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THE INFLUENCE OF THE MAIN FLOW ON THE TRANSFER FUNCTION OF TUBE-TRANSDUCER SYSTEMS USED FOR UNSTEADY PRESSURE MEASUREMENTS

BY

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ABSTRACT

An experimental investigation has been performed, which revealed a considerable difference between the dynamic response characteristics of a tube-transducer system with the entrance in still air and one having an airflow across the entrance orifice.

The differences observed could be explained theoretically by modifying the existing calculation model for still air in such a way, that the interaction between the periodically in- and outflow at the tube entrance and the main flow is taken into account.

Application of the present knowledge to the results of a joint ONERA-NLR investigation shows that satisfactory agreement is obtained between pressure distributions measured via tubes and via direct in situ pressure transducers.

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SUMMARY

An experimental investigation has been performed, which revealed a considerable difference between the dynamic response characteristics of a tube-transducer system with the entrance in still air and one having an airflow across the entrance orifice.

The differences observed could be explained theoretically by modifying the existing calculation model for still air in such a way, that the interaction between the periodically in- and outflow at the tube entrance and the main flow is taken into account.

Application of the present knowledge to the results of a joint ONERA - NLR investigation shows that satisfactory agreement is obtained between pressure distributions measured via tubes and via direct in situ pressure transducers.

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CONTENTS

1 INTRODUCTION

At NLR unsteady pressure distributions on oscillating wind tunnel models are measured, making use of a number of identical pressure tubes, which are connected via scanning valves with a limited number of pressure transducers, outside the wind tunnel. The essential step in the data reduction procedure of this method is that the unsteady pressures measured with the transducers (p_u) are reduced to the actual pressures at the model surface (p_i), with the use of the transfer function of the pressure tubes. This procedure is schematically indicated in figure 1.

For low speed measurements, with in general relatively large models and rather low frequencies, it is usual to measure the input pressure of one of the geometrically similar tubes with a transducer in the model (Ref. 1). In this way the transfer function under test conditions is known and can be applied to all other tubes, since the mutual differences in mean pressure level are negligible. The experience gained from this is that in the low speed range no significant differences occurred between the transfer function used in the wind tunnel tests and the transfer function in still air.

In the days when NLR started with unsteady measurements at high speeds, no reliable miniature transducers, compatible with the equipment, were available which could be mounted into the small size models being used. Therefore an oscillatory pressure from the model surface or from the tunnel side wall was fed into a small volume chamber outside the test section. To this chamber a direct transducer and a reference tube-transducer system were connected. For the data reduction the still air calibrations were used, which were confirmed by this reference system, that was measured simultaneously at test conditions.

Some time ago doubts arose against the results of the tubing technique for higher Mach numbers. For this reason NLR and ONERA decided to perform jointly unsteady pressure measurements on an oscillating swept wing using two different techniques:

(a) in situ micro miniature transducer (ONERA)

(b) measurement via pressure tubes and scanivalves (NLR)

This investigation was supported by the Working Group on Unsteady Aerodynamics of the AGARD Structures and Materials Panel.

Last year these tests were performed in the High Speed Tunnel (HST) of NLR in Amsterdam. It appeared that the results measured by ONERA, using in situ TELCO transducers, differed considerably from the results obtained via the tube-system of NLR (Ref. 2 and 3).

To reveal the cause of the differences NLR started a separate investigation to establish whether the airflow over the model orifices might cause a significant change in the dynamic behaviour of tube-transducer systems.

The present report gives a description of the experimental set up and the results obtained. The main outcome is that in the application of the tube technique use must be made of "in wind" transfer functions and not of those for still air. Furthermore a modified theoretical model for the tube-transducer system is presented, that shows a good agreement with the measured results. Finally this theoretical model is used to correct the NLR-results of the joint ONERA/NLR investigation, leading to reasonable agreement between the results obtained from the two different measuring techniques.

2 EXPERIMENTAL INVESTIGATION

2.1 Model and test set up

For the present investigation an existing two-dimensional model, of which the control surface could be forced into harmonic oscillations, was equipped with six miniature Kulite transducers (Fig. 2). The Kulite transducers were located in one cross section at 30; 50; 55; 60; 65 and 70% of the chord, respectively. At a distance of 10 mm aside of each in situ transducer, pressure holes were present, connected via pressure tubes to a scanning valve outside the wind tunnel. Five tubes had a length of 90 cm, and one was 180 cm long. The diameter of all tubes was 1.6 mm.

A similar tube of 90 cm as used in the model was connected with a pressure hole in the tunnel side wall, 10 mm above the control surface. The input pressure was measured with a Statham transducer mounted also in the side wall, very close to the entrance of the tube. The other end of the tube was connected with the same scanning valve as the model tubes. The main object of this system was to

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create a comparable tube system in the presence of a very thick boundary layer (± 20 mm) at the entrance.

Finally, an identical tube-system was installed completely outside the wind tunnel. This system was connected with a volume, in which an oscillatory pressure was generated by means of a piston, driven by the same excitation system as used to drive the model. The mean static pressure in this volume was kept equal to the pressure in the plenum of the test section of the wind tunnel. As NLR had no experience with the Kulite transducers, the oscillatory pressure in this reference volume was measured by both a Kulite and a Statham transducer.

2.2 Measuring procedure

To establish the influence of the flow velocity on the transfer function of the pressure tubes, the following procedure has been applied. At first the transfer functions in still air of all tubes have been determined as a function of frequency and static pressure. To do so the entrance opening of a tube and the corresponding Kulite transducer were covered by a small volume, in which an oscillatory pressure was generated with the desired frequency and at desired levels of the mean static pressure p_s (Fig. 3). The oscillatory pressure at the entrance (p_i) was measured directly by both the Statham transducer mounted to the volume and the Kulite transducer, leading to an additional check. The mean static pressure and the oscillatory pressure at the end of the tube (p_u) were measured by the Statham transducer in the scanning valve. In this way the transfer functions were completely determined.

The "in wind" transfer functions were derived from tests on the model with control surface oscillating in the Pilottunnel of NLR. The free stream Mach number was varied between 0.3 and 0.89; the frequencies used were 30, 60, 90 and 120 Hz.
The transfer functions of the model tubes are derived from the pressure ratio between the Statham transducer in the scanning valve and the Kulite transducers in the model. The local Mach number at each model orifice is derived from the local static pressures, measured simultaneaously with the Statham transducer.

Similarly, the transfer function for the tube system connected to the tunnel side wall and for the reference system outside the wind tunnel are determined. Differences between these two transfer functions **should** indicate, that aerodynamic entrance effects would be present.

3 EXPERIMENTAL RESULTS.

3.1 Measured data.

The transfer functions of the 90 cm tubes in still air have been plotted as a function of static pressure in fig. 4 - 7, for frequencies of 30, 60, 90 and 120 Hz respectively. The oscillatory input pressure applied was 100 kg/m^2. As in the atmospheric wind tunnel Mach number and static pressure are coupled, the transfer functions obtained during the wind tunnel tests can be plotted in the same figures as function of the local static pressure at each individual entrance. It must be noted that at higher values of the free stream Mach number, the local static pressures in the various points on the model differ considerably. This can be **easily seen if it is** known that the model becomes supercritical at $M_{\infty} \sim 0.85$.

3.2 Discussion of measured results.

In still air, the 90 cm tubes have almost identical dynamic characteristics, as is shown in fig. 4 - 7.
From the results for the transfer functions with wind, also plotted in fig. 4 - 7, it becomes directly apparent that the main flow has a considerable influence on the transfer functions of the tubes. The differences increase with increasing Mach number and are largest at frequencies near resonance ($\sim$ 65 Hz) as is illustrated for **example by comparing figures** 4 **and** 5.

Another important feature is that the transfer functions with wind mainly depend on the local Mach number at the entrance of the tube under consideration and not on its location on the model. For instance the transfer function of the tube at 70% of the chord is equal to the transfer of the tube at 30% **when** at both tube entrances the same local Mach numbers occur . This normally happens at different values of the free stream Mach number and, in super-

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critical cases, also in front and aft of the shock wave. This indicates that the influence of the boundary layer, which may be expected to be one of the parameters of the problem, is hardly present. This is confirmed also by the fact that the tube system in the tunnel side wall shows the same behaviour as the model tubes (see Figs. 5 and 6), although the boundary layer at the tunnel wall is roughly ten times thicker than on the model. Furthermore figures 4 - 7 indicate that no distinct different behaviour occurs if the main flow becomes supersonic.

The reference tube system outside the wind tunnel gives during the wind tunnel tests identical results as in the still air calibrations, confirming that the observed effects on the other tubes are completely flow induced.
The scatter in the results obtained from the wind tunnel tests can be ascribed to the measuring accuracy and partly also to the effects of non-linearity with respect to amplitude of the input pressure. The fact that the scatter is somewhat larger at 60 and 90 Hz confirms the observations of reference 1, that a non-linear behaviour starts to occur near a resonance frequency.

4 THEORETICAL INVESTIGATION

4.1 Modification of existing theoretical model

The transfer function of pressure tubes in still air has been the subject of an extensive study, which has been reported in reference 4. There the following type of solution for the oscillatory pressure perturbation $pe^{i\omega t}$ in a circular tube has been derived:

$$p = Ae^{\phi x} + Be^{-\phi x}$$

where ϕ is the propagation constant.
The constants A and B are determined by specifying the boundary conditions at both ends of the tube.

The boundary condition at the tube entrance used in reference 4 is simply, that the oscillatory pressure for $x = 0$ is equal to a known value p_i, imposed on the system. This implies no restriction for the oscillatory velocity u in the tube entrance, so that the air is free to move in and out the tube opening.
However, this is incorrect if a fluid flows across the orifice, because the mass of air leaving the tube causes a curvature of the streamlines of the main flow, leading locally to an additional oscillatory pressure at the tube entrance.

Thus in the case of a main flow with an oscillatory component p_i the boundary condition for $x = 0$ becomes:

$$p = p_i' = p_i + \Delta p$$

Δp can be expressed into the free stream velocity V, the tube entrance velocity u, the local mean density and an unknown coefficient C. By using this modified boundary condition, revised formulae for the transfer function have been derived, that take proper account of the flow effects at the tube entrance (see Appendix).

4.2 Verification of theoretical model

To verify the theoretical model calculations have been performed for the 90 cm and 180 cm tubes, used in the afore-mentioned experimental investigation. For the 90 cm tubes the theoretical ratios of the transfer functions with and without wind have been plotted in figures 8 - 11 as a function of local Mach number. In the same figures experimental values are drawn, derived from the corresponding curves of figures 4 - 7.

When the constant C, occurring in the expression for Δp, is taken equal to 0.9, a satisfactory agreement is obtained between theory and experiment for a wide range of Mach numbers and for all frequencies considered. The different behaviour at the higher Mach numbers of the theoretical curve compared with the experimental trend, probably may be ascribed to compressibility effects on the mentioned interference between main flow and periodically tube flow. In fact it is possible to derive C as an empirical function of M from the experiment.

In figure 12 the calculated pressure transfer with and without wind has been given as a function of frequency for a constant static pressure level corresponding to $M = 0.8$. This figure clearly indicates the large change in transfer function due to the interaction with the main flow. Similar results for the 1.80 m tube are given in figure 13. The discrepancies between measured and calculated still air results, shown in both figures, are caused by the approximation of the tube-scanning valve transducer system by one single tube with a volume at the end. Bearing this in mind, the agreement between experiment and calculations for M = 0.8 is very satisfactorily for both tube lengths.

5 APPLICATION OF THE PRESENT KNOWLEDGE TO THE JOINT ONERA-NLR INVESTIGATION.

In the ONERA/NLR tests on a swept wing model (Fig. 14) NLR used the still air transfer functions to translate the oscillatory pressures measured with the pressure transducer in the scanning valve to the actual pressures at the model surface. From the present investigation it becomes quite clear that this procedure is incorrect and may introduce large errors, especially at high-speeds and frequencies near to resonances of the tube-transducer system.

With the theoretical model of section 4, it is possible to calculate the extra correction, needed to account for the difference between the transfer function in still air and in wind. Application to the tube-systems of the model used results in the corrections, presented in figure 15. Two curves are given: one for the short tube system (length 1.40 m, diameter 1.4 mm) and one for the long tube system (length 6.60 m, diameter 1.4 mm). The figure reveals that near a frequency of 45 Hz, used for the tests with long tubes, the correction for both types of tubes has about the same phase, while the differences in amplitude are also limited. This explains why the tests with long tubes at ~45 Hz and with short tubes at ~40 Hz and ~55 Hz gave the consistent results, observed in reference 3. It is now evident that this has been a matter of accident for the frequency range considered and that both former results are not correct.

Application of the calculated corrections leads to modified NLR pressure distributions, which for some examples have been plotted in figures 16 - 19. In these figures the average value of the distributions on the upperside at section 2 and 3 (figure 14) have been given, to be directly comparable with the measured data of ONERA, obtained with the TELCO transducers and published in reference 2. The results of the two measuring techniques now show a very acceptable agreement, especially if one bears in mind the relatively strong non-linearity of the tubing system in this specific model, which has been taken into account on the basis of the still air transfer functions (see ref. 3) and the amount of scatter in the TELCO system, as already noticed in reference 2.

The results presented in figures 16 - 19 have been measured with the short tube system (tube length 1.40 m). As already mentioned also tests have been performed with a tube of 6.60 m long, which has a completely different response characteristic, as can be seen from figure 20. The short tube system shows a resonance at about 45 Hz, while the long tubes behave like semi-infinite tubes, in which no resonance occurs.

