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# An investigation of acoustically controlled turbulence amplifiers.

Gary W. Rankin
*University of Windsor*

# AN INVESTIGATION OF ACOUSTICALLY CONTROLLED TURBULENCE AMPLIFIERS

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Gary W. Rankin

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## ABSTRACT

The static and dynamic characteristics of shrouded, acoustically controlled turbulence amplifiers are investigated. The static characteristics study includes a variation of shroud diameter, gap length and supply flow conditions.

Existing analytical and empirical relationships are evaluated for the purpose of predicting these characteristics. It is found that the analytical procedure employed by Bell (Ref. 14) for unshrouded, flow controlled turbulence amplifiers reasonably describes the laminar jet pressure recovery of shrouded turbulence amplifiers. Bell's approximate method for quickly determining the maximum pressure recovered with a laminar jet is modified for operating points which are lower than the maximum. The turbulent jet recovery pressure given by Bell's procedure is not in agreement with the experimental results of this investigation.

A "jump" in the characteristic frequency occurs as the Reynolds number of the emitter tube is increased. The lower characteristic frequency can be predicted by an advanced Helmholtz resonator theory.

It is also shown that the acoustically controlled, unlike the flow controlled, turbulence amplifier can be operated in the proportional mode over a limited range of control variables.

A dynamic characteristic study is performed for

one geometrical shape with varying supply flow conditions. Both the laminar - turbulent ("switch-off") and the turbulent-laminar ("switch-on") characteristics are investigated.

The "switch on" and "switch off" characteristics of the acoustically controlled turbulence amplifier are more equal and less erratic than the flow controlled turbulence amplifier. The existing theoretical and empirical studies of these response times, originally developed for the flow controlled turbulence amplifier, agree with the present experiments only in general trends.

To my wife and parents

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NOMENCLATURE

A Area $(m^2)$

B end correction for the Helmholtz resonator neck (m)

B.N.L. background noise level (db.)

c speed of sound (m/sec.)

D Non-dimensional cavity diameter dc/ds

d diameter (m)

f frequency of sound (Hz.)

G non-dimensional gap length g/ds

g gap length (m)

h effective depth of Helmholtz Resonator (see Equ. D.4.1)(m)

K laminar jet matching parameter

L non-dimensional length $\ell$/ds

$\ell$ length (m)

N number of vent holes

p gage pressure $(N/m^2)$

Q flow rate $(m^3/sec.)$

Re Reynolds number of the supply tube $\frac{Usds}{\nu}$

St Strouhal number $\frac{fds}{Us}$

T temperature $(^{o}C)$

T$\ell$.d. laminar - turbulent delay time (m.sec.)

Tf. laminar - turbulent fall time (m.sec.)

Tt.d. turbulent - laminar delay time (m.sec.)

Tr. turbulent - laminar rise time (m.sec.)

U average velocity (m/sec.)

V volume $(m^3)$

$\beta$ momentum correction factor

$\lambda$ wavelength (m)

$\delta$ displacement thickness at the nozzle exit (m)

$\mu$ dynamic viscosity (kg/sec.m.)

$\nu$ kinematic viscosity ($m^2$/sec.)

$\rho$ density of fluid ($\frac{kg}{m^3}$)

Subscripts

a ambient

c control

char. characteristic

c.$\ell$. centerline

m.s. maximum sensitivity

n Helmholtz resonance neck

o output

r Helmholtz resonance

s supply

v venthole

# CHAPTER I

## INTRODUCTION

In general the principle of the turbulence amplifier is based upon the fact that a normally laminar jet can be made turbulent by subjecting it to certain external disturbances. The method employed to disturb the laminar jet is one criterion used to distinguish between different types of turbulence amplifier.

The basic configuration of the turbulence amplifier consists of two, small diameter, tubes located on a common centerline, with a gap between them, as shown in Fig. 1(a). The longer tube serves as a supply tube (emitter) from which a laminar jet is directed across the gap towards a second (collector) tube. This laminar jet will naturally become turbulent at some distance downstream and therefore the gap spacing must be less than this natural laminar length. The laminar jet hitting the collector causes a relatively high pressure to be recovered. This condition is referred to as the "on" state of the turbulence amplifier.

The presence of a control signal disturbance causes the laminar-turbulent transition position to move towards the emitter. Usually, only a small disturbance is needed to cause the laminar-turbulent interface to be shifted to a stable position close to the emitter exit as shown in Fig. 1(b) Because the turbulent jet spreads more than the laminar jet the pressure that is recovered at the receiver is considerably less. This condition is referred to as the "off" state of the turbulence amplifier.

The most common methods used to disturb the laminar jet are by impinging a control jet onto the main jet, transversly, near the emitter exit or by subjecting the main jet to sound at this position. These types of turbulence amplifiers are referred to as "flow controlled" and "acoustically controlled" respectively.

Another distinct classification can be made depending upon whether the main jet is enclosed in a protective cover referred to as a "shroud".

The main objective of this study is to investigate some of the characteristics of "shrouded, acoustically controlled" turbulence amplifiers. These characteristics may be discussed in terms of two types, static and dynamic.

The static characteristics involve the determination of the output pressure variation with such variables as the supply pressure, gap length, shroud diameter, control sound pressure level and frequency.

The dynamic characteristics involve measurement of the switching times from the "on" to the "off" state and vice versa for certain static characteristic settings referred to as operating conditions.

# CHAPTER II

# LITERATURE SURVEY

The material presented in this section summarizes briefly the existing literature which is pertinent to the study of acoustically controlled turbulence amplifiers.

## 2.1 Flow Controlled Turbulence Amplifier

Auger (Ref. 3) introduced the turbulence amplifier in 1962. In this and his subsequent papers (Ref. 4 and 5) emphasis was on describing the basic principle of the device and possible means of control (including acoustic). He also listed several advantages, disadvantages and possible applications. However, no rational analytical or experimental procedure was given to predict the operating characteristics of the device.

Because of the relative ease with which an operable turbulence amplifier could be constructed, a variety of devices were manufactured, marketed and applied. These included both planar and axisymmetric, shrouded and unshrouded configurations.

### 2.1.1 Analysis of Static Performance

Oels, Boucher and Markland (Ref. 30) were the first to publish results of a systematic experimental study of axisymmetric, shrouded and unshrouded turbulence amplifiers They presented some design guidelines concerning the emitter length to diameter ratio $L_s$ and the maximum output pressure available.

Verhelst (Ref. 41) presented an experimental design procedure for choosing the operating conditions of an amplifier of certain fixed geometry. However, if the geometry was changed a new set of experimental curves was required to determine the operating points and predict the amplifier performance.

Bell (Ref. 13 and 14) was the first to consolidate theory and experiment to produce an analytical procedure that reasonably describes the unshrouded, flow controlled turbulence amplifier. He separated the turbulence amplifier into its characteristic sections considering the tube flows, laminar jet, turbulent jet and receiver pick up. To model the flow in the tubes (emitter, collector and control) of the amplifier, which in most cases is developing, he used Hornbeck's (Ref. 26) open form solution. To avoid the open solution he interpolated from a table given by Hornbeck.

For the laminar jet he used Schlichting's (Ref. 34) point source model, employing centerline velocity matching to approximate the jet issuing from a source of finite size.

For the turbulent jet he used the Goertler jet model (Ref. 34) with the condition that the virtual origin was at the jet exit. This was to account for the fact that the control jet which caused the jet to become turbulent was located at a distance of 2 nozzle diameters downstream, and the exact position where the turbulent jet began, after the control, was not accurately known.

Bell calculated the blocked load output pressure in the receiver knowing the centreline velocity of the jet at the mouth. This decision was based on previous work cited in his paper.

The only characteristic which could not be predicted analytically was the natural laminar length of the jet. To aid in determining this value he presented his experimental results and those of two other investigators. Other researchers such as Gradetsky (Ref. 22), Vaz (Ref. 40), Marsters (Ref. 27) and McNaughton and Sinclair (Ref. 28) have studied this problem and can be consulted for further information.

The computer program that was written to perform calculations using Bell's analytical procedure is given in Appendix D.1.

2.1.2 Dynamic Performance

Several early investigators (Ref. 3,4,5, 25 and 41) quoted approximate values for the switching times of flow controlled turbulence amplifiers.

Siwoff (Ref. 35) demonstrated that by "inbuilding" an edge between the emitter and collector such that this edge almost touches the laminar jet, the switching time could be reduced.

Hayes (Ref. 23) was the first to perform a comprehensive experimental study of the geometrical and flow variables affecting the response time. He also developed an analytical model to predict the switching times of turbulence amplifiers. The resulting equations for the model are presented in Appendix D.2.

Experiments indicated that the shroud geometry of the amplifier affected the switching times considerably. The laminar-turbulent switching time was not equal to the turbulent-laminar time. This difference increased as the gap length was made larger or the shroud diameter smaller. It was also noticed that the turbulent-laminar switching time was quite erratic. This uncertainty increased with gap length and decreased with shroud diameter.

Abramovich and Solan (Ref. 1) found experimental correlations for the laminar-turbulent and turbulent-laminar switching times for a jet and described how these could be applied to the flow controlled turbulence amplifier. The correlations obtained are given in Appendix D.3 .

## 2.2 Acoustically Controlled Turbulence Amplifier

Auger (Ref. 5) noticed that his turbulence amplifier was sensitive to sound at frequencies of approximately 8 KHz and the sensitivity to sound increased with a larger gap between the emitter and collector. He delt mainly with applications of the device in the remainder of the paper.

Generally, in the literature, two attitudes were prevalent regarding the sensitivity of the turbulence amplifier to sound. The first one involved the identification of the problem areas of a flow controlled turbulence amplifier (response to external noise) (Ref. 12 and 23). The other involved a direct use of the phenomenon as an acoustic-fluidic transducer or a switch. In this survey emphasis is given to the papers concerning the second attitude mentioned.

Also, some investigators studied the bistable fluid amplifier as an acoustic-fluidic switch (Ref. 15, 21, and 39). However, these references will not be discussed as they do not pertain to the turbulence amplifier.

2.2.1 Analysis of Performance

In 1968 Gradetsky (Ref.22) experimentally studied two acoustically controlled turbulence amplifiers. He measured the output pressure drop with control sound over a frequency range from 200 - 10,000 Hz. At the same time the sound pressure level inside the cavity was measured. He noticed that the output pressure dropped appreciably at resonance conditions inside the cavity. However, these resonant frequencies did not correspond to those predicted using the basic Helmholtz formula (without the correction factors).

Nomota and Shimada (Ref. 29) studied what can best be described as an electric-fluidic transducer based upon the principle of acoustic control of a laminar jet. They showed that the laminar jet could be sensitive to frequencies up to 50 KHz. The sound pressure levels used in the study were not measured. Also it was noted that the acoustically controlled turbulence amplifier switching time was small, without giving any numerical values.

Beeken (Ref. 11) described the commercial form of an acoustically controlled turbulence amplifier and an acoustic generator. He mentioned possible methods of using these devices in various applications.

Tryburcy (Ref. 37) did a more comprehensive study of displacement and proximity sensing applications. A generator and sensor similar to Beeken's were used. He studied the maximum separation distance and the sensitivity of the devices as a combined unit.

2:3 Jet Sensitivity to Sound

As mentioned by Rayleigh (Ref. 32) the acoustical sensitivity of jets has been the subject of scientific study since 1858 when Leconte first noticed the "jumping" nature of a coalgas flame in response to certain notes being played on a musical instrument. Initially, the phenomenon was associated only with burning jets. However, it was shown by Tyndall that combustion was not a necessary condition for the phenomenon. Rayleigh's personal contribution was to theoretically show that inviscid plane jet flows are always unstable.

Subsequent to these early investigations, a considerable amount of work was done on both two-dimensional and axisymmetric jets. Although there is a similarity of behaviour in both cases, emphasis it on the axisymmetric case in the remainder of this section because of the present experimental arrangement. Papers concerning the instability of axisymmetric jets due to very small internal disturbances are included because of their direct relationship to the instability caused by sonic disturbances.

Batchelor and Gill (Ref. 7) solved the inviscid stability equations for an axisymmetric parallel jet. They determined that a point of inflection in the velocity profile is a necessary condition for any disturbance in the jet to be amplified. Such a point always exists downstream in a jet. This condition occurs closer to the nozzle exit for a flat velocity profile than for a parabolic one.

Viilu (Ref. 42) experimentally determined, using flow visualization, that for a real jet, a minimum Reynolds number exists below which the jet is always stable to small disturbances. He found this value to be approximately 11.

Freymuth (Ref. 20), using a hot-wire technique, experimentally studied the growth of small sonic disturbances in a jet issuing from a nozzle with a flat velocity profile except for the boundary layer. He noticed that transition of the jet to a turbulent state begins very near the nozzle exit. The effects of jet supply pressure, compressibility, viscosity and sound frequency were investigated in terms of nondimensional parameters. The characteristic length and velocity used were the local momentum thickness and the centerline velocity respectively. The only term which had an important effect on the transition was the Strouhal number. The wavelength of the vortices produced in the jet increased as the Strouhal number decreased.

Becker and Massaro (Ref. 9) used smoke photography, stroboscopic observation and a light scattering technique to study a jet emerging from a nozzle. The displacement thickness at the nozzle exit ($\delta$) could be determined from the experimental correlation shown below:

$$\frac{\delta}{ds} = \frac{0.9}{\sqrt{Re}} \qquad \text{---2.1}$$

They noticed that as the jet velocity increased, the maximum sensitive frequency increased in a stepwise manner. They attributed this to resonance effects in the supply tube. A correlation for the Strouhal number of maximum jet sensitivity and the Reynolds number was found and is given below:

$$St = \frac{fms\,ds}{U_s} = 0.012\sqrt{Re}\,;\ 1000 < Re < 10{,}000 \qquad \text{---2.2}$$

Their Strouhal number was based on the frequency of sound for maximum sensitivity to the sound, the jet average velocity and the diameter of the jet.

They also measured the growth and frequency of the vortices that occur in the jet due to natural causes and found that the above correlation also held for this case. Hence, the effect of sound is maximum when the sound wave-length is approximately equal to that of the vortices which occur naturally ($\lambda n$). A correlation for $\lambda$ n was found as well as for $\ell b$, the wave-breaking length defined as the distance from the nozzle exit to the first vortex.

These expressions are given below:

$$\frac{\lambda_n}{ds} = \frac{43}{\sqrt{Re}} \qquad 2.3$$

$$\frac{\ell_b}{ds} = \frac{107}{\sqrt{Re}} \qquad 2.4$$

It was also noted by observing equations 2.1 and 2.2, choosing as the characteristic length in the Strouhal number that this value would be a constant and independent of Reynolds number. It was then speculated that because a parabolic velocity profile has a constant ratio of displacement thickness to nozzle diameter, the Strouhal number based on the diameter of the jet should be the constant.

A discussion of the jet issuing from a square-edge orifice was also given. In this case it was pointed out that in the flow through an orifice there would be an eddy between the shoulder and the separating flow rounding the shoulder. The eddy size would be proportional to the width of the orifice wall. They postulated that this wall dimension might determine the displacement thickness at the jet exit and hence be independent of orifice diameter.

Such a case was studied by Beavers and Wilson (Ref. 8) and they found the Strouhal number based on orifice diameter to be a constant value of 0.63 over a Reynolds number range of 600 to 3200.

Bell (Ref. 12) studied the sensitive frequency range of round tubes of various $\ell s/ds$. However, he did not determine the particular frequencies associated with maximum sensitivity. Jet sensitivity was indicated by the decrease in total pressure measured on the centerline of the jet at the downstream end of the laminar jet length. He found an upper Strouhal number limit of approximately 0.5. The lower limit increased with Reynolds number.

2.4 Helmholtz Resonators

The Helmholtz resonator shown in Fig. 2 essentially consists of a relatively large cavity with a narrow opening (neck) connecting the fluid inside to the surrounding medium. When the opening is subjected to an acoustical signal, the frequency of which corresponds to the natural frequency of the resonator, the amplitude of the sound signal inside the cavity increases above that of the impressed sound.

A theoretical model of the resonator was developed about one hundred years ago, according to Rayleigh (Ref. 32) and is given below.

$$f = \frac{c}{2\pi}\sqrt{\frac{An}{Vc\ell n}} \qquad \text{--- 2.5}$$

This is essentially a lumped parameter model assuming that the only mass being accelerated is in the neck of the resonator. The fluid inside the volume is considered as a spring and the resonant frequency is considered to be independent of the shape of this cavity volume.

Not long after this formula was developed it was found to be in considerable error in predicting the resonant frequency when the length of the neck was short. This was attributed to the fact that the fluid just inside and that just outside of the neck was also undergoing some acceleration. A correction factor was added as indicated below, (Ref.36)

$$f_r = \frac{c}{2\pi}\sqrt{\frac{An}{Vc\ (\ell n+B)}} \qquad \text{--- 2.6}$$

It was shown that for necks approaching the configuration of an orifice in a plate the value of $B = \frac{\pi dn}{4}$ (Ref. 36).

Alster (Ref. 2) showed that the shape of the resonator does affect the resonant frequency and developed a complicated theoretical formula to account for this. The general formula that was developed has the restrictions that any dimension of the resonator $<< \frac{\lambda r}{4}$ and $h < dn$. The particular expression for a circular cylinder with a centred lateral hole along with the definitions of terms used are given in Appendix D.4.

# CHAPTER III

# EXPERIMENTS

## 3.1 Objectives

Although acoustically controlled turbulence amplifiers can be obtained commercially, little work has been published on a systematic experimental investigation of this device.

The present investigation aims to provide information of primary importance to the operation of shrouded, acoustically controlled turbulence amplifiers. This involves the determination of:

(a) the effect of the shroud on the output pressure with no sound.

(b) the control sound frequency to which the device is most sensitive (denoted as the characteristic frequency) as a function of the shroud geometry and flow variables.

(c) the effect of the sound pressure level on the output pressure of the device at the characteristic frequency.

(d) the dynamic switching times .

## 3.2 Test Facilities

### 3.2.1 Turbulence Amplifiers

To accomplish the objectives described in the previous section three turbulence amplifier shrouds were designed and fabricated. An axisymmetric, as opposed to a planar, geometry was chosen because of the manufacturing ease and availability of theoretical analyses.

The shrouds are identical except for the diameter and made of plexiglass. Each consisted of two sections, a barrel and an end plate. A schematic diagram with pertinent dimensions is shown in Fig. 3.

The barrel was made so that it fit tightly over the emitter tube at the lowest position. To allow for fine alignment of the emitter and collector the hole for the emitter tube, in the barrel, was drilled slightly larger than the emitter outside diameter over approximately 7/8 of the length of the hole.

In order to provide a means of moving the barrel for alignment two sets of thumb screw tighteners were attached to the end plate with an angle of 120° between them. The other ends of the thumb screws were rigidly attached to the settling chamber which is described later.

In order to vary the gap length between the emitter and the collector the hole for the collector was machined slightly larger than the tube. A set screw was provided for fastening the collector.

A modified DISA subminiature hot-wire (5 micron dia.; 0.45 mm. length) was mounted such that the hot-wire was on the centerline of the collector, approximately 0.25 mm. in front of the mouth. The hot-wire was also held in position by a set screw fastener.

3.2.2 Test Facility

Figure 4 shows a schematic diagram of the general experimental facility that was used to test the amplifiers. Air from the building compressed air facility was passed through a 3 micron filter, pressure regulators, needle valve and rotameters before entering a large settling chamber (approximately 15.24 cm. dia.; 50.8 cm. length) which contained screens, flow straighteners and pressure taps connected to an inclined manometer for measurement of the supply pressure (Ps). A bellmouth entrance led to the inlet of the emitter tube of the turbulence amplifier. Further information concerning the settling chamber, bellmouth and emitter tube construction can be found in Ref. 40.

The output pressure (Po) was measured by connecting the collector tube to a second inclined manometer.

The control sound was provided by passing the signal from a sine wave oscillator through an electronic switch, power amplifier and speaker. The frequency of this signal was measured with an electronic counter. A speaker was mounted on a tripod (not shown in Fig. 4) in such a way that it was aligned with the control hole opening of the turbulence amplifier and approximately 5cm. in front of it. A trigger signal, needed in the dynamic response tests, was taken from the electronic switch.

The sound measuring equipment consisted of a standard B&K microphone (Type 4138), preamplifier (Type 2618) and measuring amplifier (Type 2607). The microphone was held in position approximately 3mm. in front of and 2mm. to the side of the control opening. The microphone was secured by means of a specially designed holder (not shown in Fig. 4) which fastened onto the settling chamber. The holder allowed positioning of the microphone at various positions in front of the control opening. A traverse of the area around the control opening indicated a uniform sound field, hence, the position of the microphone mentioned previously was found to be acceptable.

The signal from the measuring amplifier was displayed on one channel of a dual beam oscilloscope. The second channel was connected to a DISA Type 55M10 hot-wire anemometer for the dynamic tests.

In order to provide a controlled acoustic environment for the turbulence amplifier the items shown within the dashed lines in Fig. 4 were kept inside a "soft" room enclosure. The tubes and wires required for the auxiliary equipment, that was kept outside of the room, were passed through a small hole in the enclosure. This hole was then plugged with plasticine. The "soft" room enclosure was a modified "walk-in" refrigerator. The inside dimensions were 2.79 m. by 3.38 m. by 2.29m. high. The walls, ceiling, floor and door of the refrigerator consisted of thin sheets of steel separated by approximately 7.62 cm. of styra-foam insulation. In addition to the existing structure approximately 7.62 cm. of polyurethane foam was adhered to the inner walls and ceiling of the refrigerator and also around the refrigeration unit which occupied one corner of the room. The same thickness of foam was laid on the floor, however, it was not adhered in order to facilitate movement of the tripod and settling chamber. Both the tripod and settling chamber were sitting solidly on the main floor of the refrigerator with polyurethane foam around them.

A complete list of the standard equipment and instruments mentioned in this section is given in Appendix A along with the pertinent information concerning them.

3.3 Experimental Procedure

The material in this section naturally falls into the following categories; calibration, setting up the turbulence amplifier with alignment of the emitter and collector, static characteristics and dynamic characteristics. The geometrical variables and a summary of the test programme are given in Table I.

3.3.1. Calibration

The three types of equipment which are considered in this section include the rotameters, sound measuring equipment and the hot-wire.

Two rotameters were used in this study, the ROTA L10/400 - 6185 and the ROTA L2.5/100 - 3485. Both of these were calibrated by installing a precision wet test meter in series with them. The calibration curves for these two rotameters are shown in Fig. 5 and 6.

The sound measuring equipment which required calibration included the B&K microphone, preamplifier, and measuring amplifier combination. The procedure that was used is a standard one given in Ref.6 using the B&K Type 4220 Pistonphone and therefore will not be repeated here. This calibration was performed each time the equipment was used.

In this study it was not necessary to calibrate the particular hot-wire anemometer to obtain a relationship between velocity and voltage because velocity was not actually measured. Only time readings were taken, hence, it was only necessary that the hot-wire and anemometer respond fast enough. Therefore, the standard procedure given in Ref. 18 for adjusting and measuring the time constant was performed. The time constant measured was approximately 2 microseconds.

3.3.2 Setting up the Turbulence Amplifier

A standard procedure was developed for setting up the turbulence amplifier shroud on the test stand and aligning the emitter and collector. This procedure was followed for each turbulence amplifier to assure consistency.

After a particular shroud was fitted onto the common emitter tube, the exit of the emitter tube was observed under a microscope to determine if any dirt particles were present. Any such particles were brushed away using a small, clean paint brush of the type artists use.

The emitter tube-shroud assembly was then bolted onto the settling chamber using vaseline as a sealant.

The dimensions C and D in Fig. 3 were measured using a vernier caliper and the dimension E calculated to obtain the required gap setting. This value was then set by positioning the collector tube and fastening it with a set screw. For the static characteristic study the hot-wire hole was plugged so that the inside surface was smooth. For the dynamic characteristic study the hot-wire was positioned at a small (but safe) distance from the mouth of the collector (approximately 0.25 mm.). It was centered over the opening by observing the setting under a microscope.

In both cases the end plate was then attached to the shroud by means of three screws, two of the screws were used to secure the adjustable thumb screws to the shroud as shown in Fig. 3.

The supply pressure was then increased until the output pressure dropped, indicating that the jet had become turbulent. The collector tube and shroud were moved by means of the adjustable thumb screws until the output pressure rose above the value before the drop. The supply pressure was increased again until another output pressure drop occurred. This procedure was repeated until it was not possible to increase the output pressure by any further adjustment of the alignment.

This was an extremely tedious procedure, taking as long as 3 hours to be reasonably sure that the proper alignment had been achieved.

3.3.3. Static Characteristic Study

(A) Output Pressure versus Supply Pressure

For all the geometrical combinations given in Tables I, the ouput pressure $P_0$ and supply flow rate were measured for different values of supply pressure Ps. This was done until $P_o$ dropped and began to increase again.

Results from these tests were used to obtain the $P_o$ versus Ps plots and select the different operating conditions for Ps.

(B) Output Pressure versus Sound Variables (Constant Re)

With Ps set at a particular value, $P_o$ was measured for different values of the control sound frequency f and pressure level Pc. For all the geometrical combinations, the conditions used were: $P_s = 660\ N/m^2$ (Re = 895); Pc = 90, 100, 110, and 120 db; and $170 < f < 18000$Hz. This portion of the investigation was done with the specific aim of holding the Reynolds number constant, so that the effects of shroud geometry could be brought out more clearly.

(C) Output Pressure versus Sound Frequency (Different Re)

For a given value of Pc, Po was measured for different values of f and Ps or Re in order to study the Reynolds number effects. However, this type of experimentation was carried out for two geometrical configurations only. With the $d_c$ = 0.95 cm. and g = 1.27 cm. configuration Pc = 110 db. and for the dc = 2.54 cm. and g = 3.81 cm. configuration Pc = 100db.

It should be noted that the ambient pressure, temperature and noise level were measured at the beginning of all the tests mentioned above.

3.3.4 Dynamic Characteristic Study

This study was conducted only for the dc = 2.54 cm. and g = 3.81 cm. geometrical combination.

The dynamic characteristic study consisted of the measurement of four response times, characteristic of the turbulence amplifier. These times are the laminar-turbulent delay time $T\ell$.d., laminar-turbulent fall time $T_f$., turbulent-laminar delay time Tt.d. and the turbulent-laminar rise time $T_r$. and are defined in Fig. 7. These definitions are similar to those used by Hayes (Ref. 23).

The response times were measured by photographing the trace of the hot-wire signal and the microphone signal which were simultaneously displayed on the screen of the dual-beam scope. At least three traces were photographed for each experimental condition studied. Slides were made from the film and displayed on a screen for measurement.

Such measurements were taken at a supply pressure of 1120 $N/m^2$ (Re = 1244), with control sound pressure levels of 100, 95 and 90 db. Five frequencies were chosen for study, the characteristic frequency (3100 Hz) and two frequencies on each side of this (2200, 2600, 3700 and 4400 Hz).

To investigate the effects of Reynolds number, measurements were also taken at a frequency of 3100 Hz and sound pressure level of 100db for additional supply pressures of 1220 $N/_m2$ (Re = 1332), 1030 $N/_m2$ (Re = 1153) and 834 $N/_m2$ (Re = 991).

# CHAPTER IV

## RESULTS AND DISCUSSION

In some of the figures discussed in this chapter a few data points have been omitted in order to avoid overcrowding. However, this omission does not affect the interpretation of the results.

### 4.1 Static Characteristics

Because of the large number of readings the university I.B.M. 360-65 computer and the on line Calcomp 565 plotter were used to reduce and plot the experimental data.

#### 4.1.1 Emitter Tube Characteristics

The variation of the supply flow with the supply pressure is shown in Fig. 8 along with Bell's prediction. This characteristic is not of much importance to this study as the emitter tube was not altered throughout the experiments. However, it does serve to show that the analytical procedure given by Bell for predicting the emitter tube characteristics holds for this case with about 7.5% difference from the present experimental data.

#### 4.1.2 Output Pressure versus Supply Pressure

The dimensional plots of the output pressure versus the supply pressure for the various diameter shrouds used and a gap setting of 3.81 cm. is shown in Fig. 9 (a). Bell's analytical procedure was used to calculate the laminar recovery pressure for this case and is shown as a dashed line. It should be noted, however, that the supply pressure at which transition occurs cannot be predicted from the analytical procedure. Similar plots for gaps of 2.54 and 1.27 cm. are shown in Fig. 9(b) and 9(c) respectively.

It can be seen that the laminar pressure recovered compares reasonably well with the analytical result having a maximum difference of approximately 12%.

To obtain a reasonable estimate of the output pressure for a given turbulence amplifier Bell suggested an approximate graphical method (Ref. 14). He plotted $P_o/Ps$ versus $R_e/KGL_s$, using only those values of $P_o/Ps$ near the $P_o$ versus Ps peak. In this method it is assumed that the amplifier is to be operated near the peak. In some cases this may not be desirable. It was decided to attempt to obtain a correlation for the laminar pressure recovery without the above mentioned restriction.

A plot of $P_o/Ps$ versus $R_e/KGLs$ was made as a first attempt. This graph is shown in Fig. 10. In the present investigation $L_s$ is a constant and the jet matching parameter K only varied 2.5% according to Bell's procedure. Hence both were considered constant. The lines through the data points are Bell's prediction for each gap length. Obviously, these scaling parameters are not adequate to describe the phenomenon.

It was decided to attempt a correlation of the form $P_o/Ps = ARe^B G^C$. Multiple linear regression yielded:

$$A = 1.14 \times 10^{-4}$$

$$B = 1.2$$

$$C = -0.27$$

A plot of this correlation along with the data points indicated that the exponent C = -0.27 is adequate to merge the three curves in Fig. 10 into one. Further the Reynolds number dependence is not of the form indicated above.

An attempt to fit a curve of the form

$$G^{+0.27} \; P_o/P_s = A + BRe + CRe^2 \; DRe^3 + \cdots \qquad \text{--4.1}$$

was undertaken using a standard I.B.M. program package. A second order polynomial was indicated with no further improvement obtained by going to a third order. The constants were

$$A = -0.2$$

$$B = 8.3 \times 10^{-4}$$

$$C = 1.22 \times 10^{-7}$$

A plot of the experimental $G^{0.27}Po/Ps$ versus the $G^{0.27}Po/Ps$ estimated by the equation is shown in Fig. 11 indicating that the agreement is good.

Although the different laminar-turbulent transition lengths cannot be predicted analytically, they can be compared with correlations and the data found by other investigators. A method of indicating this comparison is to plot G for transition versus Re. This plot is shown in Fig. 12 and contains curves found for free and shrouded jets.

It can be seen that even for the unshrouded free jet, large discrepancies exist not only in the magnitudes but in the shapes of the curves. The free jet transition depends upon a large number of variables such as the entrance conditions of the supply jet, ambient noise and the method of measurement. These are not taken into account in a simple plot of the type shown in Fig. 12. It would be expected that the present data would best be described by Vaz's (Ref.40) correlation, due to the fact that the settling chamber, bellmouth and supply tube used in that experiment were also used in the present study. However, a large discrepancy exists in this particular comparison also, indicating that the shroud has a significant effect.

4.1.3 Output Pressure versus Frequency

(A) Effects of Geometrical Variables (Re = constant)

The dimensional plots of ouput pressure versus the sound frequency at various control-sound pressure levels and a constant supply pressure of 660 $N/m^2$ (Re = 895) for all the geometrical configurations tested are shown in Fig. 13. The straight dashed line is the value of Po for the turbulent jet obtained from Bell's procedure. It can be seen that in some of the plots there are two and in others there is one substantial frequency range where the output pressure drops significantly. Also it is noticed that as the control sound pressure level is reduced, the sensitive frequency range becomes narrower and in some cases disappears.

The following points can be investigated using the information from these plots:

(1) the variation of the characteristic frequency (defined in Section 3.1) with the geometrical variables dc and g.

(2) the effects of the control sound pressure level on the output pressure at the characteristic frequency.

(3) a comparison between the "off" state (turbulent jet) pressure recovery and that obtained using the analytical procedure of Bell.

The characteristic frequency is defined as the frequency at which the output pressure drops the greatest percentage of the undisturbed level. In each of the plots in Fig. 13 this is just the frequency at which $P_o$ is the lowest value. To reduce the error in obtaining fchar. for each geometrical combination the value of fchar. was obtained for each sound pressure level plot that had a significant drop and then averaged. This value was then expressed in terms of a Strouhal number $\left(\frac{\text{fchar. ds}}{\text{Us}}\right)$ and the geometrical terms in G = g/ds and D = dc/ds. The plot of Strouhal number versus D for various G values is shown in Fig 14. The lines shown are the Strouhal numbers calculated using the frequency obtained from the theoretical formulas for Helmholtz resonators given in the literature survey and Appendix D.2 (Equ. 2.5, 2.6 and D.2.1) using the appropriate velocity and emitter diameter. It can be seen that G has no significant effect as the three points for different G values at each value of D lie approximately at the same point.

Comparison with the theoretical formulae show that the simple expression (Equ. 2.5) overestimates the Strouhal number. The addition of the theoretical correction factor B(Equ.2.6) overcompensates so that lower values are predicted. The theoretical formula of Alster (Equ. D.2.1) agrees quite well with the experimental data, even though the effect of the vent holes is ignored. The maximum deviation occurs at $D = 6.94$ with a difference of 12%. This may be expected as Alster points out that errors occur when $\lambda r./4$ is less than the largest dimension of the cavity. Although the condition is not violated in this case it is being approached.

A standard way of showing the effect of the control signal on a flow controlled turbulence amplifier is to plot Po versus Pc at the operating Reynolds number and characteristic frequency.

Plots similar to this are obtained for the present investigation by taking cross plots of the Po versus f plots shown in Fig. 13 at the characteristic frequency in each case. The cross plots are shown in Fig. 15. The dashed line in each case indicates the output pressure with only the background noise level present. The output pressure is unaffected by the control signal until a certain level of control is reached. The output pressure then decreases with increasing control to a value which does not change for further increases.

It was not possible to obtain the entire curve for all of the geometrical configurations due to the upper limit imposed by the speaker used and the lower limit set by the loss of accuracy in measurement of the control sound pressure level near the background noise level. However, some general observations can be made.

It is known that the transition from the "on" state to the "off" state of a flow controlled turbulence amplifier requires only a small change in the control pressure signal and it is difficult to maintain an intermediate position between "on" and "off". Also within this range the output has been noticed to consist of large, erratic flucuations. These characteristics have led to the use of the flow controlled turbulence amplifier only as a digital device.

As can be seen from Fig. 15, the output pressure decreases gradually as the control sound pressure level increases. It was also noted qualitatively that there were no large erratic output pressure fluctuations.

The above discussion leads to the possibility of operating the acoustically controlled turbulence amplifier as a proportional device. To do so the output pressure versus control pressure plot should have a straight portion. The lines passing through the data points in Fig. 15 indicate that this is approximately true for certain geometrical configurations and sound pressure level ranges. More data points would increase the confidence in this observation and hence additional experimentation was done for one particular case. The results are shown in Fig. 16 which indicate that for the dc = 0.95 cm. and g = 1.27 cm. geometry with Ps = 660 N/$m^2$ (Re = 895) and $101 < Pc < 112$ db. a proportional mode of operation is possible. The gain is -9.64 N/$m^2$ per db. The gain obtained by expressing the sound pressure as a root mean square pressure in N/$m^2$ is -18.5.

In order to compare the "off" state turbulent pressure recovery with the analytical procedure mentioned previously it must be insured that the jet is fully turbulent. The criterion used to determine whether this condition is satisfied is to observe the change in the output pressure at the characteristic frequency as the control sound pressure level is increased (see Fig. 15). If there is no substantial change the jet could "reasonably" be assumed as fully turbulent. The value of the output pressure for 120 db. was then taken as the "off " state pressure. The corresponding values for the geometrical configurations which complied with this criterion were recorded and Bell's non-dimensional parameter $\frac{G^2 Po}{41.0 Pc.\ell}$ was calculated using an experimental value of $Pc.\ell. = 1/2\ \rho\ (2U_s)^2$ Figure 17 shows this parameter as a function of D along with the constant value predicted from the analytical procedure. Unlike the unshrouded flow controlled turbulence amplifier case, the present data lie consistently above the predicted value. This could perhaps be explained by the assumed location of the virtual origin in the analytical procedure or by the effects of the shroud. However, the number of data points are considered insufficient for further analysis at this time.

(B) Effects of Reynolds Number (Pc = constant)

The dimensional plots of the variation of Po with f for two geometries at various Reynolds numbers are shown in Fig. 18. The line indicating the analytical turbulent "off" pressure is not shown as only one sound pressure level is used in each case.

The characteristic frequencies at various Reynolds numbers were taken following the definition mentioned previously and plotted against Reynolds number as shown in Fig. 19. The line going to a Re of 400 is shown dotted to indicate that a characteristic frequency was not evident at Pc = 110 db. When Pc was increased to 120 db. a characteristic frequency was found.

It is seen that a frequency "jump" occurs for each geometry considered. This is a result of the definition used to determine the characteristic frequency. When the output pressure drop at any frequency becomes larger than the one at the characteristic frequency, this new frequency becomes the characteristic. At the discontinuity, the pressure drops for both frequencies would be the same, hence, fchar. would be double valued at this Reynolds number.

The lower two frequencies correspond to those found from Alster's Helmholtz equation for a circular cylinder with a lateral hole (Equ. D.2.1). The upper frequency is not a harmonic of the lower. Neither supply tube resonance nor resonances related to the cavity could satisfactorily account for the higher characteristic frequency.

By calculating characteristic Strouhal numbers from the frequency data this information can be compared to the upper and lower limits of jet sensitivity to sound found in Ref. 12. Although the investigation cited was not detailed it can serve as a reasonable estimate of the sensitivity of jets emitting from tubes of large Ls. Figure 20 indicates this plot. The upper and lower limits are denoted by cross hatched lines. The solid lines join the data points of the characteristic frequencies taken from Fig. 19. It can be seen that almost all the Strouhal numbers lie within the limits.

A plot of Becker and Massaro's correlation (Equ. 2.2) is drawn on Fig. 20. Although there is an order of magnitude agreement of Strouhal number values, the Reynolds number dependence indicated by the experiments is opposite to that of the correlation. It is believed that this discrepancy could be attributed to some modes of cavity resonance. It is worth recalling that the lower characteristic frequency is related to a Helmholtz type resonance.

4.2 Dynamic Characteristic Study

The variation of the switching times with the control sound frequency and pressure level is shown in Fig. 21. It can be seen that within the experimental range and accuracy, the four response times are almost independent of the control sound variables. Perhaps a possible exception is that the turbulent-laminar rise time Tr. has a very weak dependence on the frequency. Further, the laminar-turbulent delay time decreases slightly but consistently with an increase in the control pressure level.

The mean of all the experimental values taken for the four response times are given below along with the standard deviation in each case. From these mean values it can be

$T_{\ell.d.}$ = 2.24 msec. (S = 0.171 msec .)

$T_{t.d.}$ = 2.40 msec. (S = 0.287 msec.)

$T_{f.}$ = 0.487 msec. ( S = 0.130 msec.)

$T_{r.}$ = 0.606 msec. (S = 0.263 msec.)

seen that the two delay times are almost equal and the difference between the fall time and the rise time is not significant. Thus the acoustically controlled amplifier tested has more equal switch "on" and switch "off" dynamics than the flow controlled turbulence amplifiers studied by Hayes (Ref. 24) This point is more emphatically made considering that Hayes found a large increase in the difference between the switch "on" and switch "off" characteristics with increasing gap length. The largest gap considered in Ref. 24 was 2.44 cm.

while the present, as noted previously is 3.81 cm.

From the standard deviations given above an indication of the erratic nature of the response time can be felt. Hayes did not express the erratic behaviour in this manner. He produced multiple traces of switching. The multiple trace photograph of the "on" and "off" switches for the present study are shown in Fig. 22. The lack of erratic behaviour in the position of the rise and the fall portions of the traces can be seen. Hayes multiple trace of the switch "on" dynamics for dc = 1.27 cm., g = 2.44 cm. and ds = 0.074 cm. is shown in Fig. 23. (taken from Ref. 23). The extremely great variation in the position of the rise portion of the trace is evident. Hence the acoustically controlled turbulence amplifier dynamics can be seen to be less erratic than the flow controlled mode of operation.

The variation of the response times with supply pressure are shown in Fig. 24 compared to Hayes theoretical and Abramovich's empirical equations (Ref. 23 and 1 respectively) for the flow controlled turbulence amplifier. Within the range tested the present data agrees with both of the above mentioned relationships in general trends only. Hayes theory predicts the laminar-turbulent delay time $T_{\ell d}$ more closely than the other three times. Abramovich's relationship predicts the turbulent-laminar rise $T_r$ time and the laminar-turbulent delay time $T_{\ell d}$ quite well but the other two times are of considerably different magnitude.

# CHAPTER V

# CONCLUSIONS

(a) Bell's Analytical Approach

(1) Bell's analytical procedure can reasonably predict the characteristics of the laminar jet in a shrouded, turbulence amplifier. However, for the turbulent jet the results of the procedure are not in agreement with the present experimental data.

(2) The approximate method put forward by Bell for determining $P_o/P_s$ at an operating point near the peak of the $P_o$ versus $P_s$ curve is extended to include operating points in the laminar portion. The following equation was obtained by curve fitting

$$G + 0.27\ P_o/P_s = -0.2\omega + 8.3 \times 10^{-4}\ Re + 1.22 \times 10^{-7}\ Re^2$$

(b) Static Characteristics

(1) A "jump" in characteristic frequency occurs as the Reynolds number of the emitter is increased, the upper characteristic frequency is yet to be predicted.

(2) The characteristic frequency of a shrouded, acoustically controlled turbulence amplifier may be determined for low Reynolds number using advanced Helmholtz resonator theory such as Alster's (Ref. 2).

(3) The Strouhal numbers at which shrouded, acoustically controlled turbulence amplifiers respond, fall within the limits of the sensitivity of a free jet given by Bell (Ref 12).

