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COMPONENT NOISE VARIABLES OF A
LIGHT OBSERVATION HELICOPTER

By: Frank Robinson

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VARIABLES OF A LIGHT OBSERVATION
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CONTENTS

	Page No.
SUMMARY	1
INTRODUCTION	2
TEST PROCEDURE	2
Description of Test Rig	2
Test Conditions	5
Data Acquisition and Processing	6
Limitations of Test Data	7
Range of instrumentation	7
Ground reflection waves	8
TEST RESULTS	8
Complete Helicopter vs Component Noise	8
Main Rotor Noise	9
Tip Speed	9
Thrust	11
Number of blades	12
Tip Shape	12
Tail Rotor Noise	13
Tip Speed	13
Number of blades	13
Blade azimuth spacing	15
Blade construction and/or airfoil	16
Thrust	16
Powerplant Noise	16
Exhaust muffler and insulated cowl doors	18
Weight Variables	19
Weight vs main rotor tip speed	20
Weight vs tail rotor tip speed	22
Weight of other variables	23

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CONTENTS (continued)

	Page No.
CONCLUSIONS	24
REFERENCES	27
APPENDIXES:	
I TEST DATA - SPECTRA PLOTS	29
II POSSIBLE ERRORS IN TEST DATA RESULTING..... FROM GROUND REFLECTION WAVES	81

FIGURES

Figure		Page No.
1	OH-6A Helicopter Mounted on Test Rig	3
2	"Quiet" Helicopter in "Baseline Less Engine" Configuration	4
2A	Microphone Height and Location Relative to Test Helicopter	6
3	OH-6A Helicopter Main Rotor Noise Level vs Tip Speed	9
4	"Quiet" Helicopter Main Rotor Noise Level vs Tip Speed	10
5	Main Rotor Noise Level Variation with Thrust	11
6	Variation in Tail Rotor Noise with Tip Speed	14
7	1/3 Octave Spectra Comparison of 4-Bladed Tail Rotors with Different Blade Azimuth Spacing	14
8	Variation in Tail Rotor Noise Level with Thrust	17
9	Noise Variation with Power of Standard OH-6A Powerplant	17
10	Comparison of "Quiet" Helicopter Engine Noise for Three Exhaust Configurations	18
11	Effect of Noise-Source Height on Error Due to Ground Reflection Waves	82
12	Effect of Microphone Height on Error Due to Ground Reflection Waves	82
13	Spectra Plot of Complete OH-6A Helicopter Recorded at 200 Ft with Two Microphone Heights	83

TABLES

Table		Page No.
I	Summary of Noise Variables	25
II	Test Data - Standard OH-6A Helicopter	31
III	Test Data - "Quiet" Helicopter	59
IV	Effect of Ground Reflection Waves on OASPL Values	84

COMPONENT NOISE VARIABLES OF A LIGHT OBSERVATION HELICOPTER

SUMMARY

A test program was conducted to isolate and evaluate the individual noise sources of a light helicopter. To accomplish this, the helicopter was mounted on a special test rig, at a 6-foot skid height, in a simulated hover. The test rig contained a dynamometer for absorbing engine power and an exhaust silencing system for reducing engine noise. This test set-up allowed the various components of the helicopter to be run and listened to individually or in any combination. The sound pressure level was recorded at a point 200 feet from the helicopter as the component parameters were systematically varied. The tests were conducted in an open area, during the middle of the night, with no wind, and with all other known variables either eliminated or kept as constant as possible.

A large quantity of noise data was obtained and processed, relating such variables as rotor tip speed, rotor thrust, tip shape, engine exhaust muffling, cowl insulation, etc., to perceived noise level as heard by an outside observer. In general, the quality of the data was good. However, some errors were introduced by ground reflection waves, instrumentation limitations, and the inherent obstinacy of 'sound' to be a repeatable, measurable quantity.

The tests were conducted using both a standard OH-6A light observation helicopter and a highly modified version of that aircraft known as the "Quiet" helicopter. For this particular helicopter, the test results showed that the most rewarding area for noise reduction was to lower the tail rotor tip speed.

This report contains a wide variety of data and frequency spectra plots to help in the understanding and reduction of helicopter noise. Wherever possible, the data has been expressed as a partial derivative to facilitate its use in helicopter preliminary design. Also included, are derivations of the weight penalties associated with the various noise reduction techniques.

INTRODUCTION

The demand for helicopters with lower external noise levels has increased considerably during recent years and will likely increase even more in years to come. Lower noise levels are desired by the military to reduce detectability and by the private sector to improve public acceptance of the helicopter.

Several highly modified helicopters have demonstrated rotary wing flight with very low external noise levels. These aircraft were not, however, designed to be operational and capable of performing the type of mission required by a light observation helicopter. Nor was there an attempt to isolate and evaluate the penalties incurred by the various quieting techniques used.

The objective of this research program was to isolate the various noise sources of the helicopter and evaluate, quantitatively, the penalties incurred as various techniques were used to reduce their noise levels. To accomplish this, it was necessary to develop a method which would allow the various components of the helicopter to be "listened to" individually. With this method, the penalty of quieting each component could be determined individually as it was varied or modified. This data could then be used to select the most fruitful areas for noise reduction in future designs and to evaluate the actual penalties incurred, in terms of lost payload or performance.

TEST PROCEDURE

Description of Test Rig

Figure 1 shows the test rig which was fabricated to hold the helicopter in a simulated six-foot hover. The entire rig is portable, with detachable cross beams and screw jacks to take the weight off the tires and make the entire unit rigid, once it is towed into position. At the rear of the unit is the dynamometer which can be connected to the aircraft's powerplant by means of a drive shaft with universal joints at each end. The Allison T-63 engine has provisions for driving from either end which allows the dynamometer drive shaft to be connected without disturbing the aircraft's regular drive system. The dynamometer cooling system consists of three automotive radiators, with electrically driven automotive fans, a cooling water reservoir, and an electrically driven circulating pump.

A separate large tank muffler, or silencer, was also fabricated and can be seen at the extreme right of Figure 2. For those test runs requiring the engine to be silenced, this tank muffler was connected to the engine exhaust with a long insulated duct, also visible in Figure 2.

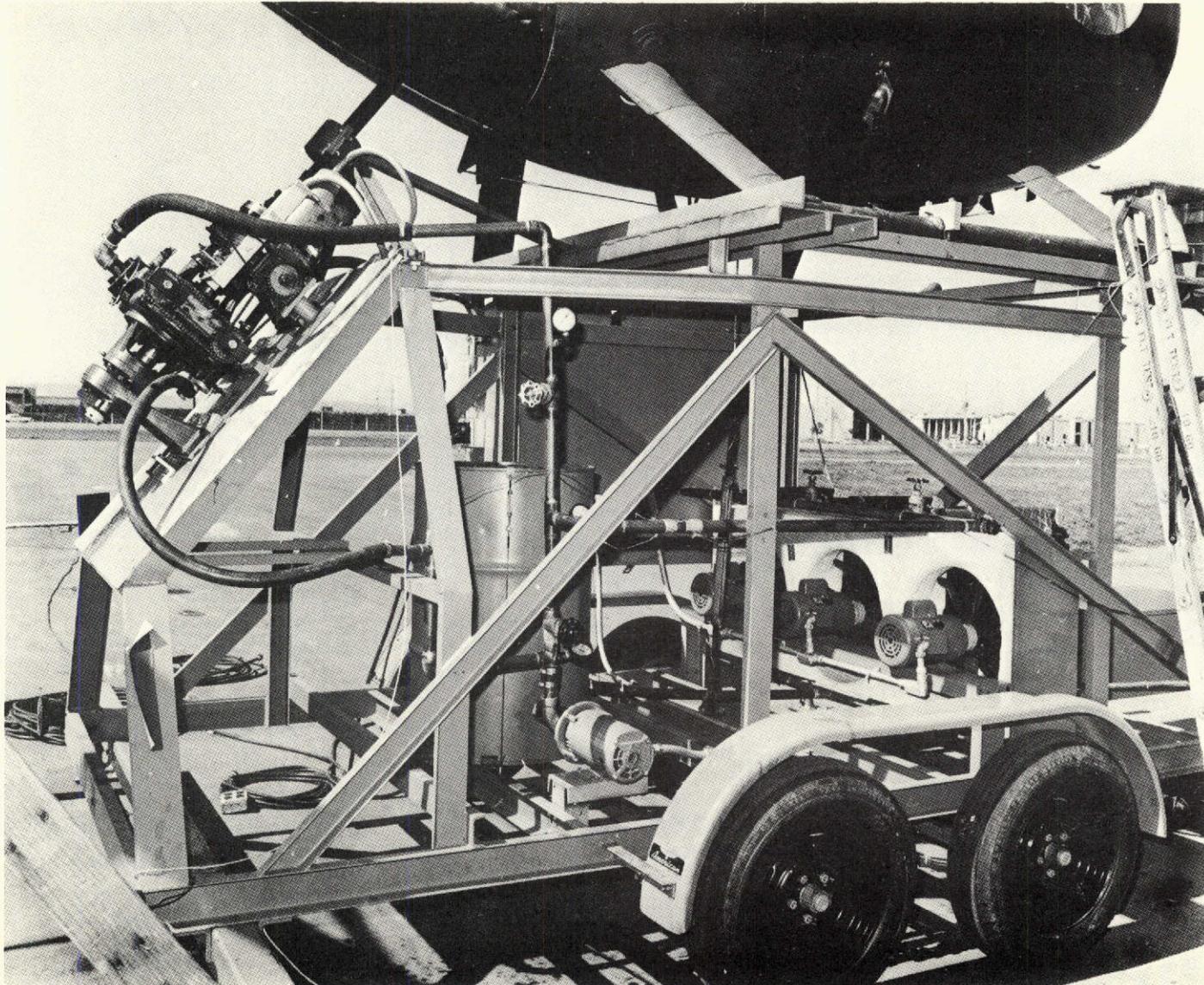


Figure 1. OH-6A Helicopter Mounted on Test Rig. Note Drive Shaft to Dynamometer and Dynamometer Cooling System

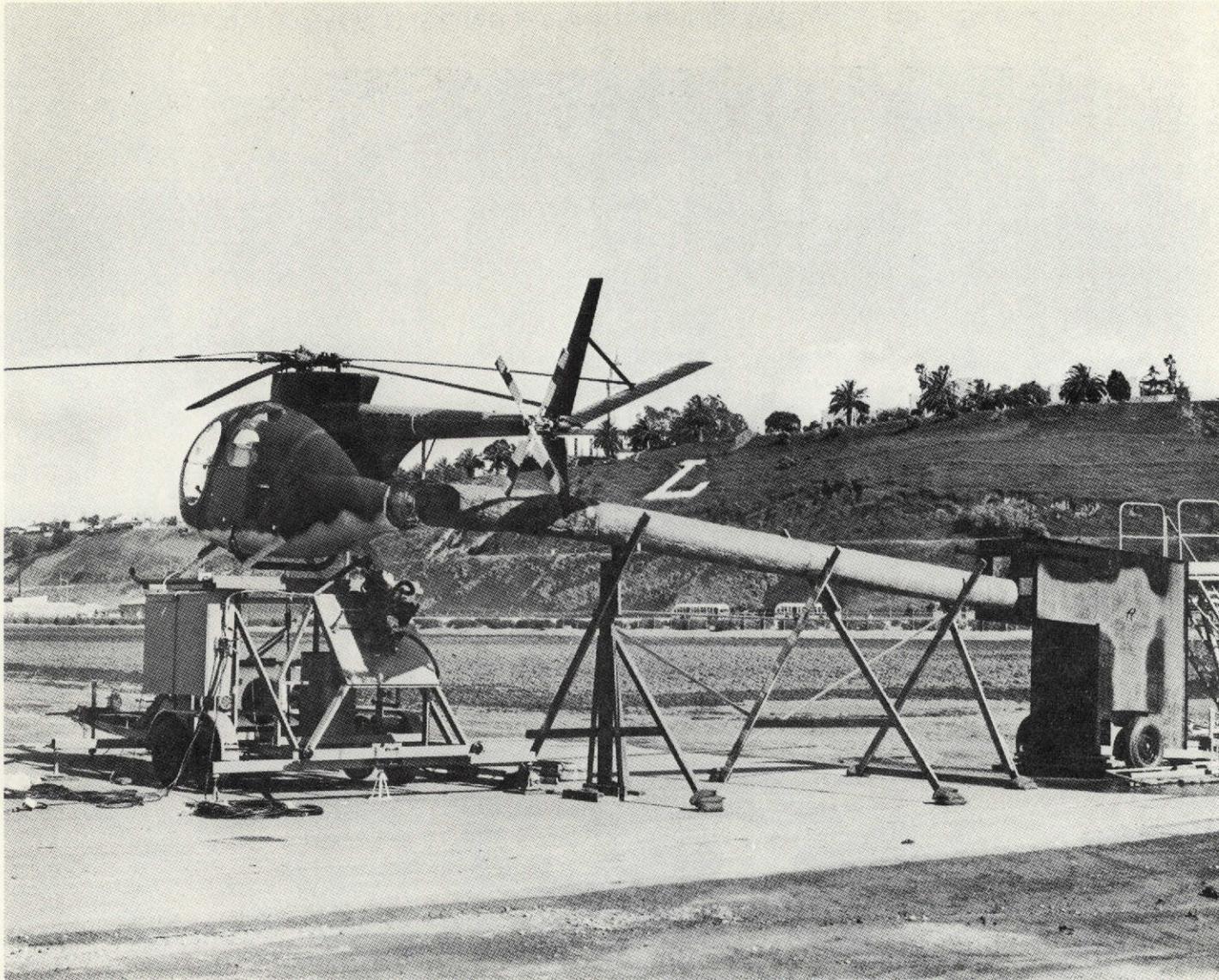


Figure 2. "Quiet" Helicopter in "Baseline Less Engine" Configuration.
Engine Exhaust is Silenced by Large Tank Muffler at Extreme Right .

When mounted on the test rig, the helicopter could be run with any combination of its major components either removed or silenced. The tail rotor could be removed and the engine silenced so only the main rotor could be heard. The main rotor could be removed and the engine silenced so only the tail rotor could be heard. Both the main and tail rotors could be removed with the dynamometer absorbing the power so only the engine could be heard. A noise level difference of 5 or 10 decibels in the frequency range of interest between the silenced components and the components being investigated is usually sufficient to make their noise contribution negligible.

The test rig worked exceptionally well. The dynamometer was able to absorb full engine power. Its cooling system dissipated the rejected heat without any problems and the noise level of the cooling fans was only 68 decibels. Narrow band spectra plots for the cooling system are presented as runs 35 and 238 in Appendix I. A narrow band spectra plot of a typical ambient is shown after run 238. There was no evidence of ground resonance or any other dynamic instability. There was, however, a noise frequency recorded which corresponded to the RPM of the dynamometer drive shaft. This could possibly be corrected by improving the shaft balance. This test rig should provide a convenient tool during future tests, for investigating the noise from any isolated component.

Test Procedure

The test aircraft was equipped with precision visual instrumentation for reading engine torque, tail rotor torque, tail rotor thrust, collective pitch and tail rotor pitch. The aircraft was flown in free hover at a 6-foot skid height and a variety of gross weights and rotor speeds to obtain calibrated readings. This enabled the pilot to duplicate the various rotor thrust and power conditions with the helicopter mounted on the test rig by setting-up the same values for collective pitch, etc., as those recorded during free hover.

The noise tests were conducted between midnight and approximately 5:00 AM to obtain the lowest background noise and the calmest wind conditions. The acceptable winds were limited to three knots and no visible precipitation was permitted. The relative humidity and temperature were monitored and all tests were conducted under similar ambient conditions. Also, tests were delayed whenever aircraft were observed flying anywhere in the surrounding area. The test rig was located in an open area where there was a minimum of reflective surfaces. The control microphone (Position No. 1) was located 200 feet from the helicopter at an azimuth position 30 degrees left of due aft (Figure 2A). The microphone at Position No. 2 was located at 200 feet, 30 degrees left of forward. The microphones were four feet above the ground and the terrain between the helicopter and the microphones was primarily grass which reduced the effects of ground reflection waves.

