research report

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TECHNICAL MEMORANDUM TM 69-4

NOISE REDUCTION STUDY OF ORBITING WORKSHOP VENTILATION FANS

By

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SUMMARY

Noise measurements made by P&VE on the ventilating fans installed in the Orbiting Workshop indicated excessively high levels, particularly in the Speech Interference Range (octaves 500, 1000, 2000 Hz) where levels of 66 dB were recorded. As a result a rudimentary experimental program to reduce the noise generated by the ventilating fans was undertaken.

As a first step, P&VE Staff members installed the fan assembly, without flow straightening vanes, inside a longer duct (nine inches rather than the standard five inch duct). Acoustic measurements made on this and the unmodified assembly are reported herein.

Removal of the vanes resulted in a SIL reduction of approximately eight dB indicating that much of the noise was generated by the interaction of the stator vanes with the rotor wake. It was found that locating the fan unit in the center of the nine inch duct further decreased the SIL by approximately three dB. The fan unit, when removed from the duct, generated a SIL of only 51 dB, indicating that the duct geometry was such that the rotor blades were encountering unnecessarily high pressure fluctuations in the duct flow.

As a result of the program, the fan unit was modified by (a) cutting away the leading portion of the support vanes effectively moving them further downstream from the rotor, (b) fitting a streamlined "bell mouth" to the inlet end of the fan duct, (c) fitting a faired "nose cone" to the rotor hub, and (d) installing an absorptive muffler on the exhaust end of the fan duct. Initial indications were that these steps resulted in substantial noise reductions.

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1.0 INTRODUCTION

The purpose of this study was to evaluate possible means of reducing the noise produced by the ventilation fans in the Orbiting Workshop. The standard configuration, shown in Figure 1, was found to be excessively annoying to the crew. The Speech Interference Level (arithmetic average sound pressure level in preferred octaves centered at 500 Hz, 1000 Hz, and 2000 Hz) generated by a single unit was measured to be approximately 66 dB three feet from the fan duct in the plane of the inlet.

An examination of the fan/duct geometry indicated some of the possible causes of the fan generated noise. The lack of a streamlined inlet shape on both the duct and the hub probably causes the flow to separate at the duct lip and at the leading edge of the hub (see Figure 1). This means that the fan tips and roots are running within a separated flow region which causes the pressure fluctuations experienced by the blades to be unnecessarily high and thus high noise levels are radiated. In addition, the support vanes, which probably also act to some extent as flow straighteners, are very close (within 1/2 fan-blade-chord) to the fan blades and thus are exposed to large flow variations and, consequently, are efficient noise generators.

The rotational speed of the fan is such that the low harmonics of the fundamental blade passage frequency fall into the Speech Interference Level range (500-2000 Hz). Fan noise is caused by pressure fluctuations on the fan blades and the supporting vanes, thus smoothing of the airflow through the ducting will result in lowering the sound harmonic levels. In addition, increasing the length of the duct in front of the fan will not only reduce the side radiated noise by changing the directional characteristics, but will also cause some attenuation of the sound propagated out of the duct. Added duct length can be expected to smooth out some of the turbulence caused by flow separation at the duct inlet, thus reducing the pressure fluctuations at the fan blades and thus the noise.

In order to determine the effect of some of these possible modifications, a test program was run with the standard Airesearch Fan unit and with a unit modified by the P&VE Staff. The modified unit, consisting of the standard fan and motor housing in a nine-inch duct with the support vanes removed, is shown in Figure 2.

2.0 TEST PROGRAM

2.1 Apparatus

Two different units were used for the test. The first, shown in Figure 1, is the standard assembly and consists of a five-inch diameter, three-blade fan mounted approximately 3/4-inch from the front of a five-inch long, 5-1/4-inch diameter duct. The motor housing is supported by five flow straightening vanes approximately 2-inches long and located 1-1/2 inches behind the fan.

The second unit, shown in Figure 2 consists of the motor housing/fan assembly of the standard unit mounted inside a 9-inch long, 5-1/4-inch diameter duct. The support vanes were removed and the motor supported from the rear. The entire unit was mounted so as to allow the fan to be positioned at any longitudinal location within the duct.

2.2 Procedure

Both units were run at the design speed of approximately 5500 rpm in a small laboratory room and the sound pressure level was measured on a three-foot radius centered at the duct inlet. The standard fan assembly was measured with the fan at the standard location within the duct and the modified assembly was measured for four fan locations within the duct. The data was recorded on magnetic tape and later reduced by a narrow bandwidth filtered (10 Hz). The resulting plots are shown in Figures 3a through 3i. The level of each harmonic of blade passage noise was read from the plots of Figure 3 and tabulated in Table I.

TABLE I

ROTATIONAL HARMONIC SOUND PRESSURE LEVELS

Case*	Harmonic Number	Sound Pressure Level-dB
1	1	44.5
1	2	44.5
1	3	48.0
1	4	48.5
1	5	42.0
1	6	39.0
1	7	41.5
1	8	39.5

Overall = 53.8 dB

Case*	Harmonic Number	Sound Pressure Level-dB
2	1	46.0
2	2	56.0
2	3	45.0
2	4	39.0
2	5	44.0
2	6	43.0
2	7	44.0
2	8	40.0
2	9	39.0
2	10	42.0

Overall = 57.6 dB

Case*	Harmonic Number	Sound Pressure Level-dB
3	1	49.5
3	2	56.0
3	3	45.5
3	4	41.5
3	5	39.5
3	6	40.0
3	7	41.0

Overall = 57.5 dB

Case*	Harmonic Number	Sound Pressure Level-dB
4	1	48.0
4	2	50.5
4	3	51.0
4	4	48.0
4	5	46.5
4	6	44.0
4	7	44.0
4	8	40.0

Overall = 56.7 dB

Case*	Harmonic Number	Sound Pressure Level-dB
5	1	45.0
5	2	43.0
5	3	43.5
5	4	47.0
5	5	38.0
5	6	42.0
5	7	42.0

Overall = 52.1 dB

Case*	Harmonic Number	Sound Pressure Level-dB
6	1	46.0
6	2	44.5
6	3	45.0
6	4	51.0
6	5	44.0
6	6	42.5
6	7	45.5

Overall = 54.8 dB

Case*	Harmonic Number	Sound Pressure Level-dB
7	1	47.0
7	2	50.5
7	3	58.5
7	4	60.0
7	5	54.0
7	6	50.0
7	7	49.0

Overall = 63.6 dB

Case*	Harmonic Number	Sound Pressure Level-dB
8	1	47.0
8	2	52.0
8	3	61.5
8	4	63.0
8	5	60.0
8	6	58.5
8	7	54.5
8	8	49.5
8	9	47.5

Overall = o7.8 dB

Case*	Harmonic Number	Sound Pressure Level-dB
9	1	45.0
9	2	45.5
9	3	56.0
9	4	55.0
9	5	56.5
9	6	53.5
9	7	53.0
9	8	48.0
9	9	49.5

Overall = 62.5 dB

*Case parameters listed on following page.

TABLE I (Continued)

Case	Fan Unit	Measurement Distance	Azimuth	Fan Location Behind Duct Inlet
1	Modified	3 feet	0°	3.5 inches
2	Modified	3 feet	0°	0.25 inches
3	Modified	3 feet	0°	8.75 inches
4	Modified	3 feet	0°	4.50 inches
5	Modified	3 feet	90°	4.50 inches
6	Modified	3 feet	160°	4.50 inches
7	Standard	3 feet	0°	As Standard Unit
8	Standard	3 feet	90°	Not
9	Standard	3 feet	160°	Variable

3.0 RESULTS AND CONCLUSIONS

Figures 3a through 3i are 10 Hz bandwidth analyses of the tape recorded data. Figures 3a through 3f are for the modified assembly and Figures 3g through 3i are for the standard assembly. In all cases the rotational speed of the motor was approximately the same (5500 rpm). The relatively high level, low frequency noise is presumably ambient noise within the test room and the one noticeable feature is that the ambient levels in the frequency range 250 Hz to 300 Hz are sufficiently high so as to mask the fundamental rotational harmonic (275 Hz) thus the first harmonic level in Table I has been estimated. Harmonics above the first, however, are very evident and their levels are easily discernable.

Also evident in all the plots of Figure 3 is a peak at approximately 3000 Hz which is not harmonically related to the fan blade passage frequency. This frequency may be associated with the rotor of the driving motor. If this is the case, increased duct length in front of the fan and a muffling device on the exhaust can be expected to reduce it to an acceptable level. Since the level changes little from test to test, it is suspected that this frequency peak is associated with the ambient room noise rather than with the fan itself.

Figure 4 shows the effect of the position of the modified fan assembly in the duct on the rotational harmonic levels measured in front of the duct. It is immediately apparent that the two positions showing the highest levels are one-quarter inch from the inlet and one-quarter inch from the outlet of the duct. The two intermediate positions are somewhat lower for the first few harmonics, but do not drop off as rapidly with increasing harmonic numbers.

Figure 5 shows the overall sound level (calculated from the harmonic levels) as a function of the distance of the fan from the inlet of the duct. It is difficult to draw any definite conclusions on the basis of only four points, but it does appear that, as expected, lower noise levels result when the fan is positioned near the middle of the duct. This is also true of the Speech Interference Level (calculated from the harmonic levels) as can be noted in Figure 6.

To avoid possible errors due to directionality effects measurements were taken at azimuth positions of 90-degrees and 160-degrees around the intake as well as directly in front. Figure 7 shows that with the fan located at the center of the duct the maximum noise is radiated forward, thus evaluation of the noise reduction in front of the fan will be an acceptable method.

Figures 8 through 10 show a comparison of the standard and modified configurations at the three azimuth locations. In all cases there is a very substantial reduction, both in the overall level and the harmonic levels. These reductions are also registered in the Speech Interference Level in preferred octave bands (PSIL) shown in Figure 11.

4.0 DISCUSSION

The noticeable effect of removing the support vanes (Figures 8 through 11) indicate that they are most probably the cause of much of the noise as they operate in the immediate wake of the fan. One of the most desirable changes to the standard fan assembly would be to completely remove the vanes. Alternatively, increasing the fan/vane separation will reduce the vane generated noise.

It is suspected that the lack of a streamlined intake on the standard duct assembly forces the flow to separate at the duct lip thus causing very high pressure fluctuations at the fan blades. The turbulent flow is smoothed somewhat in the modified assembly due to the increased duct length, but the best way to reduce these unnecessarily high pressure fluctuations is to provide a streamlined inlet shape, both on the duct and on the rotor (fan) hub to insure that the flow does not separate. In an earlier test, reductions of the order of 15 dB in the PSIL were noted when the motor/fan assembly was removed from the standard duct and run in the free air. This further serves to emphasize the importance of the separated flow in the generated noise.

5.0 RECOMMENDATIONS

On the basis of the results of this study the following recommendations were made to reduce noise generated by the ventilation fans:

a. Attach to the inlet end of the standard duct a streamlined "bellmouth" to eliminate the separated flow at the lip.

b. Attach to the fan hub a streamlined, faired "bullet" noise to eliminate the flow separation at the blunt edge of the present hub.

c. Recognizing the necessity of retaining the support vanes, increase the spacing between the fan and the support vanes to at least two fan blade chord lengths to reduce the vane generated noise.

d. Install an absorptive muffler on the exhaust end of the duct to reduce the aft generated noise.