(4) The acoustically controlled turbulence amplifier, unlike the flow controlled turbulence amplifier can be operated in a proportional mode under certain conditions of shroud geometry and control variables.

(c) Dynamic Characteristics

(1) Within the experimental range studied, the switching dynamics of the acoustically controlled turbulence amplifier is almost independent of the control sound frequency and pressure level.

(2) The two delay times (Tℓd. and Ttd.) are almost equal and the fall and the rise time (Tf. and Tr.) may also be considered equal.

(3) The switching dynamics of the sound controlled turbulence amplifier tested is less erratic and more equal than a flow controlled turbulence amplifier.

# CHAPTER VI

## RECOMMENDATIONS

(1) An analytical and experimental study of the turbulence amplifier should be undertaken which would extend Bell's procedure to account for the effect of a shroud on the laminar-jet length and the turbulent jet output pressure.

(2) Further work should be done to determine the nature of the frequency "jump" and the higher characteristic frequency that occur when the Reynolds number is increased.

(3) The many studies that have been conducted concerning the maximum sound sensitivity of jets issuing from short nozzles should be extended to cover those issuing from long, straight bore tubes.

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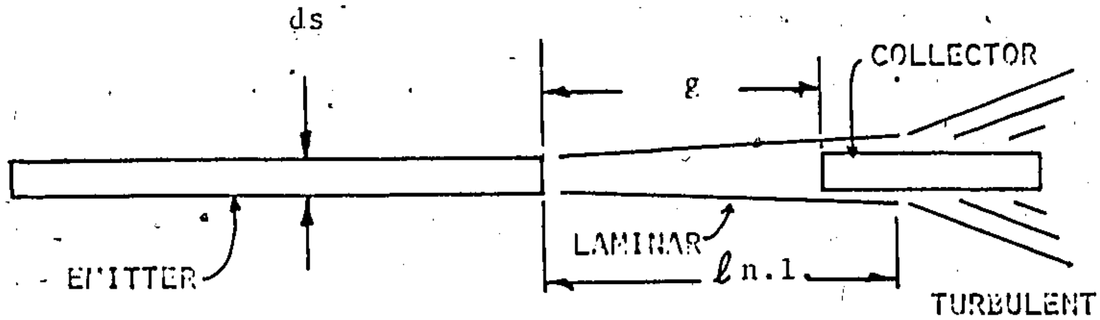
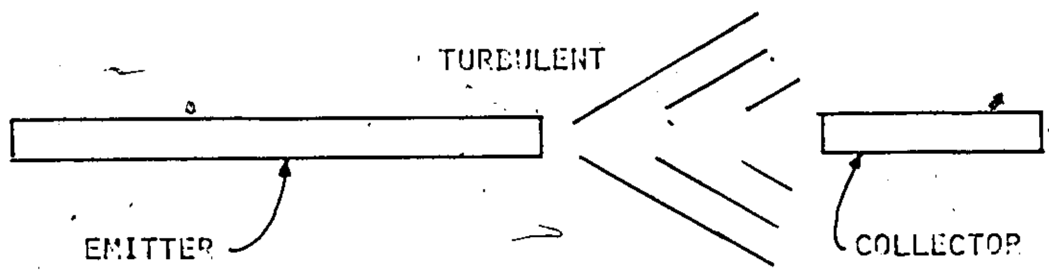



(A) "ON STATE"




(B) "OFF-STATE"

FIG. 1 TURBULENCE AMPLIFIER PRINCIPLE

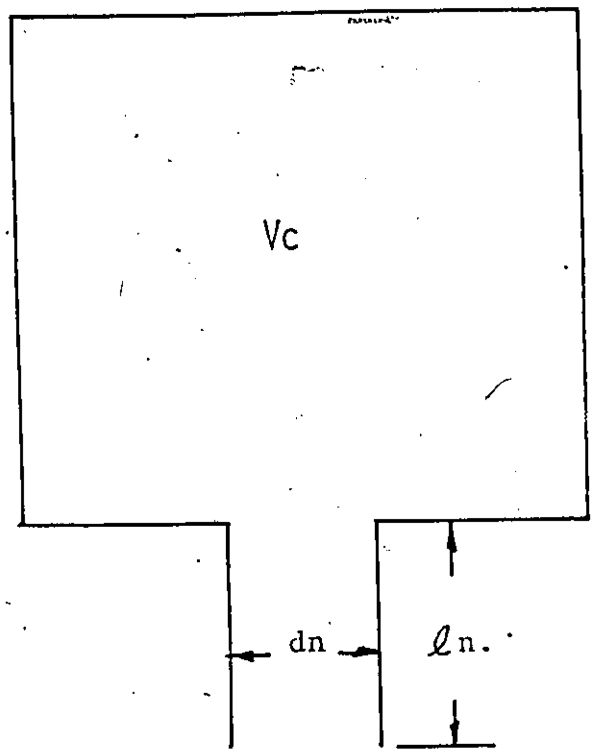



FIG. 2 . BASIC HELMHOLTZ RESONATOR

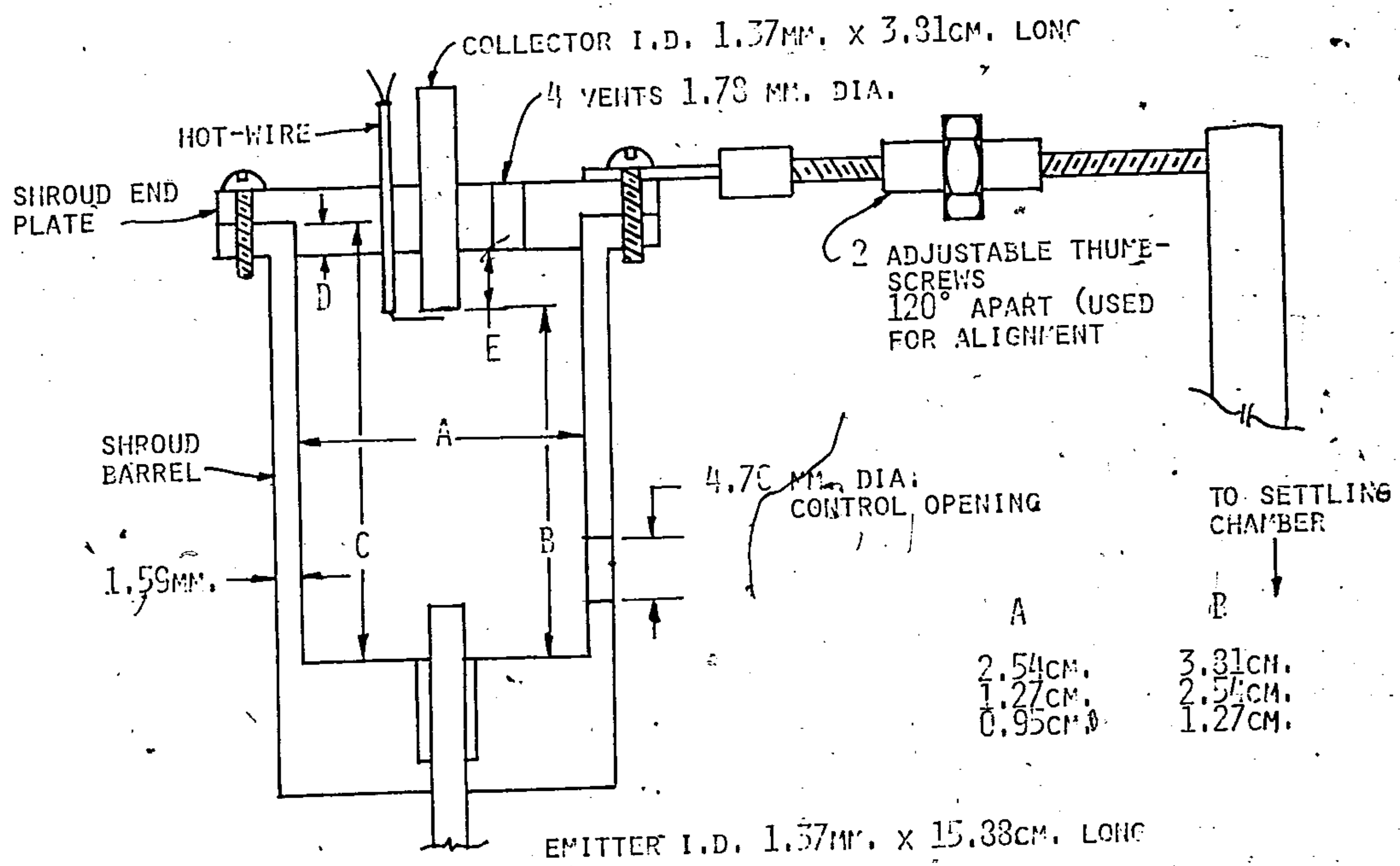



FIG. 3 EXPERIMENTAL TURBULENCE AMPLIFIER AND SUPPORT

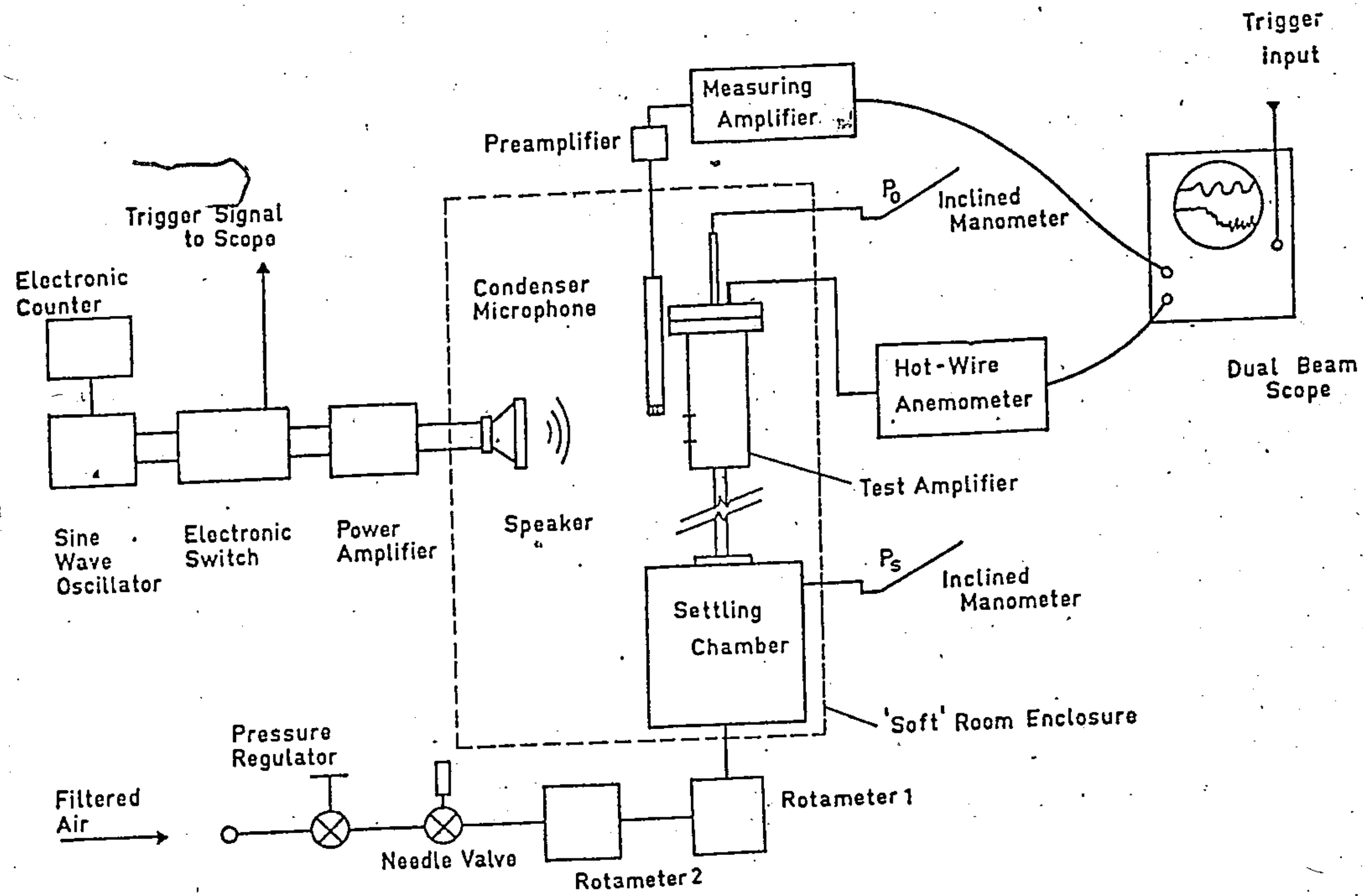



FIGURE 4 TEST FACILITY

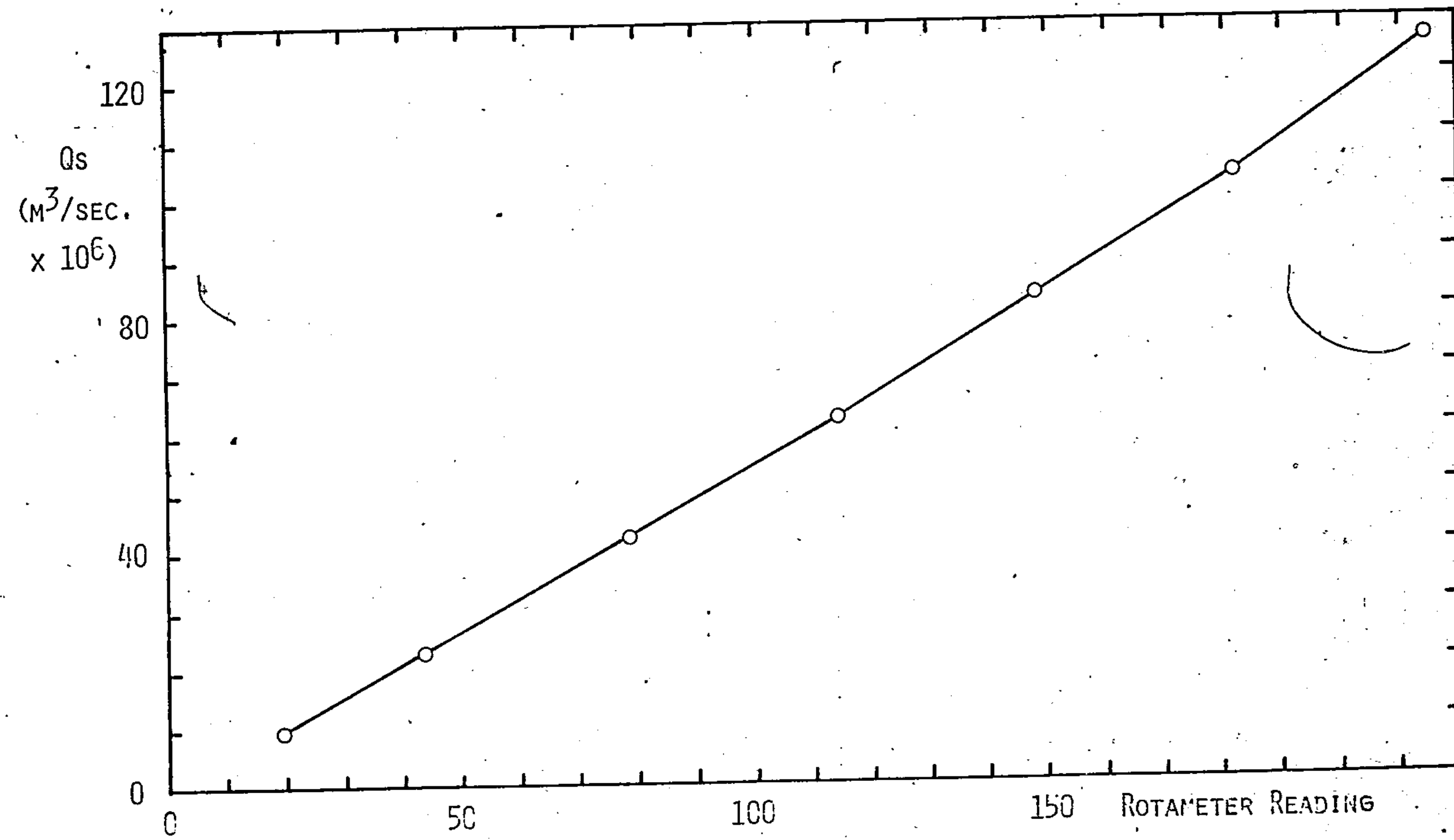



FIG. 5 CALIBRATION CURVE FOR ROTA L10/400-6185 ROTAMETER

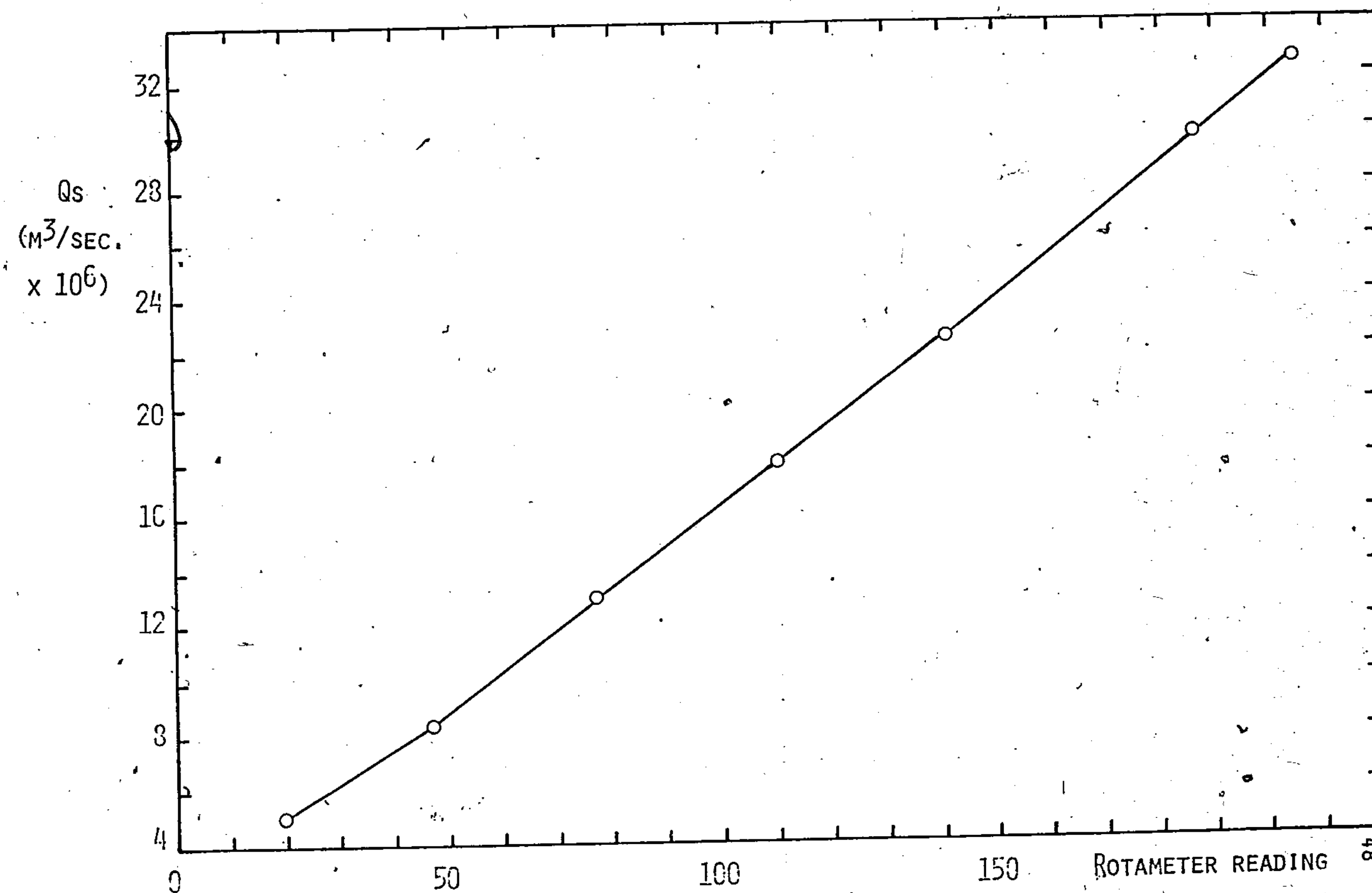



Fig. C Calibration Curve for Rota L2.5/100-3458 Rotameter

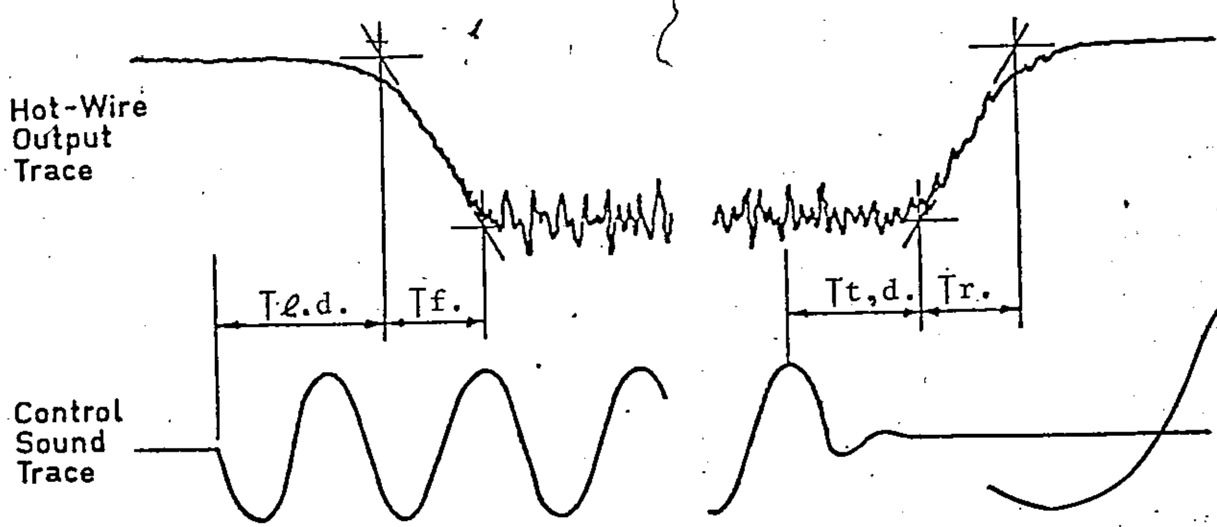



FIG. 7 RESPONSE TIME DEFINITIONS

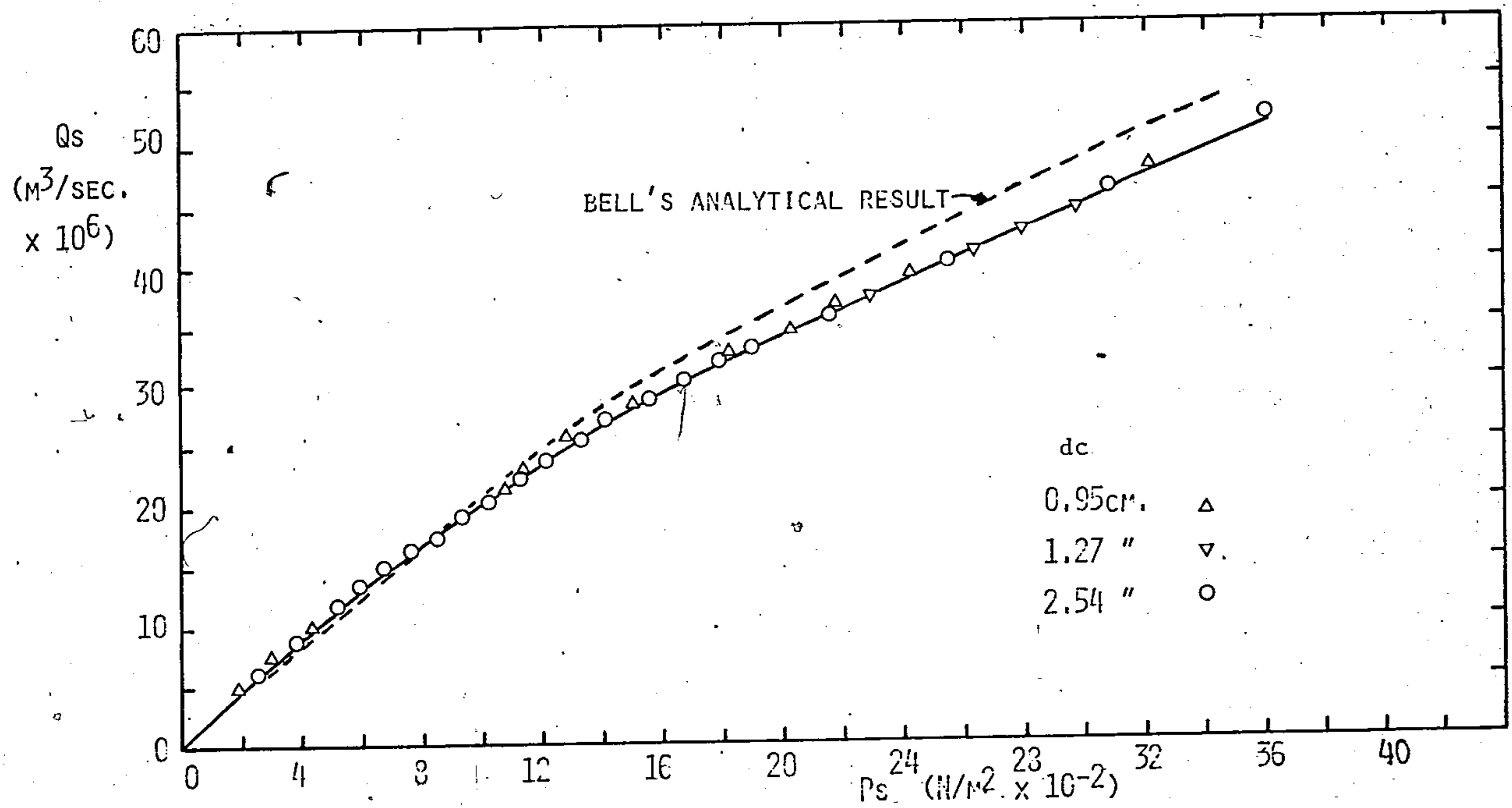



FIG. 8 SUPPLY FLOW RATE VERSUS SUPPLY PRESSURE

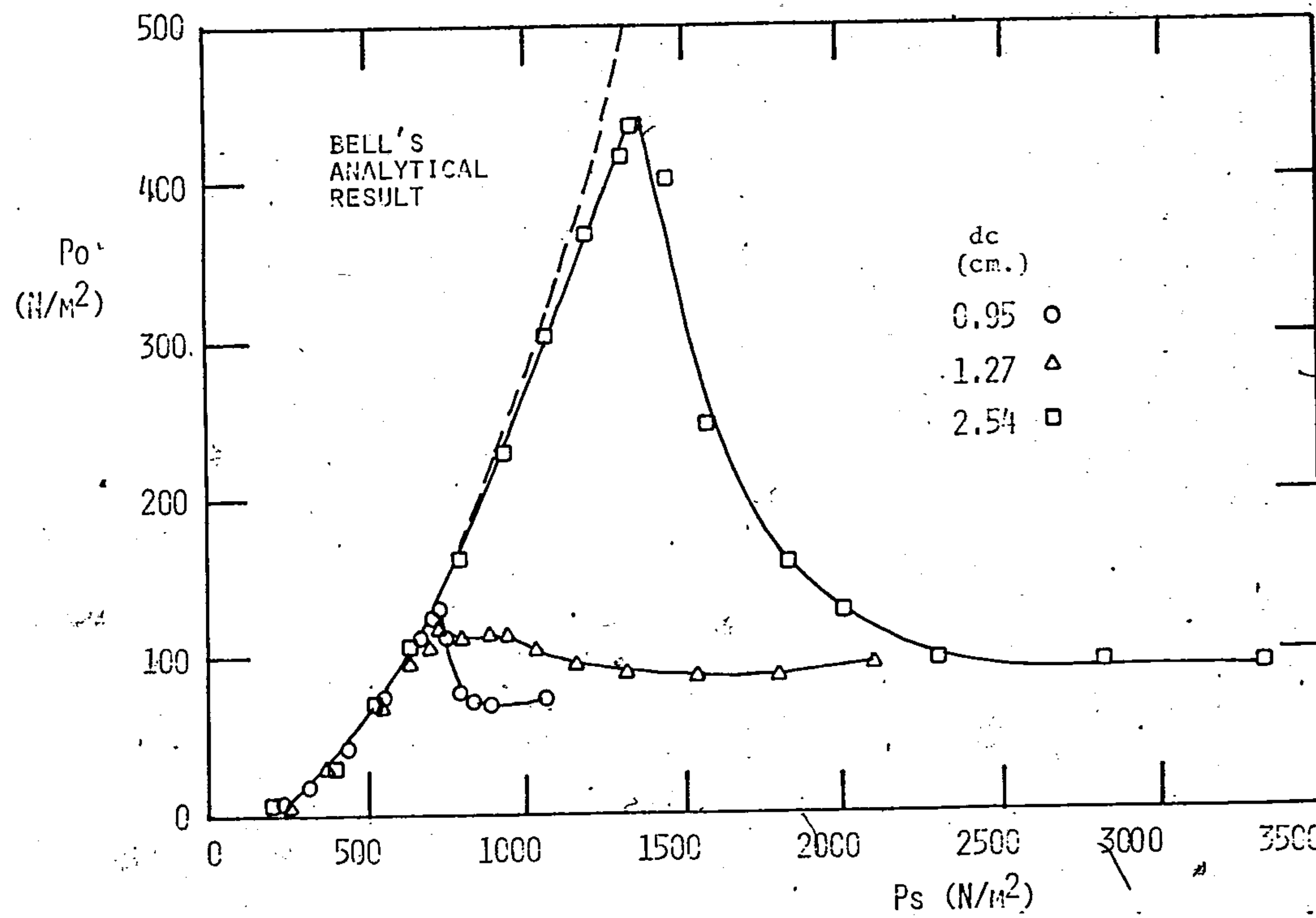



FIG. 9(A) OUTPUT PRESSURE VERSUS SUPPLY PRESSURE ( g = 3.81 CM. )

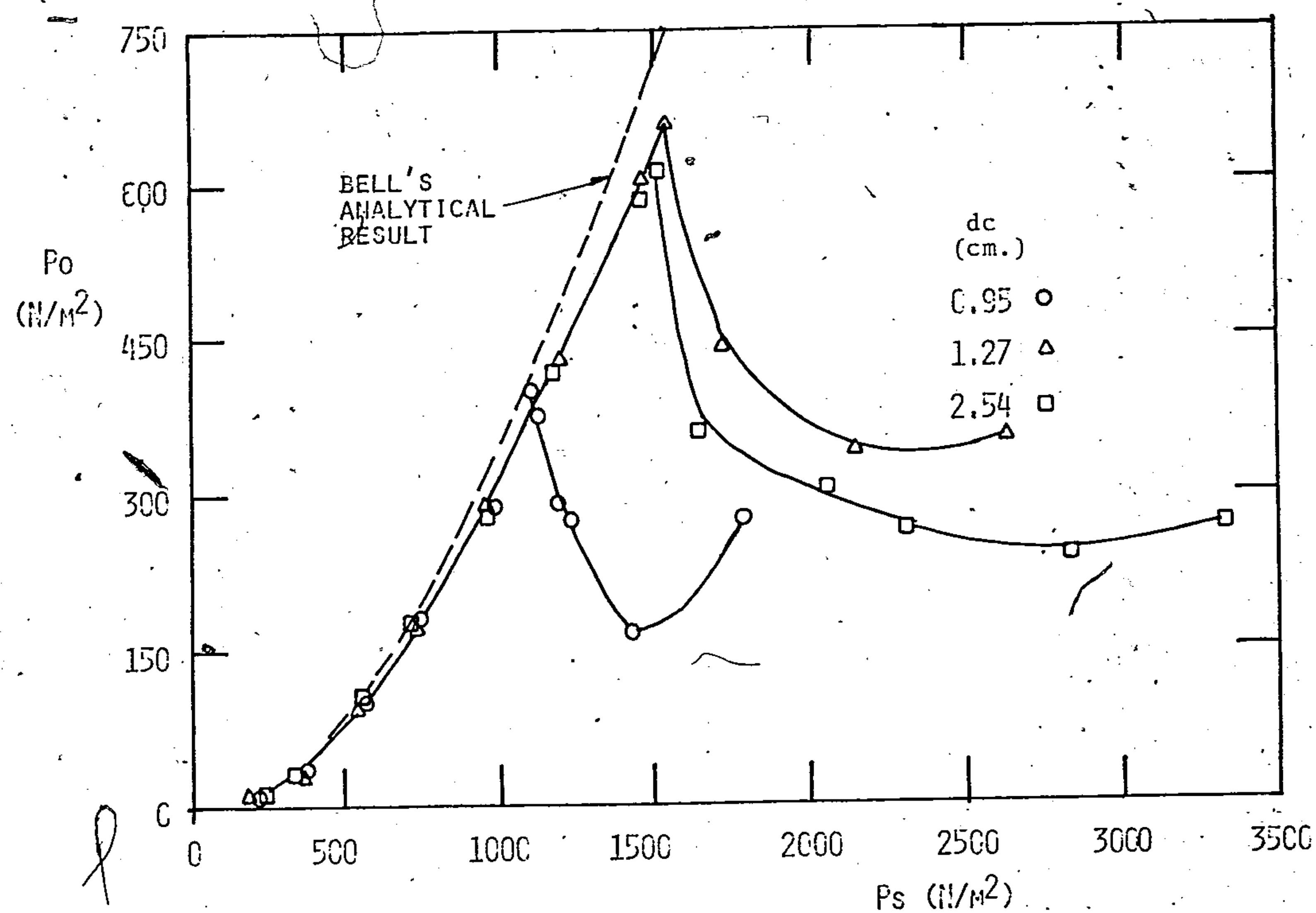



Fig. 9(b) Output Pressure Versus Supply Pressure ( g = 2.54 cm. )

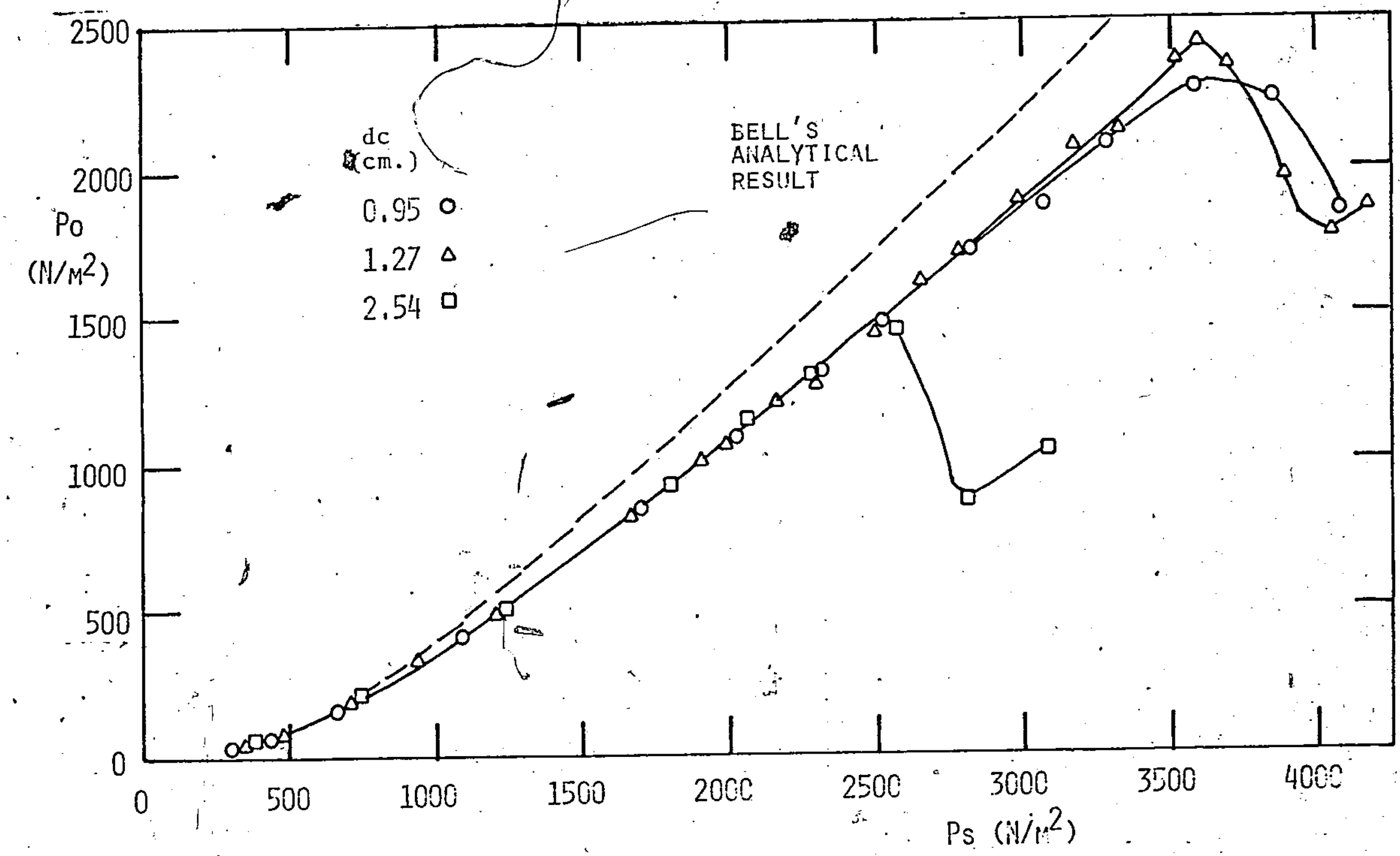



FIG. 9(c) OUTPUT PRESSURE VERSUS SUPPLY PRESSURE ( g = 1.27 CM. )