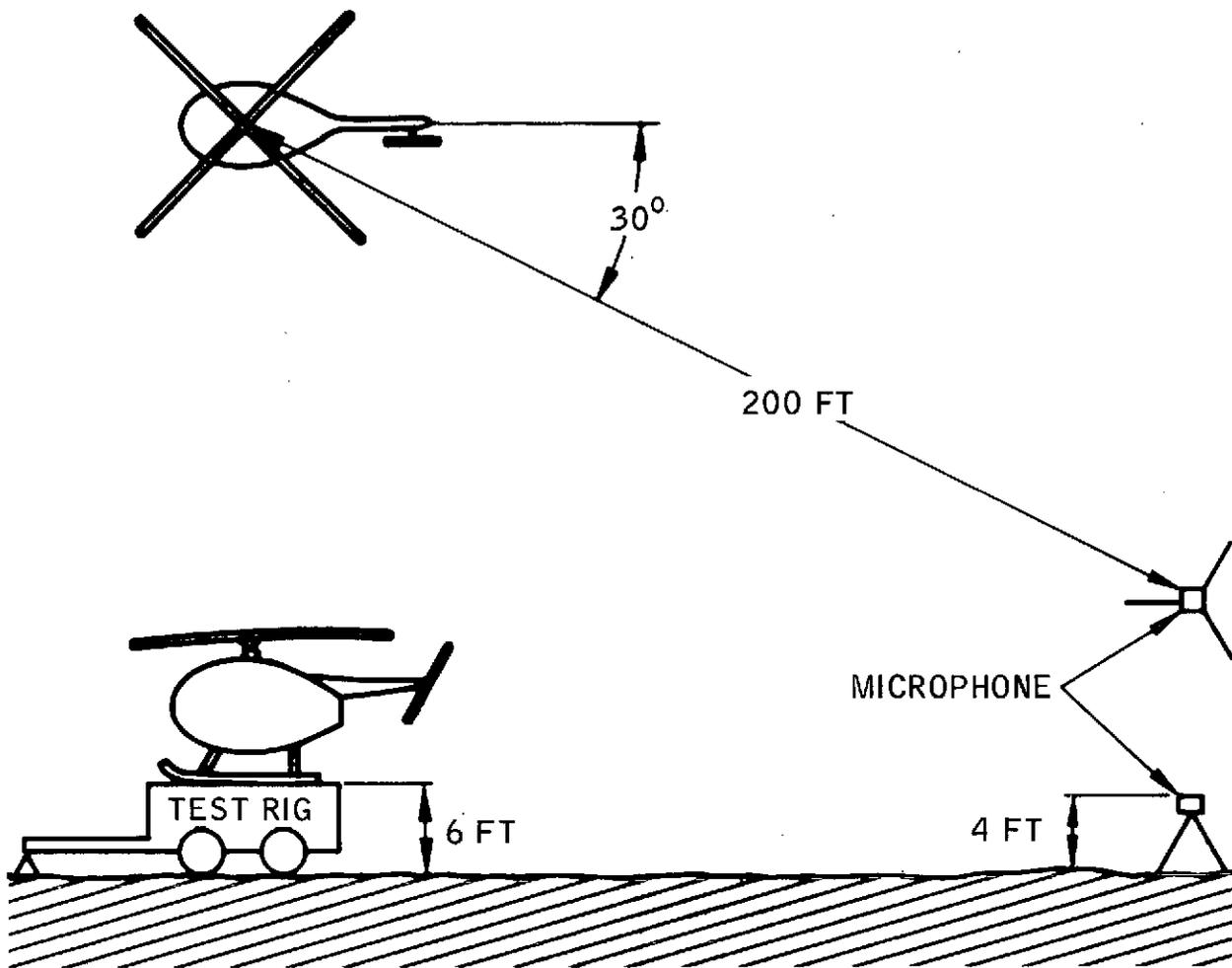


Figure 2A. Microphone Height and Location Relative to Test Helicopter

Data Acquisition and Processing

The noise data was recorded at 60 inches-per-second on one-inch magnetic tape. The data runs had a duration of 40 seconds each, with voice identification. All sound-pressure-level (SPL) data was referenced to 0.0002 dynes per square centimeter.

The following equipment was used for recording the data:

Position No. 1 — B & K Type 4131 Microphone, B & K Type 2203
Sound Level Meter

Position No. 2 — B & K Type 4145 Microphone, B & K Type 2107
Sound Level Meter

Acoustic Calibrator — B & K Piston Phone Type 4220

Tape Recorder — Pemco Model 120

The data recorded at Position No. 1 was then processed by Wyle Laboratories using a real-time-analyzer and a digital computer program for calculating perceived-noise-level (PNdB). In addition to the calculated PNdB value and the linear readings, values were also recorded using "A" scale and "D" scale electrical weighting networks. Each data point was based on an average value obtained using a 20 second portion of the record. In addition to the tabulated data, selected one-third octave plots and narrow band plots were made for a variety of test configurations.

Limitations of Test Data

Range of instrumentation. - The equipment used for recording sound pressure levels has a limited range of about 40 or 45 decibels. For each sound level being recorded, the operator set his equipment to record at the linear overall-sound-pressure-level (OASPL) indicated by his visual reading. When making a frequency spectra plot or when computing the perceived-noise-level (PNdB), if some of the sound pressure levels were considerably below the maximum level, they would become mixed with the instrumentation noise. During this test program, the high frequency (5,000 to 20,000 Hz) helicopter noise levels were usually quite low. On many, if not most, of the one-third octave plots contained in this report, the high-frequency portion of the spectra is actually instrumentation noise and moves up or down in amplitude as the operator adjusts the range setting of the recorder. The recording level is shown in parenthesis on each plot to aid in evaluating the data.

In future tests, when it is desired to improve the accuracy and resolution of the low-level, high-frequency noise sources, it is recommended that separate additional records be made with low range settings on the recording instrumentation. These records can then be used in conjunction with the initial high-level recordings to cover the entire sound pressure level and frequency range of the helicopter.

Ground reflection waves. - Frequently, when measuring sound pressure, the microphone will record two (or more) sound pressure waves coming from the same source. One pressure wave travels direct (line-of-sight), while the other wave is first reflected off the ground, or other surface, and then travels to the microphone. Since the reflected wave must travel a greater distance, it will arrive at the microphone some time increment after the direct wave. This will produce a phase shift between the two waves and thus the reflected wave may either augment or diminish the direct wave, depending on the resulting phase shift.

The possible influence of ground reflection waves on the data contained in this report is discussed in Appendix II. In general, their effects did not seriously impair the overall quality of the data.

TEST RESULTS

Complete Helicopter vs Component Noise

A wide variety of helicopter configurations were tested. These are listed in tables contained in the appendix of this report. The recorded noise levels of the three major components of the OH-6A helicopter are listed below. Records taken at four gross-weight test conditions were averaged to obtain these values and all are at 103 percent N₂ engine speed. The three separate component noise levels were added together, using the method described in reference 3, and are compared with the levels recorded for the complete helicopter. The agreement between the sum of the component noise and the noise of the complete helicopter, and, the agreement between the complete helicopter in free hover and when mounted on the test rig, are quite good.

	<u>Linear</u> db	<u>"D"</u> Weighted	<u>PNdB</u>
Main Rotor Only	85	74	79
Tail Rotor Only	86	82	89
Engine Only	<u>82</u>	<u>79</u>	<u>86</u>
Sum of Components	90	84	91
Complete OH-6A, Mounted on Test Rig	89	85	92
Complete OH-6A, In Free Hover	87	84	91

Main Rotor Noise

As discussed in Appendix II, the height of the main rotor tended to produce ground reflection waves which distorted the sound pressure readings, particularly from 500 to 1000 Hz. It is at this frequency that the broad band noise from the main rotor has its greatest influence on the calculated perceived-noise-level (PNdB). Since the linear overall-sound-pressure-levels (OASPL) were less affected by ground reflection waves, they were used to develop the parametric curves for the main rotor noise.

Tip speed. - Figure 3 shows the variation of OASPL with tip speed for the main rotor of the standard OH-6A helicopter. These tests were conducted with the tail rotor removed and the engine silenced so that the dominant noise source was the main rotor. Figure 4 shows the OASPL vs tip speed variation for the "Quiet" helicopter 5-bladed main rotor with tapered tips.

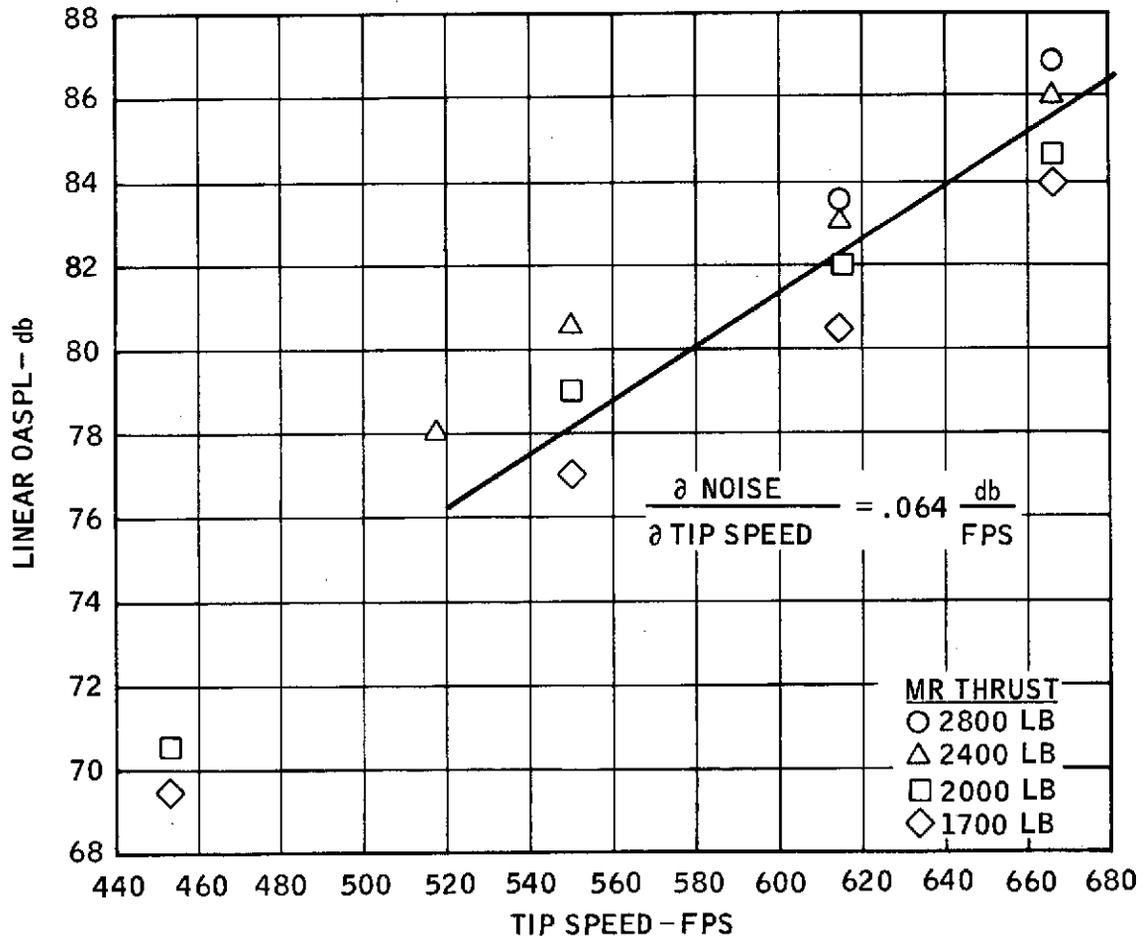


Figure 3. OH-6A Helicopter Main Rotor Noise Level vs Tip Speed

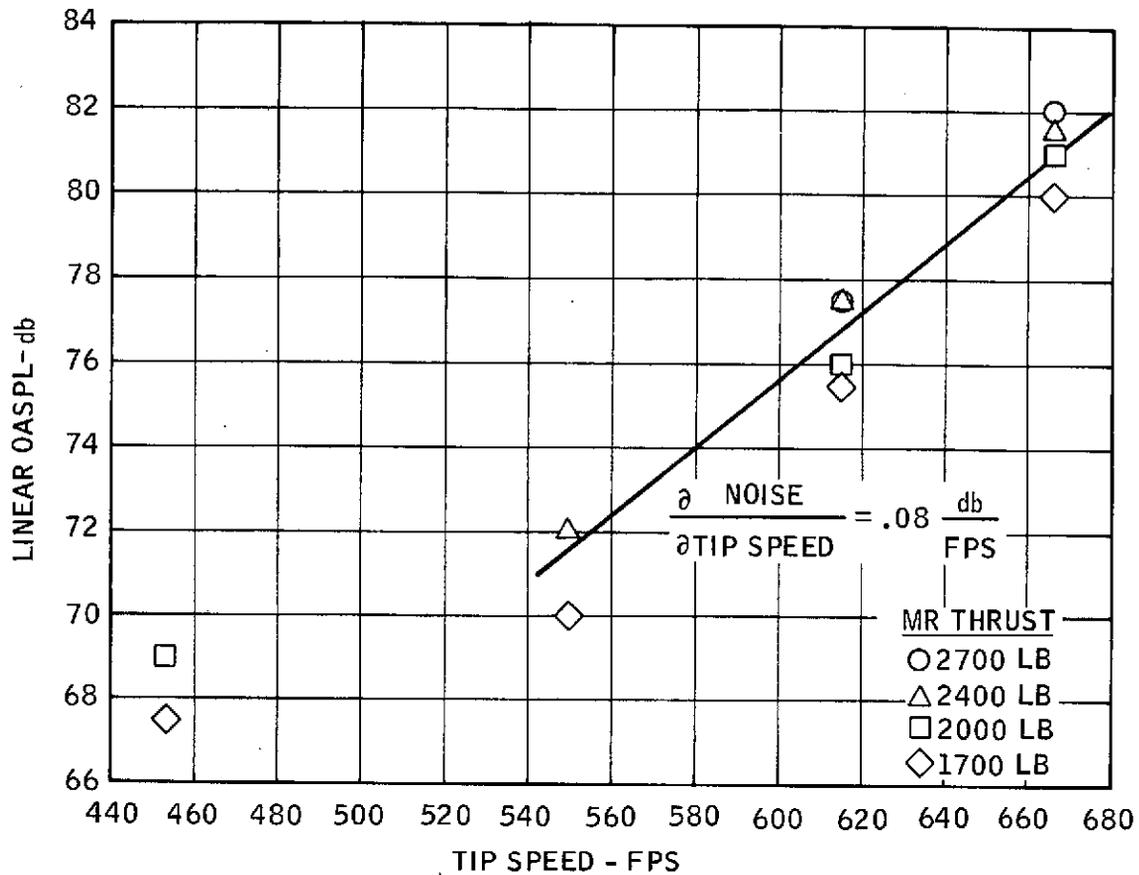


Figure 4. "Quiet" Helicopter Main Rotor Noise Level vs Tip Speed

The thrust was held constant as the rotor speed varied so there was an increase in the average blade section lift coefficient as the tip speed decreases.

For a given main rotor diameter, as the tip speed decreases the torque must increase. This increases the tail rotor thrust required. Therefore, a change in tail rotor noise must be taken into account when evaluating a noise reduction obtained by reducing main rotor tip speed.

From test data: (Figures 3 and 8)

$$\frac{\partial \text{MR Noise}}{\partial \text{MR Tip Speed}} = 0.064 \text{ db/FPS}$$

and

$$\frac{\partial \text{TR Noise}}{\partial \text{TR Thrust}} = 0.041 \text{ db/FPS}$$

Let:

$$\text{TR Thrust} = \frac{K}{\text{MR Tip Speed}'} \quad (\text{MR Tip Speed} = 666 \text{ FPS} \\ \& \text{TR Thrust} = 130 \text{ LB for OH-6A})$$

or,

$$\frac{\partial \text{TR Thrust}}{\partial \text{MR Tip Speed}} = 0.198 \text{ LB/FPS}$$

and

$$\frac{\partial \text{TR Noise}}{\partial \text{MR Tip Speed}} = (0.198)(0.041) = 0.008 \text{ db/FPS}$$

Thrust. - The variation in main rotor linear OASPL with thrust is shown in Figure 5. Two tip speeds each are shown for the standard OH-6A and the "Quiet" helicopter. The blade area is constant so, as the thrust is changed, the blade-section life-coefficient varies accordingly.

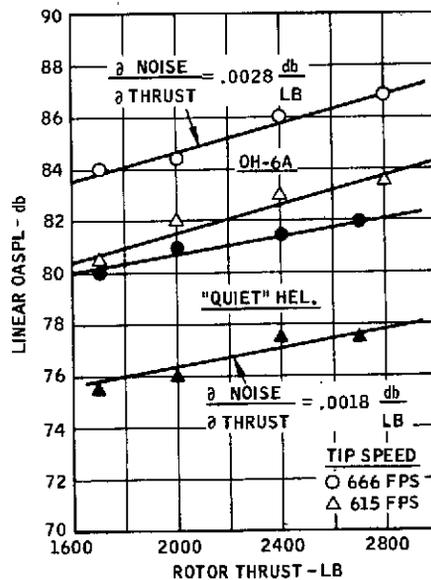


Figure 5. Main Rotor Noise Level Variation With Thrust

Number of blades. - To determine the noise variation with number of blades, it was necessary to compare the 5-bladed main rotor of the "Quiet" helicopter with the 4-bladed main rotor of the standard OH-6A. This means, of course, that since two different ships were used, many other subtle differences were present and no doubt had some effect on the test data. The linear OASPL readings at four gross weights were averaged and are compared below. The difference using linear OASPL was one decibel higher with the 4-bladed rotor. While using either the "D" weighted or the perceived-noise-level (PNdB), the 4-bladed rotor was from 6 to 8 decibels lower. As mentioned previously, a ground reflection wave could have affected the reliability of the "D" weighted and PNdB readings. However, since the data was not consistent, no conclusion was drawn concerning the relative noise level of four versus five bladed main rotors.