A sketch of the modified assembly is shown in Figure 12.

If further reductions are deemed necessary, the effect of added duct length in front of the fan may be investigated. The fan is operating below the theoretical duct cutoff frequency, thus reductions of up to 24 dB per diameter length increase are theoretically possible.

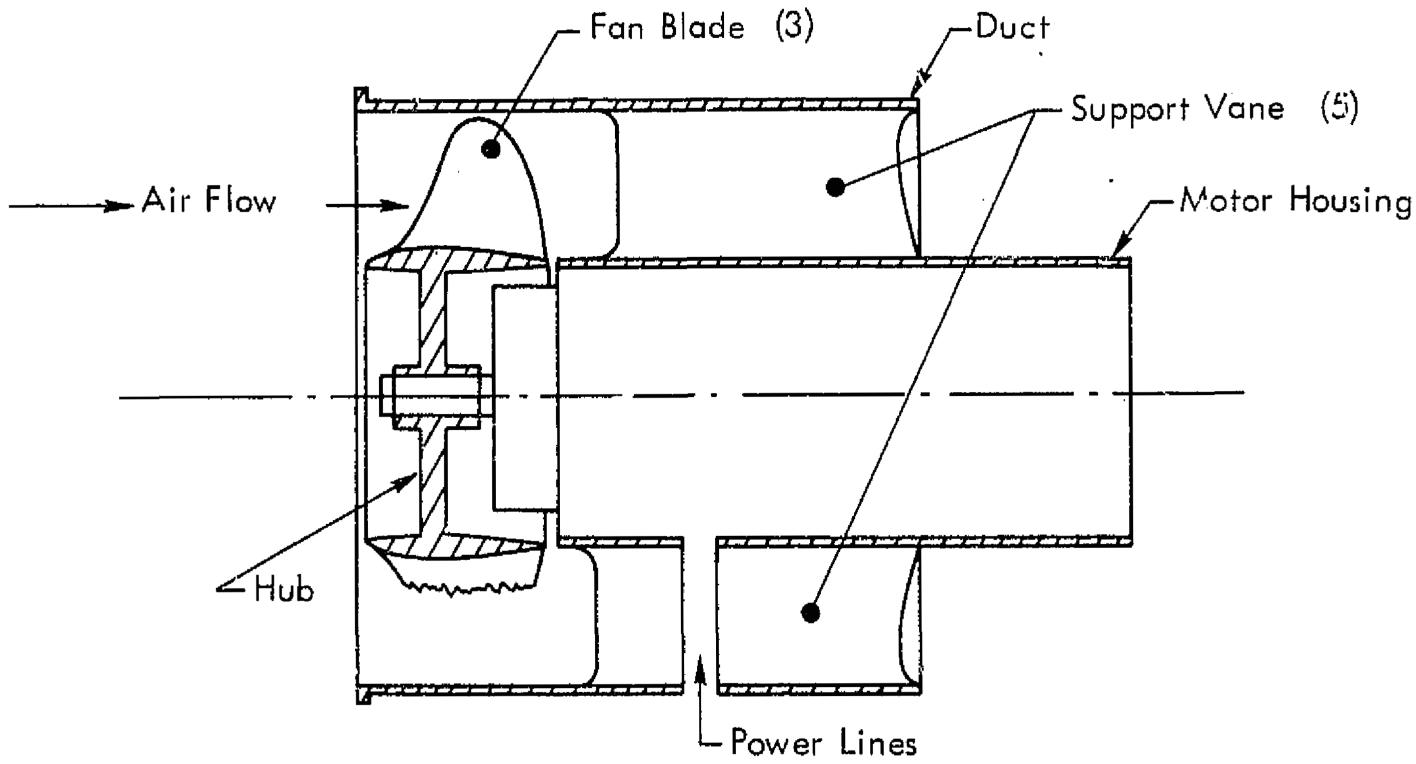

Figure 1. Cutaway View of Standard Fan Assembly

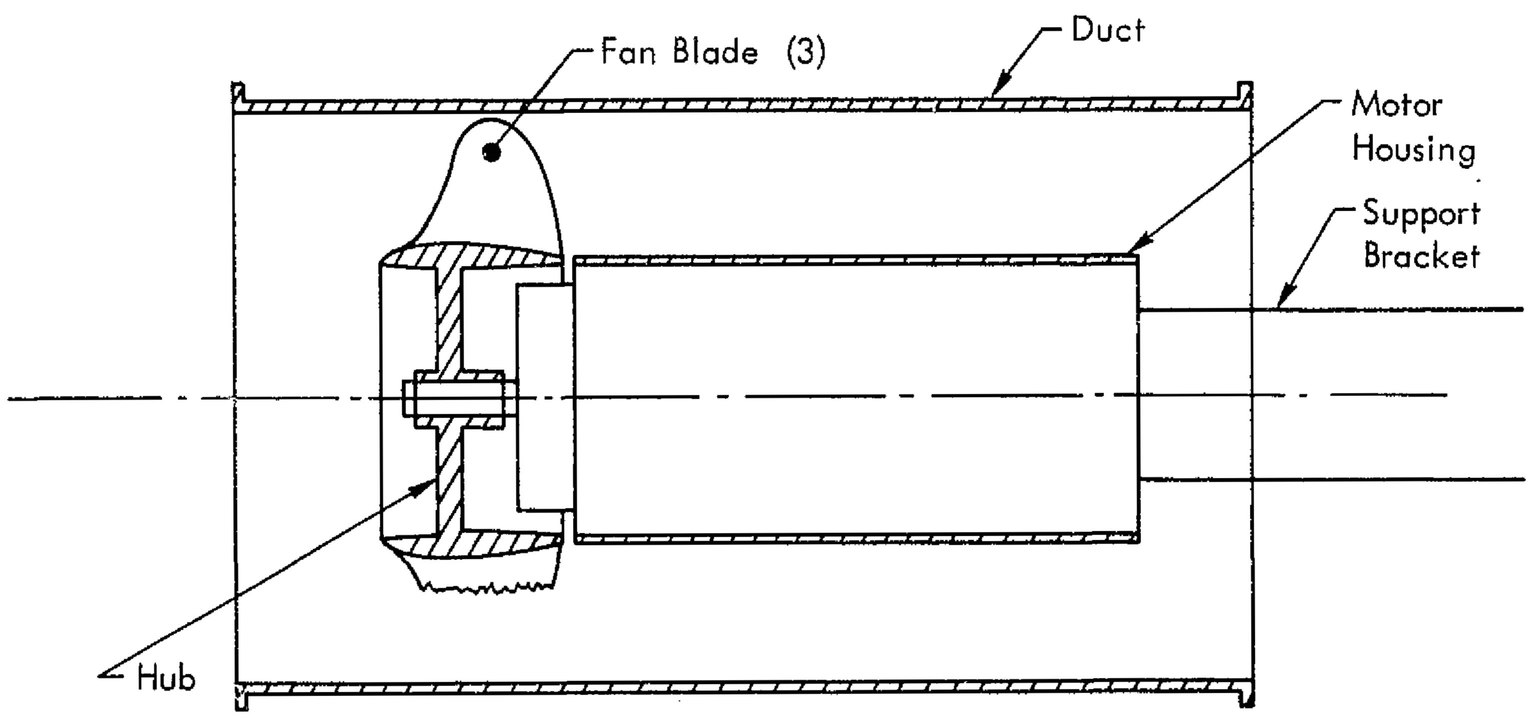

Figure 2. Cutaway View of Modified Fan Assembly

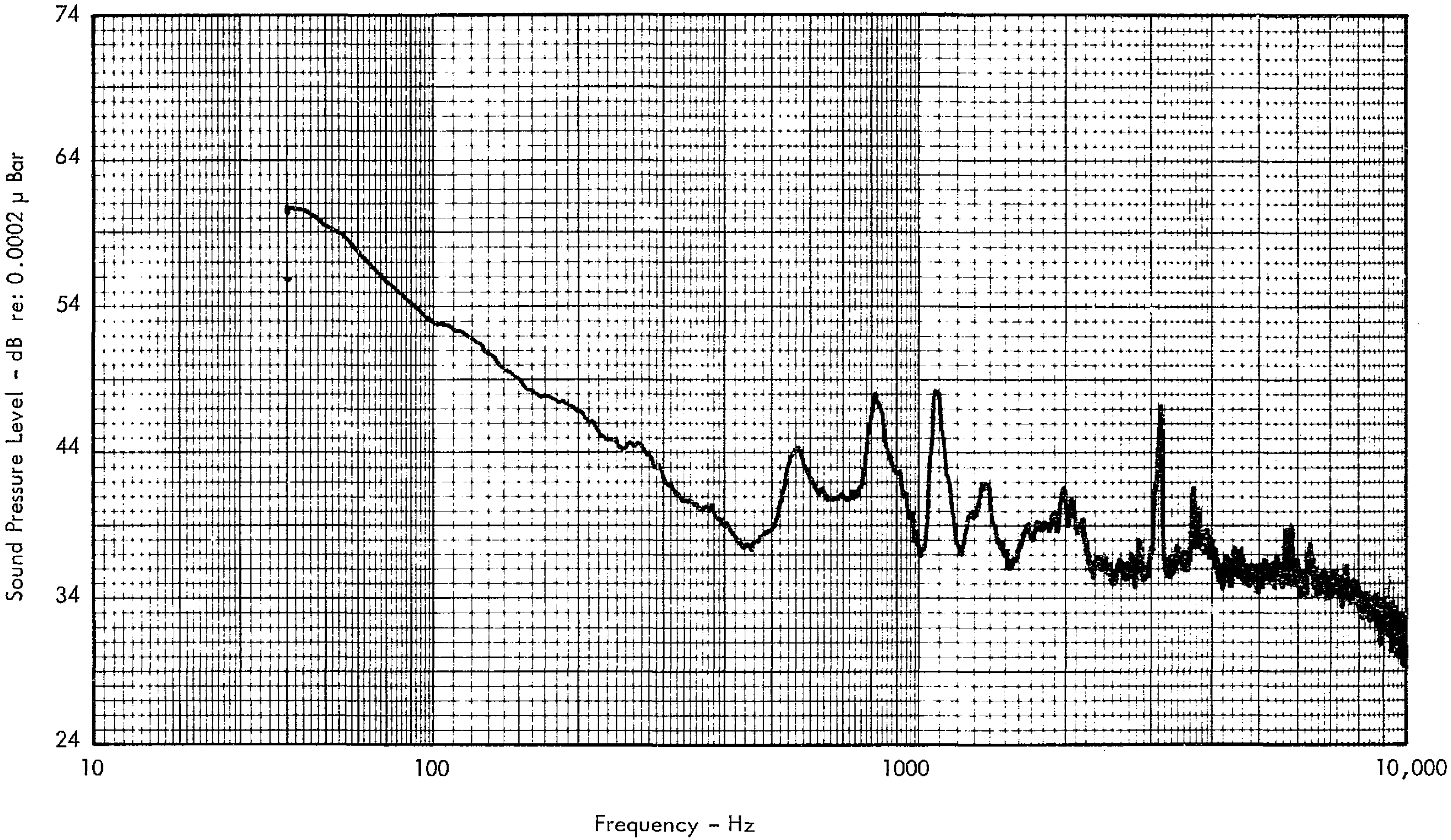

Figure 3a. Modified Fan Assembly 3 Feet in Front of Inlet. Fan 3-1/2 In. Behind Inlet.

