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PRESSURE FIELD INDUCED ON AN AIRFOIL BY AN UNSTEADY FLOW

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The noise production of propulsive systems used in the aeronautic field is principally due to the interaction between the unsteady flow produced and the rigid surfaces of the system itself. It is necessary to perform fundamental experiments on simplified models using controlled unsteady flows ; the reason for this choice is the complexity of such interaction mechanisms. This is the purpose of this study. The coherence of the pressure field induced on an airfoil by a turbulent flow is in a first step measured, and then compared with theoretical predictions using various unsteady aerodynamic transfer functions.

I. EXPERIMENTAL CONDITIONS

Two bidimensional NACA 0012 airfoils, of 8 cm chord, are placed in a turbulent stream (fig. 1). The mean flow velocity is U = 20 m/s. Thirteen pressure transducers are embedded along the chord of the first airfoil, while nine are placed spanwise on the second one [1]. An homogeneous and nearly isotropic turbulence is generated using a moving grid placed upstream the airfoil. When the grid is displaced, several turbulence intensity levels can be obtained [2].

II. RESULTS AND DISCUSSION

Measurements of the RMS pressure fluctuations along the chord show large pressure fluctuations in the leading edge region and the amplitude of these fluctuations decreases from the leading to the trailing edge region (fig. 2). The magnitude of this phenomenon decreases with the turbulence intensity level. Beside large pressure fluctuations can be observed in the trailing edge region even if there is no upstream turbulence.

The fluctuating pressure spectra measured in the leading edge region are very similar to the turbulence spectrum (fig. 3). Beside the high frequency fluctuation level decreases with the turbulence intensity. So the pressure field existing in the upstream region of the blade seems closely correlated to incident turbulent flow. On the contrary, the pressure spectra measured in the downstream region are very different of the turbulence spectrum and more these spectra do not vary with the turbulence intensity level.

Using pressure spectra measurements it is now possible to obtain the chordwise pressure distribution for different frequencies and for different turbulence intensity levels. For the higher intensity : 12,3 %, it can be noted :

. For any frequency, large pressure fluctuations are observed in the leading edge region ; but the magnitude of these fluctuations decreases with the frequency.

. An important focusing of the pressure distribution occurs in the leading edge region when the frequency increases.

. Large pressure fluctuations can also be observed in the trailing edge region.

When the turbulence intensity level decreases, the pressure fluctuation level measured in the upstream part of the blade decreases. But the pressure level measured in the downstream part keeps nearly unchanged.

III. COMPARISONS BETWEEN MEASUREMENTS AND PREDICTION

Comparisons between the measured and the predicted pressure fields are made at the highest turbulence intensity level (u'/U = 12,3 %). Six different unsteady aerodynamic transfer functions are used to compute the chordwise pressure distribution at different frequencies. They are noted as follows :

1 Two-dimensional incompressible gust [3].
2 Two-dimensional high frequency compressible gust.
3 Three-dimensional incompressible gust [4].
4 Three-dimensional nearly parallel incompressible gust.
5 Graham rule, low frequency.
6 Graham rule, high frequency.

As we can see some of these formulations take into account the three-dimensional character and the compressibility of the flow. So it is possible to compare the theoretical results obtained using the six previous formulations and it is possible to compare the theoretical results with the experimental one. Following remarks can be made :

. Formulations 1 and 2 overestimate the fluctuation levels in the upstream part of the airfoil at any frequency.

. For the frequencies lower than 700 Hz, the theoretical formulations 3, 5 and 6 give similar results.

. The focusing of the pressure field distribution observed in the upstream part of the blade is well predicted by any of the three-dimensional formulations.

. The best prediction of the pressure distribution is obtained using the Filotas theory. So in the future all predictions that we entertain will be made using this formulation.

. It can be noted that the large pressure fluctuations existing in the trailing edge region cannot be taken into account by non viscous aerodynamic theories. The reason is these fluctuations are due to the boundary layer which grows in the downstream part of the airfoil. This second pressure field is clearly shown when we compare the various pressure spectra measured along the chord with that computed using the Filotas function (fig. 4a, 4b). In the leading edge region the pressure spectra is well predicted, but for downstream location the measured spectra display high frequency fluctuations induced by the boundary layers.

