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# INVESTIGATION OF AERODYNAMIC BURNER NOISE OF LOCAL BAKARIES

BY

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Submitted in partial fulfillment of the requirements for the degree

of master of science in mechanical engineering.

Faculty of Graduate Studies,

University of Jordan.

January , 1992

Amman , Jordan

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*To my mother, Rahmeh and*
*the soul of my father, Ali*

# ACKNOWLEDGEMENTS

It is with deep pleasure I express my gratitude to all who helped me during the preparation and completion of this work. Special thanks are indebted to my supervisor, Dr. M. Audi, who without his support, encouragement, and advice, my work could have been more difficult. Also I highly appreciate the patient and support of my family during my long preoccupation with this research, especially my brother Dr. N. Nasrallah and my dearest mother, Rahmeh. It is also important to mention with gratitude the valuable effort of Miss Rama Ayyash in helping me preparing the tables of data, and the helps of Miss Reem Salah in printing the final version of this thesis. Finally, I should not forget the support given to me by all my friends throughout this work.

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# ABSTRACT

The sound field of four identical parallel micro-jets, each of 1 *mm* throat diameter is investigated. Experimental results on sound generation of a single jet , show that the magnitude of the sound pressure level is independent of the frequency of the source sound, with peak intensity lies at an angle of 36° with the jet axis. Results of four parallel jets sound field shows that the four jet arrangement, indicates a similar behaviour to the single jet case, excluding the region at the jet axis . Overall sound pressure level results confirm previous conclusion regarding the peak value.

The power watt level results of a single jet is shown to be independent of the sound source frequency, also it was found that the estimated total spectral acoustic power of a single jet is independent of the choice of the strip area.

The experimentally correlated overall sound power level with jet velocity shows that for choked jets, this power level depends on the fourth power of the jet velocity.

Comparison between results of this research and other experiments conducted on subsonic jets, shows that the choked jet directivity pattern exhibits a more peaked sound levels relative to subsonic jets.

| | |
|---|---|
| $\rho$, | Fluid density; |
| $\gamma$, | Specific heat ratio; |
| $\theta$, | Angle from the jet axis; |
| $\lambda$, | Wave length; |
| $\phi$, | Angle defined by eq.(4.1); |

**Subscripts**

| | |
|---|---|
| $o$, | Down Stream (ambient conditions); |
| $rms$, | Root Mean Square; |
| $i$, | Segment number; |
| $st.$, | Standard Conditions; |
| $cor.$, | Corrected Value; |
| $ref.$, | Reference Value; |
| $h$, | Hemispherical; |

# Chapter 1

# INTRODUCTION

## 1.1 General

In recent decades noise has become one of the major environmental problems in the industrialized countries. It affects not only health by causing loss of hearing, but it is a well known source of stress and annoyance to people. In addition, it causes property loss such as damaging structures by fatigue resulting from repeated stresses, and it peels paint and cracks wall plaster among other damaging effects.

At the beginning of the seventies concern was drawn to noise as a major environmental problem by many activities which have focused on various aspects regarding industrial and community noise. These activities include conferences, seminars and workshops. Furthermore, universities started teaching courses on industrial and environmental noise, and many research projects were initiated on jet noise when there was interest in supersonic civilian air transport.

In Jordan, the environment has recently become a major concern to the government and community. Traffic noise and noise in factories among other industrial entities are of concern in Jordan. In addition, the noise of jet burners used in local bakaries has its own role in noise generation . So, the present research is the first step in focusing attention to such as jet flows where flow and flow gradient are inherently present.

Schaffar [8] has studied experimentally the emitted noise spectrum of a cold jet at a Mach number of 0.9 with Strouhal number values below 0.5, which lead him to identify essentially the "shear noise" type. While Ahuja [9] produced empirical relations to correlate and predict accurately the noise of cold and clean jet against doppler corrected Strouhal number. He has [10] taken measurements of subsonic jet noise produced by a model jet rig in an anechoic chamber. The noise spectra for three nozzles having diameters of 2.84, 2.4 and 1.5 *inches* were considered. Tana [11] studied experimentally spectral and directivity patterns of turbulent mixing noise in the far field from subsonic and fully-expanded supersonic jet flows. He presented the effect of jet temperature and exit velocity on the overall sound intensity of the jet. Shocked jets are investigated extensively by his research [12] , where results are compared directly with the corresponding results from shock-free jets. Moon and Zelazny [13] have studied a circular jet exhausting into an ambient environment. Detailed turbulence profiles were measured at 28 axial locations extended from the nozzle exit to 12 nozzle diameters. A noise model was obtained which predicts accurately spectral distribution and directivity pattern in terms of self and shear noise components. Also MacGregor *et al* [14] studied experimentally jet noise spectra and narrow band directivities at jet Mach numbers of 0.5 and 0.9. Comparison between such results and the theory is included, where experimentally determined correction for refraction with theoretically dedicated correction for convection are obtained. Long and Arndt [15] by studying jet noise at low Reynolds number, concluded that the spectral properties of the jet noise change significantly and the relative acoustic power is found to be lower when the Reynolds number is below $10^5$. Yamamoto and Arndt [16] studied the effect of Reynolds number on the peak Strouhal frequency of a subsonic jet, stating that although peak Strouhal frequency is a weak function of Reynolds, at higher Reynolds numbers the peak Strouhal number increases with increasing emission angle.

Bechert *et al* [17] have conducted experiments on the superposition of a subsonic turbulent jet flow and pure tone sound coming from inside the nozzle. They made comparisons between the radiated sound power in the far field and the transmitted sound power from the nozzle. Parthasarathy *et al* [18] studied a method of identification and measurement of core noise and jet noise separately based on cross-correlation of signals from microphones located at widely separated angles in the far field of the jet. Michel and Fuchs [19] considered the far field condition itself, where the jet was modeled by a distribution of 160 discrete, fixed point sources. It was found that while the geometric near-field effect depends on Strouhal number, the interference near-field effect depends strongly on Mach number in addition to Strouhal number.

Heated and unheated jets are studied numerically by Maesrello and Bayliss [20], where the interaction of an acoustic pulse with the experimentally determined mean flow field of a spreading jet has been simulated. The jet itself is shown as an amplifier of sound. The difference in the spectra of the heated and unheated jets can be attributed to differences in the stability characteristics of the jet.

Shivashankara and Bhat [21] have studied a suppression mechanism of two -parallel-jet model. Results of their experiments showed that noise from a high-velocity jet is reduced by placing a second jet of lower velocity parallel to it and on the same side as the listener. Jet noise reduction is studied also by Morris *et al* [22], where the effect of introducing a second jet of smaller exit area near to the main jet leads to a refractive modification in the directivity of noise radiation of the main jet.

It should be noted that the current published experimental and theoretical jet noise research did not consider small jets, those of about 1 $mm$. Therefore, no theoretical or experimental work was done on micro-jets, such as the four parallel jets of burners used in local bakaries. The current research bridges the available gab in the field of knowledge of jet noise.

The literature review presented in this chapter provided the basic knowledge for undertaking the present work.

## 1.3 The Radiation Field of Sound Source

The character of the radiation field of a source noise depends on the distance from this source. In the source vicinity an appreciable tangential component of the velocity may exist, because the particle velocity is not necessarily in the direction of wave propagation, hence, the near-field is such a field where appreciable variations of the sound-pressure along a given radius exist. The extent of the near-field depends on the frequency and the source dimension.

Far-field condition occurs when the sound pressure level decreases by 6 dB for each doubling of distance. Within far-fields, the particle velocity is primarily in the direction of the sound wave propagation and the pressure amplitude is inversely proportional to the distance $r$ from the source. The particle velocity will be in phase with pressure at distances large compared with the wave length $\lambda$ and out of phase in the region $r$ is less than $\lambda$ [23].

The reverberant field exist when the reflected waves from the surrounding boundaries are superimposed upon the incident field. Fig(1.1) shows the characteristic difference between near, far, and reveberant fields.

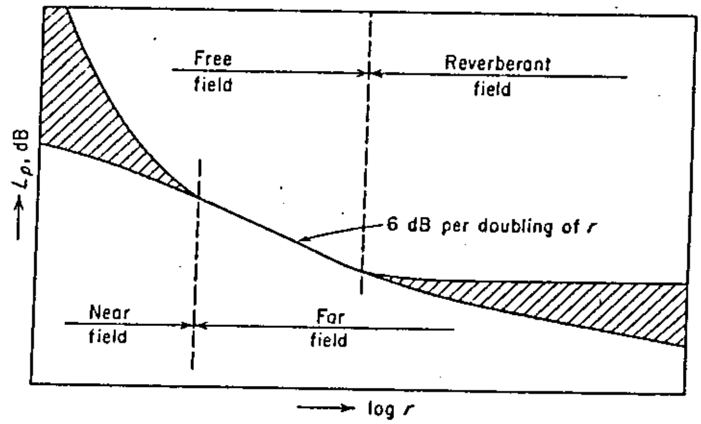


Fig.(1.1) The variation of sound-pressure level with distance from the source.

# Chapter 2

# TEST RIG AND EXPERIMENTAL PROCEDURE

## 2.1 Experimental Setup

The test rig shown schematically in fig.(2.1) was used in the experimental investigation of the noise field of a burner used in local bakaries. It is the so called "Arabian-head" burner Fig.(2.2); which is a well-known burner type in common use here. The burner consists of four identical parallel jets issuing from four nozzles each of 1.0 $mm$ base diameter made on the side of 20 $mm$ pipe having a thickness of 2.0 $mm$. While the front diameter of the nozzle is 6.0 $mm$. The burner is manufactured locally.

The heat generated from the combustion of the diesel fuel which is injected through the burner, heats the fuel flow in the pipe up until vaporization occurred, and the combustion process of fuel vapor proceeds.

Two galvanized steel tanks 3.0 $mm$ thick with different volumes are used as reservoirs of compressed air. The 0.125 $m^3$ volume tank is required to keep the pressure of the system constant throughout measuring sound pressure levels; while the $0.04m^3$ volume tank fitted, with a valve, is used to control the pressure of the air in the pipe. The test rig is rigidly supported on the solid ground at the mechanical engineering laboratories. The

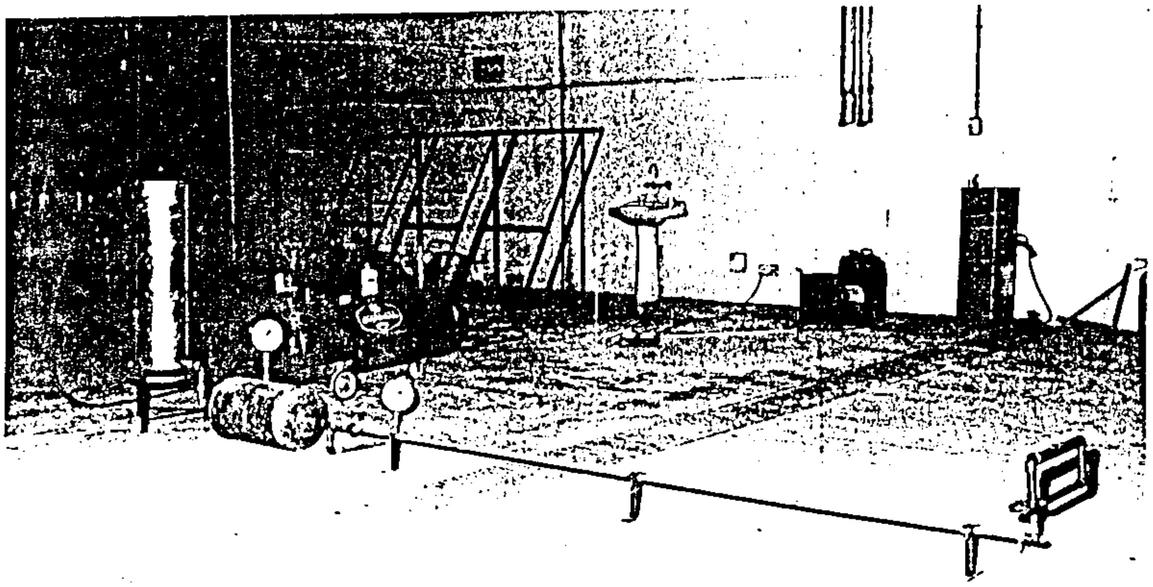

Fig.(2.3) The test rig.

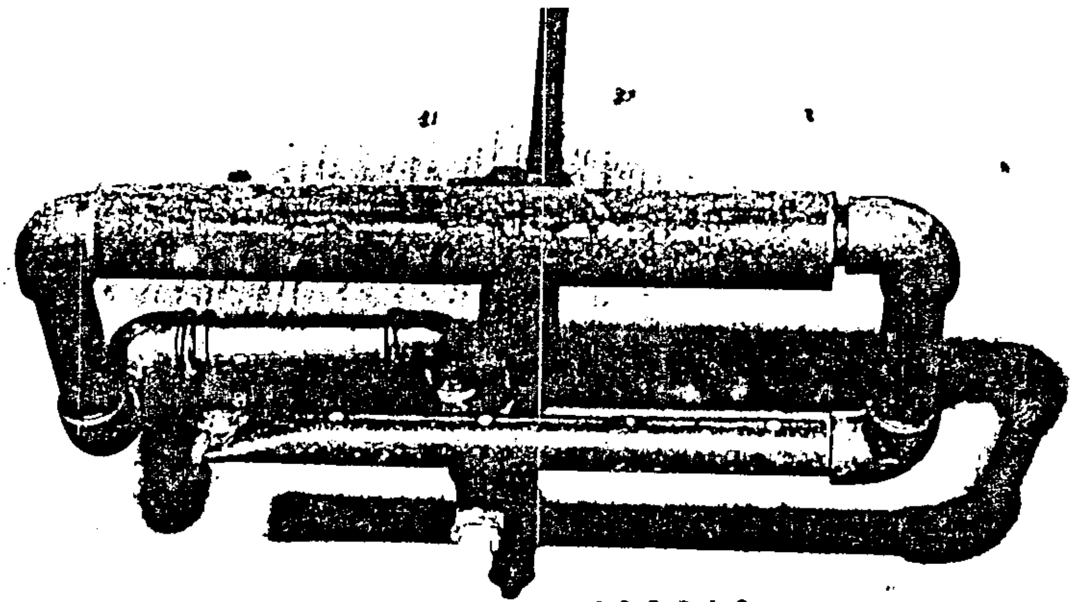



Fig. (2.4) Jet assembly.

3. $\frac{1}{2}$ inch Condenser Microphone (B&K Type 4165) is fitted with Preamplifier Type (B&K 2619).

4. Band Pass Filter (B&K Type 1618) with 21 third octave filter bands, centre frequencies 2Hz to 20 KHz, digital display of selected centre frequency and band width is provided.

5. Measuring Amplifier (B&K Type 2610) which covers an overall frequency range from 2Hz up to 200 KHz, with hold mode for both peak and RMS measurements.

6. Level Recorder (B&K Type 2307) with calibrated strip-chart paper 50 *mm* width (B&K Type QP1124) is used to record RMS level as a function of frequency.

## 2.3 Experimental Procedure

The measuring instruments are connected as shown schematically in fig.(2.6). The tested sound source is applied after a step by step calibration procedure suggested by the operation manual of the Measuring Amplifier is followed.

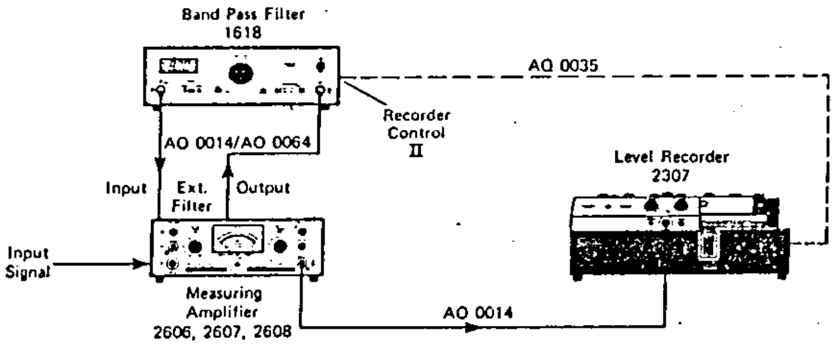


Fig.(2.6) Schematic diagram of the Measuring Instrumentation

### 2.3.1 Single Jet

Sound pressure level of the tested jet can be measured as the following step by step procedure suggests:

1. The barometric pressure, and the dry and wet bulb temperatures of the ambient air were measured and recorded at the beginning of each test period.

2. After selection of one jet from the existing four, the remaining three jets are properly closed by using screwed clamps. Then the jet under consideration is centered with the circle drawn on the ground.

3. The air compressor pressure is selected to be $5.0\frac{Kg}{cm^2}$ ( 490.50 $Kpa$), and the pressure differential setting is $1.5\frac{Kg}{cm^2}$ (147.15 $Kpa$) to ensure compressor switching on if the pressure becomes less than $3.5\frac{Kg}{cm^2}$ (343.35 $Kpa$), and switching off when the pressure exceeds $6.5\frac{Kg}{cm^2}$ (637.65 $Kpa$).

4. Measuring instruments including Condenser Microphone, Band Pass Filter, Measuring Amplifier and Level Recorder were connected as shown in fig.(2.6) and then calibrated.

5. Environmental noise was then recorded, by selection of a proper deflection of the meter on the Measuring Amplifier, followed by pressing the right-hand FILTER CONTROL MODE switch of the Band Pass Filter to "Run".

6. With the valves 2 and 3 of the test rig being closed, the power of the compressor was set to "On".

7. The Condenser Microphone was placed at the required measuring position at certain height from the ground. Typical height of the seven measuring points are tabulated in table(2.1).

8. The valves 2 and 3 are now opened until the required pressure is reached, then the right-hand FILTER CONTROL MODE switch of the Band Pass Filter is pressed to "Run".

**Table (2.1) : Coordinates of The Measuring Points**

| Station | Angle To jet axis (deg.) | Horizontal coordinate (m) | Microphone height (m) |
|---|---|---|---|
| 0 | 90 | 2.00 | 0.32 |
| 1 | 75 | 1.93 | 0.84 |
| 2 | 60 | 1.73 | 1.32 |
| 3 | 45 | 1.41 | 1.74 |
| 4 | 30 | 1.00 | 2.06 |
| 5 | 15 | 0.52 | 2.26 |
| 6 | 0 | 0.00 | 2.32 |

9. Steps 6 and 7 are repeated for other values of working pressures, to get full scheme sound pressure levels at different working pressures and various measuring positions.

10. Results are deduced from the recorded spectrograms, compared with environmentally generated noise, then tabulated properly.

### 2.3.2 Four Jets

Experimental procedure regarding four jets investigation is as follows.

1. The screwed clamps used to cover the three jets were removed, then the jet arrangement is centered with the circle drawn on the ground.

2. Steps used for single jet measurements of sound pressure level were followed for the four jets case, resulted with experimental spectrograms.

3. Numerical values of sound pressure levels are deduced from such spectrograms, compared with environmental noise, and finally tabulated.

# Chapter 3

# RESULTS AND DISCUSSION

## 3.1 Data Reduction

### 3.1.1 Introduction

A hemispherical space of four meters diameter with the jet as sound source laying at the center of the space is well suited to the case of open air above a rigid floor. The arrangement was used to collect spectral sound pressure levels of a single and four jets under five gauge pressure settings, 2.5, 3.0, 3.5, 4.0 and 4.5 bar respectively. Each of the measurements at 15° angle increments with the jet axis, resulting in four measuring stations with seven measuring points for each station. One of the experimental spectrograms of a single jet at 2.5 bar is shown in fig.(3.1), while numerical values of sound pressure levels (SPL) produced from such spectrograms are tabulated in appendix A.

Two methods of calculating segmental area required to deduce sound power levels were tested, the first one is by assuming equal area contribution of each of the seven existing experimental stations, while the other is depending on 15° strip area segments, These areas were calculated from the following relationship:

$$\begin{pmatrix} A_i = 2\pi r^2(\sin\phi 2 - \sin\phi 1) \\ \phi 1 = \theta 1 - 7.5 \\ \phi 2 = \theta 1 + 7.5 \end{pmatrix} \tag{3.1}$$

where:

$A_i$: area of segment $i$, $m^2$

$r$: radius of the hemisphere,$m$

$\theta 1$: angle from the jet axis in degrees at which the measurement is taken.

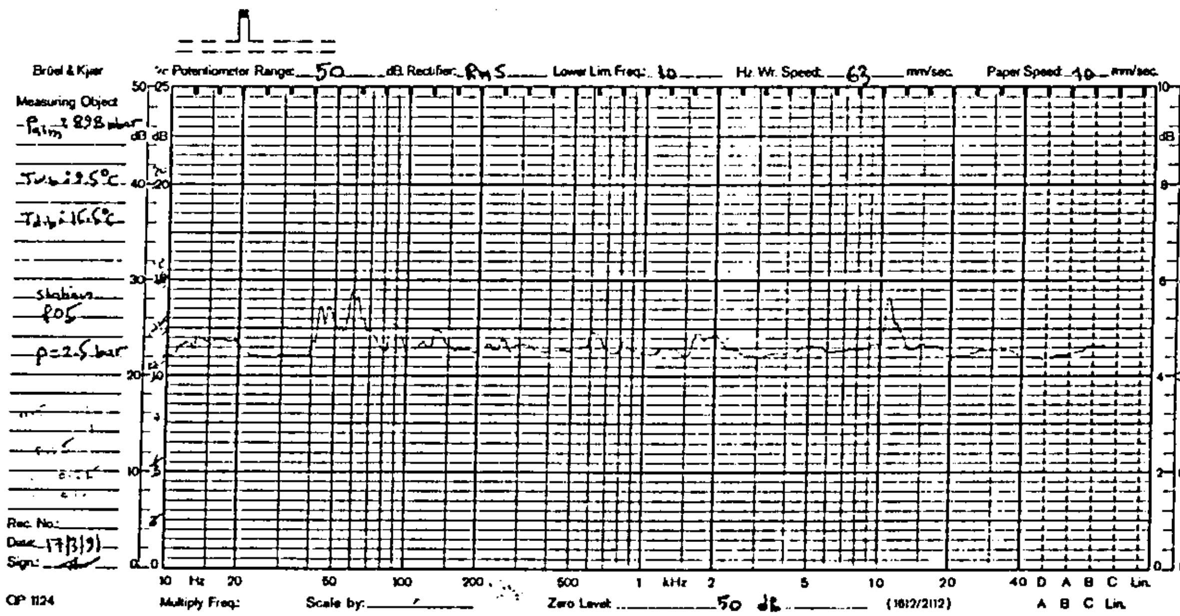


Fig.(3.1) Single jet SPL spectrogram at 2.5 bar

### 3.1.2 Sound Power level (PWL)

The root mean square pressure can be calculated from the knowledge of sound pressure levels produced from the experimental spectrograms. And directional sound power emitted by the source is determined through out calculating the sound intensity which is given by:

$$I_i = \frac{(p_{rms})^2}{\rho c} \tag{3.2}$$

where:

$I_i$:directional sound intensity, $\frac{watt}{m^2}$

$p_{rms}$:root mean square sound pressure, $\frac{N}{m^2}$

$\rho c$:characteristics resistance of the medium at a given temperature and pressure.

The density dependent of the speed of sound in any gas $c$ is given by:

$$c = \sqrt{\frac{\gamma p_s}{\rho}} \tag{3.3}$$

where:

$p_s$: gas pressure, $\frac{N}{m^2}$

$\gamma$ : ratio of specific heat of the gas at constant pressure to the specific heat at constant volume, this ratio is 1.4 for air

$\rho$: density of the gas obtained from thermodynamic tables.

The density should be corrected to compensate for the difference between experimental conditions including temperature and pressure and standard values, then for air :

$$\rho_{corr} = \frac{p_1}{p_{st}} \frac{T_{st}}{T_1} \rho_{st} \tag{3.4}$$

where:

$\rho_{corr}$ : corrected density, $\frac{kg}{m^3}$

$p_{st}$ : standard atmospheric pressure, $\frac{N}{m^2}$

$T_{st}$ : standard temperature, $^{\circ}c$

$\rho_{st}$ : air density obtained from tables at $p_{st}$ and $T_1$

$T_1$ : measured ambient temperature, $^{\circ}c$

$p_1$ : measured atmospheric pressure, $\frac{N}{m^2}$

The root mean square sound pressure is obtained from sound pressure level as suggested by Beranek [24]:

$$p_{rms} = p_{ref} 10^{(\frac{SPL}{20})} \tag{3.5}$$

where:

$p_{ref}$ :reference rms sound pressure, usually taken as $2 \times 10^{-5}$ $\frac{N}{m^2}$ for air born sound, this value represents the threshold limit of hearing.

