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COMPARISON OF ACOUSTIC PERFORMANCE OF FIVE MUFFLER CONFIGURATIONS ON A SMALL HELICOPTER

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SUMMARY

A field noise measurement program has been conducted on a standard Bell 47 series helicopter and on one that had been modified with specially designed, airframe-mounted mufflers to reduce the engine exhaust noise. The purpose of the study was to evaluate the acoustic performance of five experimental exhaust muffler configurations for a helicopter reciprocating engine in an operational environment. All muffler configurations produced beneficial engine exhaust noise reductions but some configurations were markedly better than others. Flyover noise results indicated that maximum overall noise reductions of approximately 8 dB were obtained with the various mufflers. The rotor noise was judged to be the dominant noise component for the muffler-equipped helicopters whereas the engine noise was the dominant component for the basic configuration.

INTRODUCTION

Noise problems arising from the routine operation of reciprocating-engine powered helicopters by police departments and commercial operators over populated areas have resulted in numerous community complaints and, in some cases, restrictive local ordinances. Although there are various noise sources on helicopters, the predominant source of noise for helicopters powered by reciprocating engines is generally the engine exhaust noise. A technology for muffling exhaust noise exists in the automotive industry but has seldom been applied to helicopters because of the added weight and possibility of power loss. However, recently new methods for optimizing muffler design for a helicopter have been developed which afford promise of minimizing the performance penalties (ref. 1). Thus, a series of optimized expansion-chamber mufflers were designed and built for a helicopter by using this new technology. The optimized mufflers as well as a currenttechnology automotive muffler were installed and tested on a light helicopter. This paper presents the results of this investigation.

The objective of the measurement program was to compare the noise characteristics of the standard helicopter with those of each of the modified helicopters during ground run, hover, and flyover operations and to correlate the acoustic data with aircraft operating conditions. Noise results are presented in the form of overall noise time histories and frequency spectra for both the standard and modified helicopters under similar operating conditions.

APPARATUS AND METHODS

Test Helicopter

The physical characteristics of the Bell 47 series helicopter and engine used in the tests are presented in table I; the helicopter is shown in figure 1(a) and the standard exhaust system is shown in figure 1(b). The helicopter is equipped with a single two-bladed main rotor and a single two-bladed antitorque tail rotor; it is powered by a Lycoming VO-435, horizontally opposed, six-cylinder, reciprocating engine operating at approximately 3200 rpm. On the standard VO-435 installation, the exhaust gases from each bank of three cylinders are routed through a manifold and then out a straight stack to the side and the rear of the helicopter as shown in figure 1(b). The airframe is of open construction and the landing gear is of skid design. The normal operating weight during the flyby test was approximately 1135 kg which corresponds to a hovering rotor lift coefficient of 0.38 at sea level at a rotor speed of 355 rpm.

Muffler Configurations

Two basic muffler types resulting in five different configurations were used in this investigation. The first type is an experimental expansion-chamber muffler based on a design procedure developed in reference 1. This type resulted in four different configurations. The second type is a commercially available muffler designed for automotive vehicles with engines of approximately the same displacement. In addition to these tests, investigations were made on Y-connector installations to determine their acoustic performance and effects on engine back pressure.

The expansion-chamber muffler was designed with due regard to both the target attenuation characteristics and the dimensional constraints imposed on the installation. The target attenuation characteristics were selected primarily by an attempt to reduce engine exhaust noise components to levels substantially below the levels of the rotor noise. The acoustical performance of this muffler was calculated on a digital computer by using the theoretical models which are discussed in references 2 and 3. Calculated attenuation characteristics were compared with the targeted attenuation characteristics, and the dimensions of the initial muffler were systematically altered until the predicted attenuation was at least equal to that set as an initial goal.

The configurations tested in this investigation are shown in figures 2 to 6. Each figure has a picture of the installation, a schematic diagram of the muffler, and a table of pertinent dimensions. Configuration A is shown in figure 2. In this installation, the exhaust from each bank of three cylinders is routed through an X-connector and into separate mufflers, mounted on each side of the fuselage. Configuration B (fig. 3) is a single muffler connected to the individual cylinder banks through a Y-connector. Configuration C (fig. 4) is a three-section expansion-chamber muffler mounted within the helicopter's tail boom and connected to the engine through a Y-connector. A two-section expansion-chamber muffler using a Y-connector is labeled configuration D (fig. 5). The commercial muffler configuration (fig. 6) is connected to the engine through a Y-connector.

Test Conditions

The noise measurements for the hover and flyover tests were conducted at various sites. A brief description of the test arrangement for the various muffler systems is given. The various microphone arrays used for flyover tests are shown in figure 7.

Configurations A and B.- For configurations A and B, two recording vans, each having three microphones, were located at the end of runway 17 at Langley Air Force Base. Figure 7(a) indicates the location and orientation of the test area. The tests were made with the helicopter flying north to south along the flight track.

Configurations C and D.- The muffler systems on configurations C and D were ground tested on the helicopter. Maximum power (approximately 120 kW) was used so that the helicopter was light on the landing gear. Microphones were placed at two positions: parallel and perpendicular to the axis of the aircraft. Two microphones were used at each location, one at 15 m and one at 30 m from the engine.

Configuration E.- Configuration E was flight tested at NASA Wallops Station. The microphone array used for measuring the noise in hover and flyover is shown in figure 7(b). The helicopter was flown at an altitude of 30 m and nominal airspeeds of 40 knots and 90 knots.

Noise Measuring Equipment

A schematic diagram of the noise data acquisition system is shown in figure 8. The ceramic, piezoelectric microphones are commercially available and have a frequency response flat to within 3 dB over the frequency range 12 Hz to 12 000 Hz. The signal outputs from all microphones were recorded on a multichannel frequency-modulated magnetic tape recorder at 0.76 m/sec with a center frequency of 54 kHz. The frequency response of the complete recording system was flat to within 3 dB from 12 Hz to 12 000 Hz.

The entire sound measurement system was calibrated in the field prior to and after each day's testing by means of conventional discrete frequency calibrators with a 1000 Hz sine wave signal at a sound pressure level of 114 dB. Data records were played back from the original magnetic tapes in the form of sound-pressure-level time histories and spectra data. All noise-level data are presented with a reference value of 20 μPa (0.0002 dyne/cm^2).

Atmospheric Conditions

During the flight tests, normal surface observations and recordings of temperature, humidity, and wind velocity and direction were made at a location approximately 800 m from the test area. All noise tests were made when the winds were below 10 knots. During all tests the surface temperature fell within the range of 283 K to 301 K, and the surface humidity fell within the range of 30 percent to 80 percent. The range of ambient noise level in the test areas is presented in figure 9.

MEASUREMENT RESULTS

Standard Helicopter Noise Characteristics

Narrow-band noise spectra of the standard helicopter noise are shown in figure 10. Figure 10(a) presents the noise spectrum to 2000 Hz with a 4 Hz bandwidth. The dominance of the spectrum by the engine exhaust firing frequencies is very clear. Figure 10(b) presents the same data analyzed out to 500 Hz with a bandwidth of 1 Hz. From this figure the harmonics of the main and tail rotors are apparent. This figure suggests the exhaust noise attenuation necessary to bring the noise levels of the engine firing frequencies below those of the main and tail rotors. It is obvious from this figure that the controlling engine noise occurs at harmonics of the engine firing frequency. All narrow-band data were analyzed to 10 000 Hz; however, it was found that in all cases the identifiable noise components were those below 2000 Hz.

Effects of Muffler Connectors

The various muffler configurations were connected to the engine exhaust system through crossover pipes of the Y-type. Schematic diagrams of the Y-connectors are shown in figure 11. Two different types of Y-connectors were investigated: the first had curved legs leading to the single outlet and the second had straight legs intersecting at right angles to the outlet. The measurements showed no significant differences between the two types. The engine, however, exhibited a noticeable increase in back pressure (as measured with a standard-pressure meter) with the straight-legged Y-connector. A narrow-band spectrum of the helicopter noise using this latter Y-connector is shown in figure 12. This figure shows that the odd-numbered engine firing harmonics have been substantially reduced in level probably because of internal acoustic wave cancellation. An additional configuration was tested to determine the effect of the variation of length of exhaust-tube legs which lead to the Y-connector. The narrow-band spectrum of figure 13 is for a configuration in which one leg is twice the length of the other. This situation results in increased radiated noise at some engine frequencies because of the unfavorable phasing.

Muffler Acoustic Performance

Noise spectra.- During the investigation, five muffler configurations were tested. Four were based on the computer design previously mentioned and the fifth configuration was a commercially available automotive muffler. The four computer-designed mufflers represent a progression in design toward a configuration suitable for flight application. The mufflers are evaluated in terms of their effect on overall vehicle noise and performance. The acoustic results are presented as 4-Hz bandwidth narrow-band spectra.

Configuration A: Configuration A is a dual muffler unit connected to the engine exhaust system through an X-connector as shown in the photograph of figure 2. A narrow-band spectrum of the hovering helicopter with this muffler is shown in figure 14. It can be seen that the noise levels at the identifiable engine firing frequencies have been very significantly reduced in relation to the standard helicopter, and in addition, there are significant reductions at the higher frequencies. Overall sound pressure levels are reduced only from 100 dB to 88 dB because of the remaining rotor noise.

Configuration B: Configuration B is a single unit connected to the exhaust system through a Y-connector. (See fig. 3.) The acoustic performance of this muffler is very similar to that of configuration A. A narrow-band spectrum of the noise from the hovering helicopter is shown in figure 15. By comparing configuration B (fig. 15) with configuration A (fig. 14), it can be seen that the noise reductions are of the same order of magnitude.

Configuration C: An effort was made in configuration C to further reduce muffler size and integrate the system with the helicopter in such a way as to keep drag to a minimum. The acoustic performance data (fig. 16) were taken on the ground with the helicopter operating at a power setting of 120 kW. The muffler provided useful noise reductions over a broad frequency range but was not as effective as mufflers A and B. (Compare fig. 16 with figs. 14 and 15.) Structural problems with this muffler lead to extensive changes in design which are reflected in configuration D.

Configuration D: A final design effort was made in configuration D on the expansion-chamber muffler to improve the acoustic and structural capability and make it suitable for a flight vehicle. The results of this design study were tested in prototype form. This acoustic design was refined structurally into a flight system and is shown in figure 5. The acoustic performance of the prototype and the flight design are shown in figures 17 and 18 and are presented as frequency spectra taken at an engine power setting of 120 kW.

The flight-muffler spectrum varied considerably from the prototype. Neither configuration D nor its prototype performed as well acoustically as configurations A and B. (Compare figs. 17 and 18 with figs. 14 and 15.) No additional effort was spent to determine why these mufflers did not perform as well acoustically.

Configuration E: A commercial automotive muffler (configuration E) was chosen to provide a comparison between the computer-designed expansion-chamber muffler and one which was available off the shelf. (See fig. 6.) This muffler is a two-pass design with three small resonators and is connected to the standard engine exhaust manifolds through a Y-connector. The muffler exhaust gases are ejected upward at approximately 60°.

Figure 19 is a narrow-band noise spectrum of the helicopter hovering at 129 kW. This muffler shows useful noise reductions at the identifiable firing frequencies and over a broad frequency range up to about 2000 Hz. One should note, however, that configuration E provides substantially less noise reductions over a broad range of frequencies than configurations A and B. (Compare fig. 19 with figs. 14 and 15.)

Flyover noise time history.- Muffler systems A and E were chosen for flight testing. These tests consisted of flights over the microphone arrays shown in figure 7. The acoustic results of some typical flyovers are presented in figure 20 as overall sound-pressure-noise time histories for both the standard and modified helicopters. These data have been corrected to a nominal altitude as indicated in the figure to account for small altitude variations occurring from flight to flight. It can be seen from this figure that a reduction of approximately 8 dB in the maximum overall noise levels for configurations A and E was obtained compared with those of the standard helicopter. This figure shows the especially rapid dropoff in noise level as the muffler-equipped aircraft passes over the microphone position as compared with the helicopter not equipped with a muffler.

The overall noise time histories for configurations A and E are very similar, as seen in figure 20. Shown in figure 21 is a comparison of the noise levels for each 1/3-octave band for on-track flyover data at approximately 80 knots and at an altitude of 30 m for both the standard and modified helicopters at the overhead position of figure 20. In configurations A and E, the rotor noise is judged to be the dominant noise component whereas the engine noise is dominant for the standard helicopter.

During the flight tests, noise measurements were made with the microphones located in an array perpendicular to the flight track as shown in figure 7. Overall sound pressure levels from these microphones are presented in figure 22 for an altitude of 30 m and an airspeed of approximately 80 knots for the standard and modified helicopters. For both modified helicopters, the levels are lower at all sideline distances than those for the standard helicopter.

Muffler Back Pressure

A primary criterion for the acceptance of a muffler system for aircraft use is that the system produces a low engine exhaust back pressure. High amounts of exhaust back pressure reduce engine performance through reduced volumetric efficiency and reduced mean effective cylinder pressure. Since the pressure in the exhaust pipe is oscillatory in nature, only a mean value is read at the exhaust port. In some instances complicated wave patterns can develop which might have beneficial effects on engine performance; in general, however, increases in the average measured value of exhaust port pressure is considered to impair engine performance. For the engine in this study, the manufacturer guarantees rated power at back-pressure values up to 5 cm Hg. Figure 23 shows the variation of exhaust back pressure with engine power for configurations D and E. These configurations are similar and produce less than $12\frac{1}{2}$ cm Hg back pressure at maximum power. The standard exhaust system produced no appreciable back pressure. Limited flight tests at sea-level conditions with all mufflers did not indicate any noticeable loss in helicopter performance.

CONCLUDING REMARKS

An experimental noise measurement program has been conducted under controlled conditions, on a Bell 47 helicopter in a standard configuration and equipped with five different experimental exhaust mufflers so that the effectiveness of each of the mufflers could be evaluated. All muffler configurations produced beneficial engine exhaust noise reductions but some configurations were markedly better than others. Flyover noise results indicated that maximum overall noise reductions of approximately 8 dB were obtained with the various mufflers. The rotor noise was judged to be the dominant noise component for the muffler-equipped helicopters whereas the engine noise was the dominant component for the basic configuration.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., January 18, 1974.

