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Short communication

# Estimation of the correction term of pitot tube measurements in unsteady (gusty) flows

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ABSTRACT

In rough environments (train's underbody, wind carrying sand etc.), the only feasible means of measuring flow speed is with a Pitot tube. Unsteady (gusty) flow effects can cause large errors in flow speed measurements. In this short communication work, an attempt has been made to identify these errors. Based on potential flow theory, a term that takes into account the unsteady effects has been proposed to correct the Pitot tube measurements in unsteady (gusty) flow conditions. Experiments have been performed in an open circuit-closed test-section, low-speed wind tunnel, designed and built at the Instituto de Microgravedad "Ignacio Da Riva" of the Universidad Politécnica de Madrid (IDR/UPM). Different types of Pitot tubes have been used to check the validity of the correction term proposed. It has been shown that the distance between the total and static pressure taps has a major influence on the Pitot tube correction term.

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## 1. Introduction

For many years, Pitot tubes have been used to measure the local velocity of fluid flows. The expression "Pitot tube" is credited to Henri Pitot [1] who formalized its use and gave his name to this measuring device. A standard Pitot tube consists essentially of a right-angled tube with an open end facing the fluid flow, usually referred to as the total pressure tube. The velocity is measured from the pressure difference between this tube and the static pressure tap, which is an opening flush with the tube and tangential to the flow direction. The static tap registers the static pressure. The pressure difference results from the conversion of the fluid's kinetic energy into an increase in pressure when the flow comes to rest at the orifice facing the flow. Pitot tubes are mainly used for incompressible, laminar or turbulent flows. Both static and total pressure tubes are connected to a pressure transducer to measure the pressure rise associated with the deceleration of the fluid flow.

Concerning the flow measurements and type of Pitot tube to be used, numerous studies can be found. The history of the different kinds of Pitot tubes can be found in Brown [2]. Self-averaging Pitot tubes using a total/impact pressure tube with a number of total pressure openings were developed by Taylor [3]. A simple mathematical model that corrects the velocity measurements obtained by a square nosed Pitot tube, which had a radial movement within a flow channel, can be found in Ranga Raja et al. [4]. A modified ellipsoidal Pitot tube was calibrated in a wind tunnel and used to improve the accuracy of air velocity measurements. The results obtained from this study is reported in Klopfenstein [5]. A study of several possible measurement errors of different types of Pitot tubes can be found in Paresh [6]. An in-situ portable measuring system that can be used to measure the flow rate of wells that discharge into irrigation canals was developed by Replogle and Wahlin [7].

Most of the studies in the abovementioned references consider a steady flow condition. However, the necessity of measuring flow speed in various unsteady flow conditions has been increasing. But a well-known problem in the unsteady, accelerating, or fluctuating fluid flow is, "the inertial effects of the fluid induce changes in the measurements that can be considered as an uncertainty in a Pitot tube measurements" Pratt [8]. In the present paper, to correct the Pitot tube measurements obtained under unsteady flow condition, a pressure correction term, $T_{ct}$, is proposed and implemented by the application of potential flow theory [9,10].

Indeed, the implementation process was approached in two steps. First, based on potential flow theory a correction term for the unsteady effects, $T_{ct}$, was identified. Then, an experimental test campaign was performed to obtain experimental measurements to validate the model. Measurements with four types of Pitot tubes

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**Nomenclature**

| | |
|---|---|
| $C_f$ | correction factor with respect to velocity pressure |
| $C_{f\max}$ | maximum value of the correction factor for the Pitot tube measurements |
| $f_g^N$ | nominal gust frequency |
| $f_g^F$ | gust wind frequency obtained by the sinusoidal fitting data |
| $f_m$ | electrical power frequency supplied to the fan's rotating motors |
| $p_0$ | total pressure of the Pitot tube |
| $p_e$ | static pressure the Pitot tube |
| $PT^{SP}$ | simulated pressure with the proposed correction term |
| $Q$ | intensity of the source |
| $q_{HW}$ | velocity pressure obtained from hot-wire anemometer measurements |
| $R_p$ | radius of the Pitot tube |
| $R^2$ | regression coefficient |
| $r$, $x$ | radial and longitudinal positions respectively |
| $x_e$ | distance between the static and total pressure taps of the Pitot tube |
| $x_s$ | source position along the $x$-axis |
| $T_{ct}$ | proposed pressure correction term |
| $U$ | velocity of the incident uniform flow |
| $U_a^E$ | amplitude of the velocity signal |
| $U_{mv}^E$ | mean value of measured flow speed |
| $U^F$ | sinusoidal curve fitted data |
| $U_a^F$ | amplitude of the sinusoidal oscillations obtained from the curve fitted data |
| $\Phi$ | velocity potential function |
| $\Phi_t$ | time derivative of the velocity potential function |
| $\rho_a$ | air density at room temperature |
| $\omega$ | angular frequency |
| $\varphi$ | the phase refers to the position of the rotating gate relative to the closing position |