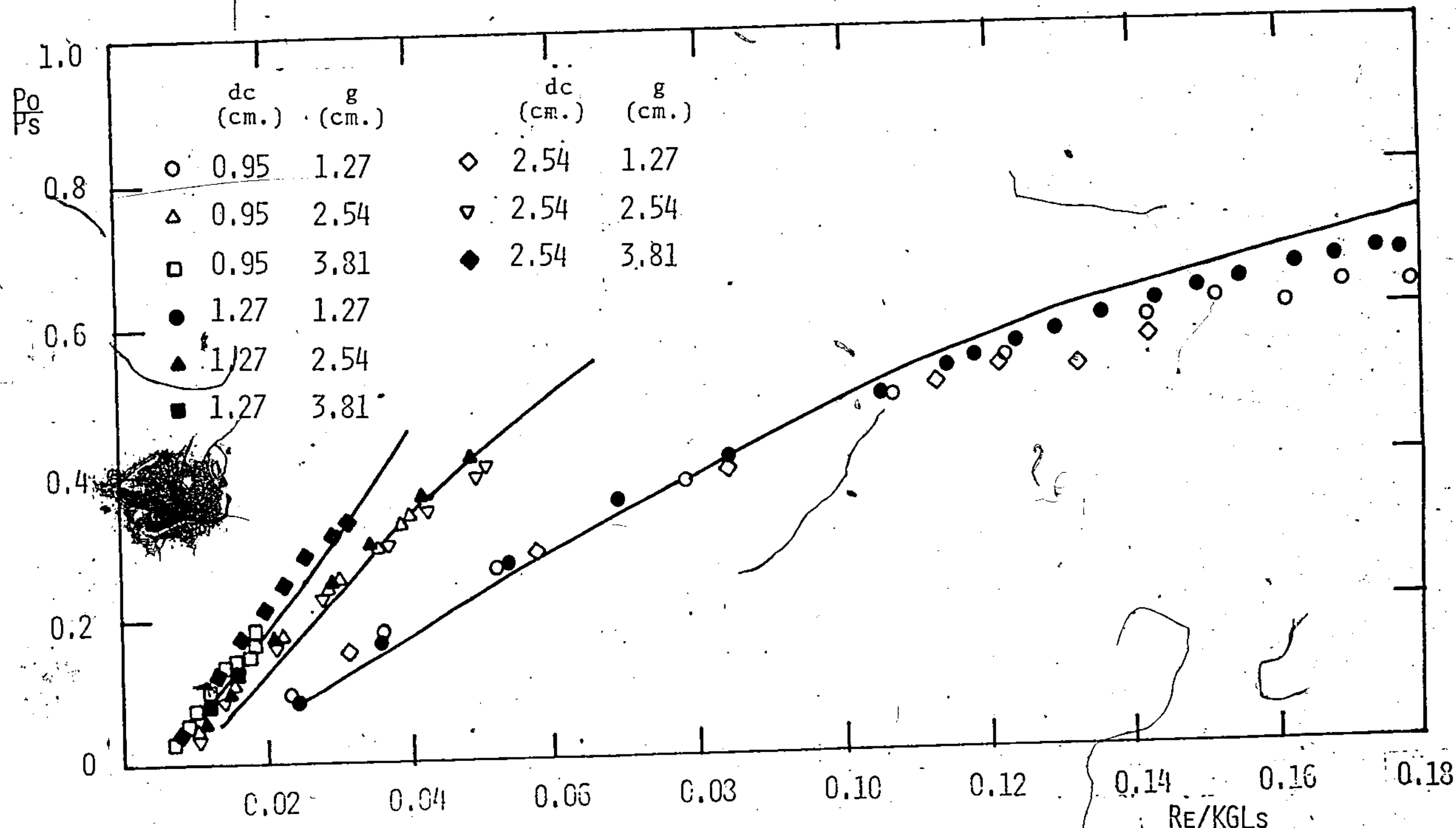



Fig. 10 Non-Dimensional Laminar Pressure Recovery

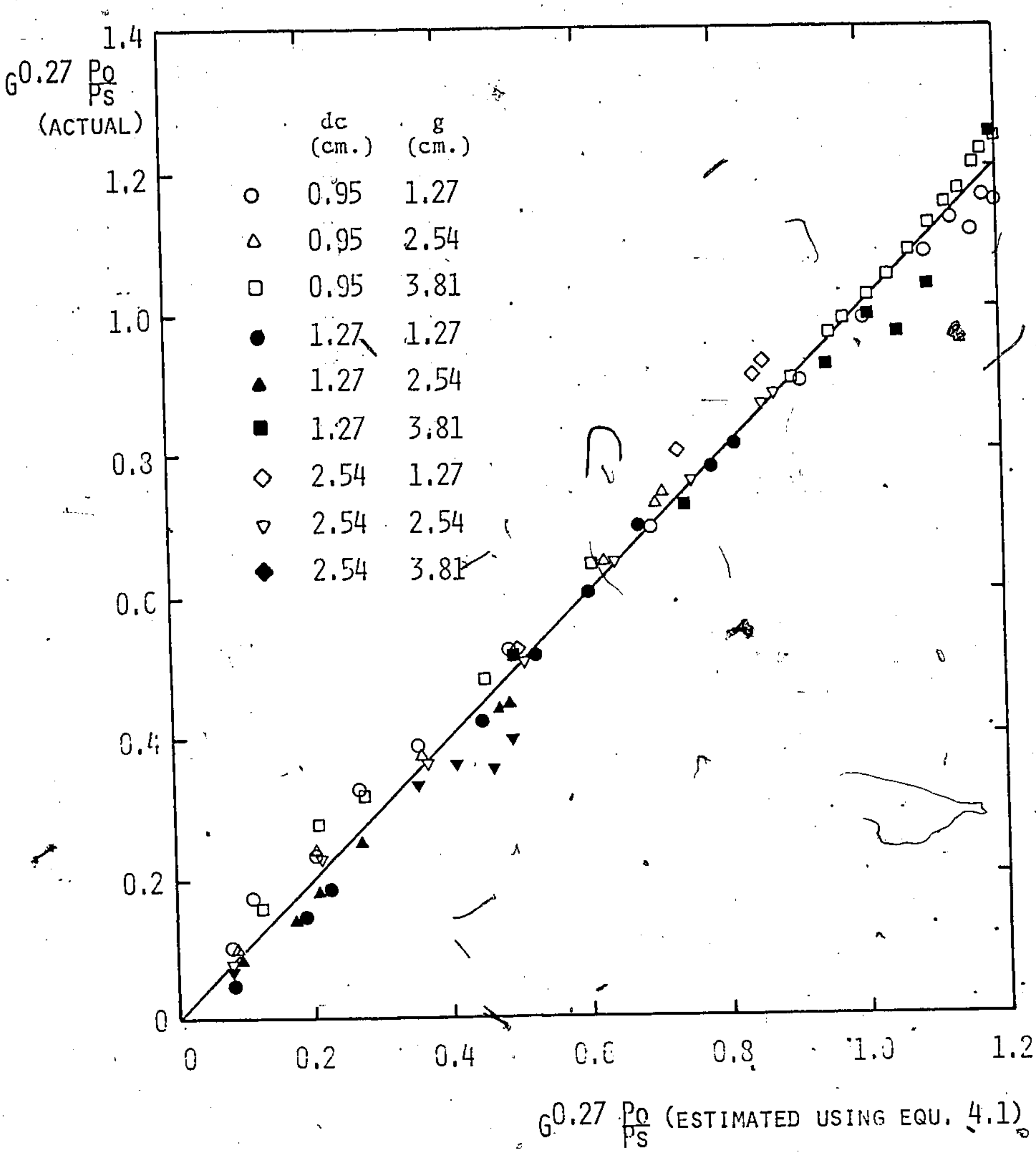



FIG. ~~11~~ A TEST OF THE POLYNOMIAL FIT

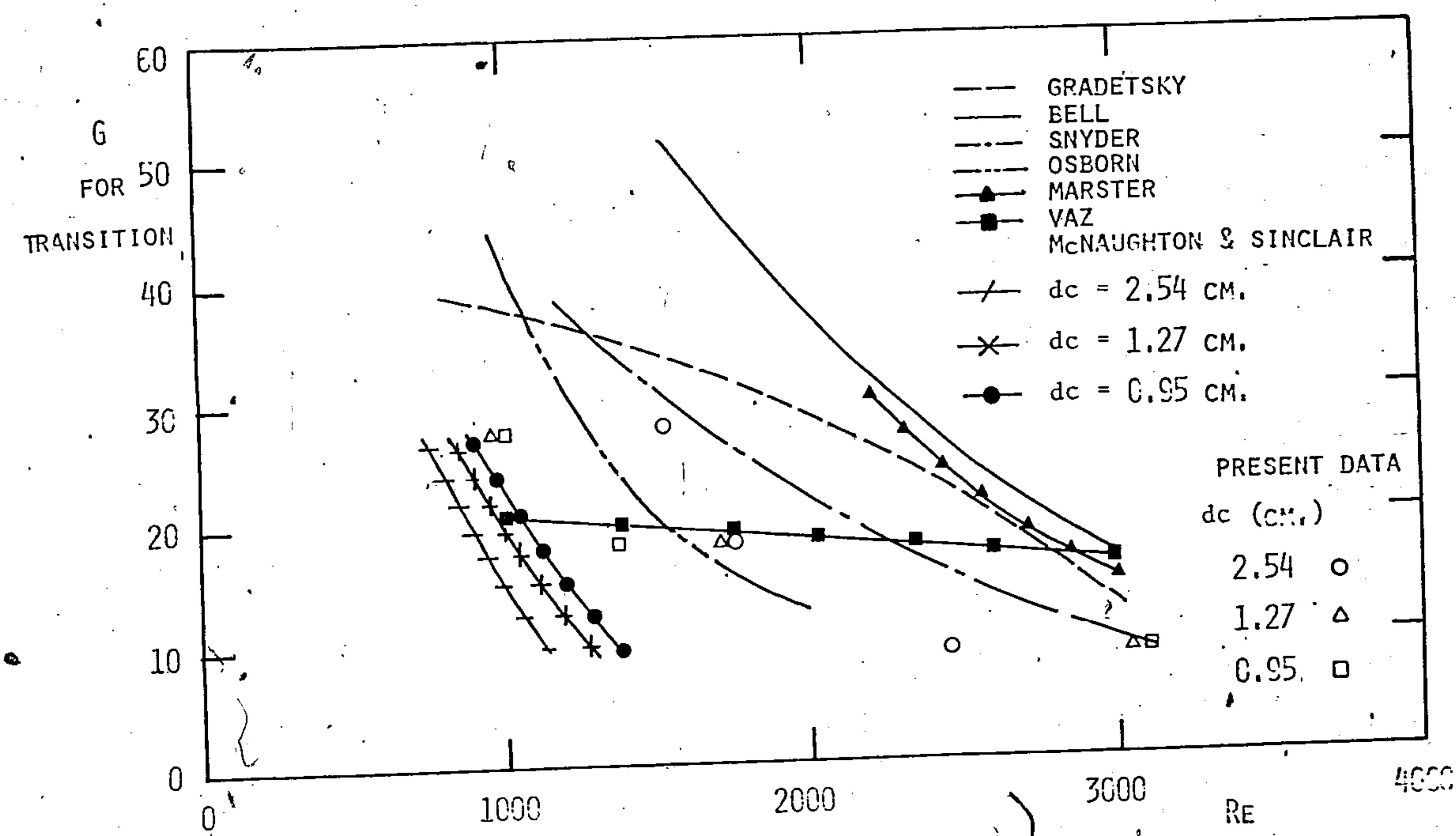



FIG. 12 NON-DIMENSIONAL GAP FOR TRANSITION VERSUS REYNOLDS NUMBER

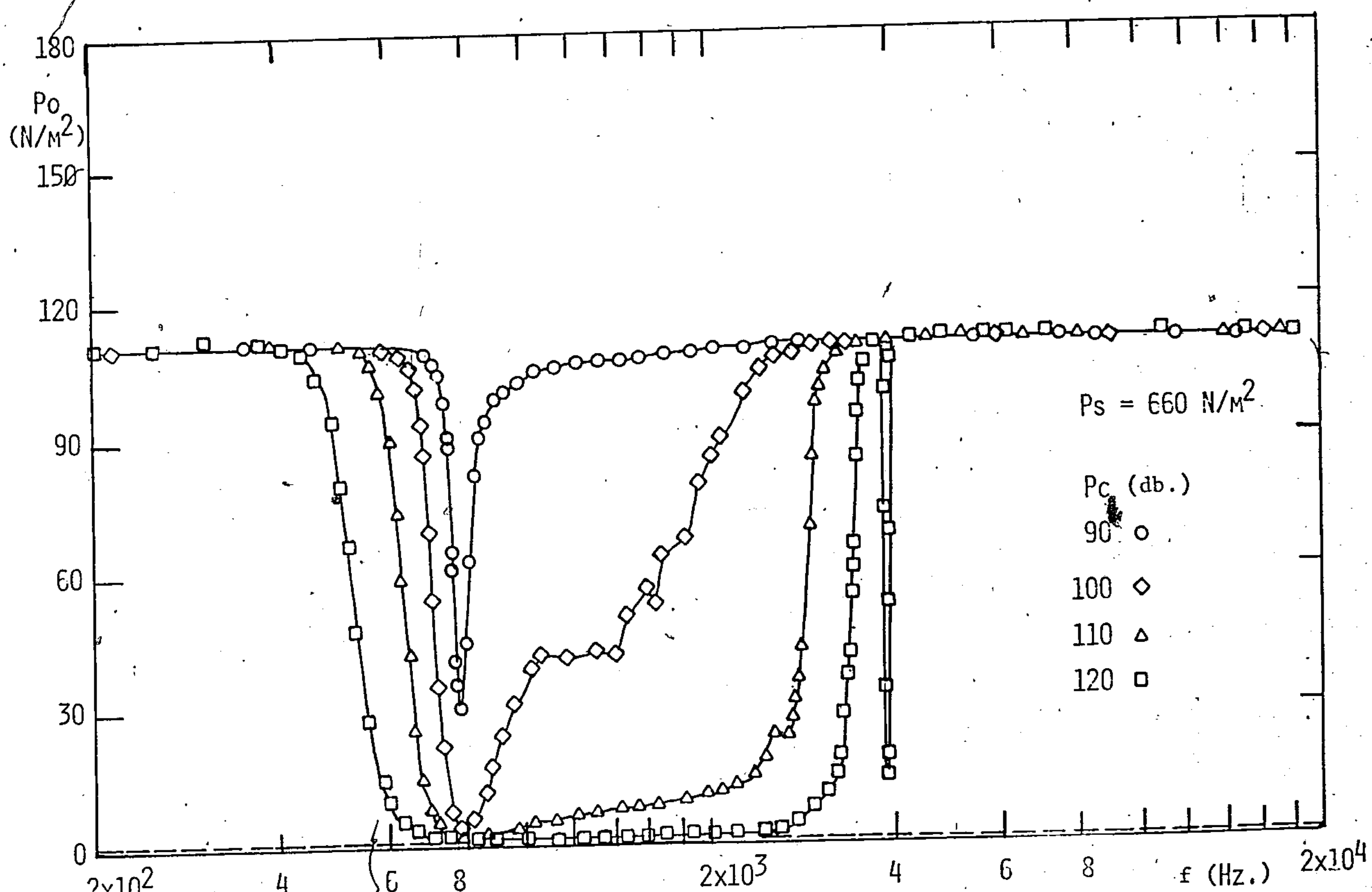



FIG. 13(A) dc = 2.54 CM. ; g = 3.81 CM.

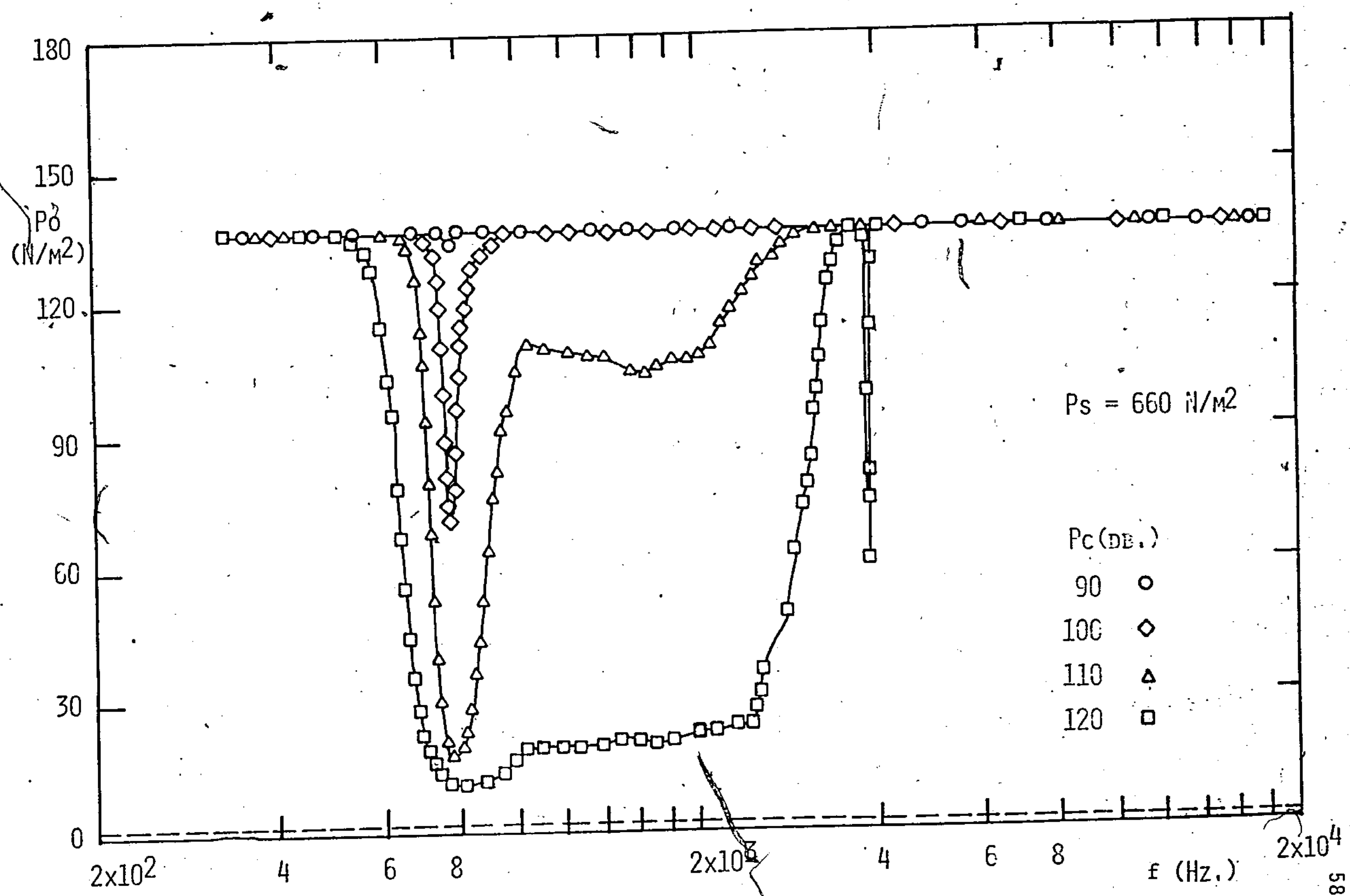



Fig. 13(b) dc = 2.54 cm. ; g = 2.54 cm.

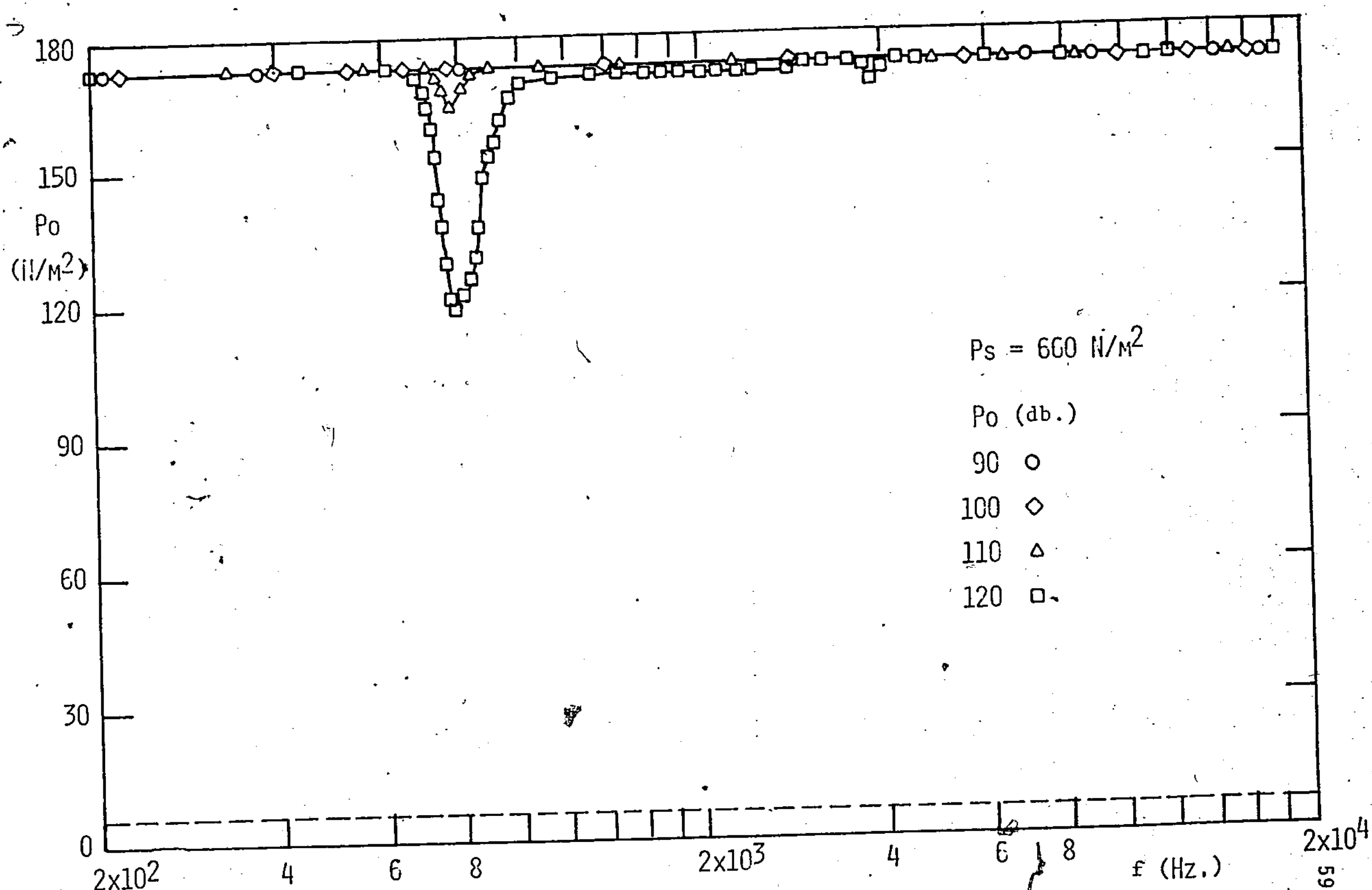



FIG. 13(c) dc = 2.54 CM. ; g = 1.27 CM.

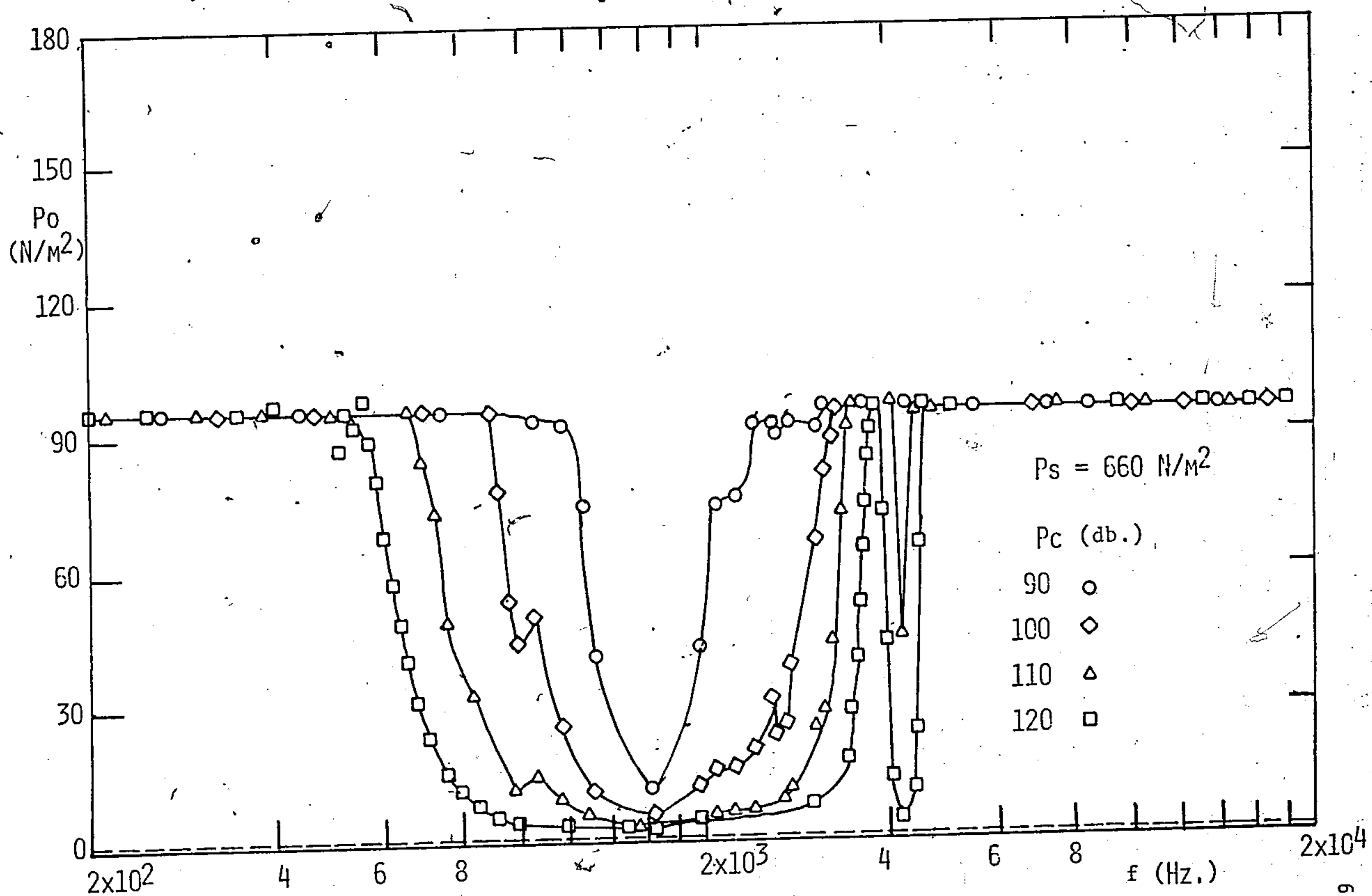



FIG. 13(D) dc = 1.27 CM. ; g = 3.81 CM.

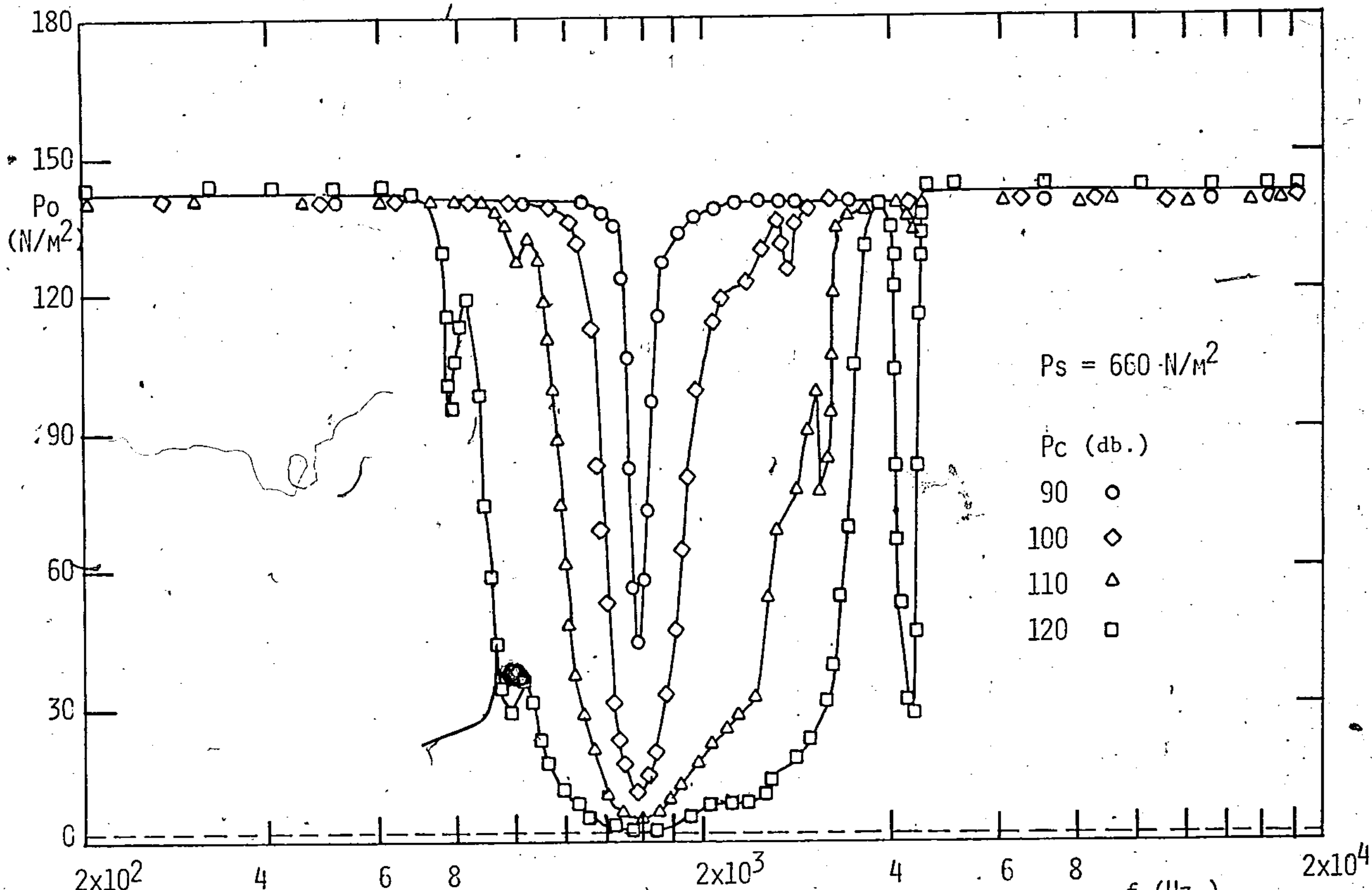



FIG. 13(E) dc = 1.27 CM. ; g = 2.54 CM.

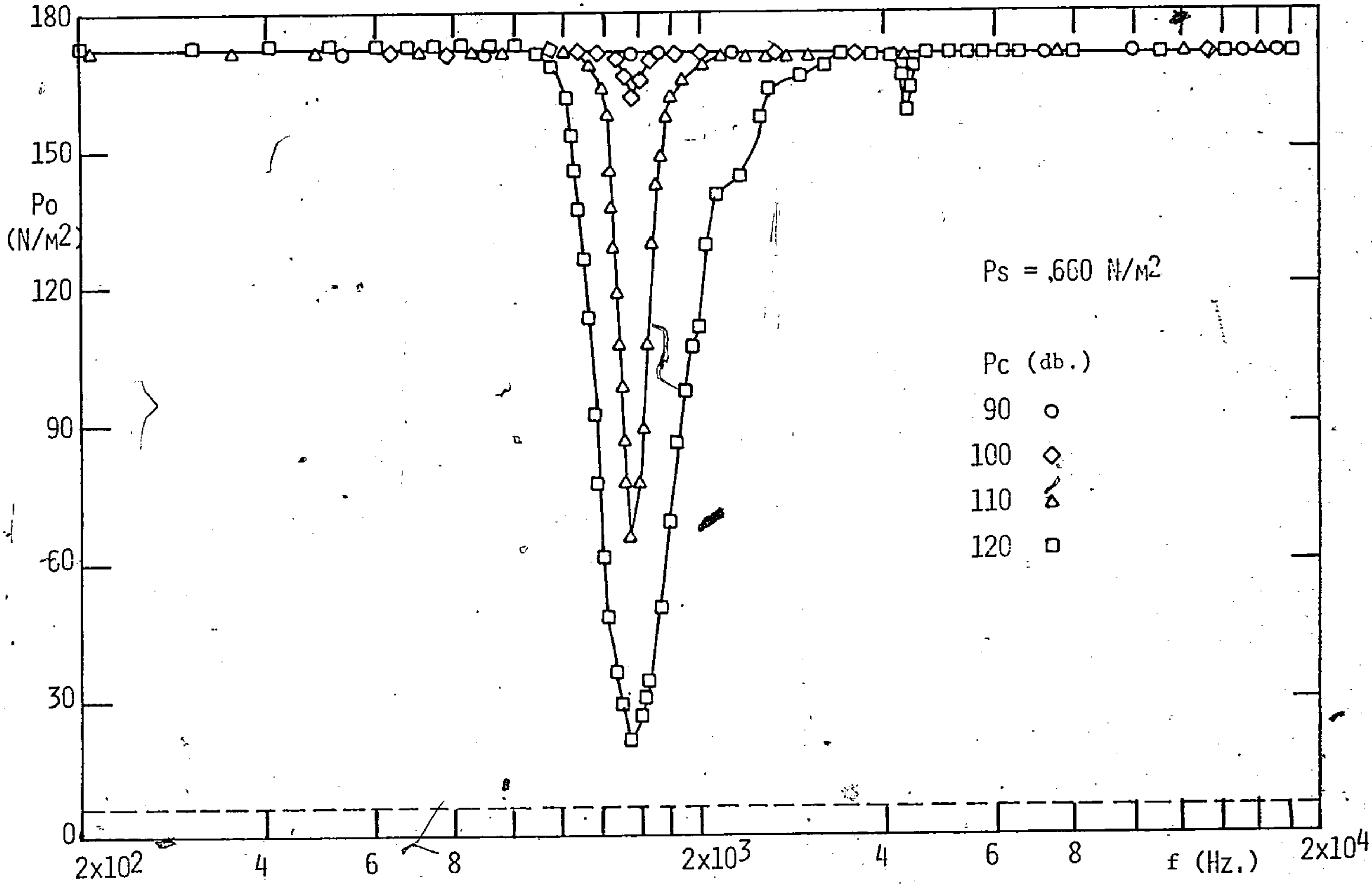



FIG. 13(F) dc = 1.27 CM.; g = 1.27 CM.

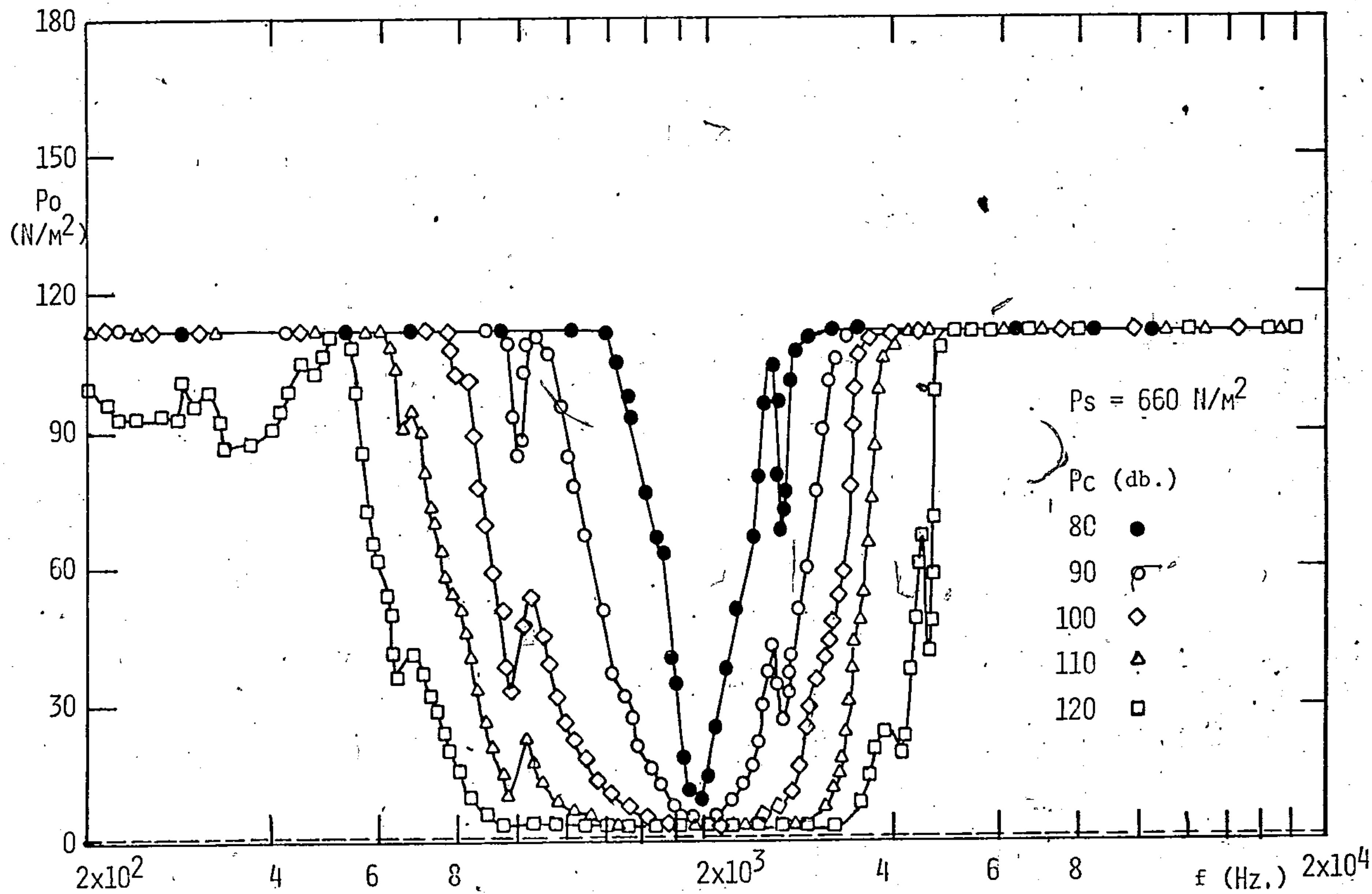



FIG. 13(G) dc = 0.95 CM. ; g = 3.81 CM.

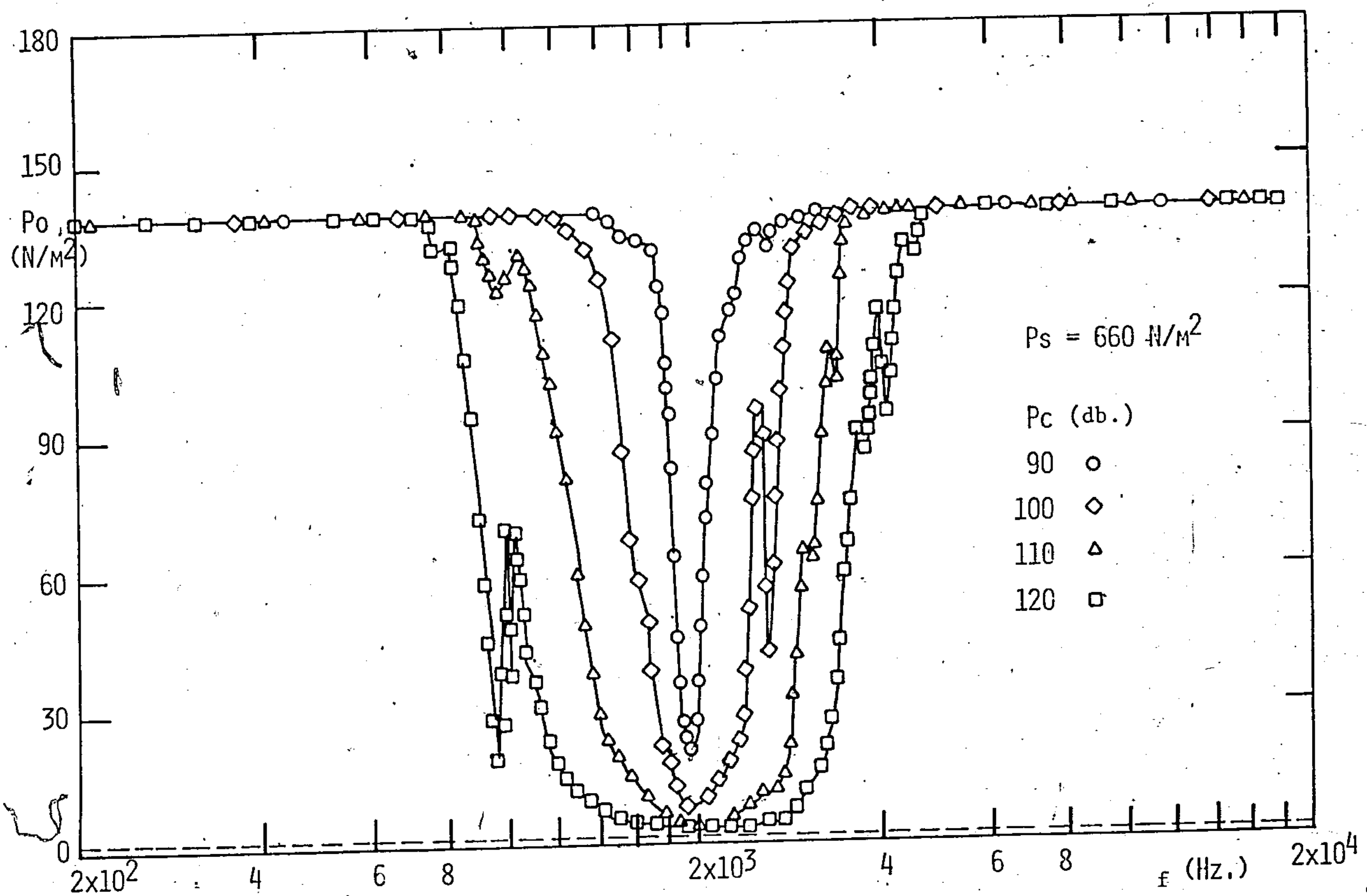



FIG. 13(H) dc = 0.95 CM. ; g = 2.54 CM.

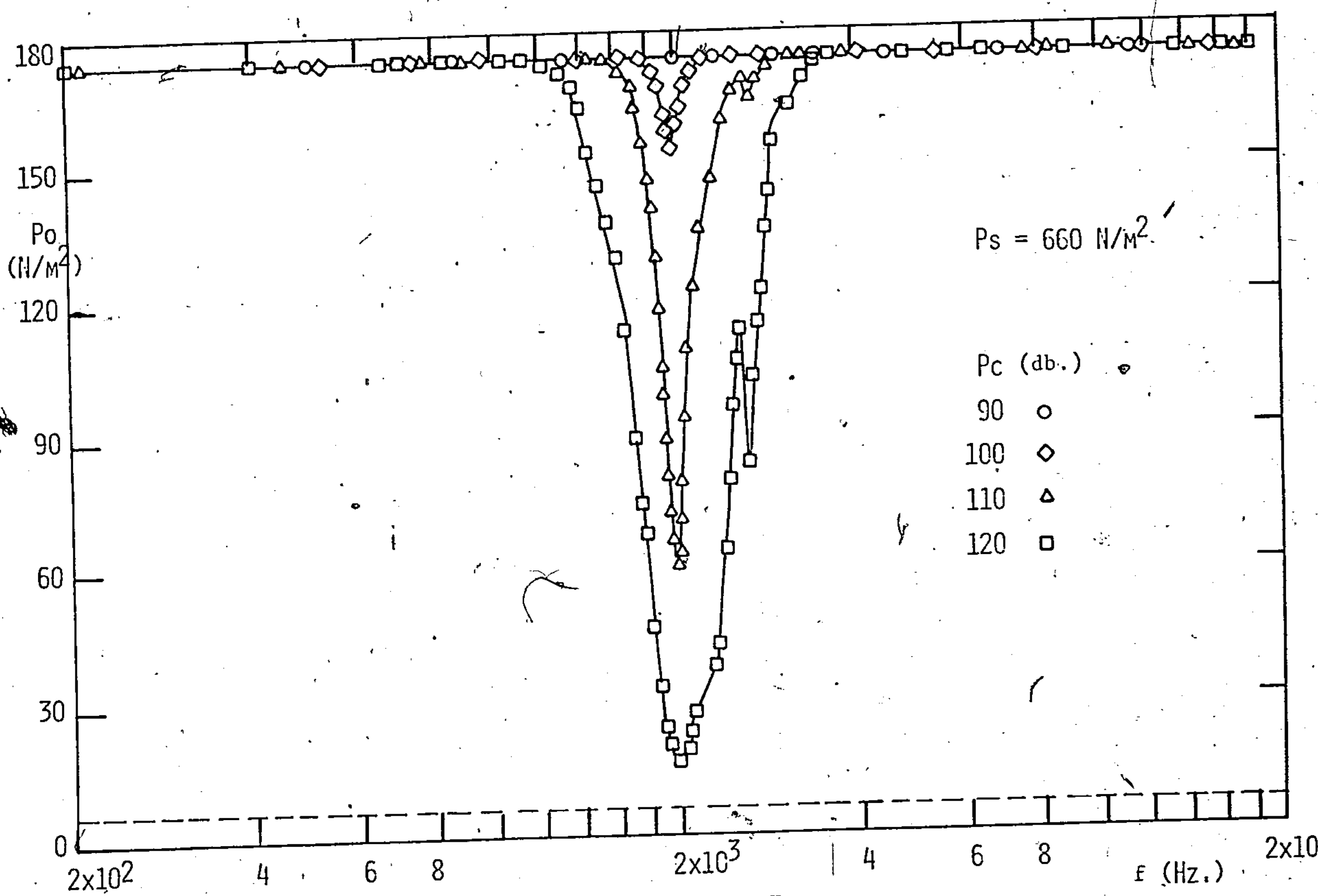



FIG. 13(I) dc = 0.95 CM. ; g = 1.27 CM.