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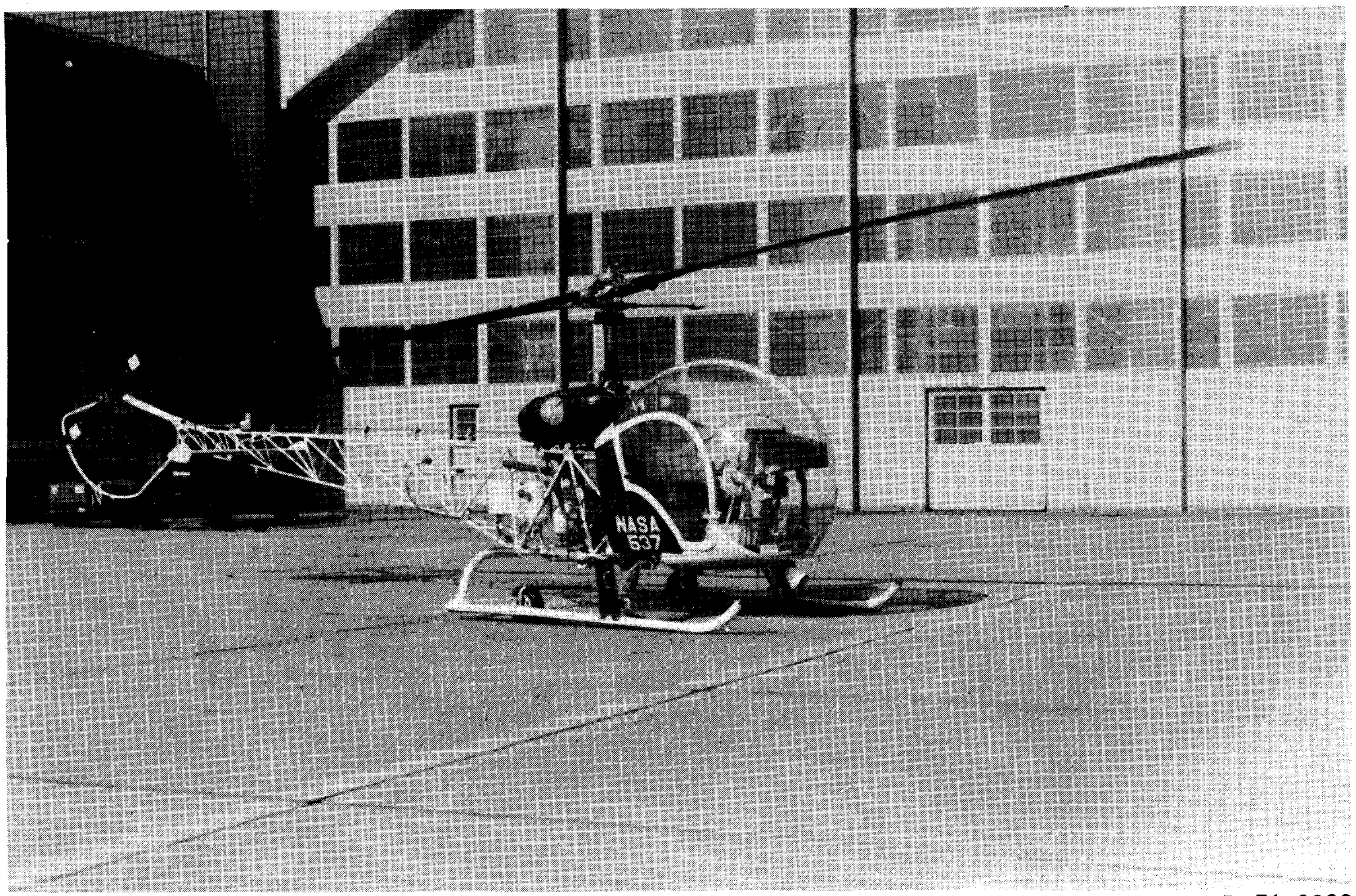
1. Alfredson, Robin J.: The Design of Exhaust Mufflers Using Linearized Theoretical Models. 1971 Intersociety Energy Conversion Engineering Conference, Soc. Automot. Eng., c.1971, pp. 1048-1052.

2. Davis, Don D.; Stokes, George M.; Moore, Dewey; and Stevens, George L., Jr.: Theoretical and Experimental Investigation of Mufflers With Comments on Engine-Exhaust Muffler Design. NACA Rep. 1192, 1954. (Supersedes NACA TN's 2893 and 2943.)

3. Parrott, Tony L.: An Improved Method for Design of Expansion-Chamber Mufflers With Application to an Operational Helicopter. NASA TN D-7309, 1973.

TABLE I.- PHYSICAL CHARACTERISTICS OF THE STANDARD BELL 47G-5 HELICOPTER

Main rotor:	
Diameter, m	11.3
Number of blades	2
Blade chord, m	0.28
Airfoil section	NACA 0015
Blade area, m^2	10.4
Disk area, m^2	330.7
Solidity	0.0314
Tip speed, m/sec	210.3
Design operating speed, rpm	355
Tail rotor:	
Diameter, m	1.7
Number of blades	2
Blade chord, m	0.10
Blade area, m^2	0.69
Disk area, m^2	7.7
Design operating speed, rpm	1920
General:	
Normal gross weight, kg	1135
Empty weight, kg	716.6
Overall length, m	13.29
Maximum power (Lycoming VO-435-23), kW	194
Maximum indicated level airspeed, knots	85
Gear ratios:	
Main rotor mast to engine	0.111
Tail rotor to engine	0.6
Cooling fan to engine	1.5
Engine characteristics:	
Firing order	145 236
Number of cylinders	6
Exhaust gas temperatures at 112 kW, K	1088.7
Gas flow Mach number at 112 kW and exhaust area of 0.0045 m^2	0.1



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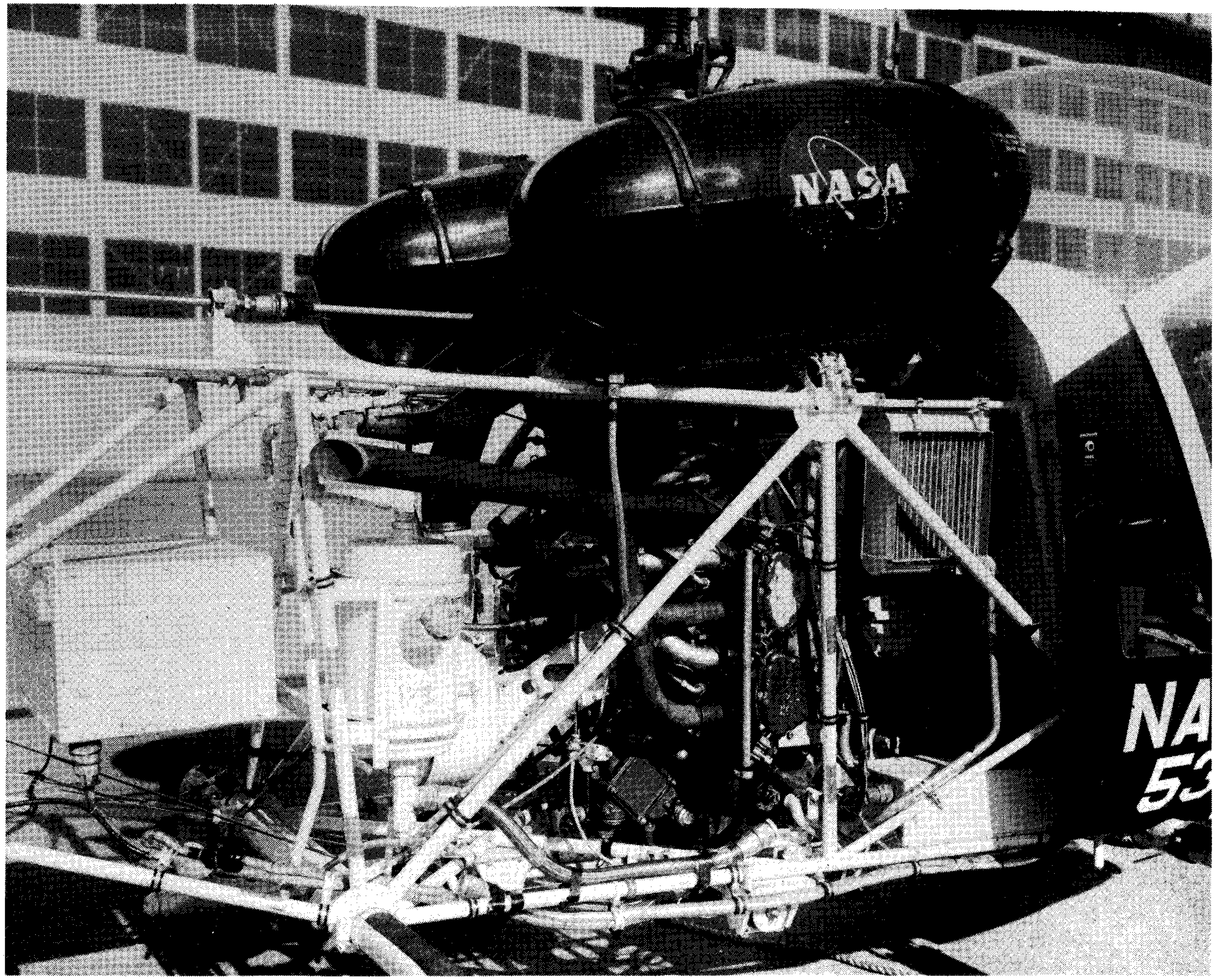
(a) Overall view.

Figure 1.- Test helicopter.



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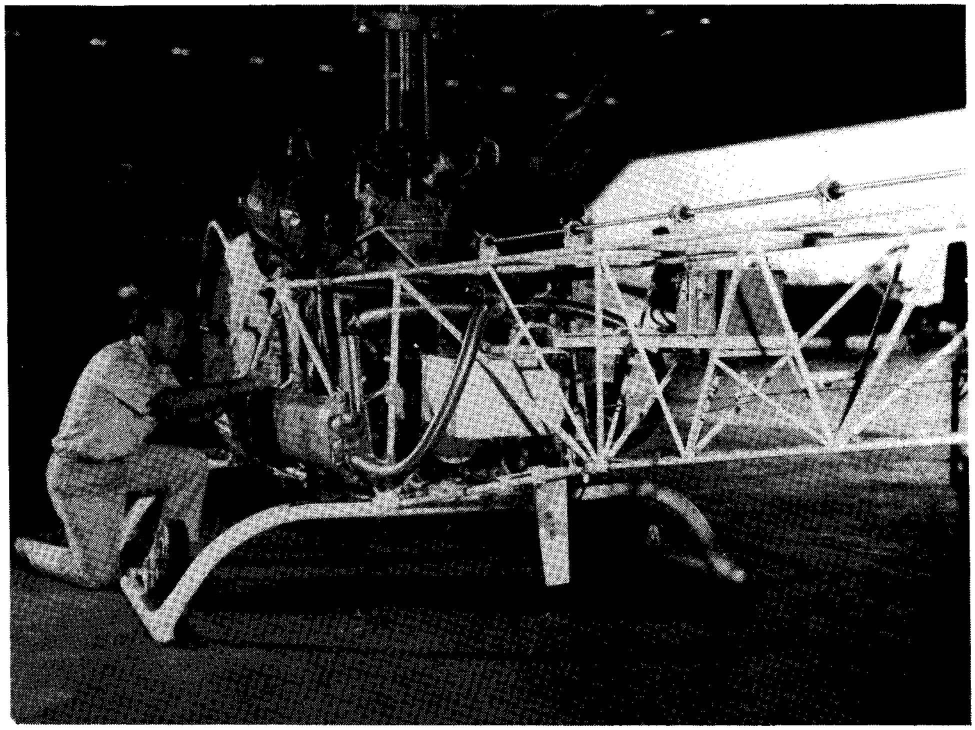
(b) Standard exhaust system.

Figure 1.- Concluded.



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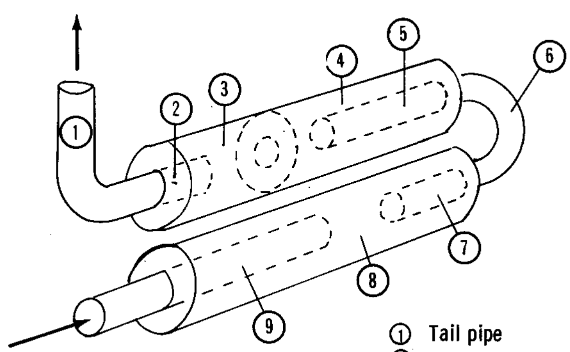
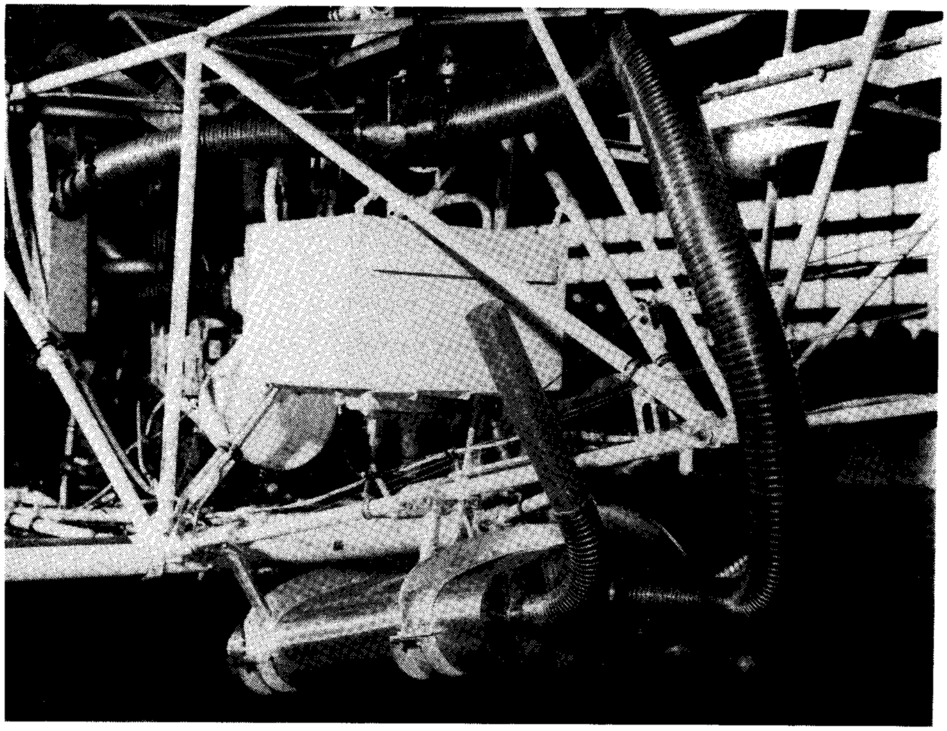


	Length, m	Equivalent area, m^2
① Tail pipe	0.301	0.051
② Extended inlet	.152	.051
③ First chamber	.305	.168
④ Second chamber	.305	.168
⑤ Extended outlet	.381	.051
⑥ Connector	.306	.051
⑦ Extended inlet	.049	.051
⑧ Third chamber	.914	.168
⑨ Extended outlet	.605	.051

Figure 2.- Schematic diagram and picture of configuration A.



