presented at the ISFFM conference [2]. A fast decrease of pressure in a closed chamber was generated and the measured differential pressure by the Pitot tube recorded, as well as the pressure inside the volume.

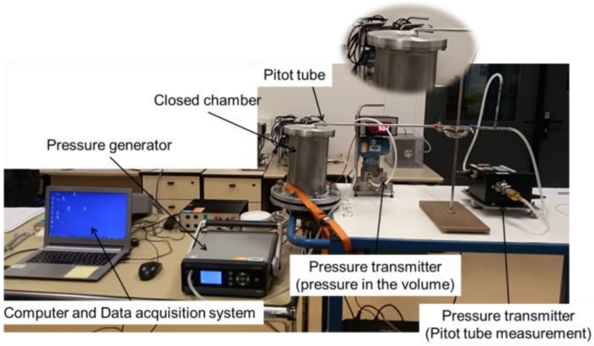

Figure 2: Experimental setup for characterization of Pitot tube

In the setup (Figure 2), the differential pressure is measured with a MKS 220D pressure transmitter (range ± 2 torr), the pressure in the chamber with a Rosemount 3051 pressure transmitter (range 0 – 400 Pa). The measurements are recorded with an Agilent 34972A data acquisition system. The closed chamber is a cylinder with a height of 27 cm and a diameter of 13.5 cm.

A pressure generator was used to set the pressure in the closed chamber at a given value over the atmospheric pressure. The tests were performed at a pressure of 50, 100 and 150 Pa.

The Pitot tube was put tightly in the closed chamber in such a way that the total pressure tap was not directly submitted to the flow generated by the pressure decrease.

The results of the tests were drawn as in Figure 3 for the Pitot tube named MAG4 and an initial pressure of 150 Pa in the closed volume.

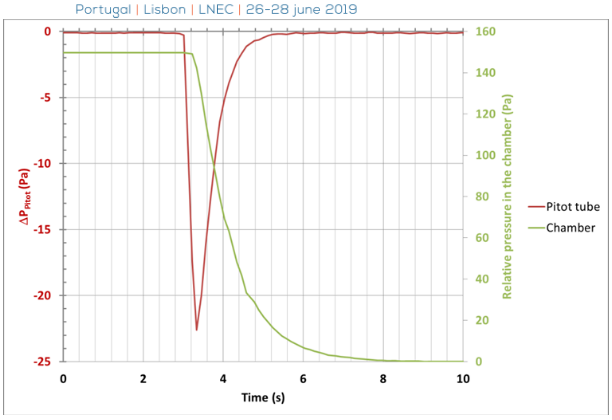

Figure 3: Differential pressure measured by the Pitot tube (MAG4) and pressure in the chamber over time

At the beginning and the end of the test, the measured differential pressure (red line, left axis) is zero as there is no flow in the volume. During the decrease of the static pressure (green line, right axis), a peak is observed in the differential pressure measurement.

In 2018, it has been shown that the value of this peak is depending on the Pitot tube type, its head diameter as shown in Figure 4.

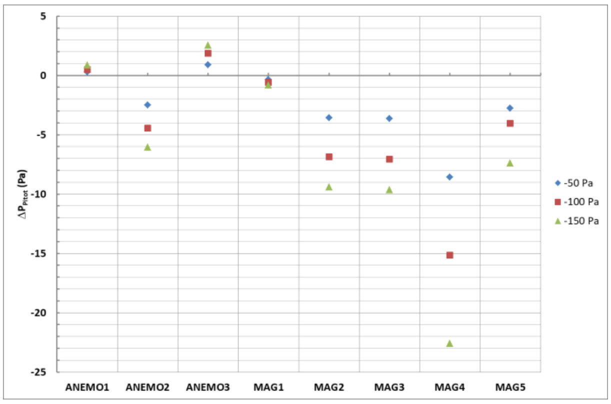

Figure 4: Maximum differential pressure measured by the Pitot tubes

It depends also on the length of the tubing between the "+" or the "-" ports of the pressure transmitter and the pressure taps at the Pitot tube.

3. Characterization of the pressure lines of the Pitot tubes

3.1 Experimental setup

In 2018, it was then demonstrated that the observed fluctuations were due to a difference in the response time of the two pressure lines of a Pitot tube. The response time of the line is depending both on its resistance and on the encapsulated volume.

In 2019, a new experiment has been set up (Figure 5) to evaluate separately the resistance of the static pressure and total pressure lines of a Pitot tube.