	<u>Linear dB</u>	<u>"D" Weighted</u>	<u>PNdB</u>
4-Bladed Main Rotor	85	74	79
5-Bladed Main Rotor	84	80	87

Tip shape. - The "Quiet" helicopter main rotor blades, with tapered-tips, were compared with standard square-tip blades run on the same helicopter. The tapered tips are fully described in Reference 1, but in essence, they consist of a trapezoidal planform about one chord length long with a 2:1 taper and 2 degrees of negative twist. The tapered tips did reduce the rotor solidity by approximately 1% but this small change should have only a negligible effect on either rotor performance or noise.

Again, the existence of a ground reflection wave, makes the "D" weighted and PNdB data questionable. However, the readings were consistent and using only the linear OASPL readings, there would appear to be a noise level reduction of at least 2 or 3 decibels due to the tapered tips.

	<u>Linear dB</u>	<u>"D" Weighted</u>	<u>PNdB</u>
<u>Tapered-Tip Blades</u>			
1st run	81	74	80
2nd run	82	77	84
Square-Tip Blades	84	80	87

Tail Rotor Noise

Tip speed. - Figure 6 shows the variation in perceived-noise-level (PNdB) with tail-rotor tip-speed for the standard OH-6A tail rotor. The tail rotor thrust, blade area, and number of blades are all held constant as the tip speed is varied. The average lift coefficient of the blades increases, as the tip speed is decreased, to maintain constant thrust. The thrust value selected for this comparison was fairly low to avoid any noise distortion due to blade stall at the lower tip speeds. The comparison was made at a thrust level of 93-96 pounds, which is the amount of tail rotor thrust required to hover at a gross weight of approximately 1700 pounds.

Number of blades. - Using the "Quiet" helicopter, two of the four tail rotor blades were removed to determine the change in noise level with number-of-blades. The average noise level recorded during five combinations of thrust and tip speed, using the 2-bladed tail rotor, were compared with the same combinations, using the 4-bladed rotor. The average lift coefficient of the 2-bladed rotor was necessarily twice that of the 4-bladed rotor for each test combination. In a new design, it would be necessary to make the total blade area of the 2-bladed tail rotor the same as the 4-bladed, to provide the same maximum thrust at the same tip speed. This could affect the noise comparison.

	<u>Linear</u> <u>dB</u>	<u>"D"</u> <u>Weighted</u>	<u>PNdB</u>
4-Bladed Tail Rotor	72.2	68.4	75.0
2-Bladed Tail Rotor	74.5	69.7	75.5
Difference	+2.3	+1.3	+0.5

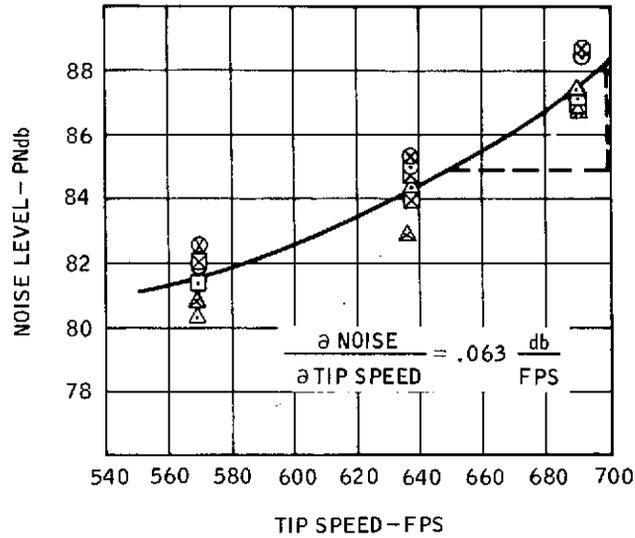


Figure 6. Variation in Tail Rotor Noise With Tip Speed

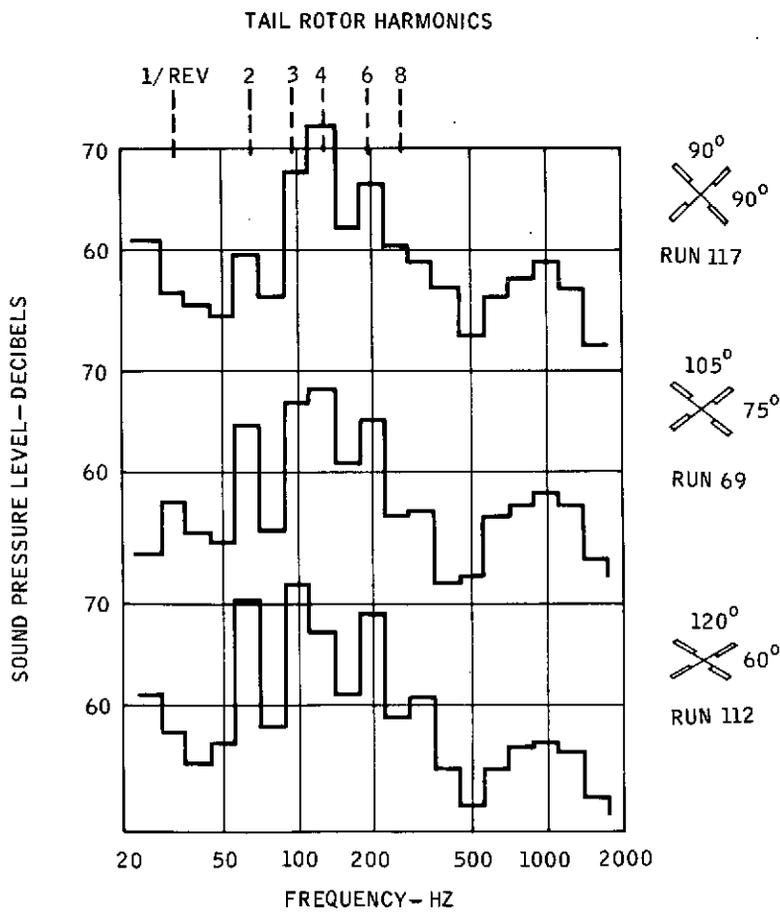


Figure 7. 1/3 Octave Spectra Comparison of 4-Bladed Tail Rotors with Different Blade Azimuth Spacing

Blade azimuth spacing. - With a 4-bladed tail rotor, the azimuth spacing between blades can be at angles other than ninety degrees by displacing one pair of blades in a scissor-like motion relative to the other pair. By arranging the blades at other than ninety degrees, the 4/rev noise component can be reduced. However, as the 4/rev is reduced the 2/rev is increased. This is apparent by comparing the 60°-120° tail rotor with the 90°-90° tail rotor in Figure 7.

There is also an increase in the 3/rev and 6/rev with the 60°-120° rotor. A 6/rev would be anticipated but it is difficult to visualize the origin of a 3/rev. Coincidentally, the engine drive shaft to the dynamometer also rotates at 103 RPS and its universal joints would produce a 206 Hz frequency. This could be the noise source at these frequencies, rather than the tail rotor.

Again using the average noise level for five combinations of thrust and tip speed, the noise level is compared for three blade spacings. The 75°-105° spacing appear to be the quietest and the 60°-120° the noisiest, with the 90°-90° falling in between. However, the differences are small and the low tip speed of the "Quiet" helicopter tail rotor (495 feet per second) places its noise level only slightly above that of the silenced engine, making the accuracy of these measurements about the same as the differences measured between tail rotors.

	<u>Linear db</u>	<u>Different from 90°</u>	<u>PNdB</u>	<u>Different from 90°</u>
60° - 120° Blade Spacing	74.8	+1.0	78.9	+2.4
75° - 105° Blade Spacing	72.2	-1.6	75.0	-1.5
90° - 90° Blade Spacing	73.8	-0-	76.5	-0-

Blade construction and/or airfoil. - Tail rotor blades fabricated of Fiberglass and steel were compared with blades fabricated of aluminum. Also, blades with a symmetrical airfoil (NACA 0014) were compared with blades having a cambered airfoil (NACA 63-415 MOD). The cambered aluminum blades had a chord length of 5.3 inches while the symmetrical Fiberglass and the cambered Fiberglass blades had a chord length of 4.8 inches. Otherwise, the rotors and test conditions were identical.

All three rotors had noise levels within a total spread of one decibel, using PNdB, linear, or "D" weighted values. This would be remarkable agreement even for the same rotor during two different test runs. Thus it can be concluded that all three rotors had essentially the same noise level. These tests were conducted using the standard OH-6A helicopter with everything silenced except the tail rotor. The higher tip speed of the OH-6A tail rotor (692 FPS) put the tail rotor noise level well above any other noise source, making this data quite reliable.

	<u>Linear</u> <u>db</u>	<u>"D"</u> <u>Weighted</u>	<u>PNdB</u>
Cambered Aluminum Blades	83.8	78.9	86.0
Cambered Fiberglass & Steel Blades	82.9	78.1	85.6
Symmetrical Fiberglass & Steel Blades	83.8	78.7	86.0

Thrust. - Figure 8 is a plot of tail rotor thrust versus noise at a constant tip speed and with constant blade area. This again means that the average lift coefficient of the blade sections must increase as the thrust increases. In a new design, the blade area would be increased to retain the same maximum thrust capability which could have some additional effect on the noise level variation with thrust.

Powerplant Noise

Both aircraft had basically the same powerplant. However, the engine in the "Quiet" helicopter did have a number of minor factory modifications to lower its noise level. These modifications are described in detail in Reference 1. Figure 9 shows the noise level variation with power of the standard OH-6A powerplant. Narrow band spectra plots are included in Appendix I for the "Quiet" powerplant (Run 30) and for the standard OH-6A powerplant (Run 201). A narrow-band plot is also included for the OH-6A powerplant with the inlet silenced, insulated cowl doors installed, and exhaust silenced (Run 180).

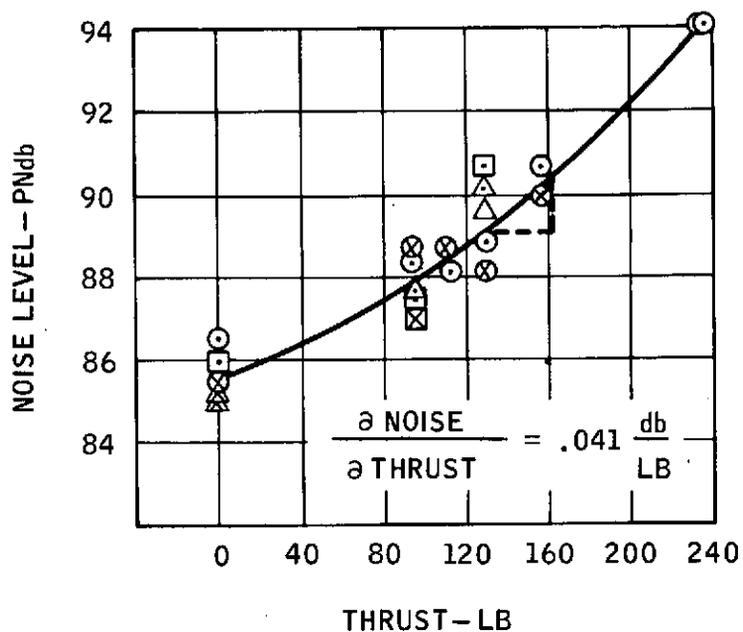


Figure 8. Variation in Tail Rotor Noise Level With Thrust

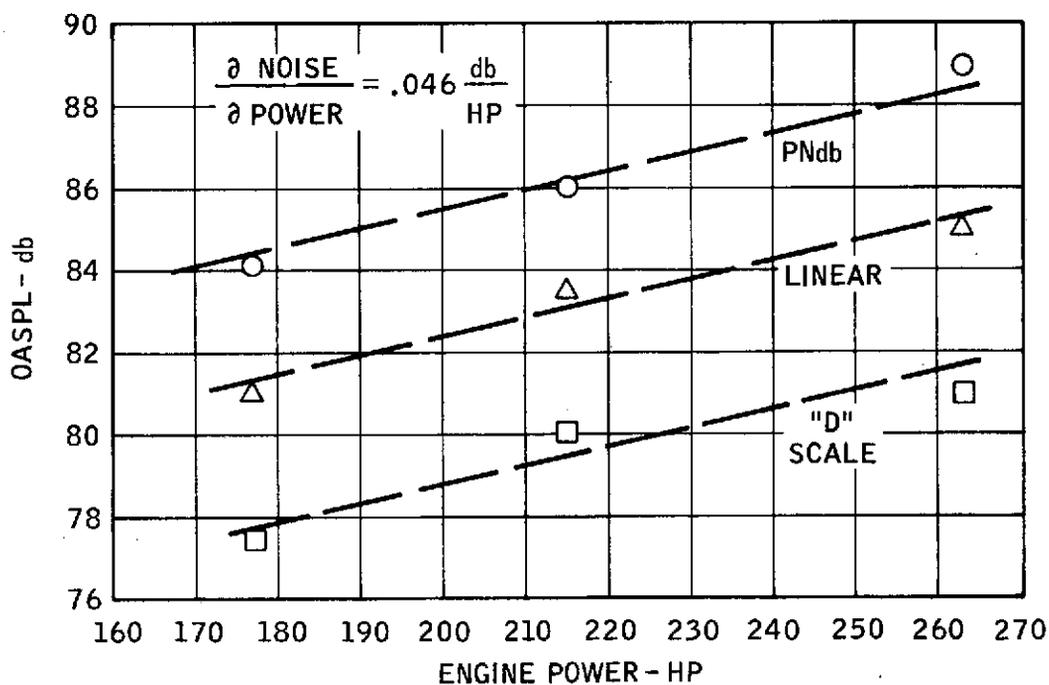


Figure 9. Noise Variation With Power of Standard OH-6A Powerplant

Two prominent frequencies occur on these plots, at 103 Hz and 206 Hz. These are the first and second harmonics of the engine output drive shaft frequency. Any out-of-balance of the drive shaft or misalignment of its universal joints, would tend to vibrate the aircraft at these frequencies. It is apparent from the narrow-band plot of Run 243, "Quiet" main rotor only, that the 103 Hz frequency does not exist when the dynamometer is removed. It is difficult to tell on the other spectra plots because both the tail rotor and the 4-bladed main rotor have harmonics at those frequencies. The existence of these two noise sources should not invalidate the comparative data, however, since the same shaft was used on all runs.

Exhaust muffler and insulated cowl doors. - Figure 10 shows third-octave spectra plots of the "Quiet" helicopter engine with no muffler, with flight-type muffler, and with the heavy ground-type muffler or silencer. The insulated cowl doors were also installed with each muffler. The overall noise levels for the various combinations are given below. They are based on an average of four power settings.