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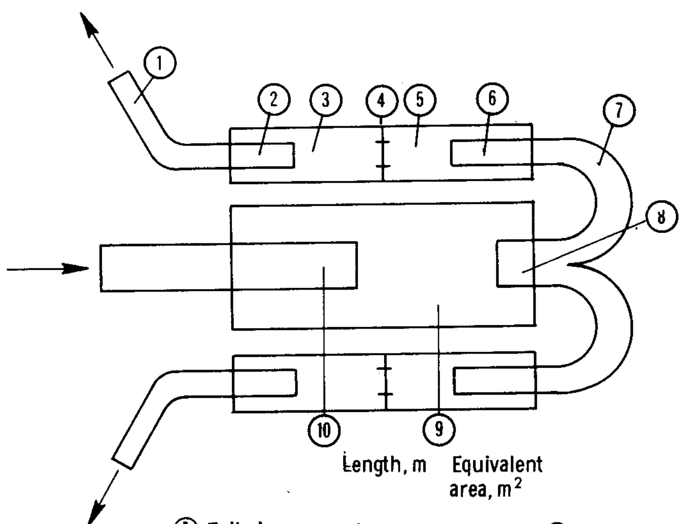
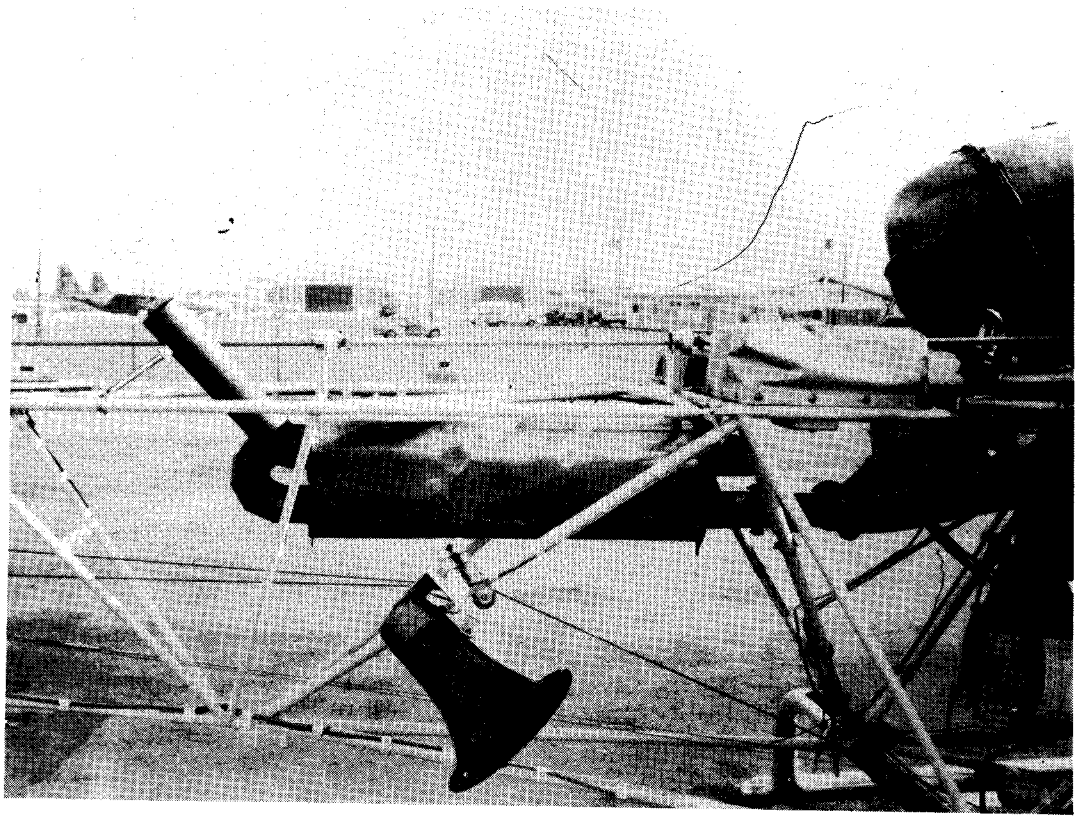


	Length, m	Equivalent area, m^2		Length, m	Equivalent area, m^2
① Tail pipe	0.605	0.051	⑥ Extended inlet	0.301	0.051
② Extended outlet	.058	.051	⑦ Connector	.610	.072
③ First chamber	.253	.155	⑧ Extended outlet	.130	.072
④ Connector	.125	.051	⑨ Third chamber	.765	.184
⑤ Second chamber	.509	.155	⑩ Extended inlet	.443	.072

Figure 3.- Schematic diagram and picture of configuration B.



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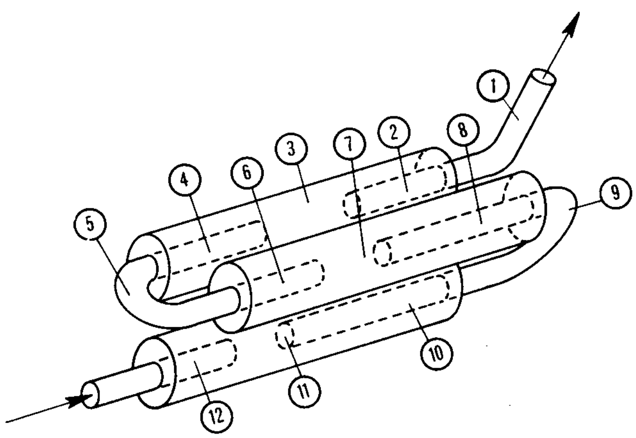
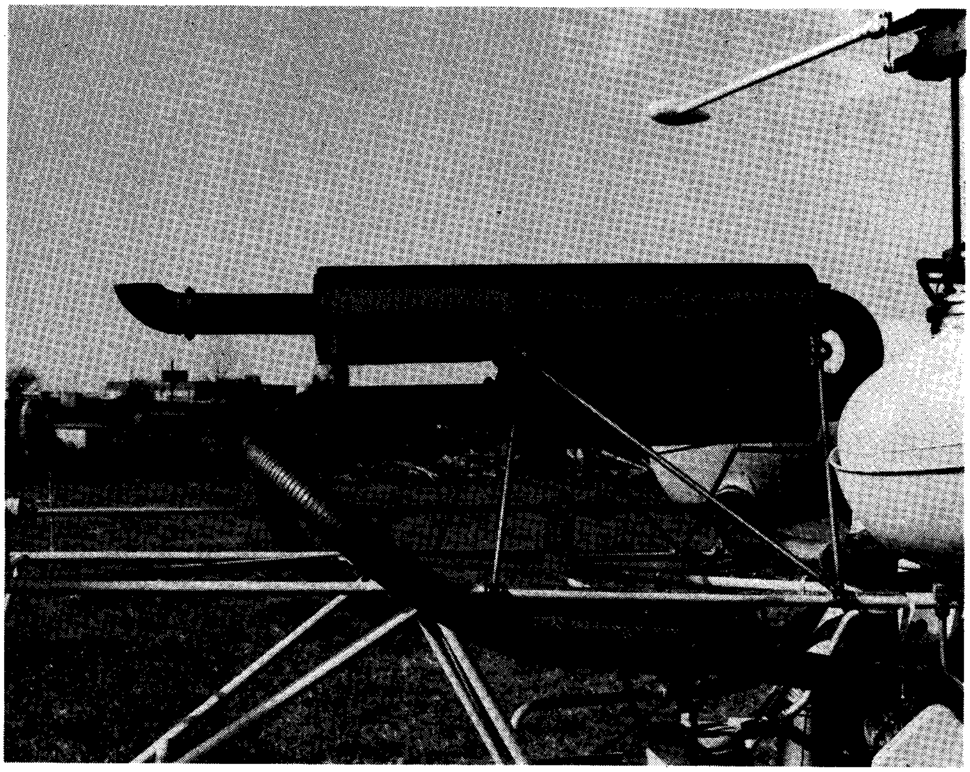


	Length, m	Equivalent area, m²		Length, m	Equivalent area, m²
(1) Tail pipe	0.475	0.00456	(7) Second chamber	0.762	0.0127
(2) Extended outlet	.155	.00456	(8) Extended inlet	.384	.00456
(3) First chamber	.762	.0127	(9) Connector	.393	.00456
(4) Extended inlet	.414	.00456	(10) Extended outlet	.506	.00456
(5) Connector	.326	.00456	(11) Third chamber	.762	.0127
(6) Extended outlet	.305	.00456	(12) Extended inlet	.140	.00456

Figure 4.- Schematic diagram and picture of configuration C.



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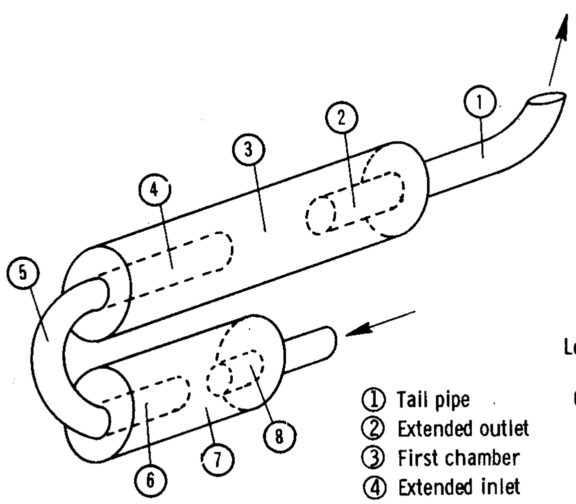
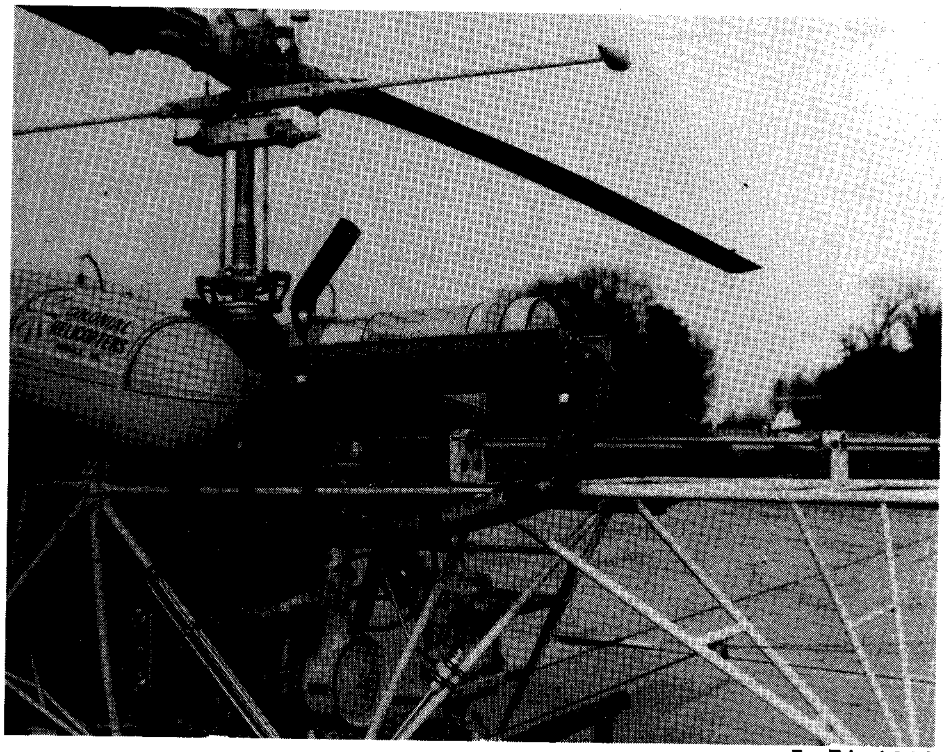


	Length, m	Equivalent area, m^2
① Tail pipe	0.355	0.00457
② Extended outlet	.241	.00457
③ First chamber	.762	.0183
④ Extended inlet	.51	.00457
⑤ Connector	.406	.00457
⑥ Extended outlet	.343	.00457
⑦ Second chamber	.555	.0183
⑧ Extended inlet	.153	.00457

Figure 5.- Schematic diagram and picture of configuration D.