To show the specific properties of these two pressure fields, we measure the modulus and the phase of the pressure fluctuation cross-spectrum for different chordwise locations. We can show a phase shift of the pressure field. To point out the convective nature of the field, it is interesting to consider this phase-shift as a convection velocity effect, so we introduce the convection velocity U_c. Two regions can still be observed :

- The upstream region, where the phase-shift is nearly zero for low frequencies, but it increases with frequency. So, we can claim that for low frequencies U_c is infinite and that, for high frequencies, U_c is nearly 0.7 times the mean flow velocity. This value corresponds to the convection velocity of a turbulent boundary layer.

- The downstream region where the convection velocity is higher for low frequencies than for high frequencies. In this last case, U_c is always lower than the mean flow velocity U_∞.

It is possible to compare the longitudinal coherence function calculated using Filotas theory, with that deduced from cross-spectrum measurements. We note that :

. Coherence decreases when the frequency increases but faster than the theoretical predictions ;

. This decreasing is faster in the downstream region ;

Here again these results do not correspond to the theoretical predictions. These phenomena seem related to the pressure field phase-shift.

Using cross-spectrum measurements we can entertain a similar analysis for the spanwise direction :

. Here again, the coherence decreases when the frequency increases faster than that obtained using theory ;

. The misfitting observed between theory and measurements increases with spanwise separation.

IV. CONCLUSIONS

When an airfoil is placed in a turbulent flow, two different pressure fields exist along the blade :

- The pressure field induced by the upstream turbulence is focused in the leading edge region. This focusing effect increases with the frequency. The spanwise coherence of this field is larger than that measured for the turbulent boundary layer. Its characteristics are well predicted by the Filotas theory.

- A convective pressure field grows in the downstream region. The magnitude of the pressure fluctuations increases exponentially downstream. This field seems induced by the transitional boundary layer and when it is compared with that induced by a turbulent boundary layer we can note that : the convection velocity is higher ; the chordwise and spanwise coherences are weaker.

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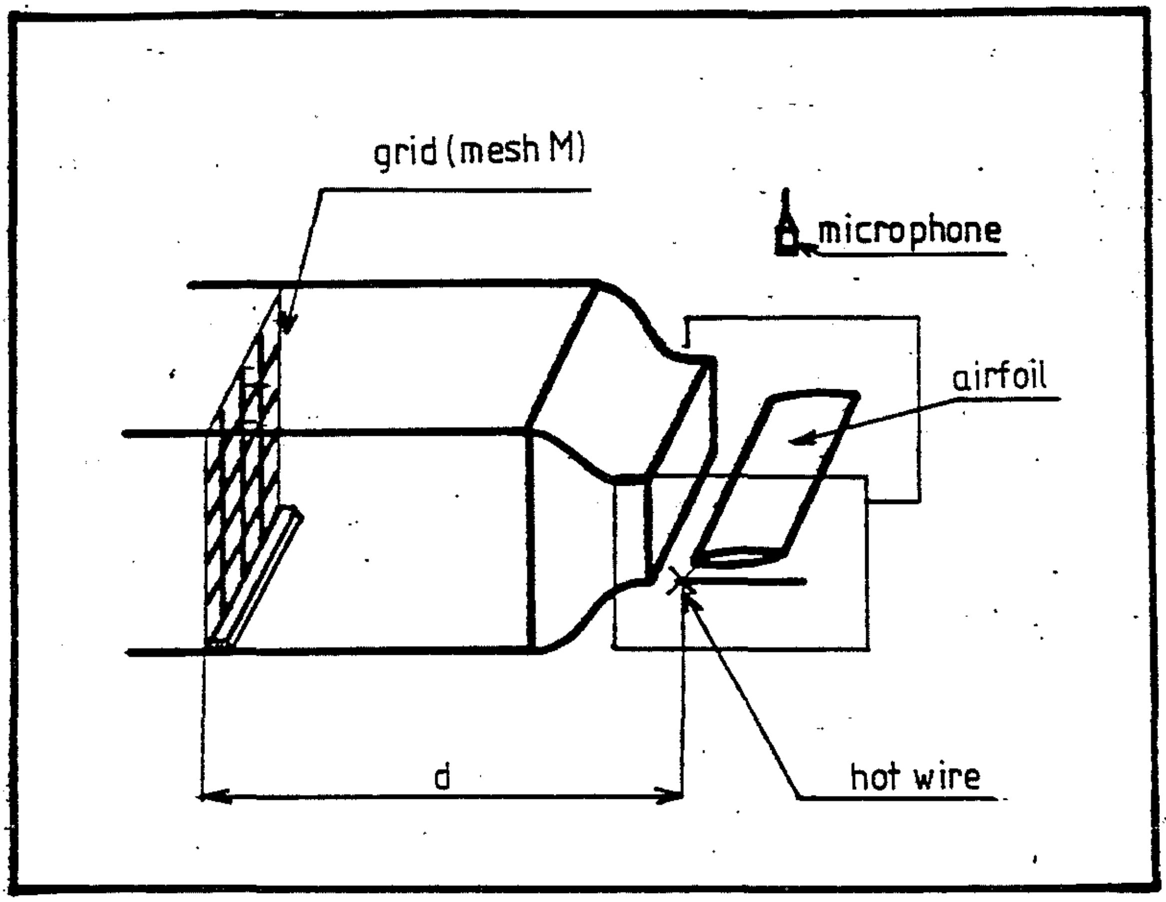