*Superscripts*

| | |
|---|---|
| • | derivative with respect to time |

*Subscripts*

| | |
|---|---|
| *max* | maximum value |
| *mean* | mean value |

were obtained, namely, Pitot tube 1 ($PT_1$), Pitot tube 2 ($PT_2$), a bi-directional flow measuring Cole-Pitot tube ($PT_3$) (additional information about Cole Pitot tubes can be found in Cole, E. S [11]), and a so-called ideal Pitot tube setup ($PT_4$). The experiments were performed by using a gust wind tunnel designed and built at Instituto Universitario de Microgravedad 'Ignacio da Riva', Universidad Politécnica de Madrid (IDR/UPM). The theoretical model and research that justifies the development of this gust wind tunnel can be found in Sanz-Andres and Navarro-Medina [12].

This paper is organized as follows: in Section 2 the theoretical approach to identify the pressure correction term, $T_{ct}$, is presented; in Section 3 the main results of the flow characterization in the test section, and the experimental setup to measure gusty flows by using the proposed Pitot tubes are presented; in Section 4 raw results from the experiments and the corrected results using the pressure correction term, $T_{ct}$, are compared; and finally, in Section 5 conclusions are drawn.

## 2. Correction term derived from potential flow theory

In this section, a correction term for the Pitot tube measurements based on potential flow theory is proposed. From potential flow theory [9,10], the velocity potential function of the uniform axisymmetric flow with a source is

$$\Phi(x, r, t) = Ux - \frac{Q}{4\pi\sqrt{\left((x - x_s)^2 + r^2\right)}} \tag{1}$$

where $r$ and $x$ are the radial and longitudinal positions, respectively, $x_s$ is the source position along the $x$-axis ($x_s = \frac{R_p}{2}$, see Annex A), $U$ is the velocity of the uniform flow, and $Q$ is the intensity of the source, which can be obtained from the geometrical condition of the Pitot tube (see Fig. 1)

$$Q = \pi R_p^2 U(t) \tag{2}$$

where $R_p$ is the radius of the Pitot tube. From, Eqs. (1) and (2), the time derivative of the velocity potential is

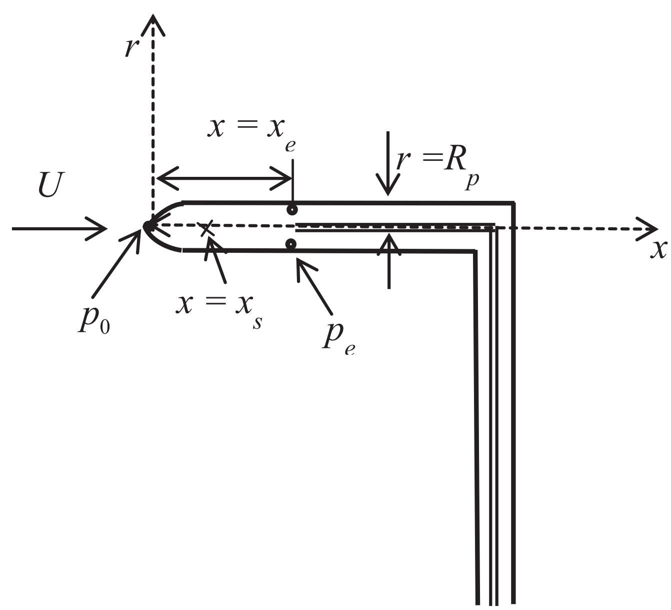


**Fig. 1.** Standard Pitot tube with nomenclature.

$$\Phi_t = \dot{U}x - \frac{\pi R_p^2 \dot{U}}{4\pi\sqrt{\left((x - x_s)^2 + r^2\right)}} \tag{3}$$

The pressure field can be calculated by using the Euler–Bernoulli equation for an unsteady flow,

$$\frac{p}{\rho_a} + \Phi_t(x, r, t) + \frac{1}{2}U^2 = C(t) \tag{4}$$

The Pitot tube total pressure, $p_0$ (i.e., at $x=0$, $r=0$) and static pressure, $p_e$ (i.e., at $x = x_e$, $r = R_p$) are calculated from Eq. (4),

$$\frac{p_0}{\rho_a} + \Phi_t(0, 0, t) = \frac{p_0}{\rho_a} - \frac{\pi R_p^2 \dot{U}}{4\pi x_s} = C(t) \tag{5}$$

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