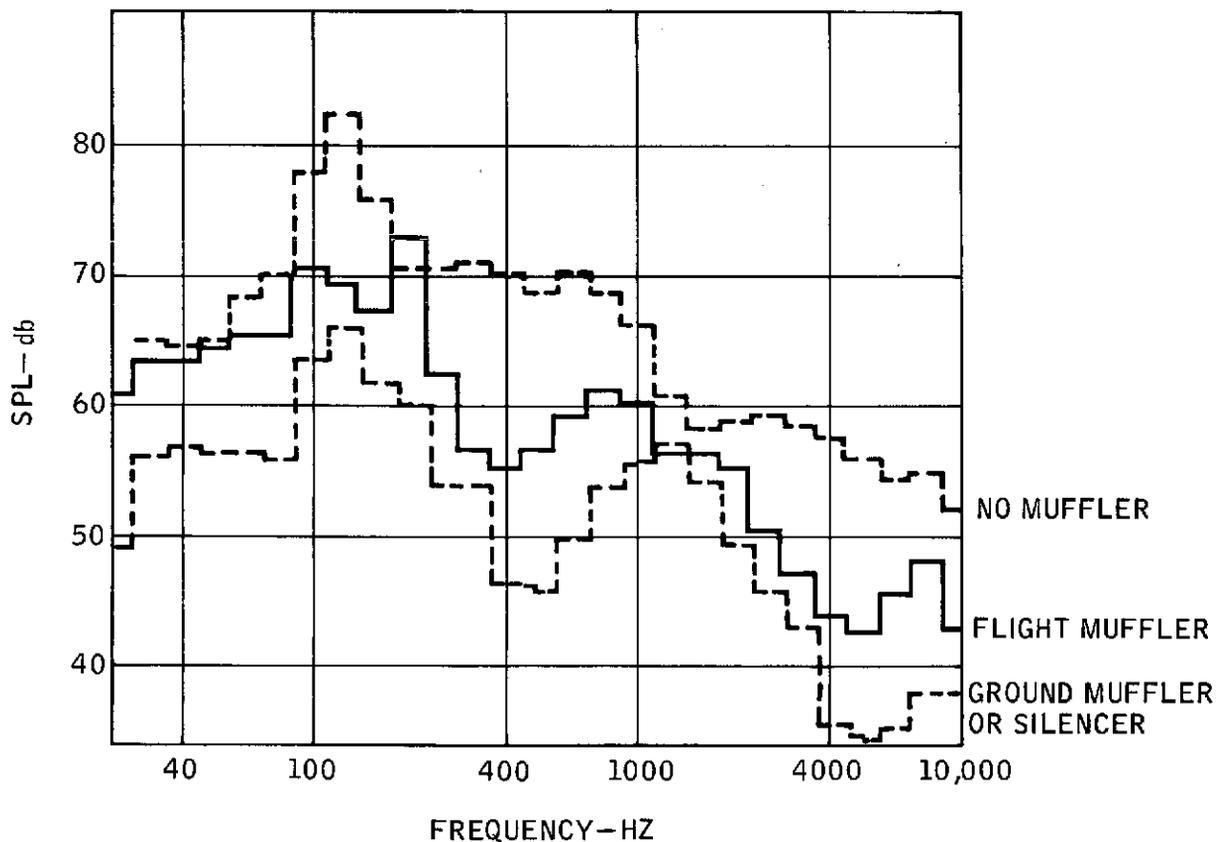


Figure 10. Comparison of "Quiet" Helicopter Engine Noise For Three Exhaust Configurations

"Quiet" Helicopter - Engine Only

<u>Configuration</u>	<u>Linear db</u>	<u>"D" Weighted</u>	<u>PNdB</u>
A. Flight muffler and cowl doors removed	85.7	81.5	88.9
B. Flight muffler installed, cowl doors removed	76.8	73.1	79.9
C. Flight muffler and insulated cowl doors installed ("Quiet" helicopter configuration)	76.7	73.0	80.5
D. Ground exhaust silencer and insulated cowl doors installed (Lowest power-on noise level)	71.5	67.3	73.2
Difference between A and C	-9.0	-8.5	-8.4
Difference between C and D	-5.2	-5.7	-7.3

All three weighting methods yielded similar results. The insulated cowl doors had little effect at this distance and angle from the hovering helicopter. They may be more effective for noise radiated to the side or below the aircraft.

The flight muffler, which weighed 71 pounds, reduced the noise level by 8 or 9 decibels. A more effective muffler could possibly reduce the exhaust noise by an additional 5 to 7 decibels. The flight muffler used on the "Quiet" helicopter was for demonstration only and was not optimized for weight or production. Nevertheless, using its weight and noise reduction, a partial derivative can be determined equal to 8.2 pounds per decibel.

Weight Variables

To evaluate the relative cost of quieting various noise sources on the OH-6A helicopter, weight was selected as the best common denominator. It would not be meaningful to use a single performance parameter such as hover ceiling, forward flight speed, range, etc., to evaluate the cost of varying tail rotor tip speed, for instance. By using weight, the cost can be expressed in terms of lost payload while the performance is kept constant.

Weight works well for main rotor tip speed, tail rotor tip speed, muffler weight, etc. It does not, however, provide a rational basis for evaluating a change such as number-of-blades or rotor-blade tip-shape. The cost of changing items of this type could better be expressed in terms of development and manufacturing dollars.

In the following subparagraphs, partial derivatives, with respect to weight, are derived for each of the pertinent variables. The weight equations used are mostly empirical but have been found to be quite reliable for estimating component weights of new helicopter designs.

Weight vs main rotor tip speed. - Reducing the main rotor tip speed increases the weight of the main rotor, drive system, tail rotor, and tailboom. The weight of these components must be increased due to the higher main rotor torque at the reduced RPM. The main rotor weight is also increased by the greater blade area required. The blade area must be increased for two reasons. The lower dynamic pressure at the reduced tip speed would require an increase in blade area to maintain the same maximum thrust capability without blade stall. In addition, if the aircraft's maximum speed is limited by roughness (retreating blade stall), in order to maintain the same forward flight capability, the blade area must be increased an additional amount to account for the higher advance ratio at a given forward speed.

The power required is assumed to remain constant. Actually, the main rotor power required decreases with tip speed while the tail rotor power must increase. When the additional blade area required at the higher advance ratio is taken into account, these changes in power required are about equal and tend to cancel.

For the OH-6A an empirical expression has been derived for calculating the blade area required to maintain a given airspeed, limited by blade stall.

$$S = \frac{T}{\rho(0.143 V_t^2 - 0.16 V_t V_R)}$$

Where:

- S = total blade area, sq. ft
- ρ = air density, slugs/cu. ft
- V_t = rotor tip speed, FPS
- V_R = forward flight speed at retreating blade stall, FPS
- T = rotor thrust, lb

An empirical expression for estimating main rotor weight is:

$$\text{Rotor Weight} = 0.036 (\text{HP})^{0.335} S^{0.67} V_t^{0.67}$$

Where

S and V_t are as above and HP is expressed in rated horsepower.

By substituting in the preceding expression for blade area, the rotor weight required can be expressed as:

$$\text{Rotor Weight} = 0.036 (\text{HP})^{0.335} \left(\frac{T}{\rho(0.143 V_t - 0.16 V_R)} \right)^{0.67}$$

For the OH-6A, let:

$$\text{HP} = 250$$

$$T = 2400$$

$$V_t = 665$$

$$V_R = 235$$

$$\rho = 0.002111 \text{ (4000 ft)}$$

or,

$$\frac{\partial \text{MR Weight}}{\partial \text{MR Tip Speed}} = -0.294 \text{ lb/FPS}$$

An empirical expression for drive system weight is:

$$\text{Drive System Weight} = \frac{K}{V_t^{0.748}} \quad (= 113.3 \text{ lb for OH-6A})$$

or,

$$\frac{\partial \text{Drive System Weight}}{\partial \text{Tip Speed}} = -0.129 \text{ lb/FPS}$$

Since, at the lower tip speed the main torque is higher, the tail rotor thrust must be greater, which increases the weight of the tail rotor and the tailboom. The tail rotor drive system weight was accounted for in the preceding drive system weight.

$$\text{TR Weight} = K T_{\text{TR}}^{1.305} = \frac{K'}{V_t^{1.305}} \quad (=6.5 \text{ lb for OH-6A})$$

or,

$$\frac{\partial \text{TR Weight}}{\partial \text{MR Tip Speed}} = -0.013 \text{ lb/FPS}$$

$$\text{Tailboom Weight} = \frac{K}{V_t} \quad (=13.3 \text{ lb for OH-6A})$$

or,

$$\frac{\partial \text{Tailboom Weight}}{\partial \text{MR Tip Speed}} = -0.020 \text{ lb/FPS}$$

Then summing all of the partial derivatives for main rotor tip speed:

$$\frac{\partial \text{Weight}}{\partial \text{MR Tip Speed}} = -0.294 - 0.129 - 0.013 - 0.020 = -0.456 \text{ lb/FPS}$$

Weight vs tail rotor tip speed. - Reducing the tail rotor tip speed increases the weight of the tail rotor due to the additional blade area required. It also increases the weight of the output portion of the tail rotor gearbox due to the higher torque required at the reduced RPM. The total rotor thrust and power required are assumed to remain constant.

An empirical expression for tail rotor weight is:

$$\text{TR Weight} = (2.672 \times 10^{-4}) (S^{1.305}) (V_t^{1.438})$$

For constant thrust:

$$S \propto \frac{1}{V_t^2}$$

Thus:

$$\text{TR Weight} = \frac{K}{V_t^{1.172}} \quad (=6.5 \text{ lb for OH-6A})$$

or,

$$\frac{\partial \text{TR Weight}}{\partial \text{TR Tip Speed}} = -0.011 \text{ lb/FPS}$$

The weight of the output portion of the tail rotor gearbox can be expressed empirically as:

$$\text{TR Output Gearbox Weight} = K \frac{(\text{HP})^{0.65}}{V_t^{0.61}}$$

Assuming constant power:

$$\text{TR Output Gearbox Weight} = \frac{K'}{V_t^{0.61}} \quad (=2.2 \text{ lb for OH-6A})$$

or

$$\frac{\partial \text{TR Gearbox Weight}}{\partial \text{TR Tip Speed}} = -0.002 \text{ lb/FPS}$$

Then summing the partial derivatives for tail rotor tip speed:

$$\frac{\partial \text{Weight}}{\partial \text{TR Tip Speed}} = -0.011 - 0.0002 = -0.013 \text{ lb/FPS}$$

Weight of other variables. - The weight of the flight exhaust muffler evaluated during this program was 71 lb. The insulated cowl doors weighed 17.4 lb. more than the standard cowl doors.

There is no particular weight penalty associated with tapered blade tips, since rotor blades usually have some installed tip weight for dynamic reasons which can be removed to keep the total weight at the blade tip constant. There would, however, be some penalty in manufacturing cost.

Increasing the number of blades is one way to increase the total blade area. This effect is accounted for in the preceding subparagraph on weight vs main rotor tip speed. There is no accepted criteria which relates total rotor weight to number of blades. Therefore, no weight penalty is assumed when only the number of blades is varied and the total blade area remains constant.

Neither is there necessarily an accepted weight penalty associated with various types of blade construction or choice of blade airfoils. Nor would varying the blade spacing likely involve any weight penalty. These items would be more apt to affect cost or reliability than weight.

CONCLUSIONS

In general, the techniques used during this test program to isolate and measure the various noise sources of the helicopter worked very well. The test results indicated that, for the OH-6A helicopter, a substantial decrease in external noise could be obtained by reducing the tail-rotor tip-speed, with only a small penalty in lost payload. A similar decrease in noise level could be achieved by adding an engine exhaust muffler. However, the weight penalty incurred by adding an exhaust muffler would be somewhat higher than that incurred by reducing the tail-rotor tip-speed.

Increasing the number of main rotor blades and decreasing the main rotor tip-speed produced only a small reduction in noise while incurring a significant weight penalty. This was probably due to the comparatively low main rotor tip-speed of the standard OH-6A helicopter (666 fps) and could still be an effective noise reduction technique for a helicopter with a higher tip-speed.

Table I lists a summary of the noise and weight variables investigated and the partial derivatives or other conclusions which were determined. It should be noted that these conclusions pertain only to the noise level heard by an observer 200 feet from and 30 degrees left of due aft, of a helicopter hovering at a 6-foot skid height. When flying overhead, the helicopter components could produce an entirely different noise spectrum to the ground observer. Also, certain noise abatement techniques, such as insulated cowl doors or engine inlet silencers, may be of much greater importance to the observer located to the side of, or within, the hovering helicopter.

TABLE I

SUMMARY OF NOISE VARIABLES

Component Noise Source	Partial Derivative (or explanation)
<u>Main Rotor</u>	
Noise vs MR Tip Speed (4-bladed)	$\frac{\partial \text{MR Noise}}{\partial \text{MR Tip Speed}} = 0.064 \frac{\text{db}}{\text{FPS}}$
Weight vs MR Tip Speed (4-bladed)	$\frac{\partial \text{Weight}}{\partial \text{MR Tip Speed}} = -0.456 \frac{\text{lb}}{\text{FPS}}$
	$\left. \begin{array}{l} \frac{\partial \text{MR Noise}}{\partial \text{MR Tip Speed}} = 0.064 \frac{\text{db}}{\text{FPS}} \\ \frac{\partial \text{Weight}}{\partial \text{MR Tip Speed}} = -0.456 \frac{\text{lb}}{\text{FPS}} \end{array} \right\} \frac{\partial \text{Weight}}{\partial \text{Noise}} = -7.13 \frac{\text{lb}}{\text{db}}$
MR Noise vs MR Thrust (4-bladed)	$\frac{\partial \text{MR Noise}}{\partial \text{MR Thrust}} = 0.0028 \frac{\text{db}}{\text{lb}}$
Noise vs MR Tip Speed (5-bladed)	$\frac{\partial \text{MR Noise}}{\partial \text{MR Tip Speed}} = 0.080 \frac{\text{db}}{\text{FPS}}$
MR Noise vs MR Thrust (5-bladed)	$\frac{\partial \text{MR Noise}}{\partial \text{MR Thrust}} = 0.0018 \frac{\text{db}}{\text{lb}}$
Noise vs Number of MR Blades	Not Conclusive
Noise vs Tapered MR Blade Tips	2 or 3 db reduction with tapered tips
<u>Tail Rotor</u>	
Noise vs TR Tip Speed (2-bladed)	$\frac{\partial \text{Noise}}{\partial \text{TR Tip Speed}} = 0.063 \frac{\text{db}}{\text{FPS}}$
Weight vs TR Tip Speed (2-bladed)	$\frac{\partial \text{Weight}}{\partial \text{TR Tip Speed}} = -0.013 \frac{\text{lb}}{\text{FPS}}$
	$\left. \begin{array}{l} \frac{\partial \text{Noise}}{\partial \text{TR Tip Speed}} = 0.063 \frac{\text{db}}{\text{FPS}} \\ \frac{\partial \text{Weight}}{\partial \text{TR Tip Speed}} = -0.013 \frac{\text{lb}}{\text{FPS}} \end{array} \right\} \frac{\partial \text{Weight}}{\partial \text{Noise}} = -0.206 \frac{\text{lb}}{\text{db}}$
Noise vs TR Thrust (2-bladed)	$\frac{\partial \text{Noise}}{\partial \text{TR Thrust}} = 0.041 \frac{\text{db}}{\text{lb}}$
Noise vs Number of TR Blades	1 or 2 db reduction with 4 blades instead of 2 blades
Noise vs TR Blade Azimuth Spacing	Compared to 90°-90°: 60°-120°, +1 or +2 db 75°-105°, -1 or -2 db
Noise of Aluminum vs Fiberglass and Steel TR Blades	Same
Noise of Symmetrical vs Cambered TR Blades	Same

TABLE I

SUMMARY OF NOISE VARIABLES (Continued)

Component Noise Source	Partial Derivative (or explanation)
<u>Powerplant</u>	
Noise vs Power	$\frac{\partial \text{Noise}}{\partial \text{Power}} = 0.046 \frac{\text{db}}{\text{HP}}$
Noise vs Muffler Weight	$\frac{\partial \text{Weight}}{\partial \text{Noise}} = 8.2 \frac{\text{lb}}{\text{db}}$
Noise Change With Insulated Cowl Doors	Nil
Noise Change With Inlet Silencer	Nil

REFERENCES

1. Barlow, W.H., McCluskey, W.C. and Ferris, H.W.: OH-6A Phase II Quiet Helicopter Program, Prepared by Hughes Tool Company, Aircraft Division, for Eustis Directorate, Fort Eustis, Va., Technical Report 72-29, September 1972
2. Boeing-Vertol Division: An Investigation of Noise Generation on a Hovering Rotor, Report No. D210-10229-1, AD 721312, January 1971
3. Peterson, Arnold P.G., and Gross, Jr., Ervin E: Handbook of Noise Measurement (Fifth Edition), General Radio Company, West Concord, Massachusetts

APPENDIX I

TEST DATA & SPECTRA PLOTS

Description of Test Aircraft

The following specifications pertain to the standard OH-6A helicopter:

	<u>Main Rotor</u>	<u>Tail Rotor</u>
Number of Blades	4	2
Rotor Diameter	26.33 ft	4.25 ft
Blade Chord	6.75 in.	5.3 in.
RPM at 103% N ₂ Engine Speed	483 RPM	3110 RPM
Tip Speed at 103% N ₂	666 FPS	692 FPS
Normal Gross Weight	2400 lb	-

The following specifications pertain to the "Quiet" helicopter. The various noise abatement modifications incorporated in this aircraft are described in more detail in Reference 1.

	<u>Main Rotor</u>	<u>Tail Rotor</u>
Number of Blades	5	4
Rotor Diameter	26.33 ft	4.84 ft
Blade Chord	6.75 in.	4.8 in.
RPM at 103% N ₂ Engine Speed	483 RPM	1956 RPM
Tip Speed at 103% N ₂	666 FPS	495 FPS
Normal Gross Weight	2400 lb	

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SPL vs Frequency Spectra Plots

Thirty-nine one-third octave and twelve narrow-band SPL vs frequency spectra plots are included. All SPL data is referenced to 0.0002 dynes per square centimeter. The test conditions are tabulated in Tables II and III and can be related to the spectra plots by run number. The narrow-band plots were made using constant 1.5, 3, 6, and 30 Hz bandwidths. The frequency ranges for each are indicated on the spectra plots.