In spite of these widely different transfer functions the results, obtained for both systems after application of the additional correction of figure 15, correlate very well, as is demonstrated in figure 21.
The tests could not be done at the same frequency, due to a failure in the spring mechanism of the model, but figure 21 clearly shows that the results of the long-tube system fit very well in between the results of the short tube system.

6 CONCLUSIONS

From the present investigation the following conclusions can be drawn:

- the transfer functions of tube transducer systems with an airflow across the tube entrance may differ considerably from the transfer functions in still air, especially at higher main flow velocities.
- this effect can be related mainly to the local Mach number. No distinct influence of the boundary layer could be observed and location of the tube orifice in front or aft of the shock wave had no influence.

- a theoretical model for calculating pressure transfer functions, in which account is taken of the main flow effects at the tube entrance, shows good agreement with experiment.
- application of the theoretical correction to the NLR results of the joint ONERA/NLR investigation leads to a satisfactory agreement between the results of both measuring techniques.
- for application of the NLR unsteady pressure measuring technique, it is advisable to use a limited number of in situ transducers in the model, either to obtain or to check the "in wind" transfer functions.

Acknowledgement.

The authors owe many thanks to Mr. J.W.G. van Nunen, Mr. P. Schippers and Mr. L. Renirie for their valuable contribution in the experimental investigations and to Mr. G.H. Huizing for writing the computer programme for the calculation of the transfer functions.

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APPENDIX

MODIFICATION OF AN EXISTING THEORETICAL MODEL FOR THE TRANSFER FUNCTION OF TUBE-TRANSDUCER SYSTEMS.

According to reference 4, the solution for the propagation of sinusoidal pressure perturbations $pe^{i\omega t}$ in a tube with circular cross section yields:

$$p = A \exp.\left[\frac{\omega x}{a_o}\sqrt{\frac{J_o\langle\alpha\rangle}{J_2\langle\alpha\rangle}}\sqrt{\frac{\gamma}{n}}\right] + B \exp.\left[\frac{-\omega x}{a_o}\sqrt{\frac{J_o\langle\alpha\rangle}{J_2\langle\alpha\rangle}}\sqrt{\frac{\gamma}{n}}\right] \quad (A.1)$$

with $\alpha = i\sqrt{i}\ R\sqrt{\frac{\rho_s\omega}{\mu}}$; the shear wave number,

$$n = \left[1 + \frac{\gamma - 1}{\gamma}\frac{J_2\langle\alpha\sqrt{Pr}\rangle}{J_o\langle\alpha\sqrt{Pr}\rangle}\right]^{-1} \quad \text{and}$$

$$Pr = \frac{\mu C_p}{\lambda}, \text{ the Prandtl number.}$$

The constants A and B occurring in (A.1) can be determined by specifying the boundary conditions at both ends of the tube.

The corresponding expression for the average value of the axial velocity perturbation is:

$$U = \frac{2}{i\omega\rho_s R^2}\frac{dp}{dx}\int_0^R\left[\frac{J_o\langle\alpha\frac{r}{R}\rangle}{J_o\langle\alpha\rangle} - 1\right] r\,dr \quad (A.2)$$

In reference 4 the boundary condition at the tube entrance is dictated by the fact, that the oscillatory pressure for $x = 0$ equals the value p_i which is imposed upon the system (see fig. a), thus

$$x = 0: \quad p = p_i \quad (A.3)$$

Note: The notation used here is the same as in reference 4, with the exception of the symbol for the frequency: in this paper ω has been used instead of ν.

This leads to a non-zero velocity U_o of the air at the tube entrance, which means that air moves periodically in and out the tube entrance.

However, in case an airstream blows across the tube entrance, the air leaving the tube has to push away the main flow, leading locally to additional oscillatory pressures at the tube entrance (Fig. b).

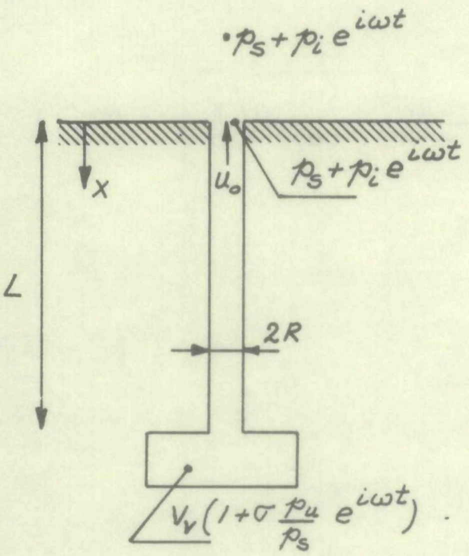

FIG. a STILL AIR

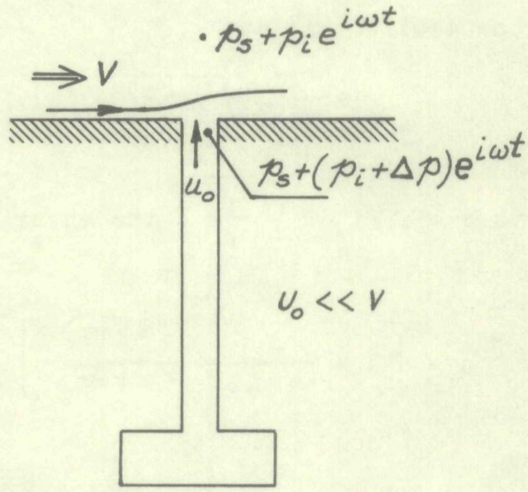

FIG. b IN CROSS WIND

This means that if an oscillatory pressure perturbation $p_i e^{i\omega t}$ is generated in the main flow, the boundary condition at the tube entrance (A.3) has to be modified into:

$$x = 0: \quad p = p_i + \Delta p \tag{A.4}$$

For the relation between Δp and the other flow parameters the following expression has been introduced:

$$\Delta p = C\rho_s u_o V \tag{A.5}$$

with C being still an unknown constant.

This type of relation, which may be derived in various ways, can be made plausible as follows:

Let us assume, for convenience in a 2-D case, that the gradient in oscillatory pressure occurring across the tube opening smooths out linearly in the tube within a distance λR from the entrance (Fig. c).

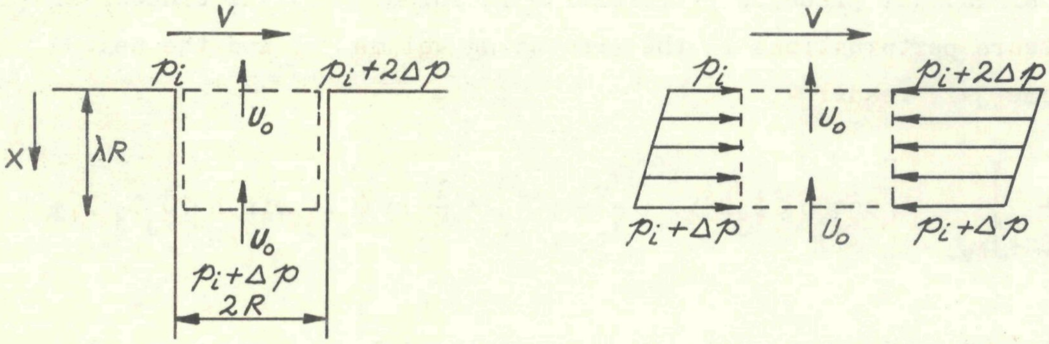

FIG. C MOMENTUM BALANCE

From the momentum balance in V-direction it then follows:

$$\rho_s u_o V 2R = -\frac{1}{2}(2p_i + \Delta p)\lambda R + \frac{1}{2}(2p_i + 3\Delta p)\lambda R = \Delta p\, \lambda R$$

or

$$\Delta p = \frac{2}{\lambda}\rho_s u_o V = C\rho_s u_o V$$

As λR can be expected to be of the order of the diameter, C will be of $O\langle 1\rangle$.

For the purpose of this investigation no further attemp has been made to determine the value of C by a more detailed theoretical investigation.

To modify the existing model of reference 4 for the interference between the periodically in-out flow at the tube entrance and the main flow, the original boundary condition (A-3) has been replaced by (A.4) and (A.5). The boundary condition at the end of the tube, i.e. the increase in mass in the instrument volume equals the mass leaving the tube, remains unchanged. In a way similar to that in reference 4, the coefficients A and B of equation (A.1) have been determined and a general recussion formula has been derived for a series connection of N tubes and N volumes.

For still air the expression of reference 4, which relates the sinusoidal pressure perturbation in volume j to the sinusoidal pressure perturbations in the preceeding volume j-1 and the next volume j+1, reads:

$$\left\{\frac{p_j}{p_{j-1}}\right\}_{v=0} = \left[\cos h\langle\phi_j L_j\rangle + \frac{V_{vj}}{V_{tj}}\left(\sigma_j + \frac{1}{k_j}\right)n_j\phi_j L_j \sin h\langle 0_j L_j\rangle + \right.$$

$$+ \frac{Vt_{j+1}\,\phi_{j+1}\,L_j\,J_o\langle\alpha_j\rangle J_2\langle\alpha_{j+1}\rangle \quad \sin h\langle\phi_j L_j\rangle}{Vt_j\,\phi_j\,L_{j+1}\,J_o\langle\alpha_{j+1}\rangle J_2\langle\alpha_j\rangle \quad \sin h\langle\phi_{j+1}L_{j+1}\rangle}\left\{\cos h\langle\phi_{j+1}L_{j+1}\rangle + \right.$$

$$\left.\left. - \frac{p_{j+1}}{p_j}\right\}\right]^{-1} \qquad \text{(A-6)}$$

$$\text{with } \phi_j = \frac{\omega}{a_{o_j}}\sqrt{\frac{J_o\langle\alpha_j\rangle}{J_2\langle\alpha_j\rangle}}\sqrt{\frac{\gamma}{n_j}}$$

In case a cross flow is present at the tube entrance formula (A-6) remains valid for $j > 2$, but the formula for j=1 changes. The modified result for j=1 becomes:

$$\left\{\frac{p_1}{p_o}\right\}_{v\neq 0} = \left[\left\{\frac{p_1}{p_o}\right\}^{-1}_{v=0} - CV\frac{\phi_1}{i\omega L_1}\frac{J_2\langle\alpha_1\rangle}{J_o\langle\alpha_1\rangle}\left\{\sin h\langle\phi_1 L_1\rangle + \right.\right.$$

$$- n_1\phi_1 L_1\frac{V_{v1}}{V_{t1}}\left(\sigma_1 + \frac{1}{k_1}\right)\cos h\langle\phi_1 L_1\rangle + \frac{Vt_2\phi_2 L_1}{Vt_1\phi_1 L_2}\frac{J_o\langle\alpha_1\rangle}{J_o\langle\alpha_2\rangle}\frac{J_2\langle\alpha_2\rangle}{J_2\langle\alpha_1\rangle} *$$

$$\left.\left.\frac{\cos h\langle\phi_1 L_1\rangle}{\sin h\langle\phi_2 L_2\rangle}\left\{\cos h\langle\phi_2 L_2\rangle - \left(\frac{p_2}{p_1}\right)_{v=0}\right\}\right\}\right]^{-1} \qquad \text{(A-7)}$$

For the single pressure measuring system of figure a and b, consisting of one tube connected at one end to an instrument volume, the modified formula becomes:

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$$j = N = 1: \quad \left\{\frac{p_1}{p_o}\right\}_{v \neq 0} = \left[\left\{\frac{p_1}{p_o}\right\}_{v=0}^{-1} - CV \frac{\phi_1}{i\omega L_1} \frac{J_2 \langle \alpha_1 \rangle}{J_o \langle \alpha_1 \rangle} \left\{ \sin h \langle \phi_1 L_1 \rangle + \right.\right.$$

$$\left.\left. - n_1 \phi_1 L_1 \frac{V_{v1}}{Vt_1} \left(\sigma_1 + \frac{1}{k_1} \right) \cos h \langle \phi_1 L_1 \rangle \right\} \right]^{-1} \qquad \text{(A-8)}$$

with (from A-6)

$$\left\{\frac{p_1}{p_o}\right\}_{v=0} = \left[\cos h \langle \phi_1 L_1 \rangle + \frac{V_{v1}}{V_{t1}} \left(\sigma + \frac{1}{k} \right) n_1 \phi_1 L_1 \sin h \langle \phi_1 L_1 \rangle \right]^{-1}$$

(A-9)