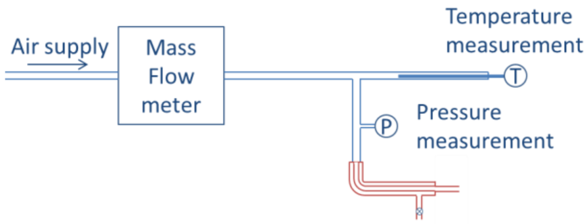

Figure 5: Scheme of the set up for the measurement of the resistance of a Pitot tube pressure line

In this experiment, the objective is to measure the flow rate at a pressure line (total or static) for a given upstream pressure while the second pressure line is kept at atmospheric pressure.

The upstream pressure is measured with a MKS 220D pressure transmitter (range ± 2 torr) and adjusted between 10 and 200 Pa.

At each upstream pressure, the mass flow rate is measured with a:

- Molbloc L meter above 75 cm^3/min
- Brooks 5850E mass flow controller between 7 and 75 cm^3/min
- Alicat MC-10SCCM mass flow controller below 7 cm^3/min

Nota: The flow rate is expressed at normal conditions of temperature and pressure (0°C, 101325 Pa).

3.2 Results and discussion

The measurements are performed for the seven Pitot tubes listed in Table 1 and the results are presented in Figure 6a and 6b as the upstream pressure against the measured mass flow.

For all the tests, the used tubing is the same and the observed difference in the resistance of the Pitot tubes is then the one due to the Pitot tube pressure line itself.

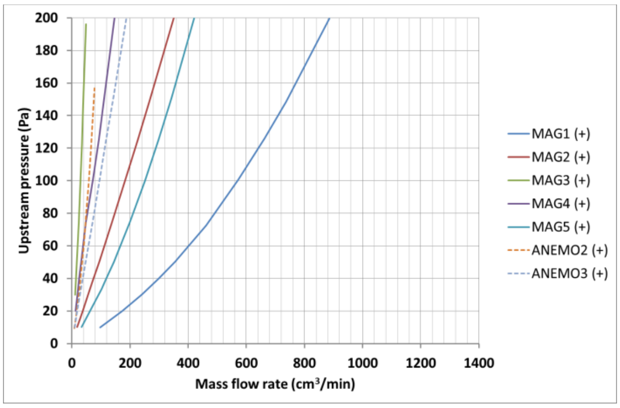

Figure 6a: Resistance of the total pressure line for the different Pitot tubes

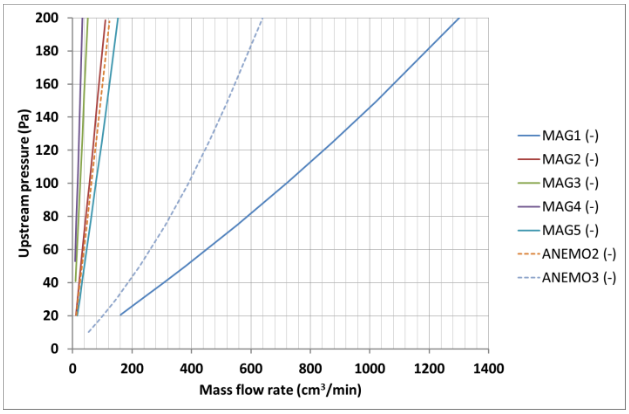

Figure 6b: Resistance of the static pressure line for the different Pitot tubes

Considering an upstream pressure, the higher the flow rate is, the faster the pressure balances in the encapsulated volume of a given Pitot tube line.

For the different Pitot tubes, the pressure is related to the mass flow rate as a linear function or a combination of a linear and a function of degree 2.

Several situations can be found. The pressure lines of the MAG4 Pitot tube are both related with a linear function to the mass flow rate as shown in Figure 7 below.

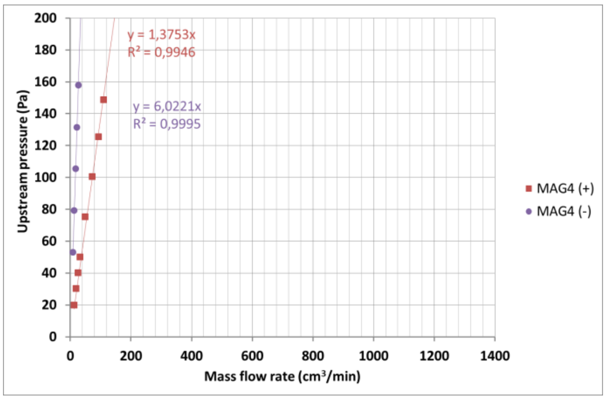

Figure 7: Resistance of the two pressure lines of the MAG4 Pitot tube

The pressure lines of the MAG1 Pitot tube are both related with a sum of a linear and a quadratic function to the mass flow rate as shown in Figure 8 below.