The spectral directional sound power is calculated from:

$$W_i = IA_i = \frac{(p_{rms}^2)}{\rho c} A_i \tag{3.6}$$

where:

$A_i$: strip area of the required segment, $m^2$

Now total spectral sound power can be calculated through summing out of all directional sound power components:

$$W = \sum_{i=1}^{N} W_i \tag{3.7}$$

where:

W: total spectral sound power, watt

N: number of tested directions=7

When the spectral sound power is known, the sound power level (PWL) can be calculated from [24]:

$$PWL = 10\log_{10}(\frac{W}{W_{ref}}) \tag{3.8}$$

where $W_{ref}$ is the reference sound power taken as $1 \times 10^{-12}$ *watt*.

Overall sound power level (OAPWL) is determined by adding spectral sound powers over all frequency bands. Equation(3.8) is used to calculate OAPWL. A similar approach can be used to calculate over all sound pressure level through adding individual spectral sound power overall frequency band, then eqs.(3.6)and (3.5) are used respectively to find $p_{rms}$, and finally overall sound pressure level can be calculated from [24]:

$$SPL = 10\log_{10}(\frac{p_{rms}}{p_{ref}})^2 \tag{3.9}$$

### 3.1.3 Directivity Index

Most sound source of practical interest are some what directive, which means that one will measure different sound pressure levels in a given frequency band for different directions at a fixed distance from the sound source.

Directivity index is a numerical measure of the directivity of sound sources. For a sound source at an angle $\theta$ and for a given frequency , directivity index $DI_\theta$ is given by:

$$DI_\theta = SPL_\theta - \overline{SPL_h} + 2.445 \tag{3.10}$$

where

$SPL_\theta$:sound pressure level measured at distance r and angle $\theta$ from the source,dB.

$\overline{SPL_h}$ : space-average mean-square sound pressure level determined over the test hemisphere.

The 2.445 dB in this equation is added because the measurement was made over a hemispherical space having a surface area of 28.63 $m^2$ instead of the full measuring sphere surface area 50.24 $m^2$. The reason for this is that the intensity at radius $r$ is 1.76 as large if a source radiates into the tested hemisphere compared to a full sphere.

To obtain a space-average mean-square sound pressure, the following procedure was used:

1. Sound pressure level at each microphone position is converted into mean square pressure ratio multiplied by the corresponding segment area.

$$A_i \frac{p_i^2}{p_{ref}^2} = A_i 10^{(\frac{SPL_i}{10})} \tag{3.11}$$

where:

$A_i$: area of the i th test segment, $m^2$

$\frac{p_i^2}{p_{ref}^2}$ : mean square sound pressure ratio of the segment under consideration.

$SPL_i$ : sound pressure level of the tested segment, dB.

2. The $A_i \frac{p_i^2}{p_{ref}^2}$ products are added over all experimental segments, and the result is divided by the total surface area of the test hemisphere, to get $\frac{p_h^2}{p_{ref}^2}$.

3. The resulting sum is converted into space-average sound pressure level by the means of eq.(3.9).

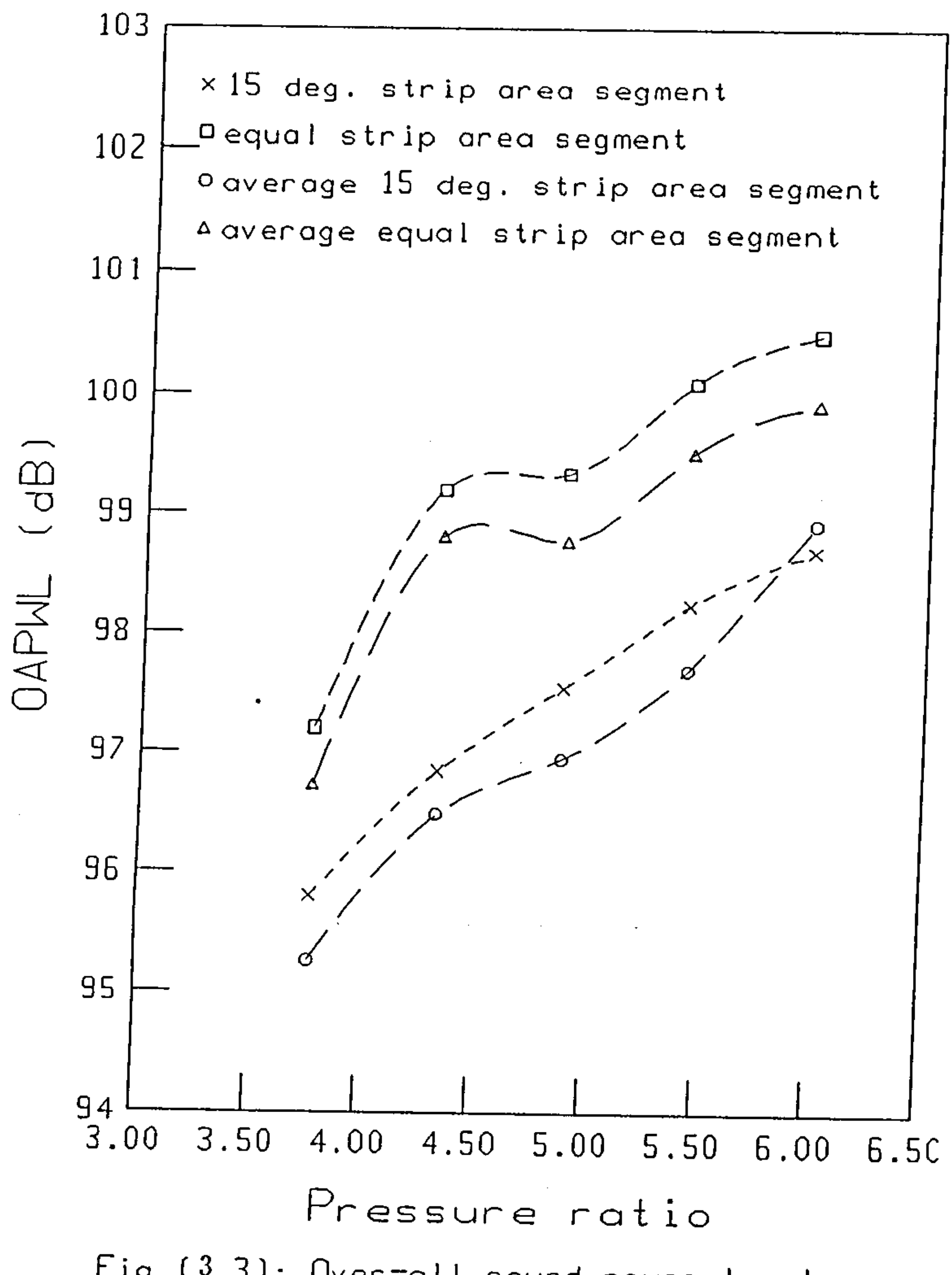


Fig.(3.3): Over-all sound power levele of four parallel jets

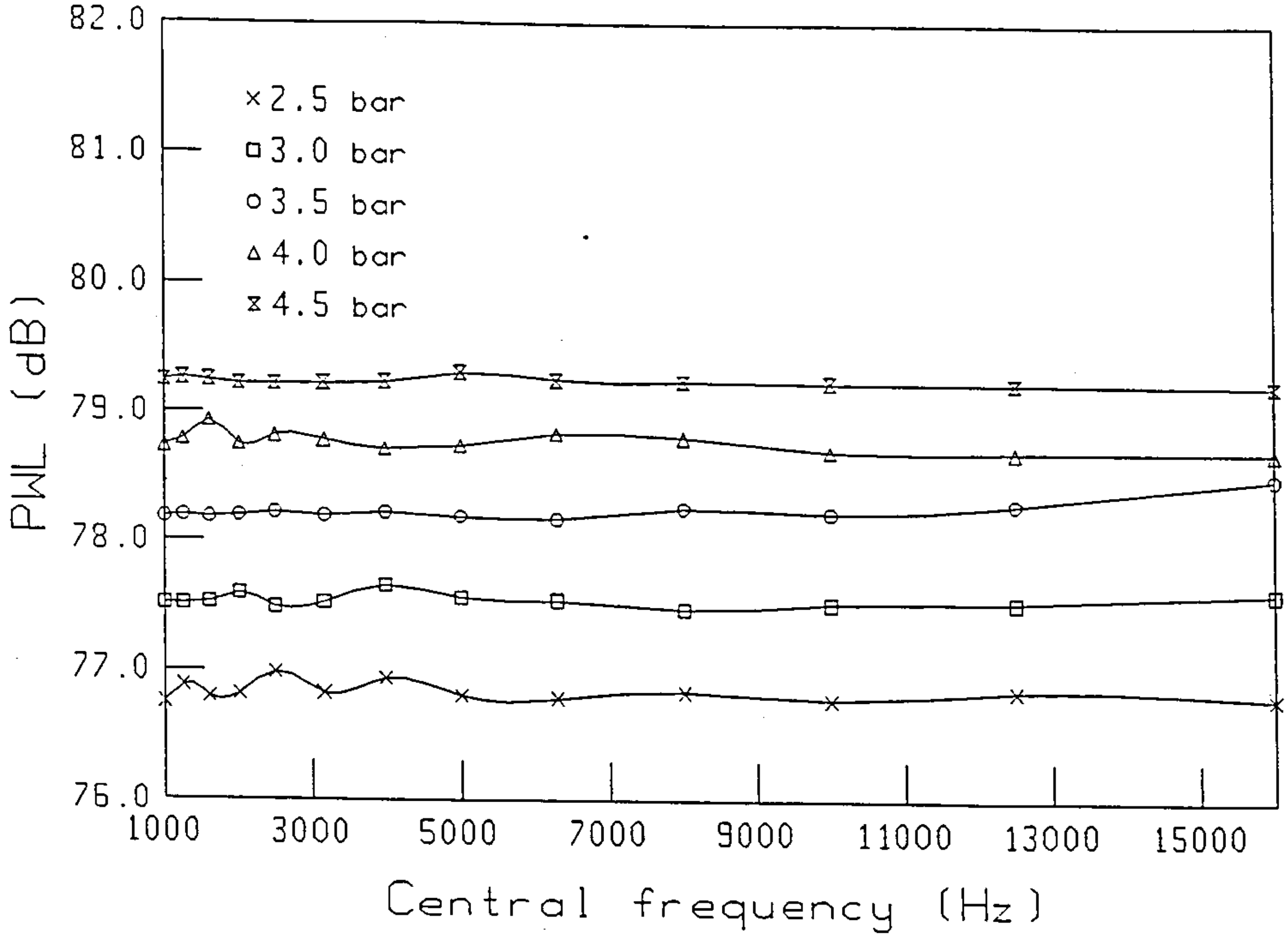


Fig.(3.4-c): Spectral sound power level of a single jet

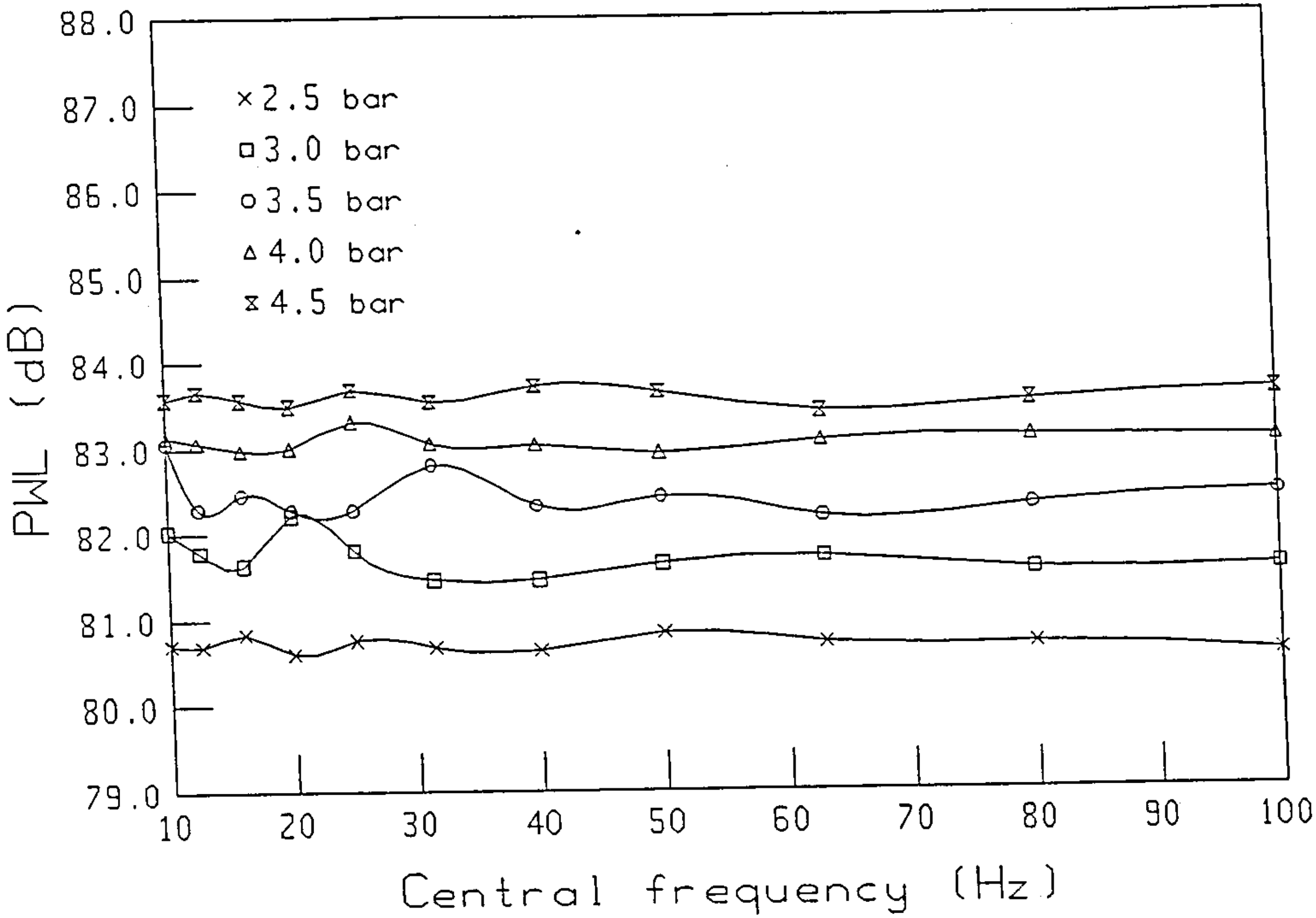


Fig.(3.5-a): Spectral sound power level of four jets

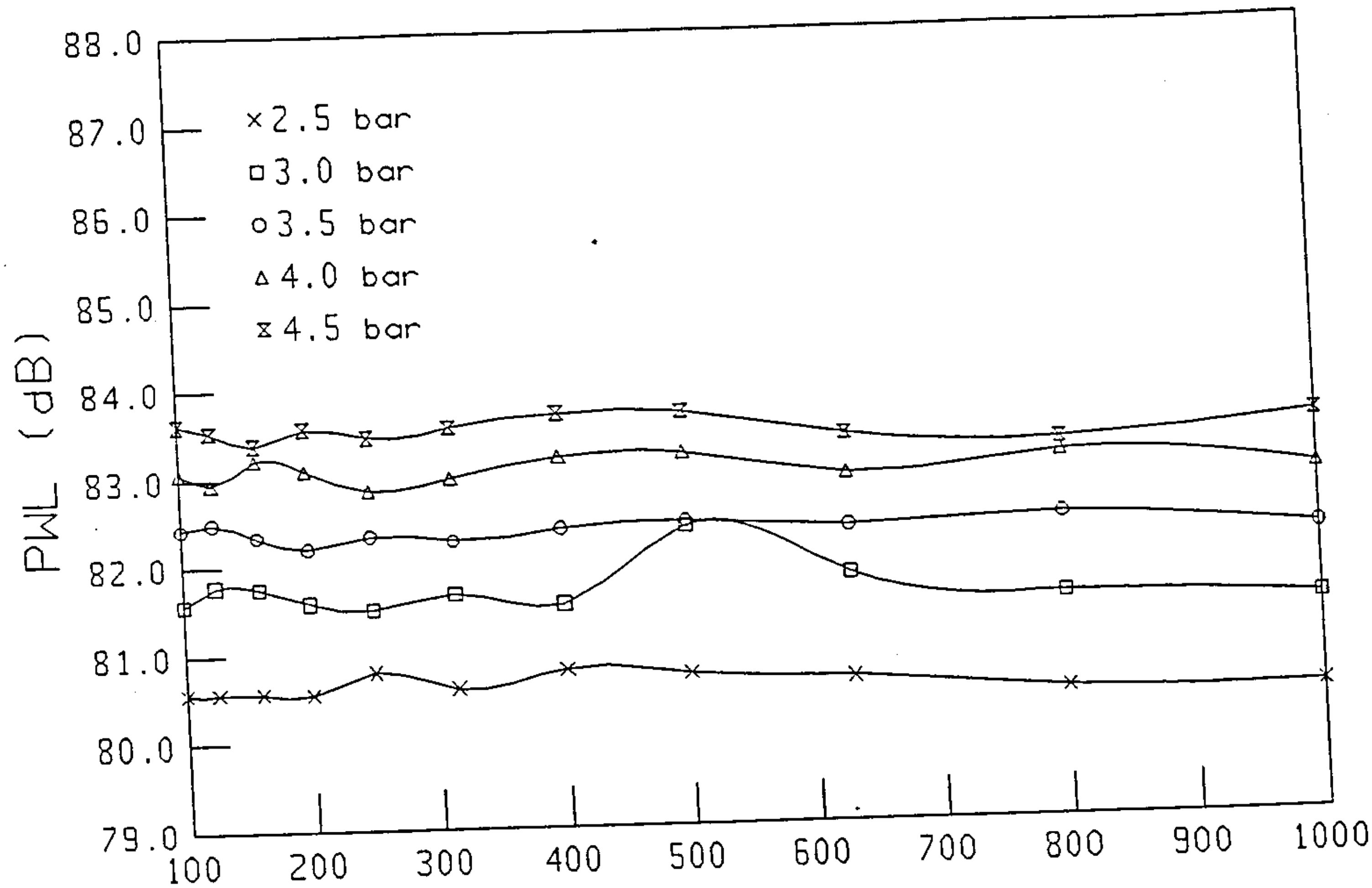


Fig.(3.5-b): Spectral sound power level of four jets

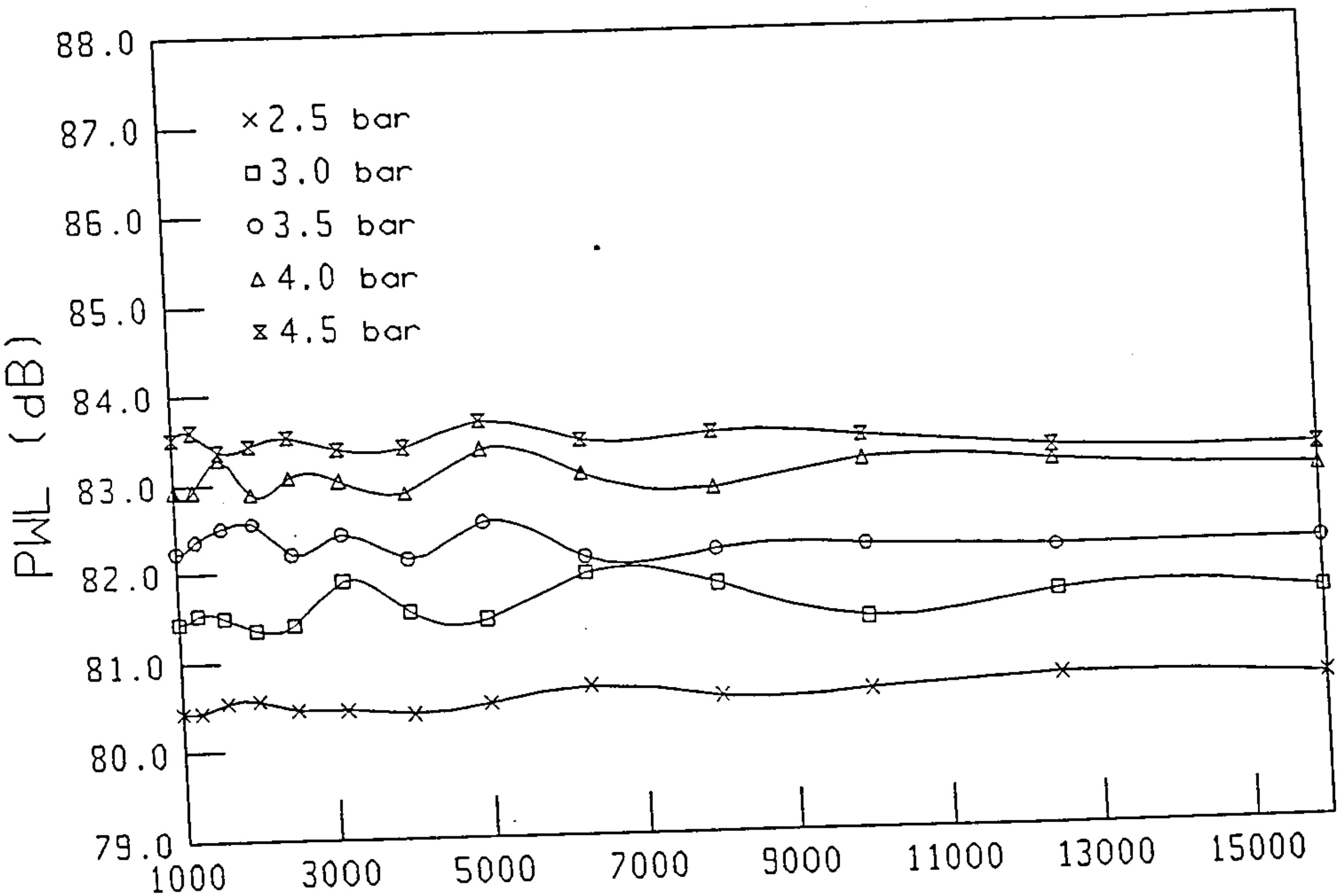


Fig.(3.5-c): Spectral sound power level of four jets

In the present research, and by using linear regression it was found that the sound power watt level for choked conditions can be expressed mathematically by:

$$PWL = 10\log_{10}(BV_j{}^n) \qquad (3.13)$$

Where B and n are constants having different numerical values, according to the selection of area segment in estimating jet acoustic power . Typical experimentally determined values for B and n are tabulated in table(3.1).

Table (3.1) Typical values of B and n

| Condition | B | n |
|---|---|---|
| Single jet 15° area segment | 11.351 | 3.012 |
| Single jet equal area segment | 21.609 | 2.906 |
| Four jets 15° area segment | 0.604 | 3.605 |
| Four jets equal area segment | 0.234 | 3.836 |
| Four jets average 15° area segment | 1.156 | 3.498 |
| Four jets average equal area segment | 0.796 | 3.624 |

Results obtained from figs.(3.6) , (3.7) and table(3.1) show that for choked jets with supersonic speeds this index indicates a lower value near the $4th$ power, which matches the $4th$ power conclusion drawn by Crule [26].

## 3.5 Directivity of Overall Sound Pressure Level

It can be concluded from fig.(3.8) that the maximum sound intensity region lies at an angle of 36° from the jet axis, while a difference of about 2 dB was noticed between maximum intensity at 36° and that at an angle of 90°from the jet axis.

The four jets directivity pattern of over all sound pressure level shown in fig.(3.9) suggested a similar behaviour to the single jet case, excluding the region at the jet axis where high sound pressure levels caused by intense turbulence occur, leading to high sound intensities.

The directional characteristics of choked jet noise will be apparent with some what more peaked than the usual subsonic jets described by Ribner [3] , because chock formation occurs outside of the nozzle and a new source of noise appears in addition to the jet noise. Fig.(3.10) with directional characteristics of relative overall sound pressure level gives good agreement with results of subsonic jets. It is shown also that a more peaked pattern than that of subsonic case can be noticed easily.

## 3.6 Directivity of Spectral Sound Pressure Level

### 3.6.1 Single Jet

It was found experimentally, figs.(3.11) to fig.(3.19) that the peak value of the sound pressure level (SPL) of a single jet over all frequency bands lies at an angle less than 45° with the jet axis. This is in full agreement with Crule [26] and Heller and Franken [27], who stated that for a gas jet, the maximum noise radiated in the annular region of 30° to 45° from the jet axis. The behaviour indicated in Fig.(3.18 ) at 3.0 bar is due to superimposed environmental noise on the measured sound level.