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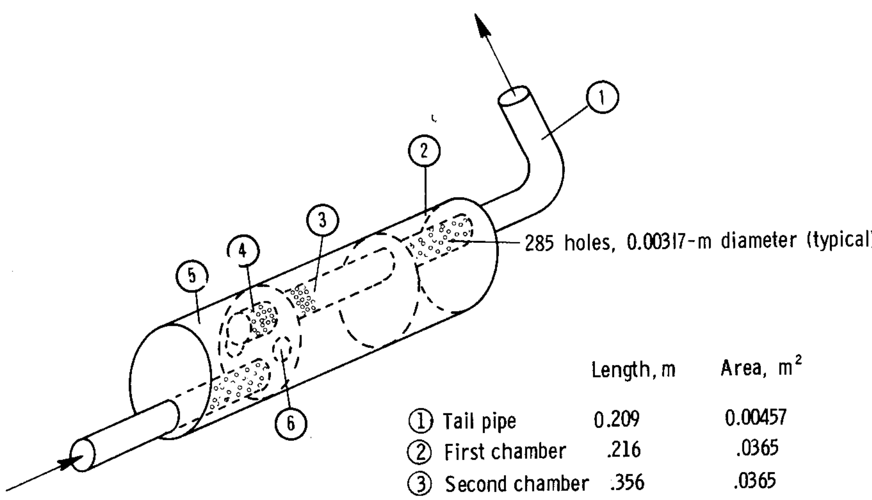
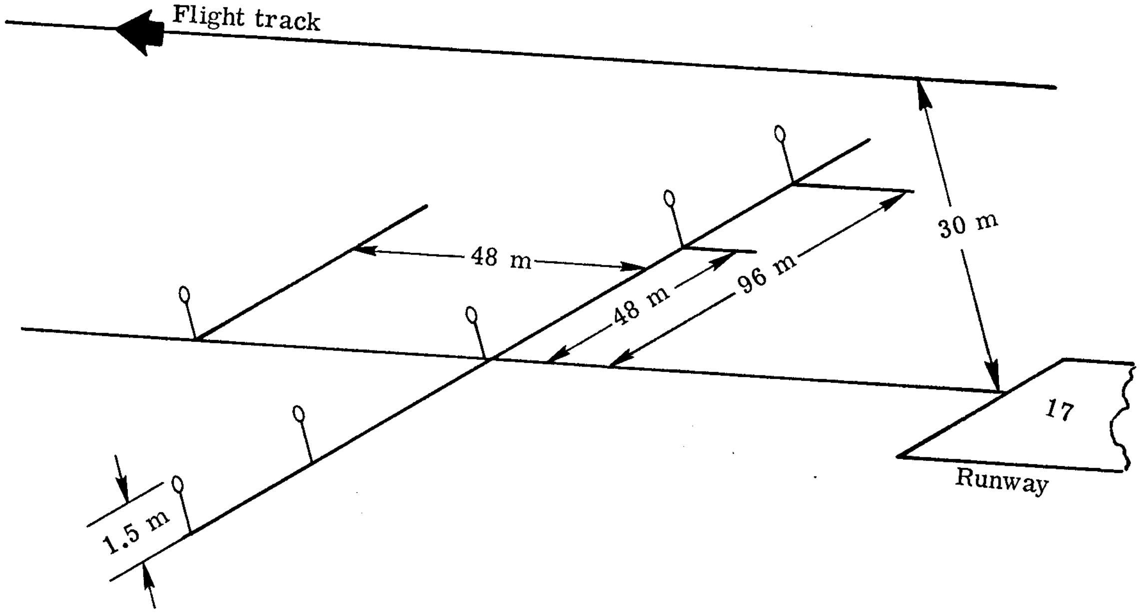
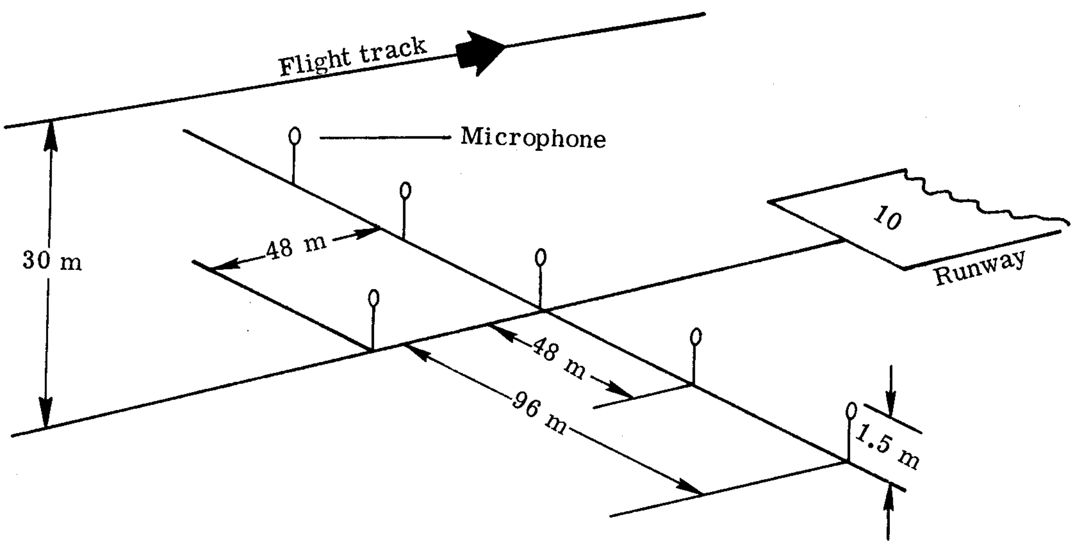


	Length, m	Area, m^2
① Tail pipe	0.209	0.00457
② First chamber	.216	.0365
③ Second chamber	.356	.0365
④ Extended outlet	.025	.00457
⑤ Third chamber	.190	.0365
⑥ Connector hole		.00134

Figure 6.- Schematic diagram and picture of configuration E.



(a) Langley Field location.



(b) Wallops Station location.

Figure 7.- Microphone arrays at test locations. Microphones are arranged symmetrically on each side of runway.

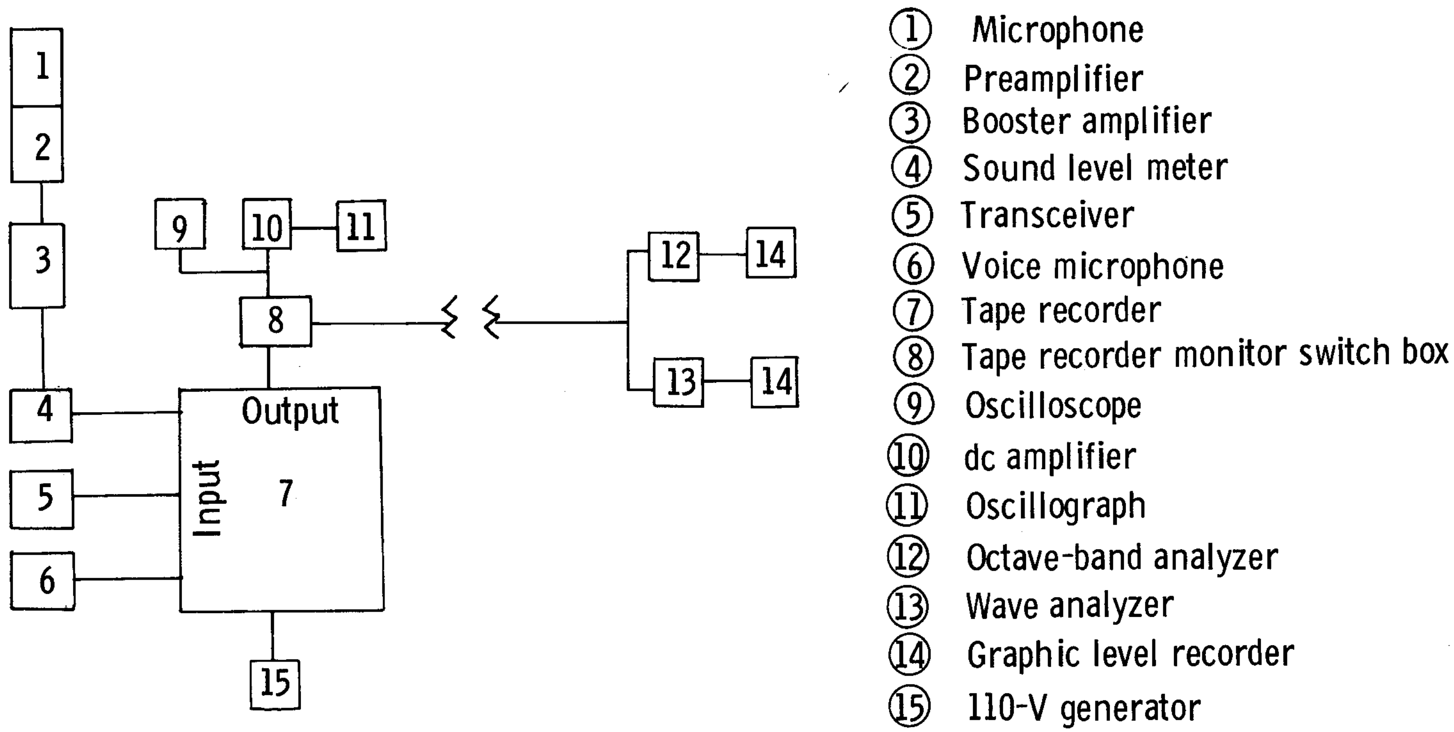


Figure 8.- Block diagram showing typical system layout for noise data acquisition.

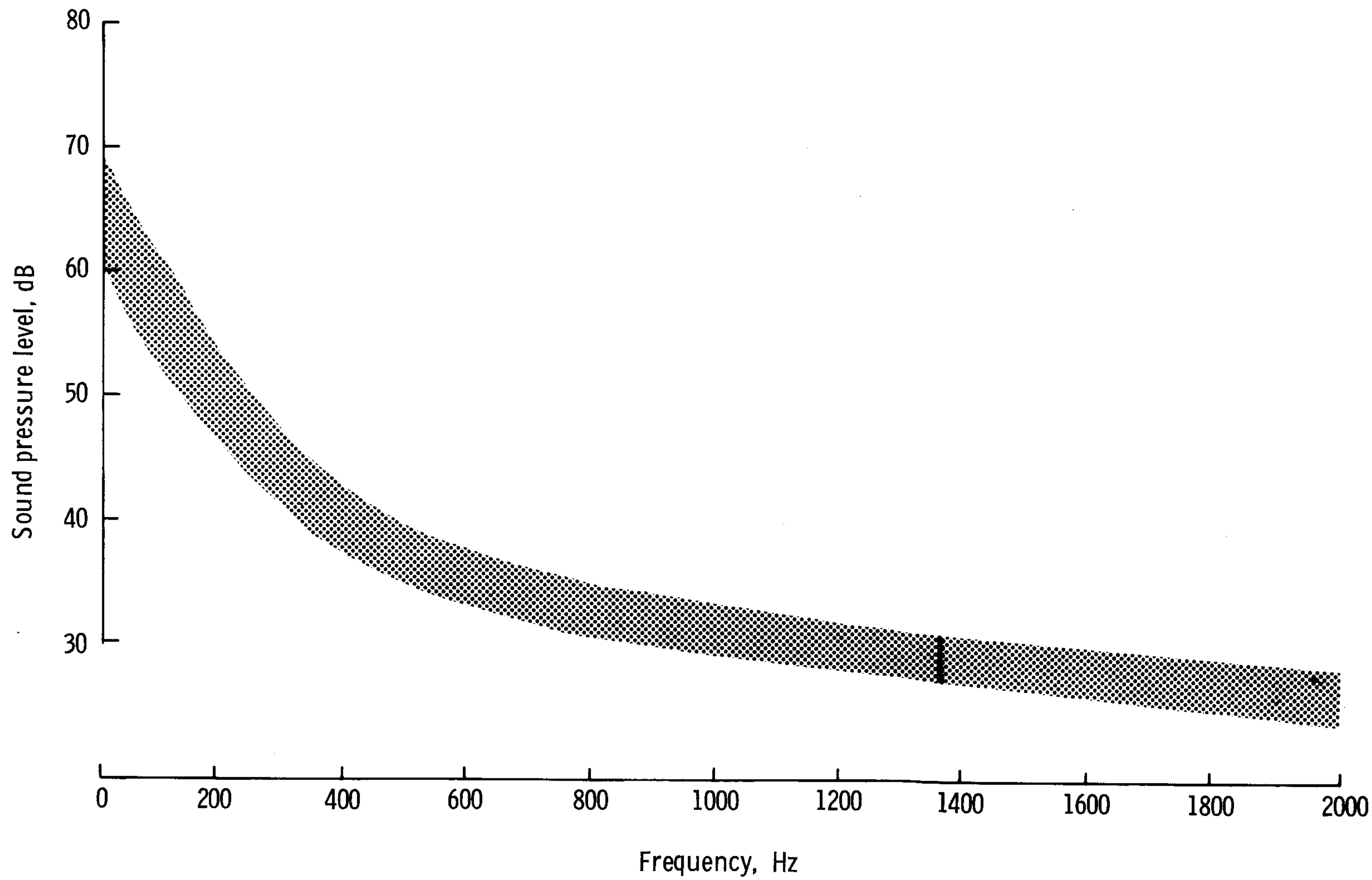
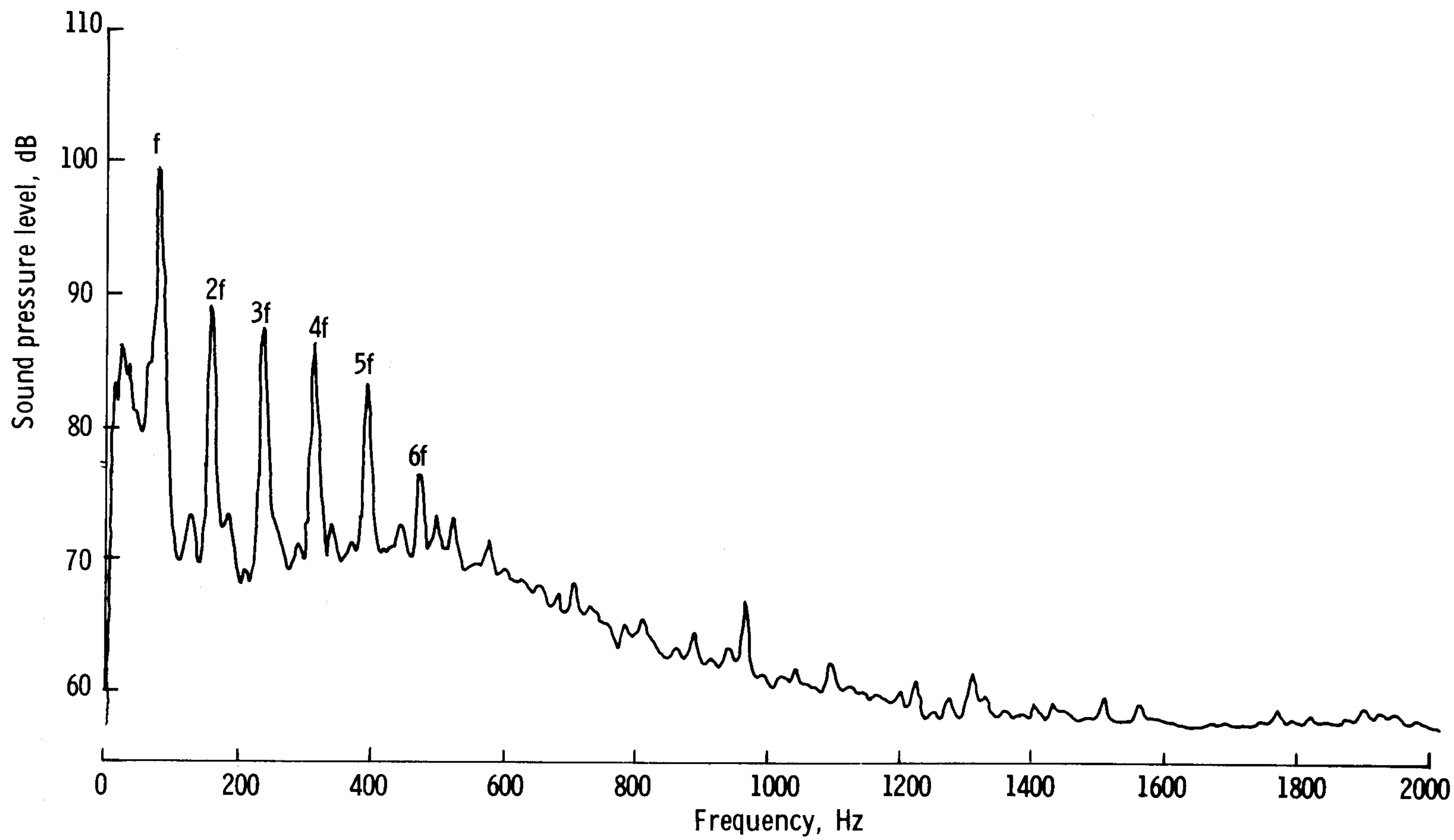
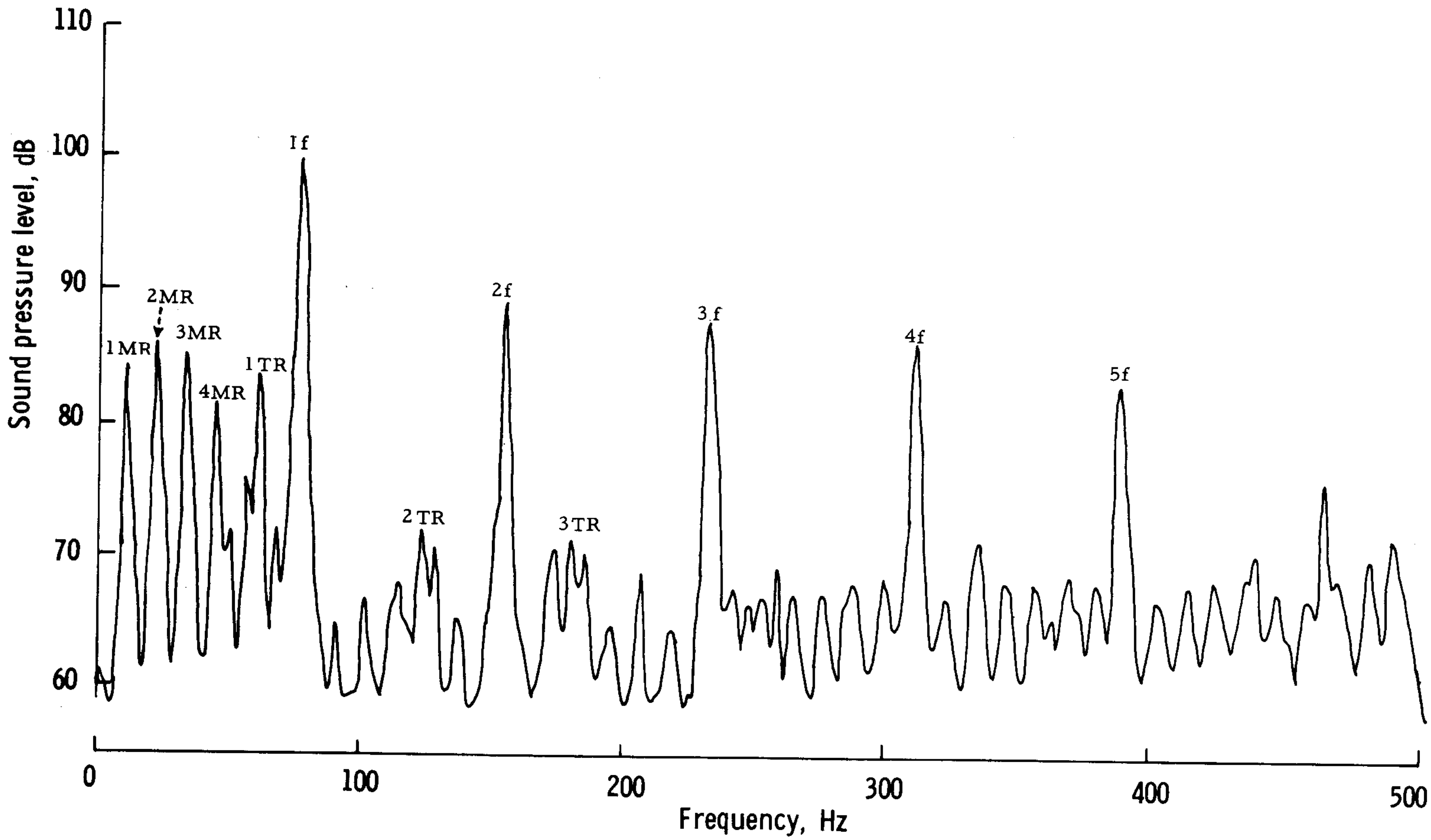