Figure 1 : Experimental set up

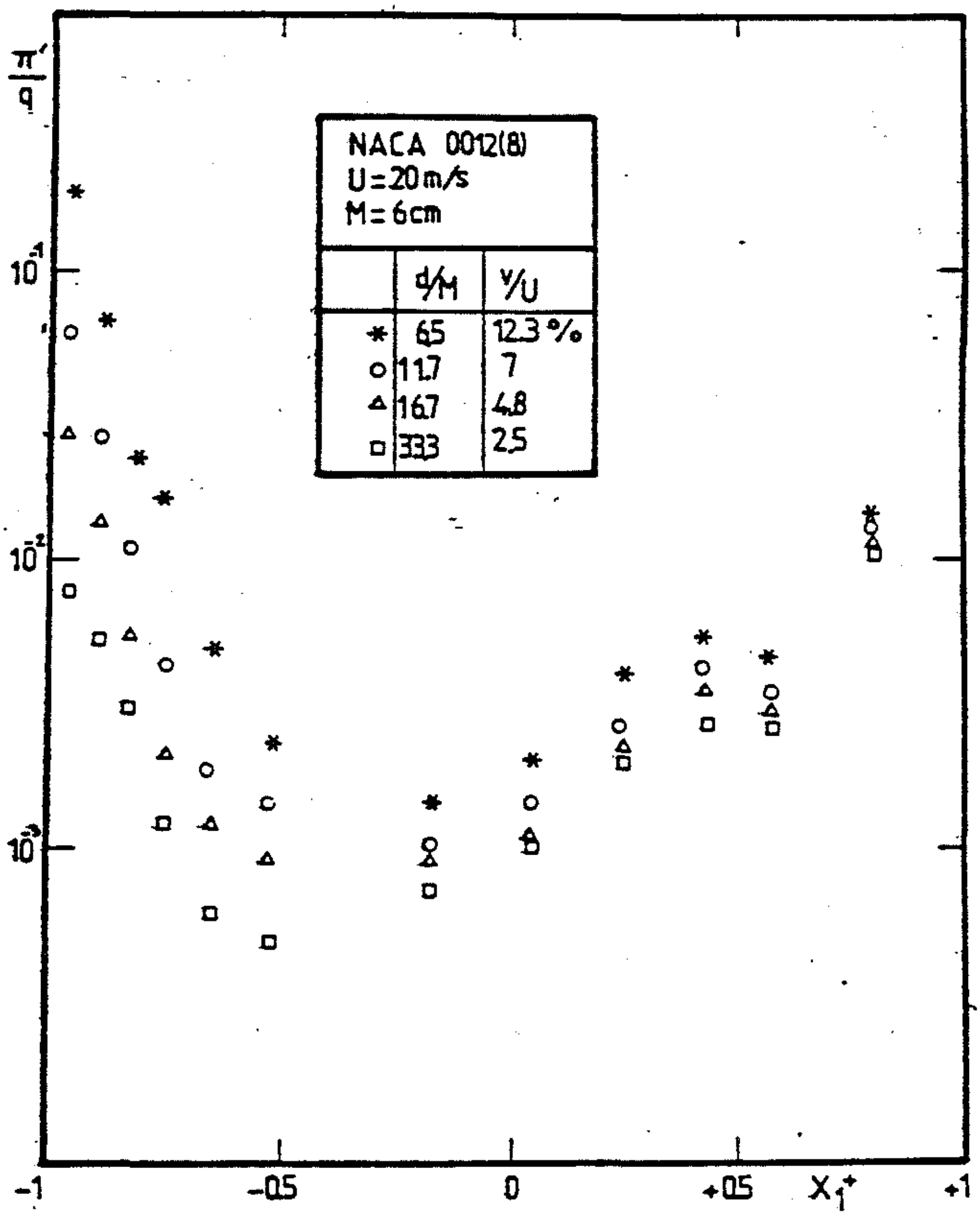

Figure 2 : Turbulence level effect on RMS fluctuating pressure distribution