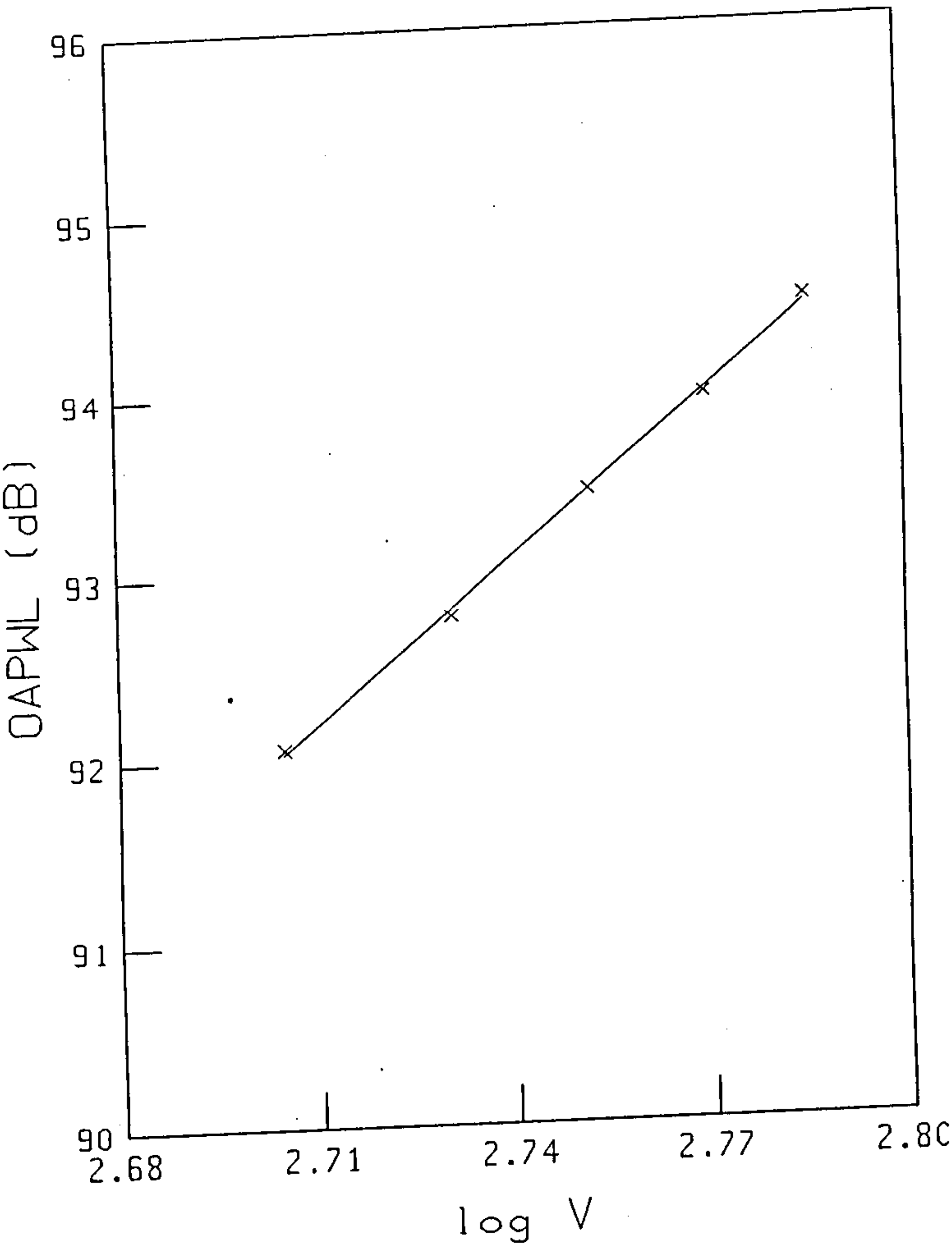


Fig.(3.6): Velocity dependence of over-all sound power level of a single jet

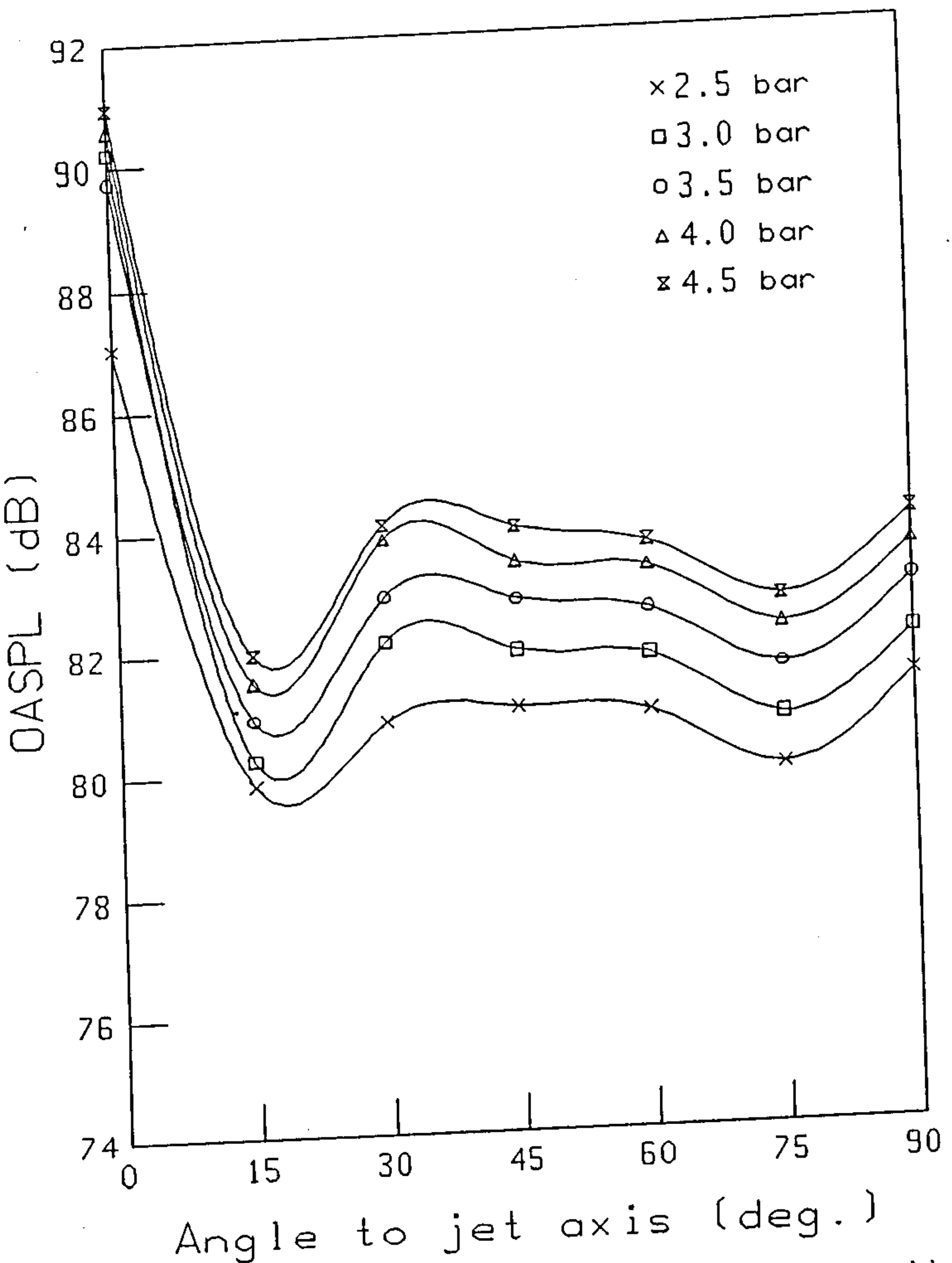


Fig.(3.9): Directivity pattern of over-all sound pressure level of four jets

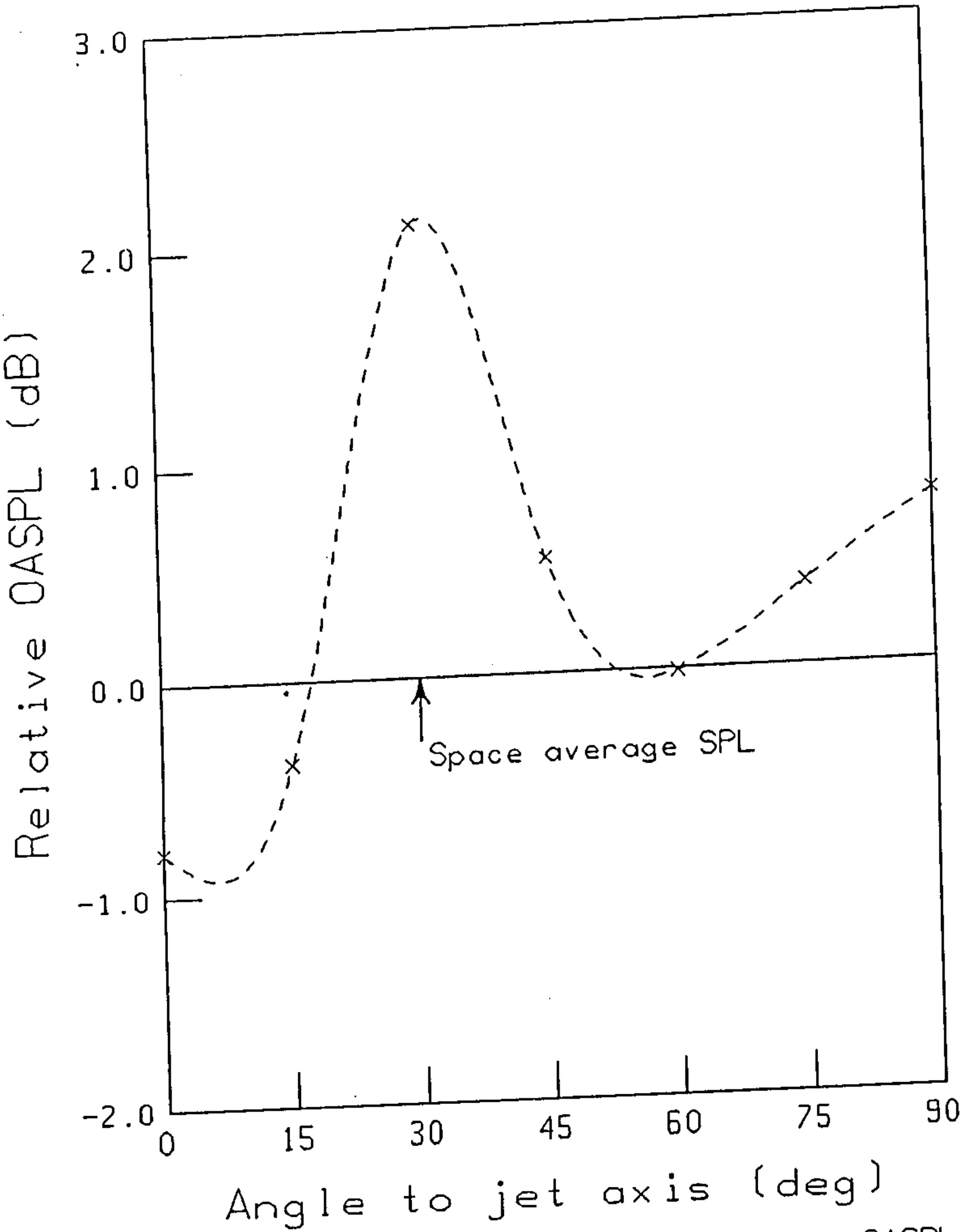


Fig.(3.10-a): Directivity of relative OASPL of a single jet at 2.5 bar

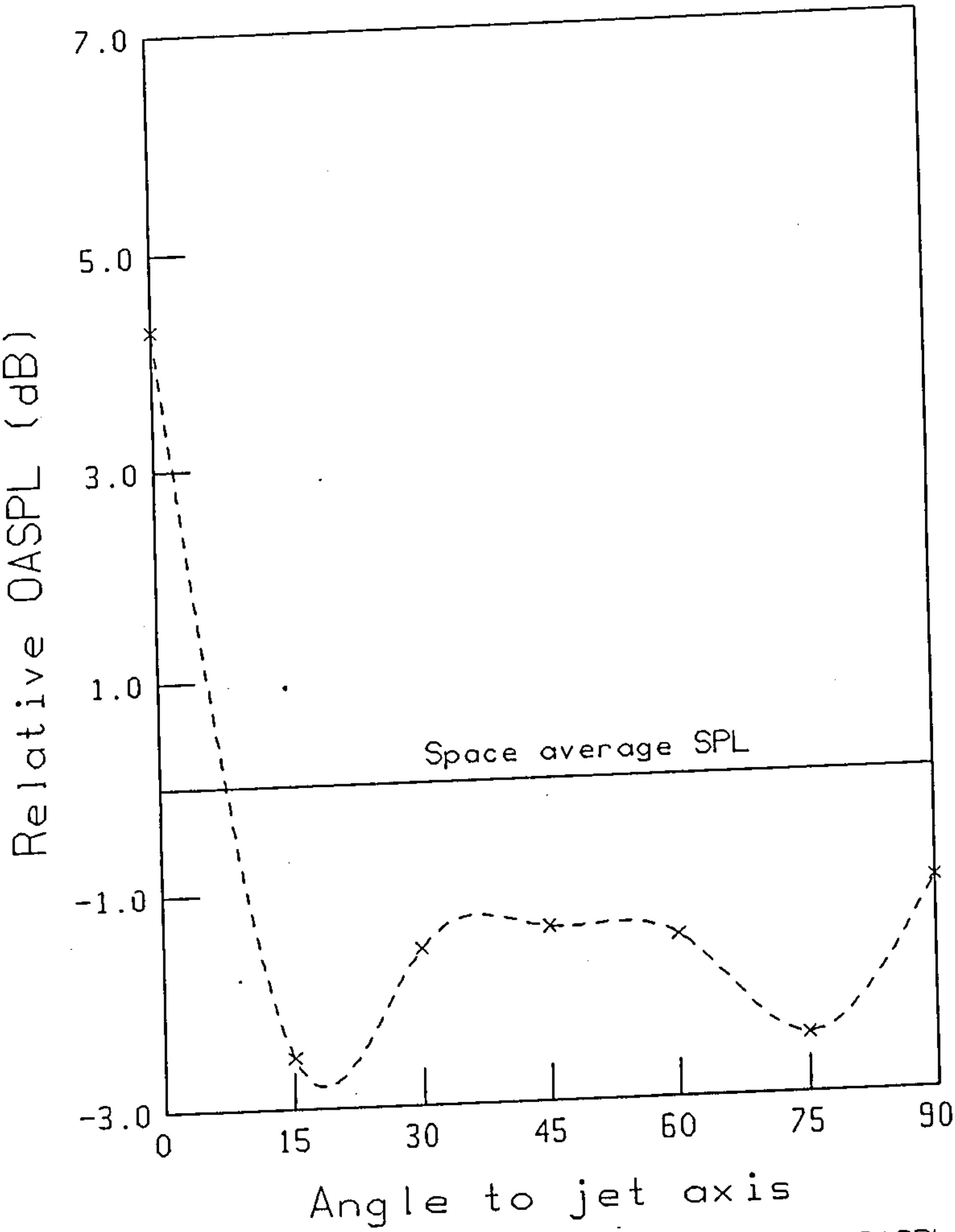


Fig.(3.10-b): Directivity of relative OASPL of four jets at 2.5 bar

This result is explained by the fact that for low frequency sound where turbulence is isotropic , there will be an interaction between turbulence and mean shear , which result in "self-noise" having its maximum intensity at 45° to the jet axis. The overall interaction between turbulence and shear will reduce this peak to an angle less than 45°. For high frequency sound coming mainly from the mixing region the maximum also will be at 45°, while the convection effects will reduce this angle.Typical directivity index of a single and four jets at a pressure of 2.5 bar is tabulated in table (3.2) and (3.3).

### 3.6.2 Four Jets

Four jets directivities of sound pressure levels shown in fig.(3.20) to fig.(3.28) at different $\frac{1}{3}$ octave frequency bands, suggests full agreement with theoretical background excluding the jet axis, where it was noted that there exist a region of high sound intensity relative to other angles (8 dB difference). This can be explained by the fact that at the jet axis there will be a very high turbulence region leading to higher rms sound pressures. Moreover, positions less than 20° from the jet axis are too close to the jet stream to permit acturate noise measurement, Franken [25] suggested that they make a negligible contribution to the sound power watt level (PWL) of the entire jet. Experimental results of the present work gives complete justification of such idea.