Figure 9.- Typical ambient noise level for test areas.



(a) Frequency spectrum from 0 to 2000 Hz with a bandwidth of 4 Hz.

Figure 10.- Narrow-band noise spectra of helicopter operating at 173 kW with standard exhaust system. Microphone located at 30 m from exhaust. (f is the fundamental firing frequency of the engine, MR represents the main rotor, and TR represents the tail rotor.)



(b) Frequency spectrum from 0 to 500 Hz with a bandwidth of 1 Hz.

Figure 10.- Concluded.

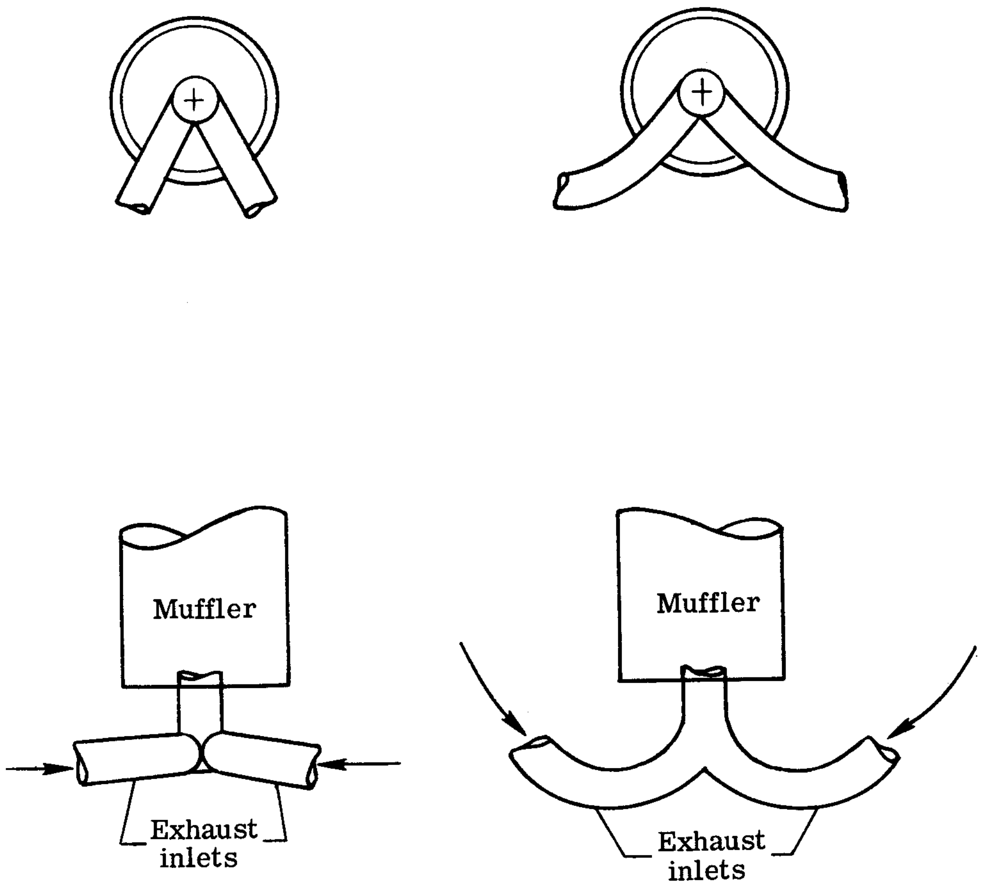


Figure 11.- Y-connectors used on muffler systems.

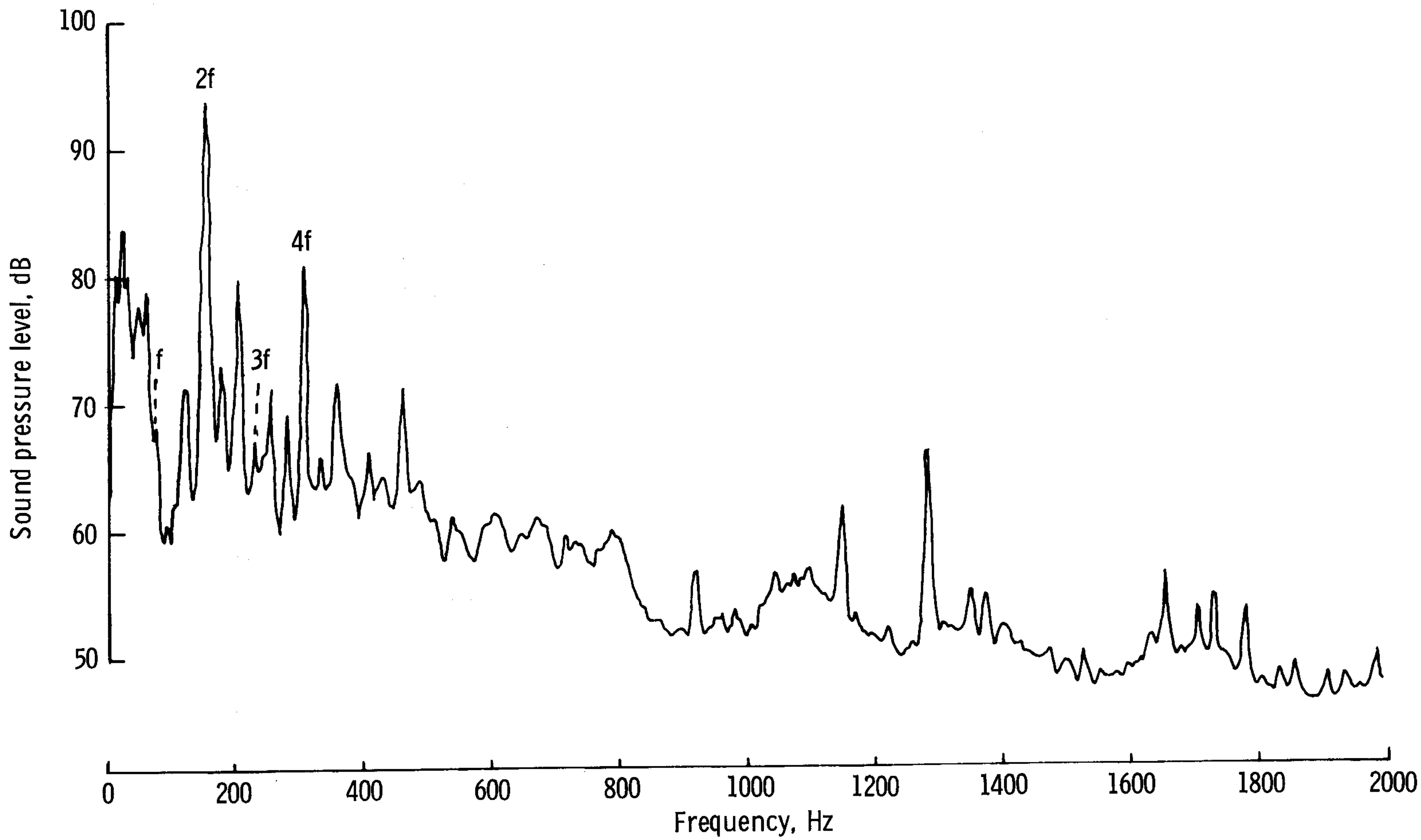


Figure 12.- Narrow-band (4-Hz) noise spectrum of helicopter operating at 120 kW with symmetric Y-connector. Microphone located 30 m from exhaust. (f is the fundamental firing frequency of the engine.)