The human ear does not have the same sensitivity to a given sound pressure level (SPL) at low frequencies that it has at high frequencies. To show what the human ear would actually hear, "equal noisiness" contours have been superimposed on some of the one-third octave plots. Both the calculated PNdB values and the "D" weighted readings are based on contours of this type.

TABLE II

TEST DATA - STANDARD OH-6A HELICOPTER

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
<u>Free Hover - 6 ft. Skid Height</u>																	
Baseline	126	666	692	-	-	-	-	103	263	2800	158	27.5	88.7	76.0	84.4	92.2	126
OH-6A in free hover	127	615	638	-	-	-	-	95	250	2800	163	27.6	87.2	77.5	85.2	92.3	127
	128(1)(2)	666	692	-	-	-	-	103	215	2400	130	20.9	87.0	76.5	83.5	92.3	128
	129	615	638	-	-	-	-	95	204	2400	135	21.5	86.0	76.5	84.4	91.6	129
	130	550	571	-	-	-	-	85	199	2400	140	24.2	85.2	75.5	83.0	88.9	130
	131	666	692	-	-	-	-	103	177	2000	112	15.8	87.0	78.0	83.0	90.9	131
	132	615	638	-	-	-	-	95	165	2000	114	15.4	85.0	74.0	81.0	89.6	132
	133	550	571	-	-	-	-	85	155	2000	121	15.8	84.0	73.0	79.5	85.7	133
	134	485	504	-	-	-	-	75	154	2000	128	19.6	82.5	69.0	78.0	84.1	134
	135	666	692	-	-	-	-	103	151	1700	93	13.1	87.0	76.0	83.0	89.6	135
	136	615	638	-	-	-	-	95	142	1700	96	11.8	84.0	77.0	81.5	88.6	136
	137	550	571	-	-	-	-	85	131	1700	98	11.1	82.0	72.0	79.0	85.6	137
	138	453	470	-	-	-	-	70	124	1700	114	13.2	81.0	69.0	78.0	83.5	138
<u>Simulated Hover - 6 ft. Skid Height</u>																	
Baseline OH-6A	211	666	692	-	-	-	-	103	263	2800	*	27.5	91.0	85.0	89.0	94.4	211
Complete aircraft	212(1)(2)	666	692	-	-	-	-	103	215	2400	*	20.9	88.5	78.0	83.0	90.5	212
	213	666	692	-	-	-	-	103	177	2000	*	15.8	88.0	78.0	85.0	92.1	213
	214	666	692	-	-	-	-	103	151	1700	96	13.1	87.0	77.0	82.5	90.2	214
	215	615	638	-	-	-	-	95	204	2400	*	21.5	91.0	77.0	82.0	91.4	215
	216	615	638	-	-	-	-	95	142	1700	*	11.8	85.0	75.0	81.0	88.2	216
	217	550	571	-	-	-	-	85	199	2400	*	24.2	85.0	74.0	81.0	88.7	217
	218	550	571	-	-	-	-	85	131	1700	*	11.1	83.0	75.0	80.0	86.9	218
	219	453	470	-	-	-	-	70	124	1700	*	13.2	81.0	71.0	77.0	83.0	219
<u>Main Rotor Only</u>																	
	148	666	-	On	On	On	-	103	250	2800	-	-	86.8	72.0	75.5	80.8	148
	149(1)(2)	666	-	On	On	On	-	103	206	2400	-	-	86.0	68.0	74.0	79.5	149
	150	666	-	On	On	On	-	103	168	2000	-	-	84.5	70.0	74.5	78.8	150
	151(1)	666	-	On	On	On	-	103	151	1700	-	-	84.0	66.0	72.0	77.6	151
	152	615	-	On	On	On	-	95	134	1700	-	-	80.5	68.0	71.5	78.4	152
	153	615	-	On	On	On	-	95	155	2000	-	-	82.0	68.0	72.0	78.0	153
	154	615	-	On	On	On	-	95	194	2400	-	-	83.0	67.0	72.0	77.8	154
	155	615	-	On	On	On	-	95	236	2800	-	-	83.5	68.0	74.0	78.2	155
	156	550	-	On	On	On	-	85	190	2400	-	-	80.5	68.5	73.0	78.4	156
	157	550	-	On	On	On	-	85	146	2000	-	-	79.0	67.0	71.0	77.9	157
	158	550	-	On	On	On	-	85	121	1700	-	-	77.0	64.0	67.0	72.7	158
	159(1)	518	-	On	On	On	-	80	179	2400	-	-	78.0	67.0	72.0	76.8	159
	160	453	-	On	On	On	-	70	135	2000	-	-	70.5	61.5	66.0	72.2	160
	161(1)	453	-	On	On	On	-	70	115	1700	-	-	69.5	62.0	66.0	71.3	161

2

TABLE II

TEST DATA - STANDARD OH-6A HELICOPTER (Continued)

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
Baseline OH-6A	205	-	-	-	-	-	On	103	153?	-	158	27.0	88.5	79.0	84.5	92.5	205
Less main rotor	206(1)	-	-	-	-	-	On	103	153?	-	130	20.9	88.0	83.0	86.0	93.5	206
(? These runs were not made at the correct baseline engine power)	207	-	-	-	-	-	On	103	153?	-	*	15.8	86.0	76.0	82.0	90.3	207
	208	-	-	-	-	-	On	103	153	-	*	13.1	84.0	74.0	81.0	88.2	208
	209	-	-	-	-	-	On	95	141?	-	*	21.5	86.0	75.0	82.0	89.9	209
	210	-	-	-	-	-	On	85	127?	-	*	24.2	87.5	77.0	82.5	90.1	210
Tail Rotor Only (w/production aluminum blades) (5.3 in. chord)	162(1)	-	692	On	On	On	On	103	114	-	0	5.0	83.5	71.0	78.5	86.4	162
	163	-	692	On	On	On	On	103	114	-	93	12.9	86.0	74.0	81.5	88.3	163
	164	-	692	On	On	On	On	103	114	-	112	15.4	86.0	73.0	81.5	88.0	164
	165(1)(2)	-	692	On	On	On	On	103	115	-	130	18.9	86.0	74.0	81.0	88.8	165
	166	-	692	On	On	On	On	103	152	-	158	24.9	87.5	75.0	83.0	90.6	166
	167(1)	-	692	On	On	On	On	103	152	-	233	49.8	92.0	78.5	87.0	94.0	167
	168	-	638	On	On	On	On	95	140	-	5	*	82.0	72.0	77.0	86.3	168
	169	-	638	On	On	On	On	95	140	-	96	14.7	82.5	70.0	78.0	84.8	169
	170	-	638	On	On	On	On	95	155	-	191	>45	93.0	78.0	87.0	94.1	170
	171	-	638	On	On	On	On	95	164	-	233	>45	94.0	79.0	88.5	95.6	171
	172	-	571	On	On	On	On	85	126	-	0	5.8	77.0	67.0	73.0	78.2	172
	173	-	571	On	On	On	On	85	126	-	96	13.1	81.0	69.0	75.5	81.9	173
	174	-	571	On	On	On	On	85	129	-	191	29.6	85.0	71.0	78.0	85.3	174
	175	-	470	On	On	On	On	70	102	-	0	4.1	74.0	67.0	71.0	78.1	175
	176	-	470	On	On	On	On	70	104	-	48	6.1	80.5	68.0	72.0	78.5	176
	177(1)	-	470	On	On	On	On	70	104	-	96	13.2	78.5	69.0	73.0	80.3	177
	178	-	470	On	On	On	On	70	104	-	143	21.0	81.0	69.0	74.0	79.7	178
Baseline OH-6A	220	666	-	-	-	-	-	103	258	2800	-	-	90.0	78.0	85.0	90.5	220
Less tail rotor	221(1)	666	-	-	-	-	-	103	217	2400	-	-	87.5	75.0	81.0	87.8	221
	222	666	-	-	-	-	-	103	174	2000	-	-	86.0	72.0	79.0	86.0	222
	223	666	-	-	-	-	-	103	149	1700	-	-	86.0	72.0	79.0	85.4	223
	224	615	-	-	-	-	-	95	200	2400	-	-	85.0	71.0	79.0	84.9	224
	225	550	-	-	-	-	-	85	187	2400	-	-	82.0	71.0	78.0	84.2	225
Tail Rotor Only w/cambered Fiber-glas tail rotor blades installed. (4.8 in. chord)	184	-	692	On	On	On	On	103	153	-	0	*	82.0	71.0	78.0	85.3	184
	185	-	692	On	On	On	On	103	153	-	96	12.5	85.0	74.0	80.0	87.6	185
	186(1)	-	692	On	On	On	On	103	153	-	130	17.0	87.0	74.0	82.5	90.0	186
	187	-	638	On	On	On	On	95	141	-	96	13.8	80.8	70.0	76.0	84.4	187
	188	-	571	On	On	On	On	85	126	-	96	*	79.5	67.0	74.0	80.6	188

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TABLE II

TEST DATA - STANDARD OH-6A HELICOPTER (Continued)

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			
														"A" Weighted db	"D" Weighted db	PNdB	Run No.
Tail Rotor Only	189	-	692	On	On	On	On	103	156	-	0	*	84.0	72.0	78.5	85.9	189
w/symmetrical	190	-	692	On	On	On	On	103	155	-	96	12.2	85.0	73.0	80.0	87.5	190
Fiberglass tail rotor blades installed	191(1)	-	692	On	On	On	On	103	153	-	130	16.4	87.0	75.5	83.0	90.4	191
(4.8 in. chord)	192	-	638	On	On	On	On	95	141	-	96	10.5	83.0	70.0	77.0	84.7	192
	193	-	571	On	On	On	On	85	126	-	96	*	80.0	69.0	75.0	81.4	193
Engine Only	200	-	-	-	-	-	On	103	263	-	-	-	85.0	75.0	81.0	88.9	200
	201(1)(2)	-	-	-	-	-	On	103	215	-	-	-	83.5	73.0	80.0	86.0	201
	202	-	-	-	-	-	On	103	177	-	-	-	81.0	72.0	77.5	84.1	202
	203	-	-	-	-	-	On	95	204	-	-	-	83.5	74.5	80.0	86.4	203
	204	-	-	-	-	-	On	85	199	-	-	-	83.0	77.0	80.5	87.7	204
Baseline OH-6A less engine	139	666	692	On	On	On	-	103	263	2800	158	29.0	89.0	78.5	84.0	92.3	139
	140(1)	666	692	On	On	On	-	103	215	2400	130	22.7	88.0	78.0	83.0	90.7	140
	141	666	692	On	On	On	-	103	177	2000	0	6.9	86.5	75.0	80.5	88.1	141
	142	666	692	On	On	On	-	103	177	2000	96	15.8	87.0	79.0	82.5	89.8	142
	143	666	692	On	On	On	-	103	177	2000	191	>30	90.0	82.0	87.0	94.0	143
	144	666	692	On	On	On	-	103	177	2000	233	>30	91.0	82.0	87.0	95.4	144
	145	666	692	On	On	On	-	103	151	1700	93	14.6	86.0	77.5	83.0	90.6	145
	146	615	638	On	On	On	-	95	204	2400	135	21.2	85.5	77.0	81.5	89.5	146
	147	550	571	On	On	On	-	85	199	2400	140	21.0	84.0	73.0	79.5	85.8	147
Engine Only w/exhaust & inlet muffled (This is the lowest baseline noise level)	179	-	-	On	On	On	On	103	263	-	-	-	74.0	64.5	70.0	76.6	179
	180(1)(2)	-	-	On	On	On	On	103	215	-	-	-	73.0	65.0	70.0	77.3	180
	181	-	-	On	On	On	On	103	177	-	-	-	73.0	64.0	69.5	75.0	181
	182	-	-	On	On	On	On	95	204	-	-	-	74.0	65.0	70.0	76.2	182
	183	-	-	On	On	On	On	85	199	-	-	-	71.0	65.0	69.0	73.8	183
Engine Only Silenced except insulated cowl doors removed	194	-	-	On	On	-	On	103	263	-	-	-	73.5	67.0	72.0	78.3	194
	195	-	-	On	On	-	On	103	215	-	-	-	72.0	65.0	69.0	74.3	195
	196	-	-	On	On	-	On	103	177	-	-	-	71.0	65.0	69.0	75.2	196
	197	-	-	On	On	-	On	103	151	-	-	-	71.0	64.5	69.0	75.2	197
	198	-	-	On	On	-	On	95	204	-	-	-	73.5	66.0	71.0	76.7	198
	199	-	-	On	On	-	On	85	199	-	-	-	71.0	64.0	68.5	74.1	199
Engine Only Silenced except inlet not muffled	226	-	-	-	On	On	On	103	263	-	-	-	71.0	63.0	68.0	73.5	226
	227(1)	-	-	-	On	On	On	103	215	-	-	-	71.0	63.5	68.0	73.9	227
	228	-	-	-	On	On	On	95	204	-	-	-	70.5	61.5	67.0	72.3	228
	229	-	-	-	On	On	On	85	199	-	-	-	68.0	62.0	66.0	72.2	229
	230	-	-	-	On	On	On	103	177	-	-	-	73.0	63.0	69.0	76.1	230
	231	-	-	-	On	On	On	103	151	-	-	-	74.0	65.0	70.0	76.4	231

TABLE II

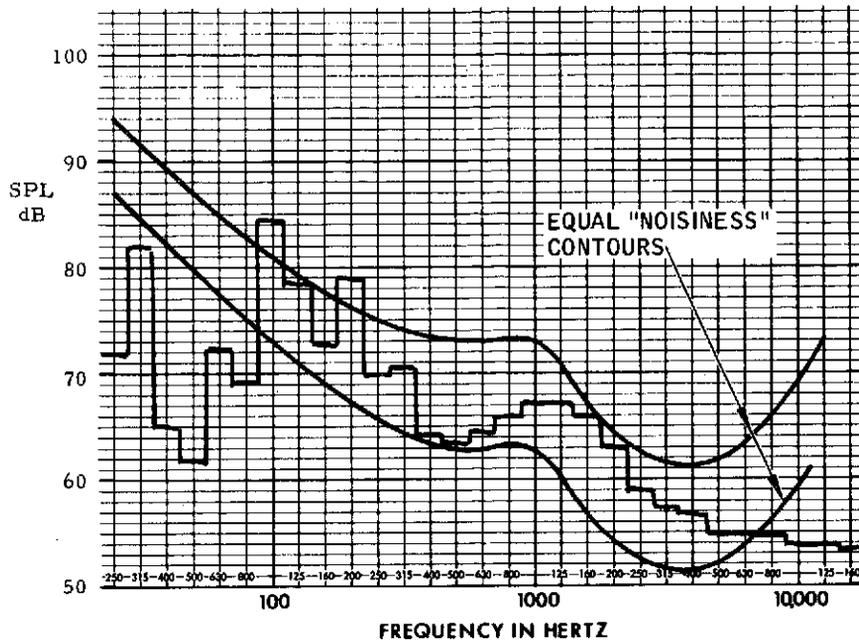
TEST DATA - STANDARD OH-6A HELICOPTER (Continued)

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
Engine Only	232	-	-	On	-	On	On	103	263	-	-	-	84.0	76.0	80.0	86.5	232
Silenced except exhaust not muffled	233(1)	-	-	On	-	On	On	103	215	-	-	-	80.0	74.0	78.0	84.2	233
	234	-	-	On	-	On	On	95	204	-	-	-	80.5	73.0	77.0	83.6	234
	235	-	-	On	-	On	On	85	199	-	-	-	80.5	73.0	77.5	83.7	235
	236	-	-	On	-	On	On	103	177	-	-	-	80.0	73.0	76.0	83.2	236
	237	-	-	On	-	On	On	103	151	-	-	-	79.0	72.0	76.0	82.9	237
Dyno Cooling System Only	238(1)(2)	-	-	-	-	-	-	-	-	-	-	-	64.5	52.0	60.0	65.4	238
Typical Ambient	- (2)	-	-	-	-	-	-	-	-	-	-	-	65.0	48.0	55.0	59.4	-

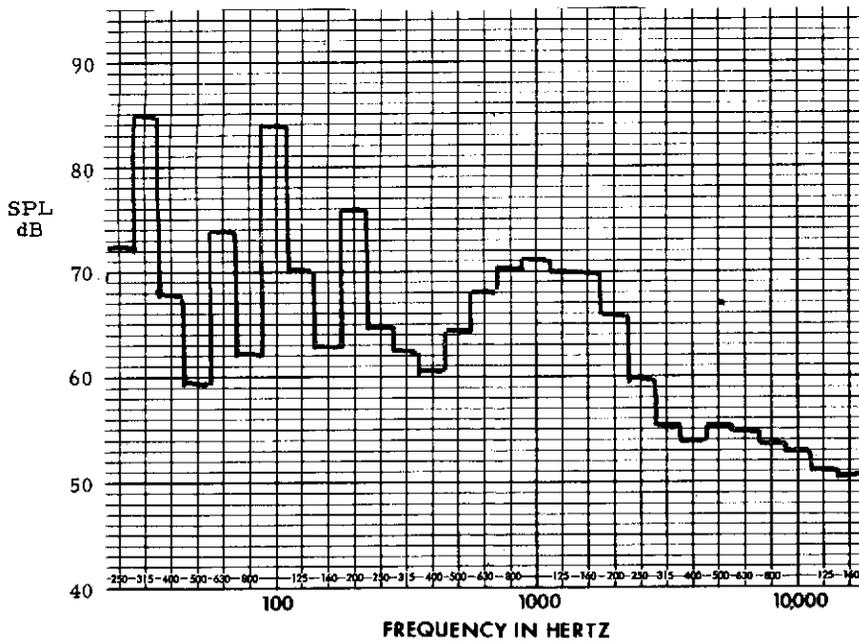
* Data not available or considered unreliable.

