



## Flow Effects on a Pressure Sensor

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### Abstract

Flow channel experiments conducted on a pressure sensor attached to differing configurations of hydro-mechanical front-ends have shown that the sensor's performance in steady laminar flow can be significantly enhanced by locating the pressure inlet at the center of a flat, thin horizontal circular plate whose diameter is 3 times or more that of the pressure housing. This enhancement arises from two main design improvements namely : (i) prevention of the transfer of the disturbed flow around the sensor housing to the pressure inlet and (ii) generation of a sufficiently thick laminar boundary layer over the pressure inlet as a result of which the pressure inlet is exposed to a much retarded flow compared to the mainstream flow. Deterioration in performance caused by nearby solid structures can be significantly reduced by the use of a second identical plate separated from the first by a distance equal to the diameter of the housing. Such a system appreciably improves the horizontal azimuthal response for turbulent flows below 100 cm./sec. Laminar flows however, may be affected by the presence of the stand-offs between the plates and Tollmien-Schlichting waves at the surface of the first plate.

## 1 Introduction

An important parameter which deteriorates the performance of a pressure sensor used for sea level measurements is the water flow at the measurement site. The pressure difference  $\Delta P$ , compared to the hydrostatic pressure at the pressure inlet is given by :

$$\Delta P = -\frac{k\rho v^2}{2} \quad (1)$$

where  $k$  is the velocity coefficient,  $\rho$  is the density of water at the inlet, and  $v$  is the mainstream flow velocity. Thus, that geometry of pressure intake for which  $k$  approaches zero is desirable. In this paper the laminar and turbulent flow responses of a pressure sensor to a variety of different pressure intake geometries and flow rates are presented and discussed. The various geometrical configurations were; a protruding pressure inlet; the use of different diameters of end-plates of the pressure housing having the pressure inlet flush with the plate; and pairs of parallel end-plates having different separations.

For sea level measurements in a coastal environment, a pressure sensor housing is often mounted on a vertical piling. In such cases, the output of the sensor is influenced by the relative orientation of the housing and the piling with respect to the flow direction. In order to investigate the extent of this influence, all the previously mentioned measurements were repeated with the pressure housing mounted near a piling model. Azimuthal responses of the sensor for these arrangements were also investigated.

## 2 Experiments and Results

The experiments were conducted using a quartz pressure sensor whose accuracy under no-flow, no-wave conditions was 0.01%. In the first experimental setting (Fig.1) the sensor was exposed to a laminar flow and in the second setting (Fig.2) it was subjected to the turbulent flow generated by a cylindrical piling mounted in the vicinity of the sensor. Response of the sensor to the 1st setting is given in Fig.3. During each set of experiments the time-averaged response (28.125 sec.) of the sensor was first monitored in still water and then at differing flow speeds generated by the high-speed flow channel of the University of Liverpool, U.K. For a protruding pressure inlet the sensor exhibited a large reduction in pressure ( $\Delta P$ ) with increasing flow speeds, reaching a value of 19.18 millibars at 200 cm./sec. As expected from Bernoulli's theory the deviations in pressure exhibited a square law relationship with respect to the flow speed. Locating the pressure inlet flush with the horizontal end plate of the sensor housing yielded a significant improvement in the sensor's response, with  $\Delta P$  less than 1 millibar at 50 cm./sec.

Locating the pressure inlet at the centre of a circular horizontal thin plate whose diameter is three times that of the pressure sensor housing (diameter =  $D$ ) yielded a significant improvement in the sensor's response, especially at large flow rates. This improvement may be understood by calculating the ratio of flow speed at the inlet,  $v$ , to the mainstream flow  $U_\infty$  for different ratios of pressure housing diameter,  $a$ , to end-plate diameter,  $r$ . In these calculations, the ratio  $v/U_\infty$  rapidly decreases and achieves a near unity value for  $a/r = 1/3$ . Thus, an increase of end-plate diameter beyond  $3D$  does not lead to appreciable improvement in the sensor's performance. In the case of laminar flow, no additional improvement was achieved by the use of a pair of parallel plates.