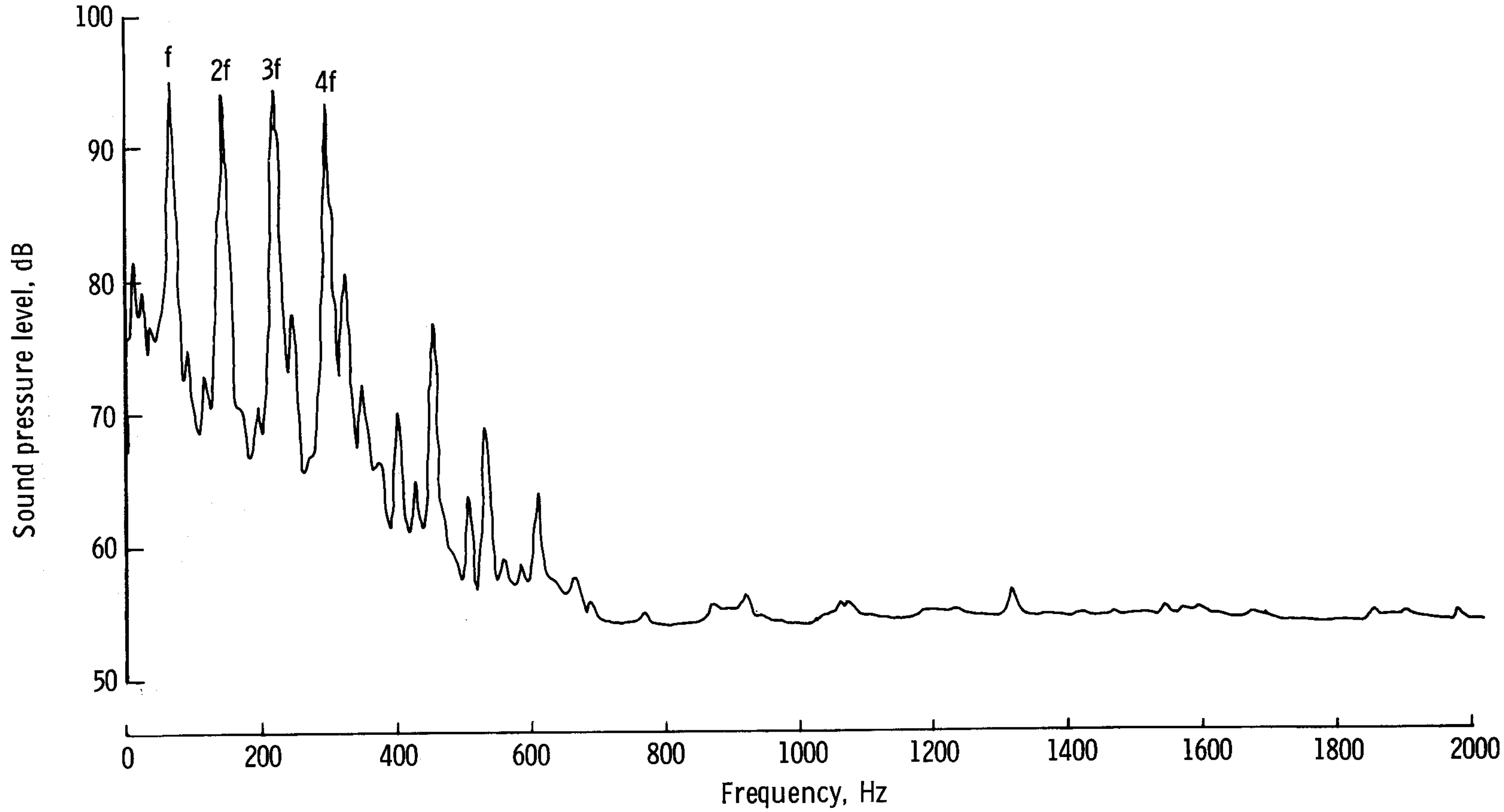


Figure 13.- Narrow-band (4-Hz) noise spectrum of helicopter operating at 120 kW with asymmetric Y-connector. Microphone located 30 m from exhaust. (f is the fundamental firing frequency of the engine.)

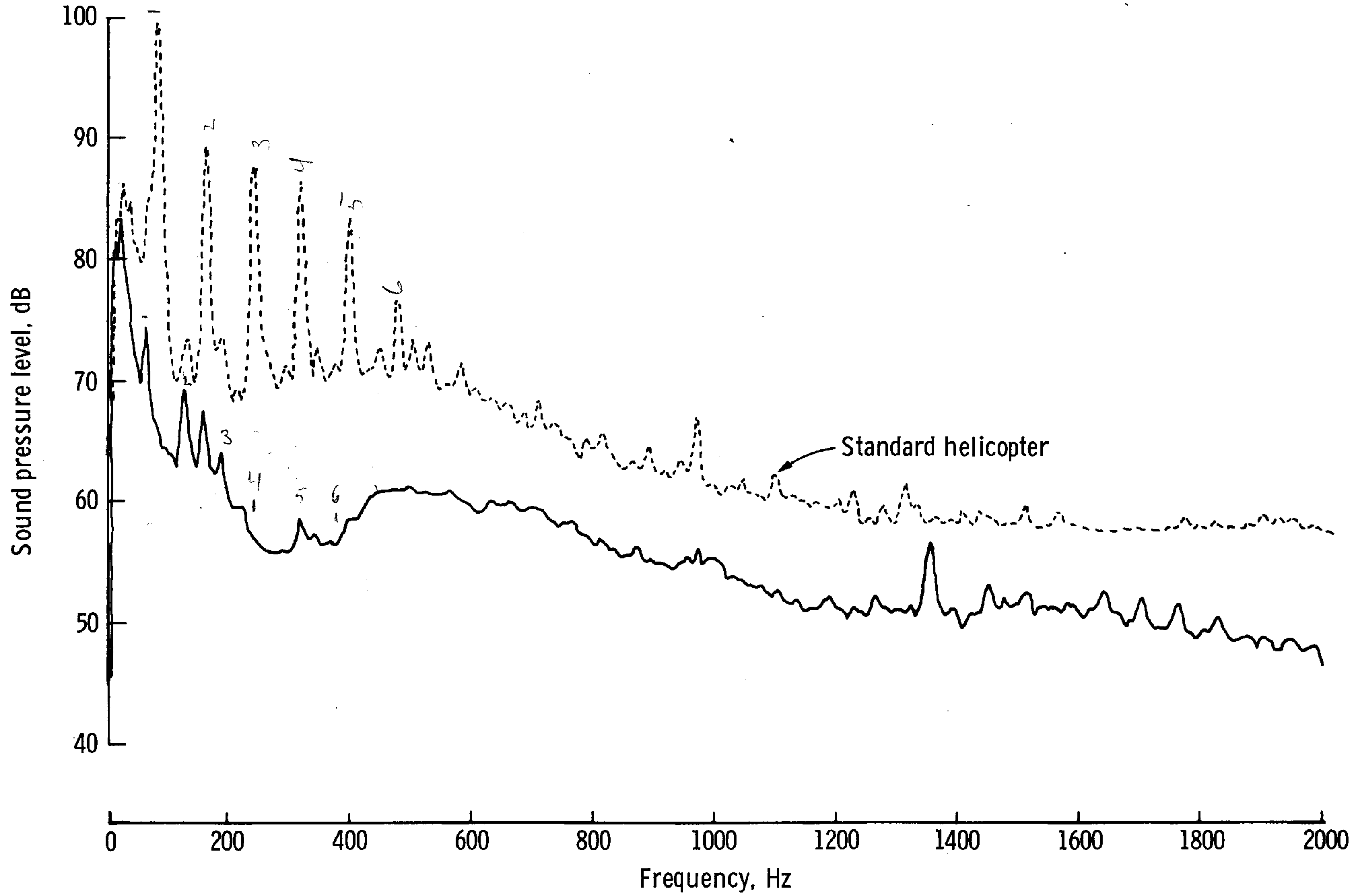


Figure 14.- Narrow-band (4-Hz) noise spectra of helicopter operating at approximately 173 kW with configuration A. Microphone located 30 m from exhaust system.

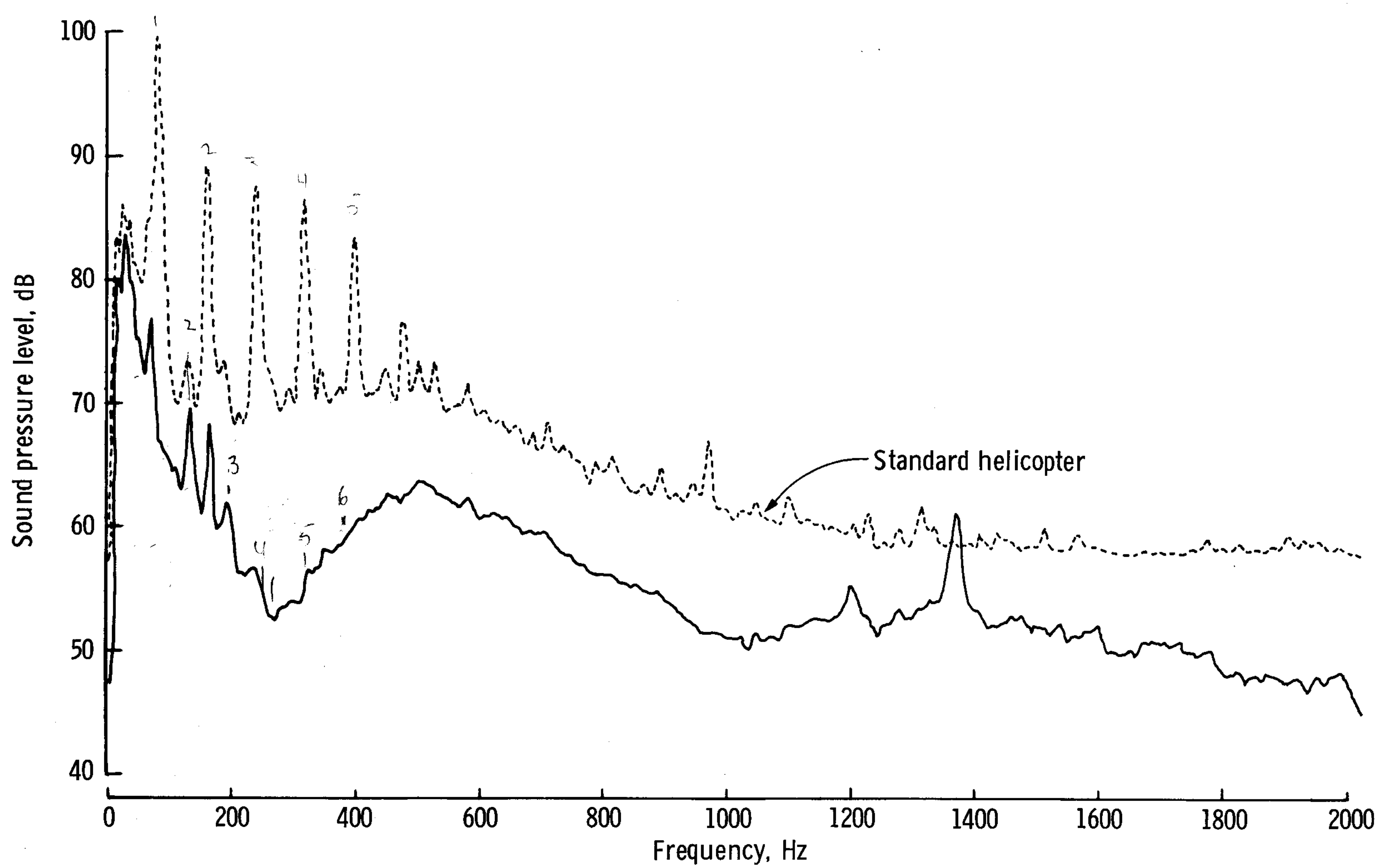


Figure 15.- Narrow-band (4-Hz) noise spectra of helicopter operating at 173 kW with configuration B. Microphone located 30 m from exhaust system.

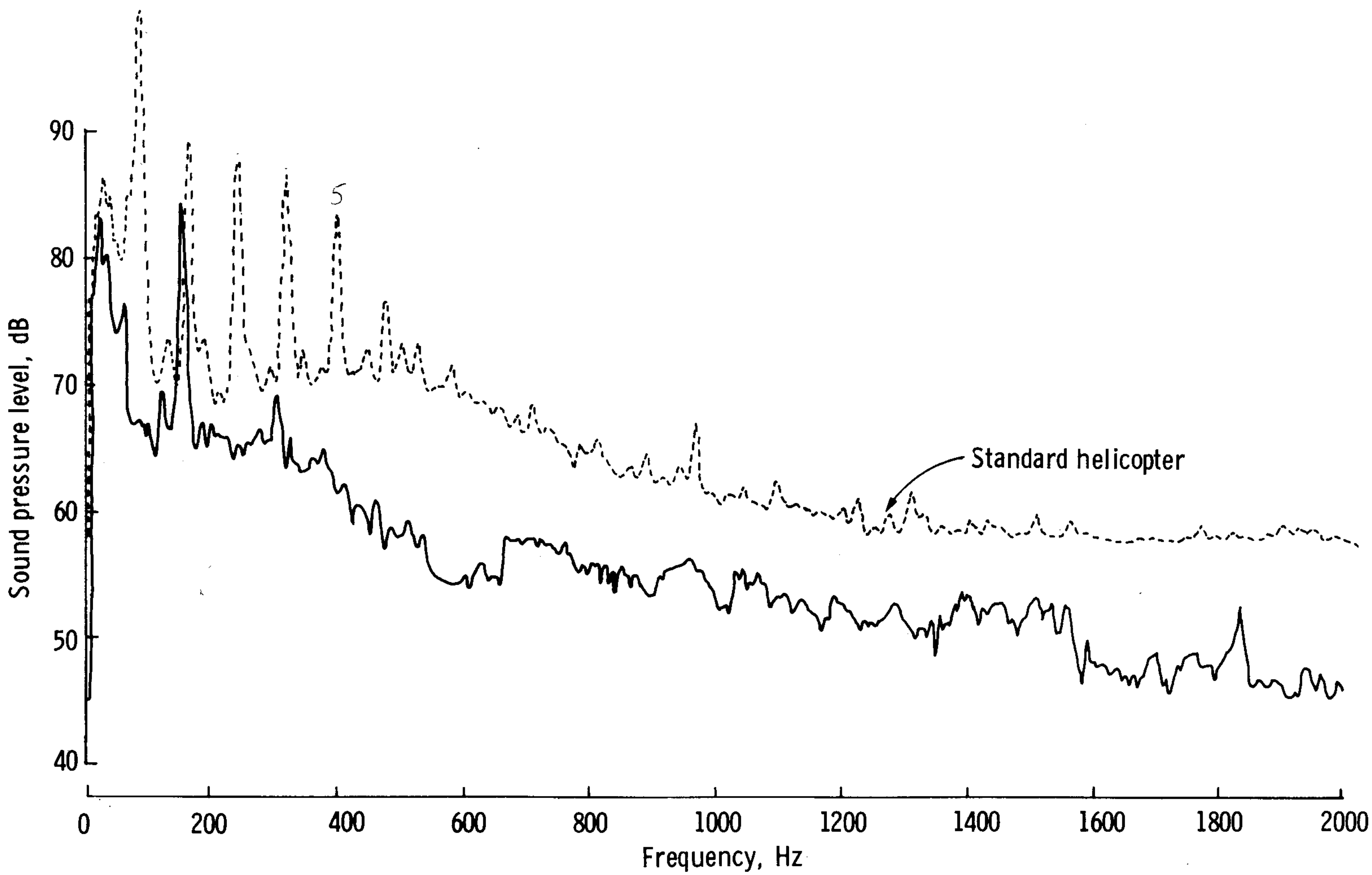


Figure 16.- Narrow-band (4-Hz) noise spectra of helicopter operating at 120 kW with configuration C. Microphone located 30 m from exhaust system.