(1) One-third octave spectra plot for this run is included.

(2) Narrow band spectra plot for this run is included.



Baseline OH-6A Helicopter - In Free Hover - 2400 lb



Baseline OH-6A Helicopter - Less Engine - 2400 lb

Run No. 128

OH-6A HELICOPTER

Free Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

Main Rotor: 666 fps
Tail Rotor: 692 fps
Cowl Doors: Standard
Exhaust: Open
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 87.0
"A": 76.5
"D": 83.5
PNdB: 92.3

(Recorded at: 90 dB)

Run No. 140

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

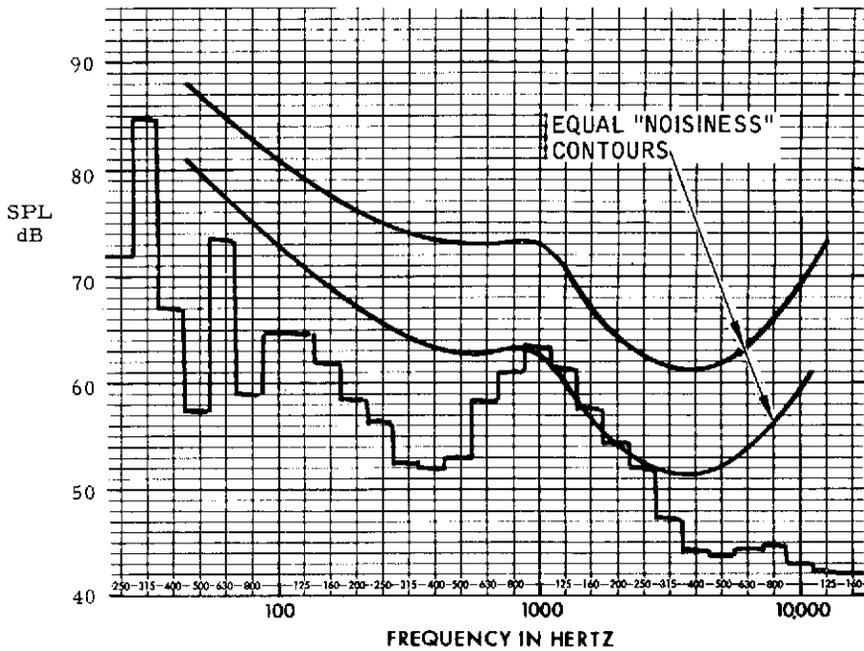
Main Rotor: 666 fps
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 88.0
"A": 78.0
"D": 83.0
PNdB: 90.7

(Recorded at: 90 dB)

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OH-6A Helicopter - Main Rotor Only, 2400 lb, 103% N₂

Run No. 149
OH-6A HELICOPTER

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

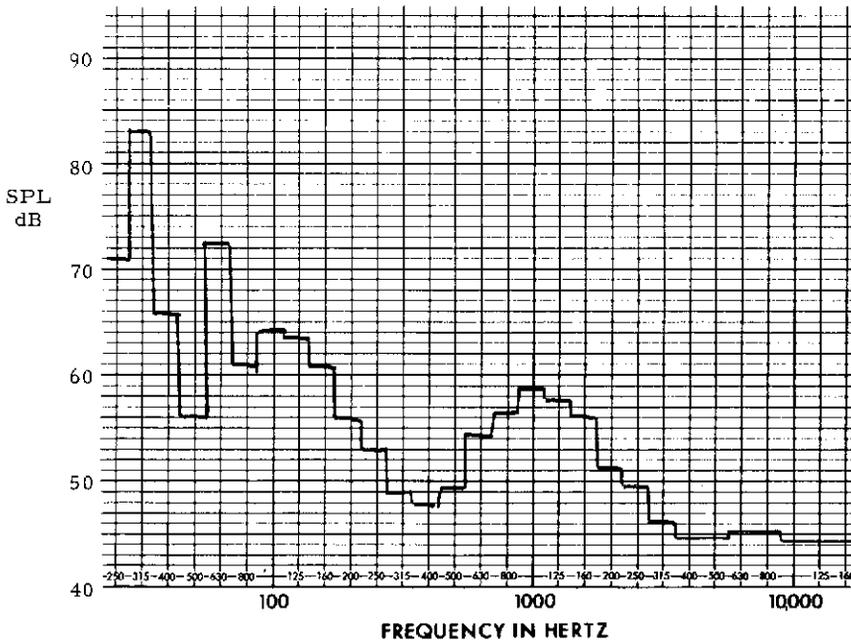
CONFIGURATION

Main Rotor: 666 fps
 Tail Rotor: Off
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 86.0
 "A": 68.0
 "D": 74.0
 PNdB: 79.5

(Recorded at: 80 dB)



OH-6A Helicopter - Main Rotor Only, 1700 lb, 103% N₂

Run No. 151
OH-6A HELICOPTER

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

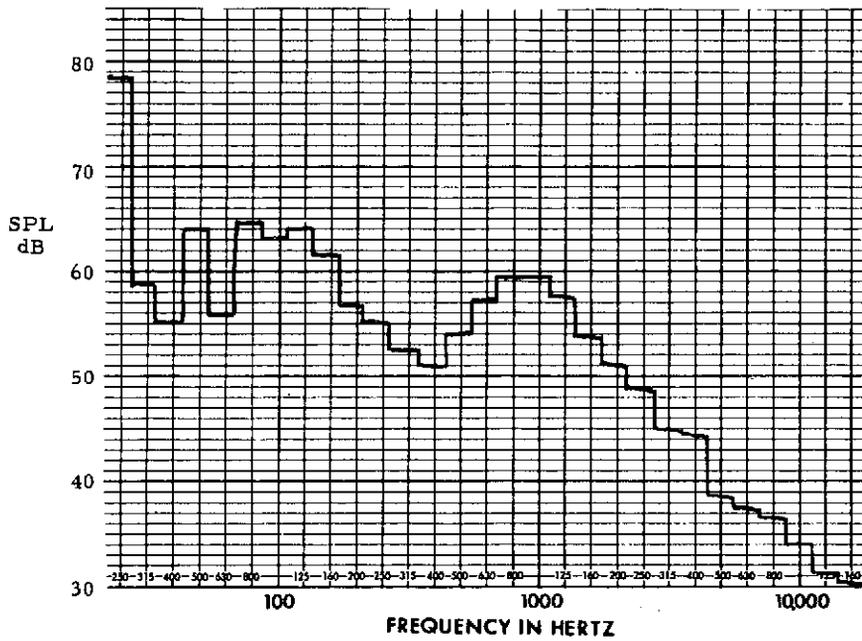
CONFIGURATION

Main Rotor: 666 fps
 Tail Rotor: Off
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 84.0
 "A": 66.0
 "D": 72.0
 PNdB: 77.6

(Recorded at: 80 dB)



OH-6A Helicopter - Main Rotor Only, 2400 lb, 80% N₂

Run No. 159

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

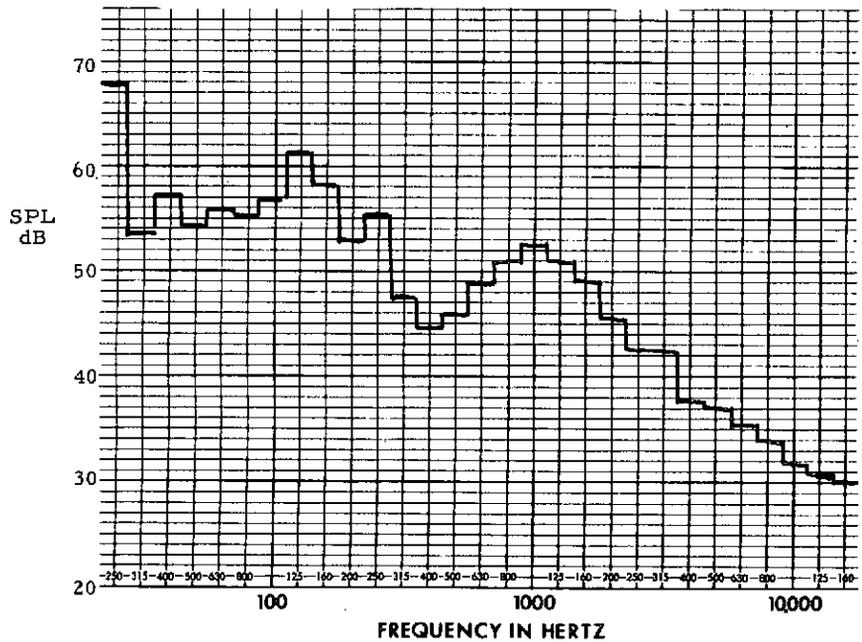
CONFIGURATION

Main Rotor: 518 fps
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 78.0
"A": 67.0
"D": 72.0
PNdB: 76.8

(Recorded at: 70 dB)



OH-6A Helicopter - Main Rotor Only, 1700 lb, 70% N₂

Run No. 161

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

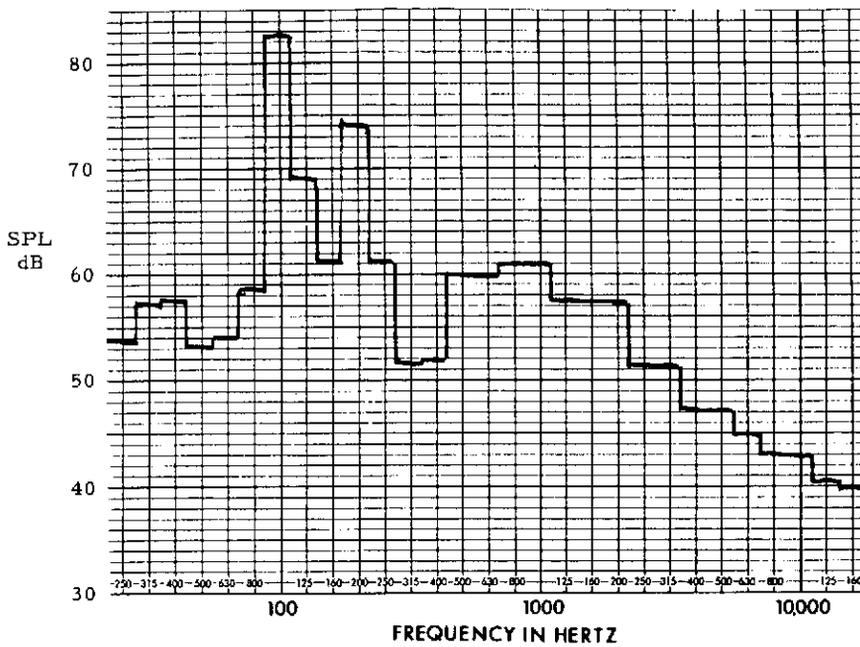
CONFIGURATION

Main Rotor: 453 fps
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 69.5
"A": 62.0
"D": 66.0
PNdB: 71.3

(Recorded at: 70 dB)



OH-6A Helicopter - Tail Rotor Only - Zero Thrust

Run No. 162

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

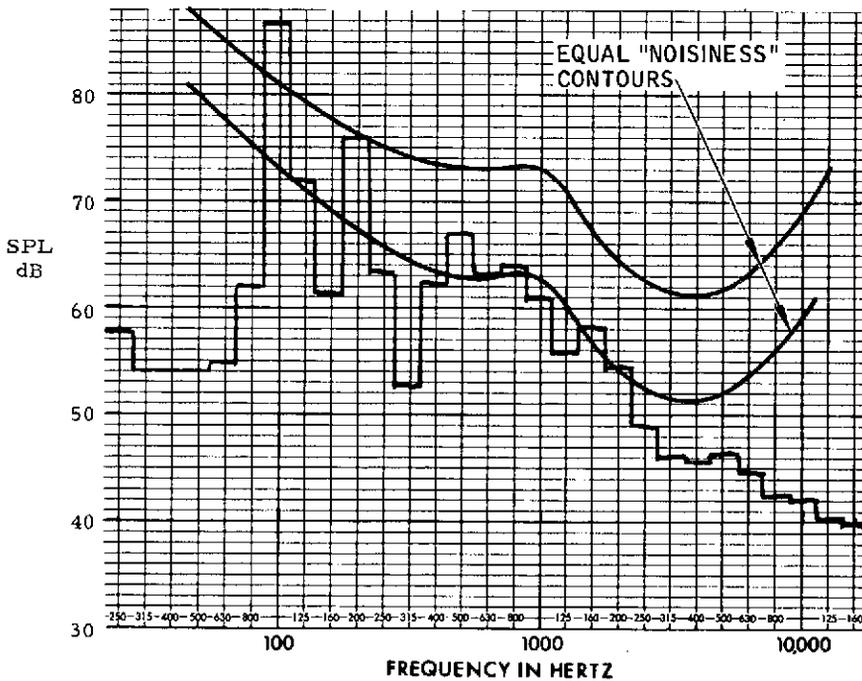
CONFIGURATION

Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 83.5
"A": 71.0
"D": 78.5
PNdB: 86.4

(Recorded at: 80 dB)



OH-6A Helicopter - Tail Rotor Only - 130 lb (Hover) Thrust

Run No. 165

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

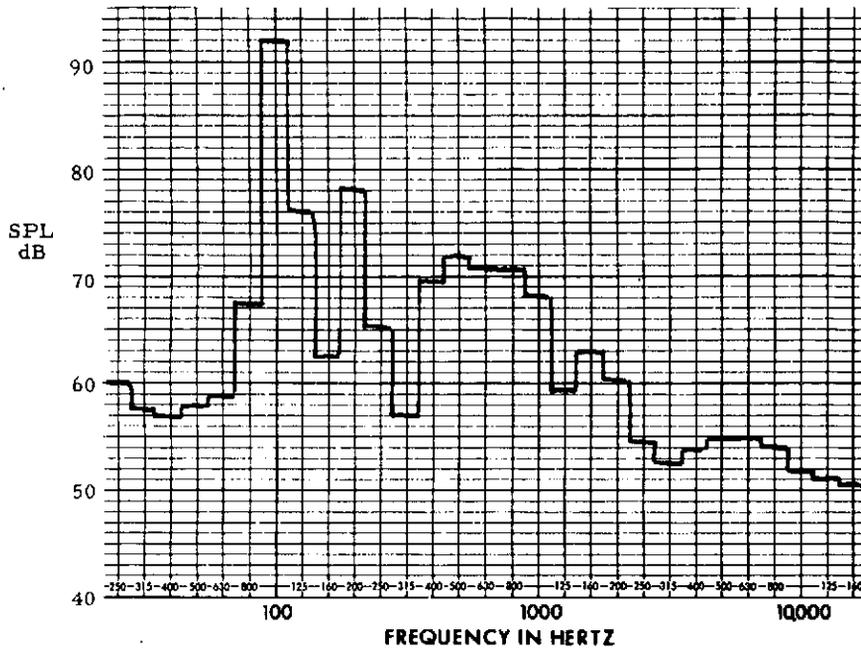
CONFIGURATION

Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 86.0
"A": 74.0
"D": 81.0
PNdB: 88.8

(Recorded at: 80 dB)