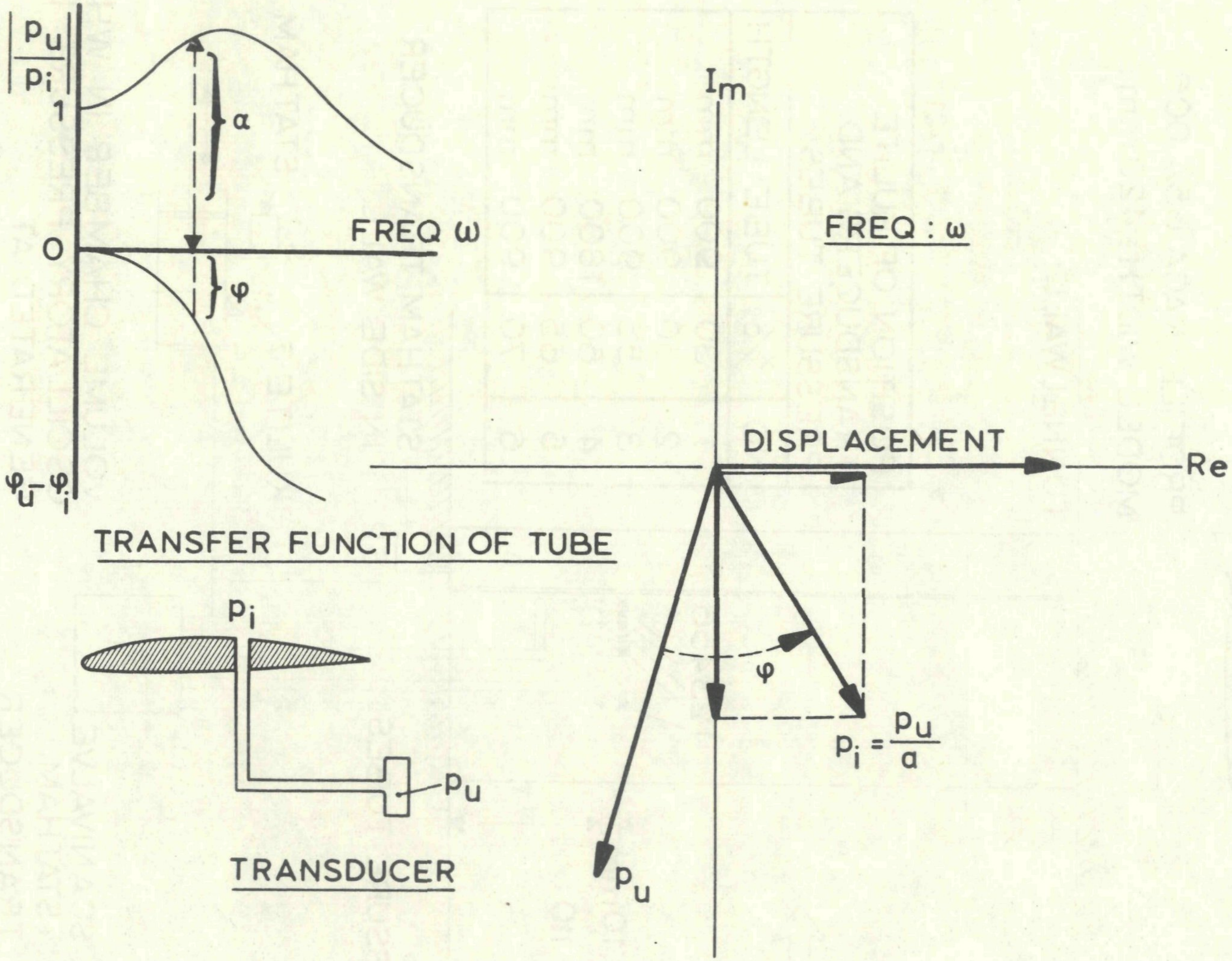
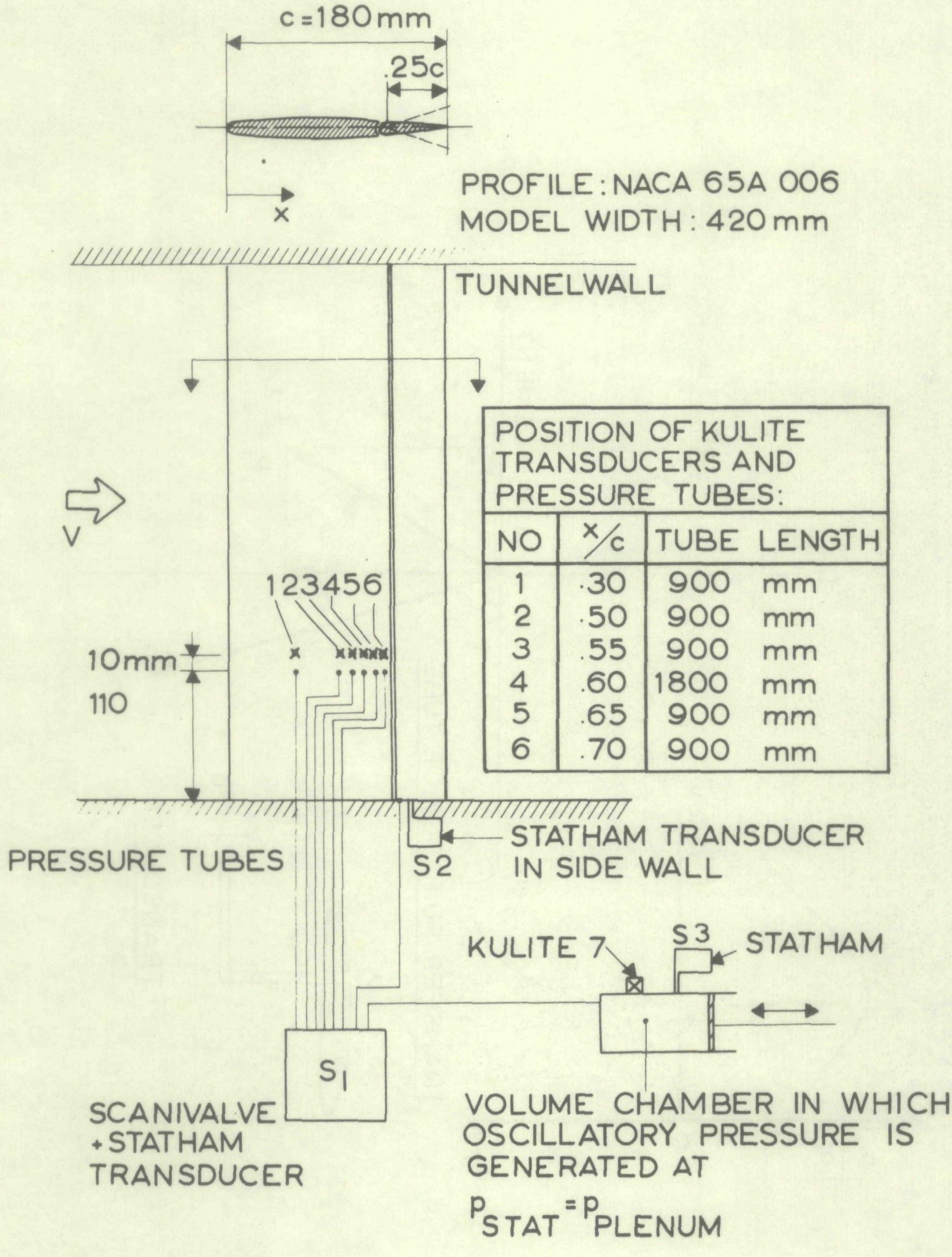


Fig. 1 Principle of data reduction procedure.



POSITION OF KULITE TRANSDUCERS AND PRESSURE TUBES:

NO	x/c	TUBE LENGTH
1	.30	900 mm
2	.50	900 mm
3	.55	900 mm
4	.60	1800 mm
5	.65	900 mm
6	.70	900 mm

Fig. 2 Two-dimensional model with oscillating control surface.
Test set up

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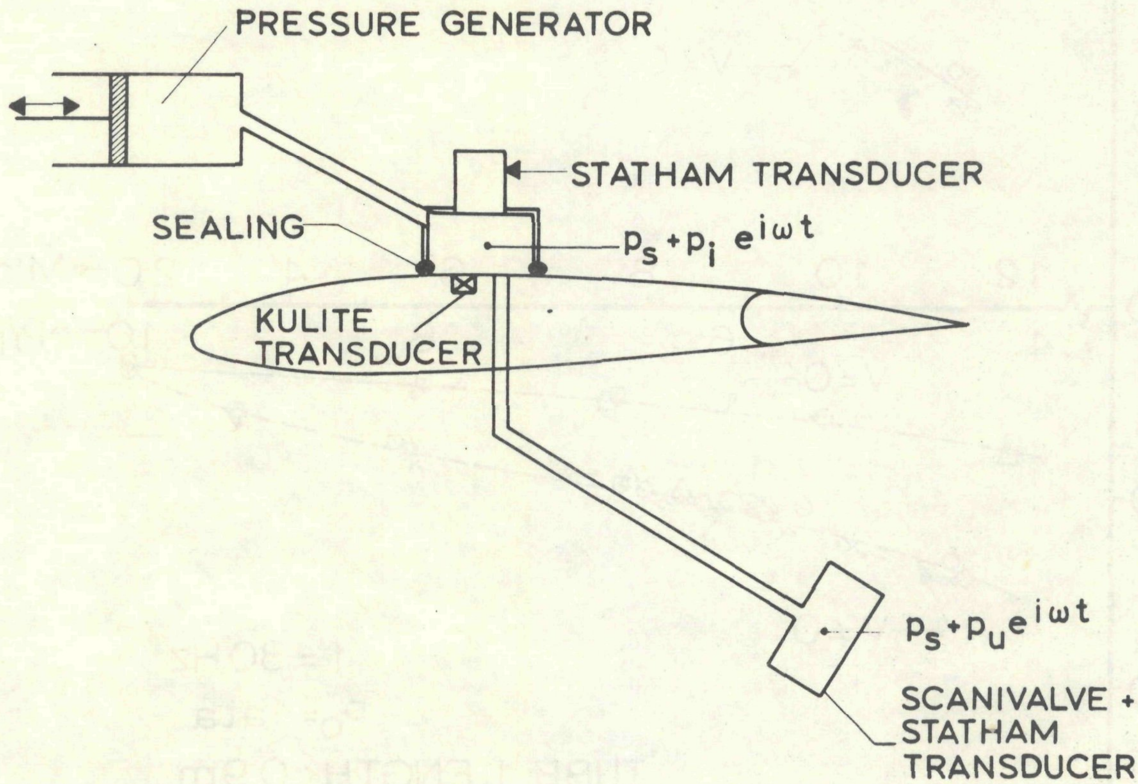

Fig. 3 Calibration in still air.

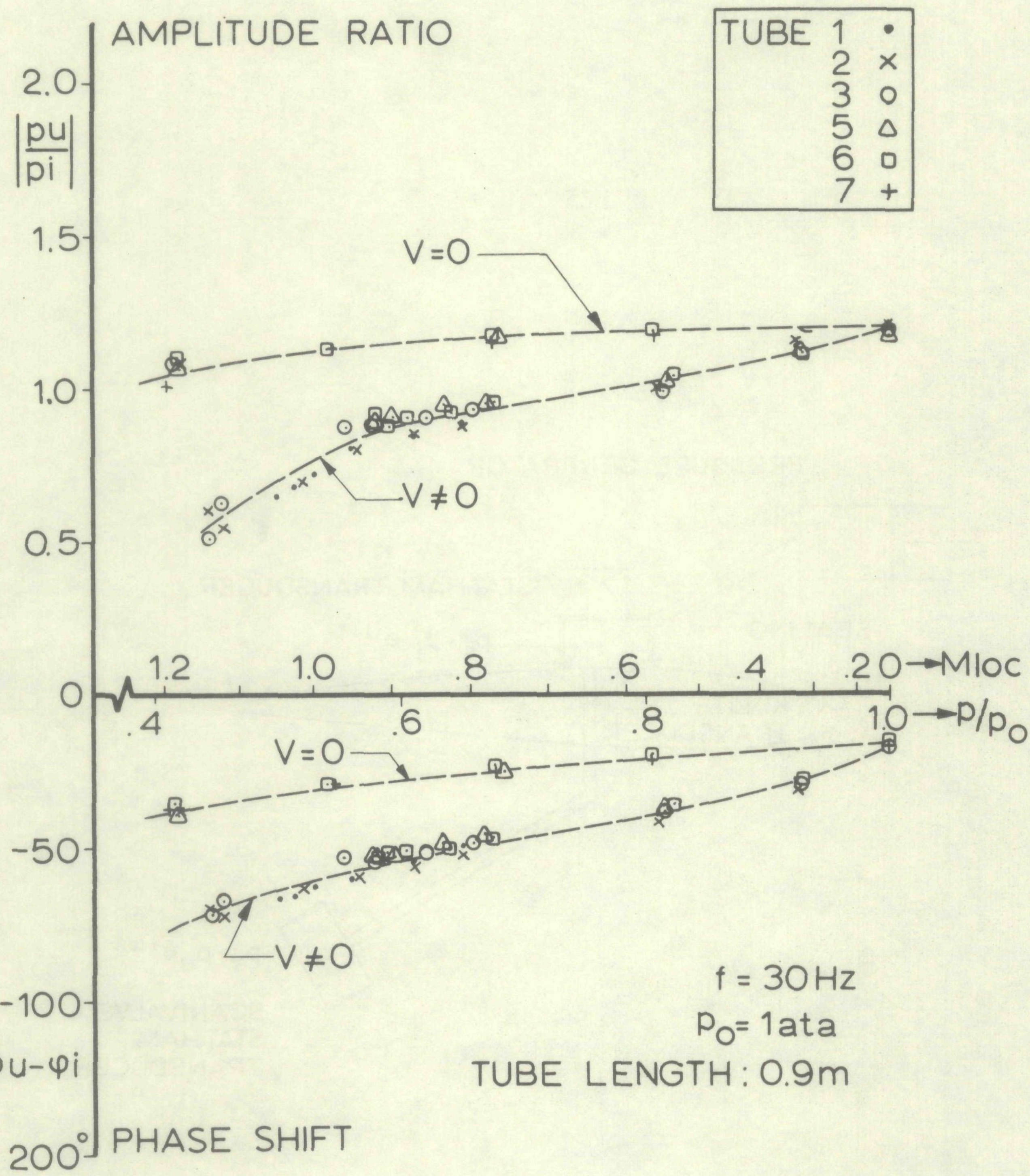

Fig. 4 Measured transfer functions in still air and with wind (30 Hz)