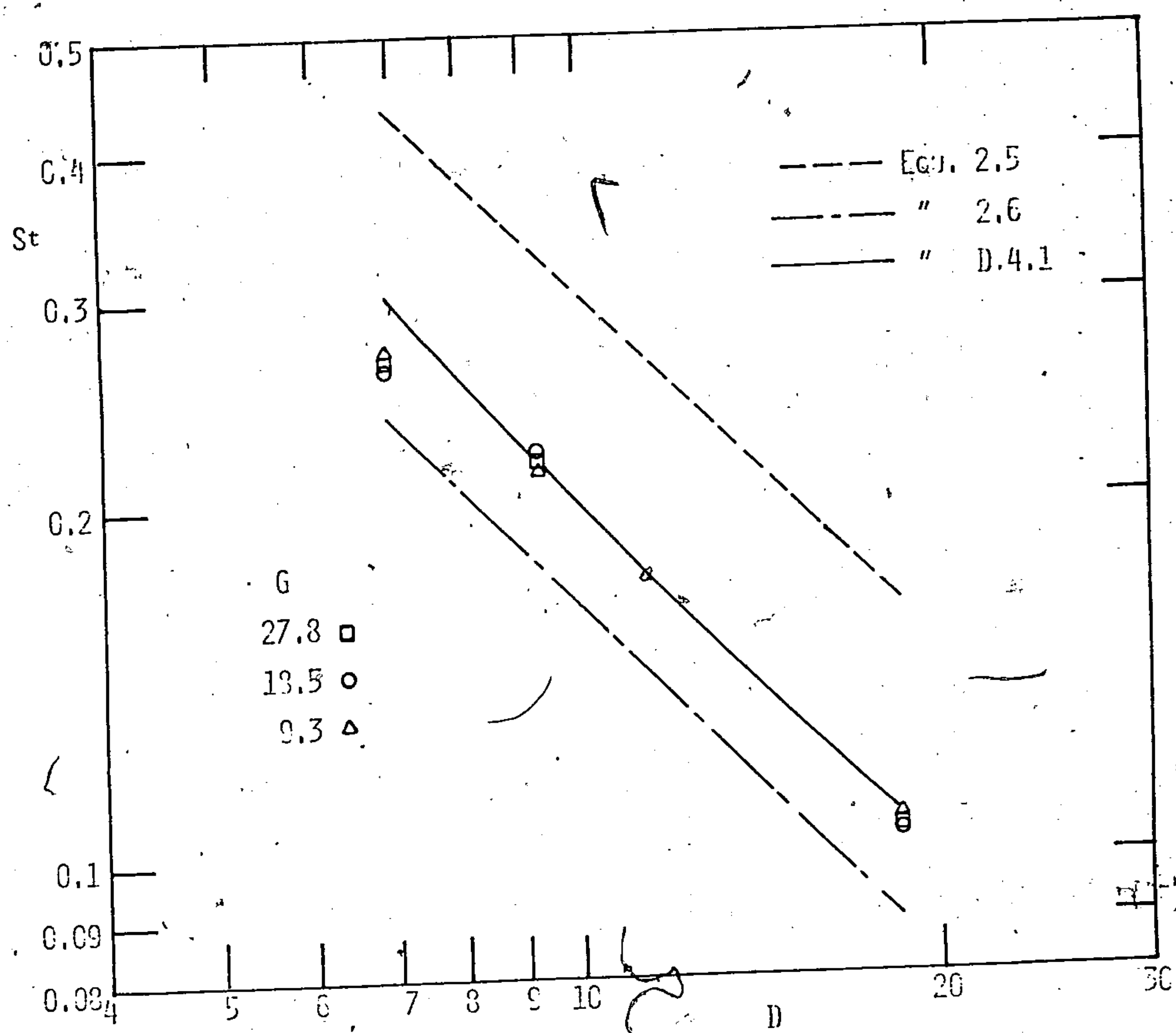



FIG. 14 STROUHAL NUMBER VERSUS NON-DIMENSIONAL SHROUD DIAMETER AND GAP LENGTH

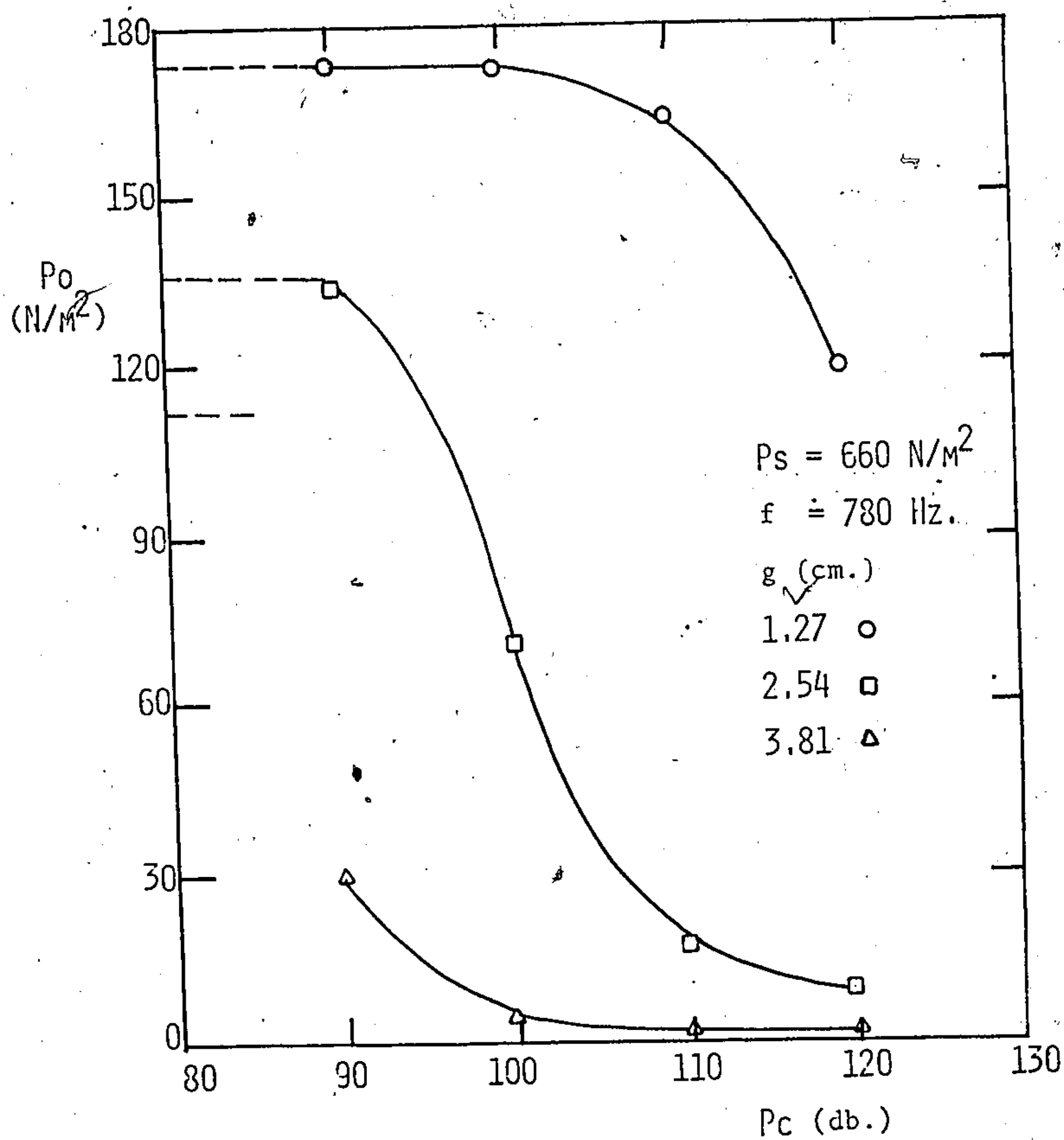



FIG. 15(A) dc = 2.54 CM.

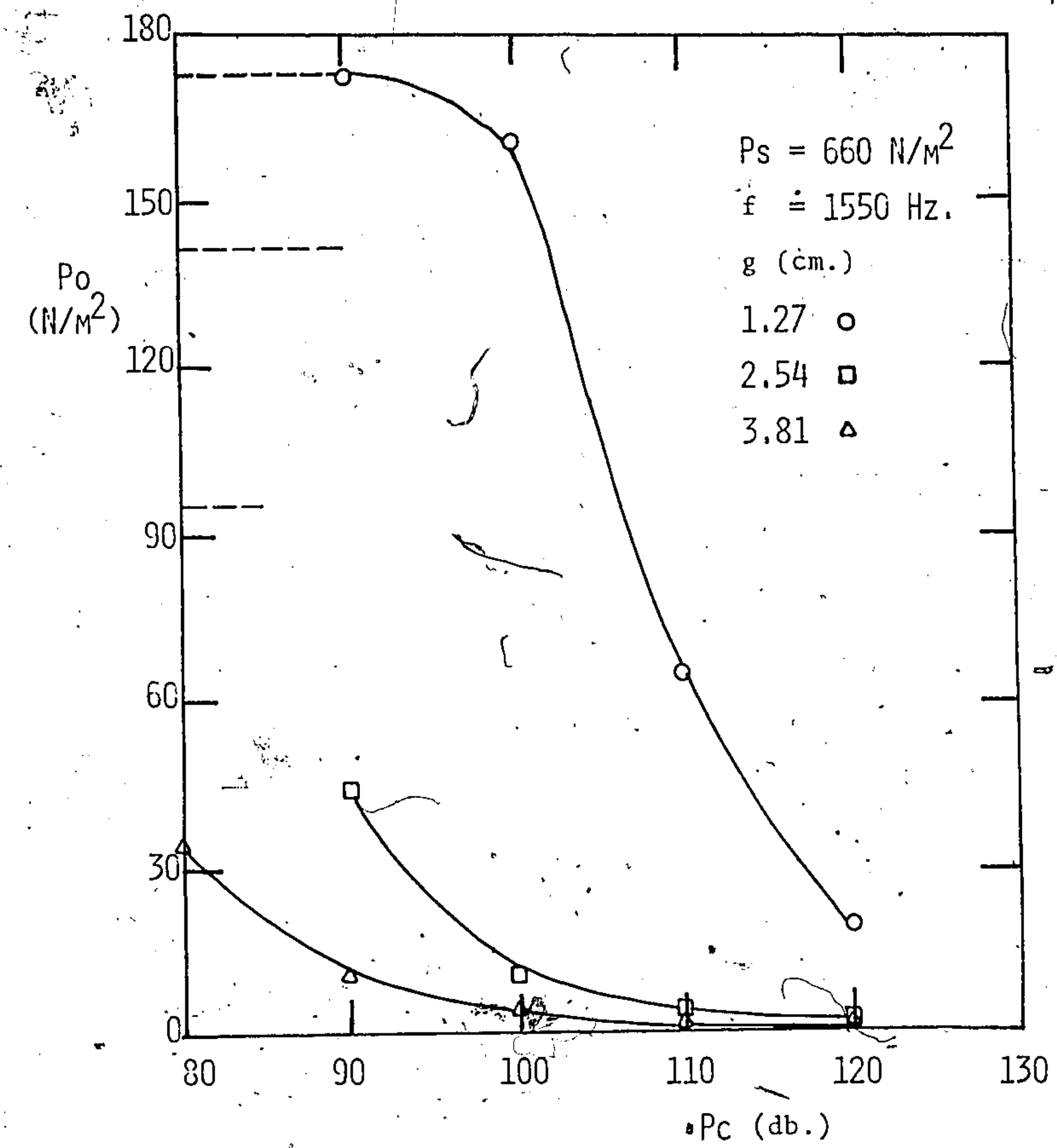



FIG. 15(B) dc = 1.27 CM.

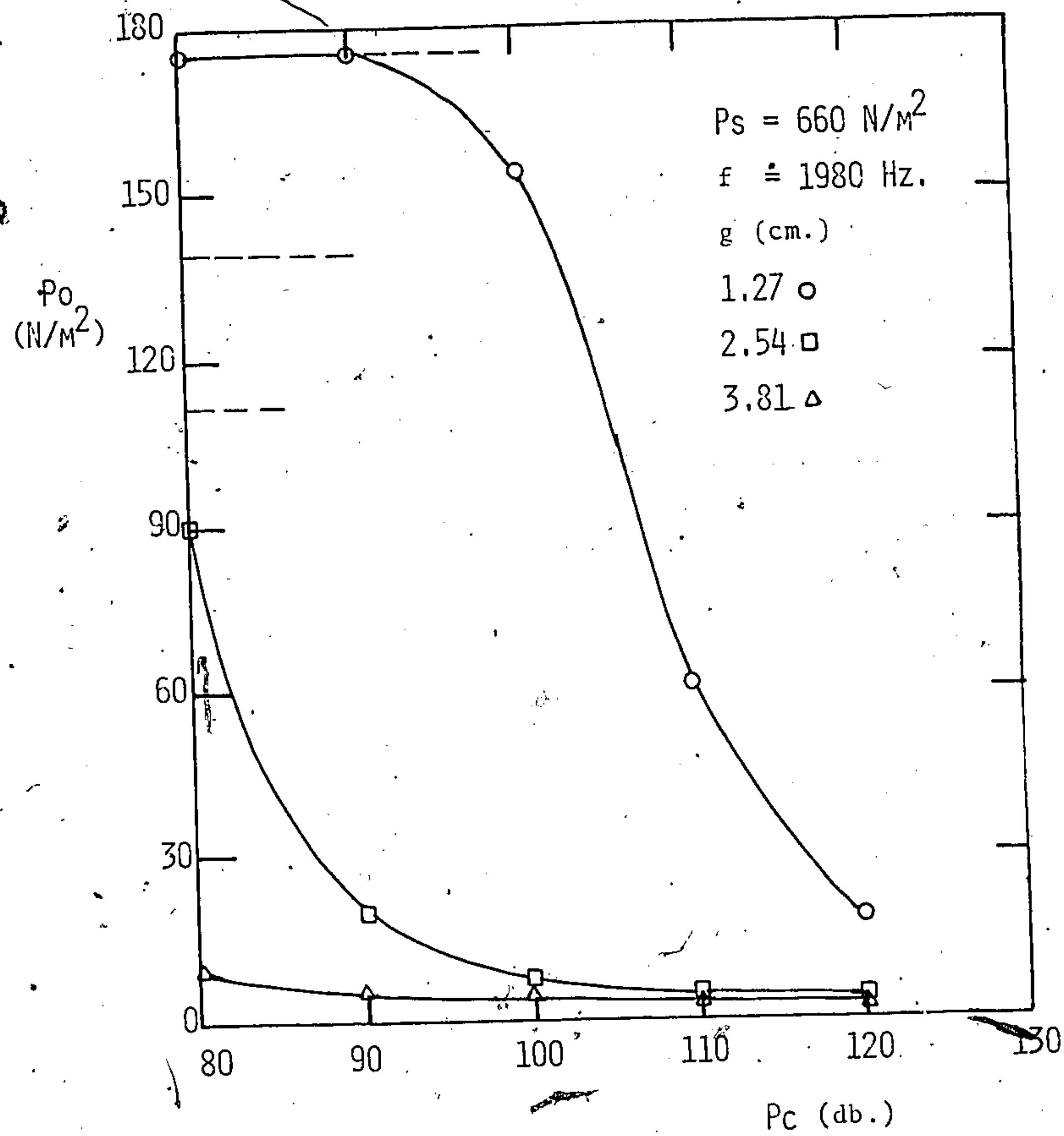



FIG. 15(c) dc = 0.95 CM.

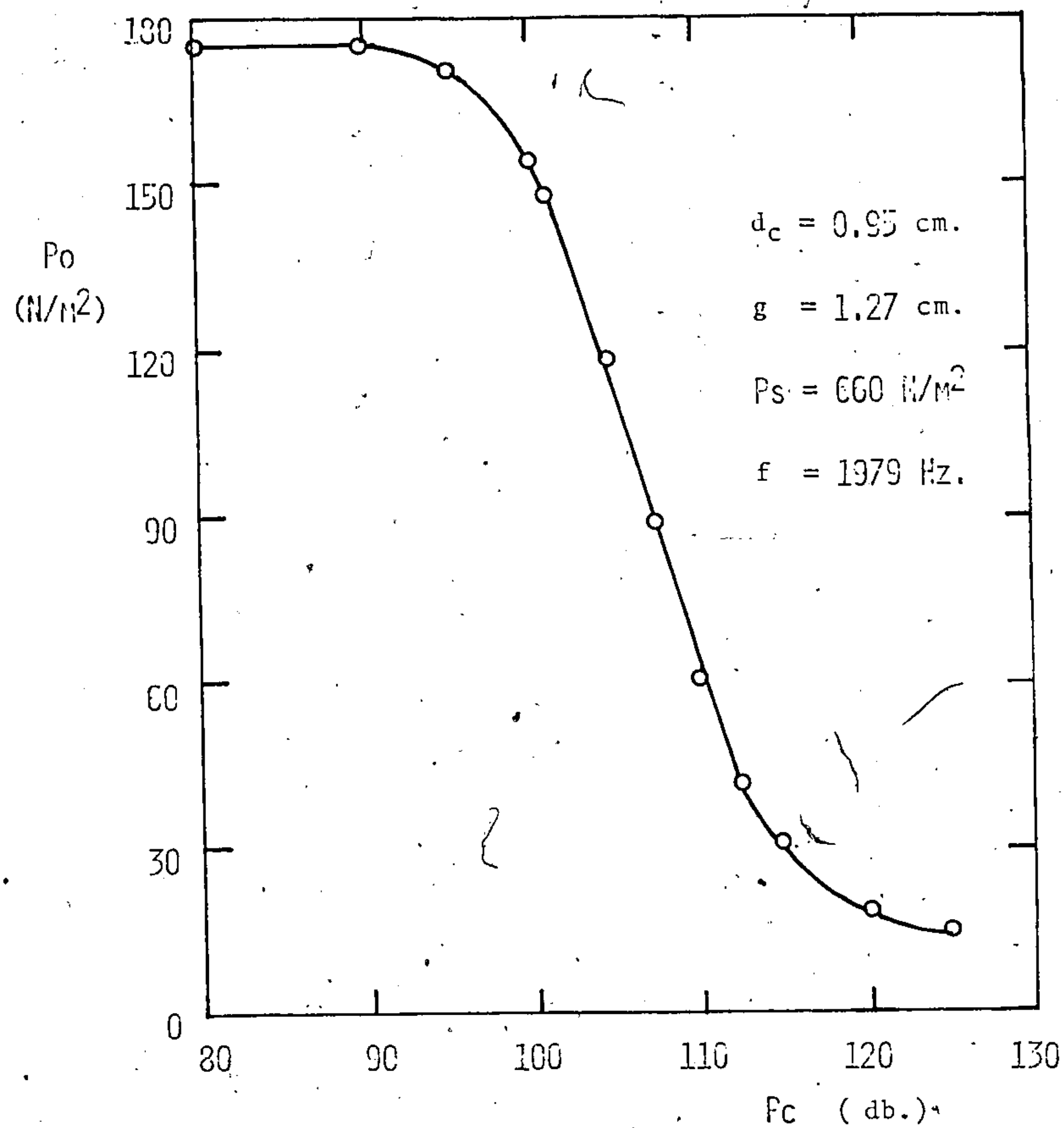



FIG. 10 PROPORTIONAL MODE OF OPERATION

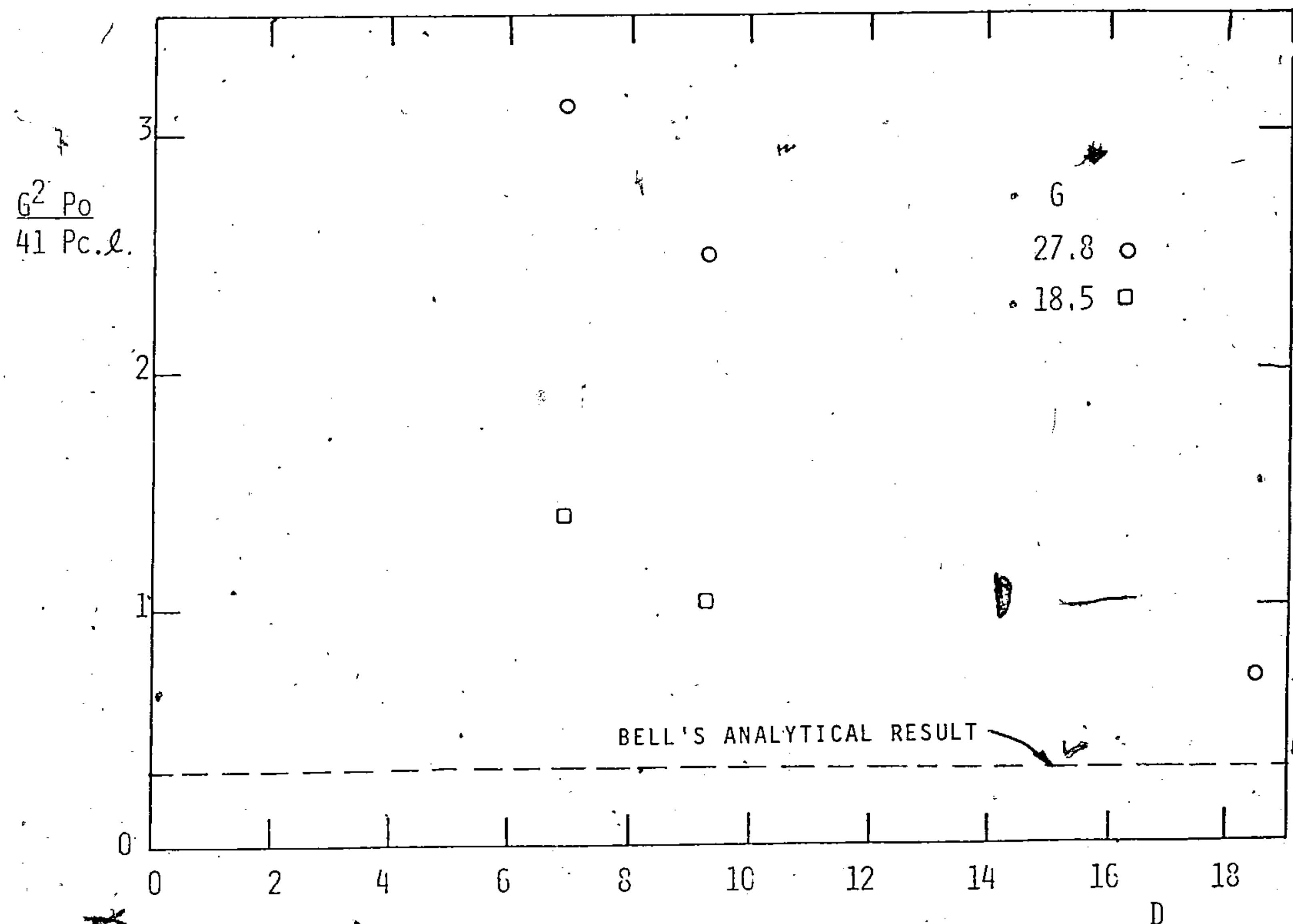



FIG. 17 NON-DIMENSIONAL TURBULENT PRESSURE RECOVERY DATA

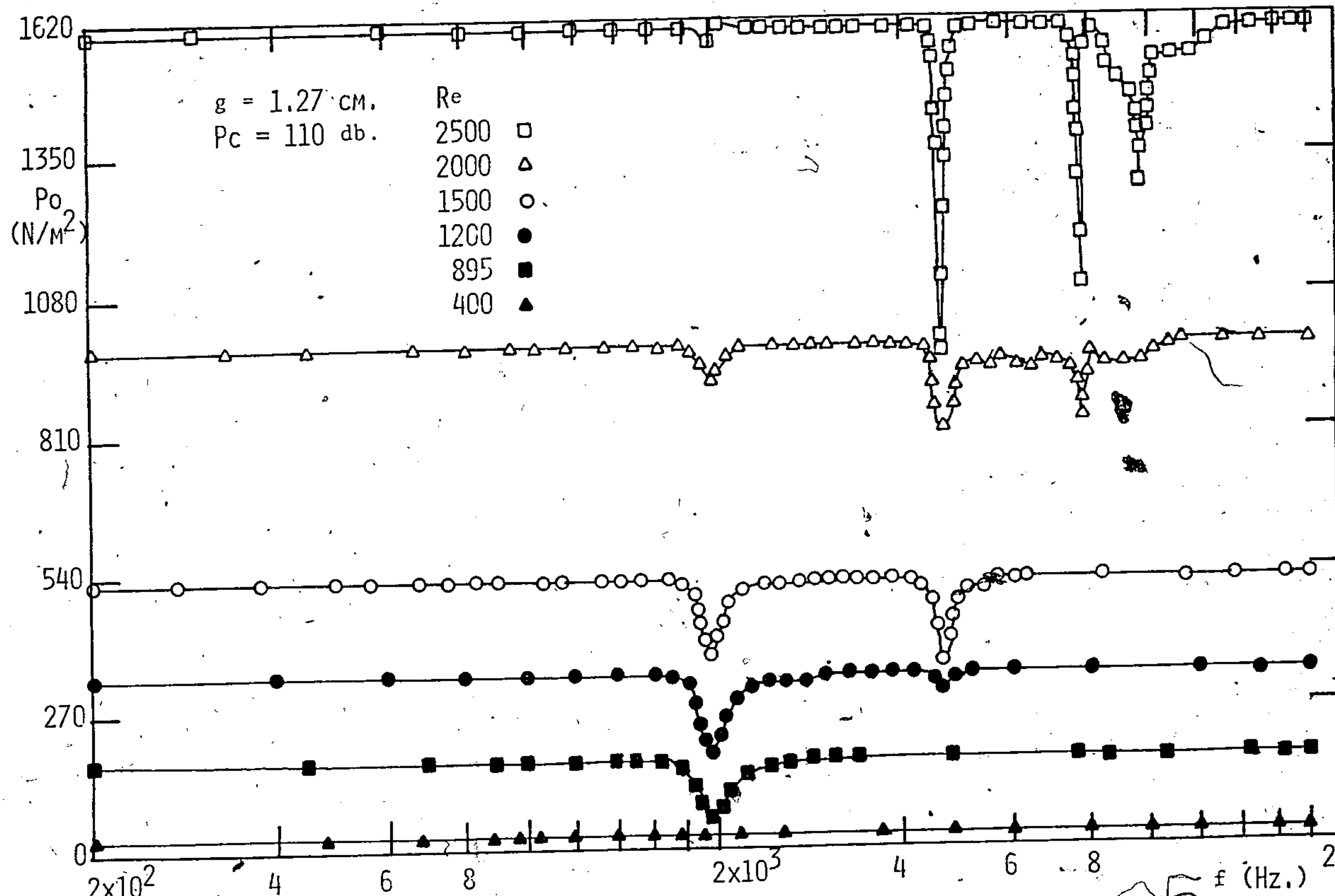



FIG. 18(A) dc = 0.95 CM.

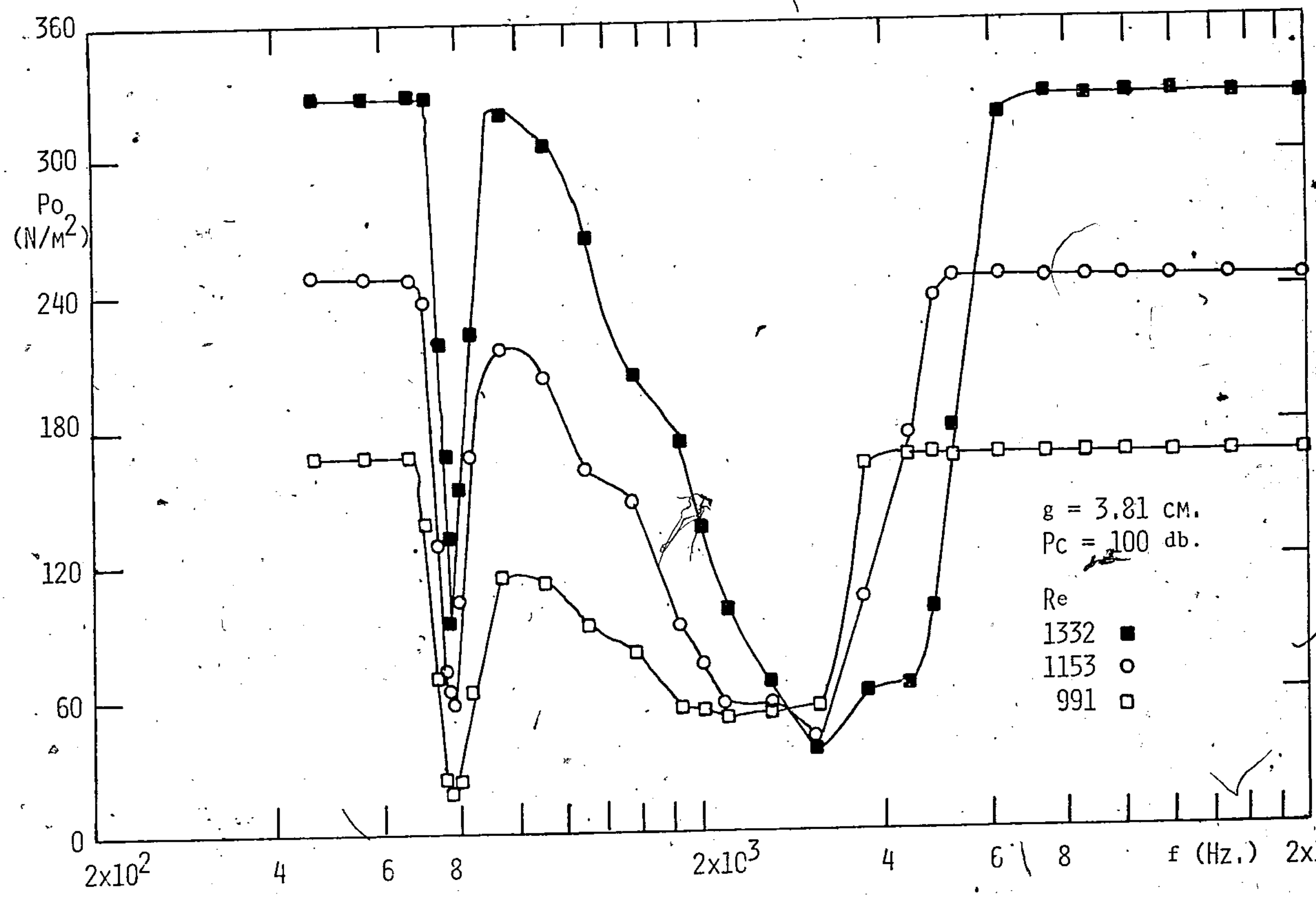



FIG. 18(B) dc = 2.54 CM.

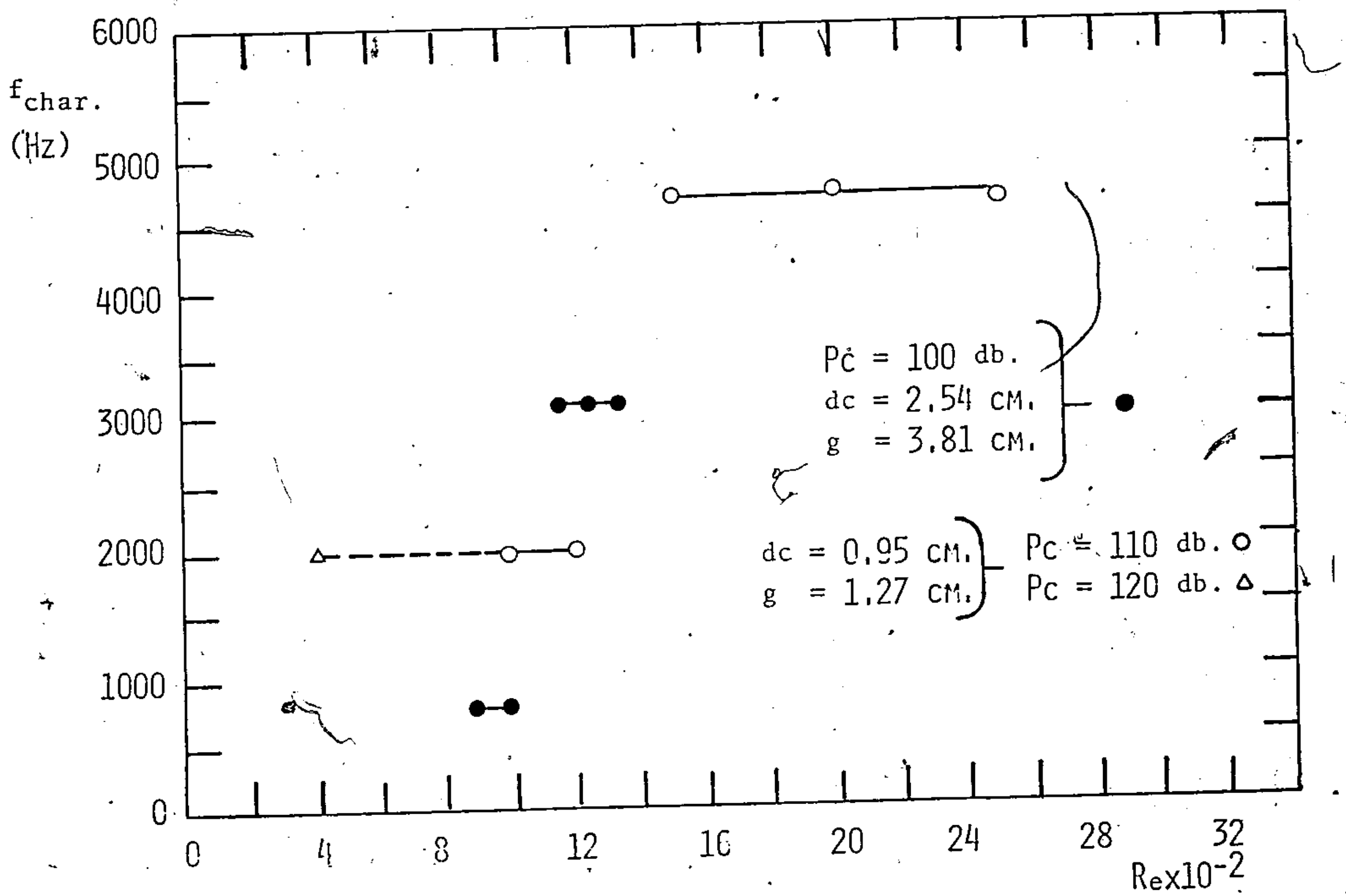



FIG. 19 CHARACTERISTIC FREQUENCY VARIATION WITH REYNOLDS NUMBER

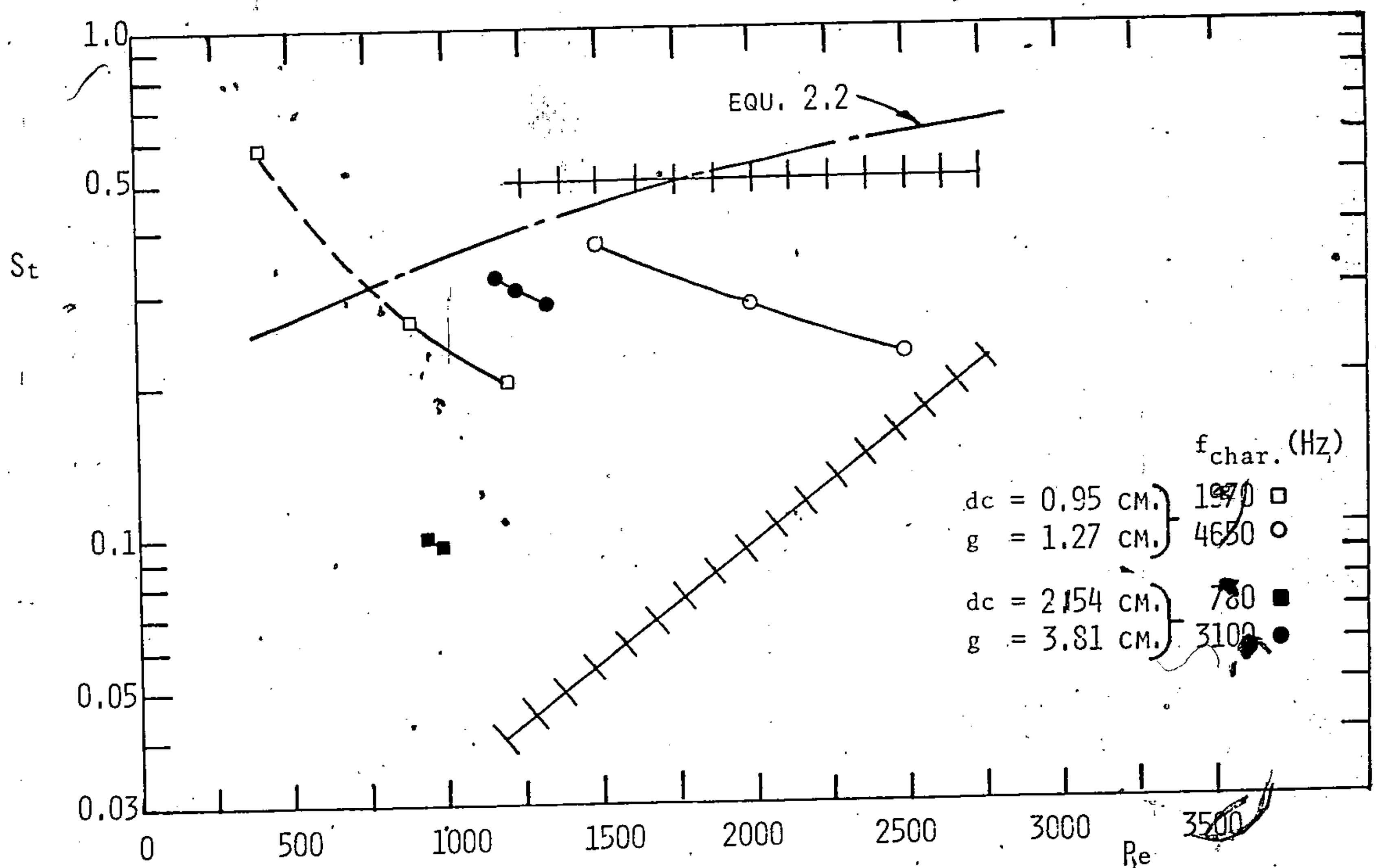
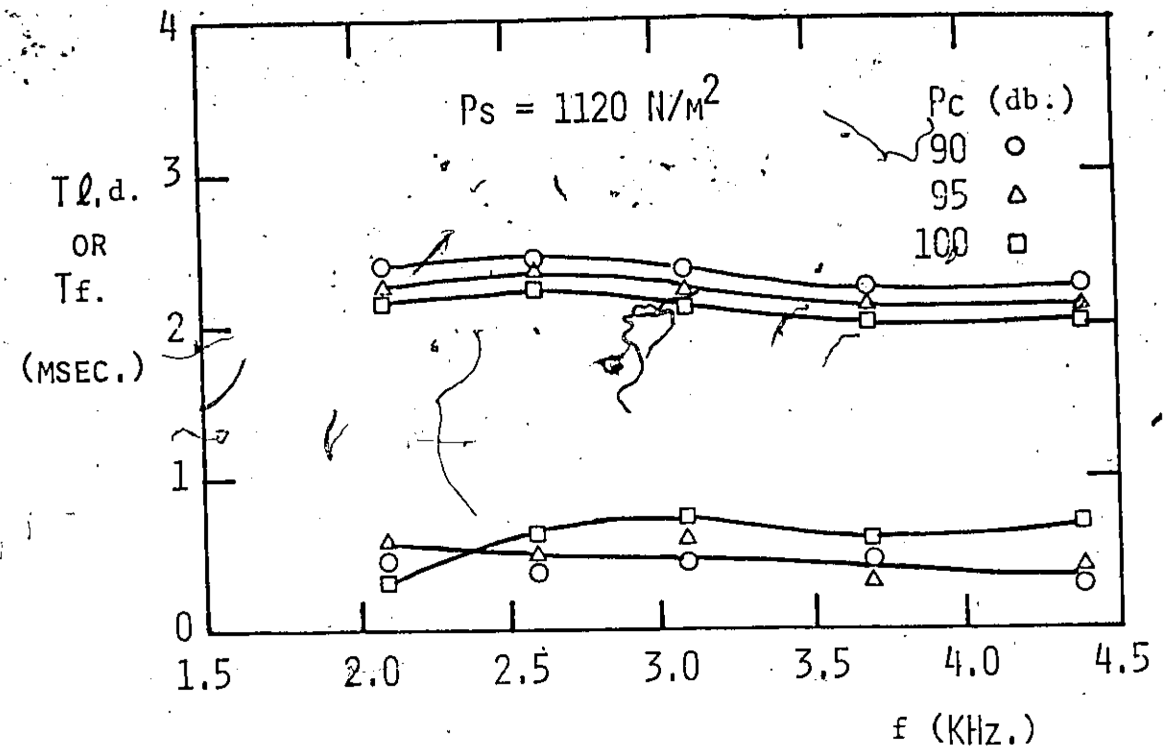



Fig. 20 Comparison of Characteristic Strouhal Numbers with Jet Sensitivity Information



