ACOUSTIC PYROMETRY FOR FLOW VELOCITY ESTIMATION: PRELIMINARY ANALYSIS

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ABSTRACT

Acoustic pyrometry uses the variations of the speed of sound in a medium to determine its temperature. One of the assumptions at the base of this technique is that the flow velocity component in the direction of the acoustic path is negligible in comparison to the speed of sound. However, if the temperature of the medium is known, the acoustic pyrometry approach can be used to determine flow speed if the flow is not perpendicular to the acoustic path. The combined approach of temperature and velocity determination is also known as acoustic tomography. This technique allows the determination of velocity and temperature maps in a flow region. Even though this is an interesting rsults, the mathematical approach to solve the velocity and temperature fields might be very complex and sensitive measurement set-up. In this study, a preliminary investigation is carried out to determine the flow velocity by starting from the time of flight of an acoustic signal moving along different acoustic paths in a constant temperature field. For this purpose, a simplified geometry is considered. The developed mathematical approach at the base of the methodology is presented in this study.

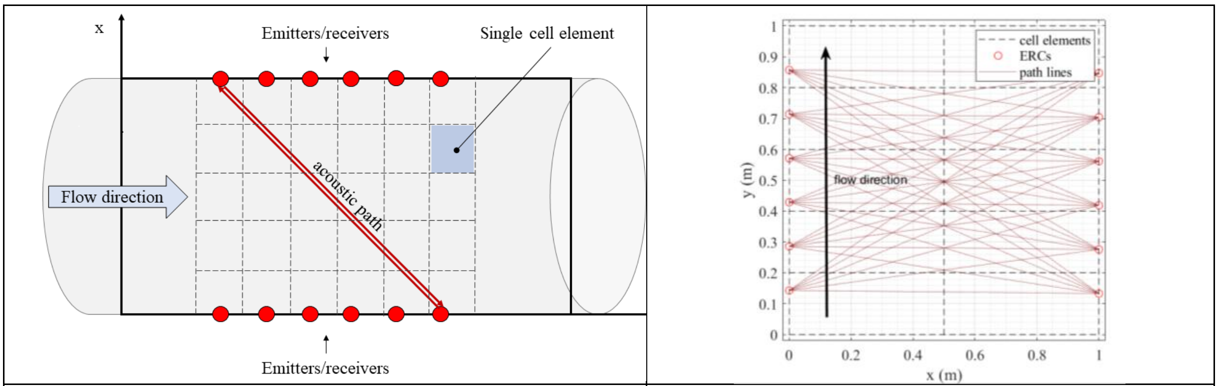
INTRODUCTION

Recently an increasing interest is being paid to acoustic pyrometry as it allows the estimation of a temperature distribution in a section with virtually no interactions with the flow. Acoustic pyrometry is based on the measurement of the time of flight of an acoustic wave along a known path. As the propagation speed of the wave is directly related to medium temperature, the travelling time of the wave can be related to the encountered temperature. If the temperature is not uniform, multiple emitter-receiver couples (ERCs) laying on the same plane can be used to reconstruction a temperature map in a section. These measurements are generally performed in a section perpendicular to flow velocity. In this way (under the hypothesis of a subsonic flow) the impact of flow velocity on temperature estimation may be considered as negligible. On the other hand, the flow velocity component along the acoustic path may be estimated with a similar approach if the flow temperature is known and an acoustic path which is not perpendicular to flow velocity vector is considered. In this case, the time-of-flight measurement provides an apparent sound speed that can be used to estimate the flow velocity component along the acoustic direction.

By combing both approaches, typically by considering two adjacent sections instrumented with several ERCs, is it possible to estimate both flow velocity map and temperature map in a region. In this case the technique is named: acoustic tomography [1,2]. In a first analysis step, the temperature map in the two sections and in the region in between is estimated directly and by interpolation, respectively. In a second analysis step, once the temperature distribution is supposed as known, the velocity field may be reconstructed by considering the ERCs in the two opposite sections. As velocity and temperature are generally not uniform, a complex mathematical approach is necessary to determine the two maps. In this study, being a first approach to acoustic tomography, the problem has been simplified to specifically focus on the problem of estimating a flow velocity map by considering the time-of-flight of an acoustic wave.

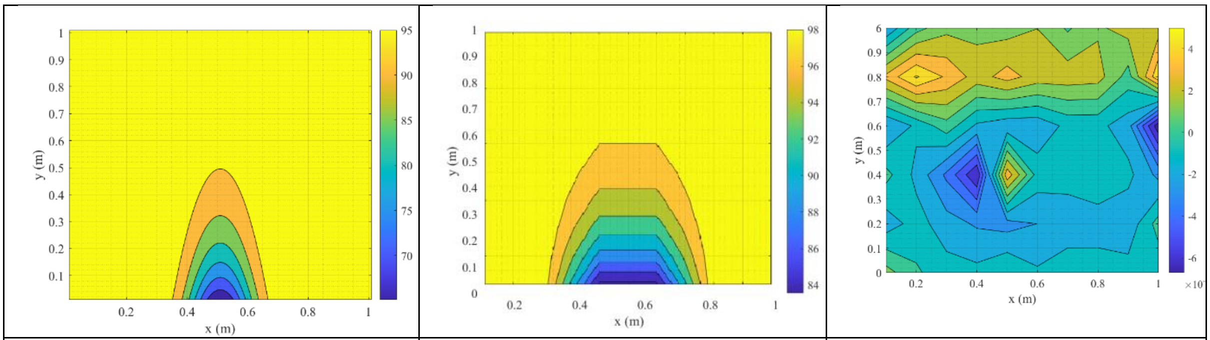
RESULTS AND DISCUSSION

This study aims at investigating the potential capability of an acoustic pyrometry setup for the estimation of flow velocity. As a case study, the flow in a circular duct with a diameter of 1meter was considered. The velocity along a plane passing for the duct axis was investigated. For this purpose, two rows of microphone/speaker couples were supposed ideally placed along two opposite duct generatrixes (Figure 1a). The distance between each emitter/receiver couple can be easily determined by considering the duct geometry and their spacing. If flow temperature is known and a subsonic flow is assumed, the estimation of the time of flight of an acoustic input between two measurement points in opposite positions allows the determination of the apparent sound velocity along the path (Figure 1). This apparent sound velocity is a composition of the velocity of sound and the flow velocity component along the acoustic path. In case of a not-uniform flow velocity, this apparent sound speed is related to all flow velocity components along the acoustic path. By using multiple acoustic paths laying on the same plane, and dividing the region in cells, a reconstruction of the velocity map in the plane is possible (Figure 1b). An iterative mathematical procedure is necessary for this calculation. This mathematical procedure in very sensitive to emitter/receiver number and spacing and number of investigation cells. To test the sensitivity of the approach to these parameters, a sample flow velocity distribution was considered (Figure 2a). This was basically a uniform flow with a strong wake in the middle region. Several combinations of emitter/receiver number and spacing, and number of investigation cells were used. The capability of reconstructing the original flow field was investigated. As an example, the flow field reconstruction and the velocity errors are shown in Figure 2b and Figure 2c, respectively, in case of 10 ERCs and a mesh of 60 cells.



(a) **(b)**

Figure 1. Considered measurement setup (a) and calculation domain in case of 10 cells and 6 emitter-receiver couples per side (b)



(a) **(b)** **(c)**

Figure 2. Given velocity profile (a), reconstructed velocity profile (b) and estimation error (c) with 10 ERC per side and 60 cells

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[2] Ziemann A, Arnold K and Raabe A “Acoustic tomography in the atmospheric surface layer”, 1999, Ann. Geophys. 17 139–48.