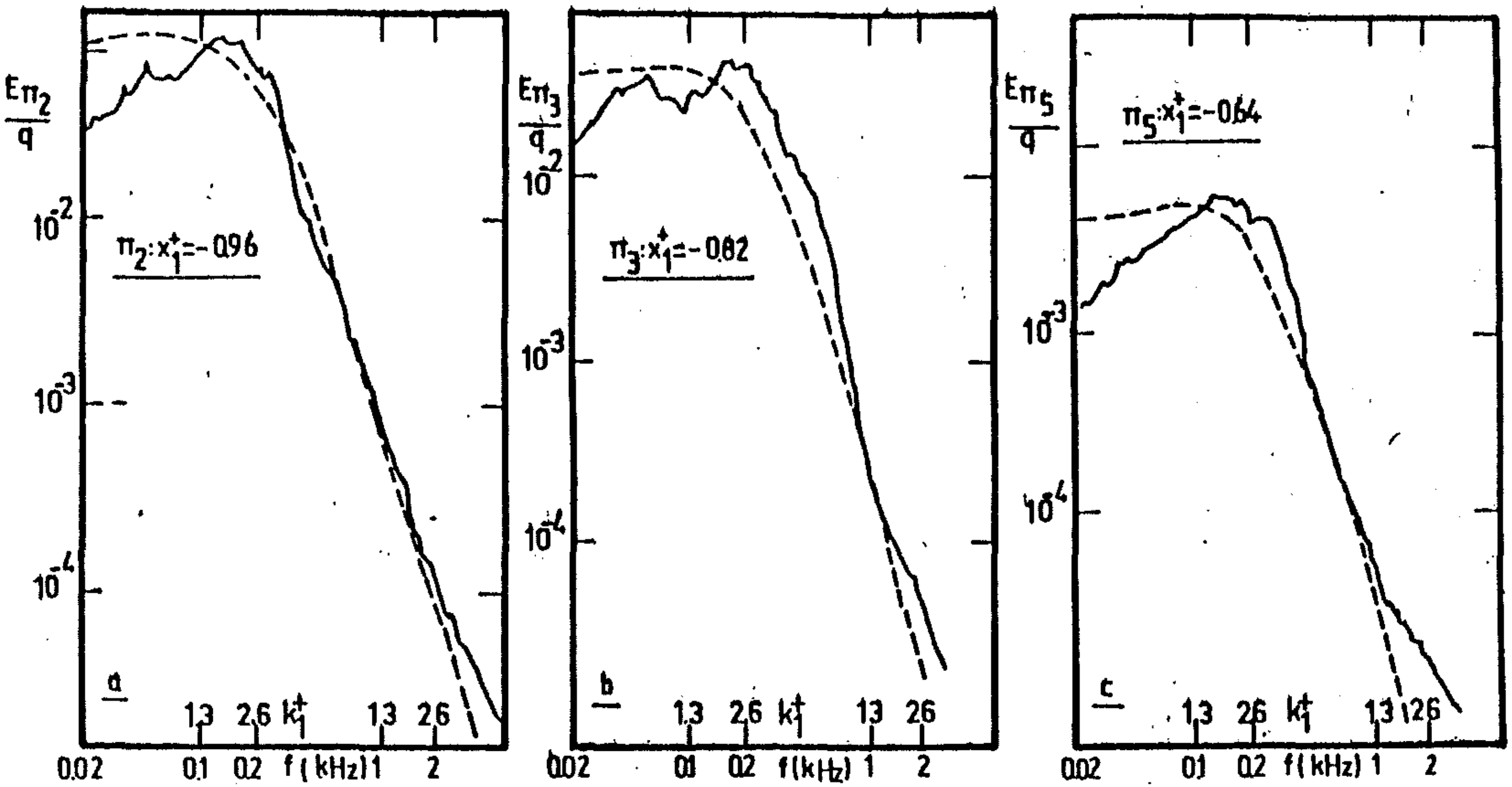

Figure 4a : Comparison of pressure spectra, measured and calculated using Filotas function, for various chord locations.