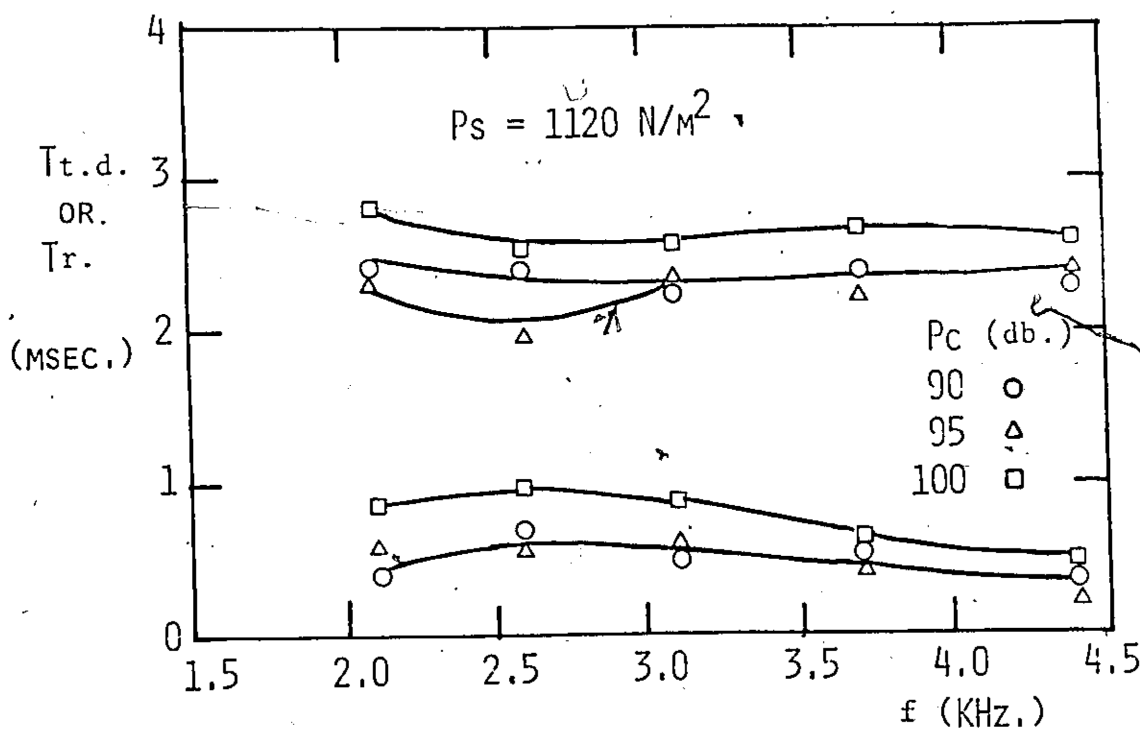
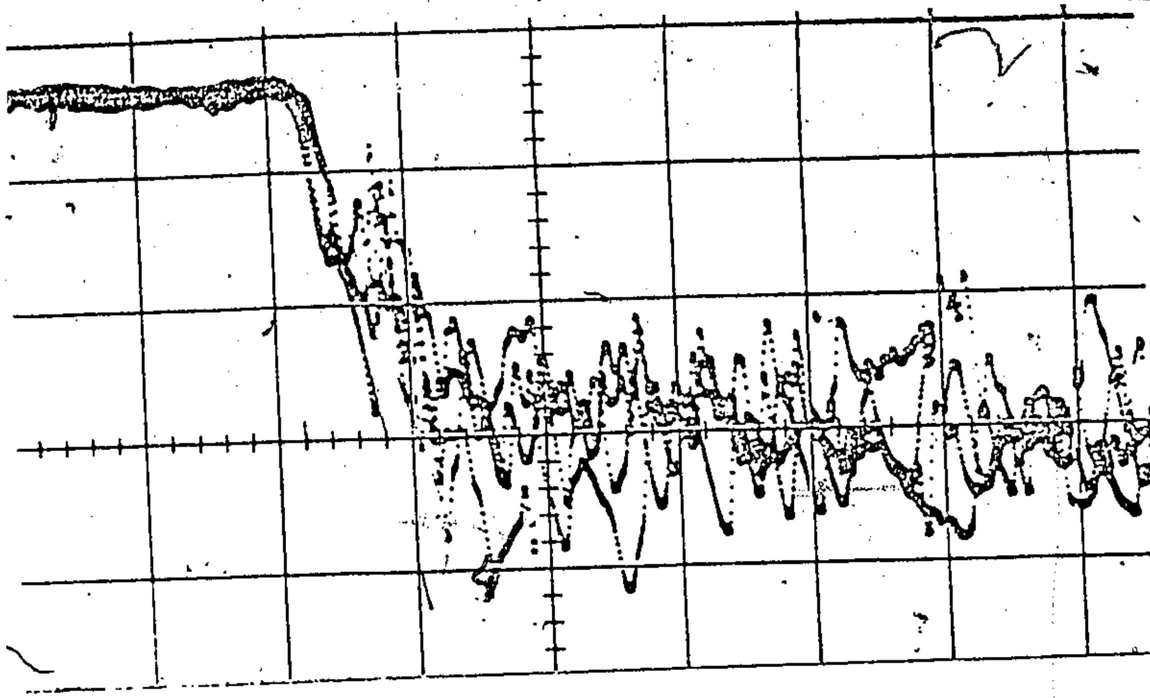
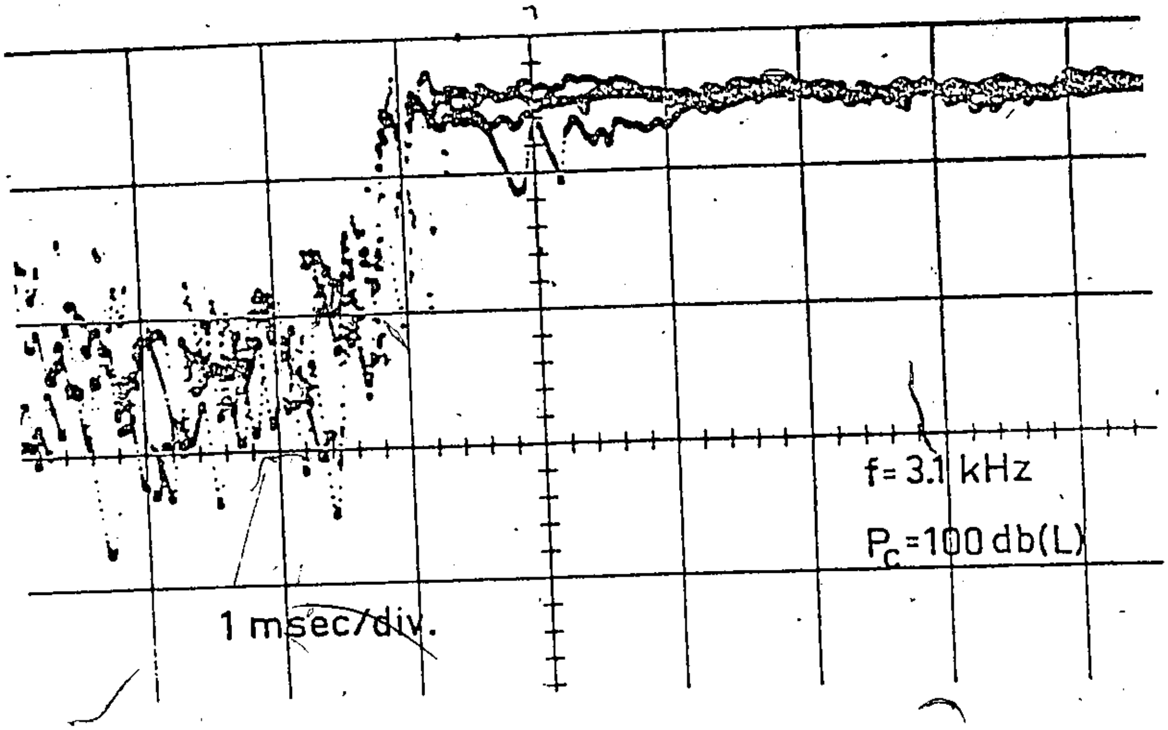




FIG. 21 EFFECT OF CONTROL SOUND VARIABLES ON RESPONSE TIME



(A) "SWITCH OFF"



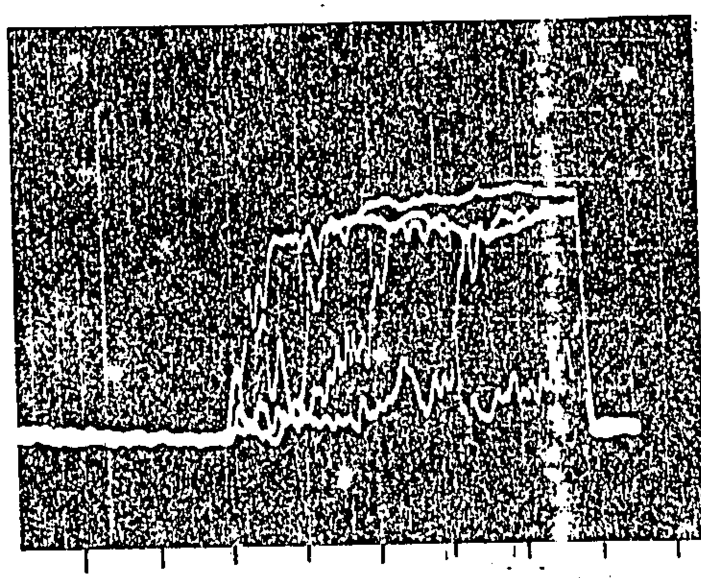

(B) "SWITCH ON"

FIG. 22 MULTIPLE TRACES OF SWITCHING

dc = 1.27 CM.      Ps = 25.4 CM. OF WATER

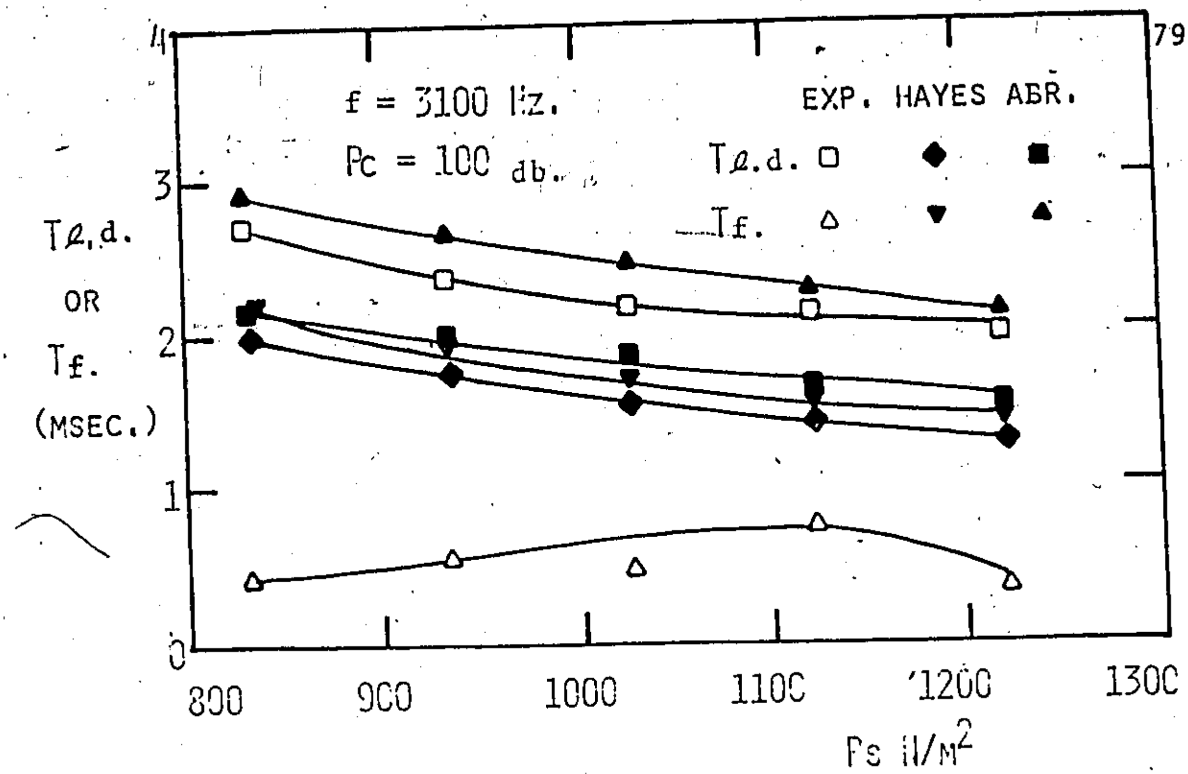
g = 2.44 CM.

PRESSURE



2 MSEC./DIV.

FIG. 23 HAYES MULTIPLE TRACE



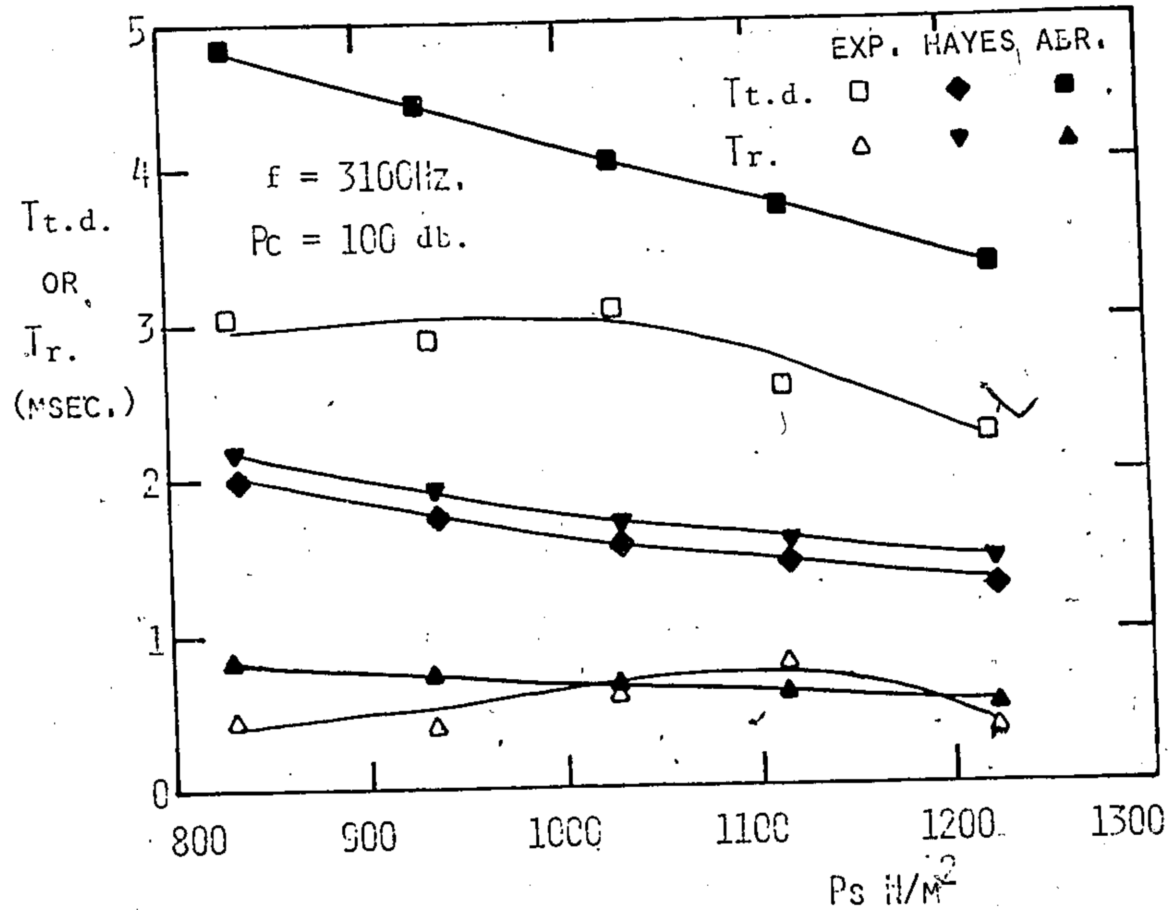




FIG. 24 RESPONSE TIME VARIATIONS WITH SUPPLY PRESSURE

| g / dc | 1.27 cm. | 2.54 cm | 3.81 cm. |
|---|---|---|---|
| 0.95 cm. | A,B,C | A,B | A,B |
| 1.27 cm. | A,B | A,B | A,B |
| 2.54 cm. | A,B | A,B | A,B,C,D |

A Po vs $P_s$

B Po vs f for Different Pc

C Po vs f for Different Re, with Pc = constant

D Switching Time

TABLE I SUMMARY OF TEST PROGRAMME

## APPENDIX A

## DIMENSIONAL ANALYSIS

The quantities which are pertinent to the present study are listed below along with their symbols and dimensions according to the MLT system.

| Quantity | Symbol | Dimension |
|---|---|---|
| supply tube diameter | ds | L |
| output tube diameter | do | L |
| shroud diameter | dc | L |
| control hole diameter (neck diameter) | dn | L |
| vent hole diameter | dv | L |
| number of vent holes | N | - |
| supply tube length | $\ell s$ | L |
| output tube length | $\ell o$ | L |
| gap length | g | L |
| control hole thickness (neck length) | $\ell n$ | L |
| vent hole thickness | $\ell v$ | L |
| supply pressure | Ps | $ML^{-1}T^{-2}$ |
| output pressure | Po | $ML^{-1}T^{-2}$ |
| control sound pressure | Pc' | $ML^{-1}T^{-2}$ |
| average supply tube velocity | Us | $LT^{-1}$ |
| average output tube velocity | Uo | $LT^{-1}$ |
| *frequency of sound | f | $T^{-1}$ |

*NOTE: The dimensions of f are actually cycles/sec. however this can be converted to rad/sec or $T^{-1}$

| | | |
|---|---|---|
| dynamic viscosity | μ | $ML^{-1}T^{-1}$ |
| density | ρ | $ML^{-}$ |
| laminar-turbulent delay time | Tℓd. | T |
| laminar-turbulent fall time | Tf. | T |
| turbulent-laminar delay time | Ttd. | T |
| turbulent-laminar rise time | Tr. | T |

The physical phenomenon of interest can be represented by writing the 23 quantities in the following form.

function (ds, do, dc, dn, dv, N, ℓs, ℓo, g, ℓn, ℓv,

Ps, Po, Pc', Us, Uo, f, ρ, μ, Tℓd, Tf, Ttd, Tr)=0

Choosing the repeating variables as

ds, Us, ρ

the following non-dimensional groups can be found by inspection.

$$\frac{do}{ds},\ \frac{dc}{ds},\ \frac{dn}{ds},\ \frac{dv}{ds},\ N,\ \frac{\ell s}{ds},\ \frac{\ell o}{ds},\ \frac{g}{ds},\ \frac{\ell n}{ds},\ \frac{\ell v}{ds}$$

Using the Buckingham $\pi$ method the remainder of the groups listed below can be found.

$$\frac{Ps}{\rho Us^2},\ \frac{Po}{\rho Us^2},\ \frac{Pc'}{\rho Us^2}$$

$$\frac{T\ell.d.Us}{ds},\ \frac{Tf.Us}{ds},\ \frac{Tt.d.Us}{ds},\ \frac{Tr.Us}{ds}$$

$$\frac{f\ ds}{Us},\ \frac{Uo}{Us}\ \text{and}\ \frac{Us\,ds/\mu}{\rho}$$

All of the quantities listed were not varied in the present experiment. Those that were varied are listed below:

$$\frac{dc}{ds},\ \frac{g}{ds},\ \frac{Ps}{\rho Us^2},\ \frac{Po}{\rho Us^2},\ \frac{Pc'}{\rho Us^2},\ \frac{T\ell.d.Us}{ds}.$$

$$\frac{Tf.Us}{ds}, \frac{Tt.d.Us}{ds}, \frac{Tr.Us}{ds}, \frac{fds}{Us}, \frac{\mu Usds}{\rho}.$$

The non-dimensional groups that were actually used in present analysis are given below with their respective symbols.

$$D = \frac{dc}{ds};\ G = \frac{g}{ds};\ Re = \frac{\mu Usds}{\rho}$$

$$ST = \frac{fds}{Us};\ Ls = \frac{\ell s}{ds};\ \frac{Po}{Ps}$$

The non-dimensional response times were not used in order to make comparisons with information in the literature.

The term $\frac{Pc'}{\rho Us^2}$ was not used due to the preference of expressing the sound pressure level in decibels with a standard reference pressure (Pr) of $2 \times 10^{-5}$ $N/m^2$ as defined below.

$$\dot{Pc} = 20 \log_{10} \frac{Pc'}{Pr} \quad (db)$$

# APPENDIX B

## UNCERTAINTY ANALYSIS

An uncertainty analysis of the experimental quantities is given below for one complete set of experimental conditions of the amplifiers. Throughout the analysis a double apostrophe after a symbol denotes the uncertainty in the quantity (ie. Re"). The conditions for which the uncertainty analysis is done are given below.

$$dc = 12.7 \times 10^{-3} m.$$

$$ds = 1.37 \times 10^{-3} m.$$

$$g = 12.7 \times 10^{-3} m.$$

$$Ps = 660 \ N/m^2 \ (Re = 895)$$

$$fchar. = 1554 \ Hz.$$

$$Po = 21 \ N/m^2$$

$$Qs = 14.9 \times 10^{-6} m^3/sec.$$

$$Pc = 120 \ db.$$

$$\nu = 0.1547 \times 10^{-4} m^2/sec.$$

(a) Supply Pressure

$$Ps = 9.78 \ Rs \sin \theta \ N/m^2$$

$$= 660 \ N/m^2$$

where

Rs = manometer reading = 135 mm. $H_2O$

$\theta$ = manometer slope = $30^o$

Rs" = ± 1mm.

$\theta$" = ± $0.25^o$ (0.00436 rad.)

$$Ps'' = \left[\left(\frac{\delta Ps}{\delta Rx} Rs''\right)^2 + \left(\frac{\delta Ps}{\delta \theta} \theta''\right)^2\right]^{1/2}$$

$$\frac{\delta Ps}{\delta Rs} = 9.78 \sin\theta = 4.89 \frac{N}{m^2 mm} H_2O$$

$$\frac{\delta Ps}{\delta \theta} = 9.78\, Rs \cos\theta = 1143$$

$$Ps'' = 7.0 \ N/m^2$$

$$\frac{Ps''}{Ps} X\, 100 \doteq 1\%$$

(b) Output Pressure

$$Po = 9.78 \frac{Ro}{S} (S.G.)$$

where

Ro = Output manometer reading = 13

S = manometer slope factor = 5

S.G. = manometer fluid specific gravity = 0.827

$$Po = 21 \ N/m^2$$

$$Ro'' = \pm\ 0.5 \ mm.$$

S" = assumed equal to 0 due to standard slope fixtures holding the tube in place

$$(S.G.)'' = 2\% = 0.016$$

$$Po'' = \left[\left(\frac{\delta Po}{\delta Ro} Ro''\right)^2 + \left(\frac{\delta Po}{\delta (S.G.)} (S.G.)''\right)^2\right]^{1/2}$$

$$\frac{\delta Po}{\delta Ro} = \frac{9.78\,(S.G.)}{S} = 1.62 \frac{N}{m^2} \ mm.\ H_2O$$

$$\frac{\delta Po}{\delta (S.G.)} = \frac{9.78 Ro}{S} = 25.4 \frac{N}{m^2}$$

$$Po'' = 0.91 \ N/m^2$$

$$\frac{Po''}{Po} X\ 100 = 4.3\%$$

(c) Reynolds Number

$$Re = \frac{4Qs}{\pi ds\, \nu} = 895$$

$Qs'' = 0.1 \times 10^{-6}\ m^3/sec.$

$ds'' = 0.03 \times 10^{-3}\ m.$

$\nu'' = 0.03 \times 10^{-6}\ m^2/sec.$

$$Re'' = \left[\left(\frac{\delta Re}{\delta Qs} Qs''\right)^2 + \left(\frac{\delta Re}{\delta ds} ds''\right)^2 + \left(\frac{\delta Re}{\delta \nu} \nu''\right)^2\right]^{1/2}$$

$$\frac{\delta Re}{\delta Qs} = \frac{4}{\pi ds \nu} = 6.0 \times 10^7\ \frac{sec.}{m^3}$$

$$\frac{\delta Re}{\delta ds} = \frac{-4}{\pi ds^2 \nu} = -6.5 \times 10^5\ m^{-3}$$

$$\frac{\delta Re}{\delta \nu} = \frac{-4Qs}{\pi ds \nu^2} = -5.8 \times 10^7\ \frac{sec.}{m^2}$$

$Re'' = 20.4$

$\frac{Re''}{Re} \times 100 \doteq 2.3\%$

(d) Non - Dimensional Shroud Diameter

$$D = \frac{dc}{ds} \doteq 9.27$$

$dc'' = \pm 0.03 \times 10^{-3} m.$

$ds'' = \pm 0.03 \times 10^{-3} m.$

$$D'' = \left[\left(\frac{\delta D}{\delta ds} ds''\right)^2 + \left(\frac{\delta D}{\delta d_c} dc''\right)^2\right]^{1/2}$$

$$\frac{\delta D}{\delta ds} = -\frac{dc}{ds^2} = -4939\ m^{-1}$$

$$\frac{\delta D}{\delta dc} = \frac{1}{ds} = 730\ m^{-1}$$

$D'' = 0.18$

$\frac{D''}{D} \times 100 \doteq 2\%$

(e) Non - Dimensional Gap Length

$$G = \frac{g}{ds} = 9.27$$

$g'' = \pm 0.15 \times 10^{-3}\ m.$

$$G'' = \left[\left(\frac{\delta G}{\delta g}\, g''\right)^2 + \left(\frac{\delta G}{\delta ds}\, ds''\right)^2\right]^{1/2}$$

$$\frac{\delta G}{\delta g} = \frac{1}{ds} = 730\ m^{-1}$$

$$\frac{\delta G}{\delta ds} = \frac{-g}{ds^2} \doteq 4939\ m^{-1}$$

$$G'' = 0.18$$

$$\frac{G''}{G} \times 100 \doteq 2\%$$

(f) Non - Dimensional Output Pressure

$$\frac{Po}{Ps} = 0.0318$$

$$\left(\frac{Po}{Ps}\right)'' = \left[\left(\frac{\delta(Po/Ps)}{\delta Po}\, Po''\right)^2 + \left(\frac{\delta(Po/Ps)}{\delta Ps}\, Ps''\right)^2\right]^{1/2}$$

$$\frac{\delta(Po/Ps)}{\delta Po} = \frac{1}{Ps} = 1.515 \times 10^{-3}\ \frac{m^2}{N}$$

$$\frac{\delta(Po/Ps)}{\delta Ps} = -\frac{Po}{Ps^2} = -4.82 \times 10^{-5}\ \frac{m^2}{N}$$

$$\left(\frac{Po}{Ps}\right)'' \doteq 0.00142$$

$$\frac{\left(\frac{Po}{Ps}\right)''}{\frac{Po}{Ps}} \times 100 \doteq 4.5\%$$

(g) $G^{0.27}\,\frac{Po}{Ps}$ (let this term be called Z in this section)

$$Z = 0.0580$$

$$Z'' = \left[\left(\frac{\delta Z}{\delta G}\, G''\right)^2 + \left(\frac{\delta Z}{\delta(Po/Ps)}\left(\frac{Po}{Ps}\right)''\right)^2\right]^{1/2}$$

$$\frac{\delta Z}{\delta G} = 0.27\, G^{-0.73}\, \frac{Po}{Ps} = 0.00169$$

$$\frac{\delta Z}{\delta(P_o/P_s)} = G^{0.27} = 1.82$$

$$Z'' = 0.0026\,,$$

$$\frac{Z''}{Z} \times 100 \doteq 4.5\%$$

(h) Characteristic Strouhal Number

$$St_{char.} = \frac{f_{char.}\, d_s}{U_s} = \frac{f_{char.}\,\pi d_s^3}{4Q_s}$$

$$f_{char.} = 1554$$

$$St_{char.} = 0.211$$

$$f_{char.}'' = \pm 10 Hz$$

$$St_{char.}'' = \left[\left(\frac{\delta St_{char.}}{\delta f_{char.}}\, f_{char.}''\right)^2 + \left(\frac{\delta St_{char.}}{\delta d_s}\, d_s''\right)^2 + \left(\frac{\delta f_{char}}{\delta Q_s}\, Q_s''\right)^2\right]^{1/2}$$

$$\frac{\delta St_{char}}{\delta f_{char.}} = \frac{\pi d^3}{4 Q_s} = 1.36 \times 10^{-4} \text{ sec.}$$

$$\frac{\delta St_{char.}}{\delta d_s} = \frac{3 d_s^2 \pi f_{char.}}{Q_s} = 461 \text{ m}^{-1}$$

$$\frac{\delta St_{char}}{\delta Q_s} = -\frac{f_{char.}\pi d_z^3}{4 Q_s^2} = -14136 \frac{\text{sec.}}{\text{m}^3}$$

$$St_{char.}'' = 0.0139$$

$$\frac{St_{char.}''}{St_{char.}} \times 100 \doteq 6.6\%$$

(i) Response Times

The response times could be measured with an uncertainty of ± 0.2 msec. considering the sweep time of the oscilloscope (1m.sec./cm.) and possible errors involving the attainment of a reading according to the definitions of the times.

(j) Control Sound Pressure Level

Based on the calibration procedure used to obtain these values and the position of the microphone in front of the control hole opening the uncertainty (Pc") is estimated as ± 1 db.

(k) $\frac{G^2 Po}{41\ Pc.\ell.}$

Only certain variables were used to calculate $\frac{G^2\widetilde{Po}}{41\ Pc.\ell.}$. The following data consists of the information required to obtain one of the points in Fig. 17.

| | |
|---|---|
| $ds = 1.37 \times 10^{-3}$ m. | fchar. = 780 Hz. |
| $dc = 25.4 \times 10^{-3}$ m. | Ro = 3 mm. |
| $g = 38.1 \times 10^{-3}$ m. | S = 25 |
| $Qs = 14.9 \times 10^{-6}\ m^3/sec.$ | S.G. = ± 0.016 |
| $Ps = 660\ N/m^2$ | $\rho = 1.189\ Kg/m^3$ |
| | $\rho'' = \pm 2.08 \times 10^{-3}\ Kg/m^3$ |

It can be shown using the previous methods that

$$Po = 0.97\ N/m^2,\ Po'' = 0.325\ N/m^2$$

$$G = 27.8 \quad \text{and } G'' = 0.619$$

also

$$Pc.\ell. = \frac{8\rho Qs}{\pi ds^2} = 24.0\ N/m^2$$

$$Pc.\ell.'' = \left[ \left(\frac{\delta Pc.\ell.}{\delta\rho}\rho''\right)^2 + \left(\frac{\delta Pc.\ell.}{\delta Qs} Qs''\right)^2 + \left(\frac{\delta Pc.\ell.}{\delta ds} ds''\right)^2 \right]^{\frac{1}{2}}$$

$$\frac{\delta Pc.\ell.}{\delta\rho} = \frac{8Qs}{\pi ds^2} = 20.2\ \frac{N.m}{Kg}$$

$$\frac{\delta Pc.\ell.}{\delta Qs} = \frac{8\rho}{\pi ds^2} = 1.61 \times 10^6\ \frac{N\ sec}{m^5}$$

$$\frac{\delta Pc.\ell.}{\delta ds} = -\frac{16\rho Qs}{\pi ds^3} = -3.51 \times 10^4\ \frac{N}{m^3}$$

$$Pc.\ell.'' = 1.07\ N/m^2$$

letting $Y = \frac{G^2 \; Po}{41.0 \; Pc. \ell .} = 0.761$

$$Y'' = \left[ \left(\frac{\delta Y}{\delta G} G''\right)^2 + \left(\frac{\delta Y}{\delta Po} Po''\right)^2 + \left(\frac{\delta Y}{\delta Pc. \ell .} Pc. \ell .\right)^2 \right]^{\frac{1}{2}}$$

$$\frac{\delta Y}{\delta G} = \frac{2GPo}{41.0 \; Pc. \ell .} = 0.055$$

$$\frac{\delta Y}{\delta Po} = \frac{G^2}{41.0 \; Pc. \ell .} = 0.785 \; \frac{m^2}{N}$$

$$\frac{\delta Y}{\delta Pc. \ell .} = - \frac{G^2 Po}{41.0(Pc. \ell .)^2} = - 0.0317 \; \frac{m^2}{N}$$

$$\frac{Y''}{Y} \times 100 = 34\%$$

# APPENDIX C

## EQUIPMENT TABLE

| No. | Equipment | Model/Type | Range | Accuracy | Measurement | Manufacturer/Company |
|---|---|---|---|---|---|---|
| 1 | Dual Beam Oscilloscope | 564 | - | - | Switching times | Tektronix, Inc. Portland, Oregon |
| 2 | Hot-Wire Anemometer | 55M | - | - | " | Disa Elektronik Herlev, Denmark |
| 3 | Measuring Amplifier | 2607 | - | - | Control Sound pressure level | B&K Copenhagen, Denmark |
| 4 | Preamplifier | 2618 | - | - | " | " |
| 5 | Condenser Microphone | 4138 | 70-180 db | ± 1 db. | " | " |
| 6 | Inclined Manometer | 320111 | 0-807 $N/m^2$ | ± 0.5% Full Scale | Output pressure | Wilh. Lambrecht Gottingen, W. Germany |
| 7 | Inclined Manometer | 9845 | 0-7000 $N/m^2$ | ± 0.2% Full Scale | Supply pressure | T.E.M. Instruments Ltd. Crawley; Sussex |
| 8 | Manometer Bank | *ME C406 | 0-9000 $N/m^2$ | ± 0.2% Full Scale | Supply pressure | U. of W. |
| 9 | Rotameter | L10/400-6185 | 0-120x$10^{-6}$ $m^3$/sec | ± 0.2% Full Scale | Supply flow | ROTA Oeflingen Baden |
| 10 | Rotameter | L2.5/100-3458 | 0-33x$10^{-6}$ $m^3$/sec | ± 0.2% Full Scale | " | " |
| 11 | Needle Valve | 1335 G2B 1" Stem | - | - | - | Hoke Inc. Cresshill, N.J. |

| No. | Equipment | Model/Type | Range | Accuracy | Measurement | Manufacturer/Company |
|---|---|---|---|---|---|---|
| 12 | Pressure Regulator | 7266-1 | 0-508 cm. $H_2O$ | - | - | Moore Products<br>Spring House, Pa. |
| 13 | Filter | A-1138-8 | - | - | - | Wilkerson Inc.<br>Englewood, Colorado |
| 14 | 8" Speaker | LS-809-14W | 170-18 KHz | - | - | Marsland Eng. Ltd.<br>Waterloo, ~~Ont~~. |
| 15 | 4" Dome Tweeter | AD.0160/TA | 1 KHz-22 KHz | - | - | DeForest (Philips)<br>Toronto, Ont. |
| 16 | 5" Speaker | AD 5060/S08 | 400-8KHz | - | - | " |
| 17 | Sine Wave Oscillator | 200 CP | 5-600KHz. | 2% | - | Hewlett Packard<br>Loveland, Col. |
| 18 | Electronic Counter | 5221B | 99999 Hz | ± 1 Hz | Control Sound<br>Frequency | Hewlett-Packard |
| 19 | Power Amplifier | ME C515 | 25W. | - | - | U. of W. |
| 20 | Electronic Switch | - | - | - | - | U. of W. |
| 21 | Sound Level Meter | 2204 | 0-20K Hz<br>0-130 db | - | Background<br>noise level | B&K, |
| 22 | Sound Level Calibrator | 4220 | 250 Hz<br>124 db. | ± 0.2db | - | " |

* NOTE: M.E. Number Correspond to the Department Stock Numbers.

## APPENDIX D

## ANALYTICAL METHODS

## APPENDIX D.1

## BELL'S ANALYTICAL PROCEDURE

A general description of the theoretical methods that Bell used is given in Chapter II. In this section, emphasis is given to the usage of the standard mathematical relationships, given by Bell in Ref. 12 for determining the characteristics of the unshrouded turbulence amplifier. In the following analysis it is assumed that ds, g, Ps, and $\ell s$ are known.

(1) Estimate Qs from

$$Qs = \frac{\pi ds^4 Ps}{128 \mu \ell s} \qquad D.1.1$$

(2) Calculate $\frac{Re}{Ls}$ from

$$\frac{Re}{Ls} = \frac{4Qs}{\pi \ell s \nu} \qquad D.1.2$$

(3) Find $\frac{Pc\ell}{Ps}$ using Table D.1.1 (Ref. 12) shown on the next page.

$\frac{Ps}{Pc\ell}$ can be found by adding 1 to $\frac{\Delta P}{1/2 \rho Us^2}$ to include the non-dimensional Bernouli pressure drop incured by the fluid passing from the settling chamber into the tube through a bellmouth entrance. $\frac{Pc\ell}{Ps}$ is then found by inverting these values and interpolating for the particular $\frac{Re}{Ls}$ found from step 2.

(4) $\lambda_o$ is found by interpolating the R=0 column of Table D.1.1 for the particular value of $\frac{Re}{Ls}$ mentioned previously.

(5) Calculate $Pc\ell$ from

$$Pc\ell = 0.5\rho\left(\frac{4\lambda_o Qs}{\pi ds^2}\right)^2 \qquad D.1.3$$

$R = \dfrac{r}{(ds/2)}$ $\qquad \lambda = \dfrac{U(R)}{(4Q_s/\pi ds^2)}$

| Re/Ls | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 | 1 | $\frac{\Delta P}{\frac{1}{2}\rho U_s^2}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 0.0000 | 0.0000 |
| 2000.0 | 1.1503 | 1.1503 | 1.1503 | 1.1503 | 1.1503 | 1.1503 | 1.1502 | 1.1485 | 1.1293 | 0.8434 | 0.0000 | 0.3220 |
| 800.0 | 1.2269 | 1.2269 | 1.2269 | 1.2269 | 1.2268 | 1.2264 | 1.2230 | 1.2016 | 1.0950 | 0.6893 | 0.0000 | 0.5034 |
| 400.0 | 1.3126 | 1.3126 | 1.3125 | 1.3124 | 1.3115 | 1.3068 | 1.2867 | 1.2144 | 1.0098 | 0.5908 | 0.0000 | 0.7204 |
| 267.0 | 1.3782 | 1.3781 | 1.3779 | 1.3770 | 1.3733 | 1.3596 | 1.3160 | 1.2000 | 0.9511 | 0.5417 | 0.0000 | 0.8960 |
| 200.0 | 1.4337 | 1.4331 | 1.4324 | 1.4299 | 1.4214 | 1.3959 | 1.3292 | 1.1814 | 0.9107 | 0.5102 | 0.0000 | 1.0505 |
| 133.0 | 1.5239 | 1.5232 | 1.5204 | 1.5120 | 1.4902 | 1.4395 | 1.3349 | 1.1476 | 0.8585 | 0.4720 | 0.0000 | 1.3217 |
| 100.0 | 1.5977 | 1.5960 | 1.5893 | 1.5727 | 1.5358 | 1.4623 | 1.3308 | 1.1218 | 0.8261 | 0.4496 | 0.0000 | 1.5610 |
| 80.0 | 1.6595 | 1.6562 | 1.6448 | 1.6188 | 1.5675 | 1.4751 | 1.3245 | 1.1023 | 0.8040 | 0.4346 | 0.0000 | 1.7827 |
| 57.1 | 1.7555 | 1.7488 | 1.7269 | 1.6831 | 1.6073 | 1.4874 | 1.3125 | 1.0757 | 0.7756 | 0.4159 | 0.0000 | 2.1400 |
| 44.4 | 1.8240 | 1.8142 | 1.7829 | 1.7244 | 1.6306 | 1.4927 | 1.3034 | 1.0588 | 0.7584 | 0.4047 | 0.0000 | 2.5692 |
| 33.3 | 1.8920 | 1.8785 | 1.8366 | 1.7626 | 1.6509 | 1.4962 | 1.2943 | 1.0433 | 0.7429 | 0.3947 | 0.0000 | 3.1064 |
| 25.0 | 1.9431 | 1.9266 | 1.8763 | 1.7901 | 1.6650 | 1.4981 | 1.2875 | 1.0321 | 0.7319 | 0.3877 | 0.0000 | 3.7894 |
| 20.0 | 1.9698 | 1.9517 | 1.8969 | 1.8042 | 1.6721 | 1.4990 | 1.2840 | 1.0264 | 0.7263 | 0.3840 | 0.0000 | 4.4520 |
| 16.0 | 1.9863 | 1.9672 | 1.9095 | 1.8128 | 1.6764 | 1.4996 | 1.2818 | 1.0229 | 0.7229 | 0.3818 | 0.0000 | 5.2688 |
| 0.0 | 2.0000 | 1.9800 | 1.9200 | 1.8200 | 1.6800 | 1.5000 | 1.2800 | 1.0200 | 0.7200 | 0.3800 | 0.0000 | $\infty$ (5.2688) |

NOTE: The value of $\frac{\Delta P}{\frac{1}{2}\rho U_s^2}$ given by Bell for $\frac{Re}{Ls} = 0$ is shown in brackets. This value must be infinity as can be easily seen by considering the cases of Ls and Re approaching infinity and zero respectively.

r is the radial distance from the centre of the tube

TABLE D.1.1 HORNBECK'S SOLUTION FOR PRESSURE DROPS IN DEVELOPING FLOW THROUGH TUBES

(6) Calculate Ps estimate from

$$Ps\ estimate = \frac{step\ 6}{step\ 4} \qquad D.I.4$$

(7) Compare Ps estimate to Ps. If they are not equal within certain error bounds guess a new value of Qs and return to Step 3. If they are equal the values of Qs, $\frac{Re}{Ls}$, $\frac{Pc\ell}{Ps}$, $Pc\ell$, $\lambda o$ are determined.

This portion of Bell's procedure was used to determine the theoretical line shown in Fig. 8.

(8) Calculate $\beta$ from Table D.I.1 by interpolating $\lambda$'s for $0<R<1.0$ at $\frac{Re}{Ls}$ from step 7 and numerically integrating these $\lambda$'s over $0<R<1.0$.

(9) Calculate K from

$$K = \frac{32\lambda o}{3\beta} \qquad D.I.5$$

(10) Calculate G from

$$G = \frac{g}{ds} \qquad D.I.6$$

(11) Calculate $\frac{Po}{Pc\ell}$ from

$$\frac{Po}{Pc\ell} = \frac{1}{\left(\frac{KG}{Re}+1\right)^2} \qquad D.I.7$$

(12) Calculate Po from

$$Po = (step\ 11) \times (Step\ 7) \qquad D.I.8$$

This value of Po with the value of Ps in step 7 were used to plot the theoretical lines in Fig. 9.