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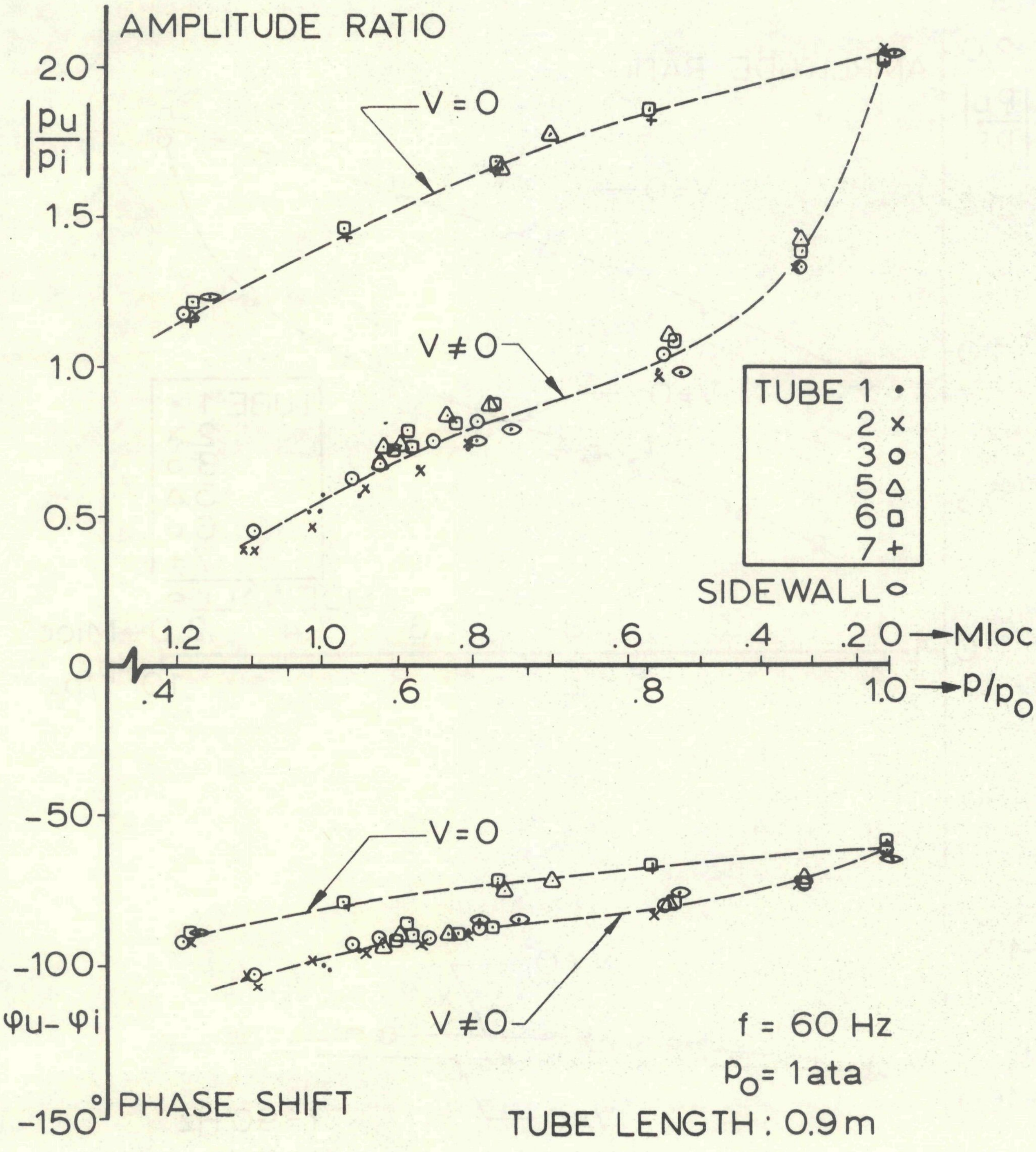

Fig. 5 Measured transfer functions in still air and with wind (60 Hz)

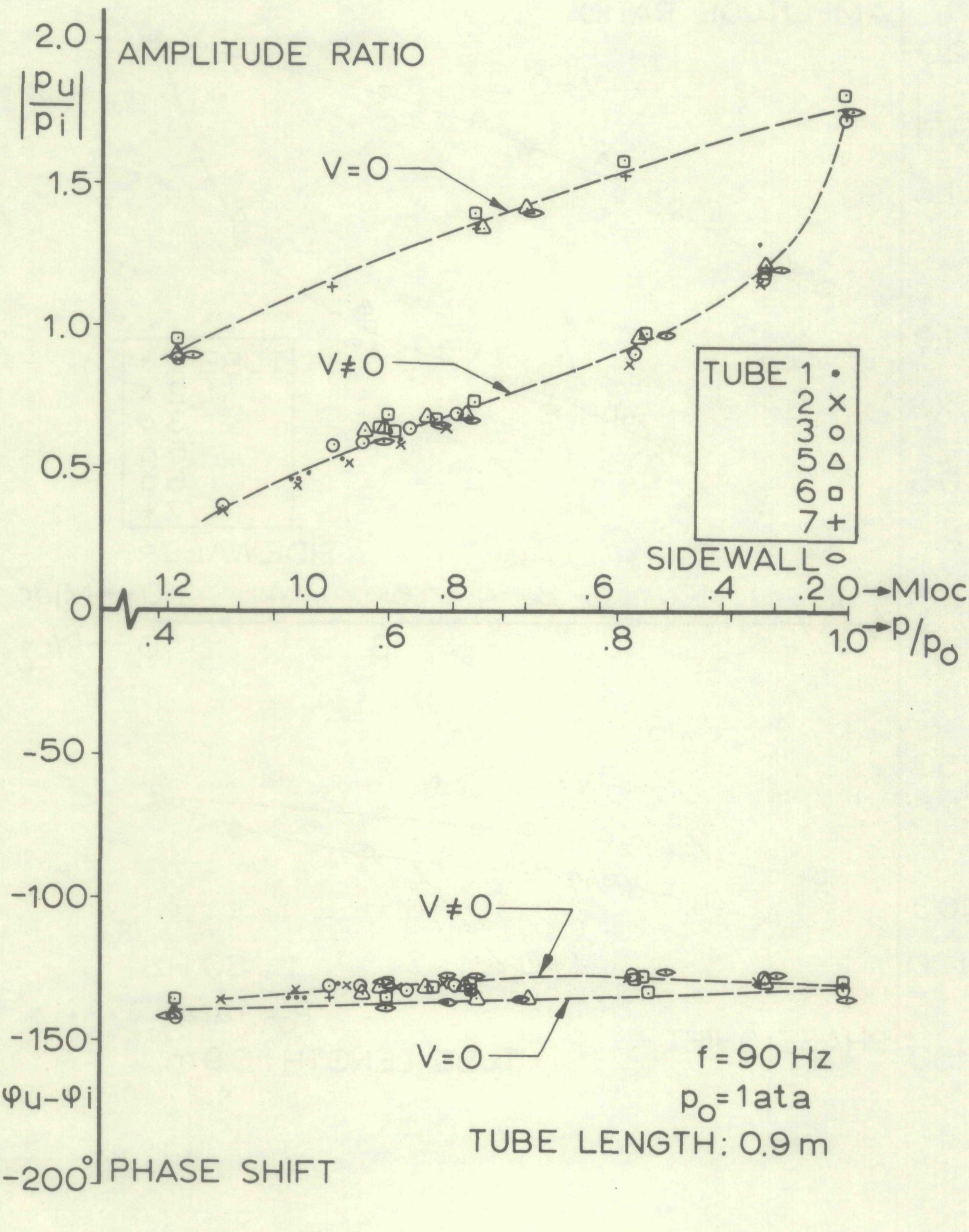

Fig. 6 Measured transfer functions in still air and with wind (90 Hz)

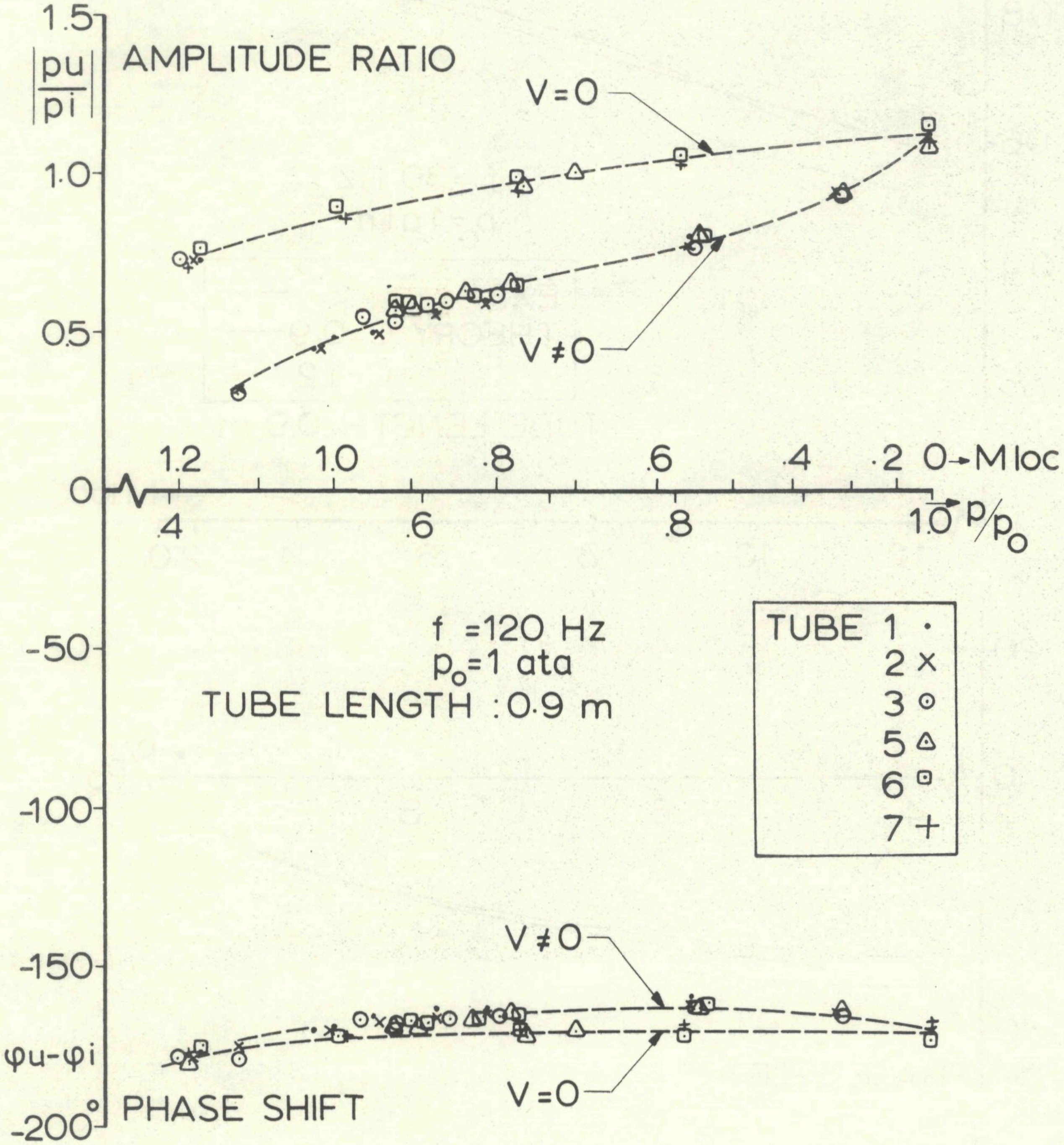

Fig. 7 Measured transfer functions in still air and with wind (120 Hz)