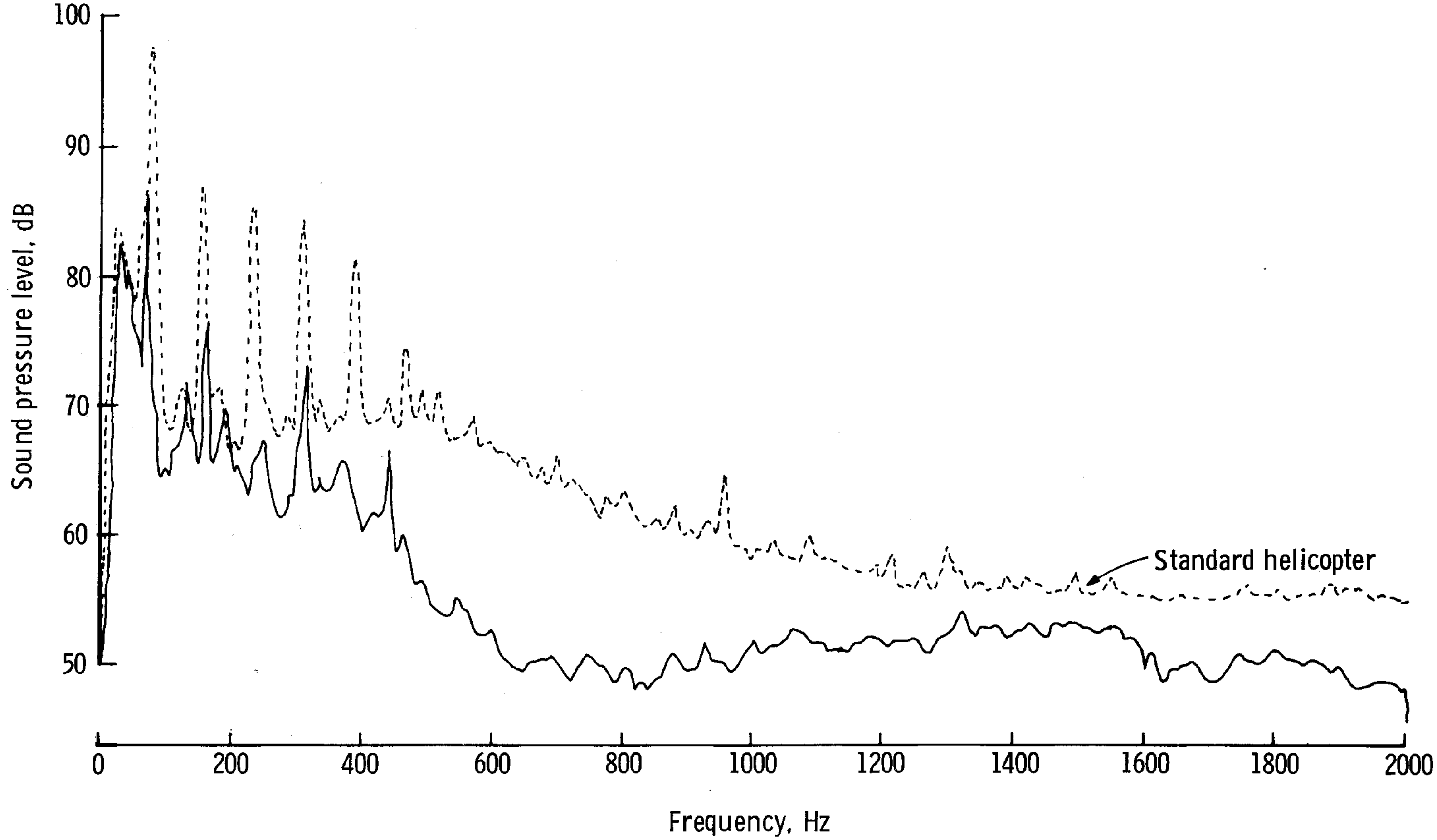


Figure 17.- Narrow-band (4-Hz) noise spectra of helicopter operating at 120 kW with the prototype of configuration D. Microphone located 30 m from exhaust system.

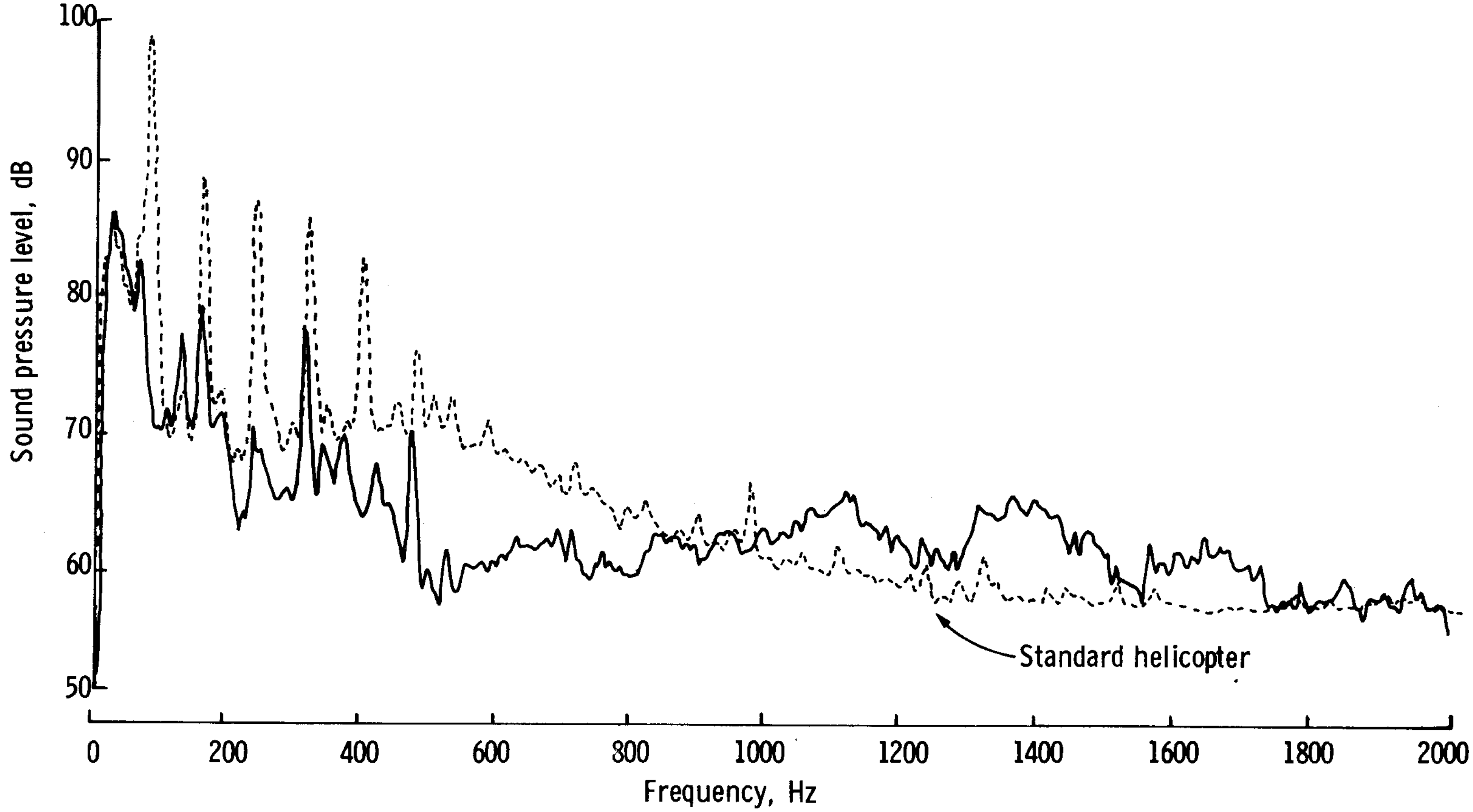


Figure 18.- Narrow-band (4-Hz) noise spectra of helicopter operating at 120 kW with configuration D. Microphone located 30 m from exhaust system.

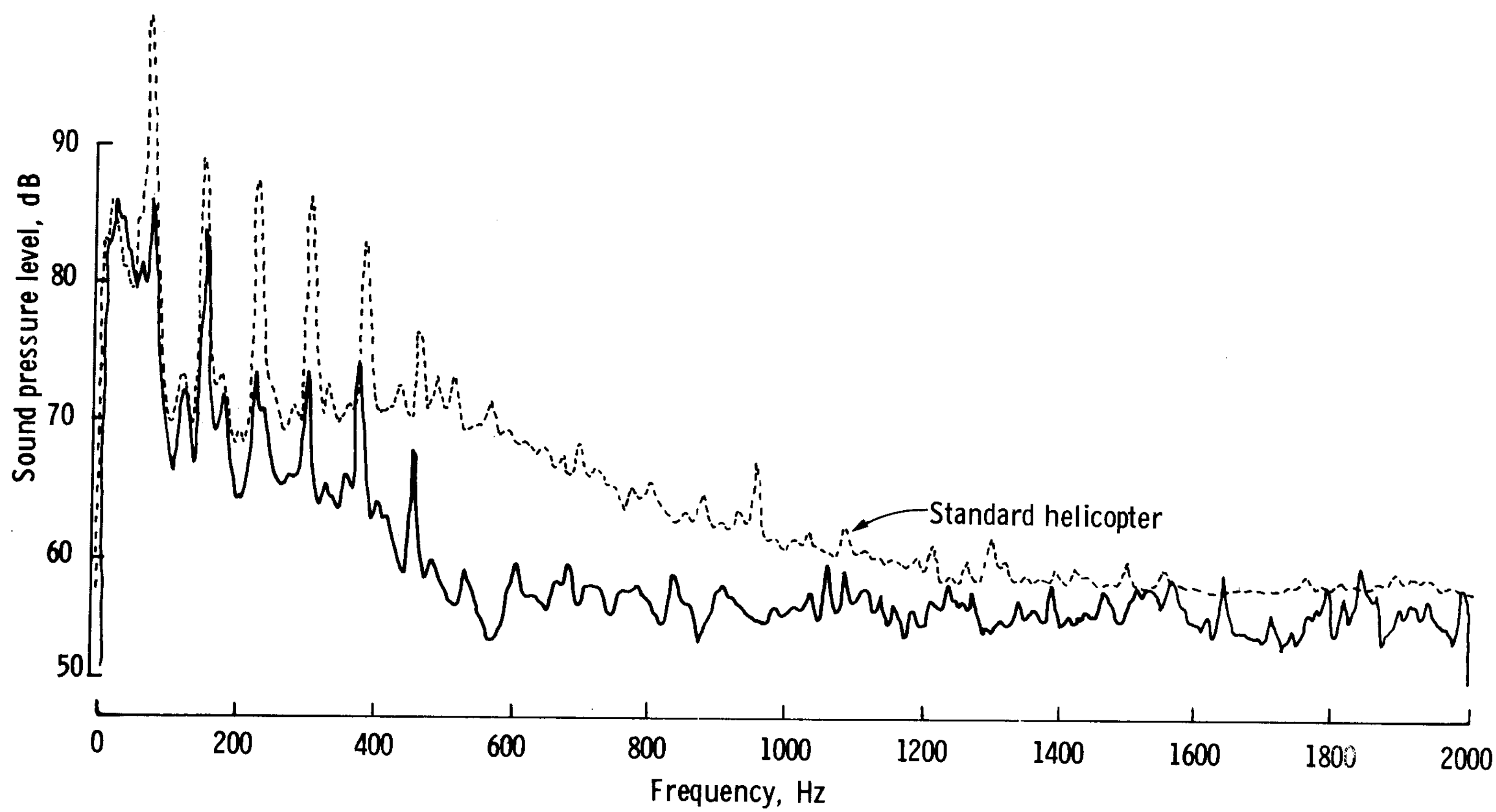


Figure 19.- Narrow-band (4-Hz) noise spectra of helicopter operating at 129 kW with configuration E. Microphone located 30 m from exhaust system.

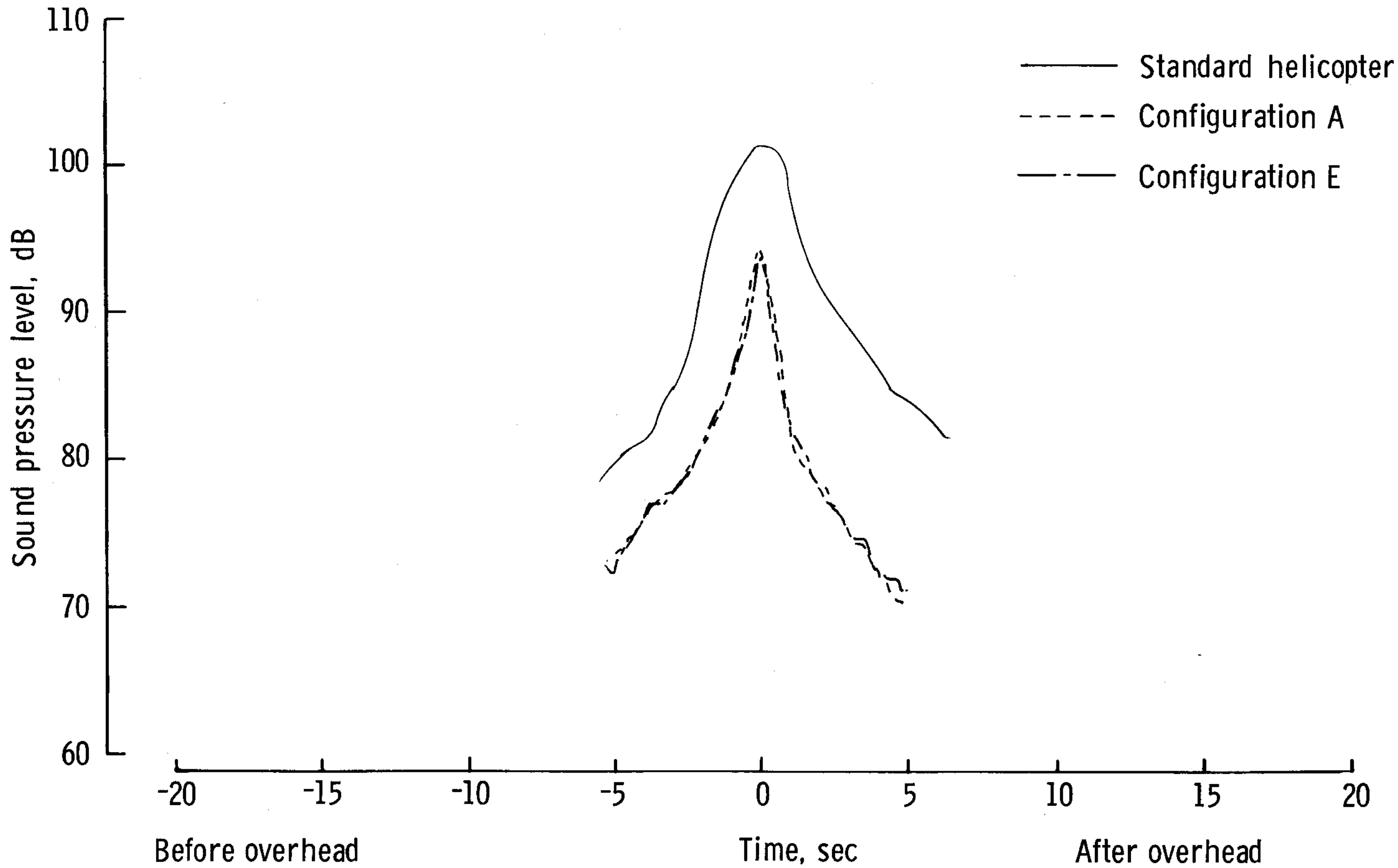


Figure 20.- Flyover noise time histories at on-track measurement location. (Airspeed approximately 80 knots, altitude 30 m.)