(13) Calculate $\frac{Re}{KGLs}$ from

$$\frac{Re'}{KGLs} = \frac{(\text{step } 7)}{(\text{step } 10)\ (\text{step } 9)} \qquad \text{D.1.9}$$

This value along with $\frac{Po}{Ps}$ from Step 7 were used to plot the theoretical lines in Fig. 10.

(14) Calculate Poturb from

$$Poturb = \frac{41.0\,\beta\, Pc\ell}{G^2\,\lambda o^2} \qquad \text{D.1.10}$$

This value was used to plot the theoretical lines in Fig. 13.

(15) Calculate $\frac{G^2Po}{41.Pc\ell}$ from

$$\frac{G^2Po}{41.Pc\ell} = \frac{\beta}{(\text{step } 14)\lambda o^2} \qquad \text{D.1.11}$$

This value was used to plot the theoretical line in Fig. 17.

The program that is used to perform the previous computations is given in the remainder of this section.

```
C    ****************************************************************************
C    BELL'S ANALYTICAL PROCEDURE (MAIN PROGRAM)
C    ****************************************************************************
C    ****************************************************************************
C    ****************************************************************************
C    ****************************************************************************
C    ****************************************************************************
      REAL K,LAMDA
      DIMENSION RE(16)
      EXTERNAL LAMDA,PEST,BETA
      COMMON REL
      READ 1 , EL , G ,D
    1 FORMAT ( 3F10.5 )
      G = G / 12.
      D = D / 12.0
      EL= EL / 12.0
      GG=G*2.54
      DD=D*2.54
      EELL=EL*2.54
      GE = G / D
      ELL = EL / D
      PRINT 100,DD,GG,ELL
  100 FORMAT('1','DIAMETER = ',F10.3,5X,'GAP = ',F10.3,5X,'L/D = ',
     1 F10.2)
      PRINT 200
  200 FORMAT('0',2X,'    Q     ',3X,'  REY   ',3X,'  REL   ',3X,' LAMDA  '
     1,3X,'   K    ',3X,'  POPS  ',3X,'    PS  ',3X,' REOKGL '/'0',
     2 'POTURB',2X,'TURB')
   10 READ 2, PS
    2 FORMAT ( F10.5 )
      IF(PS.EQ.0.0) GO TO 999
      PS=PS/248.142
      PS= PS / 12.0
      CALL PSTHEO( D , EL , PS , Q , REL , AMDA , PCLPS , PCL )
      REY = REL * EL / D
      B = BETA( LAMDA )
      K = 32.0 * AMDA / ( 3.0 * B)
      REOKG = REY / ( K * GE )
      POPCL = 1.0 / ( ( 1.0 / REOKG ) + 1.0 ) ** 2
      PO = POPCL * PCL
      PS = PS * 12.
      PCL = PCL * 12.
      PO = PO * 12.
C   PO , PS , PCL  IN INCHES OF WATER
      Q = Q * 28316.8 * 60.
C   Q IN CC / MIN
      PO=PO*248.142
      PS=PS*248.142
      PCL=PCL*248.142
      REOKGL=REOKG/ELL
      POPS=PO/PS
      YYY=GE**0.27*POPS
      POTURB=(B*41.0*PCL)/(GE*AMDA)**2.0
      TURB=B/AMDA**2.0
      Q=Q/60.
C   Q IN CC/SEC
      PRINT 4,Q,REY,REL,AMDA,K,POPS,YYY,PS,REOKGL,POPCL,PO
    4 FORMAT( 11 ( 2X , E8.3 ) )
      PRINT 5,POTURB,TURB,B
    5 FORMAT(' ',3F10.3)
      GO TO 10
  999 STOP
      END
```

```
      FUNCTION BETA( LAMDA )
      COMMON REL
      DIMENSION RE(16)
      REAL  LAMDA
      A=0.0
      B=1.0
      N=10
      H = 0.1
      SUM = 0.0
      K = N - 1
      DO 6 I = 1,K
    6 SUM = SUM + LAMDA(        A + I * H )
      BETA = ( LAMDA( A ) + LAMDA( B ) + 2.0 * SUM ) * ( H / 2.0 )
      RETURN
      END


      SUBROUTINE PSTHEO( D , EL , PS , Q , A    , AMDA , PCLPS , PCL )
      COMMON  REL
      DIMENSION RE(16)
      REAL LAMDA
      N = 0
      Q = 3.14159 * D ** 4 * PS * 0.4335 * 144. * 32.2 / ( 128. *
     1 0.1468E-04 * EL )
C   Q IN FEET**3 / SEC
   20 CONTINUE
      REL = 4.0 * Q / ( 3.14159 * EL * 1.55E-04 )
      PCLPS = PEST(REL)
      PCL = ( 8.0 * 0.0750 * ( LAMDA(0.0) * Q / ( 3.14159 * D ** 2 ) )
     1 ** 2 ) * 0.192227 / ( 12. * 32.2 )
      P1 = PCL / PCLPS
C   PCL , P1 , PS   IN FEET OF WATER
      IF ( PS - P1 .GT..0001 .AND. N .EQ. 0 ) GO TO 25
      IF(P1 - PS .GT..0001 .AND. N .EQ. 0 ) GO TO 26
      IF ( N .EQ. 0 ) GO TO 99
      IF ( PS - P1 .GT..0001 .AND. N .NE. 0 ) GO TO 27
      IF(P1 - PS .GT..0001 .AND. N .NE. 0 ) GO TO 28
      GO TO 99
   25 QRIT = 2.0 * Q
      QLEFT = Q
      GO TO 30
   26 QRIT = Q
      QLEFT = 0.0
      GO TO 30
   27 QLEFT = Q
      GO TO 30
   28 QRIT = Q
      GO TO 30
   30 Q = ( QLEFT + QRIT ) / 2.0
      N = N + 1
      GO TO 20
   99 CONTINUE
      A = REL
      AMDA = LAMDA( 0.0 )
      RETURN
      END
```

```
101   REAL FUNCTION LAMDA ( R )
102   REAL RE(16) ,     M(16,11) , RR(11)
103   COMMON REL
104   DATA RE/0.0,16.0,20.0,25.0,33.3,44.4,57.1,80.0,100.0,133.0,
      1 200.0,267.0,400.0,800.0,2000.0,9999.9/
105   DATA RR/0.0,0.1,0.2,0.3,0.4,0.5,0.6,0.7,0.8,0.9,1.0/
106   DATA M(1,1),M(2,1),M(3,1),M(4,1),M(5,1),M(6,1),M(7,1),M(8,1),
      1 M(9,1),M(10,1),M(11,1),M(12,1),M(13,1),M(14,1),M(15,1),M(16,1)/
      2                          2.0000,1.9863,1.9698,1.9431,1.8920,
      3 1.8240,1.7555,1.6595,1.5977,1.5239,1.4332,1.3782,1.3126,1.2269,
      4 1.1503,1.0000/
107   DATA M(1,2),M(2,2),M(3,2),M(4,2),M(5,2),M(6,2),M(7,2),M(8,2),
      1 M(9,2),M(10,2),M(11,2),M(12,2),M(13,2),M(14,2),M(15,2),M(16,2)/
      2                          1.9600,1.9672,1.9517,1.9266,1.8785,
      3 1.8142,1.7488,1.6562,1.5960,1.5232,1.4331,1.3781,1.3126,1.2269,
      4 1.1503,1.0000  /
108   DATA M(1,3),M(2,3),M(3,3),M(4,3),M(5,3),M(6,3),M(7,3),M(8,3),
      1 M(9,3),M(10,3),M(11,3),M(12,3),M(13,3),M(14,3),M(15,3),M(16,3)/
      2                          1.9200,1.9095,1.8969,1.8763,1.8366,
      3 1.7829,1.7269,1.6448,1.5893,1.5204,1.4324,1.3779,1.3125,
      4 1.2269,1.1503,1.0000 /
109   DATA M(1,4),M(2,4),M(3,4),M(4,4),M(5,4),M(6,4),M(7,4),M(8,4),
      1 M(9,4),M(10,4),M(11,4),M(12,4),M(13,4),M(14,4),M(15,4),M(16,4)/
      2                          1.8200,1.8128,1.8042,1.7901,1.7626,
      31.7244,1.6821,1.6188,1.5727,1.5120,1.4299,1.3770,1.3124,1.2269,
      4 1.1503,1.0000/
110   DATA M(1,5),M(2,5),M(3,5),M(4,5),M(5,5),M(6,5),M(7,5),M(8,5),
      1 M(9,5),M(10,5),M(11,5),M(12,5),M(13,5),M(14,5),M(15,5),M(16,5)/
      2                          1.6800,1.6764,1.6721,1.6650,1.6509,
      3 1.6306,1.6073,1.5675,1.5358,1.4902,1.4214,1.3733,1.3115,1.2268,
      4 1.1503,1.0000/
111   DATA M(1,6),M(2,6),M(3,6),M(4,6),M(5,6),M(6,6),M(7,6),M(8,6),
      1 M(9,6),M(10,6),M(11,6),M(12,6),M(13,6),M(14,6),M(15,6),M(16,6)/
      2                          1.5000,1.4996,1.4990,1.4981,1.4962,
      3 1.4927,1.4874,1.4751,1.4623,1.4395,1.3959,1.3596,1.3068,1.2264,
      4 1.1503,1.0000/
112   DATA M(1,7),M(2,7),M(3,7),M(4,7),M(5,7),M(6,7),M(7,7),M(8,7),
      1 M(9,7),M(10,7),M(11,7),M(12,7),M(13,7),M(14,7),M(15,7),M(16,7)/
      2                          1.2800,1.2818,1.2840,1.2875,1.2913,
      3 1.3034,1.3125,1.3245,1.3308,1.3349,1.3292,1.3160,1.2867,1.2230,
      4 1.1502,1.0000/
113   DATA M(1,8),M(2,8),M(3,8),M(4,8),M(5,8),M(6,8),M(7,8),M(8,8),
      1 M(9,8),M(10,8),M(11,8),M(12,8),M(13,8),M(14,8),M(15,8),M(16,8)/
      2                          1.0200,1.0229,1.0264,1.0321,1.0433,
      3 1.0588,1.0757,1.1023,1.1218,1.1476,1.1814,1.2000,1.2144,1.2016,
      4 1.1485,1.0000/
114   DATA M(1,9),M(2,9),M(3,9),M(4,9),M(5,9),M(6,9),M(7,9),M(8,9),
      1 M(9,9),M(10,9),M(11,9),M(12,9),M(13,9),M(14,9),M(15,9),M(16,9)/
      2                          0.7200,0.7229,0.7263,0.7319,0.7429,
      3 0.7584,0.7756,0.8040,0.8261,0.8585,0.9107,0.9511,1.0098,1.0950,
      4 1.1293,1.0000/
115   DATA  M(1,10),M(2,10),M(3,10),M(4,10),M(5,10),M(6,10),M(7,10),
      1M(8,10),M(9,10),M(10,10),M(11,10),M(12,10),M(13,10),M(14,10),
      2 M(15,10),M(16,10)/
      3                          0.3800,0.3818,0.3840,0.3877,0.3947,
      40.4047,0.4159,0.4346,0.4496,0.4720,0.5106,0.5417,0.5908,0.6893,
      5 0.8434,1.0000/
116   DATA M(1,11),M(2,11),M(3,11),M(4,11),M(5,11),M(6,11),M(7,11),
      1M(8,11),M(9,11),M(10,11),M(11,11),M(12,11),M(13,11),M(14,11),
      2 M(15,11),M(16,11)/
```

```
     3                                    0.0000,0.0000,0.0000,0.0000,0.0000,
     40.0000,0.0000,0.0000,0.0000,0.0000,0.0000,0.0000,0.0000,0.0000,
     5 0.0000,0.0000/
      NDIM = 15
      MDIM = 10
      DO 1 I = 1 , NDIM
      IF( REL .LT. RE( I + 1 ) .OR. I .EQ. NDIM ) GO TO 2
    1 CONTINUE
    2 DO 3 J = 1 , MDIM
      IF( R .LT. RR(J+1) .OR. J .EQ. MDIM ) GO TO 4
    3 CONTINUE
    4 ALPHA = ( REL - RE(I) ) / ( RE(I+1) - RE(I) )
      BETA = ( R - RR(J) ) / ( RR(J+1) - RR(J) )
      LAMDA = ( 1.0 - ALPHA ) * ( 1.0 - BETA ) *       M(I,J) +
     1 BETA * ( 1.0 - ALPHA ) *       M(I,J+1) + ALPHA * ( 1.0 - BETA )
     2 *       M(I+1,J) + ALPHA * BETA *       M(I+1,J+1)
      RETURN
      END
```

```
      FUNCTION  PEST ( REL )
      DIMENSION P(19),RE(19)
      DATA RE/0.0,5.5,10.0,12.5,16.0,20.0,25.0,33.3,44.4,57.1,80.0,
     1 100.0,133.0,200.0,267.0,400.0,800.0,2000.0,1E11/
      DATA P/0.000,0.244,0.420,0.511,0.629,0.712,0.788,0.872,0.932,
     1 0.966,0.990,0.997,1.000,1.002,1.002,1.001,1.001,1.00,1.00/
      NDIM = 18
      DO 1 I = 1 , NDIM
      IF( REL .LT. RE(I+1) .OR. I .EQ. NDIM ) GO TO 2
    1 CONTINUE
    2 PEST = P(I) + ( REL - RE(I) ) * ( P(I+1) - P(I) ) / ( RE(I+1)
     1 - RE(I) )
      RETURN
      END
```

## APPENDIX D.2

## HAYES' THEORETICAL SWITCHING TIMES

Hayes (Ref. 13) derived theoretical relationships to describe the various switching times associated with the turbulence amplifier. He assumed that the velocity profile at the emitter exit was parabolic. Schlichting's point source model (Ref. 34) was used with centerline velocity matching, to model the laminar jet. To obtain an estimate of the "so called" inviscid core length $\ell_{i.c.}$, he assumed similarity between planar and axisymmetric free laminar jet spreading and "so called" inviscid core length. He also assumed that the control action was concentrated at the point where the control jet hit the supply jet. Such an assumption is not realized in the present case and therefore the control action was assumed to occur at the jet exit. The equations obtained are shown below converted to the terms used in the present investigation.

$$Xo = 0.0624 \; ds \; Re \qquad \text{---D.2.1.}$$

$$\ell i.c. = 0.00762 \; ds \; Re \qquad \text{---D.2.2}$$

$$T\ell.d. = Tt.d. = \frac{\ell i.c.}{2Us} + \frac{g - \ell i.c.}{2Xo \; Us}\left[Xo + \frac{g - \ell i.c.}{2}\right] \qquad \text{--D.2.3.}$$

$$Tr. = Tf. = \frac{1.10g}{2Us} \qquad \text{---D.2.4.}$$

APPENDIX D.3

ABRAMOVICH'S EMPIRICAL SWITCHING TIMES

Abramovich (Ref. 1) found experimental correlations for the switching times of the laminar jet. The definitions for $T_{\ell.d.}$, Tf. and Tt.d. are similar to those of the present study. the rise time is based on 70% of the particular velocity rise. Since the velocity versus the time in this region was approximated by a straight line the time corresponds to 70% of the Tr. definition used in the present study. The empirical equations for the switching times converted to account for the present definition are given below.

$$T = \left[ A \frac{G^2}{Re} + B \frac{G^2}{Re} \right] \frac{ds^2}{2\nu\sqrt{Re}} \qquad \text{---D.3.1.}$$

| | A | B |
|---|---|---|
| Tt.d. | 1.58 | 1.48 |
| Tr. | 0.39 | 0.17 |
| $T_{\ell}$.d. | 0.60 | 0.76 |
| Tf. | 0.60 | 1.20 |

## APPENDIX D.4

## ALSTER'S HELMHOLTZ FORMULA

The equations that were given by Alster (Ref. 2) to predict the resonant frequency of a circular cylinder with a centered lateral hole are given on the next page and the computer program used to calculate the resonant frequency follows in the remainder of this section.

$$f = \frac{c}{2\pi}\sqrt{\frac{An}{1.21(Vc+Vn)\left\{\left(\frac{Vc}{Vc+Vn+V_{o1}}\right)\left(\frac{h}{h+\ell n+\ell_{o1}}\right)\left[\ell v+(\ell n+\ell_{o1})\left(1+1/2\left[\frac{(Vn+V_{o1})}{Vc}+\frac{\ell n+\ell_{o1}}{h}\right]+1/3\,\frac{Vn+V_{o1}}{Vc}\,\frac{\ell n+\ell_{o1}}{h}\right)+\ell_{o2}\right]\right\}}} \qquad \text{-------D.41}$$

where:

$v$ = form factor

$$= \frac{\pi\, dn^2}{8hVc}\left[\frac{h^3}{3}-\frac{dc^2 h}{8}-\frac{\pi dc^2}{4}\left(\sqrt{dch-h^2}+\frac{h^{1.5}}{3\sqrt{dc/2}}\right)+\frac{dc^3}{8}\left(4.88+\sin^{-1}\left(\frac{2h-dc}{dc}\right)\right)\right]$$

$h$ = effective depth of the chamber

$$= 1/2\left(dc+\sqrt{dc^2-dn^2}\right)$$

$Vc$ = effective volume of the chamber

$$= \frac{\ell c}{2}\left[dn\sqrt{dc^2-dn^2}+\frac{dn^2}{2}\sin^{-1}\sqrt{\frac{1}{2}\left(\frac{dc^2+dn^2}{dc}\right)}+\frac{dc^2}{8\pi}\right]$$

$\ell o1 + \ell o2$ = two parts of the total end correction factor due to the motion of the gas outside the resonator empirically determined to be $\ell_{o1} = \ell_{o2} = 0.24$

$V_{o1} = An\,\ell_{o1}$

```
      DIMENSION FF(10)
    5 CONTINUE
      READ 100,DC,EEL,DH,EELN
  100 FORMAT(4F10.5)
      NNN=1
      IF(DC.GT.2.0)GO TO 999
    6 CONTINUE
      IF(NNN.EQ.3) GO TO 10
      IF(NNN.GT.3) GO TO 30
      RC=DC*2.54/2.0
      RH=DH*2.54/2.0
      EL=EEL*2.54
      ELN=EELN*2.54
      C=344.0E02
      H=RC+SQRT(RC**2.0-RH**2.0)
      V1=RC**2.0*3.14159/2.0
      V2=RC**2.0*ARSIN((SQRT(RC**2.0-RH**2.0))/RC)
      V3=RH*SQRT(RC**2.0-RH**2.0)
      V=EL*(V1+V2+V3)
      ELV1=RC**3.0*(4.88+3.14159*ARSIN((H-RC)/RC))
      ELV2=3.14159*RC**2.0*(SQRT(2.0*RC*H-H**2.0)+(H**1.5/3.0/SQRT(RC)))
      ELV3=RC**2.0*H/2.0
      ELV4=H**3.0/3.0
      ELV=3.14159*RH**2.0*(ELV1-ELV2-ELV3+ELV4)/2.0/H/V
      IF(NNN.EQ.2) ELV=1.88*RH**2.0/EL
      GO TO 20
   10 CONTINUE
      RH=0.070*2.54
      H=EL
      ELN=0.1875*2.54
      ELV=(RH/RC)**2.0*H/3.0
   20 CONTINUE
      ELO1=0.24*RH
      ELO2=0.24*RH
      FN=3.14159*RH**2.0
      VO1=FN*ELO1
      VN=FN*ELN
      F1=(VN+VO1)/V
      F2=(ELN+ELO1)/H
      F3=(1.0+0.5*(F1+F2)+F1*F2/3.0)*(ELN+ELO1)
      F4=ELV+F3
      F5=V/(V+VN+VO1)
      F6=H/(H+ELN+ELO1)
      F7=F5*F6*F4+ELO2
      F8=1.21*(V+VN)*F7
      F=C*SQRT(FN/F8)/2.0/3.14159
      FF(NNN)=F
      NNN=NNN+1
      GO TO 6
   30 CONTINUE
      PRINT 200,DC,EEL,DH,EELN,FF(1),FF(2),FF(3)
  200 FORMAT(' ',7F11.5)
      GO TO 5
  999 CONTINUE
      STOP
      END
```

# APPENDIX E

## EXPERIMENTAL DATA

In general the significant figures shown in the following tables are more than those claimed on the basis of the Uncertainty Analysis (Appendix B).

## APPENDIX E.1

## OUTPUT PRESSURE VS. SUPPLY PRESSURE

d c = 0.95 cm.

| | $P_s$ ($N/m^2$) | Po ($N/m^2$) | $Q_s$ ($m^3/sec. \times 10^6$) |
|---|---|---|---|
| g = 1.27 cm | 248.1 | 23.4 | 6.7 |
| | 440.5 | 78.3 | 10.3 |
| Ta = 23.9°C | 663.8 | 174.3 | 14.9 |
| | 1[illegible]8.0 | 415.6 | 22.3 |
| Pa = 748.28 mm. Hg. | 1693.6 | 831.3 | 30.5 |
| | 2024.4 | 1093.0 | 35.0 |
| | 2528.7 | 1492.7 | 40.6 |
| B.N.L. = 66db | 2813.3 | 1729.8 | 43.3 |
| | 3079.4 | 1862.9 | 46.1 |
| | 3288.5 | 2081.5 | 48.3 |
| | 3592.7 | 2262.0 | 51.1 |
| | 3847.4 | 2250.2 | 53.3 |
| | 4080.6 | 1865.4 | 55.6 |
| g = 2.54 cm. | 217.1 | 9.7 | 6.0 |
| | 378.4 | 41.7 | 8.8 |
| Ta = 23.90°C | 558.3 | 94.4 | 12.6 |
| | 744.4 | 175.9 | 16.4 |
| Pa = 749.3 mm. Hg. | 986.4 | 288.9 | 20.2 |
| | 1116.6 | 371.2 | 22.5 |
| | 1129.0 | 379.3 | 22.7 |
| | 1172.5 | 282.4 | 23.3 |
| B.N.L. = 660 db. | 1246.9 | 262.3 | 24.7 |
| | 1420.6 | 161.4 | 27.4 |
| | 1780.4 | 181.6 | 31.8 |
| g = 3.81 cm. | 223.3 | 7.3 | 6.0 |
| | 304.0 | 16.9 | 8.0 |
| Ta = 23.9°C | 440.5 | 44.4 | 10.3 |
| | 545.9 | 75.1 | 12.6 |
| Pa = 75.84 mm. Hg. | 663.8 | 113.0 | 14.9 |
| | 707.2 | 125.9 | 15.6 |
| | 719.6 | 128.3 | 15.9 |
| B.N.L. = 68 db. | 750.6 | 113.0 | 16.4 |
| | 787.8 | 76.7 | 17.2 |
| | 837.5 | 70.2 | 17.9 |
| | 893.3 | 70.2 | 18.7 |
| | 980.2 | 70.2 | 20.2 |
| | 1073.2 | 71.8 | 21.7 |

dc = 1.27 cm.

| | $P_s$ $(N/m^2)$ | $P_o$ $(N/m^4)$ | $Q_s$ $(m^3/sec. \times 10^6)$ |
|---|---|---|---|
| g = 1.27 cm. | 246.1 | 21.7 | 6.9 |
| | 441.3 | 76.4 | 10.5 |
| Ta = 24.4°C | 666.2 | 174.0 | 15.0 |
| | 942.1 | 331.0 | 19.7 |
| Pa = 745.45 | 1200.9 | 492.2 | 24.1 |
| mm. Hg. | 1681.2 | 825.1 | 30.2 |
| | 1910.7 | 1005.0 | 32.8 |
| B.N.L. = 68 | 1985.1 | 1067.0 | 33.9 |
| db. | 2158.8 | 1203.5 | 35.6 |
| | 2289.1 | 1308.9 | 37.2 |
| | 2444.2 | 1445.4 | 38.9 |
| | 2632.7 | 1615.7 | 41.1 |
| | 2704.8 | 1748.8 | 42.8 |
| | 2955.9 | 1891.4 | 44.4 |
| | 3165.0 | 2081.5 | 46.7 |
| | 3326.5 | 2224.0 | 48.3 |
| | 3509.3 | 2378.4 | 50.0 |
| | 3602.6 | 2425.0 | 50.8 |
| | 3707.5 | 2355.1 | 51.7 |
| | 3905.7 | 1970.3 | 53.3 |
| | 4094.3 | 1774.7 | 55.0 |
| | 4181.7 | 1885.9 | 56.1 |
| g = 2.54 cm. | 210.9 | 19.7 | 6.0 |
| | 372.7 | 38.7 | 8.8 |
| Ta = 25.6°C | 545.9 | 95.7 | 12.6 |
| | 732.0 | 172.7 | 16.2 |
| Pa = 751.08 | 967.8 | 290.5 | 20.2 |
| mm. Hg. | 1203.5 | 435.8 | 24.0 |
| | 1464.0 | 605.2 | 27.9 |
| B.N.L. = 65db. | 1532.3 | 645.6 | 28.4 |
| | 1772.1 | 443.8 | 31.8 |
| | 2168.5 | 334.9 | 36.1 |
| | 2658.2 | 351.0 | 41.7 |
| | 210.9 | 5.6 | 6.0 |
| g = 3.81 cm. | 372.2 | 27.4 | 8.8 |
| | 545.9 | 73.4 | 12.6 |
| Ta = 26.7°C | 632.8 | 92.8 | 14.1 |
| | 707.2 | 101.7 | 15.6 |
| Pa = 749.55 | 744.4 | 119.4 | 16.4 |
| mm. Hg. | 794.1 | 113.8 | 17.2 |
| | 893.3 | 117.0 | 18.7 |
| B.N.L. = 66 | 930.5 | 111.4 | 19.4 |
| db. | 1029.8 | 103.2 | 20.9 |
| | 1166.3 | 95.2 | 23.2 |
| | 1315.2 | 87.2 | 25.5 |
| | 1538.5 | 79.9 | 28.7 |
| | 1799.0 | 76.7 | 31.8 |
| | 2098.6 | 82.3 | 35.0 |

dc = 2.54 cm.

| | $P_s$ ($N/m^2$) | $P_o$ ($N/m^2$) | $Q_s$ ($m^3/sec. \times 10^6$) |
|---|---|---|---|
| g = 1.27 cm. | 372.2 | 55.8 | 8.8 |
| Ta = 23.9°C | 744.4 | 210.9 | 16.4 |
| Pa = 751.84 mm. Hg. | 1203.5 | 477.7 | 24.0 |
| B.N.L.=68 db. | 1799.0 | 905.7 | 32.2 |
| | 2052.9 | 1112.0 | 35.0 |
| | 2290.6 | 1207.1 | 37.8 |
| | 2556.7 | 1444.7 | 40.6 |
| | 2813.3 | 893.4 | 43.3 |
| | 3069.9 | 1045.5 | 46.1 |
| g = 2.54cm. | 217.1 | 8.1 | 6.0 |
| Ta = 21.7°C | 366.0 | 37.1 | 8.8 |
| Pa = 749.81 mm. Hg. | 545.9 | 90.4 | 12.6 |
| B.N.L.= 67 db. | 744.4 | 171.1 | 16.4 |
| | 967.8 | 282.4 | 20.2 |
| | 1197.3 | 411.6 | 24.0 |
| | 1488.9 | 585.1 | 27.9 |
| | 1526.1 | 609.3 | 28.5 |
| | 1650.1 | 363.1 | 30.2 |
| | 2053.4 | 306.7 | 35.0 |
| | 2338.1 | 262.3 | 37.8 |
| | 2841.8 | 238.1 | 43.3 |
| | 3346.1 | 262.3 | 48.9 |
| g = 3.81cm. | 217.1 | 4.0 | 6.0 |
| Ta = 24.4°C | 372.2 | 26.6 | 8.8 |
| Pa = 748.54 mm. Hg. | 539.7 | 72.6 | 12.6 |
| B.N.L.=67 db. | 663.8 | 113.0 | 14.9 |
| | 787.8 | 164.6 | 17.2 |
| | 936.7 | 227.6 | 19.4 |
| | 1073.2 | 302.6 | 21.8 |
| | 1209.7 | 367.2 | 24.1 |
| | 1308.9 | 411.6 | 25.5 |
| | 1333.8 | 435.8 | 26.8 |
| | 1470.2 | 403.5 | 27.6 |
| | 1581.9 | 246.1 | 29.0 |
| | 1823.8 | 157.4 | 32.3 |
| | 2009.9 | 125.1 | 34.4 |
| | 2300.1 | 88.8 | 37.8 |
| | 2822.8 | 80.7 | 43.3 |
| | 3326.5 | 76.7 | 48.9 |

# APPENDIX E.2

## OUTPUT PRESSURE VS. SOUND VARIABLES

dc = 0.95 cm. $P_s$ = 660 N/$m^2$

g = 1.27 cm. $Q_s$ = $14.9 \times 10^{-6}$ $m^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) |
|---|---|---|---|---|---|---|
| 90 | 180.000 | 174.300 | 2300.000 | 174.300 | 8300.000 | 174.300 |
| | 500.000 | 174.300 | 2900.000 | 174.300 | 11400.000 | 174.300 |
| | 900.000 | 174.300 | 3700.000 | 174.300 | 14750.000 | 174.300 |
| | 1200.000 | 174.300 | 4500.000 | 174.300 | 16650.000 | 174.300 |
| | 1500.000 | 174.300 | 6900.000 | 174.300 | 18000.000 | 174.300 |
| 100 | 170.000 | 174.300 | 1947.000 | 158.200 | 2500.000 | 174.300 |
| | 520.000 | 174.300 | 1958.000 | 156.600 | 2800.000 | 174.300 |
| | 770.000 | 174.300 | 1970.000 | 154.900 | 4850.000 | 174.300 |
| | 990.000 | 174.300 | 1982.000 | 153.300 | 5700.000 | 174.300 |
| | 1150.000 | 174.300 | 1997.000 | 156.600 | 8300.000 | 174.300 |
| | 1450.000 | 174.300 | 2010.000 | 159.800 | 9400.000 | 174.300 |
| | 1550.000 | 174.300 | 2035.000 | 163.000 | 11900.000 | 174.300 |
| | 1770.000 | 174.300 | 2070.000 | 167.900 | 14600.000 | 174.300 |
| | 1800.000 | 172.700 | 2096.000 | 169.500 | 16000.000 | 174.300 |
| | 1848.000 | 171.100 | 2122.000 | 171.100 | 18000.000 | 174.300 |
| | 1888.000 | 167.900 | 2172.000 | 172.700 | | |
| | 1928.000 | 161.400 | 2234.000 | 174.300 | | |
| 110 | 180.000 | 174.300 | 1909.000 | 88.800 | 2668.000 | 164.600 |
| | 450.000 | 174.300 | 1924.000 | 80.700 | 2734.000 | 169.500 |
| | 700.000 | 174.300 | 1938.000 | 72.600 | 2771.000 | 171.100 |
| | 900.000 | 174.300 | 1958.000 | 66.200 | 2817.000 | 171.100 |
| | 1000.000 | 174.300 | 1960.000 | 64.600 | 2849.000 | 171.100 |
| | 1200.000 | 174.300 | 1979.000 | 59.700 | 2878.000 | 172.700 |
| | 1400.000 | 174.300 | 1989.000 | 62.900 | 2912.000 | 172.700 |
| | 1500.000 | 174.300 | 2004.000 | 71.000 | 2961.000 | 172.700 |
| | 1591.000 | 172.700 | 2021.000 | 79.100 | 3113.000 | 174.300 |
| | 1625.000 | 171.100 | 2053.000 | 93.600 | 3245.000 | 174.300 |
| | 1682.000 | 169.500 | 2077.000 | 108.100 | 3352.000 | 174.300 |
| | 1720.000 | 163.000 | 2126.000 | 122.700 | 3500.000 | 174.300 |
| | 1749.000 | 154.900 | 2182.000 | 135.600 | 4800.000 | 174.300 |
| | 1780.000 | 154.900 | 2222.000 | 145.300 | 7600.000 | 174.300 |
| | 1806.000 | 146.900 | 2301.000 | 146.900 | 8500.000 | 174.300 |
| | 1828.000 | 140.400 | 2393.000 | 159.800 | 10500.000 | 174.300 |
| | 1857.000 | 129.100 | 2448.000 | 164.600 | 14300.000 | 174.300 |
| | 1873.000 | 117.800 | 2521.000 | 167.900 | 16200.000 | 174.300 |
| | 1888.000 | 104.900 | 2664.000 | 169.500 | 17000.000 | 174.300 |
| | 1898.000 | 98.500 | 2625.000 | 164.600 | 18000.000 | 174.300 |

$dc = 0.95$ cm. $\qquad P_s = 660\ N/m^2$

$g = 1.27$ cm. $\qquad Q_s = 14.9 \times 10^{-6}\ m^3/\ sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 120 | 175.000 | 174.300 | 1890.000 | 24.200 | 2910.000 | 154.900 |
| | 400.000 | 174.300 | 1918.000 | 20.200 | 2967.000 | 163.000 |
| | 658.000 | 174.300 | 1939.000 | 19.400 | 3009.000 | 164.600 |
| | 825.000 | 174.300 | 1947.000 | 16.900 | 3062.000 | 163.000 |
| | 1030.000 | 174.300 | 1993.000 | 16.900 | 3100.000 | 163.000 |
| | 1126.000 | 174.300 | 2021.000 | 19.400 | 3145.000 | 163.000 |
| | 1178.000 | 174.300 | 2061.000 | 23.400 | 3207.000 | 167.900 |
| | 1213.000 | 172.700 | 2106.000 | 27.400 | 3267.000 | 169.500 |
| | 1299.000 | 171.100 | 2275.000 | 37.900 | 3333.000 | 171.100 |
| | 1350.000 | 167.900 | 2313.000 | 42.800 | 3418.000 | 173.000 |
| | 1391.000 | 163.000 | 2393.000 | 63.800 | 3469.000 | 173.000 |
| | 1429.000 | 153.300 | 2439.000 | 79.100 | 3529.000 | 17[illegible].000 |
| | 1488.000 | 145.300 | 2479.000 | 96.000 | 3601.000 | 174.300 |
| | 1547.000 | 137.200 | 2514.000 | 106.500 | 4800.000 | 174.300 |
| | 1597.000 | 129.100 | 2535.000 | 113.000 | 5700.000 | 174.300 |
| | 1646.000 | 113.000 | 2627.000 | 83.100 | 6500.000 | 174.300 |
| | 1710.000 | 88.800 | 2670.000 | 102.500 | 7800.000 | 174.300 |
| | 1738.000 | 74.200 | 2717.000 | 114.600 | 8900.000 | 174.300 |
| | 1775.000 | 67.800 | 2764.000 | 121.900 | 13500.000 | 174.300 |
| | 1812.000 | 46.800 | 2813.000 | 135.600 | 15700.000 | 174.300 |
| | 1859.000 | 33.100 | 2860.000 | 143.600 | 18000.000 | 174.300 |

dc = 0.95 cm. $P_s$ = 660 $N/m^2$

g = 2.54 cm. $Q_s$ = 14.9 x $10^{-6}$ $m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 90 | 175.000 | 138.800 | 1880.000 | 35.500 | 2349.000 | 121.100 |
| | 425.000 | 138.800 | 1892.000 | 29.900 | 2401.000 | 128.300 |
| | 625.000 | 138.800 | 1904.000 | 27.400 | 2469.000 | 133.200 |
| | 1025.000 | 138.800 | 1925.000 | 23.400 | 2563.000 | 134.800 |
| | 1114.000 | 138.800 | 1937.000 | 21.800 | 2646.000 | 130.700 |
| | 1400.000 | 138.800 | 1945.000 | 20.200 | 2684.000 | 134.000 |
| | 1473.000 | 137.200 | 1959.000 | 20.200 | 2732.000 | 135.600 |
| | 1534.000 | 134.000 | 1969.000 | 21.000 | 2833.000 | 136.400 |
| | 1602.000 | 132.300 | 1983.000 | 22.000 | 2934.000 | 137.200 |
| | 1675.000 | 133.200 | 2001.000 | 27.400 | 3030.000 | 137.200 |
| | 1729.000 | 129.900 | 2011.000 | 35.500 | 3155.000 | 138.000 |
| | 1755.000 | 127.700 | 2027.000 | 47.600 | 3200.000 | 138.800 |
| | 1796.000 | 116.200 | 2053.000 | 58.900 | 4625.000 | 138.800 |
| | 1808.000 | 105.700 | 2073.000 | 71.800 | 5825.000 | 138.800 |
| | 1814.000 | 100.100 | 2097.000 | 79.100 | 8375.000 | 138.800 |
| | 1821.000 | 94.400 | 2153.000 | 90.400 | 11465.000 | 138.800 |
| | 1831.000 | 82.300 | 2180.000 | 101.700 | 14566.000 | 138.800 |
| | 1847.000 | 62.900 | 2210.000 | 111.400 | 18000.000 | 138.800 |
| | 1864.000 | 45.200 | 2306.000 | 117.000 | | |
| 100 | 175.000 | 138.800 | 1905.000 | 8.100 | 2756.000 | 99.200 |
| | 420.000 | 138.800 | 1937.000 | 7.300 | 2803.000 | 108.900 |
| | 720.000 | 138.800 | 1980.000 | 8.100 | 2839.000 | 116.260 |
| | 800.000 | 138.800 | 2042.000 | 9.700 | 2873.000 | 122.700 |
| | 872.000 | 138.800 | 2088.000 | 11.300 | 2897.000 | 128.300 |
| | 950.000 | 138.800 | 2130.000 | 12.900 | 2954.000 | 133.200 |
| | 1018.000 | 138.800 | 2186.000 | 16.100 | 3033.000 | 134.000 |
| | 1126.000 | 138.800 | 2235.000 | 18.600 | 3135.000 | 134.800 |
| | 1203.000 | 138.000 | 2277.000 | 18.600 | 3186.000 | 135.600 |
| | 1254.000 | 135.600 | 2340.000 | 22.600 | 3224.000 | 136.400 |
| | 1301.000 | 133.200 | 2375.000 | 28.200 | 3279.000 | 136.400 |
| | 1354.000 | 130.700 | 2402.000 | 37.900 | 3320.000 | 137.200 |
| | 1413.000 | 124.300 | 2445.000 | 51.600 | 3404.000 | 137.200 |
| | 1492.000 | 111.400 | 2481.000 | 75.900 | 3477.000 | 138.000 |
| | 1524.000 | 86.300 | 2508.000 | 86.300 | 3568.000 | 138.800 |
| | 1565.000 | 67.000 | 2540.000 | 96.000 | 4500.000 | 138.800 |
| | 1627.000 | 58.100 | 2592.000 | 80.600 | 4850.000 | 138.800 |
| | 1683.000 | 49.200 | 2615.000 | 56.500 | 7850.000 | 138.800 |
| | 1702.000 | 37.900 | 2632.000 | 42.000 | 13850.000 | 138.800 |
| | 1755.000 | 21.800 | 2682.000 | 61.300 | 15850.000 | 138.800 |
| | 1800.000 | 18.600 | 2702.000 | 75.900 | 18000.000 | 138.800 |
| | 1846.000 | 12.900 | 2724.000 | 88.000 | | |

dc = 0.95 cm.

g = 2.54 cm.

$P_s$ = 660 $N/m^2$

$Q_s$ = 14.9 x $10^{-6}$ $m^3/sec.$

| Pc (db) | f (Hz) | Po (N/m²) | f (Hz) | Po (N/m²) | f (Hz) | Po (N/m²) |
|---|---|---|---|---|---|---|
| 110 | 175.000 | 138.800 | 1480.000 | 20.200 | 3087.000 | 62.000 |
| | 400.000 | 138.800 | 1527.000 | 17.800 | 3143.000 | 65.400 |
| | 750.000 | 138.800 | 1568.000 | 15.300 | 3177.000 | 75.100 |
| | 898.000 | 138.000 | 1602.000 | 13.700 | 3224.000 | 89.600 |
| | 907.000 | 133.200 | 1657.000 | 10.500 | 3295.000 | 100.900 |
| | 920.000 | 129.100 | 1706.000 | 8.900 | 3322.000 | 108.900 |
| | 940.000 | 125.900 | 1758.000 | 7.300 | 3389.000 | 106.500 |
| | 954.000 | 125.900 | 1822.000 | 6.500 | 3423.000 | 101.700 |
| | 960.000 | 125.100 | 1917.000 | 4.800 | 3465.000 | 124.300 |
| | 972.000 | 121.900 | 1979.000 | 4.800 | 3493.000 | 132.300 |
| | 983.000 | 124.300 | 2062.000 | 5.600 | 3513.000 | 134.800 |
| | 994.000 | 125.100 | 2119.000 | 5.600 | 3583.000 | 136.400 |
| | 1026.000 | 128.300 | 2225.000 | 6.500 | 3697.000 | 137.200 |
| | 1054.000 | 129.900 | 2303.000 | 6.500 | 3769.000 | 138.000 |
| | 1077.000 | 126.700 | 2378.000 | 8.100 | 3814.000 | 138.000 |
| | 1100.000 | 123.500 | 2452.000 | 8.900 | 3917.000 | 138.000 |
| | 1124.000 | 117.000 | 2511.000 | 11.300 | 4065.000 | 138.000 |
| | 1152.000 | 108.100 | 2575.000 | 12.900 | 4104.000 | 138.000 |
| | 1177.000 | 101.700 | 2598.000 | 11.300 | 4300.000 | 138.800 |
| | 1208.000 | 91.700 | 2718.000 | 12.100 | 4800.000 | 138.800 |
| | 1248.000 | 80.700 | 2765.000 | 15.300 | 5500.000 | 138.800 |
| | 1294.000 | 59.700 | 2825.000 | 21.800 | 7300.000 | 138.800 |
| | 1325.000 | 48.400 | 2869.000 | 32.300 | 8300.000 | 138.800 |
| | 1363.000 | 37.900 | 2920.000 | 41.200 | 10300.000 | 138.800 |
| | 1393.000 | 29.100 | 2957.000 | 55.700 | 16300.000 | 138.800 |
| | 1440.000 | 23.400 | 3012.000 | 64.600 | 18000.000 | [illegible] |
| 120 | 175.000 | 138.800 | 1019.000 | 69.400 | 859.000 | 107.300 |
| | 263.000 | 138.800 | 1028.000 | 63.800 | 877.000 | 94.400 |
| | 315.000 | 138.800 | 1040.000 | 58.900 | 898.000 | 72.600 |
| | 389.000 | 138.800 | 1048.000 | 51.600 | 910.000 | 58.100 |
| | 529.000 | 138.800 | 1059.000 | 42.800 | 917.000 | 45.200 |
| | 611.000 | 138.800 | 1073.000 | 40.400 | 923.000 | 30.700 |
| | 706.000 | 138.800 | 1098.000 | 36.300 | 931.000 | 28.200 |
| | 740.000 | 138.800 | 1121.000 | 30.700 | 948.000 | 19.400 |
| | 753.000 | 137.200 | 1158.000 | 23.400 | 966.000 | 27.400 |
| | 762.000 | 131.500 | 1191.000 | 18.600 | 972.000 | 38.700 |
| | 788.000 | 129.900 | 1224.000 | 15.300 | 985.000 | 51.600 |
| | 804.000 | 132.300 | 1280.000 | 12.900 | 988.000 | 70.200 |
| | 822.000 | 128.300 | 1321.000 | 10.500 | 995.000 | 37.900 |
| | 842.000 | 119.400 | 1409.000 | 8.100 | 1000.000 | 48.400 |

dc = 0.95 cm.

g = 2.54 cm.