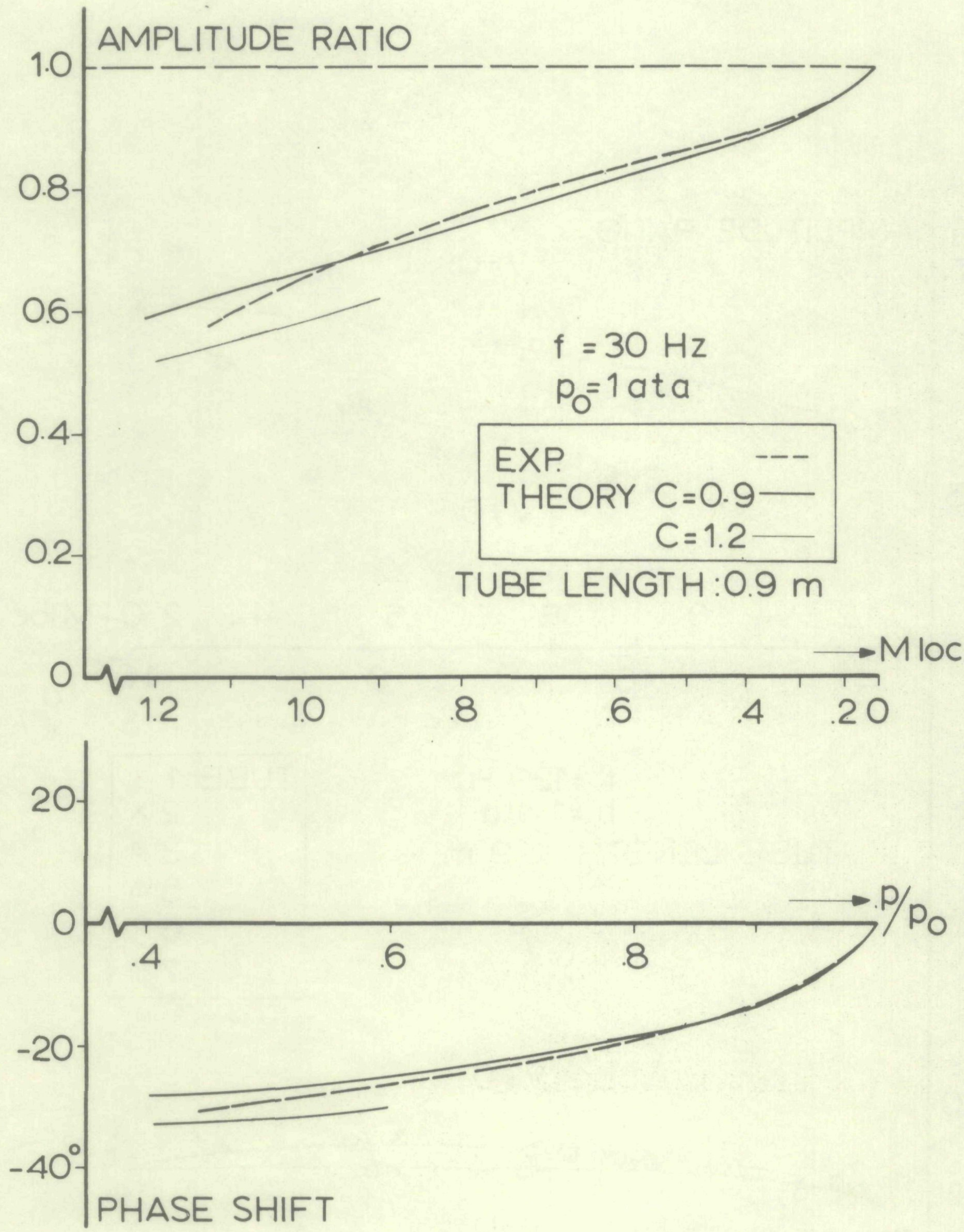

Fig. 8 Ratio of transfer functions $(p_u/p_i)_{v\neq0}$ / $(p_u/p_i)_{v=0}$ at 30 Hz

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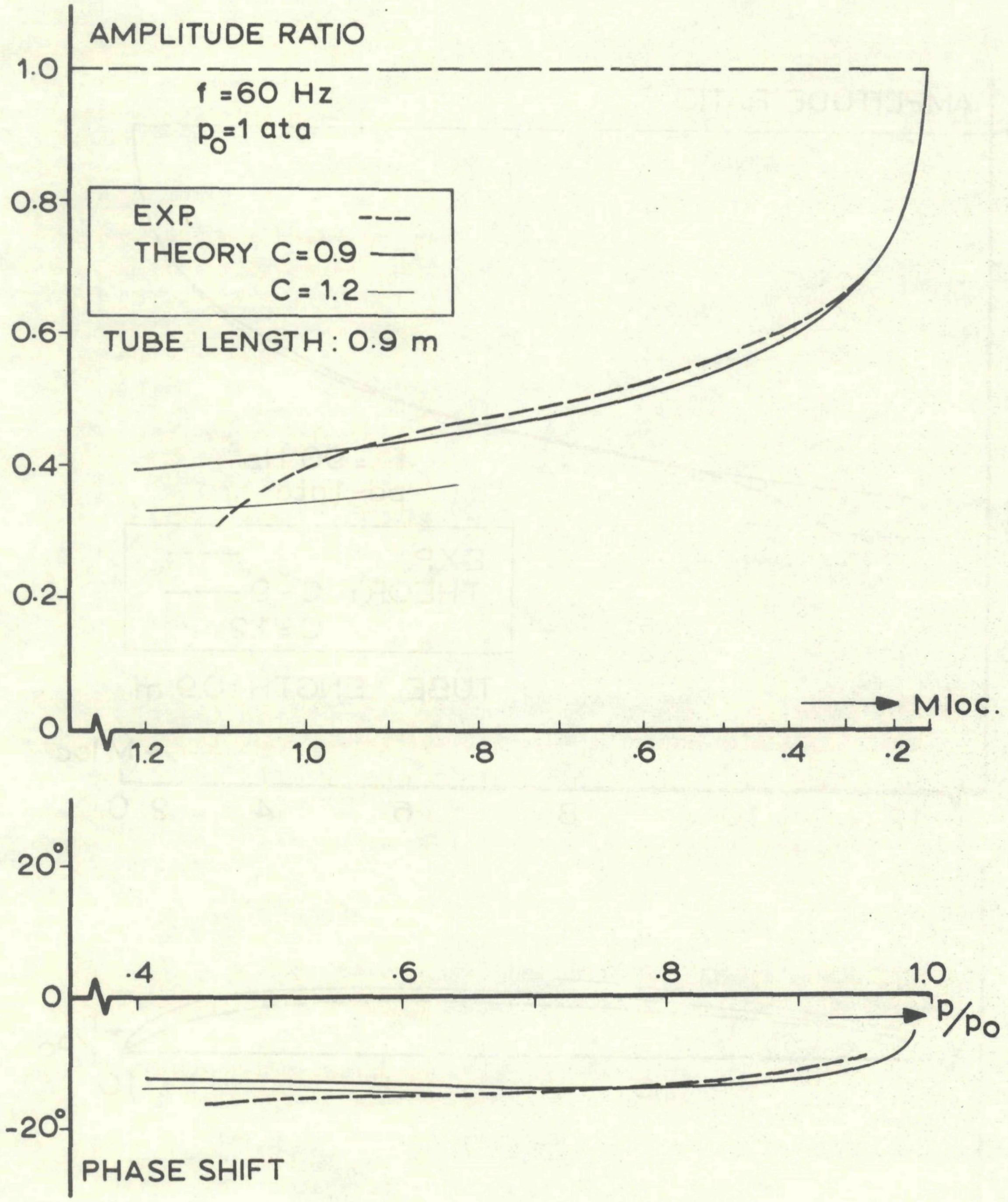

Fig. 9 Ratio of transfer functions $(p_u/p_i)_{v\neq0}$ / $(p_u/p_i)_{v=0}$ at 60 Hz

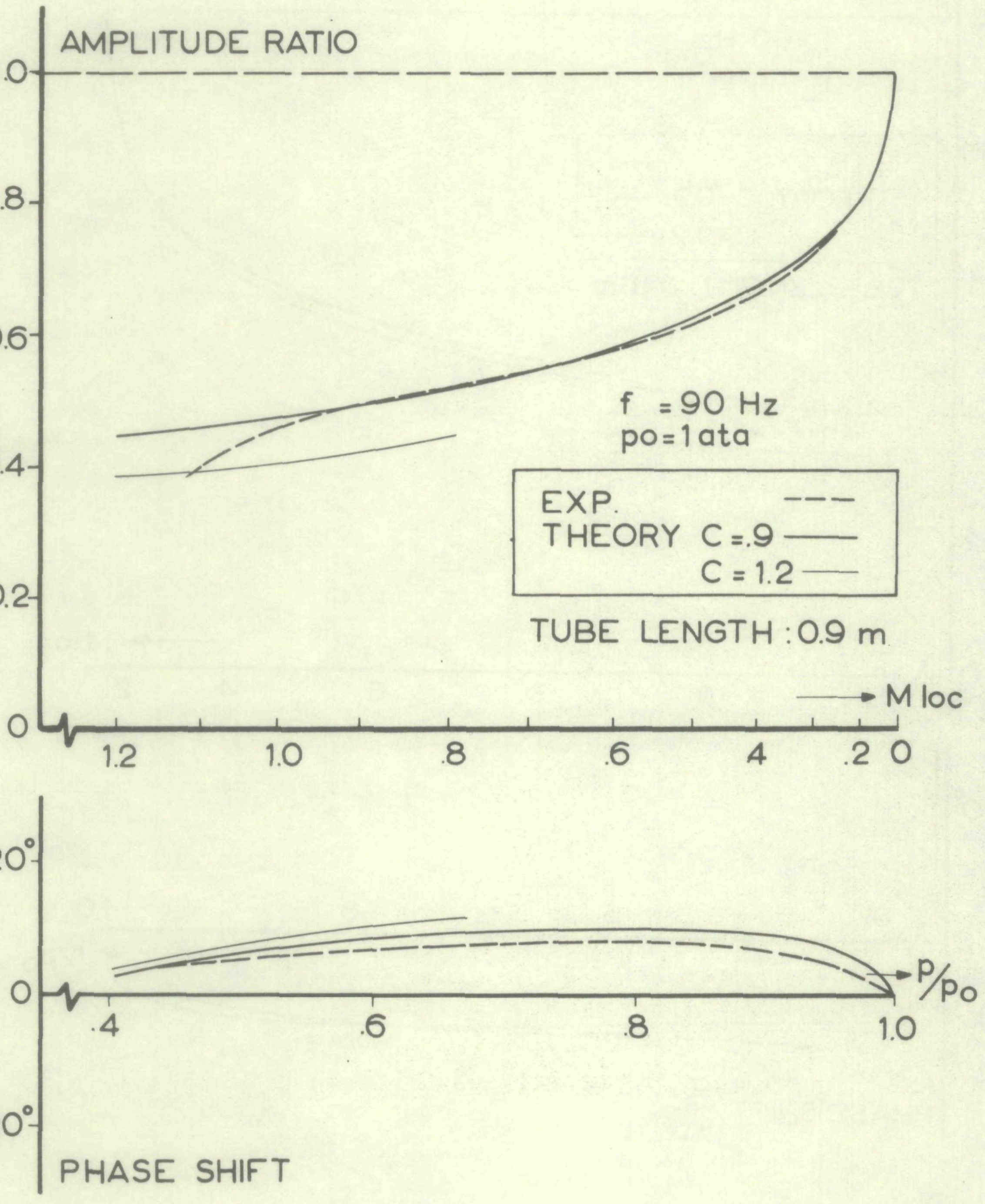

Fig. 10 Ratio of transfer functions $(p_u/p_i)_{v\neq0}$ / $(p_u/p_i)_{v=0}$ at 90 Hz.

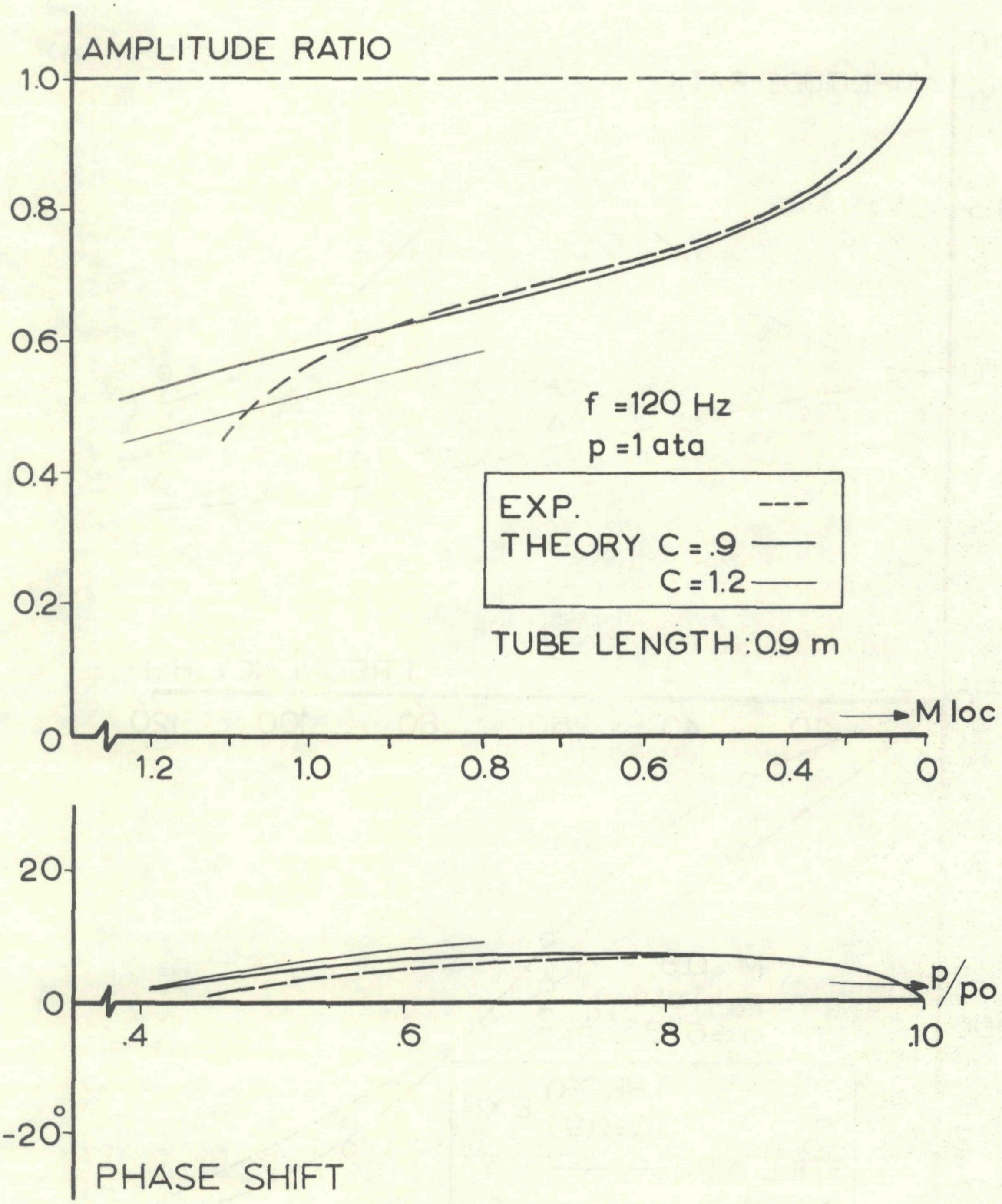

Fig. 11 Ratio of transfer functions $(p_u/p_i)_{v\neq 0}$ / $(p_u/p_i)_{v=0}$ at 120 Hz