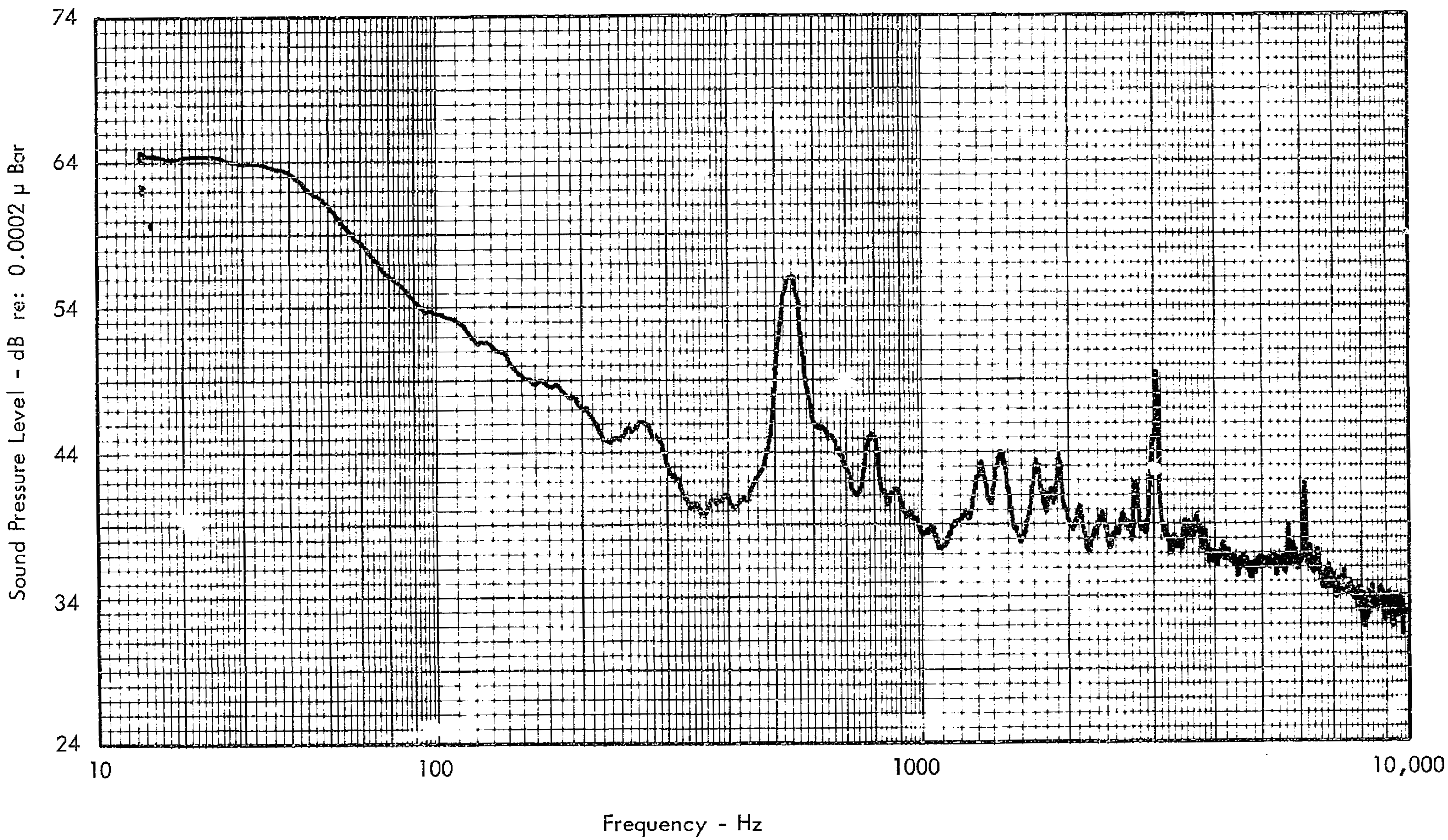

Figure 3b. Modified Fan Assembly 3 Feet in Front of Inlet. Fan 1/4 In. Behind Inlet.

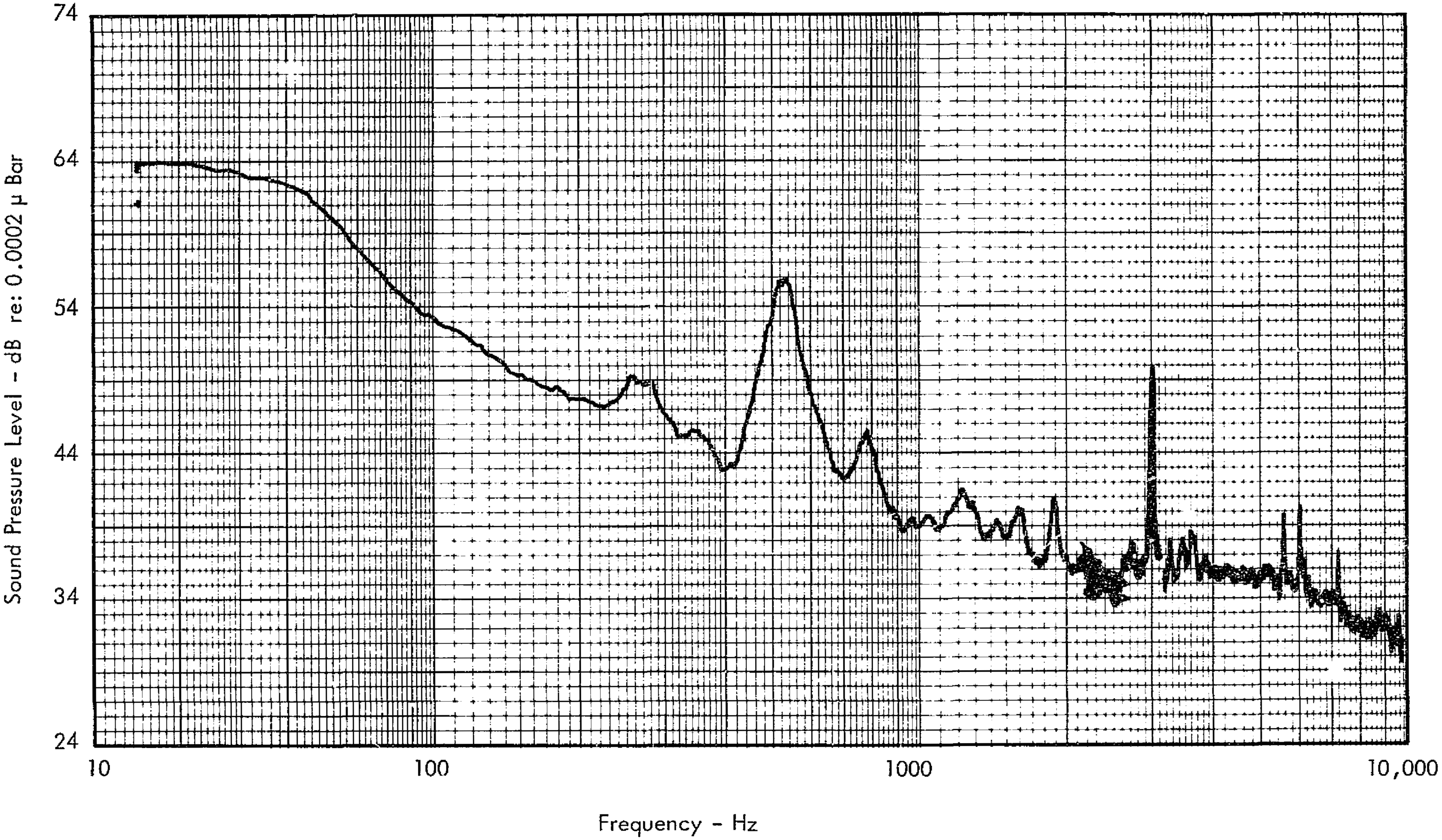

Figure 3c. Modified Fan Assembly 3 Feet in Front of Inlet. Fan 8-3/4 In. Behind Inlet.

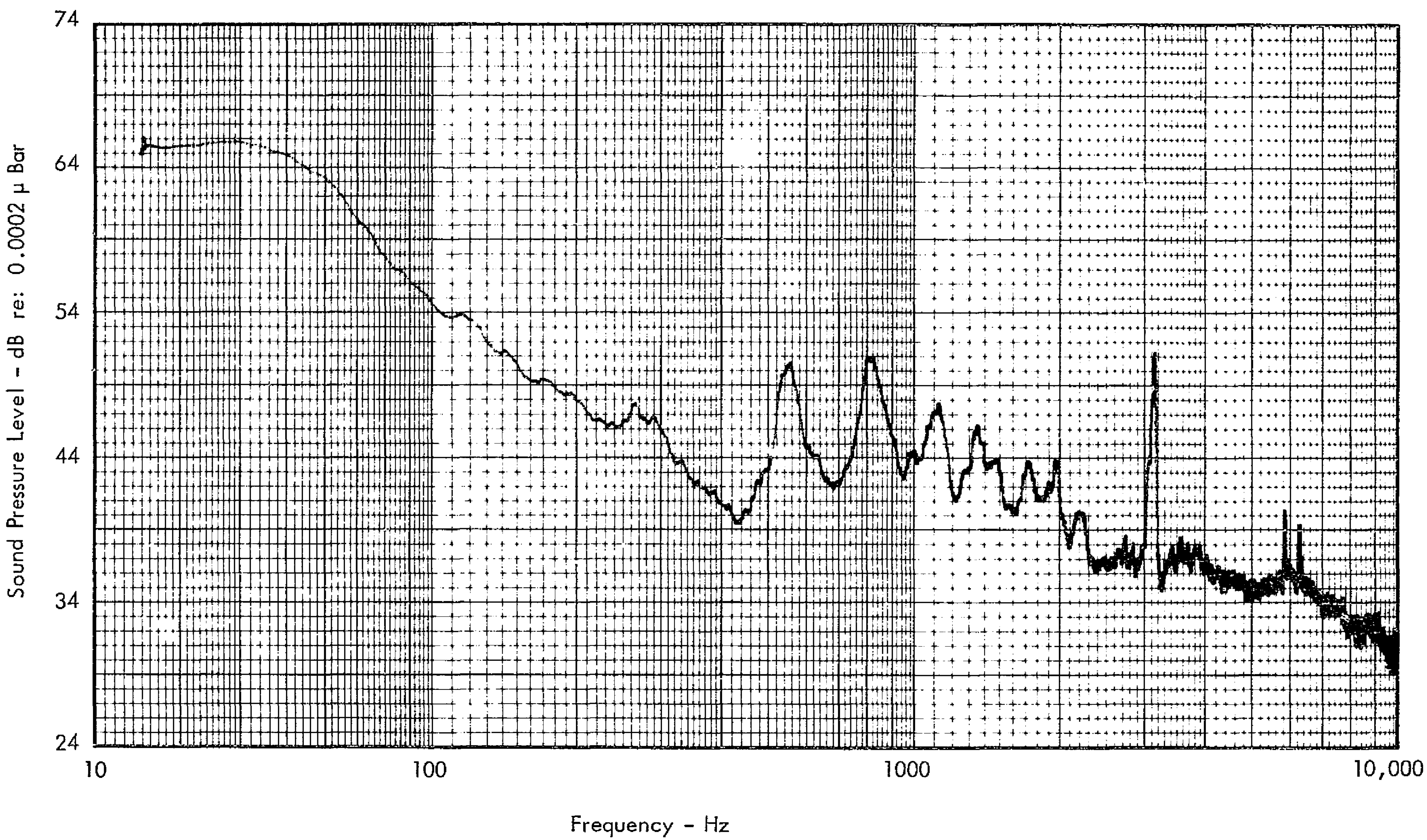

Figure 3d. Modified Fan Assembly 3 Feet in Front of Inlet. Fan 4-1/2 In. Behind Inlet.