$P_s$ = 660 $N/m^2$

$Q_s$ = 14.9 x $10^{-6}$ $m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 120 | 1482.000 | 6.500 | 3094.000 | 12.900 | 4129.000 | 93.600 |
| | 1515.000 | 6.500 | 3174.000 | 16.900 | 4167.000 | 102.500 |
| | 1592.000 | 5.600 | 3257.000 | 21.800 | 4214.000 | 109.800 |
| | 1701.000 | 4.800 | 3323.000 | 27.400 | 4261.000 | 117.000 |
| | 1807.000 | 4.000 | 3389.000 | 36.300 | 4304.000 | 124.300 |
| | 1913.000 | 4.000 | 3421.000 | 44.400 | 4377.000 | 129.900 |
| | 1992.000 | 4.000 | 3484.000 | 59.700 | 4454.000 | 131.500 |
| | 2094.000 | 4.000 | 3530.000 | 66.200 | 4495.000 | 131.500 |
| | 2165.000 | 4.000 | 3583.000 | 76.100 | 4556.000 | 130.700 |
| | 2259.000 | 4.000 | 3635.000 | 75.100 | 4586.000 | 129.100 |
| | 2368.000 | 4.000 | 3693.000 | 90.400 | 4626.000 | 128.300 |
| | 2425.000 | 4.000 | 3791.000 | 86.300 | 4679.000 | 134.000 |
| | 2469.000 | 4.000 | 3831.000 | 90.400 | 4728.000 | 137.200 |
| | 2518.000 | 4.800 | 3862.000 | 93.600 | 4747.000 | 138.000 |
| | 2547.000 | 5.600 | 3883.000 | 97.600 | 4790.000 | 138.800 |
| | 2772.000 | 5.600 | 3909.000 | 101.700 | 6000.000 | 138.800 |
| | 2818.000 | 6.500 | 3934.000 | 108.900 | 7500.000 | 138.800 |
| | 2844.000 | 8.100 | 4000.000 | 117.000 | 9600.000 | 138.800 |
| | 2889.000 | 8.100 | 4020.000 | 114.600 | 14750.000 | 138.800 |
| | 2927.000 | 9.700 | 4062.000 | 104.100 | 16750.000 | 138.800 |
| | 2991.000 | 12.100 | 4092.000 | 95.200 | 18000.000 | 138.800 |

dc = 0.95 cm.    $P_s$ = 660 $N/m^2$

g = 3.81 cm.    $Q_s$ = 14.9 x $10^{-6}$ $m^3/sec$.

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 80 | 170.000 | 112.200 | 1850.000 | 18.600 | 2648.000 | 67.800 |
| | 200.000 | 112.200 | 1900.000 | 11.300 | 2675.000 | 73.400 |
| | 500.000 | 112.200 | 1929.000 | 8.900 | 2692.000 | 76.700 |
| | 700.000 | 112.200 | 1947.000 | 9.700 | 2727.000 | 96.800 |
| | 900.000 | 112.200 | 1967.000 | 9.700 | 2753.000 | 101.700 |
| | 1227.000 | 112.200 | 2020.000 | 14.500 | 2791.000 | 108.100 |
| | 1365.000 | 111.400 | 2087.000 | 25.000 | 2876.000 | 109.800 |
| | 1429.000 | 104.900 | 2166.000 | 37.900 | 2919.000 | 110.600 |
| | 1444.000 | 103.300 | 2241.000 | 50.800 | 3046.000 | 111.400 |
| | 1457.000 | 100.100 | 2297.000 | 66.900 | 3199.000 | 112.200 |
| | 1479.000 | 101.700 | 2443.000 | 79.900 | 4200.000 | 112.200 |
| | 1497.000 | 97.600 | 2487.000 | 96.000 | 6000.000 | 112.200 |
| | 1509.000 | 92.800 | 2538.000 | 105.700 | 8000.000 | 112.200 |
| | 1604.000 | 76.700 | 2570.000 | 105.700 | 12000.000 | 112.200 |
| | 1664.000 | 66.200 | 2598.000 | 104.900 | 16000.000 | 112.200 |
| | 1698.000 | 63.800 | 2601.000 | 103.300 | 18000.000 | 112.200 |
| | 1766.000 | 40.400 | 2612.000 | 96.800 | | |
| | 1801.000 | 34.700 | 2628.000 | 79.100 | | |
| 90 | 170.000 | 112.200 | 1370.000 | 50.800 | 2527.000 | 37.100 |
| | 656.000 | 112.200 | 1415.000 | 37.100 | 2558.000 | 42.800 |
| | 885.000 | 112.200 | 1481.000 | 32.300 | 2578.000 | 42.800 |
| | 908.000 | 112.200 | 1536.000 | 27.400 | 2608.000 | 34.700 |
| | 935.000 | 112.200 | 1568.000 | 20.900 | 2625.000 | 29.100 |
| | 960.000 | 108.900 | 1583.000 | 18.600 | 2637.000 | 25.800 |
| | 979.000 | 93.600 | 1645.000 | 16.100 | 2668.000 | 25.800 |
| | 989.000 | 84.700 | 1705.000 | 12.900 | 2678.000 | 27.400 |
| | 1001.000 | 87.900 | 1776.000 | 8.100 | 2700.000 | 30.700 |
| | 1017.000 | 102.500 | 1853.000 | 6.500 | 2730.000 | 36.300 |
| | 1028.000 | 108.900 | 1913.000 | 5.600 | 2751.000 | 40.400 |
| | 1044.000 | 110.600 | 1977.000 | 4.800 | 2827.000 | 50.800 |
| | 1062.000 | 110.600 | 2032.000 | 5.600 | 2916.000 | 60.500 |
| | 1088.000 | 108.900 | 2110.000 | 6.500 | 3015.000 | 76.700 |
| | 1117.000 | 106.500 | 2175.000 | 8.900 | 3096.000 | 90.400 |
| | 1166.000 | 95.200 | 2243.000 | 10.500 | 3150.000 | 100.900 |
| | 1196.000 | 84.700 | 2317.000 | 12.900 | 3232.000 | 105.700 |
| | 1221.000 | 78.300 | 2387.000 | 16.900 | 3316.000 | 108.900 |
| | 1276.000 | 66.900 | 2430.000 | 21.800 | 3370.000 | 110.600 |
| | 1317.000 | 65.400 | 2479.000 | 29.900 | 3412.000 | 111.400 |

dc = 0.95 cm.

g = 3.81 cm.

$P_s$ = 660 $N/m^2$

$Q_s$ = 14.9 x $10^{-6}$ $m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 90 | 3525.000 | 111.400 | 7600.000 | 112.200 | 15000.000 | 112.200 |
| | 3600.000 | 112.200 | 8500.000 | 112.200 | 18000.000 | 112.200 |
| | 5400.000 | 112.200 | 10000.000 | 112.200 | | |
| 100 | 170.000 | 112.200 | 1154.000 | 31.500 | 2843.000 | 16.900 |
| | 250.000 | 112.200 | 1193.000 | 26.600 | 2911.000 | 25.000 |
| | 337.000 | 112.200 | 1221.000 | 22.600 | 2953.000 | 29.900 |
| | 460.000 | 112.200 | 1279.000 | 18.600 | 2998.000 | 34.700 |
| | 557.000 | 112.200 | 1314.000 | 15.300 | 3047.000 | 36.300 |
| | 626.000 | 112.200 | 1346.000 | 13.700 | 3124.000 | 41.200 |
| | 708.000 | 112.200 | 1409.000 | 11.300 | 3175.000 | 45.200 |
| | 767.000 | 112.200 | 1453.000 | 9.700 | 3228.000 | 48.400 |
| | 775.000 | 108.100 | 1498.000 | 8.900 | 3299.000 | 54.100 |
| | 788.000 | 102.500 | 1526.000 | 8.100 | 3345.000 | 58.900 |
| | 794.000 | 100.900 | 1547.000 | 7.300 | 3415.000 | 77.500 |
| | 814.000 | 103.300 | 1579.000 | 7.300 | 3461.000 | 91.200 |
| | 832.000 | 100.100 | 1606.000 | 6.500 | 3483.000 | 99.300 |
| | 848.000 | 88.800 | 1695.000 | 5.600 | 3508.000 | 104.900 |
| | 864.000 | 77.500 | 1754.000 | 5.600 | 3548.000 | 108.100 |
| | 882.000 | 69.400 | 1788.000 | 4.800 | 3583.000 | 109.800 |
| | 914.000 | 58.900 | 1840.000 | 4.800 | 3624.000 | 110.600 |
| | 943.000 | 50.800 | 1906.000 | 4.800 | 3756.000 | 111.400 |
| | 958.000 | 38.700 | 1993.000 | 4.800 | 3826.000 | 111.400 |
| | 967.000 | 34.700 | 2050.000 | 4.800 | 3900.000 | 112.200 |
| | 976.000 | 33.100 | 2141.000 | 4.800 | 4700.000 | 112.200 |
| | 990.000 | 35.500 | 2251.000 | 4.800 | 6400.000 | 112.200 |
| | 1001.000 | 41.900 | 2342.000 | 4.800 | 7800.000 | 112.200 |
| | 1017.000 | 47.600 | 2400.000 | 5.600 | 8600.000 | 112.200 |
| | 1030.000 | 52.500 | 2495.000 | 7.300 | 9800.000 | 112.200 |
| | 1053.000 | 54.100 | 2539.000 | 9.700 | 11000.000 | 112.200 |
| | 1063.000 | 52.500 | 2621.000 | 7.300 | 14500.000 | 112.200 |
| | 1074.000 | 50.800 | 2713.000 | 8.100 | 16500.000 | 112.200 |
| | 1096.000 | 45.700 | 2759.000 | 10.500 | 18000.000 | 112.200 |
| | 1117.000 | 39.500 | 2794.000 | 13.700 | | |
| 110 | 175.000 | 111.400 | 617.000 | 108.900 | 680.000 | 92.800 |
| | 238.000 | 111.400 | 631.000 | 103.400 | 695.000 | 89.600 |
| | 322.000 | 111.400 | 648.000 | 90.400 | 706.000 | 80.700 |
| | 473.000 | 111.400 | 662.000 | 90.400 | 719.000 | 73.400 |
| | 564.000 | 111.400 | 665.000 | 93.600 | 728.000 | 70.200 |
| | 600.000 | 111.400 | 672.000 | 94.400 | 749.000 | 63.800 |

dc = 0.95 cm.　　　$P_s$ = 660 N/m$^2$

g = 3.81 cm.　　　$Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 110 | 763.000 | 58.100 | 1510.000 | 4.800 | 3448.000 | 37.900 |
| | 782.000 | 54.100 | 1638.000 | 4.800 | 3473.000 | 43.600 |
| | 809.000 | 50.800 | 1730.000 | 4.800 | 3531.000 | 48.400 |
| | 821.000 | 45.900 | 1789.000 | 4.000 | 3606.000 | 54.900 |
| | 840.000 | 40.400 | 1836.000 | 4.000 | 3665.000 | 65.400 |
| | 861.000 | 33.100 | 1901.000 | 4.000 | 3700.000 | 75.100 |
| | 887.000 | 26.600 | 2013.000 | 4.000 | 3743.000 | 86.300 |
| | 911.000 | 20.900 | 2139.000 | 4.000 | 3792.000 | 98.500 |
| | 945.000 | 15.300 | 2221.000 | 4.000 | 3838.000 | 106.500 |
| | 965.000 | 10.500 | 2322.000 | 4.000 | 3884.000 | 108.100 |
| | 986.000 | 12.900 | 2428.000 | 4.000 | 3935.000 | 108.100 |
| | 993.000 | 15.300 | 2501.000 | 4.000 | 3988.000 | 108.900 |
| | 1009.000 | 18.600 | 2612.000 | 4.000 | 4052.000 | 108.900 |
| | 1030.000 | 23.400 | 2756.000 | 4.000 | 4093.000 | 109.800 |
| | 1049.000 | 20.900 | 2818.000 | 4.800 | 4111.000 | 108.900 |
| | 1060.000 | 17.800 | 2916.000 | 5.600 | 4221.000 | 110.600 |
| | 1086.000 | 14.500 | 2986.000 | 7.300 | 4246.000 | 111.400 |
| | 1108.000 | 12.100 | 3038.000 | 7.300 | 4417.000 | 111.400 |
| | 1164.000 | 8.900 | 3133.000 | 8.000 | 4528.000 | 111.400 |
| | 1194.000 | 8.100 | 3184.000 | 10.500 | 4620.000 | 111.400 |
| | 1222.000 | 7.300 | 3234.000 | 12.100 | 4750.000 | 111.400 |
| | 1263.000 | 6.500 | 3299.000 | 16.100 | 7000.000 | 111.400 |
| | 1315.000 | 6.500 | 3330.000 | 18.600 | 11000.000 | 111.400 |
| | 1348.000 | 5.600 | 3386.000 | 24.200 | 17000.000 | 111.400 |
| | 1415.000 | 4.800 | 3421.000 | 30.700 | 18000.000 | [illegible] |
| 120 | 183.000 | 105.700 | 348.000 | 87.900 | 535.[illegible] | 108.100 |
| | 192.000 | 103.300 | 368.000 | 87.200 | 544.000 | 98.500 |
| | 202.000 | 99.300 | 384.000 | 88.800 | 558.000 | 85.500 |
| | 216.000 | 96.000 | 401.000 | 90.400 | 569.000 | 72.600 |
| | 226.000 | 92.800 | 412.000 | 94.400 | 582.000 | 65.400 |
| | 239.000 | 92.800 | 424.000 | 98.500 | 592.000 | 62.100 |
| | 250.000 | 91.200 | 432.000 | 100.900 | 616.000 | 54.100 |
| | 264.000 | 93.600 | 445.000 | 104.900 | 623.000 | 50.000 |
| | 281.000 | 92.800 | 452.000 | 107.300 | 629.000 | 41.900 |
| | 284.000 | 100.900 | 464.000 | 102.500 | 639.000 | 36.300 |
| | 295.000 | 97.600 | 480.000 | 106.500 | 652.000 | 39.500 |
| | 300.000 | 95.200 | 488.000 | 108.900 | 661.000 | 41.900 |
| | 314.000 | 98.500 | 493.000 | 111.400 | 677.000 | 41.200 |
| | 329.000 | 91.900 | 512.000 | 112.200 | 682.000 | 41.200 |
| | 334.000 | 86.300 | 529.000 | 111.400 | 703.000 | 37.100 |

dc = 0.95 cm.

g = 3.81 cm.

$P_s$ = 660 N/$m^2$

$Q_s$ = 14.9 x $10^{-6}$ $m^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) |
|---|---|---|---|---|---|---|
| 120 | 721.000 | 32.300 | 2154.000 | 4.000 | 4410.000 | 61.300 |
| | 740.000 | 29.100 | 2224.000 | 4.000 | 4486.000 | 66.900 |
| | 763.000 | 24.700 | 2376.000 | 4.000 | 4516.000 | 62.900 |
| | 777.000 | 20.200 | 2444.000 | 4.000 | 4587.000 | 50.000 |
| | 804.000 | 16.100 | 2518.000 | 4.000 | 4607.000 | 41.900 |
| | 842.000 | 9.700 | 2700.000 | 4.000 | 4658.000 | 48.400 |
| | 900.000 | 6.500 | 2948.000 | 4.000 | 4675.000 | 58.900 |
| | 925.000 | 4.800 | 3106.000 | 4.000 | 4687.000 | 71.000 |
| | 950.000 | 4.000 | 3261.000 | 4.000 | 4699.000 | 98.500 |
| | 985.000 | 5.600 | 3350.000 | 4.000 | 4757.000 | 108.100 |
| | 1011.000 | 5.600 | 3411.000 | 4.800 | 4776.000 | 109.800 |
| | 1056.000 | 4.800 | 3526.000 | 8.100 | 4805.000 | 110.600 |
| | 1103.000 | 4.000 | 3574.000 | 8.900 | 4858.000 | 111.400 |
| | 1155.000 | 4.000 | 3665.000 | 14.500 | 5012.000 | 111.400 |
| | 1284.000 | 4.000 | 3755.000 | 20.900 | 5346.000 | 111.400 |
| | 1379.000 | 4.000 | 3848.000 | 25.000 | 5710.000 | 111.400 |
| | 1495.000 | 4.000 | 3938.000 | 24.200 | 6610.000 | 111.400 |
| | 1565.000 | 4.000 | 4017.000 | 22.600 | 8000.000 | 111.400 |
| | 1675.000 | 4.000 | 4119.000 | 19.400 | 12000.000 | 111.400 |
| | 1798.000 | 4.000 | 4192.000 | 23.400 | 16000.000 | 111.400 |
| | 1907.000 | 4.000 | 4307.000 | 37.900 | 18000.000 | 111.400 |
| | 2022.000 | 4.000 | 4360.000 | 49.200 | | |

dc = 1.27 cm. $P_s$ = 660 N/m$^2$

g = 1.27 cm. $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m2) | f ($H_z$) | Po (N/m2) | f ($H_z$) | Po (N/m2) |
|---|---|---|---|---|---|---|
| 90 | 200.000 | 171.000 | 1120.000 | 171.000 | 6300.000 | 171.000 |
| | 520.000 | 171.000 | 1552.000 | 171.000 | 9900.000 | 171.000 |
| | 870.000 | 171.000 | 2600.000 | 171.000 | 15000.000 | 171.000 |
| | 950.000 | 171.000 | 4310.000 | 171.000 | 18000.000 | 171.000 |
| 100 | 190.000 | 171.000 | 1504.000 | 166.000 | 1625.000 | 168.000 |
| | 700.000 | 171.000 | 1521.000 | 165.000 | 1660.000 | 170.000 |
| | 1200.000 | 171.000 | 1543.000 | 163.000 | 1702.000 | 171.000 |
| | 1252.000 | 171.000 | 1552.000 | 161.000 | 1818.000 | 171.000 |
| | 1345.000 | 171.000 | 1564.000 | 163.000 | 3000.000 | 171.000 |
| | 1408.000 | 171.000 | 1575.000 | 165.000 | 8000.000 | 171.000 |
| | 1463.000 | 170.000 | 1586.000 | 165.000 | 14000.000 | 171.000 |
| | 1485.000 | 168.000 | 1600.000 | 166.000 | 18000.000 | 171.000 |
| 110 | 180.000 | 171.000 | 1462.000 | 118.000 | 2152.000 | 170.000 |
| | 350.000 | 171.000 | 1482.000 | 107.000 | 2253.000 | 170.000 |
| | 480.000 | 171.000 | 1500.000 | 98.000 | 2360.000 | 170.000 |
| | 700.000 | 171.000 | 1514.000 | 86.000 | 2550.000 | 170.000 |
| | 840.000 | 171.000 | 1524.000 | 77.000 | 2750.000 | 170.000 |
| | 971.000 | 171.000 | 1551.000 | 65.000 | 2916.000 | 170.000 |
| | 1009.000 | 171.000 | 1587.000 | 77.000 | 3112.000 | 170.000 |
| | 1105.000 | 171.000 | 1614.000 | 89.000 | 3368.000 | 171.000 |
| | 1203.000 | 171.000 | 1641.000 | 107.000 | 3580.000 | 170.000 |
| | 1256.000 | 171.000 | 1666.000 | 129.000 | 3789.000 | 170.000 |
| | 1282.000 | 170.000 | 1695.000 | 142.000 | 4033.000 | 170.000 |
| | 1323.000 | 168.000 | 1727.000 | 148.000 | 4217.000 | 170.000 |
| | 1387.000 | 163.000 | 1757.000 | 157.000 | 4330.000 | 171.000 |
| | 1409.000 | 157.000 | 1784.000 | 161.000 | 5000.000 | 171.000 |
| | 1424.000 | 145.000 | 1855.000 | 165.000 | 8000.000 | 171.000 |
| | 1436.000 | 137.000 | 1941.000 | 168.000 | 12000.000 | 171.000 |
| | 1446.000 | 128.000 | 2050.000 | 168.000 | 18000.000 | 171.000 |

dc = 1.27 cm. $P_s$ = 660 N/m$^2$

g = 1.27 cm. $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f (Hz) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 120 | 175.000 | 173.000 | 1502.000 | 29.000 | 3781.000 | 171.000 |
| | 300.000 | 173.000 | 1554.000 | 21.000 | 3888.000 | 171.000 |
| | 400.000 | 173.000 | 1625.000 | 27.000 | 4033.000 | 171.000 |
| | 500.000 | 173.000 | 1644.000 | 31.000 | 4108.000 | 171.000 |
| | 600.000 | 173.000 | 1663.000 | 34.000 | 4156.000 | 170.000 |
| | 667.000 | 173.000 | 1741.000 | 50.000 | 4193.000 | 168.000 |
| | 736.000 | 173.000 | 1793.000 | 69.000 | 4230.000 | 166.000 |
| | 818.000 | 173.000 | 1830.000 | 86.000 | 4290.000 | 158.000 |
| | 912.000 | 173.000 | 1893.000 | 97.000 | 4322.000 | 160.000 |
| | 950.000 | 171.000 | 1944.000 | 107.000 | 4335.000 | 163.000 |
| | 997.000 | 173.000 | 1985.000 | 111.000 | 4374.000 | 168.000 |
| | 1049.000 | 173.000 | 2032.000 | 129.000 | 4446.000 | 171.000 |
| | 1081.000 | 171.000 | 2109.000 | 140.000 | 4513.000 | 171.000 |
| | 1109.000 | 170.000 | 2153.000 | 140.000 | 4613.000 | 171.000 |
| | 1148.000 | 168.000 | 2316.000 | 144.000 | 4761.000 | 171.000 |
| | 1183.000 | 166.000 | 2492.000 | 157.000 | 4855.000 | 171.000 |
| | 1215.000 | 161.000 | 2529.000 | 161.000 | 5041.000 | 171.000 |
| | 1235.000 | 153.000 | 2569.000 | 163.000 | 5376.000 | 171.000 |
| | 1251.000 | 145.000 | 2818.000 | 165.000 | 5704.000 | 171.000 |
| | 1267.000 | 137.000 | 2897.000 | 166.000 | 6159.000 | 171.000 |
| | 1295.000 | 126.000 | 2946.000 | 168.000 | 6463.000 | 171.000 |
| | 1325.000 | 113.000 | 3044.000 | 168.000 | 8000.000 | 171.000 |
| | 1355.000 | 92.000 | 3147.000 | 168.000 | 11000.000 | 171.000 |
| | 1375.000 | 77.000 | 3239.000 | 170.000 | 14000.000 | 171.000 |
| | 1404.000 | 61.000 | 3361.000 | 171.000 | 16000.000 | 171.000 |
| | 1427.000 | 48.000 | 3434.000 | 171.000 | 18000.000 | 171.000 |
| | 1472.000 | 36.000 | 3590.000 | 171.000 | | |

$d_c$ = 1.27 cm. $P_s = 660\ N/m^2$

$d_g$ = 2.54 cm. $Q_s = 14.9 \times 10^{-6}\ m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 90 | 180.000 | 140.000 | 1537.000 | 44.000 | 2334.000 | 140.000 |
| | 500.000 | 140.000 | 1559.000 | 44.000 | 2401.000 | 140.000 |
| | 800.000 | 140.000 | 1583.000 | 58.000 | 2505.000 | 140.000 |
| | 1010.000 | 140.000 | 1602.000 | 73.000 | 2603.000 | 140.000 |
| | 1104.000 | 140.000 | 1628.000 | 96.000 | 2696.000 | 140.000 |
| | 1250.000 | 140.000 | 1662.000 | 115.000 | 2772.000 | 140.000 |
| | 1295.000 | 139.000 | 1694.000 | 127.000 | 2964.000 | 140.000 |
| | 1349.000 | 138.000 | 1793.000 | 133.000 | 3245.000 | 140.000 |
| | 1406.000 | 135.000 | 1873.000 | 136.000 | 7000.000 | 140.000 |
| | 1448.000 | 123.000 | 1943.000 | 137.000 | 13000.000 | 140.000 |
| | 1486.000 | 106.000 | 2010.000 | 138.000 | 17000.000 | 140.000 |
| | 1504.000 | 82.000 | 2100.000 | 139.000 | | |
| | 1522.000 | 56.000 | 2202.000 | 140.000 | | |
| 100 | 175[illegible] | 140.00 | 1512.000 | 15.00 | 2694.000 | 125.00 |
| | 269.000 | 140.00 | 1552.000 | 11.00 | 2754.000 | 136.00 |
| | 476.000 | 140.00 | 1613.000 | 15.00 | 2818.000 | 138.00 |
| | 634.000 | 140.00 | 1657.000 | 20.00 | 2929.000 | 139.00 |
| | 700.000 | 140.00 | 1732.000 | 33.00 | 3115.000 | 140.00 |
| | 953.000 | 140.00 | 1789.000 | 47.00 | 3371.000 | 140.00 |
| | 1008.000 | 139.00 | 1832.000 | 64.00 | 3583.000 | 140.00 |
| | 1122.000 | 139.00 | 1862.000 | 80.00 | 3800.000 | 140.00 |
| | 1200.000 | 136.00 | 1938.000 | 99.00 | 4054.000 | 140.00 |
| | 1234.000 | 132.00 | 2047.000 | 114.00 | 4168.000 | 140.00 |
| | 1305.000 | 112.00 | 2115.000 | 119.00 | 4252.000 | 139.00 |
| | 1338.000 | 83.00 | 2269.000 | 123.00 | 4309.000 | 139.00 |
| | 1355.000 | 69.00 | 2330.000 | 122.00 | 6100.000 | 140.00 |
| | 1384.000 | 53.00 | 2464.000 | 130.00 | 9000.000 | 140.00 |
| | 1421.000 | 31.00 | 2552.000 | 135.00 | 11000.000 | 140.00 |
| | 1449.000 | 23.00 | 2605.000 | 136.00 | 18000.000 | 140.00 |
| | 1479.000 | 18.00 | 2614.000 | 132.00 | | |
| 110 | 175.000 | 140.00 | 1014.000 | 129.00 | 1412.000 | 10.00 |
| | 300.000 | 140.00 | 1032.000 | 132.00 | 1460.000 | 7.00 |
| | 450.000 | 140.00 | 1057.000 | 129.00 | 1499.000 | 6.00 |
| | 600.000 | 140.00 | 1073.000 | 127.00 | 1572.000 | 5.00 |
| | 758.000 | 140.00 | 1095.000 | 118.00 | 1601.000 | 5.00 |
| | 774.000 | 138.00 | 1112.000 | 110.00 | 1654.000 | 6.00 |
| | 790.000 | 140.00 | 1135.000 | 99.00 | 1700.000 | 8.00 |
| | 802.000 | 140.00 | 1152.000 | 88.00 | 1754.000 | 10.00 |
| | 828.000 | 140.00 | 1173.000 | 74.00 | 1821.000 | 13.00 |
| | 872.000 | 140.00 | 1190.000 | 61.00 | 1944.000 | 18.00 |
| | 914.000 | 138.00 | 1210.000 | 48.00 | 2045.000 | 22.00 |
| | 945.000 | 135.00 | 1238.000 | 37.00 | 2152.000 | 25.00 |
| | 973.000 | 132.00 | 1278.000 | 28.00 | 2262.000 | 28.00 |
| | 983.000 | 127.00 | 1317.000 | 21.00 | 2298.000 | 25.00 |
| | 993.000 | 126.00 | 1364.000 | 14.00 | 2408.000 | 32.00 |

dc = 1.27 cm. $P_s$ = 660 N/m$^2$

g = 2.54 cm. $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 110 | 2517.000 | 54.00 | 3206.000 | 120.00 | 4386.000 | 137.00 |
| | 2594.000 | 68.00 | 3232.000 | 134.00 | 4415.000 | 139.00 |
| | 2800.000 | 77.00 | 3385.000 | 137.00 | 4514.000 | 139.00 |
| | 2837.000 | 87.00 | 3589.000 | 138.00 | 6000.000 | 139.00 |
| | 2919.000 | 90.00 | 3889.000 | 139.00 | 8000.000 | 139.00 |
| | 3010.000 | 98.00 | 4070.000 | 139.00 | 12000.000 | 139.00 |
| | 3048.000 | 77.00 | 4122.000 | 138.00 | 15000.000 | 139.00 |
| | 3143.000 | 84.00 | 4230.000 | 136.00 | 17000.000 | 139.00 |
| | 3172.000 | 94.00 | 4313.000 | 131.00 | | |
| | 3189.000 | 106.00 | 4346.000 | 133.00 | | |
| 120 | 175.000 | 143.60 | 1246.000 | 9.00 | 3916.000 | 139.00 |
| | 319.000 | 143.60 | 1300.000 | 6.00 | 3963.000 | 134.00 |
| | 400.000 | 143.60 | 1347.000 | 5.00 | 3996.000 | 128.00 |
| | 500.000 | 143.60 | 1423.000 | 4.00 | 4013.000 | 121.00 |
| | 600.000 | 143.60 | 1536.000 | 3.00 | 4022.000 | 103.00 |
| | 667.000 | 142.00 | 1664.000 | 3.00 | 4039.000 | 82.00 |
| | 718.000 | 140.00 | 1788.000 | 5.00 | 4056.000 | 66.00 |
| | 752.000 | 129.00 | 1884.000 | 6.00 | 4107.000 | 52.00 |
| | 761.000 | 115.00 | 2031.000 | 8.00 | 4137.000 | 44.00 |
| | 769.000 | 100.00 | 2127.000 | 9.00 | 4253.000 | 31.00 |
| | 775.000 | 95.00 | 2212.000 | 9.00 | 4300.000 | 28.00 |
| | 789.000 | 105.00 | 2341.000 | 9.00 | 4344.000 | 46.00 |
| | 803.000 | 113.00 | 2495.000 | 11.00 | 4361.000 | 82.00 |
| | 819.000 | 119.00 | 2549.000 | 14.00 | 4377.000 | 115.00 |
| | 863.000 | 98.00 | 2796.000 | 19.00 | 4399.000 | 128.00 |
| | 879.000 | 74.00 | 2946.000 | 23.00 | 4416.000 | 133.00 |
| | 903.000 | 58.00 | 3126.000 | 31.00 | 4489.000 | 143.60 |
| | 923.000 | 44.00 | 3202.000 | 39.00 | 4576.000 | 143.60 |
| | 942.000 | 34.00 | 3296.000 | 54.00 | 5000.000 | 143.60 |
| | 977.000 | 29.00 | 3388.000 | 69.00 | 7000.000 | 143.60 |
| | 1021.000 | 36.00 | 3459.000 | 104.00 | 10000.000 | 143.60 |
| | 1051.000 | 31.00 | 3610.000 | 130.00 | 13000.000 | 143.60 |
| | 1085.000 | 23.00 | 3687.000 | 139.00 | 16000.000 | 143.60 |
| | 1120.000 | 18.00 | 3784.000 | 142.00 | 18000.000 | 143.60 |
| | 1183.000 | 12.00 | 3889.000 | 142.00 | | |

dc = 1.27 cm.

g = 3.81 cm.

$P_s$ = 660 $N/m^2$

$Q_s$ = 14.9 x $10^{-6}$ $m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 90 | 400.000 | 95.20 | 2608.000 | 89.60 | 3664.000 | 95.20 |
| | 500.000 | 95.20 | 2702.000 | 92.00 | 3694.000 | 96.80 |
| | 1058.000 | 92.80 | 2765.000 | 92.80 | 3732.000 | 95.20 |
| | 1177.000 | 92.00 | 3045.000 | 91.20 | 3800.000 | 96.00 |
| | 1281.000 | 74.20 | 3122.000 | 96.00 | 3937.000 | 96.00 |
| | 1325.000 | 41.20 | 3242.000 | 95.20 | 3961.000 | 96.80 |
| | 1636.000 | 11.30 | 3362.000 | 96.80 | 4036.000 | 96.00 |
| | 1973.000 | 42.80 | 3426.000 | 95.20 | 4200.000 | 97.60 |
| | 2100.000 | 74.20 | 3472.000 | 96.00 | 4400.000 | 96.80 |
| | 2256.000 | 75.90 | 3542.000 | 96.80 | 4434.000 | 95.20 |
| | 2423.000 | 92.00 | 3589.000 | 95.20 | 4485.000 | 95.20 |
| | 2590.000 | 92.00 | 3622.000 | 95.20 | 4600.000 | 92.80 |
| 100 | 400.000 | 95.20 | 2423.000 | 20.20 | 3664.000 | 96.80 |
| | 500.000 | 95.20 | 2590.000 | 31.50 | 3694.000 | 96.00 |
| | 900.000 | 95.20 | 2608.000 | 23.40 | 3732.000 | 96.80 |
| | 927.000 | 77.50 | 2702.000 | 25.80 | 3800.000 | 96.80 |
| | 964.000 | 53.30 | 2765.000 | 38.70 | 3937.000 | 96.80 |
| | 990.000 | 43.60 | 3045.000 | 66.20 | 3961.000 | 98.50 |
| | 1058.000 | 50.00 | 3122.000 | 81.50 | 4036.000 | 96.80 |
| | 1177.000 | 25.80 | 3242.000 | 88.80 | 4200.000 | 99.30 |
| | 1281.000 | 15.30 | 3362.000 | 96.80 | 4400.000 | 96.80 |
| | 1325.000 | 11.30 | 3426.000 | 96.80 | 4434.000 | 95.20 |
| | 1636.000 | 4.80 | 3472.000 | 96.00 | 4485.000 | 95.20 |
| | 1973.000 | 12.10 | 3542.000 | 96.00 | 4600.000 | 92.80 |
| | 2100.000 | 16.10 | 3589.000 | 96.00 | | |
| | 2256.000 | 16.10 | 3622.000 | 96.80 | | |
| 110 | 400.000 | 96.80 | 2256.000 | 6.45 | 3622.000 | 98.50 |
| | 662.000 | 95.20 | 2423.000 | 6.45 | 3664.000 | 97.60 |
| | 694.000 | 83.90 | 2590.000 | 10.50 | 3694.000 | 98.50 |
| | 732.000 | 72.60 | 2608.000 | 8.90 | 3732.000 | 97.60 |
| | 768.000 | 48.40 | 2702.000 | 8.90 | 3800.000 | 96.80 |
| | 846.000 | 32.20 | 2765.000 | 11.30 | 3937.000 | 100.90 |
| | 975.000 | 11.30 | 3045.000 | 25.80 | 3961.000 | 100.90 |
| | 1058.000 | 14.50 | 3122.000 | 28.20 | 4036.000 | 99.30 |
| | 1177.000 | 8.90 | 3242.000 | 43.60 | 4200.000 | 45.20 |
| | 1281.000 | 5.60 | 3362.000 | 72.60 | 4400.000 | 96.80 |
| | 1325.000 | 4.80 | 3426.000 | 91.20 | 4434.000 | 95.20 |
| | 1636.000 | 2.40 | 3472.000 | 96.00 | 4485.000 | 95.20 |
| | 1973.000 | 4.80 | 3542.000 | 97.60 | 4600.000 | 92.80 |
| | 2100.000 | 5.64 | 3589.000 | 98.50 | | |

dc = 1.27 cm.

g = 3.81 cm.

$P_s$ = 660 N/m$^2$

$Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 120 | 175.000 | 95.20 | 717.000 | 23.40 | 3622.000 | 64.60 |
| | 400.000 | 97.60 | 765.000 | 15.30 | 3664.000 | 74.20 |
| | 500.000 | 90.40 | 805.000 | 11.30 | 3694.000 | 84.70 |
| | 509.000 | 87.20 | 860.000 | 8.07 | 3732.000 | 90.40 |
| | 520.000 | 95.20 | 922.000 | 5.60 | 3800.000 | 95.20 |
| | 540.000 | 92.00 | 950.000 | 4.80 | 3937.000 | 71.80 |
| | 560.000 | 97.60 | 1000.000 | 4.00 | 3961.000 | 43.60 |
| | 575.000 | 88.70 | 1200.000 | 3.20 | 4036.000 | 13.70 |
| | 590.000 | 79.90 | 1500.000 | 3.20 | 4200.000 | 4.80 |
| | 603.000 | 67.80 | 3000.000 | 8.07 | 4400.000 | 11.30 |
| | 625.000 | 57.30 | 3426.000 | 17.80 | 4434.000 | 24.20 |
| | 643.000 | 48.40 | 3472.000 | 29.10 | 4485.000 | 65.40 |
| | 662.000 | 40.40 | 3542.000 | 40.40 | 4600.000 | 92.80 |
| | 684.000 | 31.50 | 3589.000 | 52.50 | 18000.000 | 95.20 |

dc = 2.54 cm.

g = 1.27 cm.

$P_s$ = 660 N/m$^2$

$Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| | | | | | | |
|---|---|---|---|---|---|---|
| 90 | 185.000 | 173.00 | 4000.000 | 173.00 | 11000.000 | 173.00 |
| | 850.000 | 173.00 | 7000.000 | 173.00 | 15000.000 | 173.00 |
| | 1450.000 | 173.00 | 9000.000 | 173.00 | 17000.000 | 173.00 |
| | | | | | 18000.000 | 173.00 |
| 100 | 190.000 | 173.00 | 3000.000 | 173.00 | 10000.000 | 173.00 |
| | 800.000 | 173.00 | 6000.000 | 173.00 | 13000.000 | 173.00 |
| | 1500.000 | 173.00 | 8000.000 | 173.00 | 16000.000 | 173.00 |
| | | | | | 18000.000 | 173.00 |
| 110 | 180.000 | 173.00 | 773.000 | 166.20 | 1500.000 | 173.00 |
| | 400.000 | 173.00 | 782.000 | 164.60 | 2200.000 | 173.00 |
| | 600.000 | 173.00 | 789.000 | 166.20 | 4800.000 | 173.00 |
| | 720.000 | 173.00 | 800.000 | 167.90 | 6300.000 | 173.00 |
| | 743.000 | 173.00 | 828.000 | 169.90 | 12000.000 | 173.00 |
| | 753.000 | 171.10 | 833.000 | 171.10 | 18000.000 | 173.00 |
| | 759.000 | 169.50 | 840.000 | 173.00 | | |
| | 765.000 | 167.90 | 1100.000 | 173.00 | | |

dc = 2.54 cm. $\qquad$ $P_s$ = 660 N/m$^2$

g = 1.27 cm. $\qquad$ $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f (Hz) | Po (N/m$^2$) | f (Hz) | Po (N/m$^2$) | f (Hz) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 120 | 175.000 | 173.00 | 898.000 | 153.30 | 3221.000 | 173.00 |
| | 335.000 | 173.00 | 921.000 | 156.60 | 3412.000 | 173.00 |
| | 442.000 | 173.00 | 939.000 | 161.40 | 3550.000 | 173.00 |
| | 563.000 | 173.00 | 973.000 | 166.20 | 3656.000 | 173.00 |
| | 611.000 | 173.00 | 1015.000 | 169.50 | 3756.000 | 173.00 |
| | 684.000 | 171.10 | 1155.000 | 170.30 | 3792.000 | 171.10 |
| | 693.000 | 169.50 | 1338.000 | 171.10 | 3828.000 | 169.50 |
| | 701.000 | 167.90 | 1476.000 | 171.10 | 3858.000 | 167.90 |
| | 711.000 | 164.60 | 1641.000 | 171.10 | 3928.000 | 169.50 |
| | 723.000 | 159.60 | 1782.000 | 171.10 | 3974.000 | 171.10 |
| | 732.000 | 153.30 | 1852.000 | 171.10 | 4017.000 | 171.10 |
| | 741.000 | 143.60 | 1900.000 | 171.10 | 4039.000 | 171.10 |
| | 750.000 | 137.20 | 1965.000 | 171.10 | 4104.000 | 173.00 |
| | 761.000 | 129.10 | 2029.000 | 171.10 | 4210.000 | 173.00 |
| | 770.000 | 121.10 | 2154.000 | 171.10 | 4443.000 | 173.00 |
| | 782.000 | 119.40 | 2242.000 | 171.10 | 4584.000 | 173.00 |
| | 797.000 | 121.10 | 2353.000 | 171.10 | 4675.000 | 173.00 |
| | 811.000 | 122.70 | 2476.000 | 171.10 | 6000.000 | 173.00 |
| | 835.000 | 125.90 | 2700.000 | 171.10 | 8000.000 | 173.00 |
| | 853.000 | 130.70 | 2815.000 | 171.10 | 11000.000 | 173.00 |
| | 864.000 | 137.20 | 3000.000 | 173.00 | 18000.000 | 173.00 |
| | 879.000 | 148.50 | 3150.000 | 173.00 | | |

d c = 2.54 cm. $\qquad$ $P_s$ = 660 N/m$^2$

g = 2.54 cm. $\qquad$ $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| | | | | | | |
|---|---|---|---|---|---|---|
| 90 | 165.000 | 136.00 | 787.000 | 133.10 | 2300.000 | 136.00 |
| | 360.000 | 136.00 | 792.000 | 134.70 | 4800.000 | 136.00 |
| | 540.000 | 136.00 | 802.000 | 135.50 | 5600.000 | 136.00 |
| | 680.000 | 136.00 | 810.000 | 136.00 | 7800.000 | 136.00 |
| | 700.000 | 136.00 | 889.000 | 136.00 | 11500.000 | 136.00 |
| | 723.000 | 136.00 | 972.000 | 136.00 | 13750.000 | 136.00 |
| | 745.000 | 136.00 | 1031.000 | 136.00 | 16750.000 | 136.00 |
| | 771.000 | 134.70 | 1350.000 | 136.00 | 18000.000 | 136.00 |
| | 777.000 | 133.90 | 1550.000 | 136.00 | | |
| | 781.000 | 133.90 | 1850.000 | 136.00 | | |

dc = 2.54 cm.

g = 2.54 cm.