The set of experiments in the second setting were performed with this housing mounted in the neighbourhood of a cylindrical vertical piling model whose diameter was  $2D$ . Pressure reduction as a function of flow speed for different configurations in this setting are shown in Fig. 4. The horizontal azimuthal response of the pressure sensor for differing flow arrival angles indicated that the effect of having a piling in the vicinity of the pressure sensor housing is to give rise to a larger  $\Delta P$  for some flow directions. While this error was less than 2 millibars for flows less than 50 cm./sec., and all azimuthal angles, the corresponding error for flow speeds greater than 100 cm./sec. was very significant. The values of  $\Delta P$  were minimum for  $\theta = 180^\circ$  and maximum for  $\theta = 90^\circ$  and  $135^\circ$ . This shows that for a pressure housing without an end plate, the response of a pressure sensor is highly sensitive to the direction of flow arrival, especially at large flow speeds. The azimuthal response of this configuration (shown in

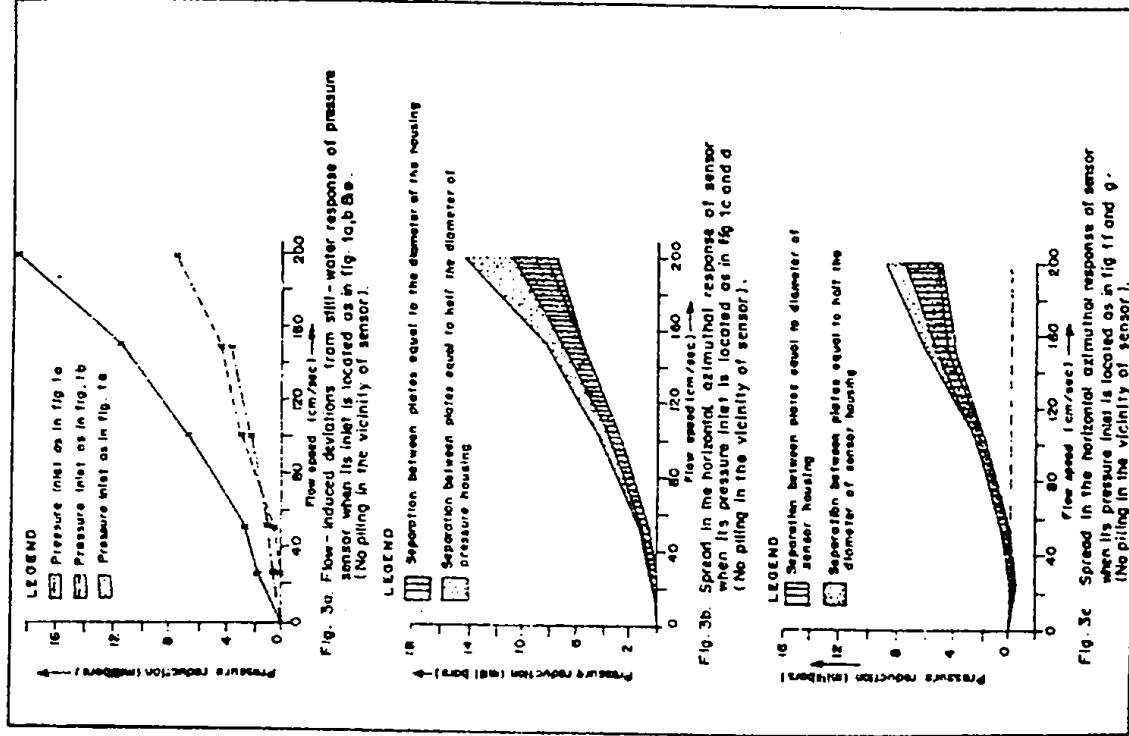
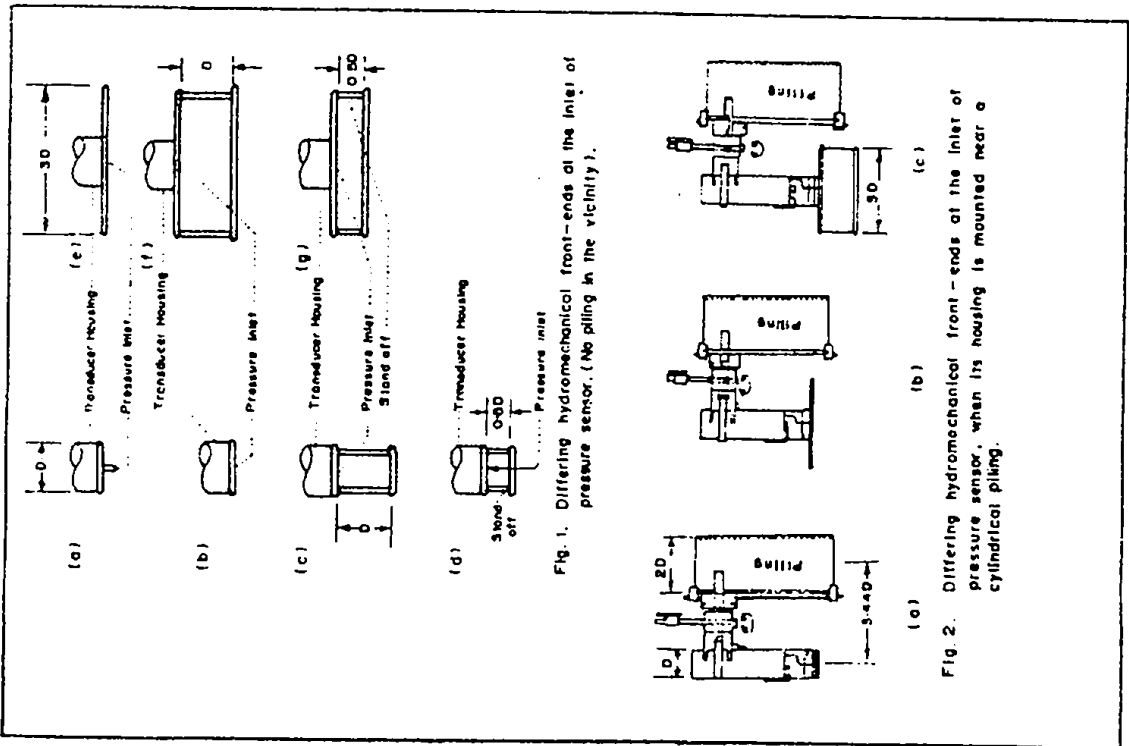