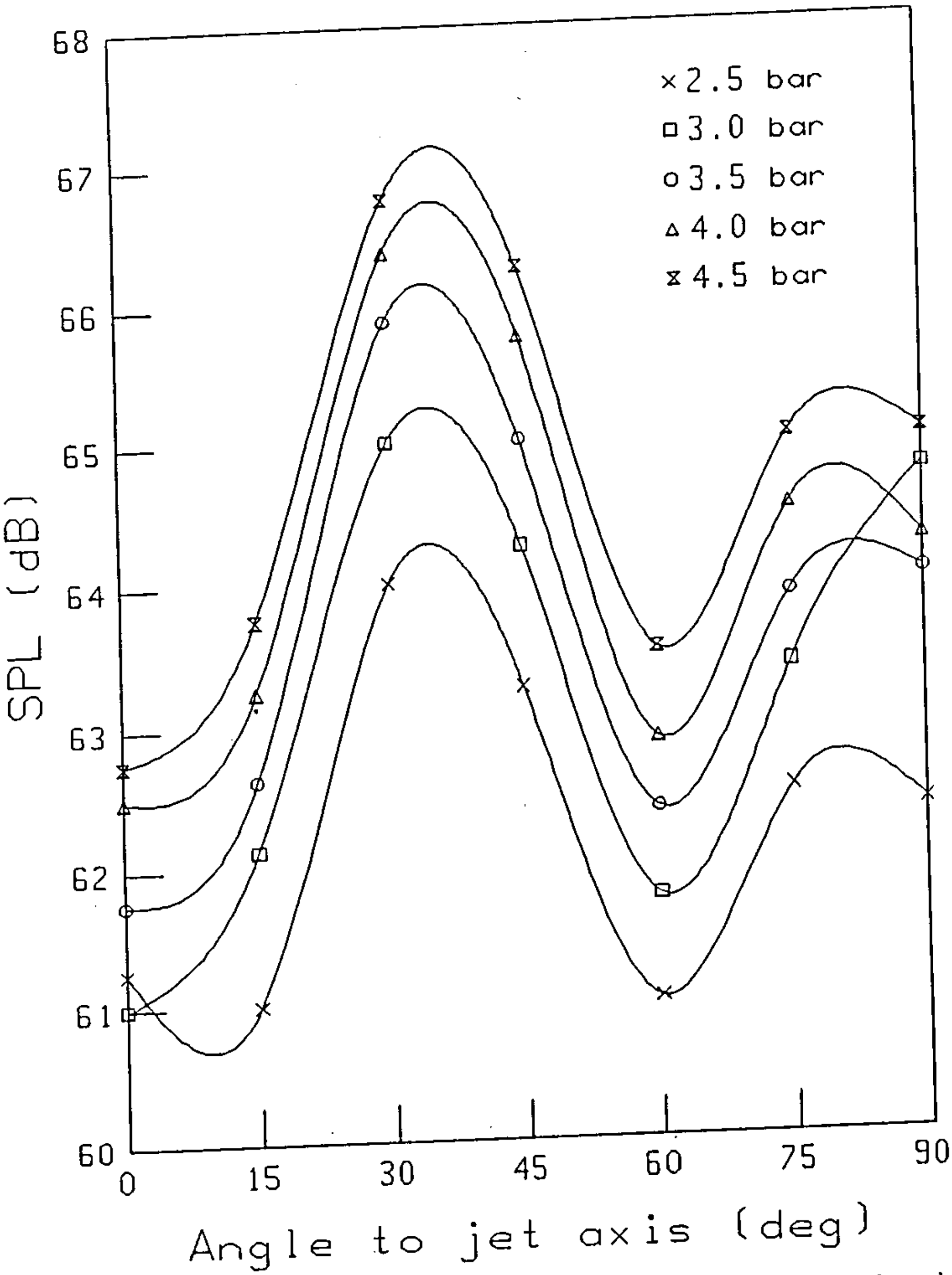


Fig.(3.11): Directivity of SPL of a single jet at central frequency=10 Hz

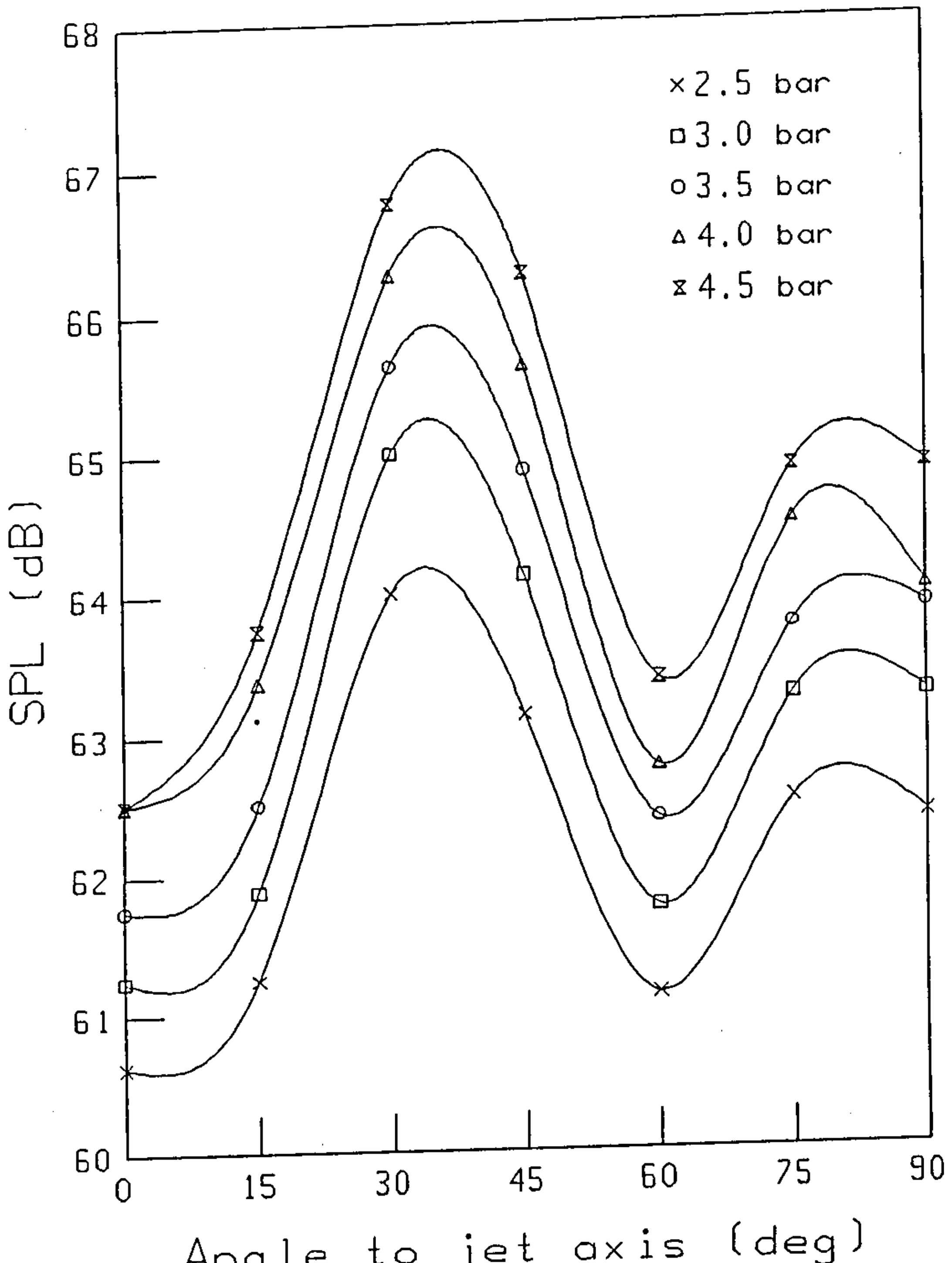


Fig.(3.12): Directivity of SPL of a single jet at central frequency=100 Hz

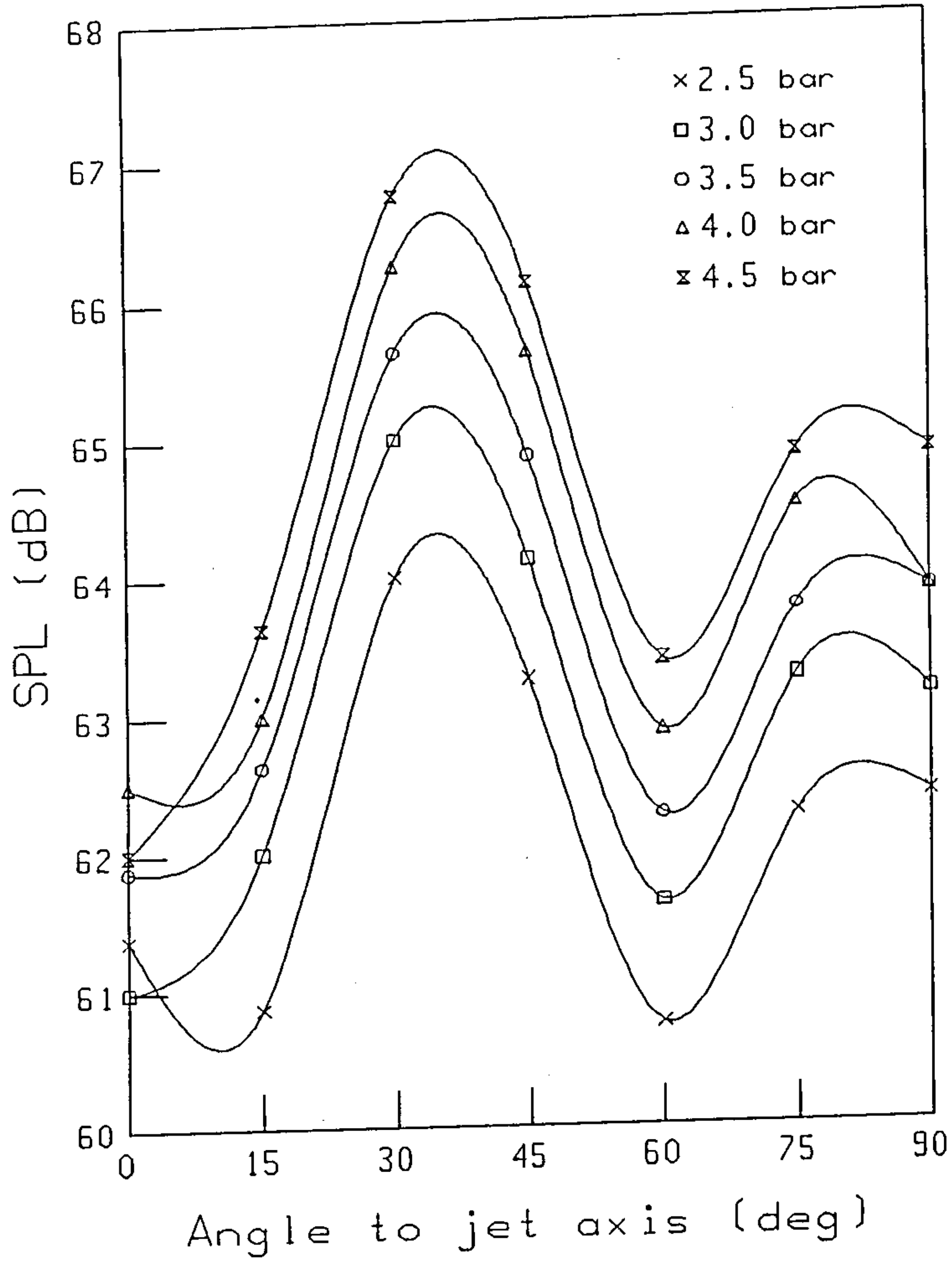


Fig.(3.15): Directivity of SPL of a single jet at central frequency=3150 Hz

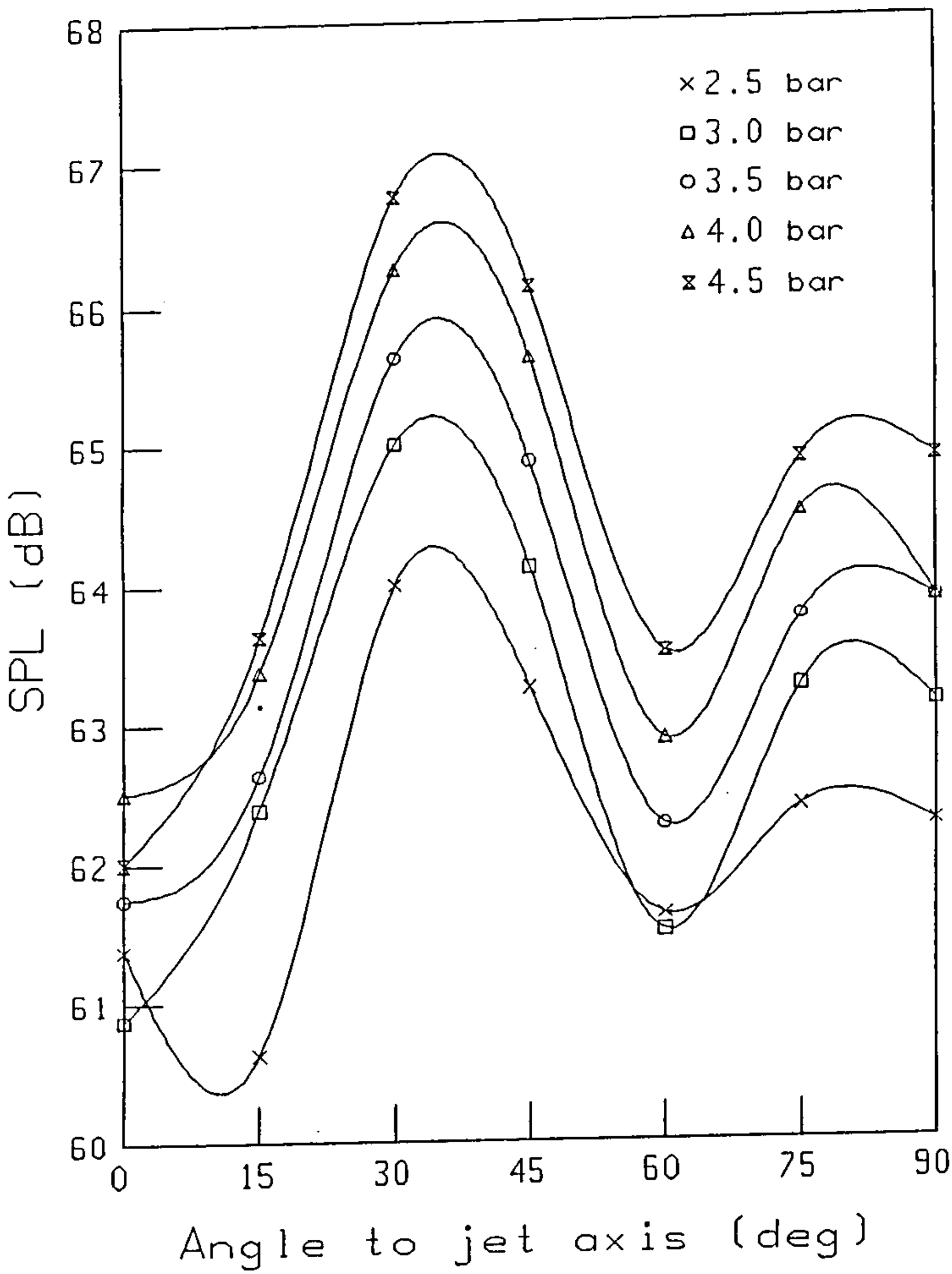


Fig.(3.16): Directivity of SPL of a single jet at central frequency=5000 Hz

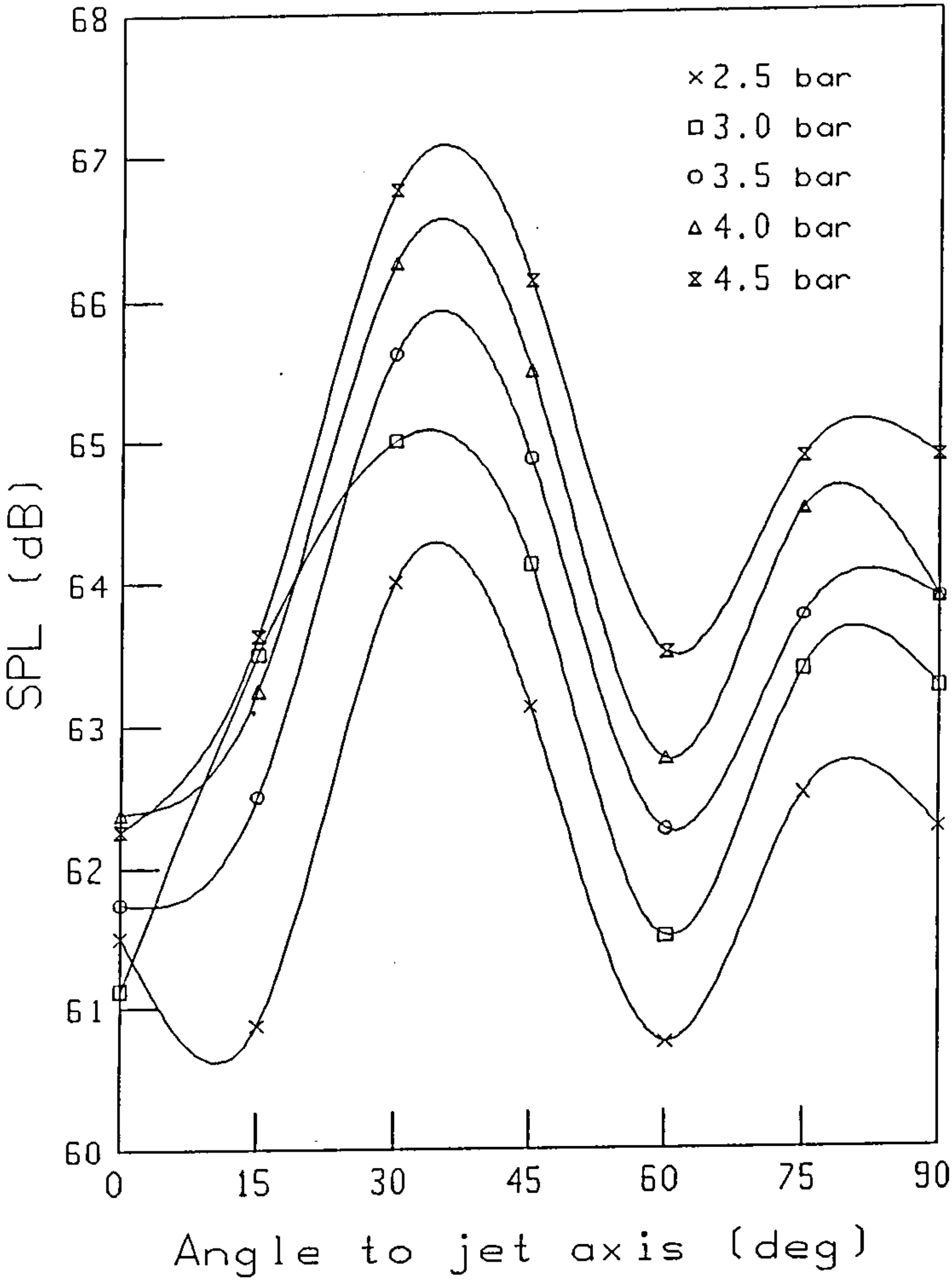


Fig.(3.18): Directivity of SPL of a single jet at central frequency=10000 Hz

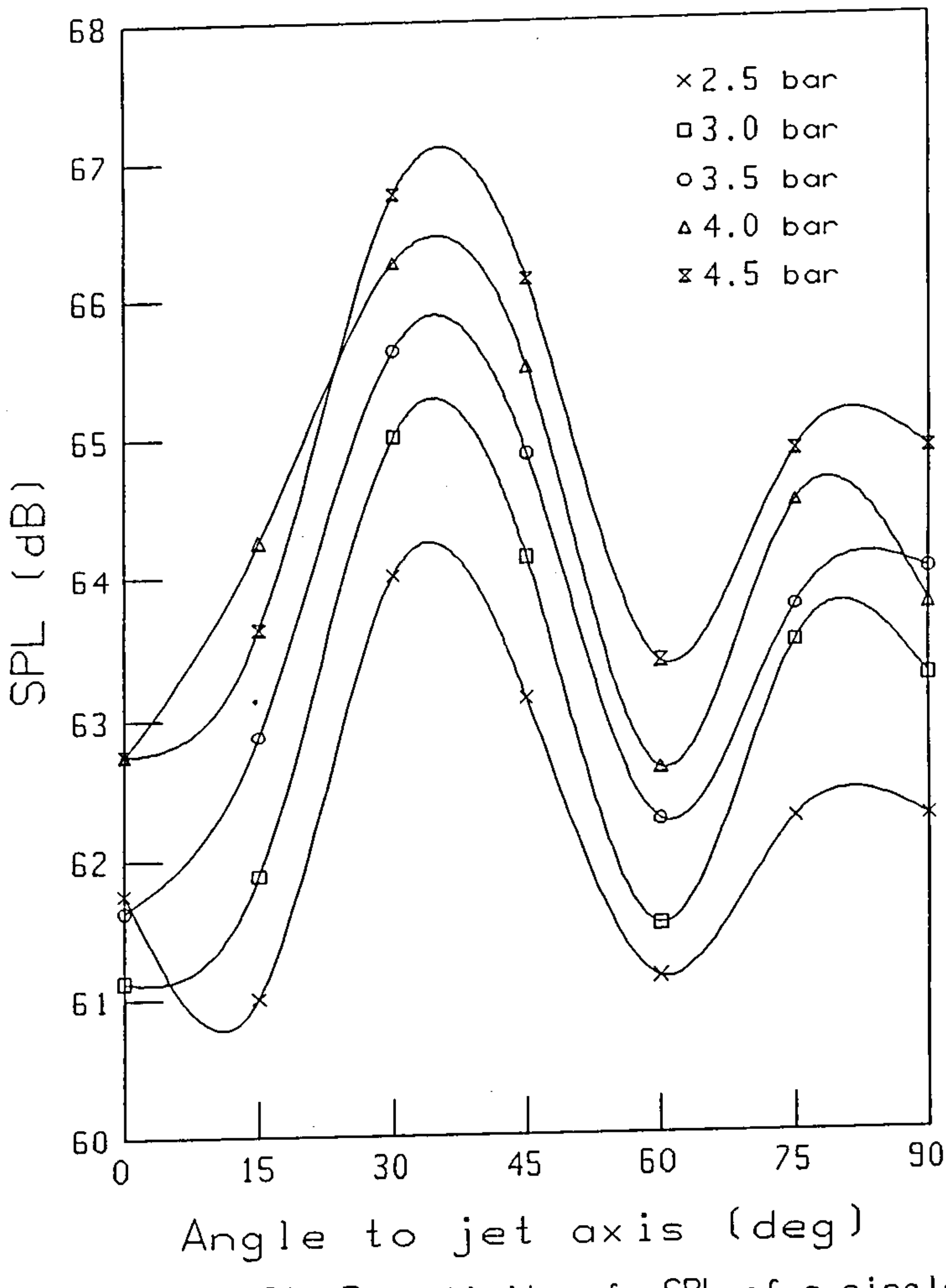


Fig. (3.19): Directivity of SPL of a single jet at central frequency=16000 Hz

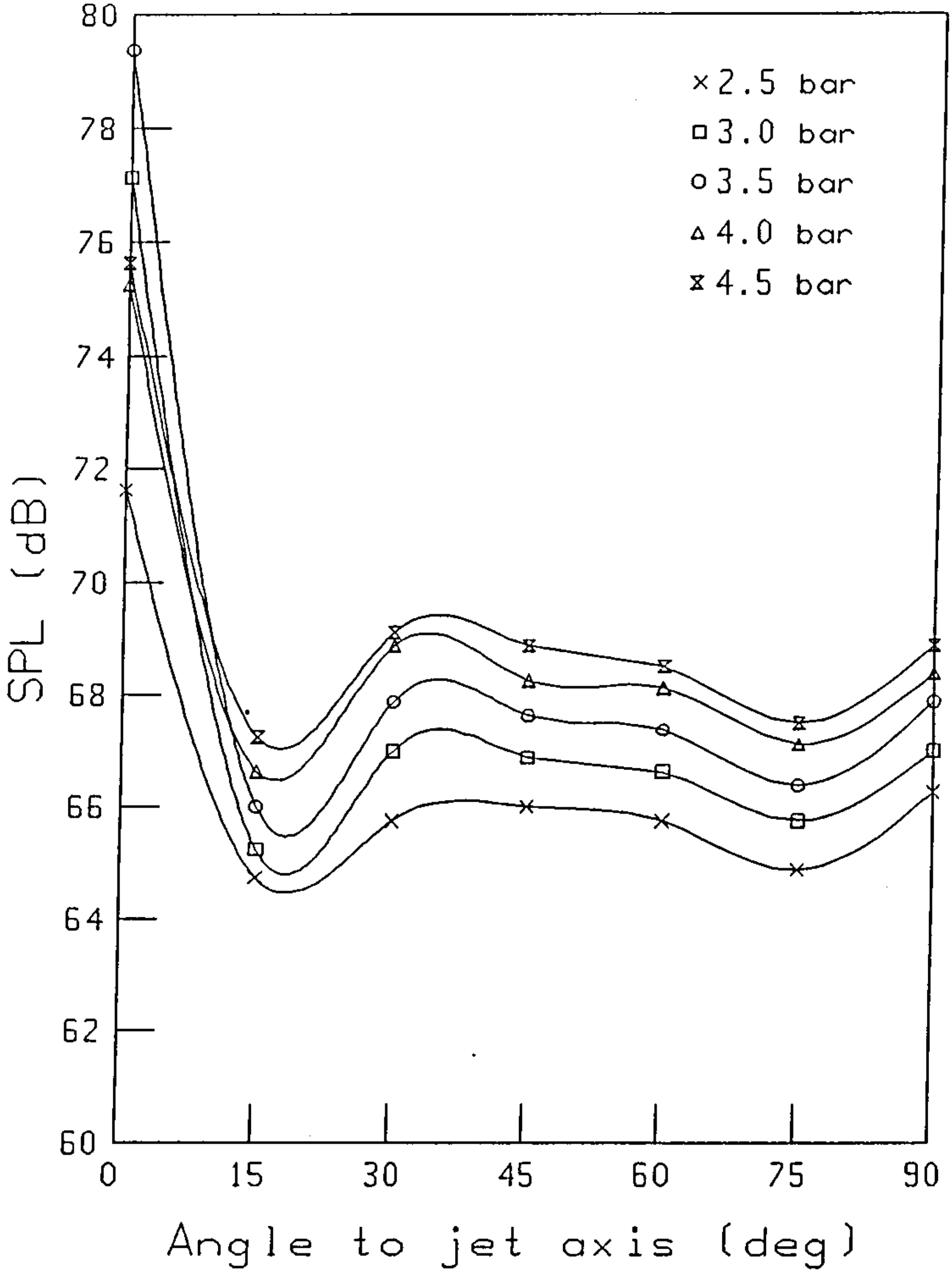


Fig.(3.20): Directivity of SPL of four jets at central frequency=10 Hz

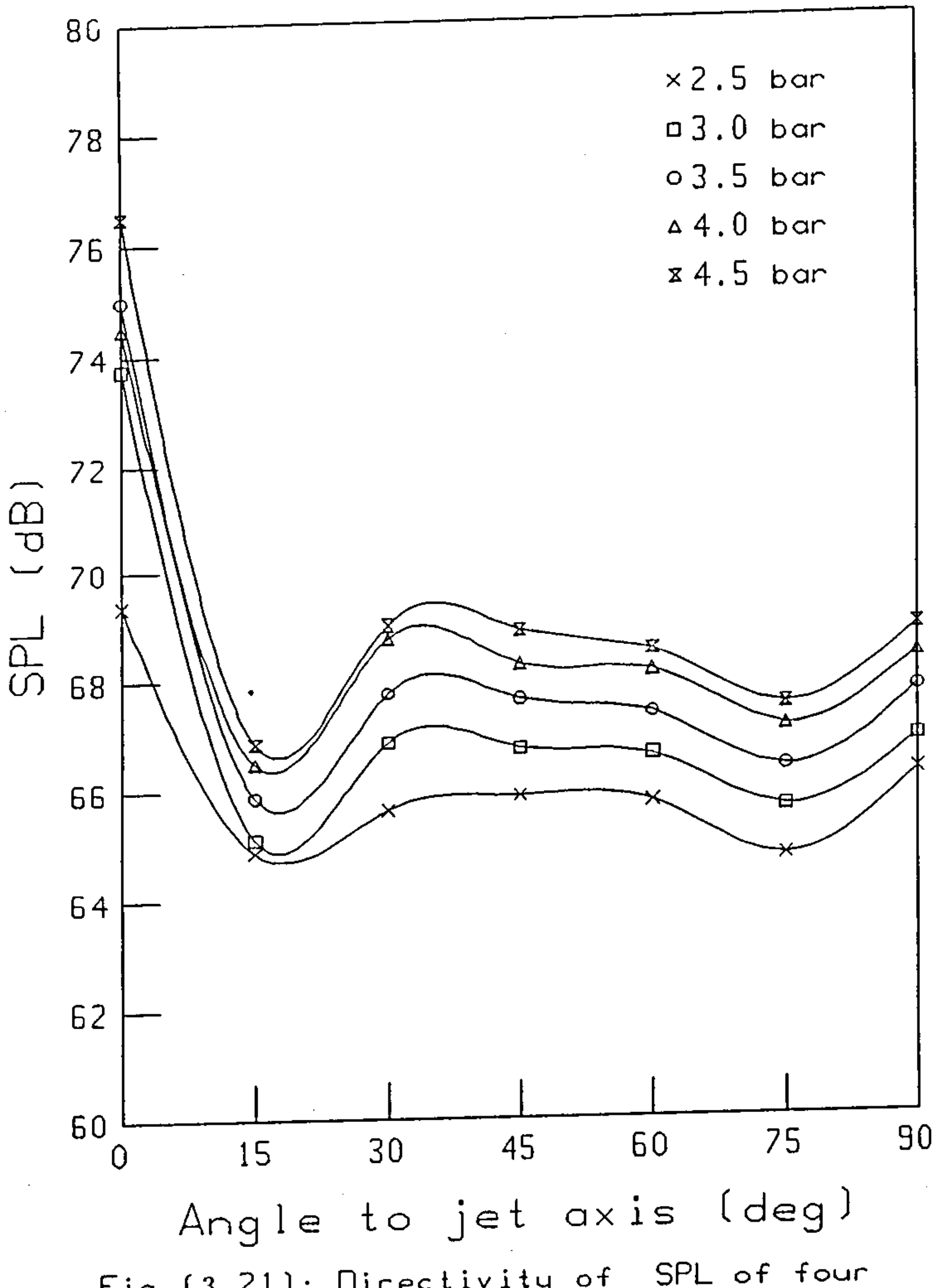


Fig.(3.21): Directivity of SPL of four jets at central frequency=100 Hz

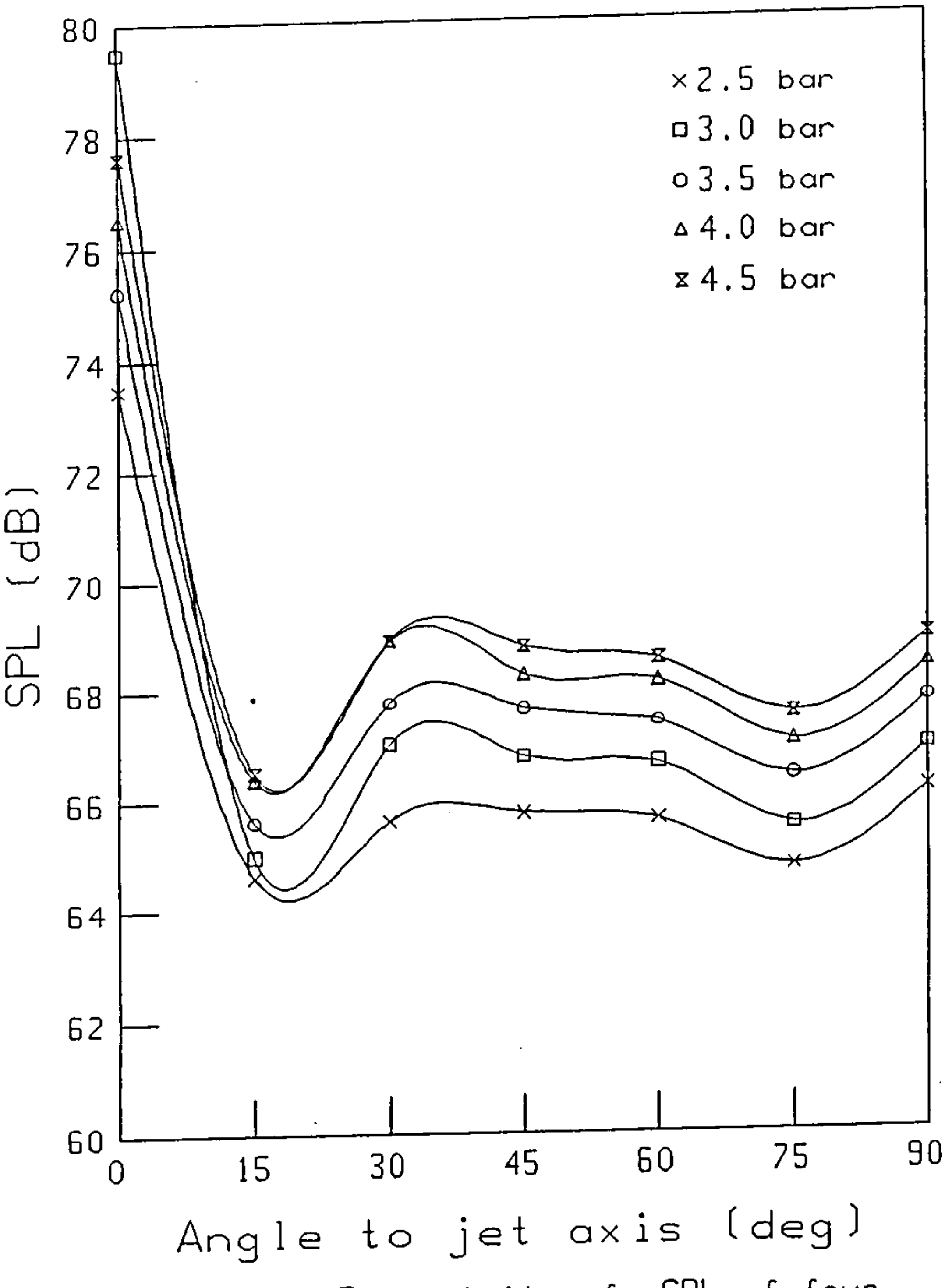


Fig.(3.22): Directivity of SPL of four jets at central frequency=500 Hz

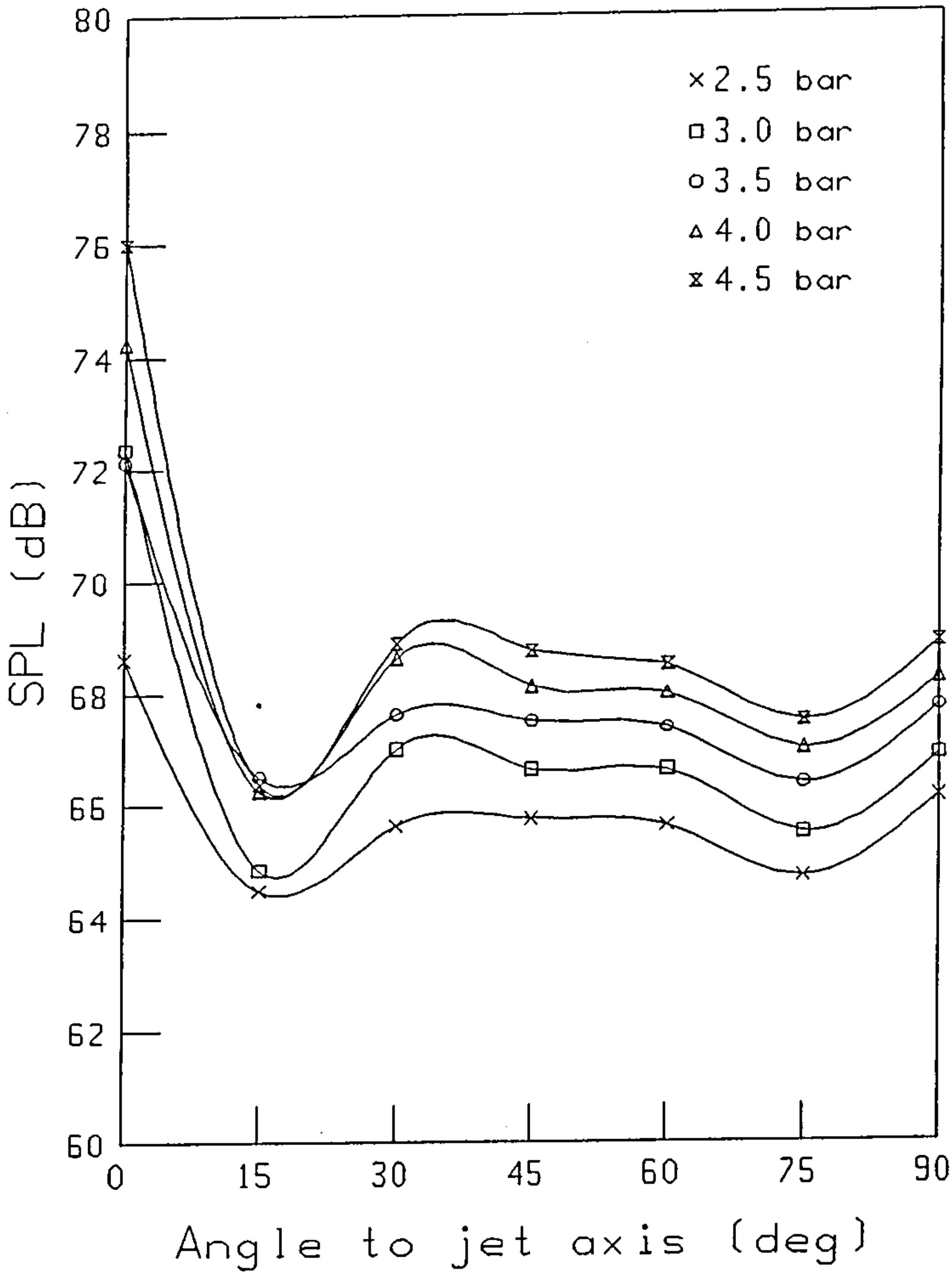


Fig.(3.23): Directivity of SPL of four jets at central frequency=1000 Hz

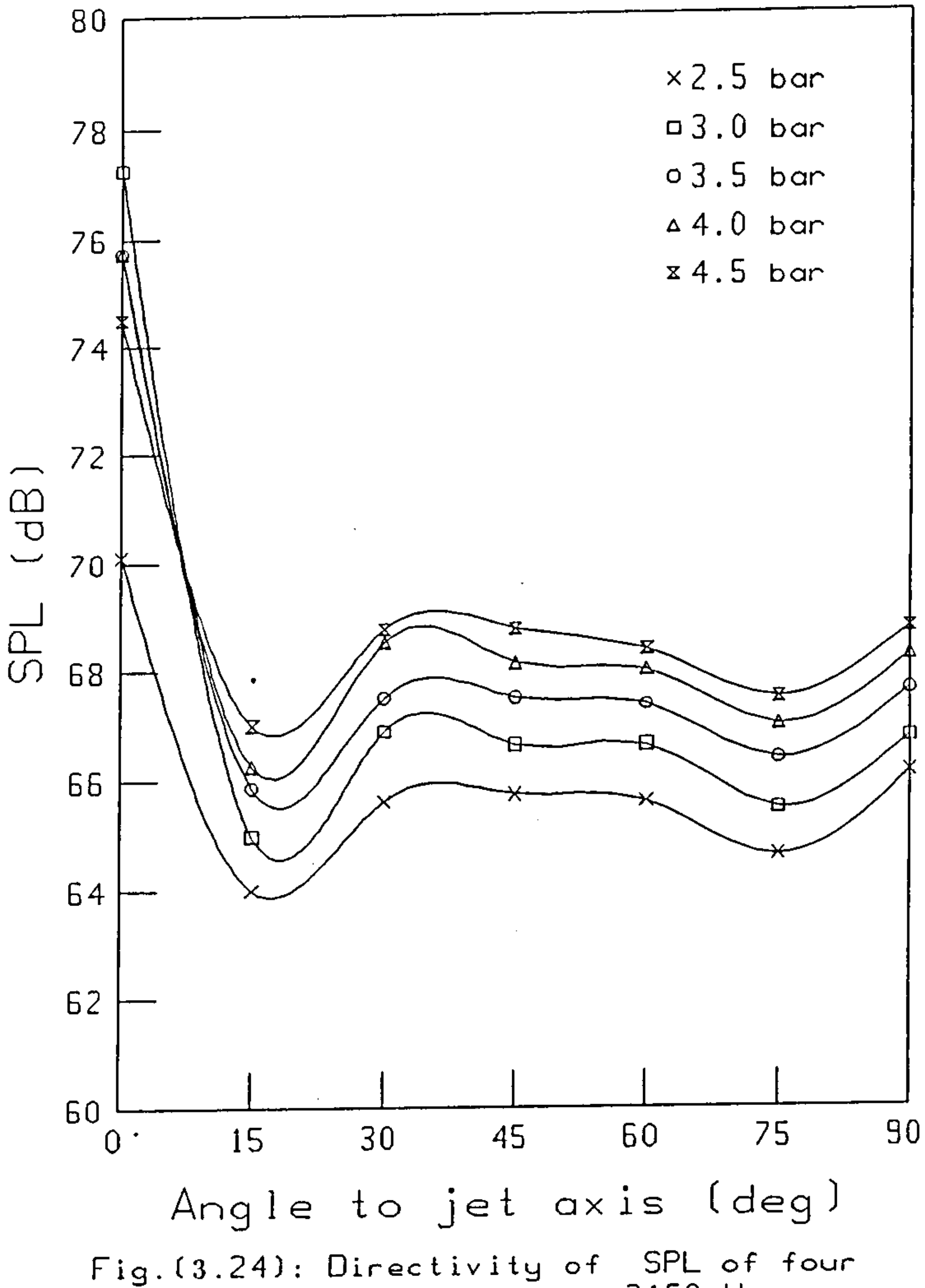


Fig.(3.24): Directivity of SPL of four jets at central frequency=3150 Hz

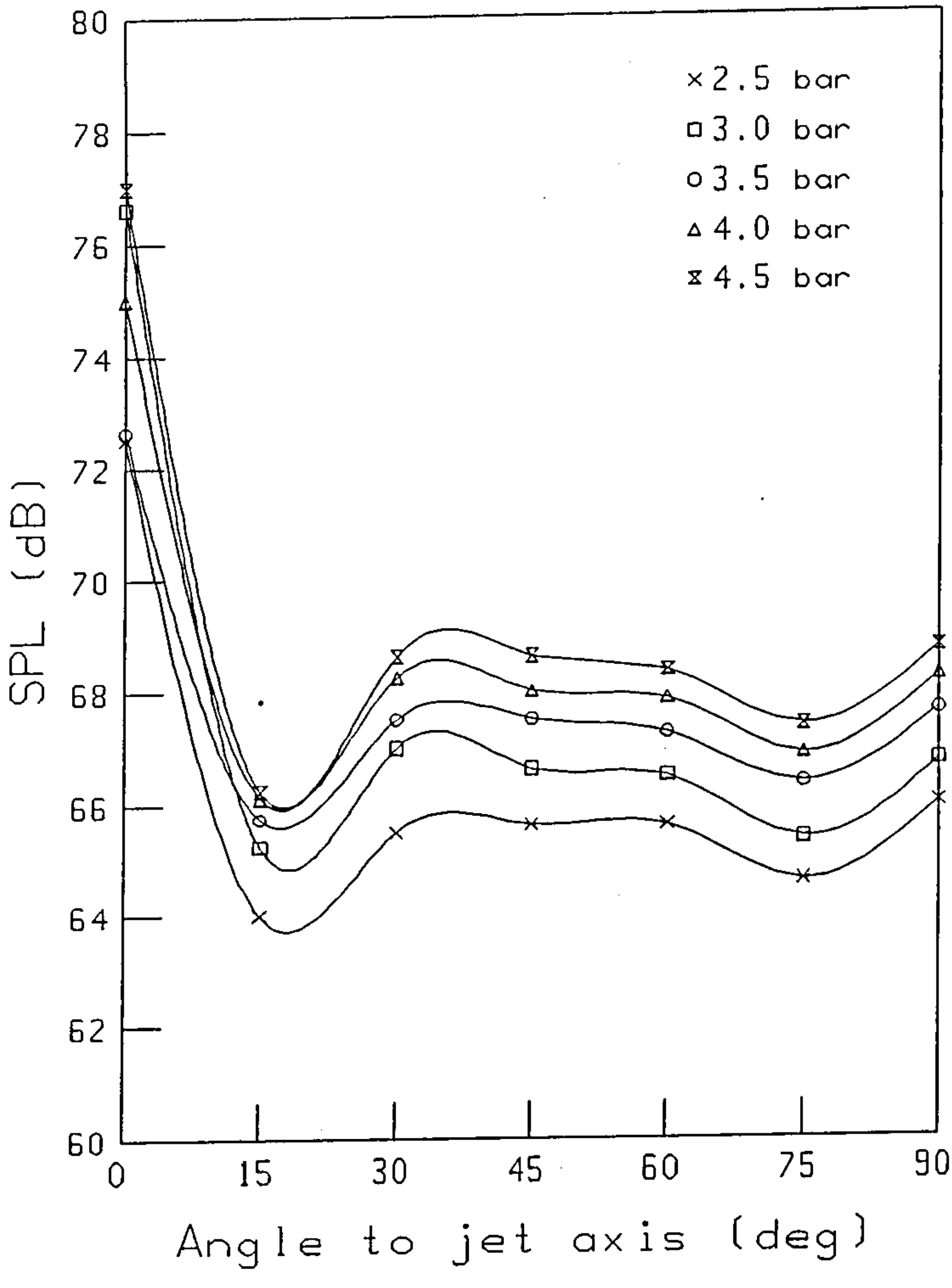


Fig.(3.26): Directivity of SPL of four jets at central frequency=8000 Hz

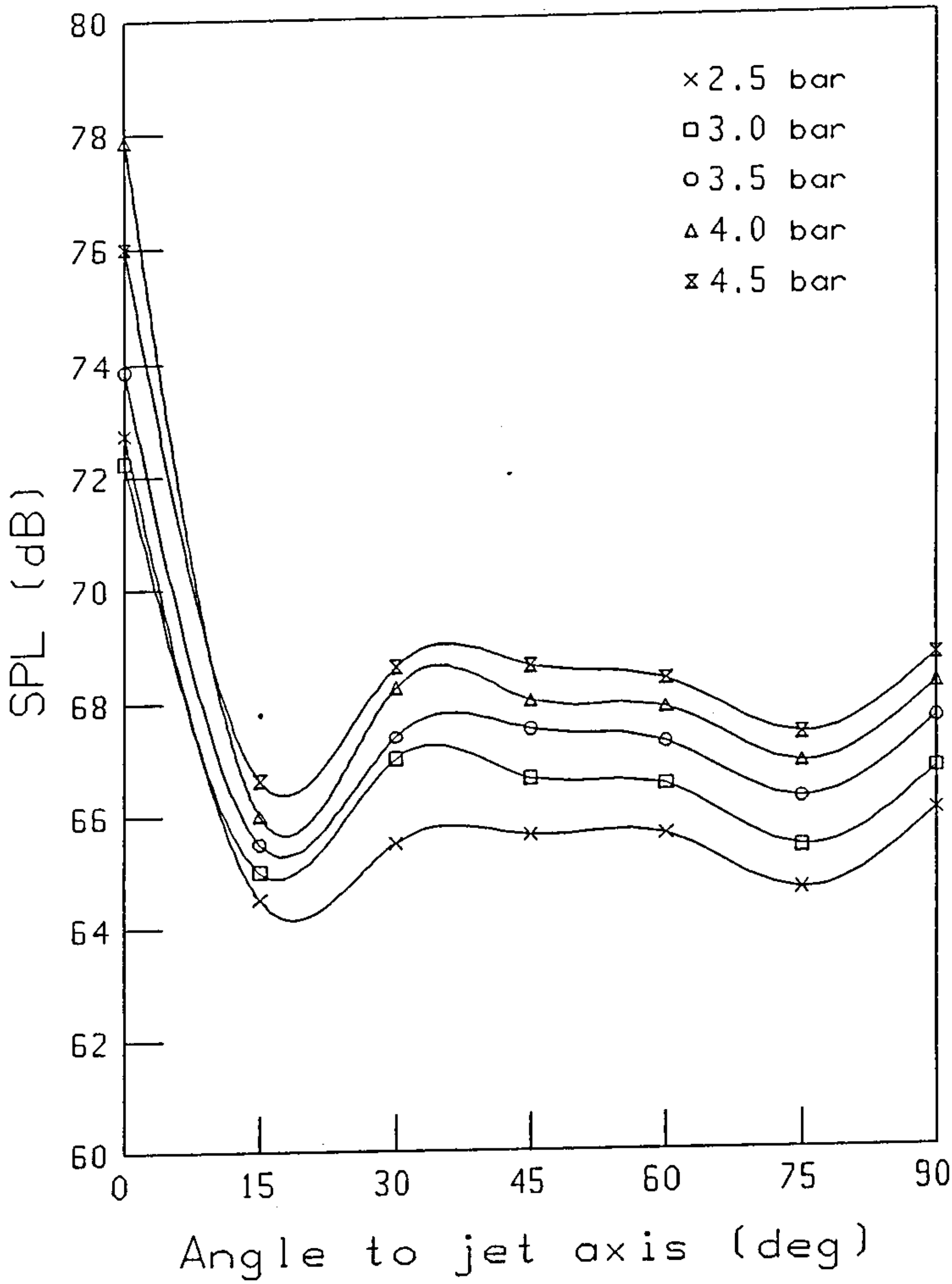


Fig.(3.27): Directivity of SPL of four jets at central frequency=10000 Hz

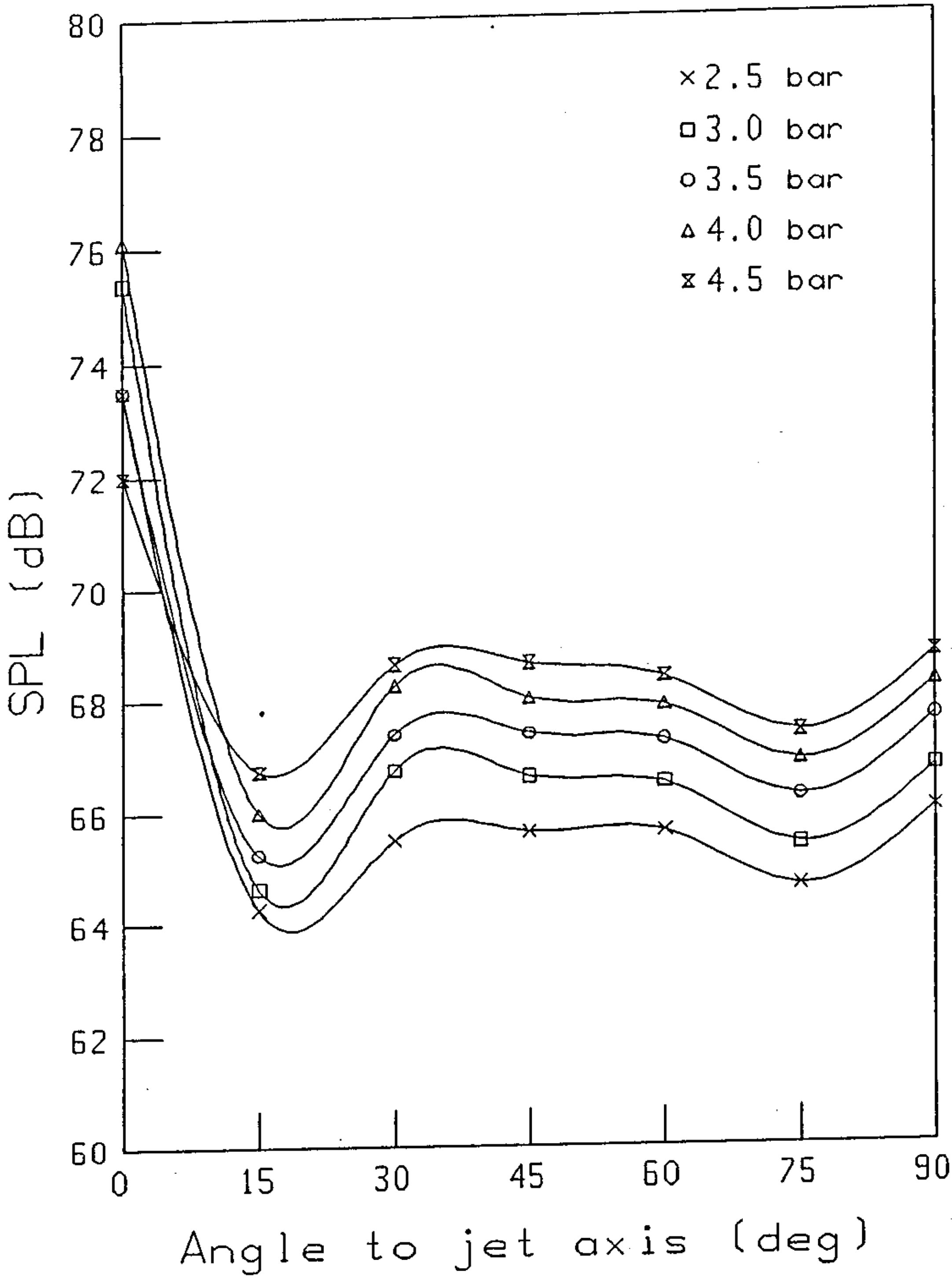


Fig.(3.28): Directivity of SPL of four jets at central frequency=16000 Hz

Table (3.2) :Directivity Index of a single jet at 2.5 Bar

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 1.59 | 1.47 | 4.97 | 2.84 | 2.34 | 2.72 | 3.09 |
| 12.5 | 1.55 | 2.05 | 4.42 | 2.80 | 2.80 | 2.67 | 2.92 |