$P_s$ = 660 N/m$^2$

$Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 100 | 180.000 | 135.50 | 789.000 | 75.80 | 1240.000 | 135.50 |
| | 370.000 | 135.50 | 792.000 | 86.30 | 1308.000 | 135.50 |
| | 470.000 | 135.50 | 799.000 | 95.90 | 1428.000 | 135.50 |
| | 520.000 | 135.50 | 807.000 | 103.30 | 1540.000 | 135.50 |
| | 605.000 | 135.50 | 816.000 | 112.10 | 1618.000 | 135.50 |
| | 696.000 | 135.50 | 823.000 | 116.20 | 1822.000 | 135.50 |
| | 710.000 | 134.70 | 831.000 | 118.60 | 1904.000 | 135.50 |
| | 726.000 | 133.10 | 837.000 | 121.00 | 2090.000 | 135.50 |
| | 736.000 | 130.70 | 843.000 | 123.40 | 2182.000 | 135.50 |
| | 745.000 | 125.10 | 849.000 | 125.90 | 2318.000 | 135.50 |
| | 751.000 | 118.60 | 854.000 | 128.30 | 2504.000 | 135.50 |
| | 758.000 | 109.70 | 880.000 | 130.70 | 2733.000 | 135.50 |
| | 764.000 | 99.20 | 908.000 | 132.20 | 2931.000 | 135.50 |
| | 768.000 | 88.70 | 924.000 | 133.10 | 3600.000 | 135.50 |
| | [illegible] | 80.70 | 946.000 | 134.70 | 6500.000 | 135.50 |
| | 775.000 | 74.20 | 968.000 | 135.50 | 10500.000 | 135.50 |
| | 780.000 | 72.60 | 1047.000 | 135.50 | 16500.000 | 135.50 |
| | 783.000 | 70.90 | 1141.000 | 135.50 | 18000.000 | 135.50 |
| 110 | 175.000 | 136.00 | 867.000 | 43.50 | 2132.000 | 109.70 |
| | 350.000 | 136.00 | 882.000 | 52.40 | 2205.000 | 114.60 |
| | 450.000 | 136.00 | 898.000 | 63.70 | 2306.000 | 117.80 |
| | 500.000 | 136.00 | 912.000 | 75.80 | 2411.000 | 121.80 |
| | 600.000 | 136.00 | 929.000 | 81.50 | 2504.000 | 125.00 |
| | 646.000 | 134.70 | 947.000 | 91.20 | 2547.000 | 128.30 |
| | 661.000 | 132.30 | 966.000 | 95.70 | 2736.000 | 129.90 |
| | 669.000 | 130.70 | 970.000 | 92.80 | 2800.000 | 132.30 |
| | 682.000 | 125.00 | 1002.000 | 104.00 | 2923.000 | 133.90 |
| | 698.000 | 117.90 | 1030.000 | 108.90 | 3031.000 | 134.70 |
| | 705.000 | 105.70 | 1059.000 | 109.70 | 3191.000 | 134.70 |
| | 711.000 | 92.80 | 1086.000 | 109.70 | 3260.000 | 135.50 |
| | 717.000 | 79.10 | 1097.000 | 108.90 | 3399.000 | 135.50 |
| | 722.000 | 67.80 | 1121.000 | 108.90 | 3471.000 | 136.00 |
| | 729.000 | 52.40 | 1227.000 | 108.10 | 3668.000 | 136.00 |
| | 738.000 | 39.50 | 1321.000 | 107.30 | 3790.000 | 136.00 |
| | 748.000 | 29.80 | 1412.000 | 107.30 | 3846.000 | 134.70 |
| | 763.000 | 20.90 | 1473.000 | 105.70 | 3856.000 | 133.90 |
| | 771.000 | 19.30 | 1529.000 | 104.90 | 3900.000 | 135.50 |
| | 780.000 | 17.70 | 1557.000 | 104.00 | 6000.000 | 136.00 |
| | 792.000 | 18.50 | 1622.000 | 103.30 | 8000.000 | 136.00 |
| | 809.000 | 20.10 | 1733.000 | 104.90 | 12000.000 | 136.00 |
| | 820.000 | 23.40 | 1822.000 | 106.50 | 18000.000 | 136.00 |
| | 832.000 | 28.20 | 1941.000 | 106.50 | | |
| | 849.000 | 36.30 | 2029.000 | 107.30 | | |

dc = 2.54 cm. $P_s$ = 660 N/$m^2$

g = 2.54 cm. $Q_s$ = 14.9 x $10^{-6}$ $m^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) | f ($H_z$) | Po (N/$m^2$) |
|---|---|---|---|---|---|---|
| 120 | 175.000 | 136.00 | 946.000 | 13.70 | 3171.000 | 99.20 |
| | 330.000 | 136.00 | 970.000 | 15.30 | 3208.000 | 106.50 |
| | 460.000 | 136.00 | 988.000 | 16.90 | 3249.000 | 113.80 |
| | 482.000 | 136.00 | 1005.000 | 18.50 | 3312.000 | 123.40 |
| | 505.000 | 135.50 | 1038.000 | 19.30 | 3365.000 | 126.70 |
| | 536.000 | 133.90 | 1098.000 | 19.30 | 3384.000 | 128.30 |
| | 564.000 | 131.50 | 1181.000 | 19.30 | 3432.000 | 130.70 |
| | 578.000 | 127.50 | 1264.000 | 19.30 | 3463.000 | 132.30 |
| | 600.000 | 114.60 | 1380.000 | 20.10 | 3504.000 | 134.70 |
| | 612.000 | 102.50 | 1487.000 | 20.90 | 3545.000 | 135.50 |
| | 623.000 | 94.40 | 1595.000 | 20.90 | 3620.000 | 136.00 |
| | 634.000 | 78.20 | 1696.000 | 20.10 | 3729.000 | 136.00 |
| | 642.000 | 66.90 | 1810.000 | 20.90 | 3787.000 | 135.50 |
| | 651.000 | 55.60 | 1933.000 | 21.80 | 3818.000 | 133.90 |
| | 663.000 | 44.40 | 2008.000 | 22.60 | 3835.000 | 128.30 |
| | 675.000 | 35.50 | 2136.000 | 22.60 | 3845.000 | 98.40 |
| | 683.000 | 28.20 | 2226.000 | 24.20 | 3852.000 | 74.20 |
| | 695.000 | 22.60 | 2341.000 | 24.20 | 3869.000 | 60.50 |
| | 716.000 | 18.50 | 2444.000 | 24.20 | 3875.000 | 80.70 |
| | 728.000 | 16.10 | 2480.000 | 28.20 | 3883.000 | 112.90 |
| | 744.000 | 13.70 | 2538.000 | 31.40 | 3894.000 | 128.30 |
| | 758.000 | 12.90 | 2562.000 | 36.30 | 3924.000 | 133.10 |
| | 775.000 | 12.00 | 2808.000 | 49.20 | 3945.000 | 135.50 |
| | 782.000 | 11.30 | 2896.000 | 62.90 | 4000.000 | 136.00 |
| | 813.000 | 11.30 | 2972.000 | 73.40 | 7000.000 | 136.00 |
| | 846.000 | 11.30 | 3060.000 | 78.20 | 11000.000 | 136.00 |
| | 881.000 | 12.00 | 3090.000 | 83.90 | 17500.000 | 136.00 |
| | 916.000 | 12.90 | 3136.000 | 94.40 | | |

dc = 2.54 cm. $P_s$ = 660 $N/m^2$

g = 3.81 cm. $Q_s$ = $14.9 \times 10^{-6}$ $m^3/sec.$

| Pc (db) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | $Po_2$ ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 90 | 170.000 | 111.00 | 787.000 | 36.00 | 1536.000 | 108.00 |
| | 450.000 | 111.00 | 803.000 | 45.00 | 1691.000 | 109.00 |
| | 600.000 | 111.00 | 818.000 | 63.00 | 1780.000 | 109.00 |
| | 689.000 | 109.00 | 834.000 | 82.00 | 1871.000 | 109.00 |
| | 714.000 | 107.00 | 847.000 | 92.00 | 2023.000 | 110.00 |
| | 725.000 | 104.00 | 867.000 | 94.00 | 2294.000 | 110.00 |
| | 738.000 | 98.00 | 899.000 | 100.00 | 2544.000 | 111.00 |
| | 748.000 | 91.00 | 948.000 | 101.00 | 2600.000 | 111.00 |
| | 753.000 | 88.00 | 983.000 | 103.00 | 5500.000 | 111.00 |
| | 759.000 | 65.00 | 1044.000 | 105.00 | 7300.000 | 111.00 |
| | 762.000 | 61.00 | 1131.000 | 106.00 | 8600.000 | 111.00 |
| | 768.000 | 41.00 | 1222.000 | 107.00 | 11500.000 | 111.00 |
| | 775.000 | 36.00 | 1320.000 | 107.00 | 14500.000 | 111.00 |
| | 782.000 | 31.00 | 1424.000 | 107.00 | 18000.000 | 111.00 |
| 100 | 170.000 | 111.00 | 861.000 | 12.60 | 1919.000 | 80.00 |
| | 500.000 | 111.00 | 880.000 | 17.80 | 2018.000 | 86.00 |
| | 589.000 | 110.00 | 912.000 | [illegible] | 2082.000 | 90.00 |
| | 620.000 | 109.00 | 961.000 | 32.00 | 2154.000 | 91.00 |
| | 648.000 | 107.00 | 993.000 | 37.00 | 2275.000 | 100.00 |
| | 660.000 | 103.00 | 1028.000 | 40.00 | 2420.000 | 105.00 |
| | 676.000 | 94.00 | 1054.000 | 43.00 | 2499.000 | 107.00 |
| | 687.000 | 87.00 | 1069.000 | 42.00 | 2561.000 | 108.00 |
| | 699.000 | 70.00 | 1094.000 | 42.00 | 2655.000 | 107.00 |
| | 706.000 | 55.00 | 1190.000 | 41.60 | 2720.000 | 108.00 |
| | 720.000 | 36.00 | 1298.000 | 43.30 | 2760.000 | 109.00 |
| | 734.000 | 22.00 | 1393.000 | 42.30 | 2912.000 | 110.00 |
| | 753.000 | 7.40 | 1475.000 | 50.60 | 3292.000 | 111.00 |
| | 778.000 | 4.20 | 1581.000 | 57.00 | 6000.000 | 111.00 |
| | 785.000 | 4.20 | 1611.000 | 53.00 | 9000.000 | 111.00 |
| | 811.000 | 5.20 | 1666.000 | 64.00 | 15000.000 | 111.00 |
| | 842.000 | 8.40 | 1823.000 | 68.00 | 18000.000 | 111.00 |
| 110 | 170.000 | 112.00 | 720.000 | 5.20 | 1638.000 | 9.00 |
| | 400.000 | 112.00 | 743.000 | 2.90 | 1755.000 | 9.40 |
| | 500.000 | 111.00 | 758.000 | 1.90 | 1890.000 | 10.90 |
| | 538.000 | 110.00 | 787.000 | 1.60 | 1980.000 | 11.60 |
| | 558.000 | 107.00 | 858.000 | 1.90 | 2084.000 | 11.90 |
| | 578.000 | 101.00 | 883.000 | 2.90 | 2199.000 | 13.20 |
| | 603.000 | 90.00 | 974.000 | 4.20 | 2266.000 | 14.50 |
| | 619.000 | 74.00 | 1017.000 | 5.50 | 2374.000 | 15.80 |
| | 628.000 | 59.00 | 1124.000 | 6.10 | 2459.000 | 19.00 |
| | 644.000 | 42.00 | 1231.000 | 7.10 | 2506.000 | 23.20 |
| | 658.000 | 26.00 | 1312.000 | 7.70 | 2589.000 | 25.50 |
| | 676.000 | 15.00 | 1442.000 | 8.00 | 2603.000 | 27.60 |
| | 702.000 | 8.07 | 1526.000 | 8.40 | 2694.000 | 24.20 |

dc = 2.59 cm. $P_s$ = 660 N/m$^2$

g = 3.81 cm. $Q_s$ = 14.9 x $10^{-6}$ m$^3$/sec.

| Pc (db) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 110 | 2719.000 | 28.40 | 3207.000 | 108.00 | 3892.000 | 109.00 |
| | 2741.000 | 32.60 | 3311.000 | 110.00 | 3913.000 | 110.00 |
| | 2776.000 | 37.10 | 3500.000 | 110.00 | 3989.000 | 111.00 |
| | 2809.000 | 43.60 | 3614.000 | 111.00 | 4082.000 | 111.00 |
| | 2918.000 | 70.00 | 3712.000 | 111.00 | 4120.000 | 111.00 |
| | 2950.000 | 86.00 | 3808.000 | 111.00 | 6500.000 | 111.00 |
| | 2987.000 | 98.00 | 3844.000 | 111.00 | 8000.000 | 111.00 |
| | 3042.000 | 101.00 | 3871.000 | 110.00 | 14000.000 | 111.00 |
| | 3105.000 | 106.00 | 3883.000 | 110.00 | 18000.000 | 111.00 |
| 120 | 170.000 | 113.00 | 1644.000 | 1.90 | 3827.000 | 108.00 |
| | 251.000 | 111.00 | 1819.000 | 1.90 | 3847.000 | 100.00 |
| | 302.000 | 113.00 | 1915.000 | 2.30 | 3858.000 | 74.00 |
| | 370.000 | 112.00 | 2039.000 | 2.30 | 3866.000 | 34.00 |
| | 382.000 | 111.00 | 2158.000 | 2.60 | 3875.000 | 15.00 |
| | 405.000 | 111.00 | 2445.000 | 2.90 | 3901.000 | 19.00 |
| | 434.000 | 109.00 | 2544.000 | 3.60 | 3910.000 | 53.00 |
| | 457.000 | 104.00 | 2664.000 | 4.20 | 3913.000 | 69.00 |
| | 485.000 | 94.00 | 2760.000 | 4.80 | 3924.000 | 96.00 |
| | 501.000 | 80.00 | 2850.000 | 6.10 | 3946.000 | 107.00 |
| | 517.000 | 67.00 | 2965.000 | 8.70 | 3986.000 | 109.00 |
| | 531.000 | 48.00 | 3014.000 | 9.40 | 4027.000 | 110.00 |
| | 552.000 | 28.00 | 3109.000 | 11.90 | 4111.000 | 111.00 |
| | 587.000 | 15.00 | 3218.000 | 15.80 | 4220.000 | 111.00 |
| | 602.000 | 10.00 | 3247.000 | 19.00 | 4326.000 | 111.00 |
| | 632.000 | 6.00 | 3293.000 | 28.70 | 4425.000 | 111.00 |
| | 660.000 | 4.00 | 3337.000 | 37.40 | 4572.000 | 112.00 |
| | 701.000 | 2.00 | 3362.000 | 42.00 | 4688.000 | 112.00 |
| | 750.000 | 2.00 | 3398.000 | 55.00 | 4798.000 | 112.00 |
| | 835.000 | 2.00 | 3417.000 | 61.00 | 4964.000 | 112.00 |
| | 885.000 | 1.30 | 3433.000 | 66.00 | 5204.000 | 112.00 |
| | 914.000 | 0.90 | 3460.000 | 85.00 | 5656.000 | 112.00 |
| | 1000.000 | 1.00 | 3491.000 | 95.00 | 6122.000 | 112.00 |
| | 1122.000 | 1.00 | 3520.000 | 102.00 | 7090.000 | 112.00 |
| | 1225.000 | 1.00 | 3569.000 | 106.00 | 11000.000 | 112.00 |
| | 1328.000 | 1.30 | 3594.000 | 107.00 | 15000.000 | 112.00 |
| | 1435.000 | 1.60 | 3658.000 | 109.00 | 18000.000 | 112.00 |
| | 1546.000 | 1.60 | 3792.000 | 110.00 | | |

dc = 2.54 cm.

g = 3.81 cm.

Pc = 100 db.

| $P_s$ (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) | f ($H_z$) | Po (N/m$^2$) |
|---|---|---|---|---|---|---|
| 834 | 460.000 | 167.90 | 940.000 | 112.90 | 4400.000 | 167.90 |
| | 560.000 | 167.90 | 1100.000 | 111.40 | 4800.000 | 167.90 |
| | 660.000 | 167.90 | 1300.000 | 92.00 | 5200.000 | 166.20 |
| | 700.000 | 137.20 | 1550.000 | 80.70 | 6200.000 | 167.90 |
| | 740.000 | 69.40 | 1850.000 | 64.90 | 7400.000 | 167.90 |
| | 760.000 | 24.20 | 2000.000 | 54.20 | 8600.000 | 167.90 |
| | 770.000 | 19.40 | 2200.000 | 50.00 | 10000.000 | 167.90 |
| | 780.000 | 17.80 | 2600.000 | 75.90 | 12000.000 | 167.90 |
| | 800.000 | 24.20 | 3100.000 | 83.90 | 15000.000 | 167.90 |
| | 840.000 | 62.90 | 3700.000 | 163.00 | 20000.000 | 167.90 |
| 920 | 460.000 | 201.80 | 940.000 | 167.90 | 4400.000 | 200.10 |
| | 560.000 | 201.80 | 1100.000 | 154.70 | 4800.000 | 201.80 |
| | 660.000 | 201.80 | 1300.000 | 127.50 | 5200.000 | 201.80 |
| | 700.000 | [illegible] | 1550.000 | 119.40 | 6200.000 | 201.80 |
| | 740.000 | 95.20 | 1850.000 | 72.60 | 7400.000 | 201.80 |
| | 760.000 | 53.30 | 2000.000 | 61.30 | 8600.000 | 201.80 |
| | 770.000 | 37.10 | 2200.000 | 50.00 | 10000.000 | 201.80 |
| | 780.000 | 32.30 | 2600.000 | 58.10 | 12000.000 | 201.80 |
| | 800.000 | 56.50 | 3100.000 | 54.90 | 15000.000 | 201.80 |
| | 840.000 | 112.90 | 3700.000 | 163.00 | 20000.000 | 201.80 |
| 1030 | 460.000 | 246.90 | 940.000 | 216.30 | 4400.000 | 177.50 |
| | 560.000 | 246.90 | 1100.000 | 203.40 | 4800.000 | 237.30 |
| | 660.000 | 246.90 | 1300.000 | 161.40 | 5200.000 | 246.90 |
| | 700.000 | 235.60 | 1550.000 | 146.90 | 6200.000 | 246.90 |
| | 740.000 | 129.10 | 1850.000 | 92.00 | 7400.000 | 246.90 |
| | 760.000 | 72.60 | 2000.000 | 75.90 | 8600.000 | 246.90 |
| | 770.000 | 64.60 | 2200.000 | 56.50 | 10000.000 | 246.90 |
| | 780.000 | 56.50 | 2600.000 | 55.70 | 12000.000 | 246.90 |
| | 800.000 | 103.30 | 3100.000 | 43.60 | 15000.000 | 246.90 |
| | 840.000 | 167.90 | 3700.000 | 104.90 | 20000.000 | 246.90 |
| 1120 | 460.000 | 285.00 | 1100.000 | 226.70 | 5200.000 | 57.80 |
| | 560.000 | 281.50 | 1300.000 | 186.30 | 6200.000 | 55.00 |
| | 660.000 | 284.00 | 1550.000 | 181.30 | 7400.000 | 55.00 |
| | 700.000 | 279.00 | 1850.000 | 111.60 | 8600.000 | 55.00 |
| | 750.000 | 142.50 | 2000.000 | [illegible] | 10000.000 | 55.00 |
| | 770.000 | 87.40 | 2600.000 | 55.00 | 12000.000 | 55.00 |
| | 780.000 | 73.00 | 3100.000 | 42.00 | 15000.000 | 55.00 |
| | 800.000 | 108.60 | 3700.000 | 66.30 | [illegible] | 55.00 |
| | 840.000 | 187.80 | 4400.000 | 71.20 | 20000.000 | 55.00 |
| | 940.000 | 213.70 | 4800.000 | 144.00 | | |

d c = 2.54 cm.

g = 3.81 cm.

Pc = 100 db.

| $P_s$ ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 1220 | 460.000 | 327.60 | 940.000 | 319.60 | 4400.000 | 66.20 |
| | 560.000 | 327.60 | 1100.000 | 305.00 | 4800.000 | 98.50 |
| | 660.000 | 327.60 | 1300.000 | 264.70 | 5200.000 | 179.30 |
| | 700.000 | 327.60 | 1550.000 | 203.40 | 6200.000 | 319.60 |
| | 740.000 | 217.90 | 1850.000 | 174.30 | 7400.000 | 327.60 |
| | 760.000 | 167.90 | 2000.000 | 135.60 | 8600.000 | 327.60 |
| | 770.000 | 132.30 | 2200.000 | 98.50 | 10000.000 | 327.60 |
| | 780.000 | 59.70 | 2600.000 | 66.20 | 12000.000 | 327.60 |
| | 800.000 | 153.30 | 3100.000 | 38.70 | 15000.000 | 327.60 |
| | 840.000 | 222.70 | 3700.000 | 64.60 | 20000.000 | 327.60 |

dc = 0.95 cm.

g = 1.27 cm.

Pc = 110 db.

| | | | | | | |
|---|---|---|---|---|---|---|
| 260 | 175.000 | 25.80 | 1600.000 | 25.80 | 6000.000 | 25.80 |
| | 205.000 | 25.80 | 1800.000 | 25.80 | 8000.000 | 25.80 |
| | 480.000 | 25.80 | 1900.000 | 25.80 | 10000.000 | 25.80 |
| | 680.000 | 25.80 | 2000.000 | 25.80 | 12000.000 | 25.80 |
| | 890.000 | 25.80 | 2200.000 | 25.80 | 14000.000 | 25.80 |
| | 1050.000 | 25.80 | 2600.000 | 25.80 | 16000.000 | 25.80 |
| | 1200.000 | 25.80 | 3700.000 | 25.80 | 18000.000 | 25.80 |
| | 1400.000 | 25.80 | 4800.000 | 25.80 | | |
| 974 | 175.000 | 338.90 | 1925.000 | 209.80 | 2455.000 | 326.80 |
| | 400.000 | 338.90 | 1951.000 | 189.60 | 2490.000 | 330.90 |
| | 600.000 | 338.90 | 1976.000 | 177.50 | 2529.000 | 330.90 |
| | 800.000 | 338.90 | 1994.000 | 181.60 | 2564.000 | 334.90 |
| | 1000.000 | 338.90 | 2006.000 | 197.70 | 2585.000 | 330.90 |
| | 1200.000 | 338.90 | 2021.000 | 213.90 | 2593.000 | 326.80 |
| | 1400.000 | 338.90 | 2032.000 | 221.90 | 2610.000 | 322.80 |
| | 1600.000 | 338.90 | 2053.000 | 242.10 | 2627.000 | 314.70 |
| | 1650.000 | 338.90 | 2076.000 | 262.30 | 2649.000 | 314.70 |
| | 1710.000 | 334.90 | 2110.000 | 278.40 | 2662.000 | 314.70 |
| | 1771.000 | 330.80 | 2173.000 | 290.50 | 2674.000 | 318.80 |
| | 1821.000 | 318.80 | 2205.000 | 302.60 | 2687.000 | 322.80 |
| | 1843.000 | 306.70 | 2248.000 | 318.80 | 2710.000 | 326.80 |
| | 1865.000 | 286.50 | 2300.000 | 314.70 | 2745.000 | 326.80 |
| | 1879.000 | 262.30 | 2318.000 | 310.70 | 2795.000 | 330.90 |
| | 1890.000 | 246.10 | 2354.000 | 314.70 | 2814.000 | 330.90 |
| | 1915.000 | 221.90 | 2403.000 | 322.80 | 2856.000 | 330.90 |

dc = 0.95 cm.

g = 1.27 cm.

Pc = 110 db.

| $P_s$ ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 974 | 2891.000 | 334.90 | 3494.000 | 338.90 | 4673.000 | 310.70 |
| | 2915.000 | 334.90 | 3523.000 | 338.90 | 4704.000 | 314.70 |
| | 2962.000 | 334.90 | 3600.000 | 338.90 | 4754.000 | 322.80 |
| | 3019.000 | 338.90 | 3700.000 | 338.90 | 4797.000 | 326.80 |
| | 3071.000 | 338.90 | 3800.000 | 338.90 | 4851.000 | 330.90 |
| | 3148.000 | 338.90 | 3900.000 | 338.90 | 4911.000 | 334.90 |
| | 3187.000 | 338.90 | 4000.000 | 338.90 | 4976.000 | 334.90 |
| | 3234.000 | 338.90 | 4143.000 | 338.90 | 5000.000 | 334.90 |
| | 3266.000 | 338.90 | 4204.000 | 334.90 | 5052.000 | 338.90 |
| | 3295.000 | 338.90 | 4294.000 | 334.90 | 6000.000 | 338.90 |
| | 3317.000 | 338.90 | 4348.000 | 330.90 | 8000.000 | 338.90 |
| | 3335.000 | 338.90 | 4426.000 | 326.80 | 12000.000 | 338.90 |
| | 3352.000 | 338.90 | 4521.000 | 322.80 | 15000.000 | 338.90 |
| | 3384.000 | 338.90 | 4575.000 | 314.70 | 18000.000 | 338.90 |
| | 3410.000 | 338.90 | 4619.000 | 306.70 | | |
| | 3433.000 | 338.90 | 4663.000 | 306.70 | | |
| 1253 | 168.000 | 524.60 | 2025.000 | 407.50 | 3864.000 | 524.60 |
| | 278.000 | 524.60 | 2041.000 | 427.70 | 4060.000 | 524.60 |
| | 377.000 | 524.60 | 2054.000 | 439.80 | 4165.000 | 520.50 |
| | 496.000 | 524.60 | 2063.000 | 451.90 | 4185.000 | 516.50 |
| | 564.000 | 524.60 | 2074.000 | 464.00 | 4212.000 | 516.50 |
| | 674.000 | 524.60 | 2096.000 | 480.20 | 4287.000 | 512.40 |
| | 747.000 | 524.60 | 2131.000 | 492.30 | 4366.000 | 508.40 |
| | 833.000 | 524.60 | 2188.000 | 504.40 | 4395.000 | 500.30 |
| | 908.000 | 524.60 | 2224.000 | 508.40 | 4429.000 | 492.30 |
| | 1070.000 | 524.60 | 2304.000 | 508.40 | 4469.000 | 476.10 |
| | 1128.000 | 524.60 | 2403.000 | 512.40 | 4535.000 | 427.70 |
| | 1176.000 | 524.60 | 2460.000 | 516.50 | 4565.000 | 407.50 |
| | 1328.000 | 524.60 | 2525.000 | 520.50 | 4609.000 | 359.10 |
| | 1400.000 | 524.60 | 2554.000 | 524.60 | 4641.000 | 351.00 |
| | 1533.000 | 524.60 | 2610.000 | 516.50 | 4690.000 | 351.00 |
| | 1600.000 | 524.60 | 2631.000 | 512.40 | 4728.000 | 367.20 |
| | 1703.000 | 524.60 | 2675.000 | 512.40 | 4770.000 | 411.60 |
| | 1742.000 | 520.50 | 2702.000 | 516.50 | 4787.000 | 443.90 |
| | 1785.000 | 516.50 | 2744.000 | 520.50 | 4814.000 | 459.90 |
| | 1815.000 | 512.40 | 2798.000 | 520.50 | 4878.000 | 476.10 |
| | 1880.000 | 496.30 | 2838.000 | 520.50 | 4913.000 | 488.20 |
| | 1897.000 | 464.00 | 2910.000 | 524.60 | 5002.000 | 500.30 |
| | 1917.000 | 439.80 | 3050.000 | 524.60 | 5051.000 | 504.40 |
| | 1939.000 | 407.50 | 3164.000 | 524.60 | 5084.000 | 504.40 |
| | 1972.000 | 379.30 | 3242.000 | 524.60 | 5129.000 | 500.30 |
| | 1997.000 | 383.30 | 3375.000 | 524.60 | 5161.000 | 500.30 |
| | 2008.000 | 387.40 | 3565.000 | 524.60 | 5216.000 | 500.30 |

dc = 0.95 cm.

g = 1.27 cm.

Pc = 110 db.

| $P_s$ ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) | f ($H_z$) | Po ($N/m^2$) |
|---|---|---|---|---|---|---|
| 1253 | 5267.000 | 504.40 | 5706.000 | 520.50 | 8400.000 | 524.60 |
| | 5326.000 | 504.40 | 5788.000 | 520.50 | 11400.000 | 524.60 |
| | 5490.000 | 504.40 | 5874.000 | 520.50 | 13700.000 | 524.60 |
| | 5541.000 | 508.40 | 5988.000 | 520.50 | 16500.000 | 524.60 |
| | 5599.000 | 516.50 | 6310.000 | 524.60 | 18000.000 | 524.60 |
| 1898 | 166.000 | 979.96 | 4387.000 | 970.20 | 6878.000 | 960.44 |
| | 205.000 | 979.96 | 4429.000 | 955.56 | 7028.000 | 955.56 |
| | 234.000 | 979.96 | 4477.000 | 901.27 | 7218.000 | 940.62 |
| | 448.000 | 979.96 | 4514.000 | 857.05 | 7288.000 | 930.86 |
| | 668.000 | 979.96 | 4561.000 | 822.58 | 7430.000 | 940.62 |
| | 808.000 | 979.96 | 4588.000 | 812.52 | 7574.000 | 930.86 |
| | 960.000 | 979.96 | 4660.000 | 812.52 | 7619.000 | 921.10 |
| | 1050.000 | 979.96 | 4714.000 | 802.76 | 7678.000 | 886.63 |
| | 1180.000 | 979.96 | 4757.000 | 812.52 | 7731.000 | 842.10 |
| | 1350.000 | 979.96 | 4783.000 | 822.58 | 7758.000 | 832.34 |
| | 1500.000 | 979.96 | 4818.000 | 842.10 | 7800.000 | 822.58 |
| | 1650.000 | 979.96 | 4857.000 | 871.69 | 7843.000 | 837.22 |
| | 1791.000 | 979.96 | 4889.000 | 886.63 | 7859.000 | 852.17 |
| | 1800.000 | 979.98 | 4929.000 | 911.03 | 7883.000 | 886.63 |
| | 1838.000 | 975.08 | 4997.000 | 935.74 | 7906.000 | 904.95 |
| | 1856.000 | 965.32 | 5078.000 | 945.50 | 7954.000 | 940.621 |
| | 1902.000 | 950.68 | 5173.000 | 940.62 | 7998.000 | 955.56 |
| | 1955.000 | 930.86 | 5265.000 | 945.50 | 8034.000 | 965.32 |
| | 1972.000 | 921.10 | 5360.000 | 935.74 | 8113.000 | 965.32 |
| | 1990.000 | 916.22 | 5515.000 | 940.62 | 8154.000 | 960.44 |
| | 2004.000 | 930.86 | 5596.000 | 950.68 | 8230.000 | 950.68 |
| | 2020.000 | 940.62 | 5721.000 | 955.56 | 8317.000 | 945.50 |
| | 2061.000 | 950.68 | 5891.000 | 950.68 | 8427.000 | 945.50 |
| | 2087.000 | 960.44 | 6026.000 | 935.74 | 8575.000 | 935.74 |
| | 2148.000 | 965.32 | 6043.000 | 930.86 | 8709.000 | 935.74 |
| | 2180.000 | 970.20 | 6071.000 | 925.98 | 8873.000 | 940.62 |
| | 2203.000 | 975.08 | 6095.000 | 940.62 | 9000.000 | 935.74 |
| | 2237.000 | 979.96 | 6141.000 | 950.68 | 9149.000 | 945.50 |
| | 2500.000 | 979.96 | 6210.000 | 935.74 | 9298.000 | 945.50 |
| | 2600.000 | 979.96 | 6231.000 | 925.98 | 9429.000 | 945.50 |
| | 2700.000 | 979.96 | 6331.000 | 935.74 | 9680.000 | 935.74 |
| | 2800.000 | 979.96 | 6355.000 | 935.74 | 9828.000 | 940.62 |
| | 3000.000 | 979.96 | 6458.000 | 930.86 | 9987.000 | 955.56 |
| | 3200.000 | 979.96 | 6518.000 | 925.98 | 10098.000 | 960.44 |
| | 3400.000 | 979.96 | 6544.000 | 935.74 | 10253.000 | 965.32 |
| | 3600.000 | 979.96 | 6578.000 | 955.56 | 10387.000 | 965.32 |
| | 3800.000 | 979.96 | 6631.000 | 955.56 | 10617.000 | 970.20 |
| | 4000.000 | 979.96 | 6663.000 | 940.62 | 10780.000 | 975.08 |
| | 4150.000 | 979.96 | 6711.000 | 945.50 | 10980.000 | 979.96 |
| | 4302.000 | 979.96 | 6790.000 | 955.56 | 11000.000 | 979.96 |
| | 4346.000 | 975.08 | 6827.000 | 965.32 | | |

dc = 0.95 cm.

g = 1.27 cm.

Pc = 110 db.

| $P_s$ (N/m²) | f ($H_z$) | Po (N/m²) | f ($H_z$) | Po (N/m²) | f ($H_z$) | Po (N/m²) |
|---|---|---|---|---|---|---|
| 1898 | 13000.000 | 979.96 | | | | |
| | 15000.000 | 979.96 | | | | |
| | 18000.000 | 979.96 | | | | |
| 2647 | 170.000 | 1600.90 | 4956.000 | 1594.70 | 9627.000 | 1396.10 |
| | 300.000 | 1600.90 | 5025.000 | 1600.90 | 9651.000 | 1352.70 |
| | 600.000 | 1600.90 | 5200.000 | 1600.90 | 9700.000 | 1290.60 |
| | 800.000 | 1600.90 | 5400.000 | 1600.90 | 9786.000 | 1383.70 |
| | 1000.000 | 1600.90 | 5800.000 | 1600.90 | 9825.000 | 1402.30 |
| | 1200.000 | 1600.90 | 6300.000 | 1600.90 | 9965.000 | 1433.40 |
| | 1400.000 | 1600.90 | 6800.000 | 1600.90 | 10068.000 | 1476.80 |
| | 1600.000 | 1600.90 | 7000.000 | 1600.90 | 10114.000 | 1501.60 |
| | 1800.000 | 1613.30 | 7200.000 | 1600.90 | 10204.000 | 1538.80 |
| | 1838.000 | 1619.50 | 7370.000 | 1569.90 | 10326.000 | 1538.80 |
| | 1897.000 | 1625.70 | 7500.000 | 1588.50 | 10472.000 | 1532.60 |
| | 1981.000 | 1576.10 | 7634.000 | 1588.50 | 10625.000 | 1526.40 |
| | 2026.000 | 1588.00 | 7654.000 | 1563.70 | 10820.000 | 1545.60 |
| | 2067.000 | 1607.00 | 7670.000 | 1538.80 | 11066.000 | 1538.80 |
| | 2081.000 | 1613.00 | 7686.000 | 1495.40 | 11267.000 | 1545.00 |
| | 2300.000 | 1600.90 | 7705.000 | 1427.20 | 11390.000 | 1538.80 |
| | 2400.000 | 1600.90 | 7716.000 | 1389.90 | 11507.000 | 1545.00 |
| | 2600.000 | 1600.90 | 7748.000 | 1303.10 | 11615.000 | 1532.60 |
| | 2800.000 | 1600.90 | 7784.000 | 1191.40 | 11873.000 | 1538.80 |
| | 3000.000 | 1600.90 | 7821.000 | 1092.10 | 11976.000 | 1545.00 |
| | 3700.000 | 1600.90 | 7859.000 | 1290.60 | 12032.000 | 1551.30 |
| | 3400.000 | 1600.90 | 7882.000 | 1493.60 | 12215.000 | 1557.50 |
| | 3800.000 | 1600.90 | 7895.000 | 1489.20 | 12312.000 | 1563.70 |
| | 4200.000 | 1600.90 | 7943.000 | 1563.70 | 12450.000 | 1569.90 |
| | 4400.000 | 1600.90 | 8002.000 | 1588.50 | 12620.000 | 576.10 |
| | 4494.000 | 1576.10 | 8111.000 | 1594.70 | 12836.000 | 1582.30 |
| | 4530.000 | 1538.80 | 8200.000 | 1588.50 | 13032.000 | 1588.50 |
| | 4576.000 | 1433.40 | 8286.000 | 1576.10 | 13336.000 | 1594.70 |
| | 4592.000 | 1365.10 | 8400.000 | 1576.10 | 13855.000 | 1594.70 |
| | 4615.000 | 992.80 | 8487.000 | 1557.50 | 14152.000 | 1600.90 |
| | 4623.000 | 967.60 | 8567.000 | 1526.40 | 14500.000 | 1600.90 |
| | 4659.000 | 1110.70 | 8840.000 | 1495.40 | 15000.000 | 1582.30 |
| | 4687.000 | 1241.00 | 9004.000 | 1482.90 | 15069.000 | 1582.30 |
| | 4723.000 | 1340.30 | 9159.000 | 1501.60 | 15125.000 | 1588.50 |
| | 4737.000 | 1396.10 | 9294.000 | 1495.40 | 15267.000 | 1600.90 |
| | 4759.000 | 1458.20 | 9395.000 | 1464.40 | 16000.000 | 1600.90 |
| | 4791.000 | 1507.80 | 9451.000 | 1451.90 | 17000.000 | 1600.90 |
| | 4867.000 | 1557.60 | 9530.000 | 1439.60 | 18000.000 | 1600.90 |

$dc = 0.95$ cm.

$g = 1.27$ cm.

$P_s = 660\ N/m^2$

$f = 1979\ H_z$

$Q_s = 14.9 \times 10^{-6}\ m^3/sec.$

| Pc (db) | Po ($N/m^2$) |
|---|---|
| 90 | 174.3 |
| 95 | 171.1 |
| 100 | 156.6 |
| 102 | 146.9 |
| 105 | 117.8 |
| 107.5 | 88.8 |
| 110 | 61.3 |
| 112.5 | 41.2 |
| 115.0 | 30.7 |
| 120 | 17.8 |
| 125 | 15.3 |

APPENDIX E.3

SWITCHING TIMES

dc = 2.54 cm.

g = 3.81 cm.

$P_s$ = 1120 $N/m^2$ (Re = 1244)

$Q_s$ = 18.7 x $10^{-6}$ $m^3$/sec.

| f ($H_z$) | Pc (db.) | Tℓ.d. (m.sec.) | Tf. (m.sec.) | Tt.d. (m.sec.) | Tr. (m.sec.) |
|---|---|---|---|---|---|
| 2200 | 90 | 2.4 | 0.4 | 2.4 | 0.4 |
| 2200 | 95 | 2.3 | 0.5 | 2.4 | 0.6 |
| 2200 | 100 | 2.2 | 0.4 | 2.8 | 0.9 |
| 2600 | 90 | 2.0 | 0.4 | 2.4 | 0.7 |
| 2600 | 95 | 2.4 | 0.5 | 2.0 | 0.5 |
| 2600 | 100 | 2.3 | 0.6 | 2.5 | 0.9 |
| 3100 | 90 | 2.4 | 0.5 | 2.2 | 0.5 |
| 3100 | 95 | 2.2 | 0.6 | 2.3 | 0.6 |
| 3100 | 100 | 2.2 | 0.7 | 2.5 | 0.8 |
| 3700 | 90 | 2.3 | 0.5 | 2.4 | 0.5 |
| 3700 | 95 | 2.2 | 0.3 | 2.2 | 0.5 |
| 3700 | 100 | 2.1 | 0.5 | 2.7 | 0.6 |
| 4400 | 90 | 2.2 | 0.3 | 2.3 | 0.4 |
| 4400 | 95 | 2.2 | 0.3 | 2.4 | 0.2 |
| 4400 | 100 | 2.1 | 0.7 | 2.6 | 0.5 |

dc = 2.54 cm.

g = 3.81 cm.

Pc = 100 db.

f = 3100 $H_z$.

| $P_s$ ($N/m^2$) | $Q_s$ ($m^3/sec. \times 10^{-6}$) | Tℓ.d. | Tf. | Tt.d. | Tr. |
|---|---|---|---|---|---|
| 1220 | 23.5 | 2.0 | 0.3 | 2.4 | 0.5 |
| 1030 | 20.5 | 2.0 | 0.5 | 2.7 | 1.3 |
| 920 | 19.3 | 2.3 | 0.8 | 3.0 | 0.5 |
| 834 | 17.5 | 2.7 | 0.4 | 3.0 | 0.6 |

## VITA AUCTORIS

| | |
|---|---|
| 1948 | Born in Chatham, Ontario, Canada on April 23. |
| 1965 | Completed high school Chatham Kent Secondary School, Chatham, Ontario, Canada in June. |
| 1968 | Recieved the Mechanical Technologist Diploma from St. Clair College, Windsor, Ontario, Canada in May. |
| 1971 | Recieved the Degree of Bachelor of Applied Science in Mechanical Engineering from the University of Windsor, Windsor, Ontario, Canada in May. |
| 1974 | Currently a candidate for the Degree of Master of Applied Science in Mechanical Engineering at the University of Windsor, Windsor, Ontario, Canada. |