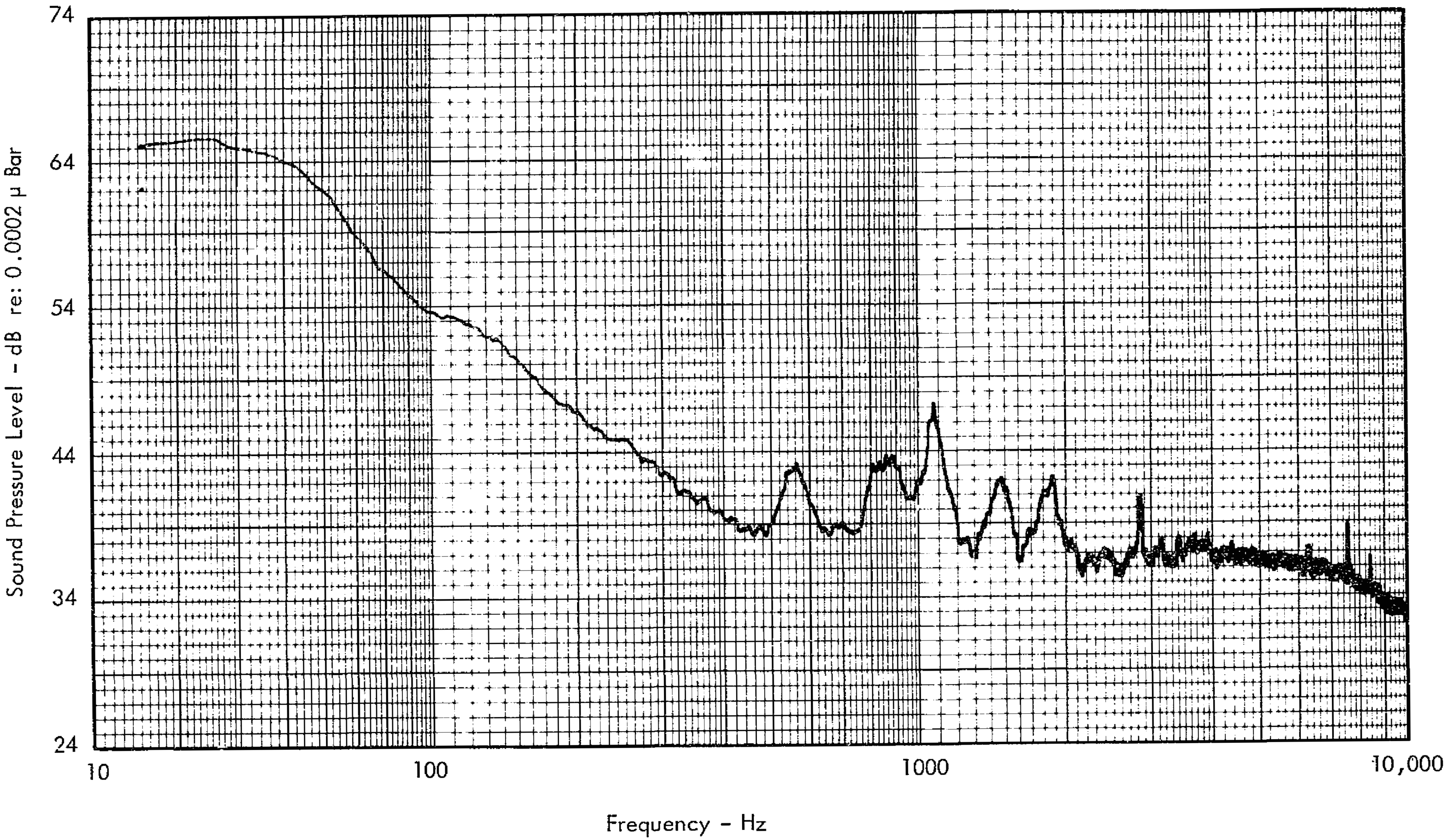

Figure 3e. Modified Fan Assembly 3 Feet to Side of Inlet (Azimuth 90°). Fan 4-1/2 In. Behind Inlet.

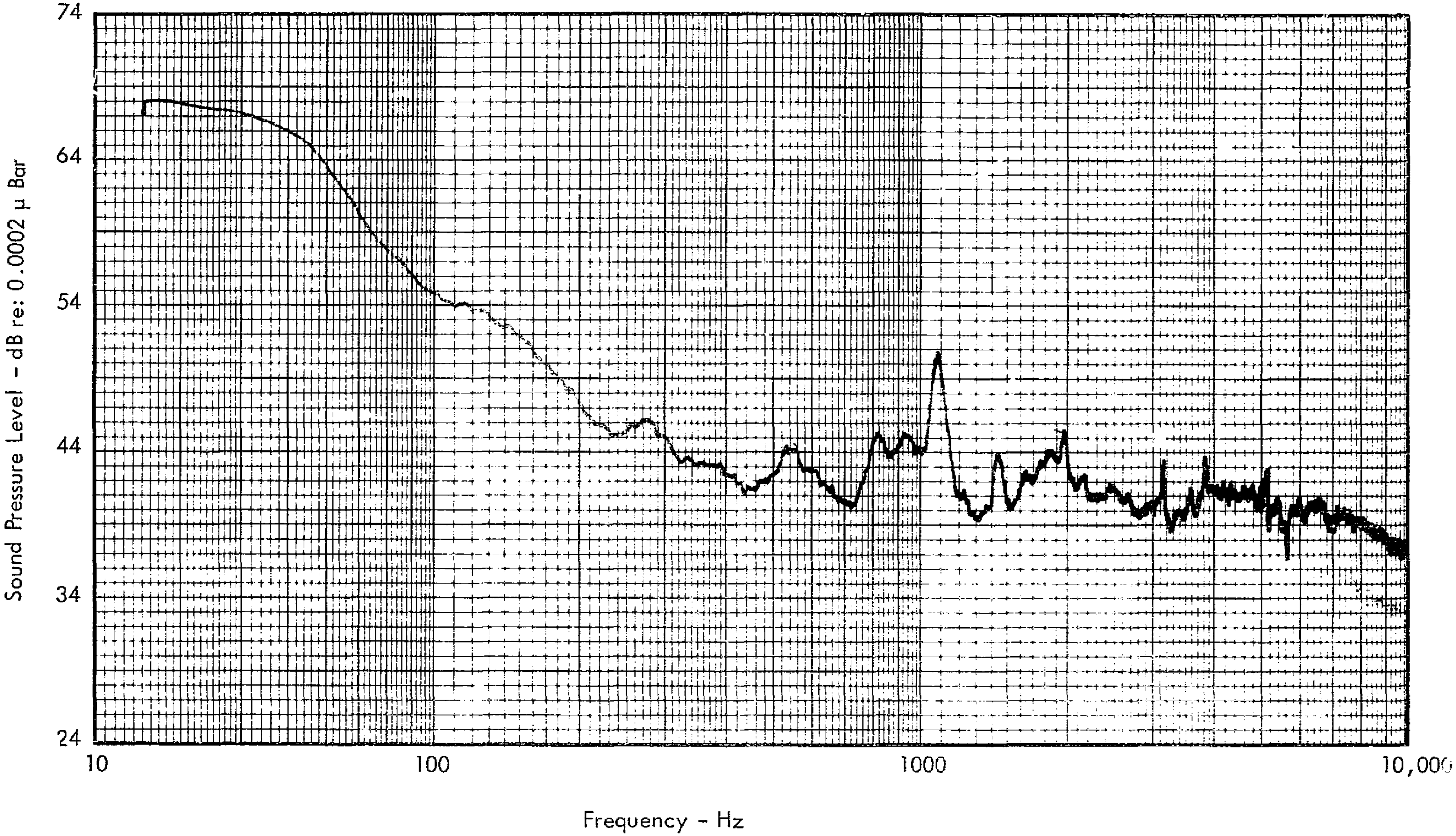

Figure 3f. Modified Fan Assembly, Azimuth 160°, 3 Feet Distance. Fan 4-1/2 In. Behind Inlet.