Fig. 12

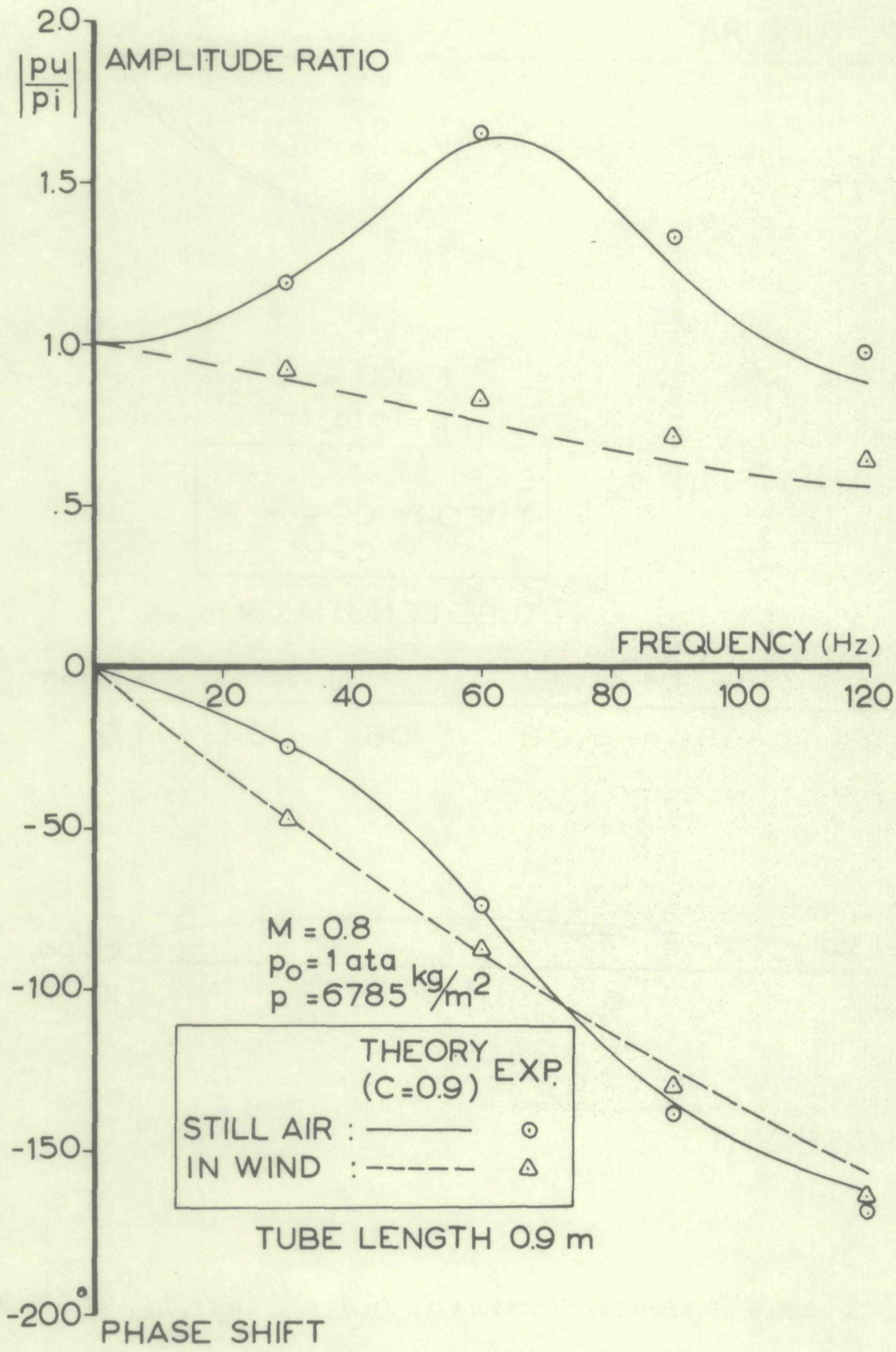

Fig. 12 Transfer function of 0.9 m tubes at p_s = 6785 kg/m^2
Comparison between experiment and theory with and without wind

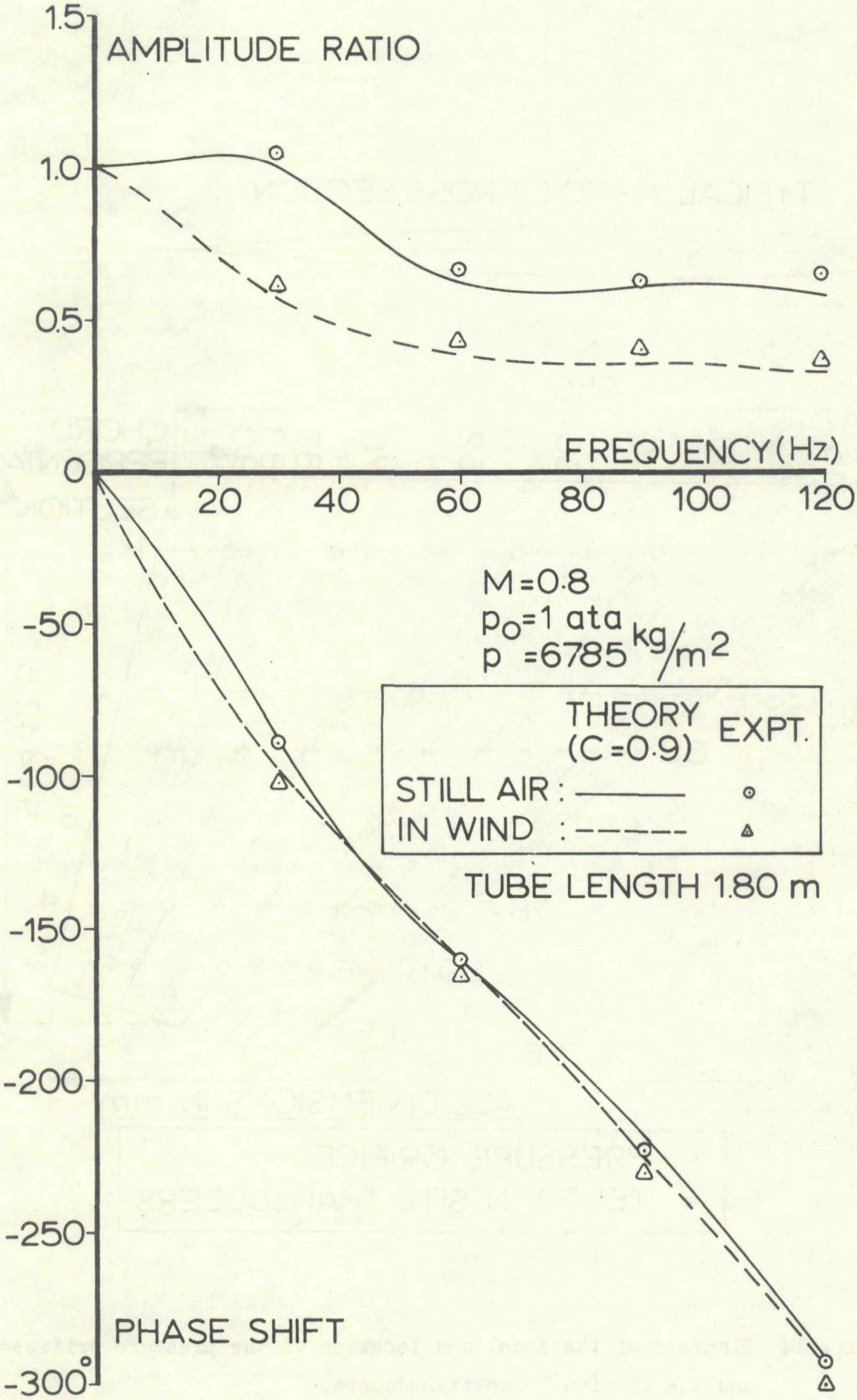

Fig. 13 Transfer function of 1.80 m at p_s = 6785 kg/m^2

Comparison between experiment and theory with and without wind

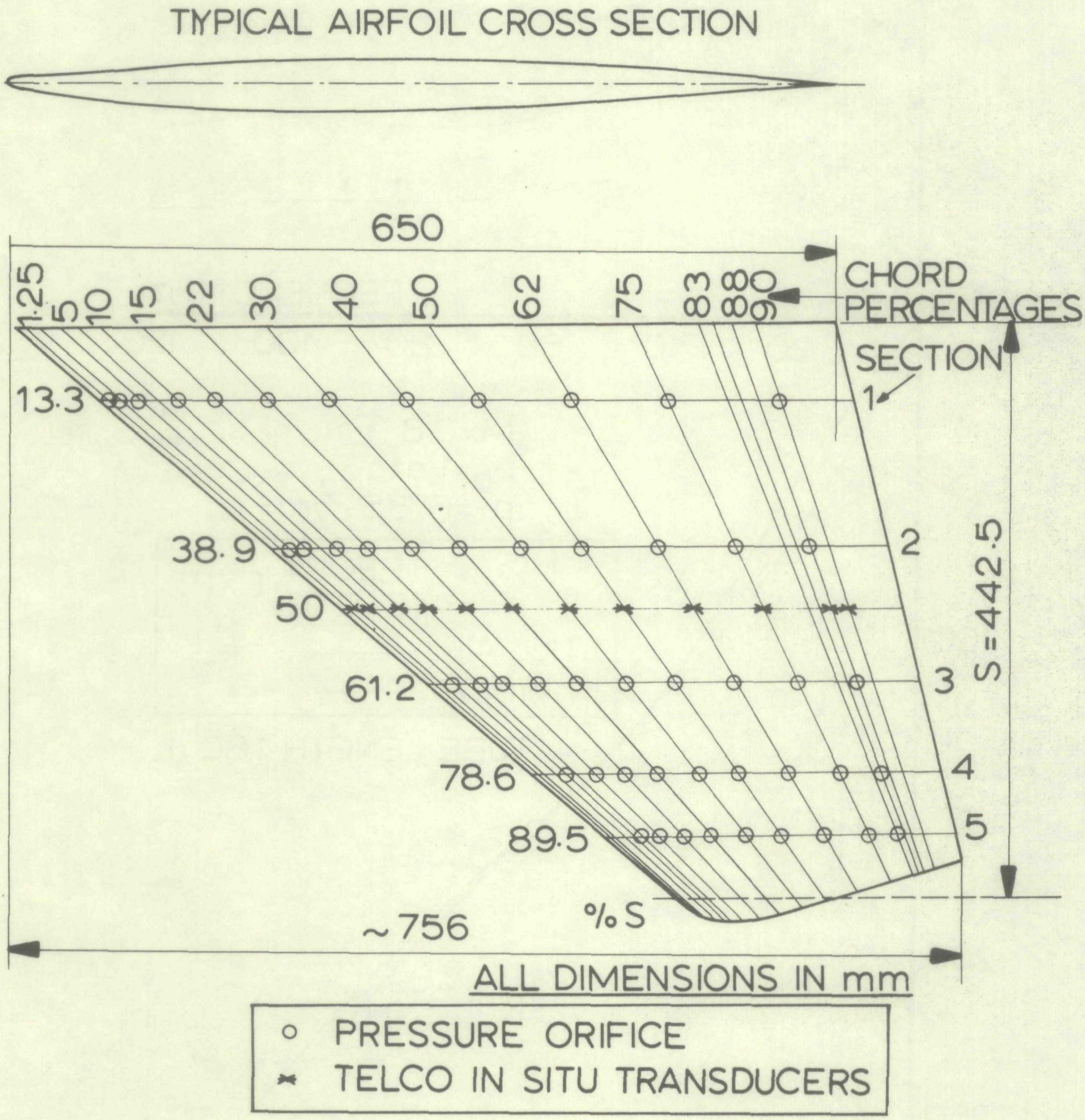

Fig. 14 Planform of the model and location of the pressure orifices and the in situ Telco transducers.