OH-6A Helicopter - Tail Rotor Only - 233 lb Thrust

Run No. 167

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

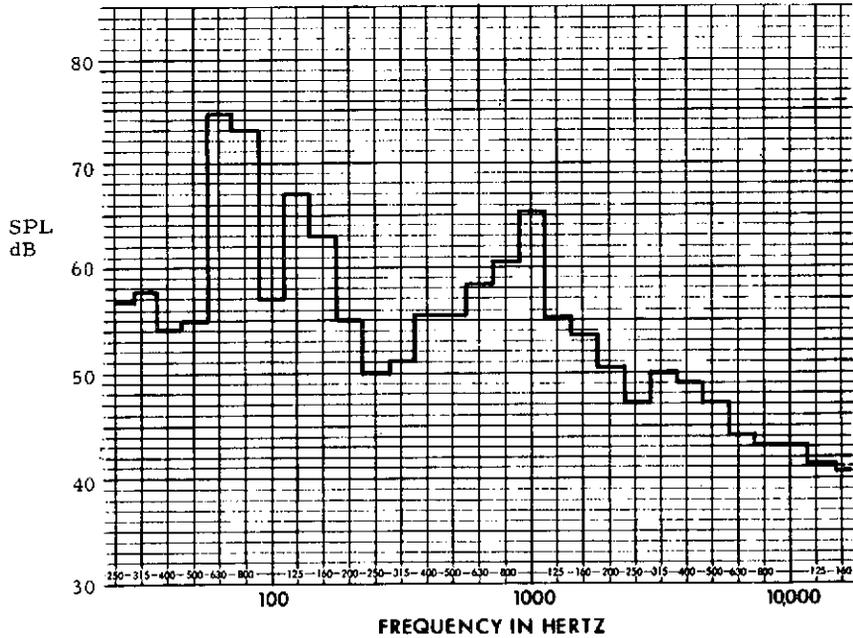
CONFIGURATION

Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 92.0
"A": 78.5
"D": 87.0
PNdB: 94.0

(Recorded at: 90 dB)



OH-6A Helicopter - Tail Rotor Only - 96 lb Thrust - 70% N₂

Run No. 177

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

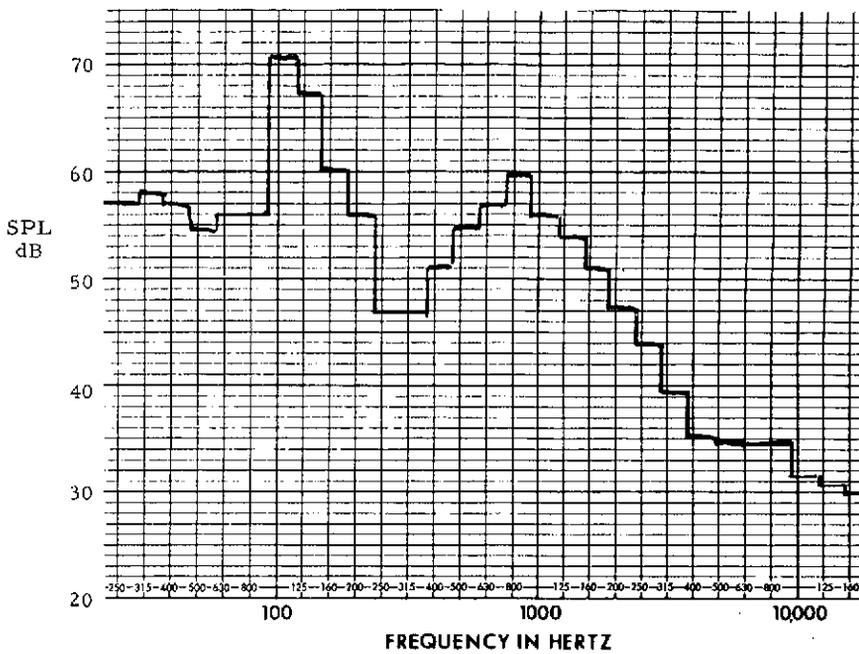
CONFIGURATION

Main Rotor: Off
Tail Rotor: 470 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 78.5
"A": 69.0
"D": 73.0
PNdB: 80.3

(Recorded at: 80 dB)



Run No. 180

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

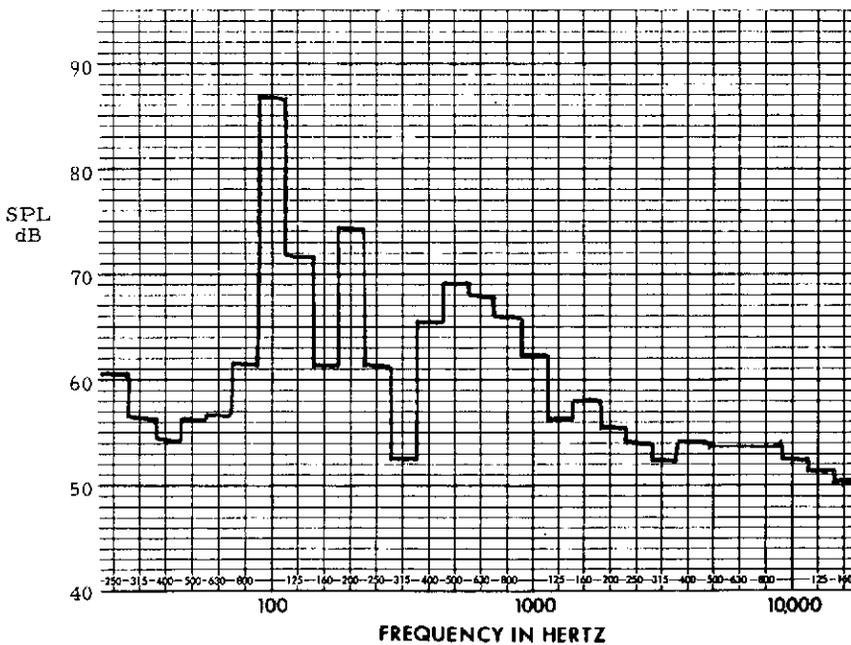
CONFIGURATION

Main Rotor: Off
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 73.0
"A": 65.0
"D": 70.0
PNdB: 77.3

(Recorded at: 70 dB)



Run No. 186

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

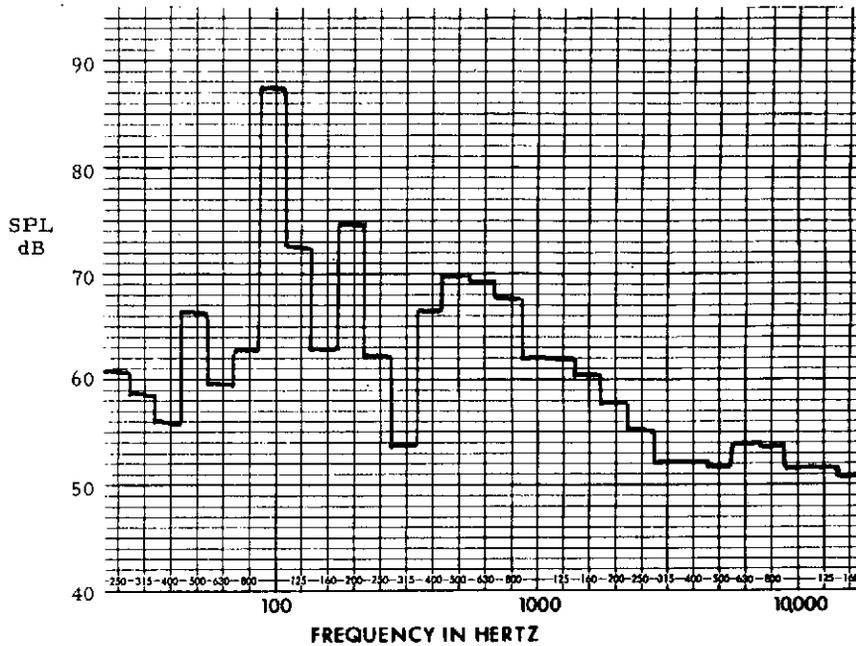
CONFIGURATION

Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 87.0
"A": 74.0
"D": 82.5
PNdB: 90.0

(Recorded at: 90 dB)

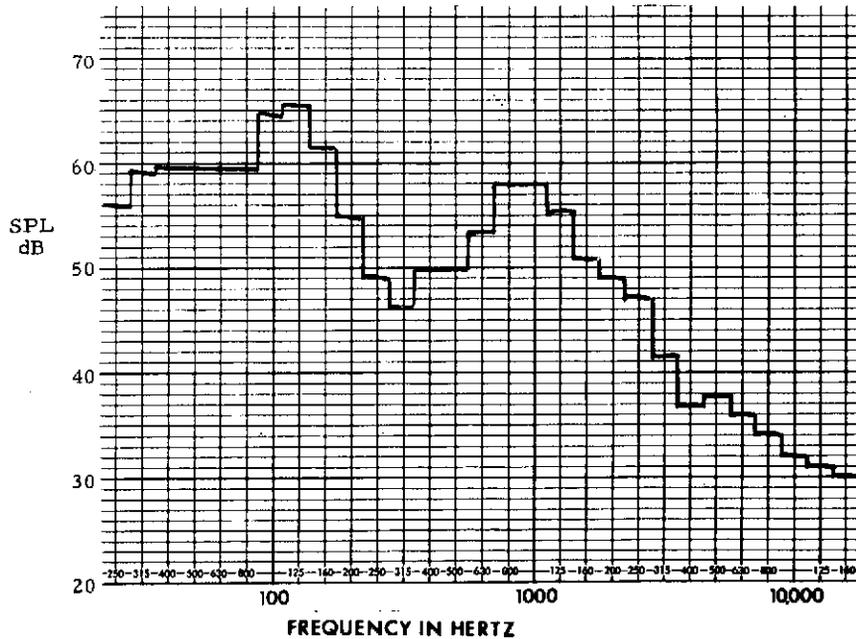


OH-6A Helicopter - Tail Rotor Only w/Symmetrical
Fibreglas Tail Blades Installed - 130 lb Thrust

Run No. 191
OH-6A HELICOPTER
Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION
Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL
Linear: 87.0
"A": 75.5
"D": 83.0
PNdB: 90.4
(Recorded at: 90 dB)

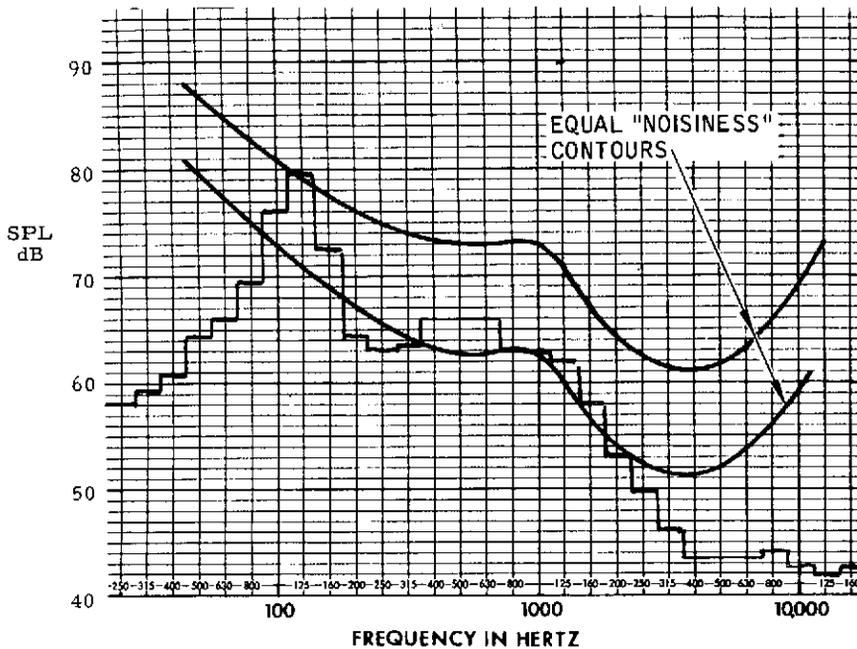


OH-6A Helicopter - Engine Only Silenced Except Insulated
Cowl Doors Removed - 215 HP

Run No. 195
OH-6A HELICOPTER
Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION
Main Rotor: Off
Tail Rotor: Off
Cowl Doors: Standard
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL
Linear: 72.0
"A": 65.0
"D": 69.0
PNdB: 74.3
(Recorded at: 70 dB)



Run No. 201

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

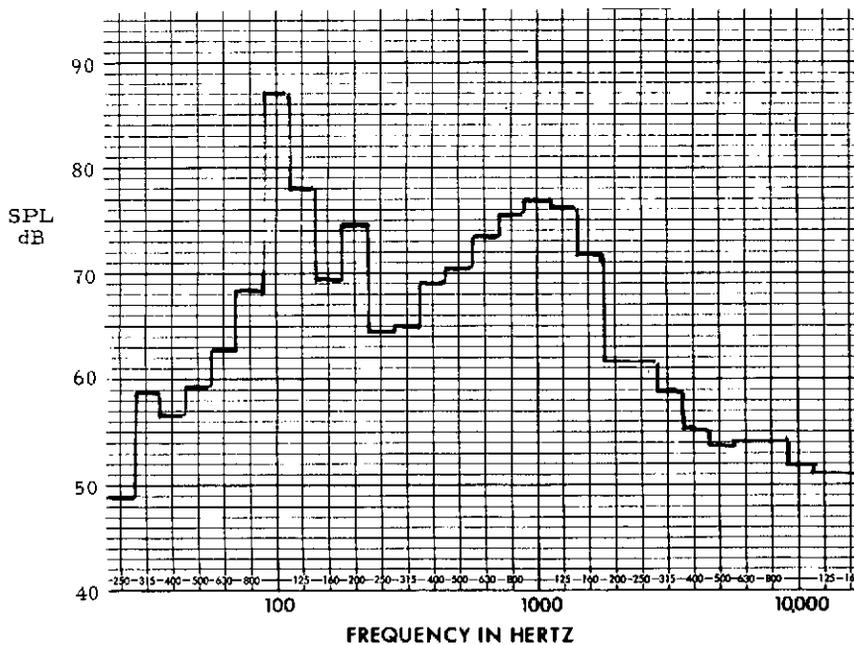
Main Rotor: Off
Tail Rotor: Off
Cowl Doors: Standard
Exhaust: Open
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 83.5
"A": 73.0
"D": 80.0
PNdB: 86.0

(Recorded at: 80 dB)

OH-6A Helicopter - Engine Only - Standard Configuration - 215 HP



Run No. 206

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

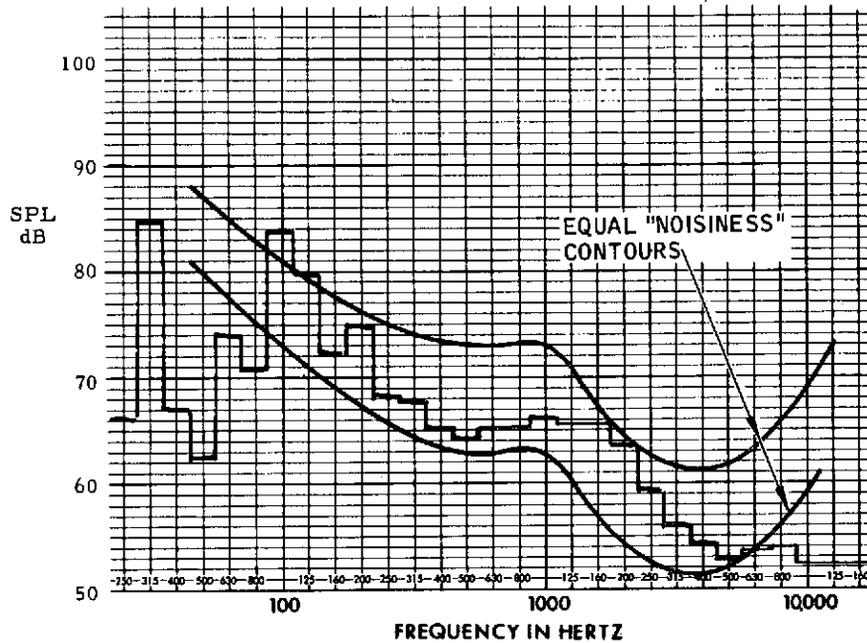
Main Rotor: Off
Tail Rotor: 692 fps
Cowl Doors: Standard
Exhaust: Open
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 88.0
"A": 83.0
"D": 86.0
PNdB: 93.5

(Recorded at: 90 dB)

Baseline OH-6A Helicopter - Less Main Rotor (low power)



Baseline OH-6A Helicopter - Complete Aircraft - 2400 lb - 103% N₂

Run No. 212
OH-6A HELICOPTER
 Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