| 16.0 | 1.02 | 1.64 | 4.02 | 2.77 | 2.39 | 2.14 | 2.52 |
| 20.0 | 1.02 | 2.02 | 4.40 | 3.52 | 2.02 | 2.52 | 3.14 |
| 25.0 | 1.67 | 1.05 | 4.17 | 3.05 | 1.92 | 2.42 | 5.05 |
| 31.5 | 1.11 | 1.48 | 4.73 | 3.11 | 2.23 | 2.86 | 3.36 |
| 40.0 | 1.72 | 1.47 | 4.47 | 3.22 | 2.35 | 2.97 | 3.10 |
| 50.0 | 1.04 | 3.54 | 4.29 | 3.04 | 2.16 | 2.79 | 4.79 |
| 63.0 | 1.20 | 4.32 | 4.32 | 2.70 | 2.32 | 2.82 | 4.32 |
| 80.0 | 2.19 | 1.94 | 4.57 | 2.82 | 2.57 | 2.94 | 3.32 |
| 100.0 | 1.06 | 1.94 | 4.44 | 2.81 | 3.06 | 2.94 | 2.94 |
| 125.0 | 1.15 | 2.15 | 4.40 | 2.78 | 3.90 | 2.90 | 2.90 |
| 160.0 | 0.99 | 1.86 | 4.49 | 2.74 | 2.49 | 2.86 | 3.11 |
| 200.0 | 1.05 | 1.68 | 4.08 | 2.80 | 2.43 | 2.80 | 3.05 |
| 250.0 | 1.09 | 1.84 | 4.47 | 3.22 | 2.47 | 2.97 | 3.09 |
| 315.0 | 1.03 | 2.16 | 4.78 | 2.78 | 2.41 | 3.03 | 3.16 |
| 400.0 | 1.11 | 1.74 | 4.61 | 3.11 | 2.36 | 3.11 | 3.11 |
| 500.0 | 1.17 | 1.79 | 4.42 | 4.02 | 2.29 | 2.92 | 3.04 |
| 630.0 | 1.01 | 2.76 | 4.51 | 3.26 | 2.38 | 3.01 | 3.13 |
| 800.0 | 1.02 | 1.76 | 4.52 | 2.76 | 2.52 | 3.02 | 3.02 |
| 1000.0 | 1.14 | 1.76 | 4.52 | 2.76 | 2.52 | 3.02 | 3.02 |
| 1250.0 | 2.13 | 1.76 | 4.38 | 2.63 | 2.26 | 2.76 | 2.88 |
| 1600.0 | 2.47 | 1.60 | 4.47 | 2.85 | 2.47 | 2.85 | 3.10 |
| 2000.0 | 2.45 | 2.45 | 4.57 | 2.70 | 2.20 | 2.82 | 3.07 |
| 2500.0 | 3.78 | 1.65 | 4.40 | 2.78 | 2.15 | 2.65 | 2.90 |
| 3150.0 | 1.82 | 1.44 | 4.57 | 2.82 | 2.44 | 2.82 | 3.07 |
| 4000.0 | 2.08 | 1.58 | 4.45 | 2.95 | 2.20 | 2.70 | 2.83 |
| 5000.0 | 1.84 | 2.09 | 4.06 | 2.59 | 2.46 | 2.84 | 3.09 |
| 6300.0 | 1.98 | 1.73 | 4.86 | 2.61 | 2.36 | 2.86 | 3.11 |
| 8000.0 | 2.06 | 1.80 | 4.80 | 3.30 | 2.43 | 2.93 | 3.18 |
| 10000.0 | 1.99 | 2.12 | 4.74 | 2.74 | 2.74 | 2.99 | 3.24 |
| 12500.0 | 2.04 | 3.17 | 4.67 | 3.04 | 2.92 | 2.92 | 3.04 |
| 16000.0 | 2.23 | 2.10 | 4.85 | 2.85 | 2.48 | 2.85 | 3.10 |