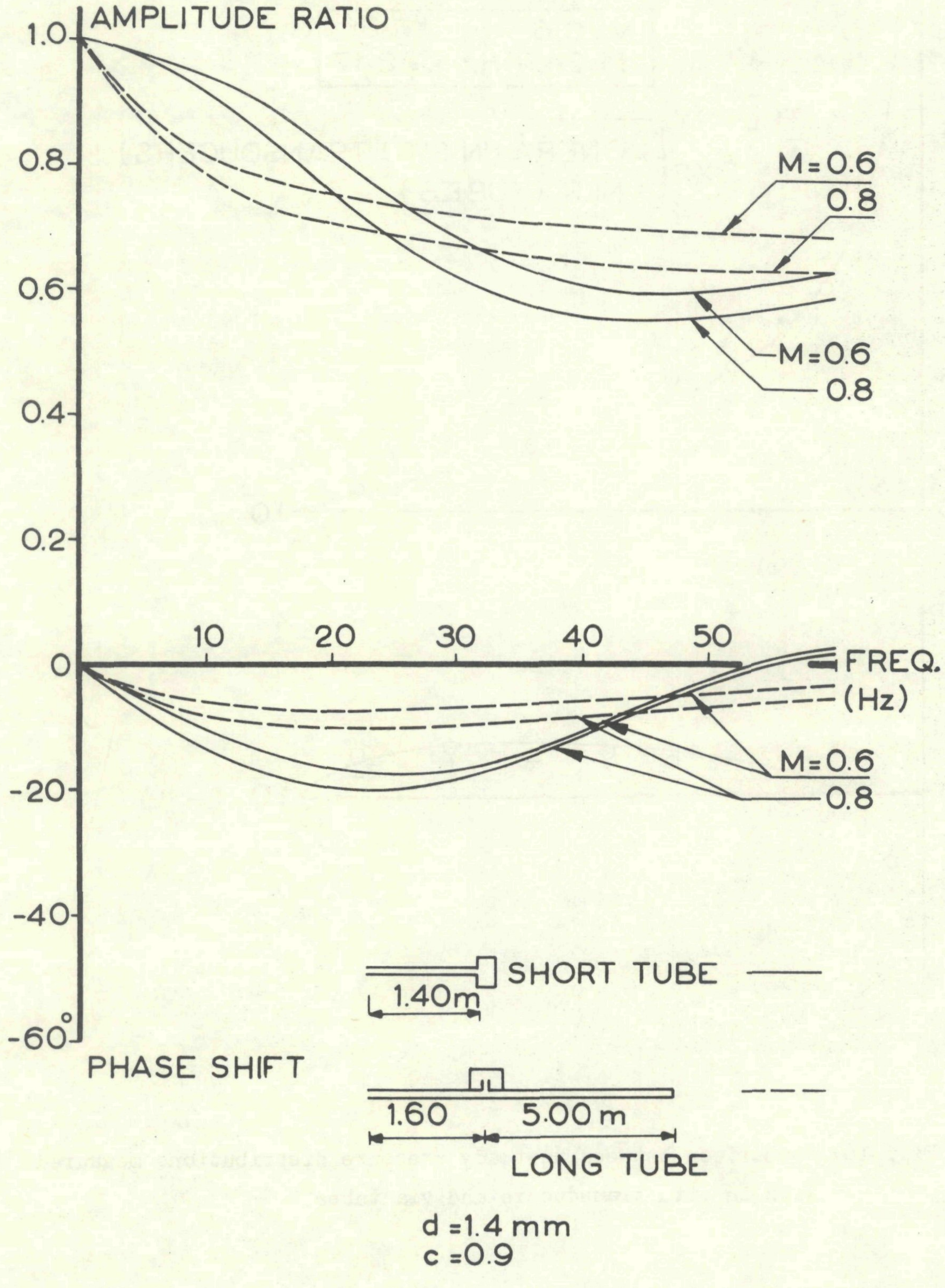

Fig. 15 Calculated ratio of transfer functions $(p_u/p_i)_{v\neq0}$ / $(p_u/p_i)_{v=0}$ for tube systems applied in ONERA/NLR investigation.

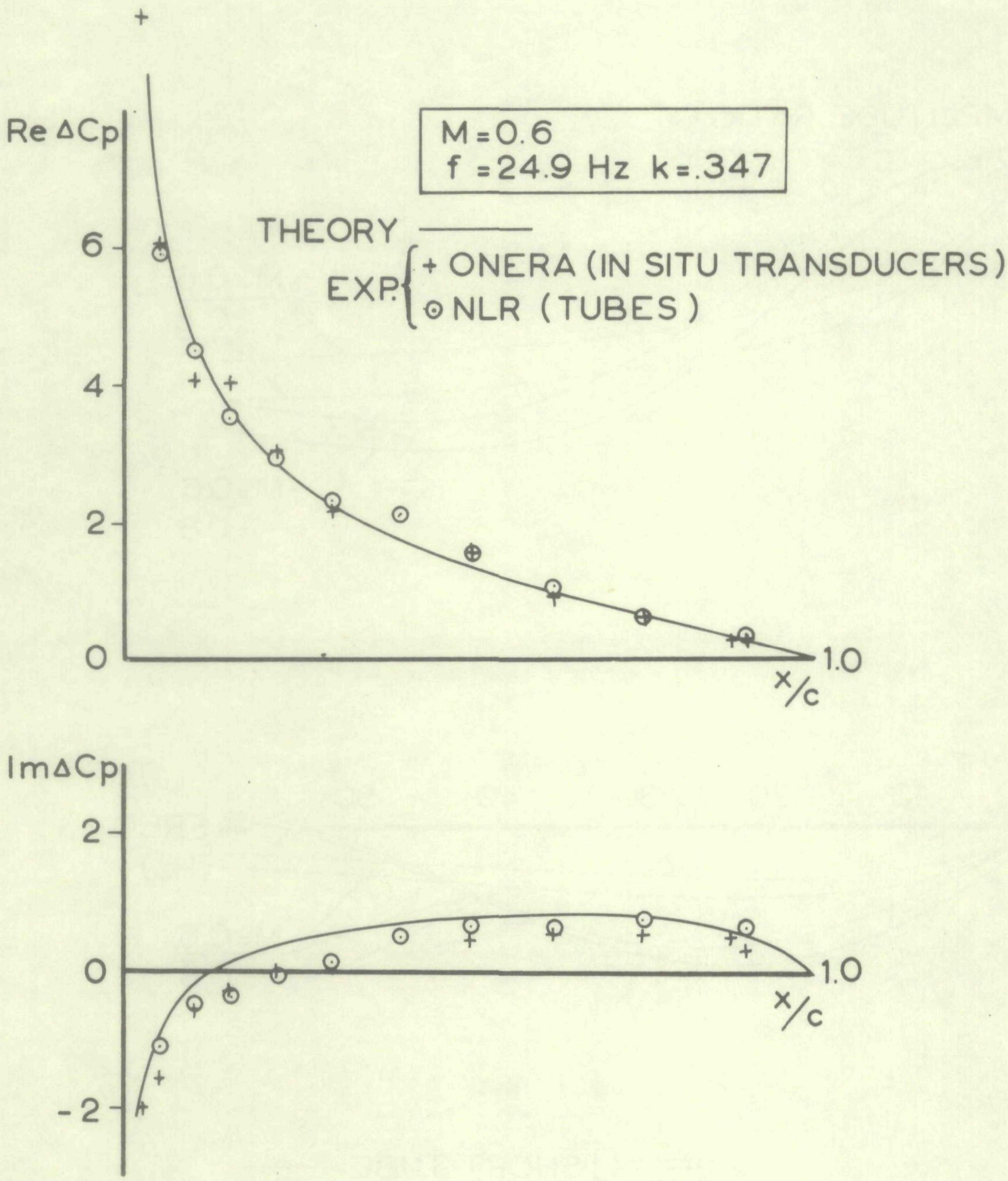

Fig. 16 Comparison between unsteady pressure distributions measured with in situ transducers and via tubes.

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Fig. 17

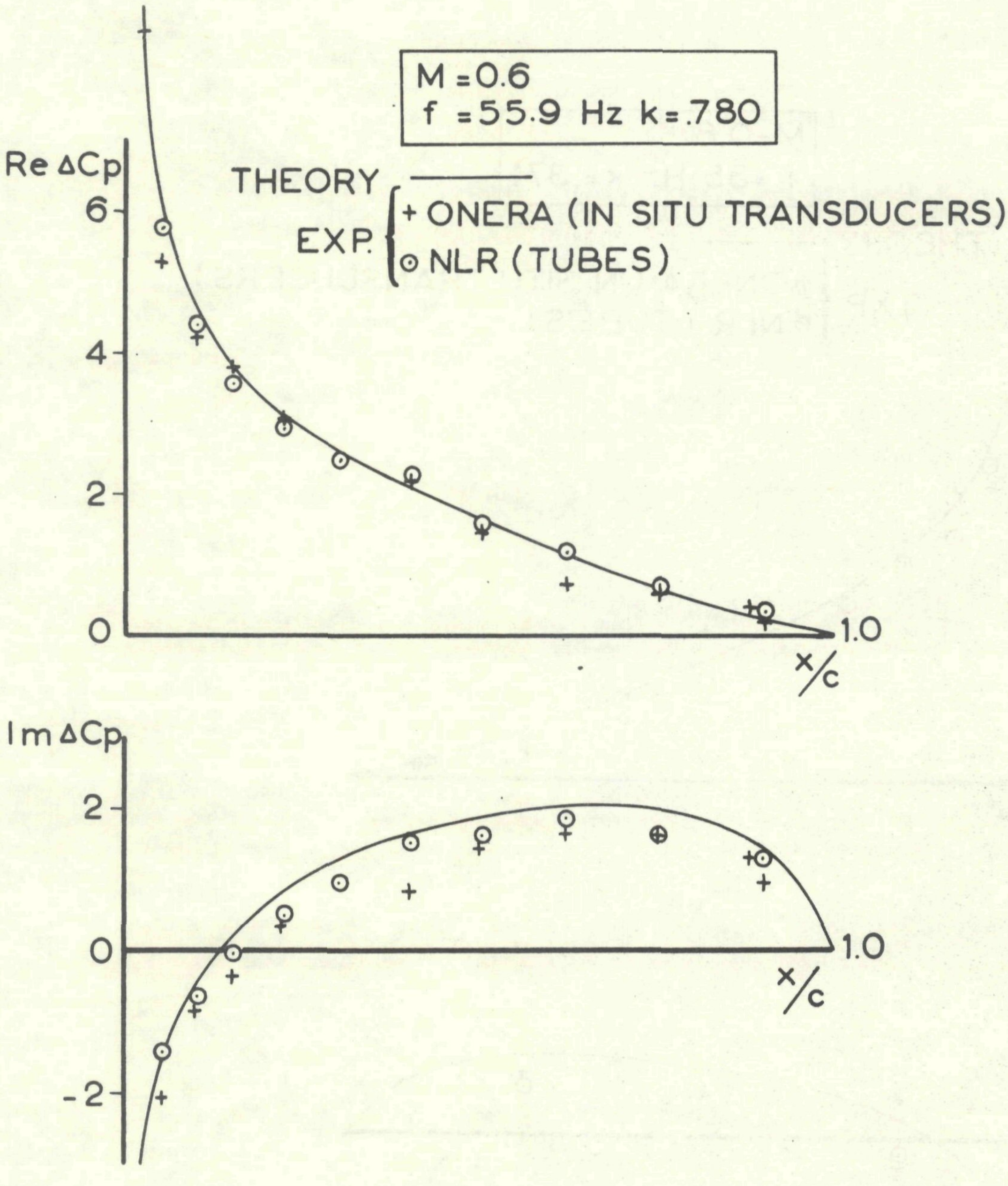

Fig. 17 Comparison between unsteady pressure distributions measured with in situ transducers and via tubes.

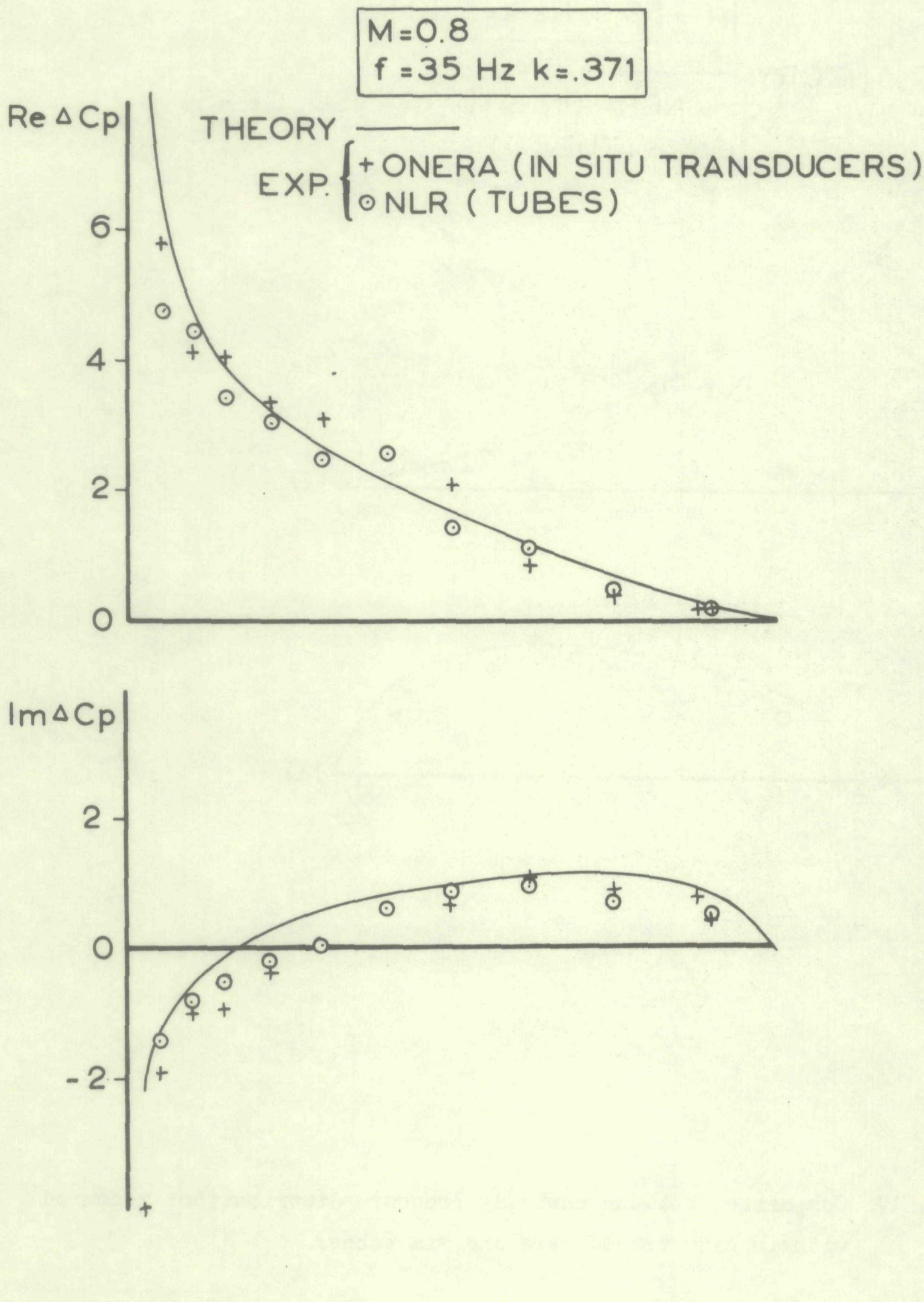

Fig. 18 Comparison between unsteady pressure distributions measured with in situ transducers and via tubes.