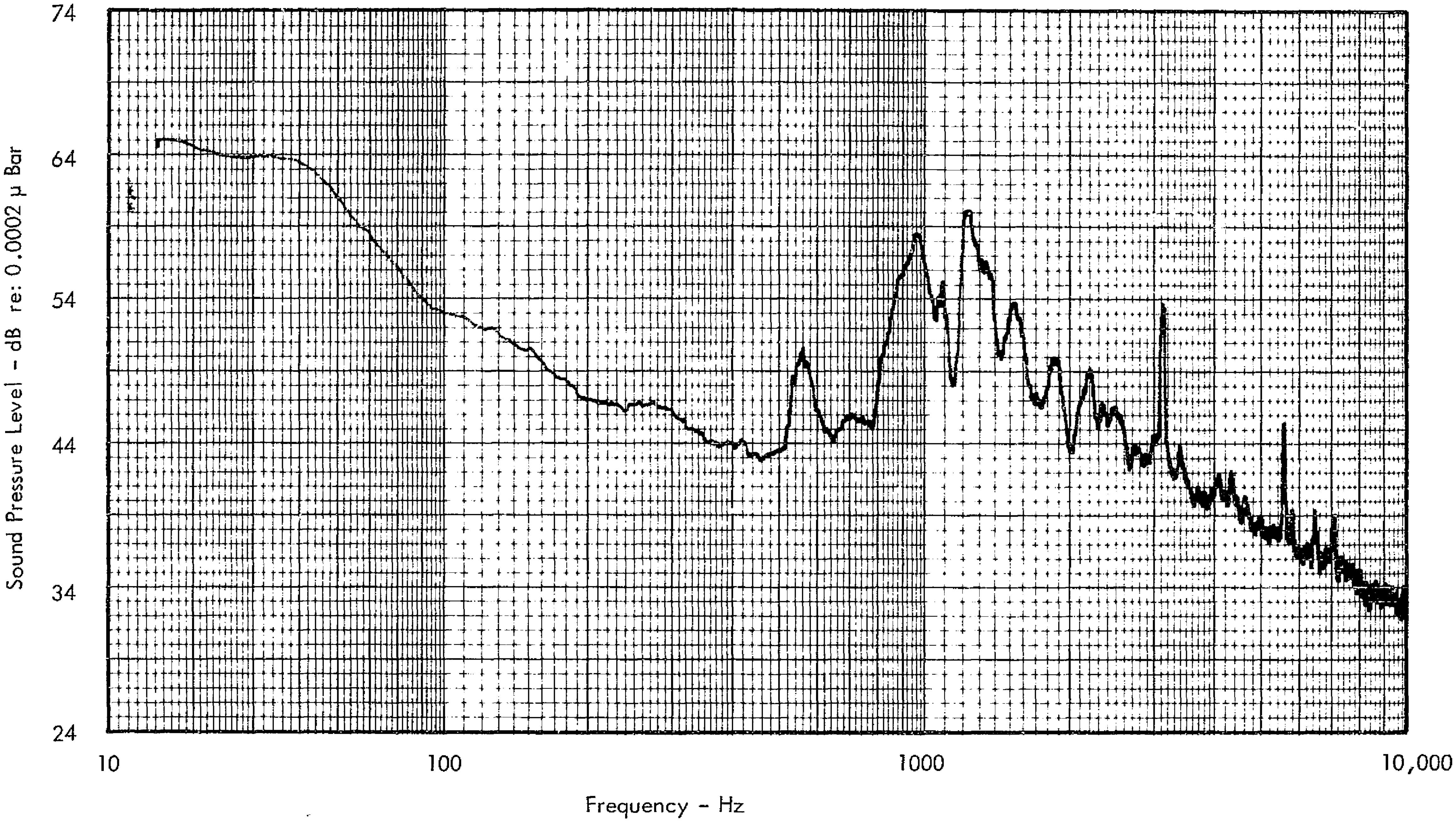

Figure 3g. Standard Fan Assembly 3 Feet in Front of Inlet (Azimuth 0°).

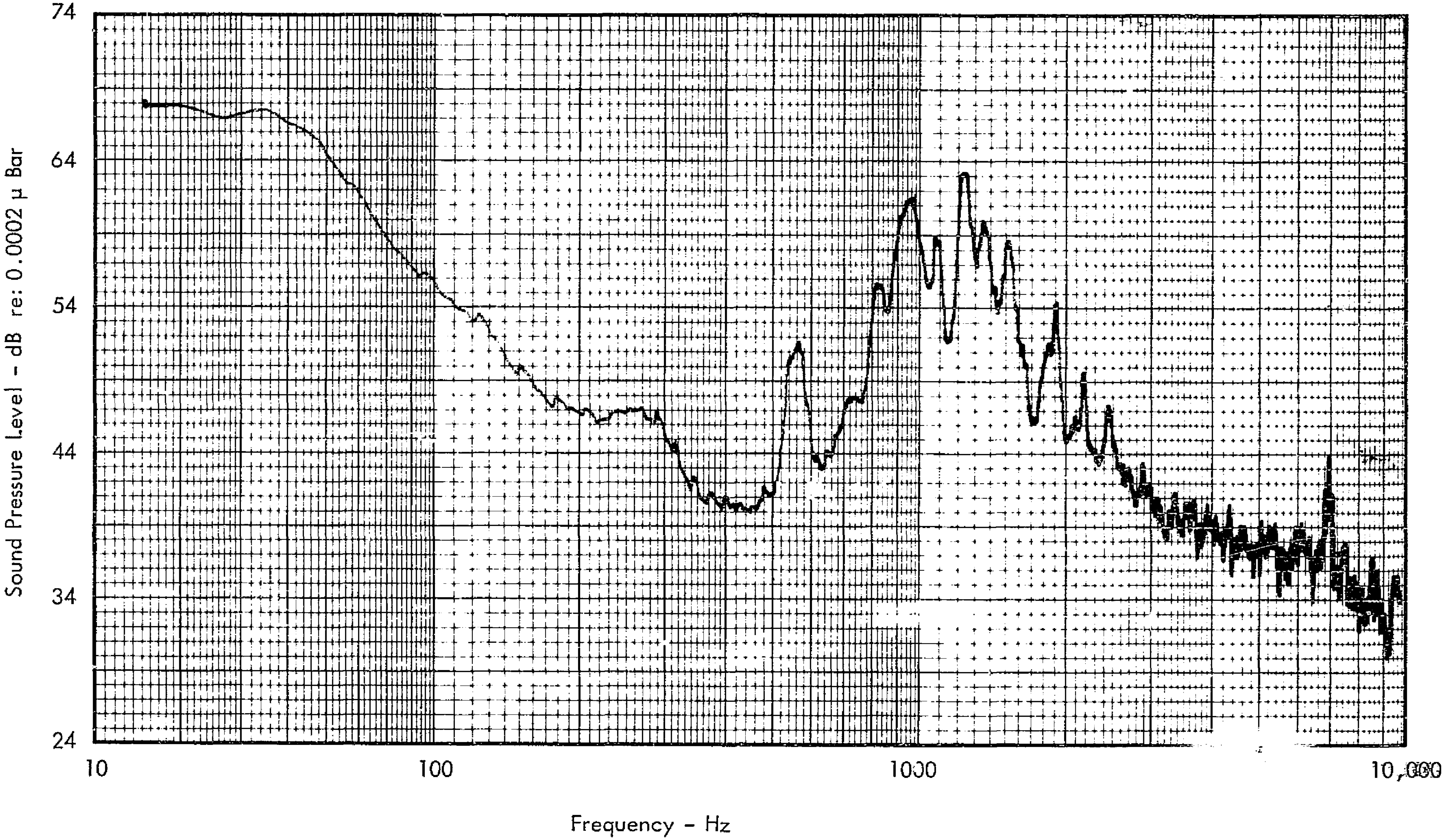

Figure 3h. Standard Fan Assembly 3 Feet to Side of Inlet (Azimuth 90°).

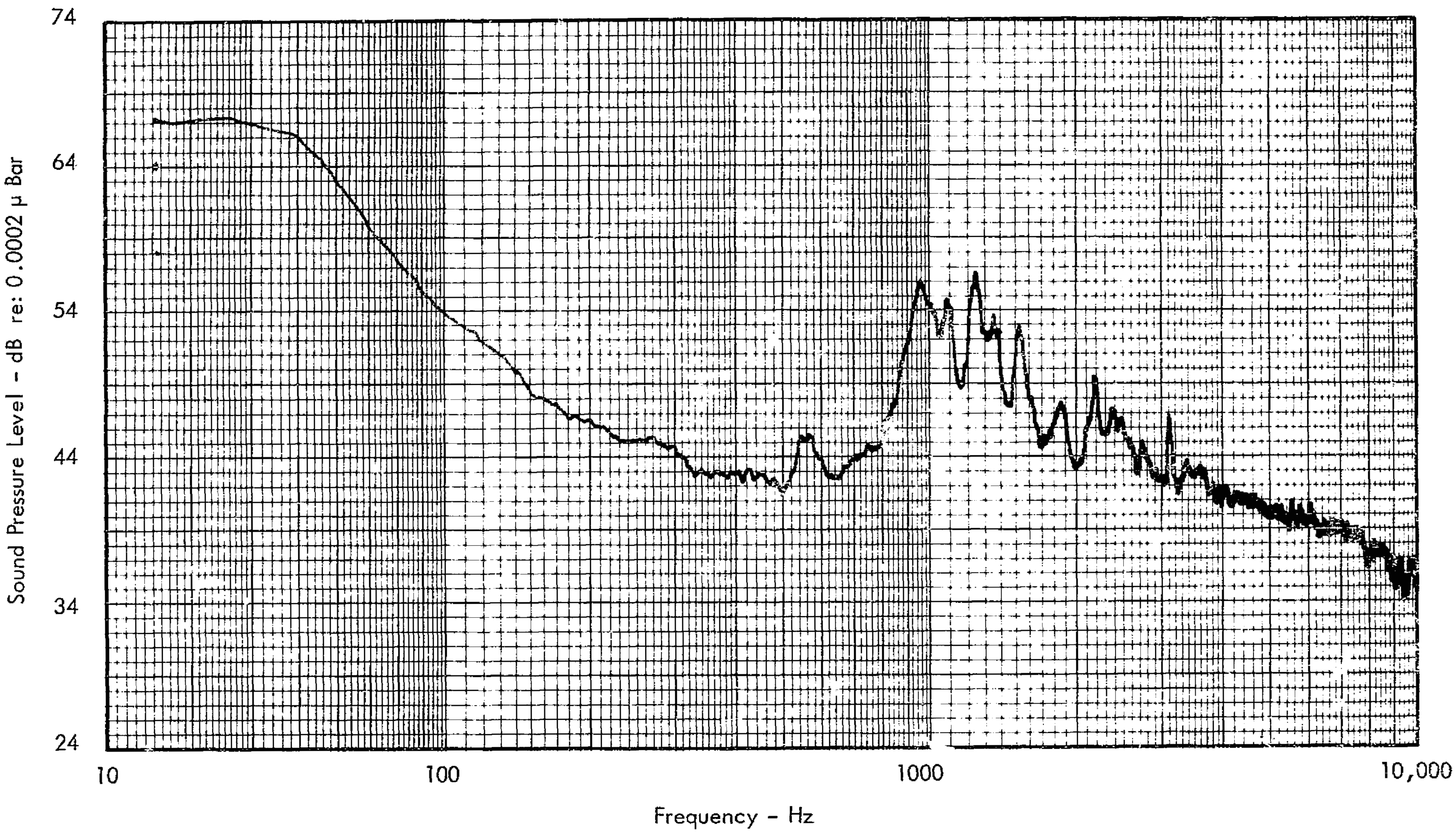

Figure 3i. Standard Fan Assembly 3 Feet at Azimuth 160°.