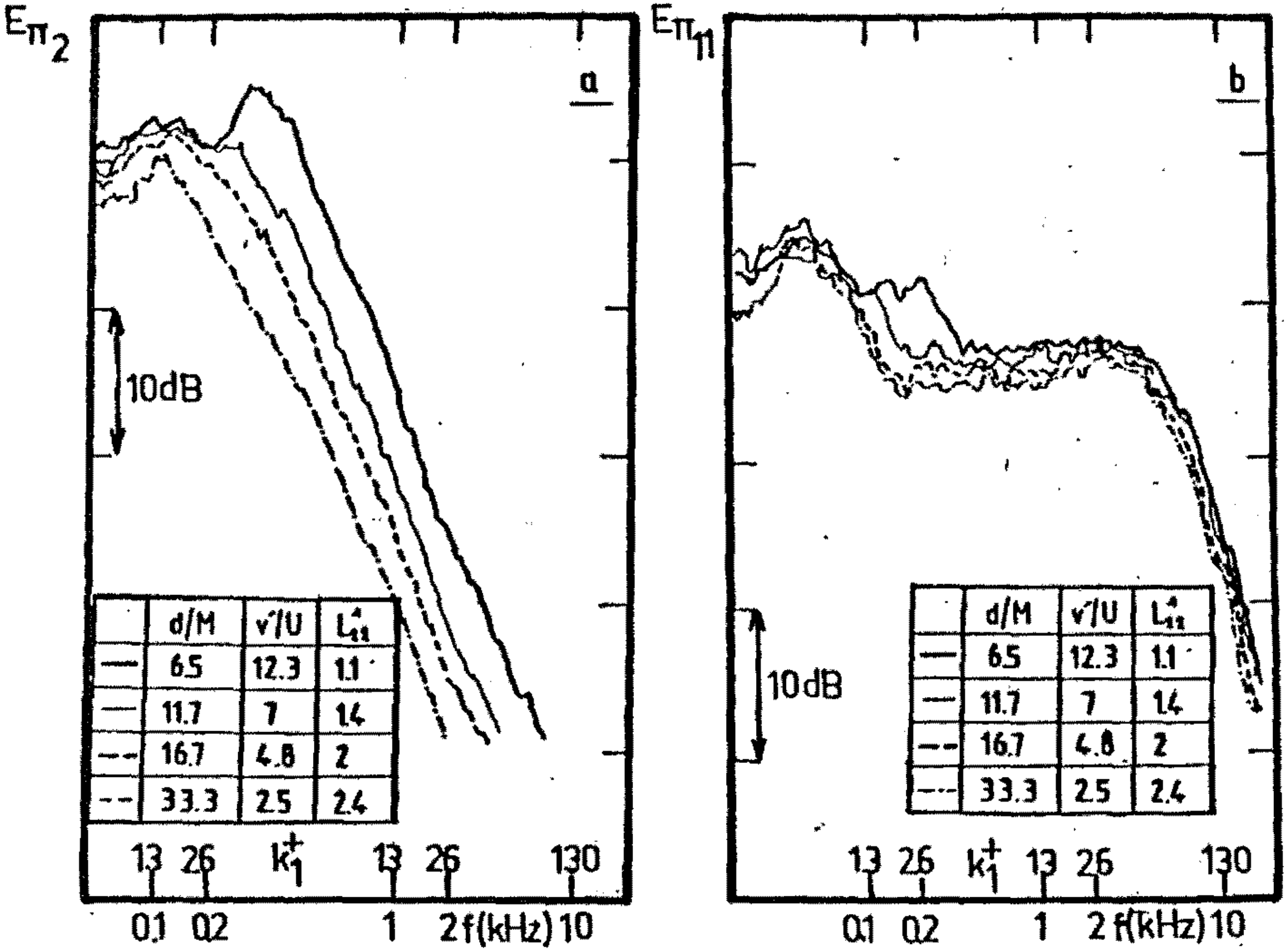

Figure 3 : Fluctuating pressure spectrum at different chord locations, for various turbulence levels