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Fig. 19

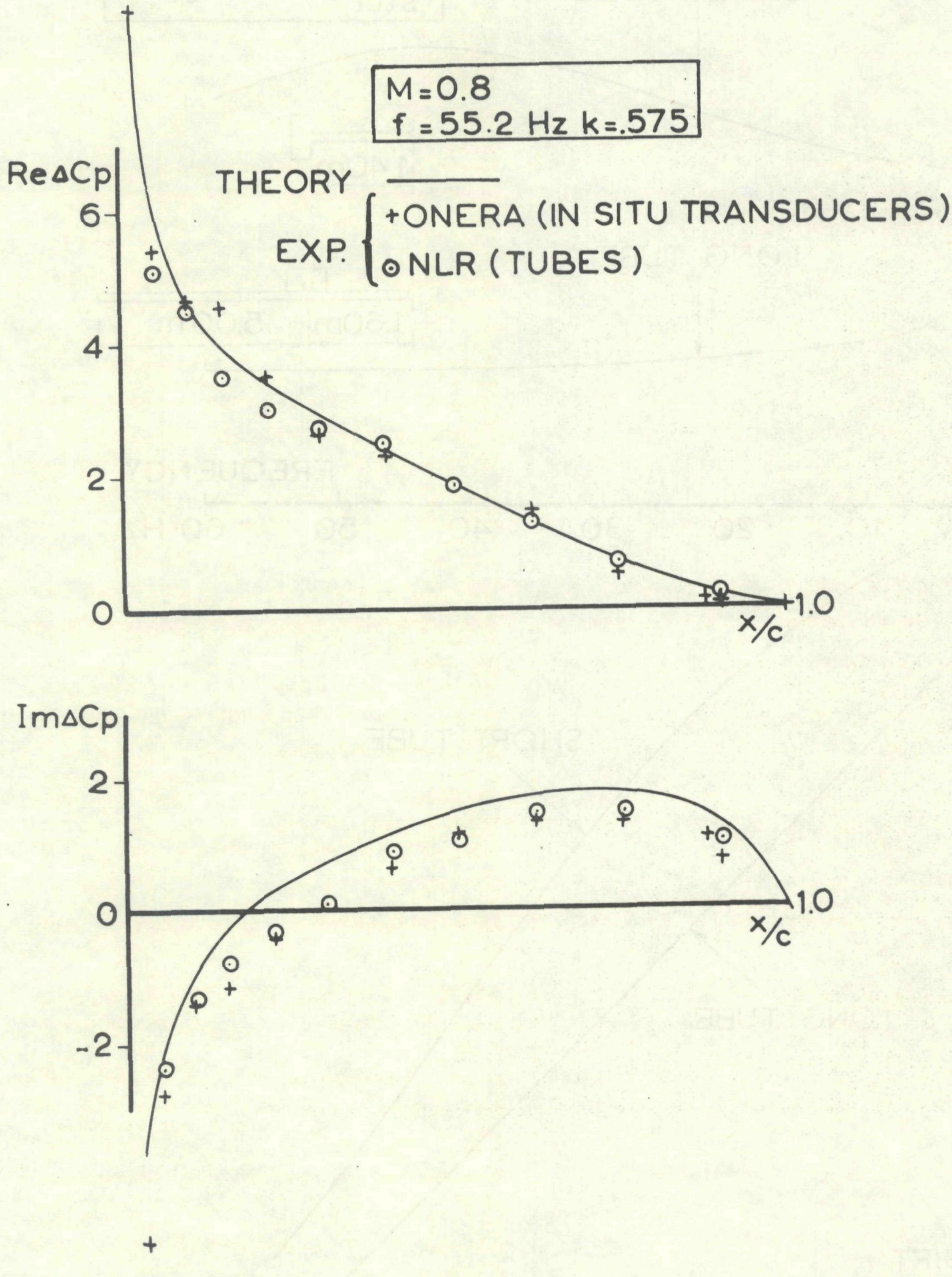

Fig. 19 Comparison between unsteady pressure distributions measured with in situ transducers and via tubes.

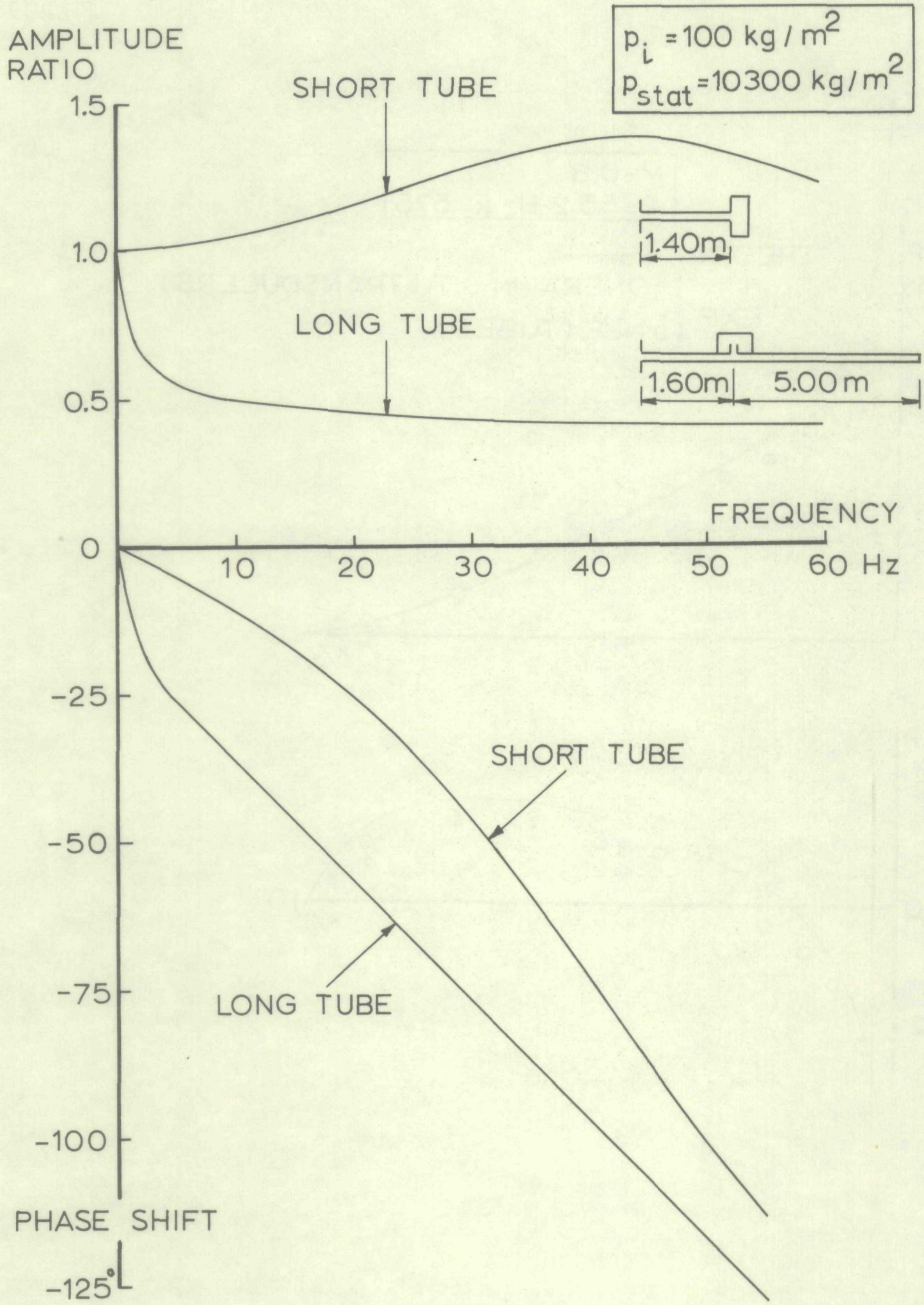

Fig. 20 Comparison of measured frequency response of short and long tube-system, used in Onera-NLR investigation.

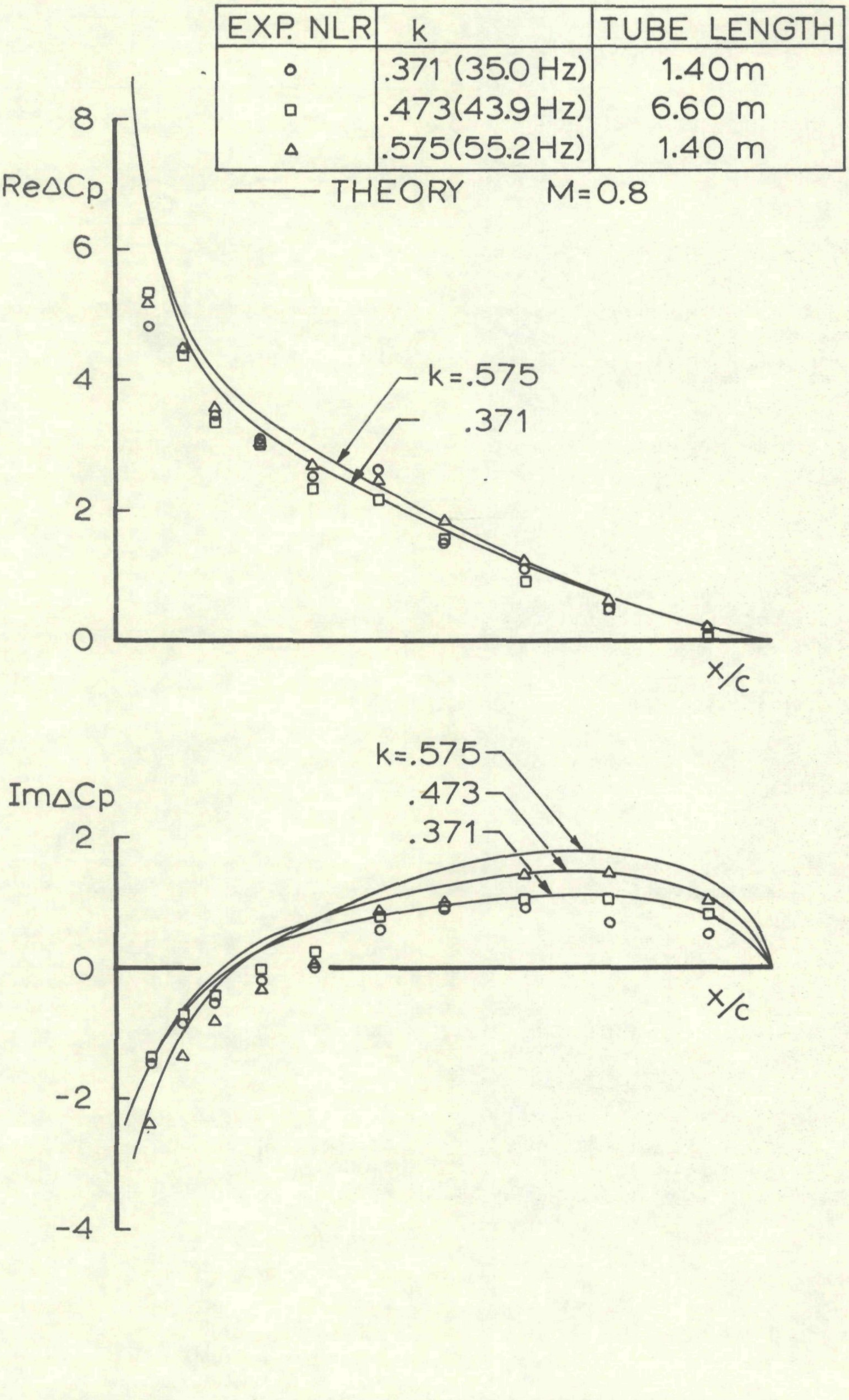

Fig. 21 Comparison of unsteady pressure measurements obtained with different tube lengths.