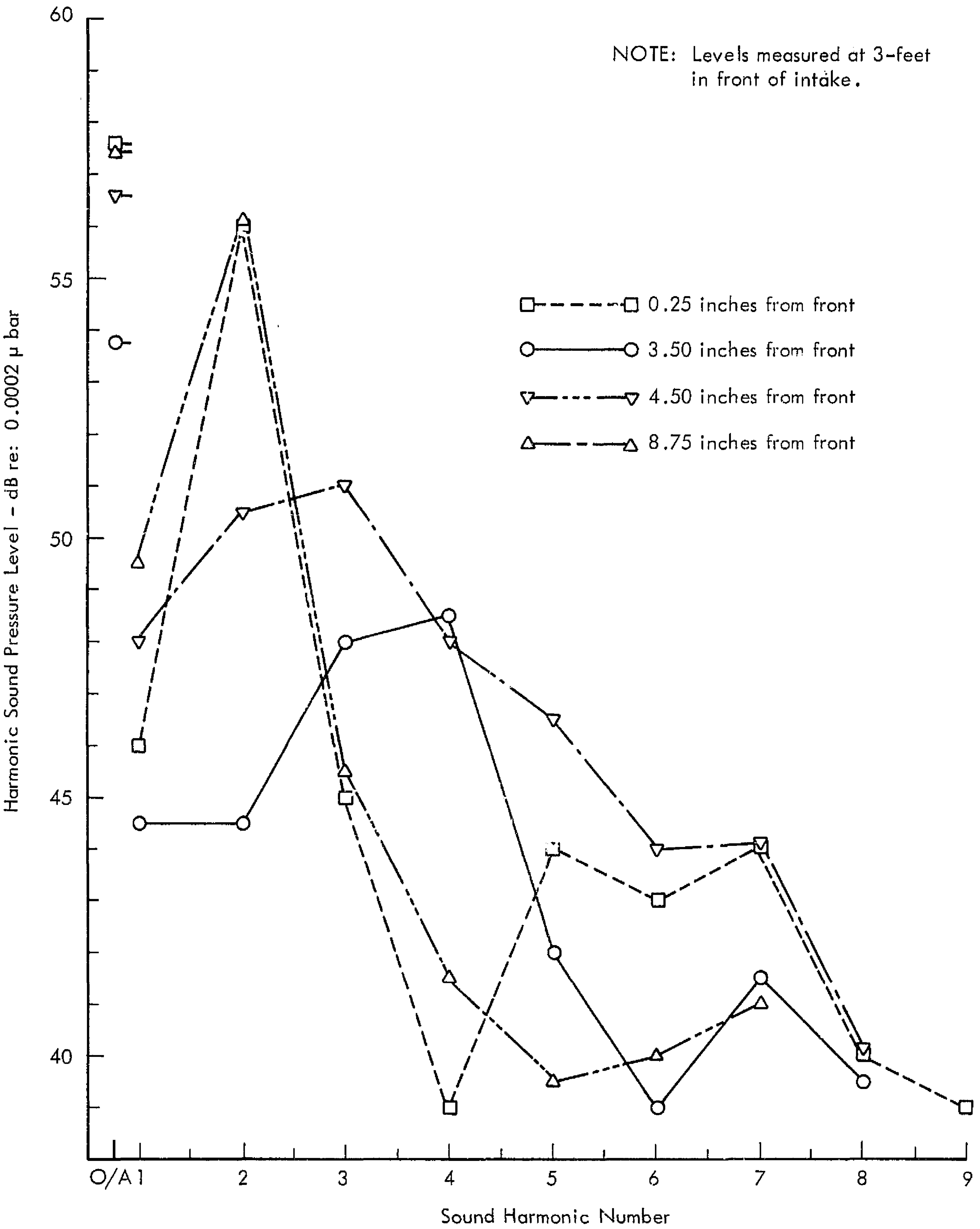

Figure 4. Effect on Harmonic Levels of Fan Position in Duct - Modified Fan Assembly

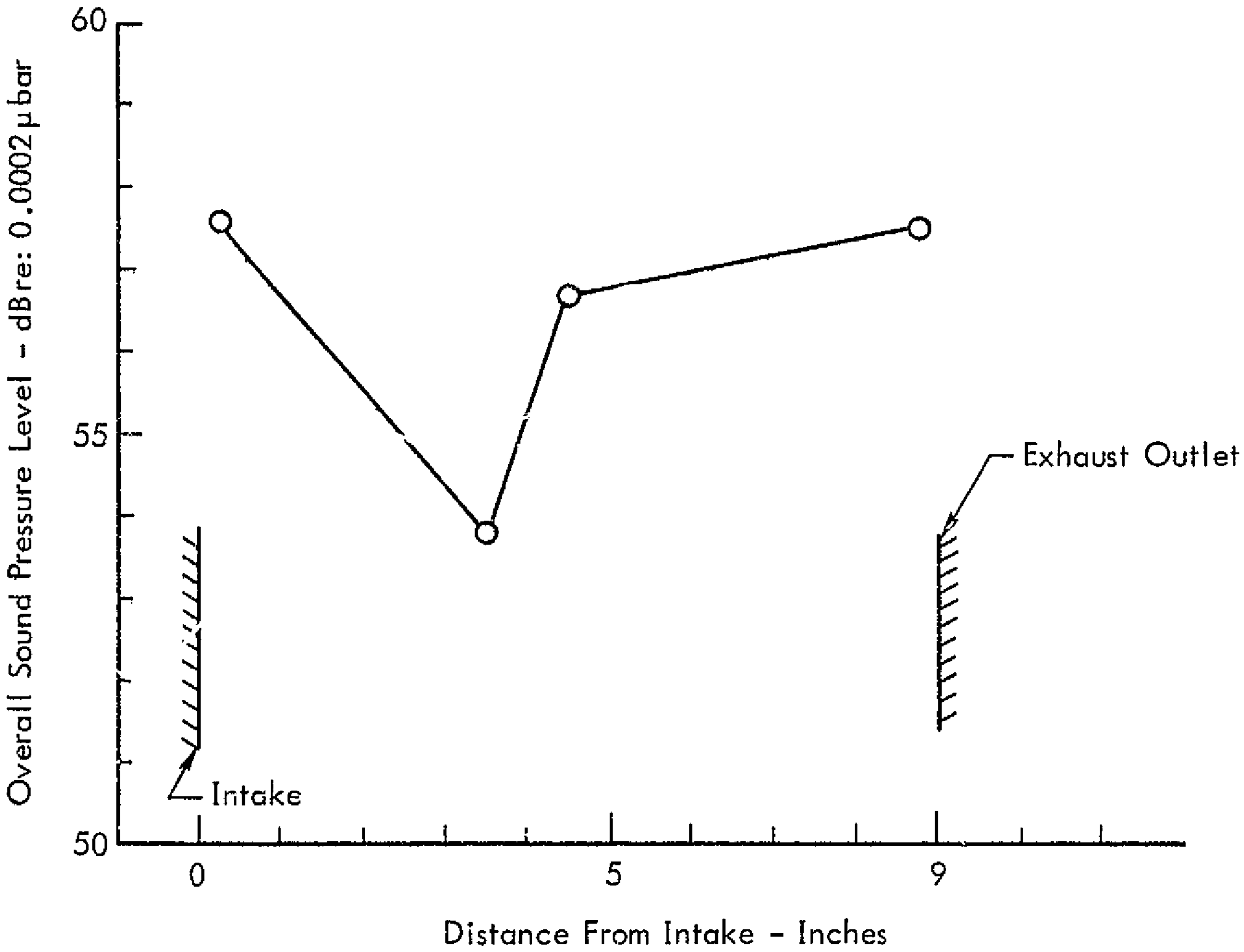

Figure 5. Effect of Fan Location in Duct on Overall* Sound Pressure Level - Modified Fan Assembly. (*Calculated from harmonic levels (measured).)

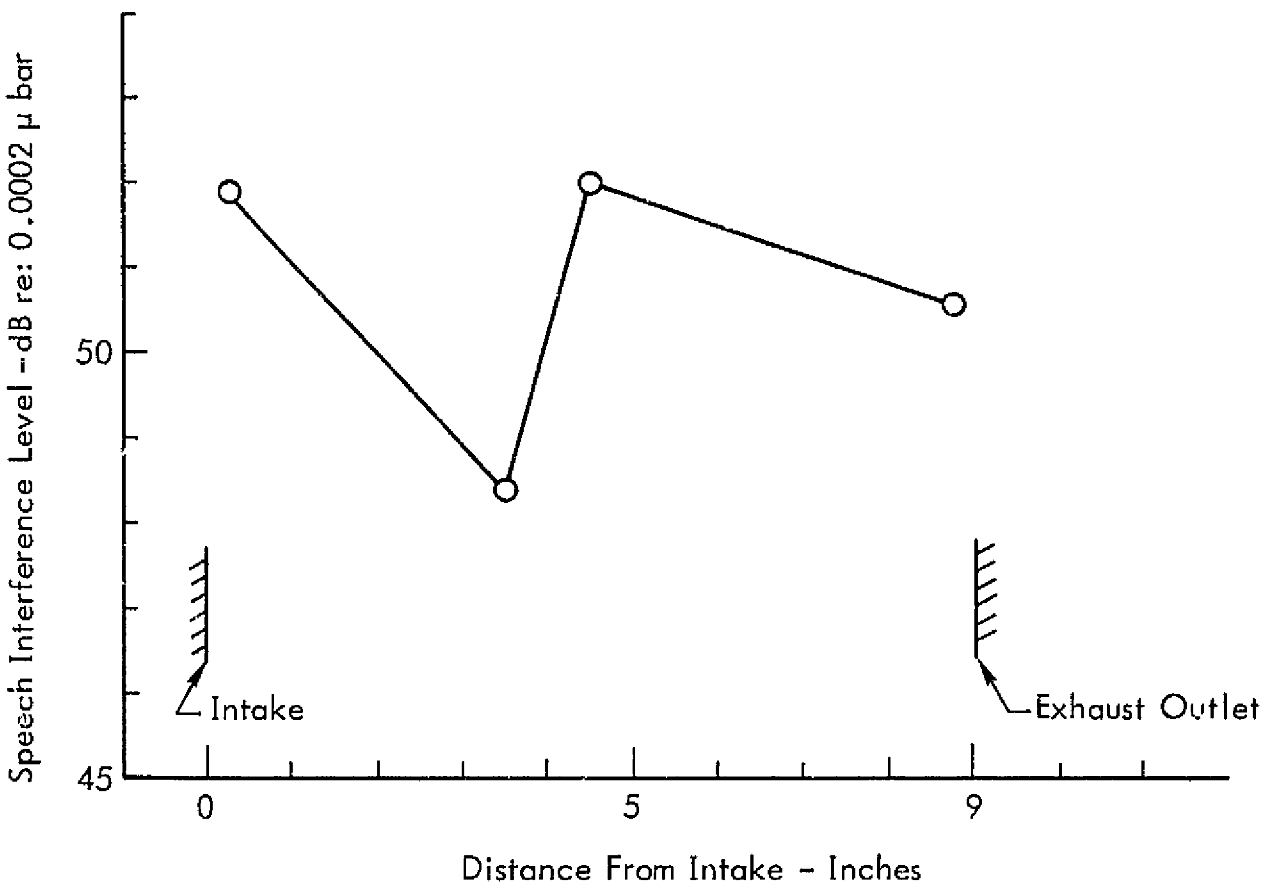

Figure 6. Effect of Fan Location in Duct on Speech Interference Level* - Modified Fan Assembly. (*Calculated from harmonic levels (measured).)