Table (3.3) :Directivity Index of Four jets at 2.5 Bar

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 8.20 | 1.32 | 2.32 | 2.57 | 2.32 | 1.45 | 2.82 |
| 12.5 | 7.73 | 1.35 | 2.35 | 2.60 | 2.35 | 1.48 | 2.85 |
| 16.0 | 9.95 | 1.45 | 2.20 | 2.33 | 2.20 | 1.33 | 2.70 |
| 20.0 | 5.94 | 1.69 | 2.44 | 2.56 | 2.44 | 1.56 | 2.94 |
| 25.0 | 9.28 | 1.53 | 2.28 | 2.41 | 2.28 | 1.28 | 2.78 |
| 31.5 | 7.86 | 1.86 | 2.36 | 2.49 | 2.36 | 1.36 | 2.86 |
| 40.0 | 7.65 | 1.65 | 2.28 | 2.53 | 2.40 | 1.40 | 2.90 |
| 50.0 | 10.45 | 1.32 | 2.07 | 2.32 | 2.20 | 1.20 | 2.70 |
| 63.0 | 8.83 | 1.58 | 2.21 | 2.46 | 2.33 | 1.33 | 2.83 |
| 80.0 | 8.60 | 1.60 | 2.22 | 2.47 | 2.35 | 1.35 | 2.85 |
| 100.0 | 6.10 | 1.60 | 2.35 | 2.60 | 2.48 | 1.48 | 2.98 |
| 125.0 | 6.22 | 1.60 | 2.35 | 2.60 | 2.47 | 1.47 | 2.97 |
| 160.0 | 6.23 | 1.48 | 2.35 | 2.60 | 2.48 | 1.48 | 2.98 |
| 200.0 | 6.50 | 1.62 | 2.37 | 2.62 | 2.50 | 1.50 | 2.87 |
| 250.0 | 10.24 | 1.50 | 2.12 | 2.37 | 2.24 | 1.24 | 2.62 |
| 315.0 | 7.95 | 1.57 | 2.32 | 2.45 | 2.45 | 1.45 | 2.82 |
| 400.0 | 10.50 | 1.25 | 2.13 | 2.25 | 2.25 | 1.25 | 2.64 |
| 500.0 | 10.08 | 1.20 | 2.20 | 2.33 | 2.20 | 1.33 | 2.70 |
| 630.0 | 9.05 | 1.41 | 2.28 | 2.41 | 2.28 | 1.41 | 2.78 |
| 800.0 | 5.21 | 1.71 | 2.46 | 2.59 | 2.46 | 1.59 | 2.96 |
| 1000.0 | 5.47 | 1.35 | 2.47 | 2.60 | 2.47 | 1.60 | 2.97 |
| 1250.0 | 5.22 | 1.47 | 2.47 | 2.60 | 2.47 | 1.60 | 2.97 |
| 1600.0 | 8.49 | 0.99 | 2.37 | 2.49 | 2.37 | 1.37 | 2.87 |
| 2000.0 | 8.84 | 0.97 | 2.34 | 2.47 | 2.34 | 1.34 | 2.84 |
| 2500.0 | 6.83 | 1.08 | 2.46 | 2.58 | 2.46 | 1.46 | 2.96 |
| 3150.0 | 6.96 | 0.84 | 2.46 | 2.59 | 2.46 | 1.46 | 2.96 |
| 4000.0 | 6.27 | 1.02 | 2.52 | 2.64 | 2.52 | 1.52 | 2.89 |
| 5000.0 | 8.79 | 0.54 | 2.29 | 2.54 | 2.42 | 1.42 | 2.79 |
| 6300.0 | 10.88 | 0.38 | 2.13 | 2.25 | 2.25 | 1.25 | 2.63 |
| 8000.0 | 9.27 | 0.77 | 2.27 | 2.40 | 2.40 | 1.40 | 2.77 |
| 10000.0 | 9.48 | 1.23 | 2.23 | 2.36 | 2.36 | 1.36 | 2.73 |
| 12500.0 | 10.73 | 1.23 | 2.10 | 2.23 | 2.23 | 1.23 | 2.60 |
| 16000.0 | 10.18 | 0.93 | 2.18 | 2.30 | 2.30 | 1.30 | 2.68 |

# Chapter 4

# CONCLUSION AND RECOMMENDATIONS

## 4.1 Conclusion

This research is considered as the first step in studying the sound field, and directivity pattern of micro-jets, with the attempt to correlate the sound power watt level with the jet velocity.

The present investigation of aerodynamic generated noise from a micro- jet source, offers general concluding remarks, which can be summarized as follows:

1. The sound pressure level (SPL) exhibits a nearly uniform value overall frequency spectrum, for both single and four parallel jet arrangements because of the relatively small dimension of the sound source.

2. Directivity pattern of a single supersonic jet suggests that, the peak sound pressure level lies at an angle of 36° with the jet axis, which is in a close agreement with other experimental investigations conducted by Ahuja[9] and Tana [11].

3. According to the formation of high turbulence region, the directivity pattern of

the four parallel jets indicates high intensity at the jet axis, otherwise, a relatively peaked value of (SPL) occurs at 36° from the jet axis.

4. The overall sound pressure level (OASPL) of a single supersonic jet has its peak value at 36° from the jet axis, with an over all sound pressure behaviour similar to that of sound pressure level.

5. Over all sound power level exhibits a nearly uniform value over all frequency spectra, except at certain frequencies at which resonance occurs, according to the nearly constant behaviour of the sound pressure level.

6. The correlation of overall sound power level of single and four parallel jet cases, indicates a good agreement with the $V_j^4$ model

7. Experimental investigation of supersonic jets indicates that, they have a more peaked value of (SPL), compared with subsonic jets.

## 4.2 Recommendations

For further studies in the micro-jet research, the following recommendations may be stated.

1. It is recommended to use Parallel jet of various diameter of each nozzle in order to suppress noise generation from the 'Arabian- Head' jet arrangement.

2. Effect of noise suppression schemes previously studied on large jets may be investigated for micro-jets.

3. Various jet arrangements may be investigated, in order to determine their role on the resulted directivity, and spectral sound pressure levels.

4. The effect of spatial distances on the measured sound pressure levels may be investigated, in order to determine the relation of sound pressure level with distance from the source.

5. Prediction techniques may be produced, in order to perform a whole correlating scheme of aerodynamic noise generated by micro-jets.

6. The noise field of micro-jets having various throat diameters may be investigated experimentally, and comparative study between experimental study and large jets prediction techniques may be applied.

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Table (A.1): Single Jet Spectral SPL in (dB) for Station 0

$P_{working}$:2.5 bar  $P_{ambient}$ :0.904 bar  $T_{ambient}$ :10.0° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.250 | 61.125 | 64.625 | 62.500 | 62.000 | 62.375 | 62.750 |
| 12.5 | 61.250 | 61.750 | 64.125 | 62.500 | 62.500 | 62.375 | 62.625 |
| 16.0 | 61.250 | 61.875 | 64.250 | 63.000 | 62.625 | 62.375 | 62.750 |
| 20.0 | 60.875 | 61.875 | 64.250 | 63.375 | 61.875 | 62.375 | 63.000 |
| 25.0 | 61.625 | 61.000 | 64.125 | 63.000 | 61.875 | 62.375 | 65.000 |
| 31.5 | 60.750 | 61.125 | 64.375 | 62.750 | 61.875 | 62.500 | 63.000 |
| 40.0 | 61.250 | 61.000 | 64.000 | 62.750 | 61.875 | 62.500 | 62.625 |
| 50.0 | 60.750 | 63.250 | 64.000 | 62.750 | 61.875 | 62.500 | 64.500 |
| 63.0 | 60.875 | 64.000 | 64.000 | 62.375 | 62.000 | 62.500 | 64.000 |
| 80.0 | 61.750 | 61.500 | 64.125 | 62.375 | 62.125 | 62.500 | 62.875 |
| 100.0 | 60.625 | 61.500 | 64.000 | 62.375 | 62.625 | 62.500 | 62.500 |
| 125.0 | 60.750 | 61.750 | 64.000 | 62.375 | 63.500 | 62.500 | 62.500 |
| 160.0 | 60.500 | 61.375 | 64.000 | 62.250 | 62.000 | 62.375 | 62.625 |
| 200.0 | 60.625 | 61.250 | 64.250 | 62.375 | 62.000 | 62.375 | 62.625 |
| 250.0 | 60.625 | 61.375 | 64.000 | 62.750 | 62.000 | 62.500 | 62.625 |
| 315.0 | 60.500 | 61.625 | 64.250 | 62.250 | 61.875 | 62.500 | 62.625 |
| 400.0 | 60.625 | 61.250 | 64.125 | 62.625 | 61.875 | 62.625 | 62.625 |
| 500.0 | 60.750 | 61.375 | 64.000 | 64.500 | 61.875 | 62.500 | 62.625 |
| 630.0 | 60.500 | 62.250 | 64.000 | 62.750 | 61.875 | 62.500 | 62.625 |
| 800.0 | 60.500 | 61.250 | 64.000 | 62.250 | 62.000 | 62.500 | 62.500 |
| 1000.0 | 60.625 | 61.250 | 64.000 | 62.250 | 62.000 | 62.500 | 62.500 |
| 1250.0 | 61.750 | 61.375 | 64.000 | 62.250 | 61.875 | 62.375 | 62.500 |
| 1600.0 | 62.000 | 61.125 | 64.000 | 62.375 | 62.000 | 62.375 | 62.625 |
| 2000.0 | 62.000 | 62.000 | 64.125 | 62.250 | 61.750 | 62.375 | 62.625 |
| 2500.0 | 63.500 | 61.375 | 64.125 | 62.500 | 61.875 | 62.375 | 62.625 |
| 3150.0 | 61.375 | 61.000 | 64.125 | 62.375 | 62.000 | 62.375 | 62.625 |
| 4000.0 | 61.750 | 61.250 | 64.125 | 62.625 | 61.875 | 62.375 | 62.500 |
| 5000.0 | 61.375 | 61.625 | 64.500 | 62.125 | 62.000 | 62.375 | 62.625 |
| 6300.0 | 61.500 | 61.250 | 64.375 | 62.125 | 61.875 | 62.375 | 62.625 |
| 8000.0 | 61.625 | 61.375 | 64.375 | 62.875 | 62.000 | 62.500 | 62.750 |
| 10000.0 | 61.500 | 61.625 | 64.250 | 62.250 | 62.250 | 62.500 | 62.750 |
| 12500.0 | 61.625 | 62.750 | 64.250 | 62.625 | 62.500 | 62.500 | 62.625 |
| 16000.0 | 61.750 | 61.625 | 64.375 | 62.375 | 62.000 | 62.375 | 62.625 |

**Table (A.2): Single Jet Spectral SPL in (dB) for Station 0**

$P_{working}$:3.0 bar $P_{ambient}$ :0.904 bar $T_{ambient}$ :10.0° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.000 | 64.000 | 64.750 | 62.750 | 62.750 | 63.000 | 63.375 |
| 12.5 | 61.500 | 64.000 | 64.875 | 62.750 | 62.875 | 63.000 | 63.375 |
| 16.0 | 61.500 | 64.375 | 64.625 | 62.750 | 62.875 | 63.000 | 63.375 |
| 20.0 | 61.500 | 64.250 | 64.750 | 62.750 | 62.750 | 63.000 | 63.250 |
| 25.0 | 61.375 | 64.000 | 65.000 | 62.750 | 62.750 | 63.125 | 63.250 |
| 31.5 | 61.250 | 64.000 | 65.000 | 62.750 | 62.750 | 63.250 | 63.250 |
| 40.0 | 61.500 | 64.000 | 64.875 | 62.750 | 62.750 | 63.000 | 63.500 |
| 50.0 | 61.500 | 63.750 | 64.625 | 62.750 | 62.750 | 63.000 | 63.625 |
| 63.0 | 61.500 | 63.750 | 64.625 | 62.750 | 62.750 | 63.000 | 63.500 |
| 80.0 | 61.500 | 63.500 | 64.500 | 62.750 | 62.750 | 63.000 | 63.375 |
| 100.0 | 61.250 | 63.750 | 64.500 | 62.750 | 62.750 | 63.000 | 63.375 |
| 125.0 | 61.500 | 63.625 | 64.500 | 62.750 | 62.750 | 62.875 | 63.375 |
| 160.0 | 61.750 | 63.875 | 64.500 | 62.750 | 62.750 | 62.875 | 63.375 |
| 200.0 | 61.750 | 63.625 | 64.500 | 62.750 | 62.750 | 62.875 | 63.375 |
| 250.0 | 61.500 | 63.625 | 64.500 | 62.750 | 62.750 | 62.875 | 63.375 |
| 315.0 | 61.750 | 63.625 | 64.375 | 62.750 | 62.750 | 63.000 | 63.375 |
| 400.0 | 61.500 | 63.625 | 64.375 | 62.750 | 62.750 | 63.000 | 63.250 |
| 500.0 | 61.750 | 63.625 | 64.375 | 62.750 | 62.750 | 63.000 | 63.375 |
| 630.0 | 61.000 | 63.250 | 64.375 | 62.750 | 62.750 | 63.000 | 63.250 |
| 800.0 | 61.500 | 63.500 | 64.250 | 62.750 | 62.750 | 63.000 | 63.375 |
| 1000.0 | 61.375 | 63.625 | 64.250 | 62.750 | 62.750 | 63.000 | 63.250 |
| 1250.0 | 61.250 | 63.375 | 64.250 | 62.750 | 62.750 | 63.000 | 63.250 |
| 1600.0 | 61.125 | 63.500 | 64.625 | 62.750 | 62.750 | 63.000 | 63.250 |
| 2000.0 | 61.500 | 64.000 | 64.250 | 62.750 | 62.750 | 63.000 | 63.250 |
| 2500.0 | 61.000 | 63.500 | 64.250 | 62.750 | 62.625 | 63.000 | 63.250 |
| 3150.0 | 61.000 | 63.375 | 64.250 | 62.750 | 62.625 | 63.000 | 63.250 |
| 4000.0 | 61.125 | 63.625 | 64.375 | 62.750 | 62.625 | 63.000 | 63.250 |
| 5000.0 | 60.875 | 63.750 | 64.500 | 62.750 | 62.625 | 63.000 | 63.250 |
| 6300.0 | 61.125 | 63.125 | 64.500 | 62.875 | 62.625 | 63.000 | 63.250 |
| 8000.0 | 61.375 | 63.125 | 64.250 | 62.750 | 62.625 | 63.000 | 63.000 |
| 10000.0 | 61.125 | 63.125 | 64.250 | 62.625 | 62.625 | 63.000 | 63.000 |
| 12500.0 | 61.250 | 63.625 | 65.000 | 62.625 | 62.750 | 63.000 | 63.000 |
| 16000.0 | 61.120 | 62.750 | 66.375 | 62.625 | 62.750 | 63.000 | 63.000 |

# Table (A.3): Single Jet Spectral SPL in (dB) for Station 0

$P_{working}$:3.5 bar $P_{ambient}$ :0.904 bar $T_{ambient}$ :10.0° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.750 | 63.625 | 65.250 | 64.000 | 64.000 | 64.000 | 64.000 |
| 12.5 | 61.750 | 63.875 | 65.125 | 64.000 | 63.875 | 64.500 | 64.000 |
| 16.0 | 61.125 | 63.875 | 65.125 | 64.000 | 63.625 | 64.000 | 64.000 |
| 20.0 | 61.125 | 64.125 | 65.000 | 64.125 | 63.750 | 65.750 | 64.000 |
| 25.0 | 61.125 | 63.000 | 65.000 | 64.000 | 64.250 | 64.875 | 64.000 |
| 31.5 | 61.125 | 63.500 | 65.000 | 64.000 | 63.875 | 63.875 | 64.125 |
| 40.0 | 61.750 | 64.250 | 65.000 | 64.000 | 63.875 | 64.250 | 64.000 |
| 50.0 | 62.000 | 63.750 | 65.000 | 64.000 | 64.500 | 64.250 | 64.000 |
| 63.0 | 61.875 | 64.000 | 65.000 | 64.000 | 64.000 | 63.750 | 64.000 |
| 80.0 | 61.625 | 64.000 | 65.000 | 64.000 | 63.875 | 63.750 | 64.000 |
| 100.0 | 61.750 | 63.500 | 65.000 | 64.250 | 63.875 | 63.875 | 64.000 |
| 125.0 | 61.750 | 63.500 | 65.000 | 64.125 | 64.500 | 63.875 | 64.000 |
| 160.0 | 61.750 | 63.500 | 65.000 | 64.125 | 63.875 | 63.750 | 63.875 |
| 200.0 | 61.750 | 63.750 | 65.000 | 64.000 | 63.750 | 63.625 | 63.875 |
| 250.0 | 61.625 | 64.500 | 65.000 | 64.000 | 63.500 | 63.625 | 63.875 |
| 315.0 | 61.750 | 64.125 | 65.000 | 64.000 | 63.875 | 63.625 | 63.875 |
| 400.0 | 61.750 | 64.375 | 65.125 | 64.000 | 64.000 | 64.000 | 63.875 |
| 500.0 | 62.000 | 64.250 | 65.250 | 64.375 | 63.750 | 63.625 | 63.875 |
| 630.0 | 61.750 | 64.250 | 65.250 | 64.250 | 64.125 | 63.625 | 63.875 |
| 800.0 | 61.750 | 64.250 | 65.000 | 64.000 | 63.750 | 63.750 | 63.875 |
| 1000.0 | 61.750 | 64.375 | 65.375 | 64.000 | 63.750 | 63.625 | 63.875 |
| 1250.0 | 61.875 | 64.000 | 65.000 | 64.250 | 63.875 | 63.625 | 64.000 |
| 1600.0 | 62.000 | 63.750 | 65.000 | 64.000 | 63.750 | 63.875 | 63.875 |
| 2000.0 | 61.875 | 64.000 | 65.000 | 64.000 | 63.625 | 63.625 | 63.875 |
| 2500.0 | 61.875 | 64.000 | 65.000 | 64.000 | 64.000 | 63.625 | 63.875 |
| 3150.0 | 61.875 | 64.250 | 65.250 | 64.000 | 63.625 | 63.750 | 64.000 |
| 4000.0 | 61.875 | 64.250 | 65.250 | 64.500 | 63.500 | 63.750 | 64.000 |
| 5000.0 | 61.750 | 64.250 | 65.125 | 64.000 | 63.750 | 63.625 | 64.000 |
| 6300.0 | 61.750 | 64.125 | 65.125 | 64.000 | 63.750 | 63.875 | 64.375 |
| 8000.0 | 61.750 | 64.250 | 65.375 | 64.000 | 63.750 | 63.875 | 64.250 |
| 10000.0 | 61.750 | 64.000 | 66.000 | 64.000 | 64.000 | 63.875 | 64.250 |
| 12500.0 | 61.625 | 64.000 | 67.125 | 64.000 | 64.000 | 63.750 | 64.000 |
| 16000.0 | 61.625 | 64.3765 | 68.000 | 64.000 | 64.500 | 63.625 | 65.375 |

Table (A.5): Single Jet Spectral SPL in (dB) for Station 0

$P_{working}$:4.5 bar $P_{ambient}$ :0.904 bar $T_{ambient}$:10.0° C

| Frequency(Hz) | Angle to jet axis (deg) 0 | 15 | 30 | 45 | 60 | 75 | 90 |
|---|---|---|---|---|---|---|---|
| 10.0 | 62.750 | 64.750 | 66.500 | 65.000 | 65.000 | 64.875 | 65.000 |
| 12.5 | 62.750 | 65.125 | 66.625 | 65.000 | 65.000 | 64.875 | 65.000 |
| 16.0 | 63.375 | 65.125 | 66.500 | 65.000 | 65.000 | 64.875 | 65.000 |
| 20.0 | 62.625 | 65.000 | 66.500 | 64.875 | 65.000 | 64.875 | 65.000 |
| 25.0 | 62.625 | 65.000 | 66.500 | 64.875 | 65.000 | 64.875 | 65.000 |
| 31.5 | 62.6250 | 65.500 | 66.500 | 65.000 | 65.000 | 64.875 | 65.000 |
| 40.0 | 62.625 | 65.000 | 66.500 | 65.000 | 65.000 | 64.875 | 65.000 |
| 50.0 | 62.625 | 65.250 | 66.500 | 65.000 | 65.000 | 64.875 | 65.000 |
| 63.0 | 62.750 | 65.375 | 66.375 | 65.000 | 65.000 | 64.875 | 64.875 |
| 80.0 | 62.750 | 65.375 | 66.375 | 65.125 | 65.000 | 64.875 | 64.875 |
| 100.0 | 62.500 | 65.375 | 66.250 | 64.875 | 65.000 | 64.875 | 64.875 |
| 125.0 | 62.375 | 65.375 | 66.625 | 64.875 | 65.000 | 64.875 | 64.875 |
| 160.0 | 63.750 | 65.375 | 66.000 | 65.000 | 65.000 | 64.875 | 64.875 |
| 200.0 | 62.750 | 65.500 | 66.375 | 65.000 | 65.000 | 64.875 | 64.875 |
| 250.0 | 62.250 | 65.500 | 66.375 | 65.000 | 65.000 | 64.875 | 64.875 |
| 315.0 | 62.500 | 65.500 | 66.375 | 64.875 | 65.000 | 64.875 | 64.875 |
| 400.0 | 62.250 | 65.500 | 66.375 | 64.875 | 65.000 | 64.875 | 64.875 |
| 500.0 | 62.625 | 65.500 | 66.375 | 65.000 | 65.000 | 64.875 | 64.875 |
| 630.0 | 62.500 | 65.500 | 66.375 | 64.875 | 65.000 | 64.875 | 65.000 |
| 800.0 | 62.500 | 65.500 | 66.375 | 64.750 | 65.000 | 64.875 | 64.875 |
| 1000.0 | 62.500 | 65.500 | 66.375 | 65.000 | 65.000 | 64.875 | 64.875 |
| 1250.0 | 62.500 | 65.500 | 66.375 | 65.000 | 65.000 | 64.875 | 64.375 |
| 1600.0 | 62.250 | 65.250 | 66.250 | 65.000 | 65.000 | 64.875 | 64.875 |
| 2000.0 | 62.125 | 65.375 | 66.250 | 64.875 | 65.000 | 64.875 | 64.875 |
| 2500.0 | 62.000 | 65.375 | 66.250 | 64.500 | 65.125 | 64.875 | 64.875 |
| 3150.0 | 62.000 | 65.500 | 66.250 | 64.500 | 65.125 | 64.875 | 64.875 |
| 4000.0 | 62.000 | 65.500 | 66.375 | 64.500 | 65.125 | 64.875 | 64.875 |
| 5000.0 | 62.000 | 65.375 | 66.375 | 64.500 | 65.125 | 64.875 | 64.875 |
| 6300.0 | 62.375 | 65.500 | 66.250 | 64.500 | 65.125 | 64.875 | 64.875 |
| 8000.0 | 62.500 | 65.500 | 66.250 | 64.500 | 65.000 | 64.875 | 64.875 |
| 10000.0 | 62.250 | 65.375 | 66.250 | 64.875 | 65.000 | 64.875 | 64.875 |
| 12500.0 | 62.750 | 65.375 | 66.250 | 64.875 | 65.000 | 64.875 | 64.875 |
| 16000.0 | 62.750 | 65.375 | 66.250 | 64.875 | 65.000 | 64.875 | 64.875 |