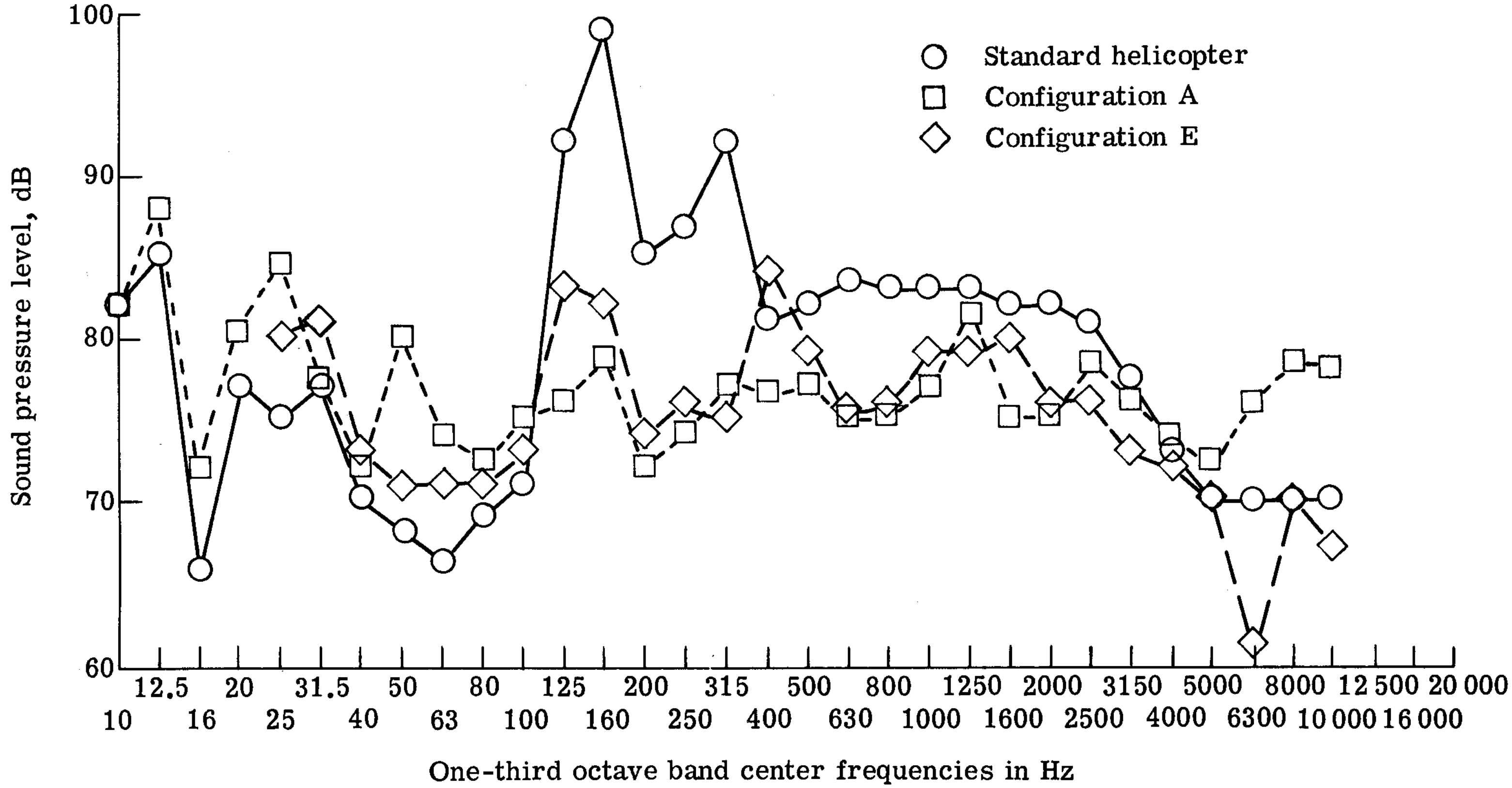


Figure 21.- Measured on-track flyover noise spectra of the three configurations at an airspeed of 80 knots and at an altitude of 30 m.

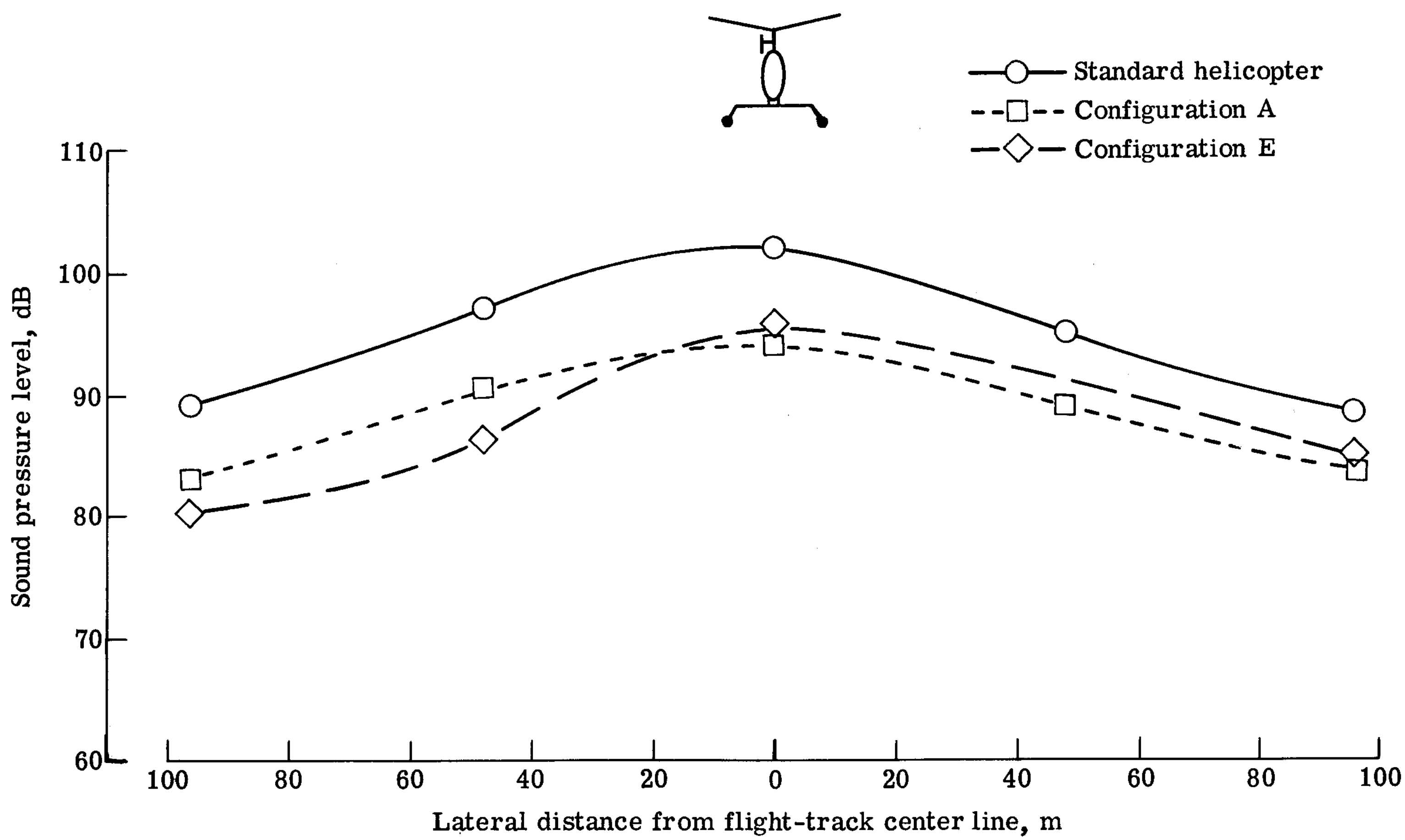


Figure 22.- Peak noise levels as measured at various lateral distances from flight track of the three configurations at approximately 80 knots and 30 m.

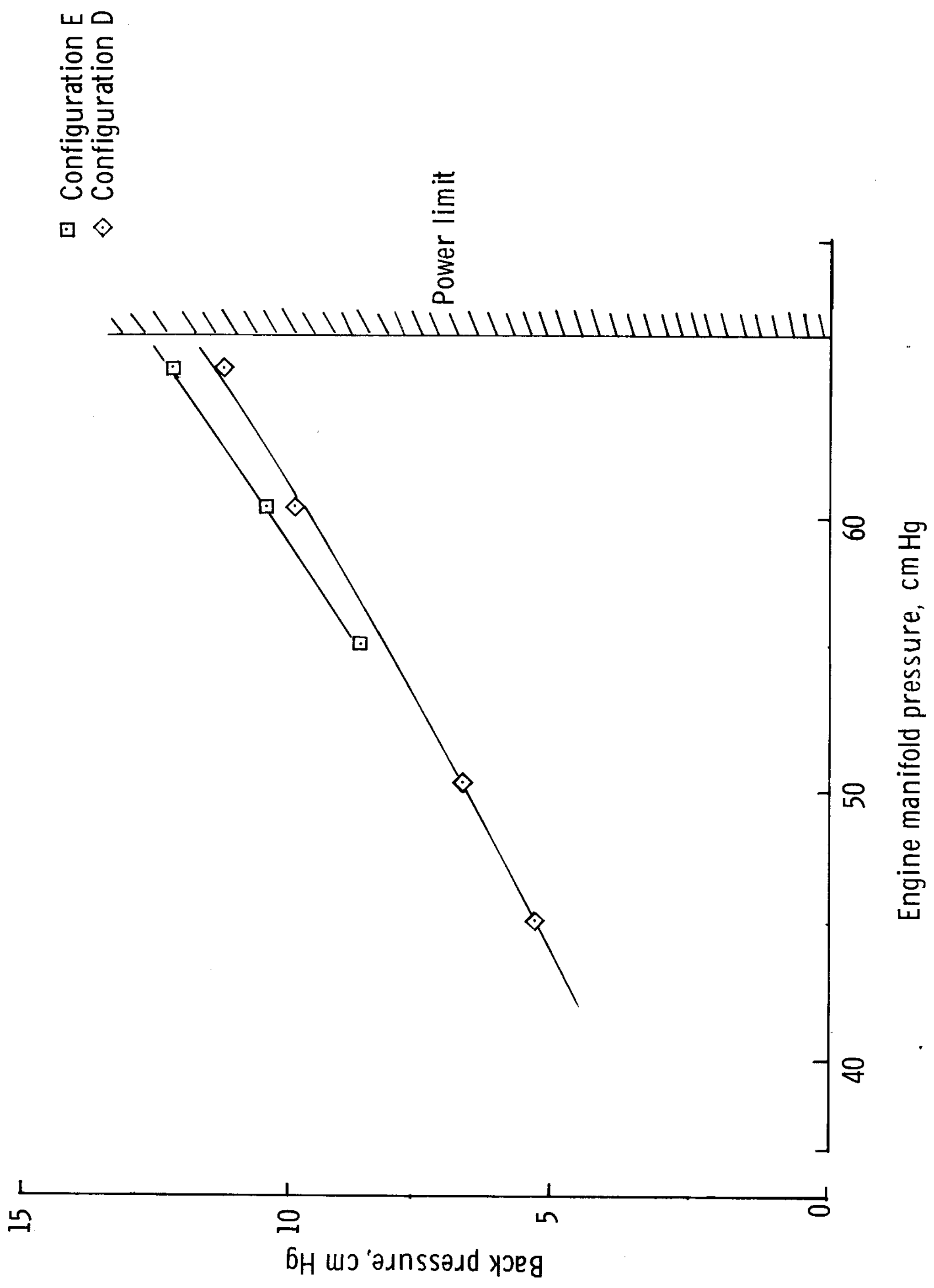


Figure 23.- Maximum engine back pressure.

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16. Abstract

A field noise measurement program has been conducted on a standard Bell 47 series helicopter and on one that had been modified with specially designed, airframe-mounted mufflers to reduce the engine exhaust noise. The purpose of the study was to evaluate the acoustic performance of five experimental exhaust muffler configurations for a helicopter reciprocating engine in an operational environment. All muffler configurations produced beneficial engine exhaust noise reductions but some configurations were markedly better than others. Flyover noise results indicated that maximum overall noise reductions of approximately 8 dB were obtained with the various mufflers. The rotor noise was judged to be the dominant noise component for the muffler-equipped helicopters whereas the engine noise was the dominant component for the basic configuration.

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