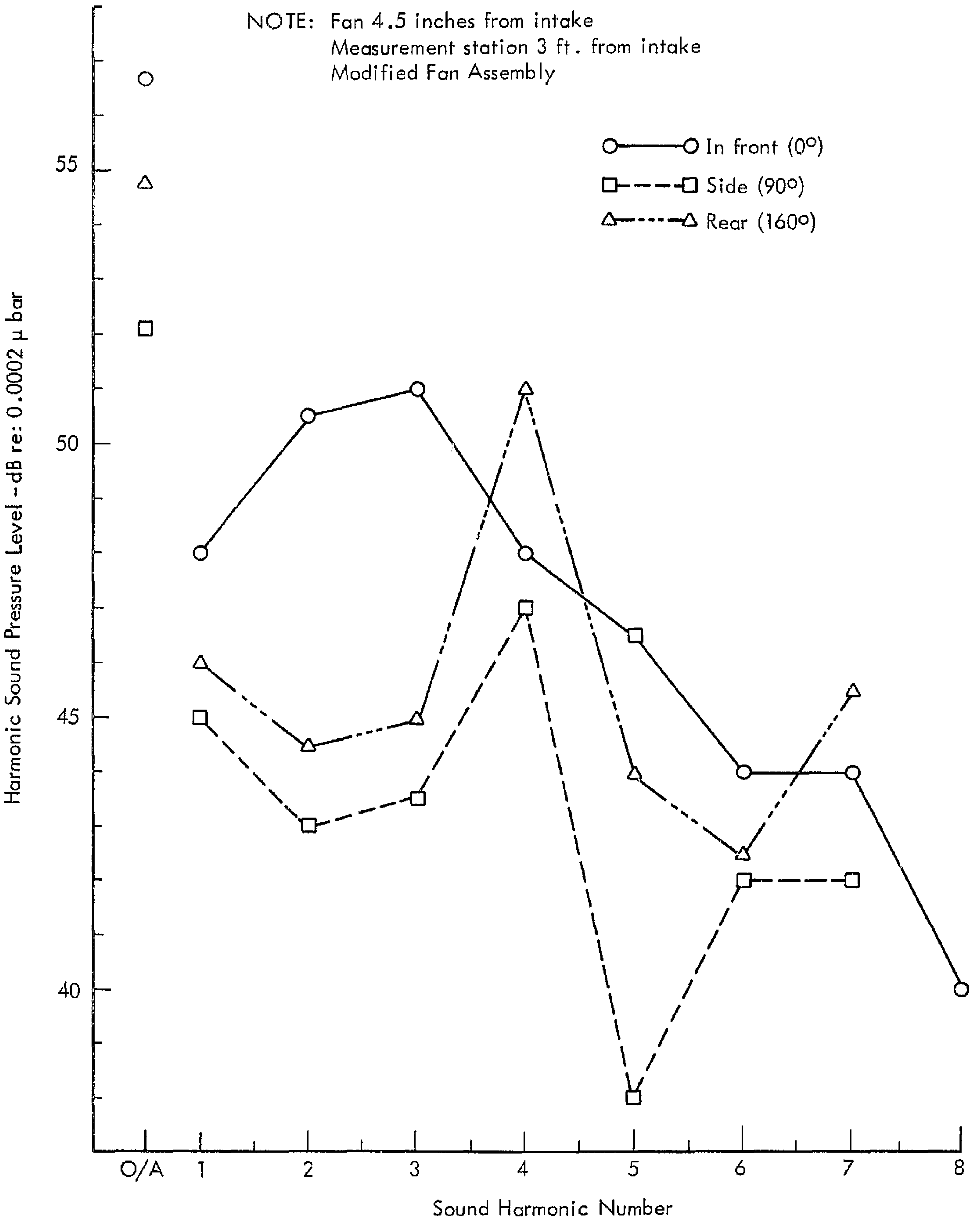

Figure 7. Effect on Harmonic Levels of Measurement Station Azimuth Location

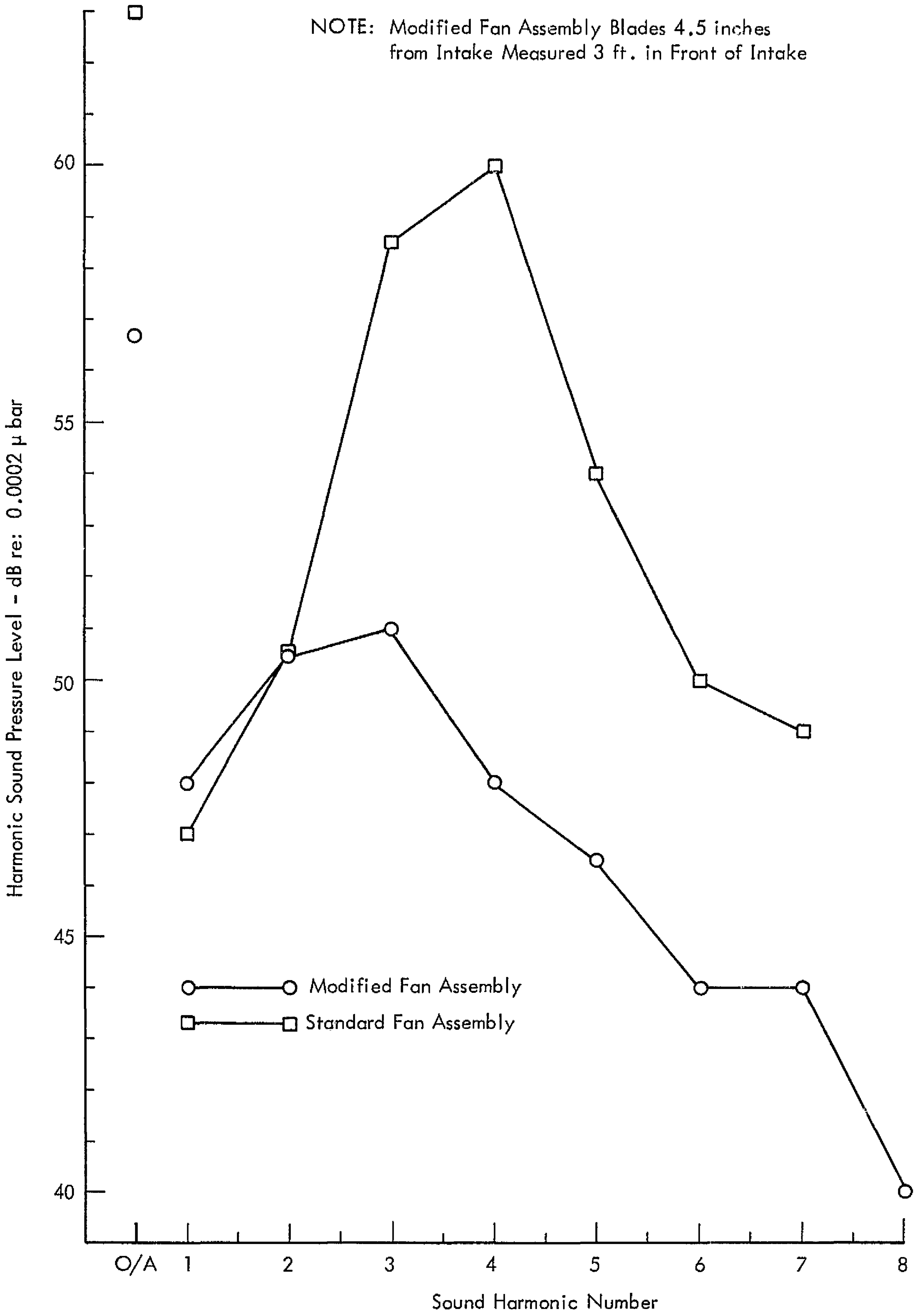

Figure 8. Comparison of Standard Fan Assembly with Modified Fan Assembly - Azimuth 0°

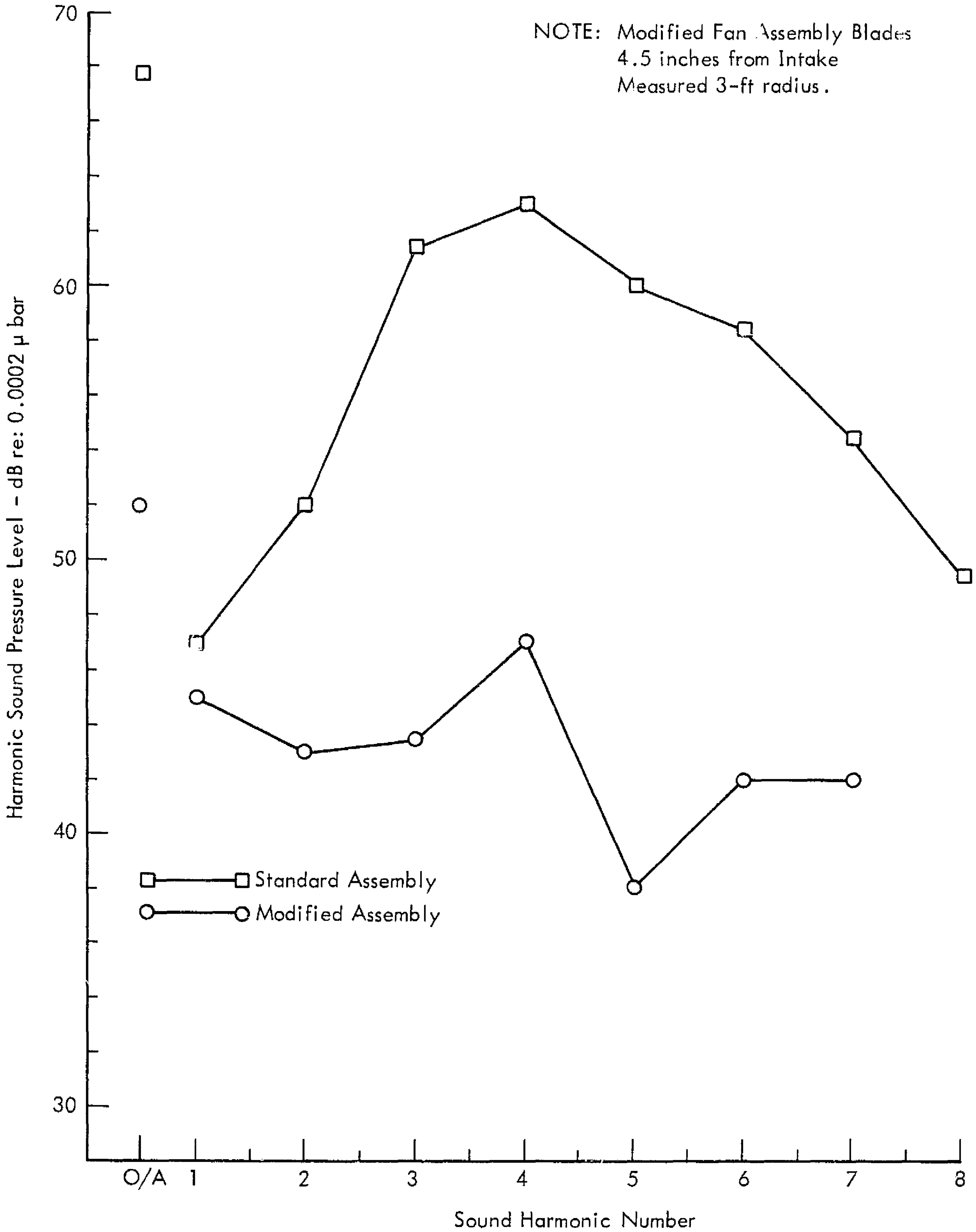

Figure 9. Comparison of Standard Fan Assembly With Modified Assembly - Azimuth 90°.