Fig. 2b) resulted in a spread of nearby 2 millibars. Use of a pair of parallel plates of diameter  $3D$  gave a reduced spread in azimuthal response for flow ranging from 0 to 100 cm./sec.

### 3 Discussion of Results

From boundary layer theory, the velocity  $u$  within the laminar boundary layer of a flat plate is given as [1]:

$$\frac{u}{U_\infty} = 0.332 \eta - 0.00229 \eta^4 + 1.996 \times 10^{-5} \eta^7 - 1.567 \times 10^{-7} \eta^{10} + 1.129 \times 10^{-9} \eta^{13} \quad (2)$$

where  $U_\infty$  is the mainstream flow, and

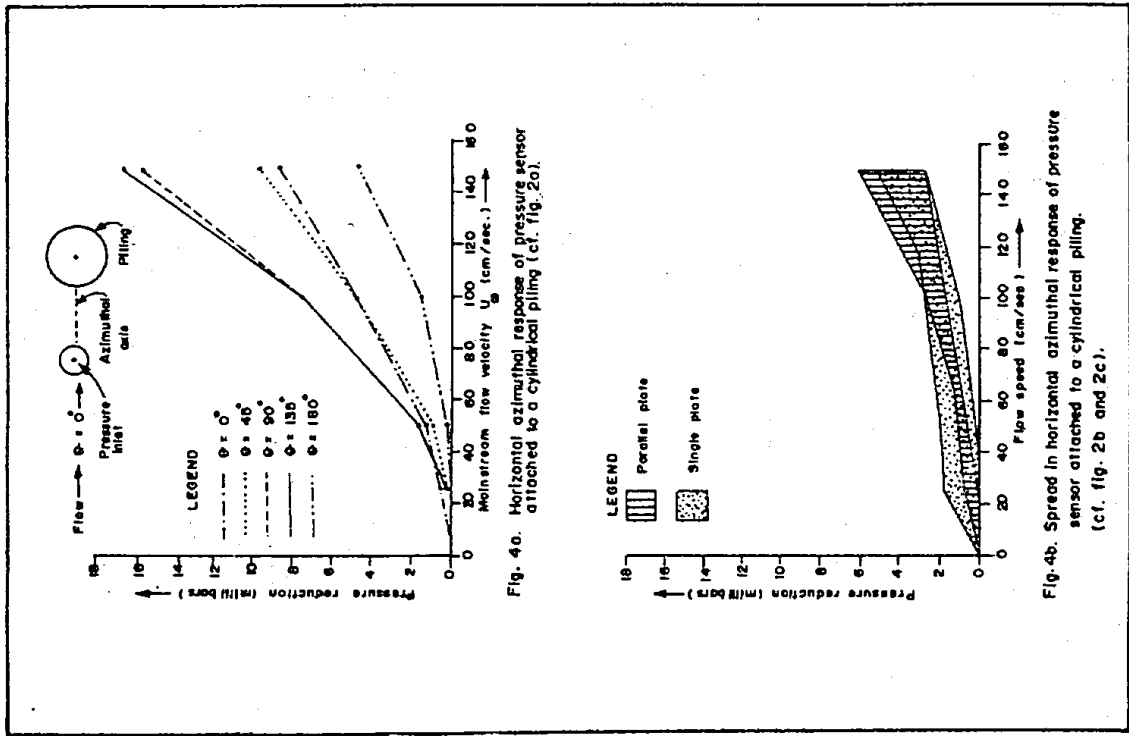
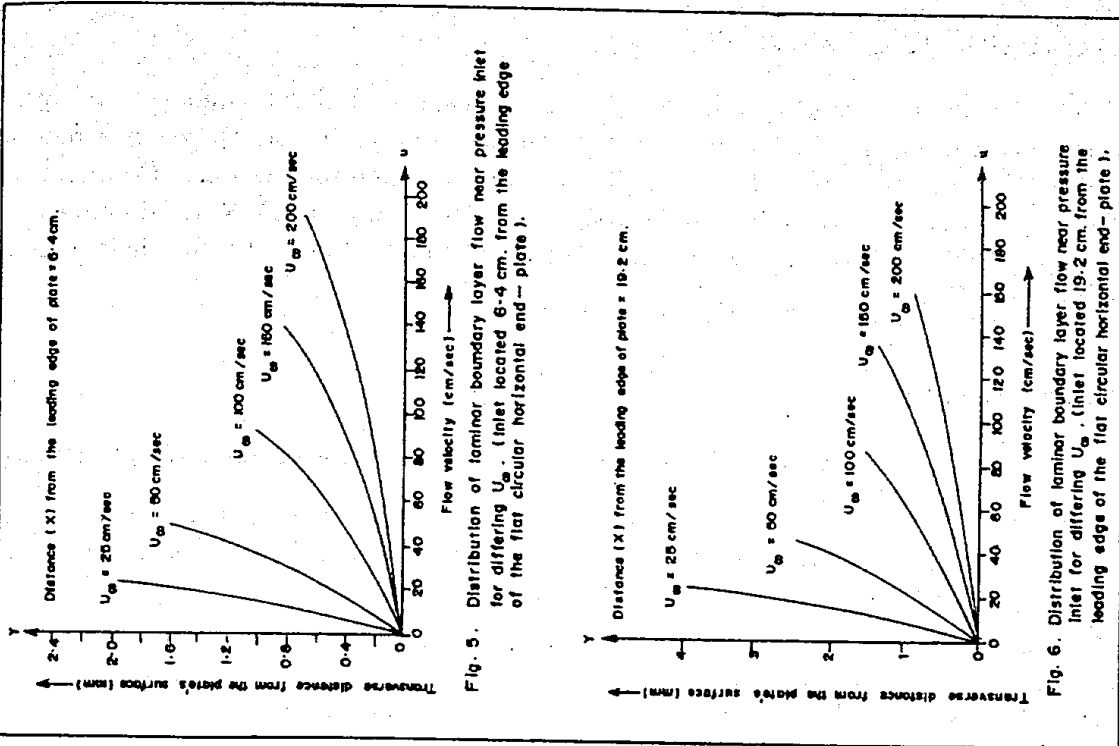
$$\eta = y \sqrt{\frac{U_\infty}{\nu x}} \quad (3)$$

In this relation  $y$  is the distance normal to the plate,  $x$  is the distance along the plate from its leading edge, and  $\nu$  is the kinematic viscosity of the fluid. Based on expressions (2) and (3) the distribution of flow velocities in the vicinity of the pressure inlet with the use of plates of diameter  $D$  and  $3D$  are shown in Figs. (5) and (6). The protruding pressure inlet exhibited large  $\Delta P$  values because the inlet was beyond the laminar boundary layer of the plate. The smaller values obtained when the pressure inlet remained flush with the end plate of the sensor's housing can be attributed to a retarded flow in the close vicinity of the pressure inlet. The reason for improved performance associated with the use of a thin plate of diameter  $3D$ , appears to be due to isolation of the pressure inlet from the disturbed flow in the vicinity of the sensor housing. A larger laminar boundary layer associated with a large thin plate may also have contributed to the enhanced performance.

The observed  $\Delta P$  and spread in the azimuthal response of the sensor when close to a large piling arise from the flow separation and the associated flow-field modifications near the pressure inlet. An appreciable improvement in the sensor's performance, upto 100 cm./sec. with the use of a large thin parallel-plate front-end mechanism arises from its ability to stabilize turbulent flows upto a certain Reynold's number. A detailed description of the experiments and a comprehensive analysis of the observed results is being communicated [2].

### 4 Conclusions

A protruding pressure inlet on a pressure sensor is most susceptible to flow-induced errors. When not in the vicinity of large flow-disturbing structures, the flow performance of the sensor, upto 100 cm./sec., can be significantly improved by locating the inlet at the centre of a thin horizontal circular plate whose diameter is  $3D$  or more. However, if the sensor is located near a flow-disturbing structure, its performance can be enhanced by protecting its inlet with a pair of large thin parallel plates separated by a distance equal to  $D$ .



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