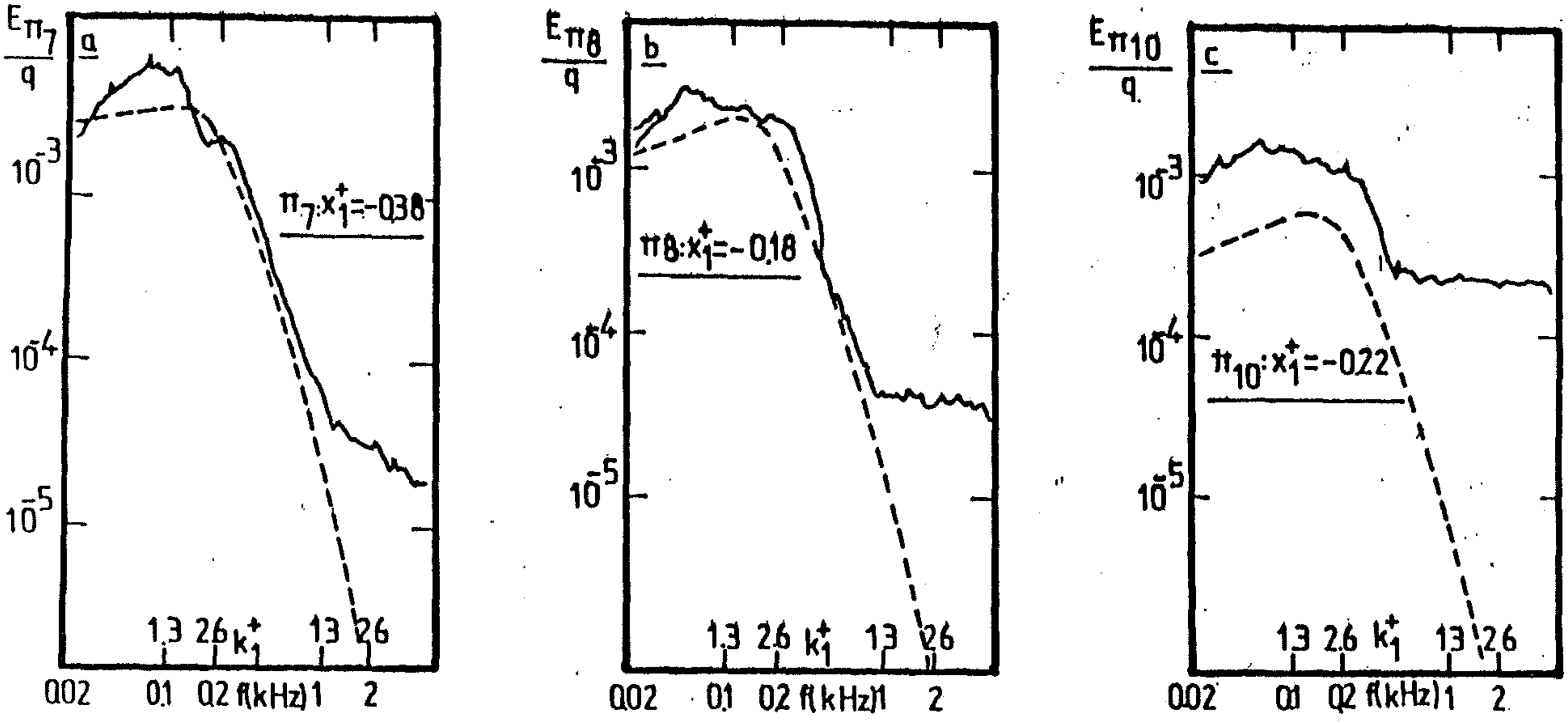

Figure 4b : Comparison of pressure spectra, measured and calculated using Filotas function, for various chord locations.