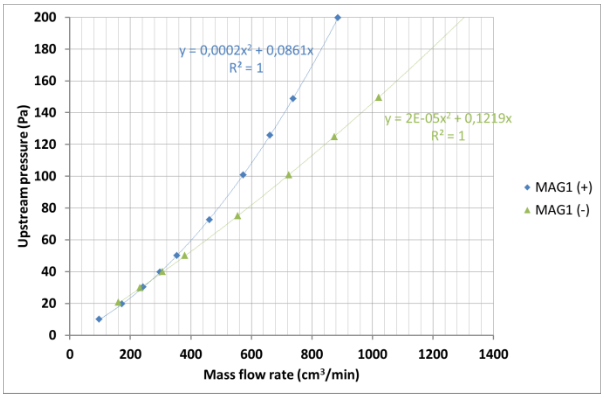

Figure 8: Resistance of the two pressure lines of the MAG1 Pitot tube

Moreover, some intermediate situation can be found, as for Pitot tube MAG5 with a static pressure line presenting a linear function when the total one is the sum of a linear function and a quadratic one.

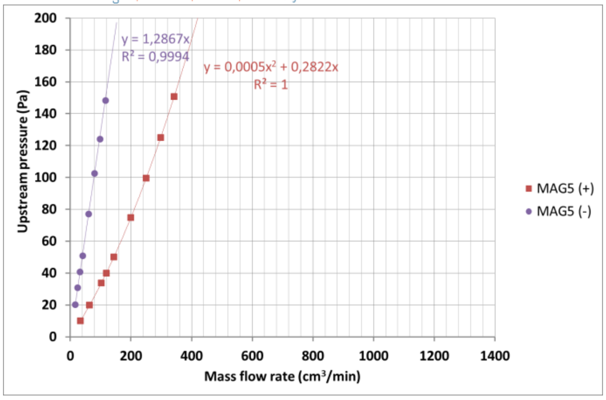

Figure 9: Resistance of the two pressure lines of the MAG5 Pitot tube

Furthermore, it can be noticed that for all Pitot tubes the resistance is almost equivalent for the two pressure lines except for the straight and non-normalized one, named ANEMO3 for which the total pressure line is much more resistant than the static one as shown in Figure 10.

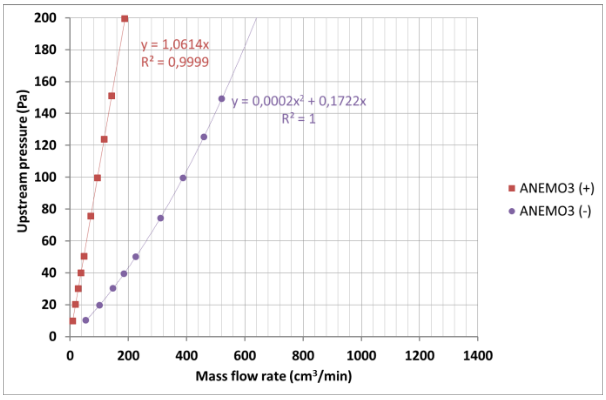

Figure 10: Resistance of the two pressure lines of the ANEMO3 Pitot tube

When the resistance is high, it is then driven by a linear relation to the mass flow rate whereas it is driven by the sum of a linear and a quadratic function when it is low. This behaviour is neither explicitly related to the type of the Pitot tube nor by its diameter.

When the resistance of the static pressure line is low (MAG1, see Figure 8 and ANEMO3, see Figure 10), the time to reach the equilibrium in the encapsulated volume is small. As a consequence, the error on the measurement of the fluctuations of the static pressure in a pipe is small. The differential pressure measured by the Pitot tube when submitting to a step change of pressure is then close to zero for the MAG1 Pitot tube which presents also a low resistance on the total pressure line and slightly positive for the ANEMO3 Pitot tube with a higher resistance on the total pressure line.

4. Conclusion

Unexpected of fluctuations in flow can be observed when using a Pitot tube in a pressurized pipe. In 2018, this phenomenon has been highlighted for different types of Pitot tubes.

The objective of the tests carried out this year was to highlight the characteristics of the static and total pressure lines separately.

It has been identified that the phenomenon is mainly driven by the resistance of the static pressure line.

Some further investigations should be performed to be able to give recommendations for the design a low resistance static pressure line of a Pitot tube, and to deduce a predictive model allowing the determination of the expected fluctuations for a given Pitot tube.

References

[1] ISO 3966: *Measurement of fluid flow in closed conduits — Velocity area method using Pitot static tubes*, 2008.
[2] Care I, Fourneaux F, "Investigation of in-line pressure effect on Pitot tube measurements" in *ISFFM Proc*., 2018.