### Table (A.7): Single Jet Spectral SPL in (dB) for Station 1

$P_{working}$:3.0 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.000 | 62.875 | 63.000 | 64.500 | 63.125 | 65.000 | 61.500 |
| 12.5 | 61.500 | 62.000 | 63.500 | 64.500 | 63.250 | 65.000 | 61.250 |
| 16.0 | 61.500 | 63.000 | 63.125 | 64.500 | 63.375 | 64.750 | 61.250 |
| 20.0 | 61.500 | 63.000 | 63.375 | 64.500 | 63.375 | 62.250 | 61.250 |
| 25.0 | 61.375 | 63.500 | 63.000 | 64.500 | 63.500 | 62.875 | 61.250 |
| 31.5 | 61.250 | 62.875 | 63.000 | 64.500 | 63.375 | 62.250 | 61.375 |
| 40.0 | 61.500 | 62.625 | 62.875 | 64.500 | 63.375 | 61.750 | 61.375 |
| 50.0 | 61.500 | 61.875 | 63.125 | 64.500 | 63.250 | 62.000 | 61.375 |
| 63.0 | 61.500 | 63.500 | 63.375 | 64.500 | 63.250 | 62.500 | 61.375 |
| 80.0 | 61.500 | 62.500 | 63.250 | 64.625 | 63.125 | 61.625 | 61.500 |
| 100.0 | 61.500 | 62.500 | 63.250 | 64.625 | 63.125 | 61.625 | 61.500 |
| 125.0 | 61.250 | 62.625 | 63.250 | 64.625 | 63.375 | 61.875 | 61.500 |
| 160.0 | 61.750 | 61.500 | 63.250 | 64.625 | 63.250 | 61.750 | 61.375 |
| 200.0 | 61.750 | 61.625 | 63.500 | 64.625 | 63.250 | 61.625 | 61.250 |
| 250.0 | 61.500 | 61.750 | 63.500 | 64.625 | 63.250 | 61.750 | 61.500 |
| 315.0 | 61.750 | 62.500 | 63.375 | 64.500 | 63.125 | 61.500 | 61.500 |
| 400.0 | 61.500 | 62.625 | 63.000 | 64.625 | 63.250 | 61.625 | 61.375 |
| 500.0 | 61.750 | 61.875 | 63.375 | 64.625 | 63.125 | 61.625 | 61.375 |
| 630.0 | 61.000 | 61.875 | 63.250 | 64.625 | 63.125 | 61.625 | 61.500 |
| 800.0 | 61.500 | 62.500 | 63.125 | 64.500 | 63.125 | 61.750 | 61.375 |
| 1000.0 | 61.375 | 61.750 | 62.875 | 64.500 | 63.125 | 62.250 | 61.375 |
| 1250.0 | 61.250 | 62.500 | 63.000 | 64.500 | 63.125 | 62.125 | 61.375 |
| 1600.0 | 61.125 | 61.500 | 63.000 | 64.500 | 63.125 | 62.000 | 61.250 |
| 2000.0 | 61.500 | 64.375 | 63.125 | 64.500 | 63.125 | 61.875 | 61.250 |
| 2500.0 | 61.000 | 61.750 | 63.125 | 64.625 | 63.000 | 61.875 | 61.250 |
| 3150.0 | 61.000 | 61.875 | 63.375 | 64.500 | 63.000 | 62.000 | 61.250 |
| 4000.0 | 61.125 | 61.500 | 63.500 | 64.500 | 63.125 | 61.750 | 61.250 |
| 5000.0 | 60.875 | 61.875 | 63.500 | 64.500 | 63.375 | 62.125 | 61.250 |
| 6300.0 | 61.125 | 62.625 | 63.375 | 64.500 | 63.125 | 62.250 | 61.250 |
| 8000.0 | 61.375 | 61.500 | 63.375 | 64.500 | 63.500 | 61.500 | 61.250 |
| 10000.0 | 61.125 | 62.500 | 63.500 | 64.375 | 63.500 | 61.750 | 61.250 |
| 12500.0 | 61.250 | 61.750 | 63.500 | 64.375 | 63.500 | 61.750 | 61.250 |
| 16000.0 | 61.125 | 61.125 | 63.125 | 64.750 | 63.125 | 61.750 | 61.250 |

# Table (A.8): Single Jet Spectral SPL in (dB) for Station 1

$P_{working}$:3.5 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.750 | 62.375 | 63.250 | 65.000 | 64.250 | 62.875 | 66.750 |
| 12.5 | 61.750 | 62.250 | 63.125 | 64.875 | 64.000 | 62.000 | 65.000 |
| 16.0 | 61.125 | 62.375 | 63.375 | 64.875 | 64.125 | 62.000 | 65.625 |
| 20.0 | 61.125 | 62.125 | 63.500 | 65.125 | 64.125 | 62.000 | 63.250 |
| 25.0 | 61.125 | 63.000 | 63.500 | 65.000 | 64.125 | 62.000 | 62.500 |
| 31.5 | 61.125 | 62.500 | 63.500 | 65.000 | 64.000 | 62.000 | 62.125 |
| 40.0 | 61.750 | 63.500 | 63.375 | 65.000 | 63.875 | 62.125 | 62.250 |
| 50.0 | 62.000 | 62.125 | 63.250 | 65.000 | 63.750 | 62.000 | 62.125 |
| 63.0 | 61.875 | 62.375 | 63.750 | 65.000 | 63.750 | 61.875 | 62.250 |
| 80.0 | 61.625 | 62.250 | 63.125 | 65.000 | 63.750 | 62.000 | 62.000 |
| 100.0 | 61.750 | 63.000 | 63.375 | 65.000 | 63.750 | 62.375 | 62.000 |
| 125.0 | 61.750 | 63.250 | 63.500 | 65.000 | 63.750 | 62.000 | 62.000 |
| 160.0 | 61.750 | 63.000 | 63.375 | 64.875 | 63.875 | 62.250 | 62.000 |
| 200.0 | 61.750 | 63.000 | 63.625 | 65.000 | 63.875 | 62.000 | 62.000 |
| 250.0 | 61.625 | 62.000 | 63.625 | 65.000 | 63.750 | 61.875 | 62.125 |
| 315.0 | 61.750 | 63.250 | 63.250 | 65.000 | 64.000 | 61.875 | 62.375 |
| 400.0 | 61.750 | 62.250 | 63.500 | 65.000 | 64.000 | 62.000 | 62.250 |
| 500.0 | 62.000 | 66.250 | 63.250 | 65.000 | 63.750 | 62.000 | 62.250 |
| 630.0 | 61.750 | 63.125 | 63.250 | 65.000 | 63.750 | 62.000 | 62.000 |
| 800.0 | 61.750 | 62.250 | 63.125 | 65.000 | 63.875 | 61.750 | 62.250 |
| 1000.0 | 61.750 | 63.250 | 63.125 | 65.000 | 63.875 | 61.750 | 62.250 |
| 1250.0 | 61.875 | 61.750 | 63.500 | 65.125 | 63.875 | 61.750 | 62.000 |
| 1600.0 | 62.000 | 62.750 | 63.375 | 65.000 | 63.875 | 61.750 | 62.125 |
| 2000.0 | 61.875 | 64.000 | 63.250 | 65.000 | 64.000 | 61.750 | 62.125 |
| 2500.0 | 61.875 | 62.250 | 63.625 | 65.000 | 64.000 | 61.750 | 62.125 |
| 3150.0 | 61.875 | 62.125 | 63.625 | 65.000 | 63.875 | 61.750 | 62.000 |
| 4000.0 | 61.875 | 62.125 | 63.750 | 65.000 | 63.750 | 61.750 | 62.250 |
| 5000.0 | 61.750 | 62.500 | 63.500 | 65.000 | 63.875 | 61.750 | 62.125 |
| 6300.0 | 61.750 | 62.000 | 63.500 | 65.000 | 63.750 | 61.750 | 62.000 |
| 8000.0 | 61.750 | 63.000 | 64.000 | 65.125 | 63.750 | 61.750 | 62.000 |
| 10000.0 | 61.750 | 62.875 | 63.250 | 65.000 | 63.625 | 61.750 | 62.000 |
| 12500.0 | 61.625 | 62.750 | 64.000 | 65.000 | 63.625 | 61.750 | 62.500 |
| 16000.0 | 61.625 | 63.125 | 63.375 | 65.000 | 63.750 | 61.875 | 62.250 |

## Table (A.9): Single Jet Spectral SPL in (dB) for Station 1

$P_{working}$:4.0 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 62.500 | 62.500 | 64.375 | 65.750 | 64.750 | 62.750 | 62.500 |
| 12.5 | 62.375 | 62.500 | 64.375 | 65.750 | 64.750 | 62.500 | 62.500 |
| 16.0 | 62.375 | 62.375 | 64.375 | 65.750 | 64.750 | 62.500 | 62.375 |
| 20.0 | 62.125 | 62.875 | 64.125 | 65.750 | 64.750 | 62.500 | 62.375 |
| 25.0 | 62.125 | 65.000 | 64.250 | 65.750 | 64.750 | 62.500 | 62.375 |
| 31.5 | 62.500 | 63.875 | 64.000 | 65.750 | 64.750 | 62.500 | 62.375 |
| 40.0 | 62.500 | 63.375 | 64.000 | 65.625 | 64.750 | 62.500 | 62.500 |
| 50.0 | 62.500 | 63.375 | 64.250 | 65.750 | 64.625 | 62.500 | 62.375 |
| 63.0 | 62.500 | 63.000 | 64.375 | 65.750 | 64.625 | 62.125 | 62.375 |
| 80.0 | 62.750 | 62.750 | 64.125 | 65.750 | 64.625 | 62.500 | 62.375 |
| 100.0 | 62.500 | 62.625 | 64.125 | 65.750 | 64.625 | 62.750 | 62.375 |
| 125.0 | 62.500 | 62.500 | 64.000 | 65.750 | 64.625 | 63.750 | 62.375 |
| 160.0 | 62.500 | 62.500 | 64.250 | 65.625 | 64.625 | 62.750 | 62.375 |
| 200.0 | 62.500 | 62.625 | 64.375 | 65.625 | 64.625 | 62.750 | 62.375 |
| 250.0 | 62.500 | 62.625 | 64.375 | 65.625 | 64.625 | 62.625 | 62.375 |
| 315.0 | 62.375 | 62.625 | 64.375 | 65.750 | 64.500 | 62.625 | 62.375 |
| 400.0 | 62.125 | 62.625 | 64.000 | 65.500 | 64.500 | 62.625 | 62.375 |
| 500.0 | 62.250 | 62.625 | 64.000 | 65.500 | 64.375 | 62.750 | 62.375 |
| 630.0 | 62.250 | 63.500 | 64.250 | 65.500 | 64.375 | 62.750 | 62.375 |
| 800.0 | 62.250 | 62.500 | 64.375 | 65.750 | 64.375 | 62.625 | 62.375 |
| 1000.0 | 62.250 | 62.625 | 64.250 | 65.625 | 64.375 | 62.625 | 62.500 |
| 1250.0 | 62.250 | 62.625 | 64.250 | 65.625 | 64.375 | 62.750 | 62.500 |
| 1600.0 | 62.500 | 62.625 | 64.000 | 65.625 | 64.375 | 62.750 | 62.500 |
| 2000.0 | 62.500 | 62.625 | 64.250 | 65.625 | 64.375 | 62.750 | 62.500 |
| 2500.0 | 62.500 | 62.500 | 64.250 | 65.625 | 64.375 | 62.750 | 62.375 |
| 3150.0 | 62.250 | 62.750 | 64.250 | 65.625 | 64.500 | 62.750 | 62.250 |
| 4000.0 | 62.250 | 63.000 | 64.375 | 65.625 | 64.375 | 62.875 | 62.625 |
| 5000.0 | 62.250 | 63.000 | 64.375 | 65.375 | 64.375 | 62.875 | 62.500 |
| 6300.0 | 62.125 | 64.250 | 64.375 | 65.500 | 64.375 | 63.125 | 62.625 |
| 8000.0 | 62.375 | 62.625 | 64.125 | 65.500 | 64.250 | 62.750 | 62.250 |
| 10000.0 | 62.375 | 62.750 | 64.125 | 65.625 | 64.375 | 62.750 | 62.625 |
| 12500.0 | 62.250 | 62.625 | 64.375 | 65.625 | 64.375 | 62.625 | 62.500 |
| 16000.0 | 62.725 | 63.125 | 64.375 | 65.625 | 64.375 | 62.725 | 62.500 |

## Table (A.10): Single Jet Spectral SPL in (dB) for Station 1

$P_{working}$:4.5 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 62.750 | 63.375 | 64.750 | 66.375 | 65.000 | 63.875 | 62.875 |
| 12.5 | 62.750 | 63.375 | 64.500 | 66.375 | 65.000 | 65.500 | 62.875 |
| 16.0 | 62.375 | 63.375 | 64.500 | 66.250 | 65.000 | 64.000 | 62.875 |
| 20.0 | 62.625 | 63.375 | 64.125 | 66.250 | 65.000 | 64.000 | 62.875 |
| 25.0 | 62.625 | 63.375 | 64.500 | 66.250 | 65.000 | 64.500 | 62.875 |
| 31.5 | 62.625 | 63.375 | 64.500 | 66.250 | 64.625 | 63.750 | 63.000 |
| 40.0 | 62.625 | 63.250 | 64.500 | 66.250 | 64.625 | 63.500 | 63.000 |
| 50.0 | 62.625 | 63.500 | 64.250 | 66.375 | 64.375 | 63.500 | 63.000 |
| 63.0 | 62.750 | 63.500 | 64.250 | 66.375 | 64.500 | 63.750 | 63.375 |
| 80.0 | 62.750 | 63.250 | 64.500 | 66.375 | 64.625 | 64.250 | 63.000 |
| 100.0 | 62.500 | 63.250 | 64.750 | 66.375 | 64.375 | 63.875 | 63.250 |
| 125.0 | 62.375 | 63.375 | 65.000 | 66.250 | 64.375 | 63.500 | 63.125 |
| 160.0 | 63.750 | 63.375 | 64.750 | 66.375 | 64.375 | 63.375 | 63.000 |
| 200.0 | 62.750 | 63.250 | 64.750 | 66.375 | 64.500 | 63.250 | 63.000 |
| 250.0 | 62.250 | 63.250 | 64.750 | 66.250 | 64.625 | 63.375 | 63.000 |
| 315.0 | 62.500 | 63.375 | 64.750 | 66.375 | 64.625 | 63.250 | 62.875 |
| 400.0 | 62.250 | 63.375 | 64.875 | 66.375 | 64.500 | 63.250 | 63.000 |
| 500.0 | 62.250 | 63.375 | 64.500 | 66.375 | 64.625 | 63.250 | 63.000 |
| 630.0 | 62.500 | 63.375 | 64.250 | 66.500 | 64.500 | 63.375 | 63.000 |
| 800.0 | 62.500 | 63.750 | 64.750 | 66.250 | 64.500 | 63.375 | 63.000 |
| 1000.0 | 62.500 | 63.125 | 64.250 | 66.250 | 64.625 | 63.250 | 62.875 |
| 1250.0 | 62.375 | 63.250 | 64.375 | 66.250 | 64.750 | 63.250 | 62.875 |
| 1600.0 | 62.250 | 63.250 | 63.750 | 66.250 | 64.750 | 63.375 | 62.875 |
| 2000.0 | 62.125 | 63.250 | 63.750 | 66.250 | 64.500 | 63.250 | 62.750 |
| 2500.0 | 62.000 | 63.125 | 64.125 | 66.250 | 64.500 | 63.125 | 62.875 |
| 3150.0 | 62.000 | 63.250 | 64.500 | 66.250 | 64.500 | 63.125 | 62.875 |
| 4000.0 | 62.000 | 63.250 | 64.500 | 66.250 | 64.500 | 63.125 | 63.000 |
| 5000.0 | 62.000 | 63.250 | 64.500 | 66.250 | 64.500 | 63.125 | 63.000 |
| 6300.0 | 62.375 | 63.250 | 64.750 | 66.250 | 64.500 | 63.125 | 63.250 |
| 8000.0 | 62.500 | 63.250 | 64.750 | 66.250 | 64.500 | 63.250 | 63.000 |
| 10000.0 | 62.250 | 63.250 | 64.250 | 66.250 | 64.625 | 63.250 | 63.125 |
| 12500.0 | 62.750 | 63.125 | 64.250 | 66.250 | 64.625 | 63.250 | 62.875 |
| 16000.0 | 62.750 | 63.625 | 64.250 | 66.250 | 64.625 | 63.000 | 62.875 |

**Table (A.11): Single Jet Spectral SPL in (dB) for Station 2**

$P_{working}$:2.5 bar    $P_{ambient}$ :0.897 bar    $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.250 | 61.000 | 64.000 | 63.250 | 61.000 | 62.500 | 62.375 |
| 12.5 | 61.250 | 60.750 | 64.000 | 63.250 | 61.250 | 62.500 | 62.375 |
| 16.0 | 61.250 | 61.250 | 64.000 | 63.250 | 60.875 | 62.250 | 62.375 |
| 20.0 | 60.875 | 60.875 | 64.000 | 63.250 | 61.000 | 62.875 | 62.375 |
| 25.0 | 61.625 | 60.750 | 64.000 | 63.250 | 61.500 | 62.625 | 62.375 |
| 31.5 | 60.750 | 61.375 | 64.000 | 63.250 | 62.125 | 62.500 | 62.375 |
| 40.0 | 61.250 | 60.875 | 64.000 | 63.125 | 61.500 | 62.500 | 62.375 |
| 50.0 | 60.750 | 60.872 | 64.000 | 63.125 | 60.875 | 62.500 | 62.375 |
| 63.0 | 60.875 | 60.875 | 64.000 | 63.125 | 61.125 | 62.750 | 62.375 |
| 80.0 | 61.750 | 61.125 | 64.000 | 63.125 | 61.125 | 62.500 | 62.375 |
| 100.0 | 60.625 | 61.250 | 64.000 | 63.125 | 61.125 | 62.500 | 62.375 |
| 125.0 | 60.750 | 60.875 | 64.000 | 63.125 | 60.875 | 62.500 | 62.375 |
| 160.0 | 60.500 | 60.875 | 64.000 | 63.125 | 61.500 | 62.250 | 62.375 |
| 200.0 | 60.625 | 61.000 | 64.000 | 63.125 | 60.875 | 62.375 | 62.375 |
| 250.0 | 60.625 | 61.000 | 64.000 | 63.125 | 61.500 | 62.375 | 62.375 |
| 315.0 | 60.500 | 60.750 | 64.000 | 63.125 | 61.000 | 62.375 | 62.375 |
| 400.0 | 60.625 | 60.875 | 64.000 | 63.125 | 61.000 | 62.625 | 62.375 |
| 500.0 | 60.750 | 61.000 | 64.000 | 63.000 | 60.875 | 62.250 | 62.375 |
| 630.0 | 60.500 | 61.000 | 64.000 | 63.000 | 61.000 | 62.250 | 62.375 |
| 800.0 | 60.500 | 60.750 | 64.000 | 63.000 | 61.000 | 62.500 | 62.250 |
| 1000.0 | 60.625 | 60.750 | 64.000 | 63.000 | 61.000 | 62.375 | 62.250 |
| 1250.0 | 61.750 | 61.000 | 64.000 | 63.000 | 61.000 | 62.750 | 62.250 |
| 1600.0 | 62.000 | 60.875 | 64.000 | 63.250 | 60.750 | 62.500 | 62.250 |
| 2000.0 | 62.000 | 60.875 | 64.000 | 63.250 | 61.000 | 62.500 | 62.250 |
| 2500.0 | 63.500 | 61.000 | 64.000 | 63.350 | 60.750 | 62.250 | 62.375 |
| 3150.0 | 61.375 | 60.875 | 64.000 | 63.250 | 60.750 | 62.250 | 62.375 |
| 4000.0 | 61.750 | 61.000 | 64.000 | 63.875 | 61.250 | 62.250 | 62.250 |
| 5000.0 | 61.375 | 60.625 | 64.000 | 63.250 | 61.625 | 62.375 | 62.250 |
| 6300.0 | 61.500 | 60.750 | 64.000 | 63.125 | 62.000 | 62.375 | 62.250 |
| 8000.0 | 61.625 | 60.875 | 64.000 | 63.125 | 61.500 | 62.250 | 62.250 |
| 10000.0 | 61.500 | 60.875 | 64.000 | 63.125 | 60.750 | 62.500 | 62.250 |
| 12500.0 | 61.625 | 61.125 | 64.000 | 63.125 | 61.125 | 62.500 | 62.250 |
| 16000.0 | 61.750 | 61.000 | 64.000 | 63.125 | 61.125 | 62.250 | 62.250 |

## Table (A.12): Single Jet Spectral SPL in (dB) for Station 2

$P_{working}$:3.0 bar  $P_{ambient}$ :0.897 bar  $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.000 | 62.125 | 65.000 | 64.250 | 61.750 | 63.375 | 64.750 |
| 12.5 | 61.500 | 64.500 | 65.000 | 64.250 | 61.750 | 63.375 | 63.500 |
| 16.0 | 61.500 | 63.250 | 65.000 | 64.250 | 61.875 | 63.250 | 63.500 |
| 20.0 | 61.500 | 62.375 | 65.000 | 64.250 | 61.625 | 63.250 | 63.500 |
| 25.0 | 61.375 | 62.000 | 65.000 | 64.250 | 61.625 | 63.250 | 63.500 |
| 31.5 | 61.250 | 62.000 | 65.000 | 64.250 | 61.750 | 63.500 | 63.500 |
| 40.0 | 61.500 | 61.750 | 65.000 | 64.250 | 61.625 | 63.250 | 63.500 |
| 50.0 | 61.500 | 61.750 | 65.000 | 64.250 | 61.625 | 63.250 | 63.500 |
| 63.0 | 61.500 | 61.875 | 65.000 | 64.250 | 61.750 | 63.250 | 63.375 |
| 80.0 | 61.500 | 61.875 | 65.000 | 64.125 | 61.750 | 63.500 | 63.250 |
| 100.0 | 61.250 | 61.875 | 65.000 | 64.125 | 61.750 | 63.250 | 63.250 |
| 125.0 | 61.500 | 61.750 | 65.000 | 64.125 | 61.625 | 63.250 | 63.125 |
| 160.0 | 61.750 | 61.625 | 65.000 | 64.125 | 61.625 | 63.125 | 63.250 |
| 200.0 | 61.750 | 61.750 | 65.000 | 64.125 | 61.625 | 63.125 | 63.250 |
| 250.0 | 61.500 | 61.750 | 65.000 | 64.125 | 61.625 | 63.125 | 63.250 |
| 315.0 | 61.750 | 61.750 | 65.000 | 64.125 | 61.625 | 63.125 | 63.250 |
| 400.0 | 61.500 | 61.750 | 65.000 | 64.125 | 61.125 | 63.125 | 63.250 |
| 500.0 | 61.750 | 61.750 | 65.000 | 64.125 | 62.000 | 63.125 | 63.250 |
| 630.0 | 61.000 | 62.750 | 65.000 | 64.125 | 61.875 | 63.125 | 63.250 |
| 800.0 | 61.500 | 62.500 | 65.000 | 64.125 | 61.625 | 63.125 | 63.250 |
| 1000.0 | 61.375 | 62.000 | 65.000 | 64.125 | 61.625 | 63.250 | 63.250 |
| 1250.0 | 61.250 | 62.000 | 65.000 | 64.125 | 61.625 | 63.250 | 63.250 |
| 1600.0 | 61.125 | 63.500 | 65.000 | 64.125 | 61.750 | 63.125 | 63.125 |
| 2000.0 | 61.500 | 64.875 | 65.000 | 64.125 | 61.625 | 63.250 | 63.125 |
| 2500.0 | 61.000 | 62.750 | 65.000 | 64.125 | 61.625 | 63.250 | 63.125 |
| 3150.0 | 61.000 | 62.000 | 65.000 | 64.125 | 61.625 | 63.250 | 63.125 |
| 4000.0 | 61.125 | 62.125 | 65.000 | 64.125 | 61.625 | 63.250 | 63.125 |
| 5000.0 | 60.875 | 62.375 | 65.000 | 64.125 | 61.500 | 63.250 | 63.125 |
| 6300.0 | 61.125 | 62.250 | 65.000 | 64.125 | 61.500 | 63.250 | 63.125 |
| 8000.0 | 61.375 | 62.000 | 65.000 | 64.125 | 61.500 | 63.375 | 63.125 |
| 10000.0 | 61.125 | 63.500 | 65.000 | 64.125 | 61.500 | 63.375 | 63.250 |
| 12500.0 | 61.250 | 62.125 | 65.000 | 64.125 | 61.625 | 63.250 | 63.250 |
| 16000.0 | 61.125 | 61.875 | 65.000 | 64.125 | 61.500 | 63.500 | 63.250 |