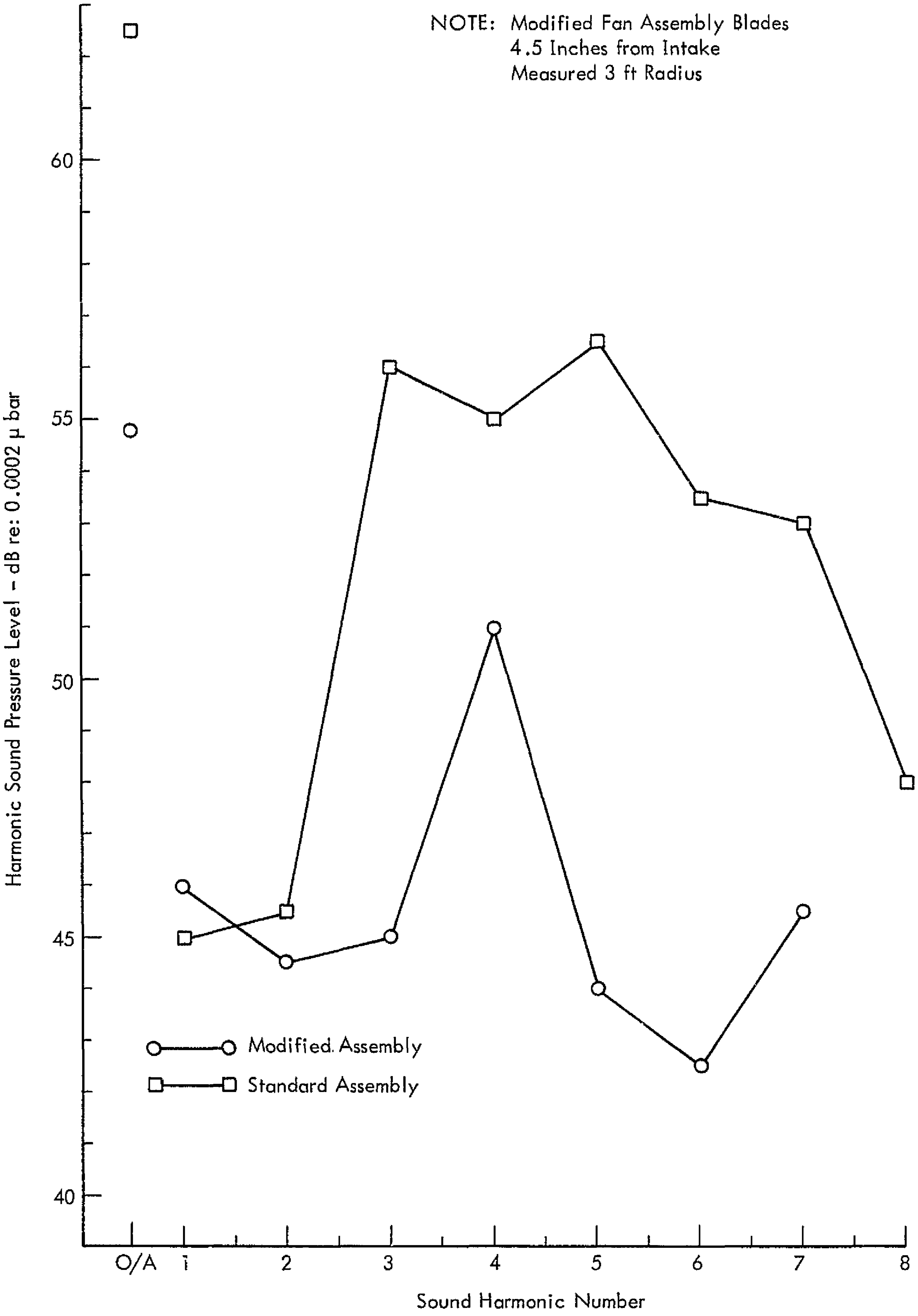

Figure 10. Comparison of Standard Fan Assembly with Modified Assembly - Azimuth 160°.

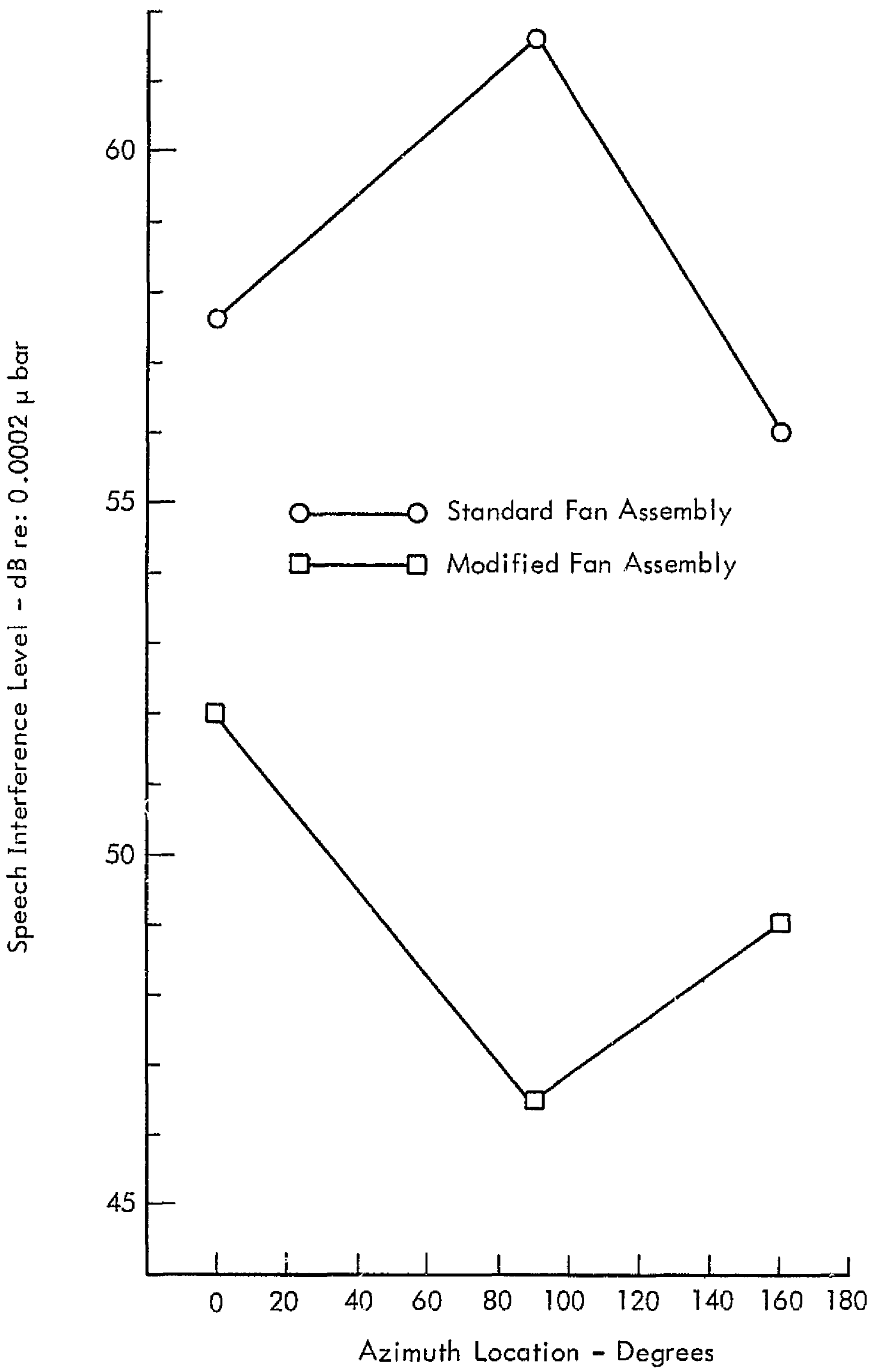

Figure 11. Comparison of Speech Interference Level* of Standard Fan Assembly with Modified Assembly (*Measured on 3-ft radius)

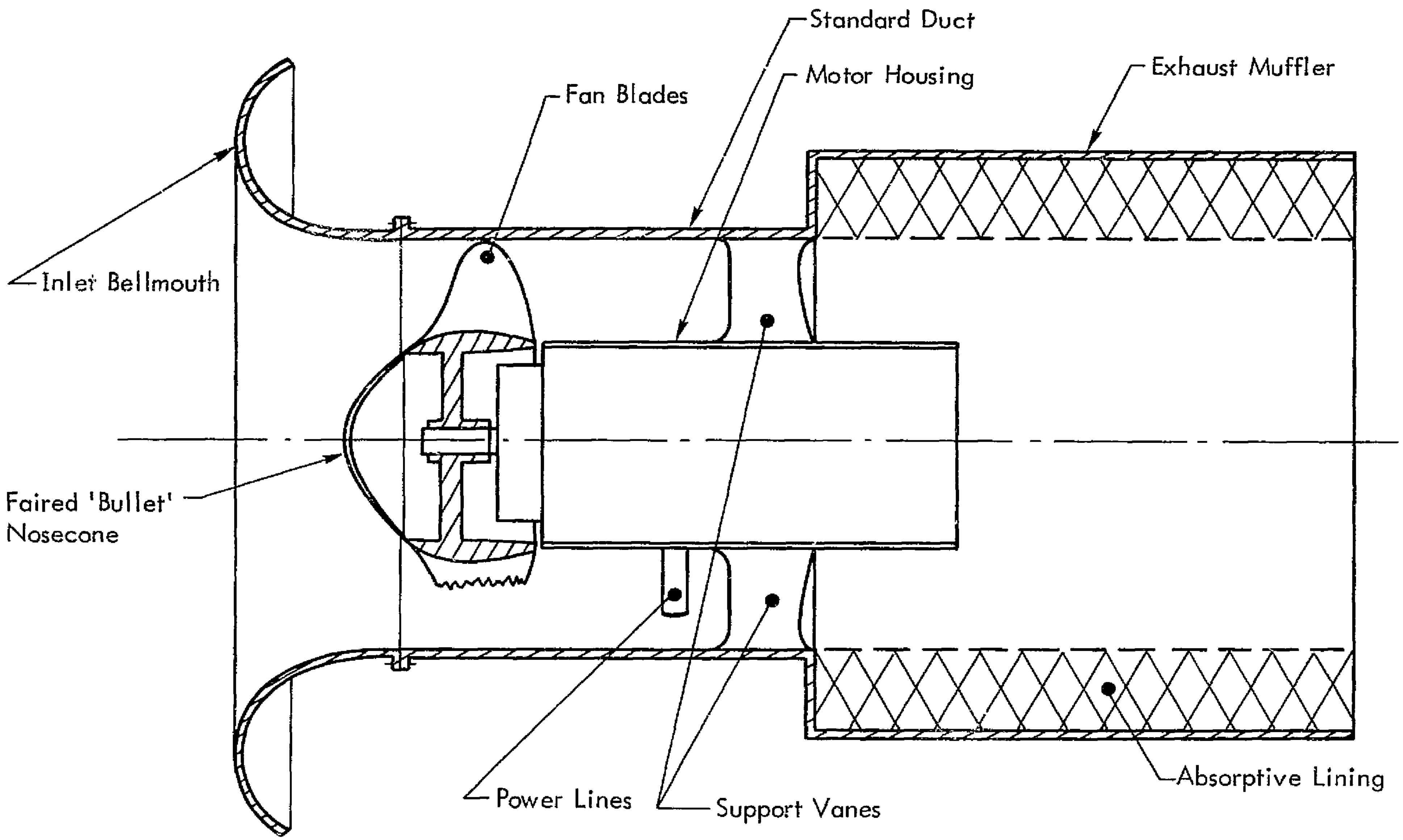

Figure 12. Recommended Modified Ventilating Fan Unit