Table (A.13): Single Jet Spectral SPL in (dB) for Station 2

$P_{working}$:3.5 bar $P_{ambient}$ :0.897 $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.750 | 62.625 | 65.875 | 65.000 | 62.375 | 63.875 | 64.000 |
| 12.5 | 61.750 | 62.750 | 65.750 | 65.500 | 62.500 | 63.875 | 63.875 |
| 16.0 | 61.125 | 63.125 | 65.750 | 65.000 | 62.500 | 63.875 | 64.000 |
| 20.0 | 61.125 | 62.500 | 65.750 | 65.000 | 62.375 | 63.875 | 63.875 |
| 25.0 | 61.125 | 62.500 | 65.750 | 65.000 | 62.375 | 63.875 | 64.000 |
| 31.5 | 61.125 | 62.500 | 65.750 | 65.000 | 62.375 | 63.875 | 64.000 |
| 40.0 | 61.750 | 62.625 | 65.625 | 65.000 | 62.375 | 63.750 | 64.000 |
| 50.0 | 62.000 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 63.0 | 61.875 | 62.500 | 65.625 | 64.875 | 62.375 | 63.750 | 64.125 |
| 80.0 | 61.625 | 62.625 | 65.625 | 64.875 | 62.375 | 63.750 | 64.000 |
| 100.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.375 | 63.750 | 63.875 |
| 125.0 | 61.750 | 62.375 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 160.0 | 61.750 | 62.375 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 200.0 | 61.750 | 62.750 | 65.625 | 64.875 | 62.625 | 63.750 | 63.875 |
| 250.0 | 61.625 | 62.500 | 65.625 | 64.875 | 62.375 | 63.750 | 63.875 |
| 315.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 400.0 | 61.750 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 500.0 | 62.000 | 62.500 | 65.625 | 64.875 | 62.375 | 63.750 | 63.875 |
| 630.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 800.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |
| 1000.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.875 | 63.875 |
| 1250.0 • | 61.875 | 62.875 | 65.625 | 64.875 | 62.250 | 63.875 | 63.875 |
| 1600.0 | 62.000 | 62.750 | 65.625 | 64.875 | 62.250 | 63.875 | 64.000 |
| 2000.0 | 61.875 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 2500.0 | 61.875 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 3150.0 | 61.875 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 4000.0 | 61.875 | 62.875 | 65.625 | 64.875 | 62.500 | 63.750 | 63.875 |
| 5000.0 | 61.750 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 6300.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 63.750 |
| 8000.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 63.625 |
| 10000.0 | 61.750 | 62.500 | 65.625 | 64.875 | 62.250 | 63.750 | 63.875 |
| 12500.0 | 61.625 | 62.625 | 65.625 | 64.875 | 62.250 | 63.750 | 63.750 |
| 16000.0 | 61.625 | 62.875 | 65.625 | 64.875 | 62.250 | 63.750 | 64.000 |

Table (A.14): Single Jet Spectral SPL in (dB) for Station 2

$P_{working}$:4.0 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 62.500 | 63.250 | 66.375 | 65.750 | 62.875 | 64.500 | 64.250 |
| 12.5 | 62.375 | 63.375 | 66.375 | 65.750 | 62.875 | 64.500 | 64.125 |
| 16.0 | 62.375 | 63.000 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 20.0 | 62.125 | 64.125 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 25.0 | 62.125 | 63.500 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 31.5 | 62.500 | 63.000 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 40.0 | 62.500 | 63.375 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 50.0 | 62.500 | 63.125 | 66.375 | 65.750 | 62.875 | 64.500 | 64.000 |
| 63.0 | 62.500 | 63.250 | 66.375 | 65.625 | 62.875 | 64.500 | 64.000 |
| 80.0 | 62.750 | 63.000 | 66.250 | 65.625 | 62.750 | 64.500 | 64.000 |
| 100.0 | 62.500 | 63.375 | 66.250 | 65.625 | 62.750 | 64.500 | 64.000 |
| 125.0 | 62.500 | 63.125 | 66.250 | 65.625 | 62.875 | 64.500 | 64.000 |
| 160.0 | 62.500 | 63.125 | 66.250 | 65.625 | 62.875 | 64.500 | 64.250 |
| 200.0 | 62.500 | 63.125 | 66.250 | 65.625 | 62.875 | 64.500 | 64.000 |
| 250.0 | 62.500 | 63.250 | 66.250 | 65.625 | 62.875 | 64.500 | 64.000 |
| 315.0 | 62.375 | 63.125 | 66.250 | 65.625 | 63.125 | 64.500 | 64.000 |
| 400.0 | 62.125 | 63.625 | 66.250 | 65.625 | 63.000 | 64.500 | 63.875 |
| 500.0 | 62.250 | 63.125 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 630.0 | 62.250 | 63.125 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 800.0 | 62.250 | 63.125 | 66.250 | 65.625 | 63.000 | 64.375 | 63.875 |
| 1000.0 | 62.250 | 64.000 | 66.250 | 65.625 | 62.875 | 64.375 | 63.875 |
| 1250.0 | 62.250 | 63.250 | 66.250 | 65.625 | 62.875 | 64.375 | 63.875 |
| 1600.0 | 62.500 | 63.125 | 66.250 | 65.625 | 62.875 | 64.375 | 63.875 |
| 2000.0 | 62.500 | 63.000 | 66.250 | 65.625 | 62.875 | 64.375 | 63.875 |
| 2500.0 | 62.500 | 63.750 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 3150.0 | 62.500 | 63.000 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 4000.0 | 62.500 | 63.250 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 5000.0 | 62.500 | 63.375 | 66.250 | 65.625 | 62.875 | 64.500 | 63.875 |
| 6300.0 | 62.125 | 63.750 | 66.250 | 65.500 | 62.750 | 64.500 | 63.875 |
| 8000.0 | 62.375 | 63.125 | 66.250 | 65.500 | 62.750 | 64.500 | 63.875 |
| 10000.0 | 62.375 | 63.250 | 66.250 | 65.500 | 62.750 | 64.500 | 63.875 |
| 12500.0 | 62.250 | 63.500 | 66.250 | 65.500 | 62.750 | 64.500 | 63.875 |
| 16000.0 | 62.750 | 64.250 | 66.250 | 65.500 | 62.625 | 64.500 | 63.750 |

# Table (A.15): Single Jet Spectral SPL in (dB) for Station 2

$P_{working}$:4.5 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 62.750 | 63.750 | 66.750 | 66.250 | 63.500 | 65.000 | 65.000 |
| 12.5 | 62.750 | 63.750 | 66.750 | 66.250 | 63.500 | 65.000 | 65.000 |
| 16.0 | 62.375 | 63.625 | 66.750 | 66.250 | 63.500 | 65.000 | 65.000 |
| 20.0 | 62.625 | 63.625 | 66.750 | 66.250 | 63.500 | 65.000 | 65.000 |
| 25.0 | 62.625 | 63.625 | 66.750 | 66.250 | 63.375 | 65.000 | 65.000 |
| 31.5 | 62.625 | 63.625 | 66.750 | 66.250 | 63.375 | 65.000 | 65.000 |
| 40.0 | 62.625 | 63.625 | 66.750 | 66.250 | 63.375 | 65.000 | 65.000 |
| 50.0 | 62.625 | 63.625 | 66.750 | 66.250 | 63.375 | 64.875 | 65.000 |
| 63.0 | 62.750 | 63.625 | 66.750 | 66.250 | 63.375 | 65.000 | 65.000 |
| 80.0 | 62.750 | 63.625 | 66.750 | 66.250 | 63.375 | 65.000 | 65.000 |
| 100.0 | 62.500 | 63.750 | 66.750 | 66.250 | 63.375 | 64.875 | 64.875 |
| 125.0 | 62.375 | 63.500 | 66.750 | 66.250 | 63.375 | 64.875 | 64.875 |
| 160.0 | 63.750 | 63.500 | 66.750 | 66.250 | 63.375 | 64.875 | 64.875 |
| 200.0 | 62.750 | 63.500 | 66.750 | 66.250 | 63.375 | 64.875 | 64.875 |
| 250.0 | 62.250 | 63.625 | 66.750 | 66.250 | 63.375 | 64.875 | 64.875 |
| 315.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 400.0 | 62.250 | 63.500 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 500.0 | 62.625 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 630.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 800.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 1000.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 1250.0 | 62.375 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 1600.0 | 62.250 | 63.750 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 2000.0 | 62.125 | 63.750 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 2500.0 | 62.000 | 63.750 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 3150.0 | 62.000 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 4000.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 5000.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.500 | 64.875 | 64.875 |
| 6300.0 | 62.375 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 8000.0 | 62.500 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |
| 10000.0 | 62.250 | 63.625 | 66.750 | 66.125 | 63.500 | 64.875 | 64.875 |
| 12500.0 | 62.750 | 63.625 | 66.750 | 66.125 | 63.500 | 64.875 | 64.875 |
| 16000.0 | 62.750 | 63.625 | 66.750 | 66.125 | 63.375 | 64.875 | 64.875 |

Table (A.16): Single Jet Spectral SPL in (dB) for Station 3

$P_{working}$:2.5 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.250 | 60.375 | 61.750 | 60.625 | 61.375 | 61.000 | 60.250 |
| 12.5 | 61.250 | 60.500 | 61.375 | 60.750 | 61.500 | 61.000 | 60.125 |
| 16.0 | 61.250 | 60.375 | 61.375 | 60.750 | 61.250 | 61.000 | 60.125 |
| 20.0 | 60.875 | 60.875 | 61.375 | 60.625 | 61.000 | 61.125 | 60.000 |
| 25.0 | 61.625 | 60.625 | 61.375 | 60.625 | 61.125 | 61.000 | 59.875 |
| 31.5 | 60.750 | 60.500 | 61.750 | 60.625 | 61.250 | 60.875 | 60.000 |
| 40.0 | 61.250 | 60.250 | 61.625 | 60.625 | 61.125 | 61.000 | 60.000 |
| 50.0 | 60.750 | 60.625 | 61.750 | 60.625 | 61.250 | 61.000 | 59.875 |
| 63.0 | 60.875 | 60.500 | 61.2500 | 60.625 | 61.250 | 61.125 | 59.875 |
| 80.0 | 61.750 | 61.125 | 61.375 | 60.750 | 61.125 | 61.250 | 59.625 |
| 100.0 | 60.625 | 61.500 | 61.250 | 60.750 | 61.250 | 61.500 | 60.000 |
| 125.0 | 60.750 | 60.375 | 61.750 | 60.750 | 61.625 | 61.250 | 60.000 |
| 160.0 | 60.500 | 61.000 | 61.500 | 60.625 | 61.750 | 61.000 | 59.875 |
| 200.0 | 60.625 | 60.750 | 61.625 | 61.125 | 62.000 | 61.000 | 59.875 |
| 250.0 | 60.625 | 60.375 | 61.625 | 60.625 | 61.500 | 60.875 | 59.875 |
| 315.0 | 60.500 | 60.000 | 61.500 | 60.625 | 61.250 | 61.000 | 59.750 |
| 400.0 | 60.625 | 60.000 | 61.625 | 60.625 | 61.375 | 61.000 | 59.875 |
| 500.0 | 60.750 | 60.375 | 60.750 | 60.625 | 61.375 | 61.250 | 59.875 |
| 630.0 | 60.500 | 61.500 | 61.000 | 60.625 | 61.375 | 61.000 | 59.625 |
| 800.0 | 60.500 | 60.875 | 61.250 | 60.625 | 61.750 | 61.000 | 59.625 |
| 1000.0 | 60.625 | 61.250 | 61.000 | 60.625 | 61.500 | 61.500 | 59.750 |
| 1250.0 | 61.750 | 60.375 | 60.750 | 60.625 | 61.375 | 61.000 | 59.750 |
| 1600.0 | 62.000 | 60.250 | 60.625 | 60.750 | 61.500 | 60.875 | 60.000 |
| 2000.0 | 62.000 | 60.625 | 60.625 | 60.750 | 61.625 | 61.000 | 59.500 |
| 2500.0 | 63.500 | 60.000 | 60.750 | 61.000 | 61.250 | 60.875 | 59.750 |
| 3150.0 | 61.375 | 60.250 | 60.875 | 61.500 | 61.375 | 61.250 | 59.875 |
| 4000.0 | 61.750 | 60.125 | 60.875 | 60.500 | 61.250 | 62.750 | 59.750 |
| 5000.0 | 61.375 | 60.125 | 60.875 | 60.625 | 61.250 | 61.500 | 59.750 |
| 6300.0 | 61.500 | 60.250 | 60.875 | 60.625 | 61.125 | 61.000 | 59.875 |
| 8000.0 | 61.625 | 60.250 | 60.875 | 61.500 | 61.250 | 61.000 | 59.625 |
| 10000.0 | 61.500 | 60.125 | 60.875 | 61.250 | 61.125 | 60.750 | 59.500 |
| 12500.0 | 61.625 | 60.000 | 60.875 | 60.750 | 61.125 | 60.875 | 59.750 |
| 16000.0 | 61.750 | 60.250 | 60.875 | 60.750 | 61.250 | 61.000 | 59.625 |

Table (A.17): Single Jet Spectral SPL in (dB) for Station 3

$P_{working}$:3.0 bar $P_{ambient}$ :0.897 bar $T_{ambient}$ :15.5° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 61.000 | 61.500 | 62.000 | 61.625 | 61.750 | 61.500 | 60.500 |
| 12.5 | 61.500 | 61.250 | 62.125 | 62.375 | 61.750 | 61.375 | 60.500 |
| 16.0 | 61.500 | 61.000 | 61.875 | 61.875 | 61.750 | 61.500 | 60.625 |
| 20.0 | 61.500 | 61.625 | 61.750 | 61.625 | 61.750 | 61.625 | 60.625 |
| 25.0 | 61.375 | 63.250 | 61.875 | 61.625 | 61.750 | 61.500 | 60.625 |
| 31.5 | 61.250 | 61.250 | 61.875 | 61.625 | 62.000 | 61.250 | 60.500 |
| 40.0 | 61.500 | 61.125 | 62.125 | 61.625 | 61.875 | 61.500 | 60.500 |
| 50.0 | 61.500 | 61.750 | 62.000 | 61.500 | 61.750 | 61.250 | 60.500 |
| 63.0 | 61.500 | 61.375 | 63.500 | 61.500 | 61.750 | 61.250 | 60.500 |
| 80.0 | 61.500 | 60.875 | 61.750 | 61.625 | 61.750 | 61.375 | 60.500 |
| 100.0 | 61.250 | 61.125 | 64.000 | 61.500 | 61.750 | 61.375 | 60.500 |
| 125.0 | 61.500 | 61.125 | 62.000 | 61.500 | 61.875 | 61.375 | 60.500 |
| 160.0 | 61.750 | 60.875 | 62.000 | 61.500 | 61.875 | 61.375 | 60.625 |
| 200.0 | 61.750 | 61.000 | 62.000 | 61.500 | 61.750 | 61.375 | 60.625 |
| 250.0 | 61.500 | 61.000 | 61.875 | 61.500 | 61.875 | 61.250 | 60.500 |
| 315.0 | 61.750 | 60.750 | 61.750 | 61.500 | 61.625 | 61.250 | 60.500 |
| 400.0 | 61.500 | 61.125 | 61.750 | 61.375 | 61.750 | 61.250 | 60.500 |
| 500.0 | 61.750 | 61.250 | 61.750 | 61.375 | 62.000 | 61.250 | 60.500 |
| 630.0 | 61.000 | 61.250 | 62.000 | 61.375 | 61.625 | 61.250 | 60.500 |
| 800.0 | 61.500 | 63.625 | 61.750 | 61.375 | 61.750 | 61.375 | 60.500 |
| 1000.0 | 61.375 | 62.000 | 61.625 | 61.375 | 61.750 | 61.375 | 60.500 |
| 1250.0 | 61.250 | 61.000 | 61.750 | 61.375 | 61.750 | 61.500 | 60.500 |
| 1600.0 | 61.125 | 60.875 | 62.000 | 61.500 | 61.750 | 61.625 | 60.500 |
| 2000.0 | 61.500 | 60.750 | 61.875 | 61.750 | 61.750 | 61.500 | 60.500 |
| 2500.0 | 61.000 | 60.750 | 61.625 | 61.625 | 61.750 | 61.625 | 60.500 |
| 3150.0 | 61.000 | 61.875 | 61.750 | 62.625 | 61.750 | 61.375 | 60.500 |
| 4000.0 | 61.125 | 61.000 | 61.750 | 65.000 | 61.750 | 61.500 | 60.500 |
| 5000.0 | 60.875 | 61.000 | 61.750 | 62.375 | 61.750 | 61.500 | 60.500 |
| 6300.0 | 61.125 | 60.875 | 62.000 | 61.750 | 61.625 | 61.750 | 60.500 |
| 8000.0 | 61.375 | 60.875 | 61.875 | 61.500 | 61.750 | 61.500 | 60.500 |
| 10000.0 | 61.125 | 60.750 | 61.750 | 61.750 | 61.750 | 61.500 | 60.500 |
| 12500.0 | 61.250 | 61.250 | 61.750 | 61.500 | 61.750 | 61.500 | 60.500 |
| 16000.0 | 61.125 | 60.875 | 61.625 | 62.250 | 61.750 | 61.500 | 60.500 |

Table (A.23): Four Jets Spectral SPL in (dB) for Station 0

$P_{working}$:3.5 bar $P_{ambient}$ :0.902 bar $T_{ambient}$:16.0° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 79.375 | 66.000 | 67.875 | 67.625 | 67.375 | 66.375 | 67.875 |
| 12.5 | 72.000 | 65.875 | 67.875 | 67.625 | 67.375 | 66.375 | 67.875 |
| 16.0 | 75.000 | 65.500 | 67.875 | 67.625 | 67.375 | 66.375 | 67.875 |
| 20.0 | 71.250 | 66.000 | 67.875 | 67.625 | 67.375 | 66.375 | 67.875 |
| 25.0 | 71.500 | 65.875 | 67.875 | 67.625 | 67.375 | 66.375 | 67.875 |
| 31.5 | 78.250 | 65.625 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 40.0 | 73.375 | 65.625 | 67.875 | 67.625 | 67.375 | 66.375 | 67.750 |
| 50.0 | 75.125 | 65.500 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 63.0 | 70.750 | 65.500 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 80.0 | 73.250 | 65.875 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 100.0 | 75.000 | 65.875 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 125.0 | 75.875 | 65.375 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 160.0 | 73.875 | 65.625 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 200.0 | 70.875 | 65.750 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 250.0 | 73.375 | 66.250 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 315.0 | 72.750 | 65.500 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 400.0 | 74.500 | 65.625 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 500.0 | 75.250 | 65.625 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 630.0 | 74.000 | 65.750 | 67.750 | 67.625 | 67.375 | 66.375 | 67.750 |
| 800.0 | 75.625 | 65.750 | 67.500 | 67.500 | 67.375 | 66.375 | 67.750 |
| 1000.0 | 72.125 | 66.500 | 67.625 | 67.500 | 67.375 | 66.375 | 67.750 |
| 1250.0 | 74.625 | 65.750 | 67.625 | 67.500 | 67.375 | 66.375 | 67.750 |
| 1600.0 | 76.000 | 65.625 | 67.625 | 67.500 | 67.375 | 66.375 | 67.625 |
| 2000.0 | 77.000 | 65.750 | 67.500 | 67.500 | 67.375 | 66.375 | 67.625 |
| 2500.0 | 73.000 | 65.625 | 67.500 | 67.500 | 67.375 | 66.375 | 67.625 |
| 3150.0 | 75.750 | 65.875 | 67.500 | 67.500 | 67.375 | 66.375 | 67.625 |
| 4000.0 | 71.500 | 65.625 | 67.500 | 67.500 | 67.375 | 66.375 | 67.625 |
| 5000.0 | 77.000 | 65.500 | 67.500 | 67.500 | 67.250 | 66.375 | 67.625 |
| 6300.0 | 71.750 | 65.625 | 67.500 | 67.500 | 67.250 | 66.375 | 67.625 |
| 8000.0 | 72.625 | 65.750 | 67.500 | 67.500 | 67.250 | 66.375 | 67.625 |
| 10000.0 | 73.875 | 65.500 | 67.375 | 67.500 | 67.250 | 66.250 | 67.625 |
| 12500.0 | 72.750 | 65.500 | 67.375 | 67.500 | 67.250 | 66.250 | 67.625 |
| 16000.0 | 73.500 | 65.250 | 67.375 | 67.375 | 67.250 | 66.250 | 67.625 |

**Table (A.25): Four Jets Spectral SPL in (dB) for Station 0**

$P_{working}$:4.5 bar $P_{ambient}$:0.902 bar $T_{ambient}$:16.0° C

| Frequency(Hz) | Angle to jet axis (deg) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 15 | 30 | 45 | 60 | 75 | 90 |
| 10.0 | 75.625 | 67.250 | 69.125 | 68.875 | 68.500 | 67.500 | 68.875 |
| 12.5 | 77.000 | 66.750 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 16.0 | 75.750 | 67.125 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 20.0 | 74.500 | 67.250 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 25.0 | 77.000 | 67.250 | 69.125 | 68.875 | 68.500 | 67.500 | 68.875 |
| 31.5 | 75.500 | 66.875 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 40.0 | 77.500 | 66.875 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 50.0 | 76.750 | 66.875 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 63.0 | 73.000 | 67.000 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 80.0 | 75.375 | 66.750 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 100.0 | 76.500 | 66.875 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 125.0 | 75.500 | 66.875 | 69.000 | 68.875 | 68.500 | 67.500 | 68.875 |
| 160.0 | 73.250 | 66.750 | 69.000 | 68.750 | 68.500 | 67.500 | 68.875 |
| 200.0 | 76.250 | 66.875 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 250.0 | 75.000 | 66.625 | 69.125 | 68.875 | 68.500 | 67.500 | 68.875 |
| 315.0 | 76.000 | 67.125 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 400.0 | 77.500 | 67.000 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 500.0 | 77.625 | 66.500 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 630.0 | 73.750 | 66.875 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 800.0 | 71.500 | 66.250 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 1000.0 | 76.000 | 66.375 | 68.875 | 68.750 | 68.500 | 67.500 | 68.875 |
| 1250.0 | 77.000 | 66.750 | 68.875 | 68.750 | 68.500 | 67.500 | 68.750 |
| 1600.0 | 74.165 | 66.375 | 68.875 | 68.750 | 68.500 | 67.500 | 68.750 |
| 2000.0 | 75.250 | 66.625 | 68.750 | 68.750 | 68.500 | 67.500 | 68.750 |
| 2500.0 | 76.250 | 67.250 | 68.625 | 68.750 | 68.500 | 67.500 | 68.750 |
| 3150.0 | 74.500 | 67.000 | 68.750 | 68.750 | 68.375 | 67.500 | 68.750 |
| 4000.0 | 75.125 | 66.250 | 68.750 | 68.750 | 68.375 | 67.500 | 68.750 |
| 5000.0 | 78.000 | 66.500 | 68.750 | 68.750 | 68.375 | 67.500 | 68.750 |
| 6300.0 | 75.875 | 66.500 | 68.750 | 68.625 | 68.375 | 67.500 | 68.750 |
| 8000.0 | 77.000 | 66.250 | 68.625 | 68.625 | 68.375 | 67.375 | 68.750 |
| 10000.0 | 76.000 | 66.625 | 68.625 | 68.625 | 68.375 | 67.375 | 68.750 |
| 12500.0 | 73.500 | 66.500 | 68.625 | 68.625 | 68.375 | 67.375 | 68.750 |
| 16000.0 | 72.000 | 66.750 | 68.625 | 68.625 | 68.375 | 67.375 | 68.750 |

ملخص البحث
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يتناول هذا البحث الضوضاء المنبعثة من نافثة واحدة واربع نافثات حرة صغيرة، تستخدم كحارقات في بعض المخابز المحلية، ويساوي قطر حلق كل منها ١ ملم، عند قيم ضغط مختلفة من ٢,٥ ضغط جوي وحتى ٤,٥ ضغط جوي، بخطوة مقدارها ٠,٥ ضغط جوي.

بينت النتائج ان مستوى ضغط الصوت الأقصى لنافثه واحدة يقع على زاوية مقدارها ٣٦ درجة من محور النافثه، كما اكدت نتائج دراسة النافثات الأربع الأخرى تلك الملاحظة باستثناء المنطقة الواقعة على محور النافثات الأربع. وانسجمت متجهية مستويات ضغوط الصوت الإجمالية لنافثة واحدة واربع نافثات على التوالي مع تلك النتائج.

النتائج المستخلصه من التجارب لمستويات الطاقة الصوتية، بينت ان مستوى الطاقة الصوتية المنبعثة منها لا يعتمد على تردد الصوت الصادر من النافثات في المجال الذي قيست فيه تلك الطاقة، وان ارتباط مستوى الطاقة الصوتية الاجمالي في حالة السريان المخنوق، الذي تتساوى فيه سرعة الهواء عند الحلق مع سرعة الصوت، يتبع الأس الرابع لتلك السرعة.

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