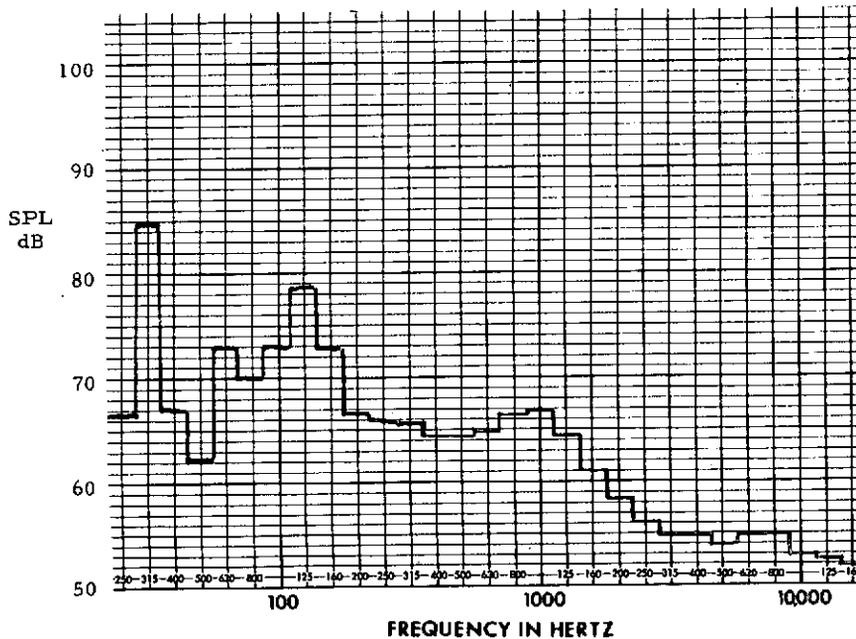
CONFIGURATION

Main Rotor: 666 fps
 Tail Rotor: 692 fps
 Cowl Doors: Standard
 Exhaust: Open
 Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 88.5
 "A": 78.0
 "D": 83.0
 PNdB: 90.5

(Recorded at: 90 dB)



Baseline OH-6A Helicopter - Less Tail Rotor - 2400 lb - 103% N₂

Run No. 221
OH-6A HELICOPTER
 Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

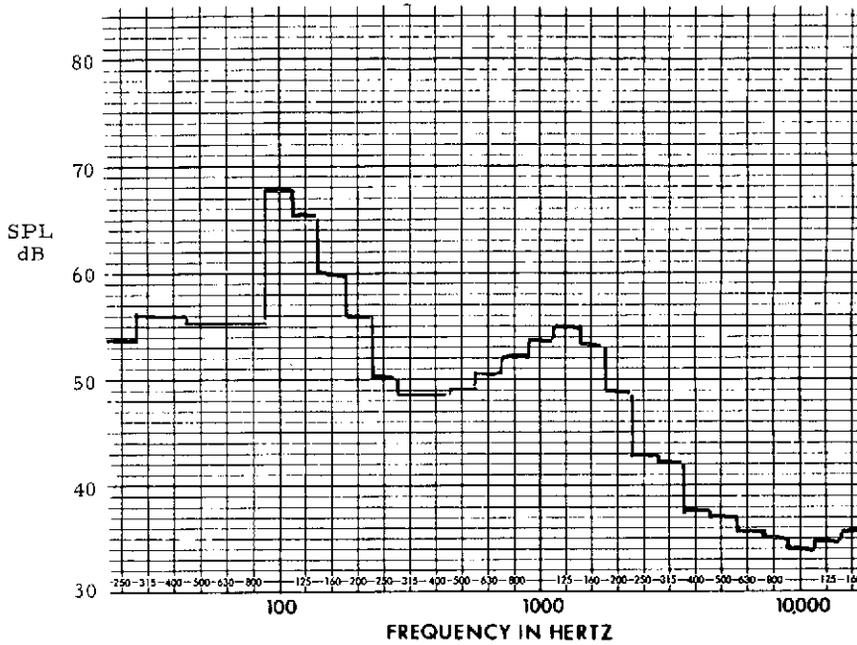
CONFIGURATION

Main Rotor: 666 fps
 Tail Rotor: Off
 Cowl Doors: Standard
 Exhaust: Open
 Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 87.5
 "A": 75.0
 "D": 81.0
 PNdB: 87.8

(Recorded at: 90 dB)



Run No. 227

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

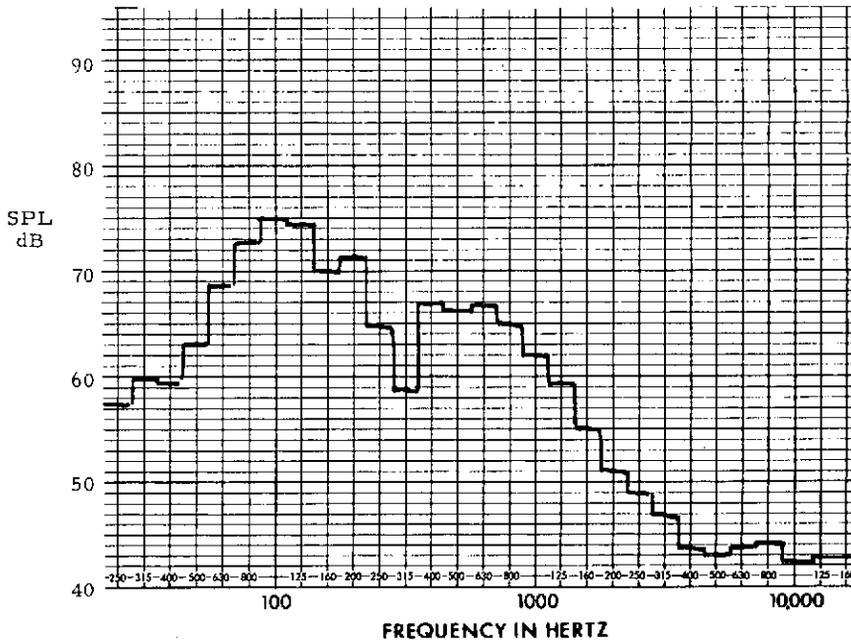
Main Rotor: Off
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 71.0
"A": 63.5
"D": 68.0
PNdB: 73.9

(Recorded at: 70 dB)

OH-6A Helicopter - Engine Only Silenced Except Inlet Not Muffled - 215 HP



Run No. 233

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

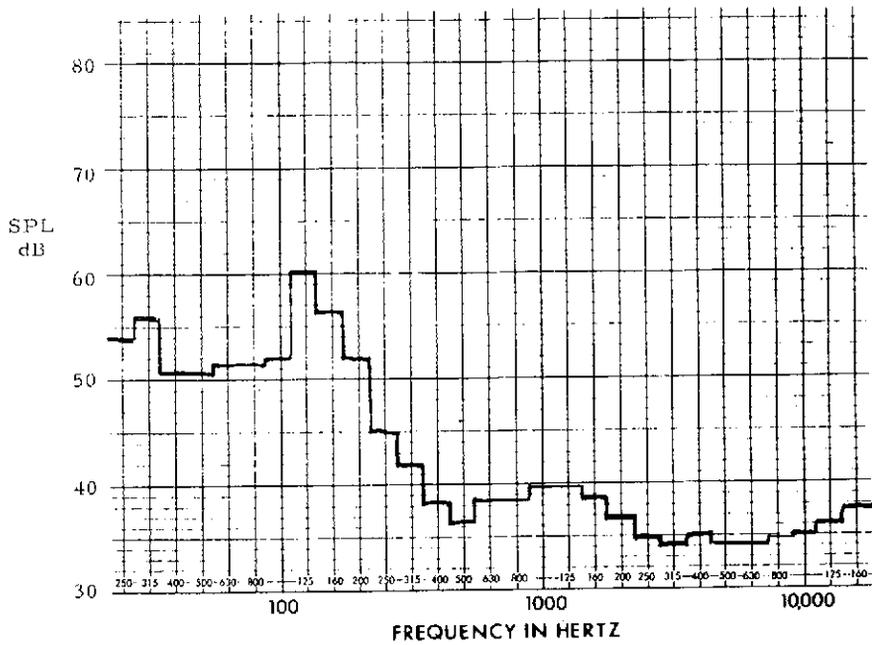
Main Rotor: Off
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Open
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 80.0
"A": 74.0
"D": 78.0
PNdB: 84.2

(Recorded at: 80 dB)

OH-6A Helicopter - Engine Only Silenced Except Exhaust Not Muffled - 215 HP



Run No. 238

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

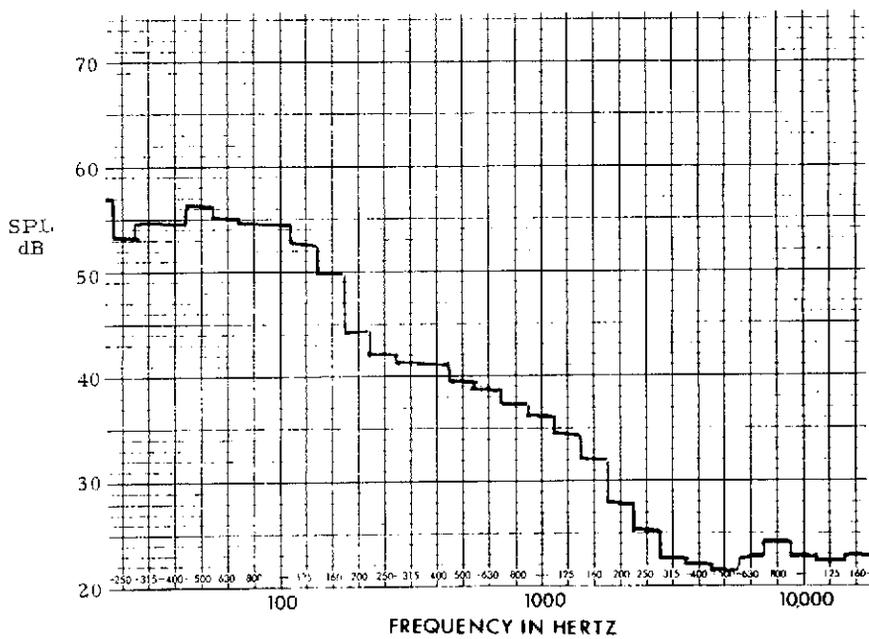
CONFIGURATION

Main Rotor: DYNO
Tail Rotor: COOLING
Cowl Doors: SYSTEM
Exhaust: ONLY
Dynamometer:

OVERALL NOISE LEVEL

Linear: 64.5
"A": 52.0
"D": 60.0
PNdB: 65.4

(Recorded at: 70 dB)



Run No. *

OH-6A HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

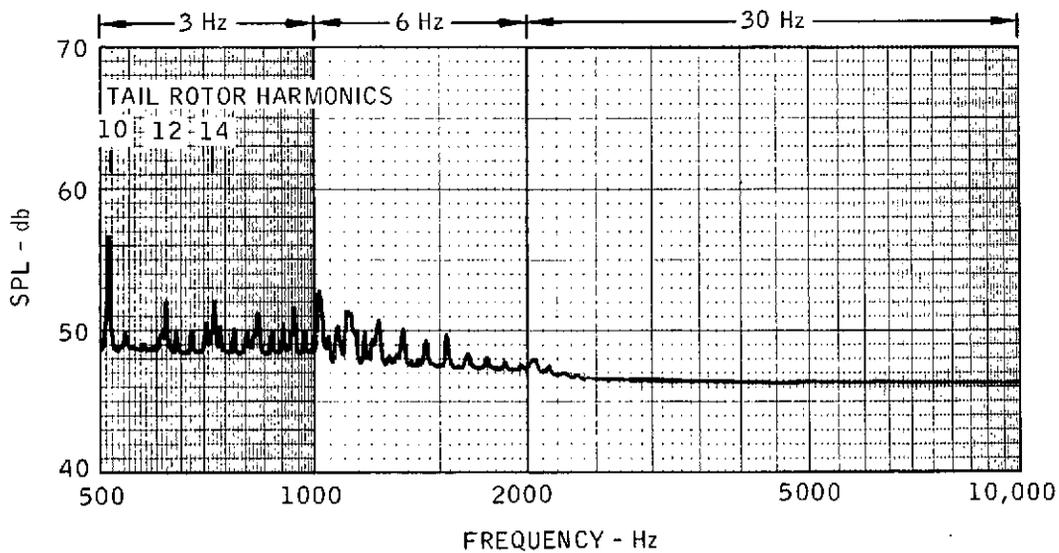
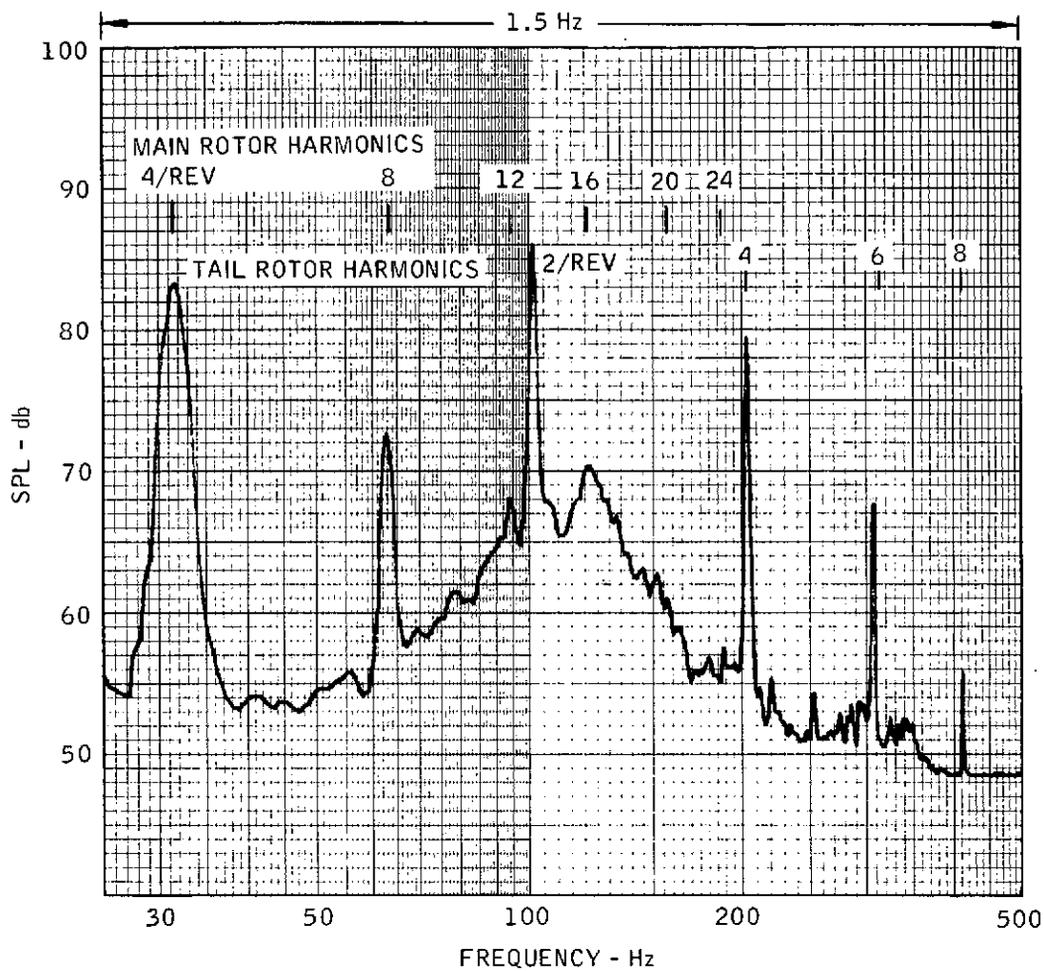
CONFIGURATION

Main Rotor: * AMBIENT
Tail Rotor: PRIOR TO
Cowl Doors: RUN 200
Exhaust:
Dynamometer:

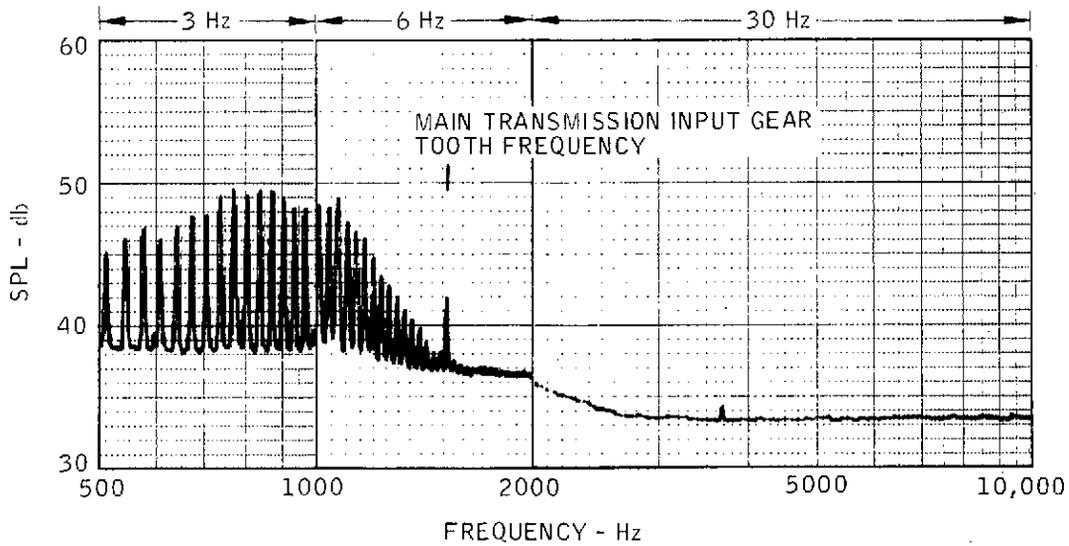
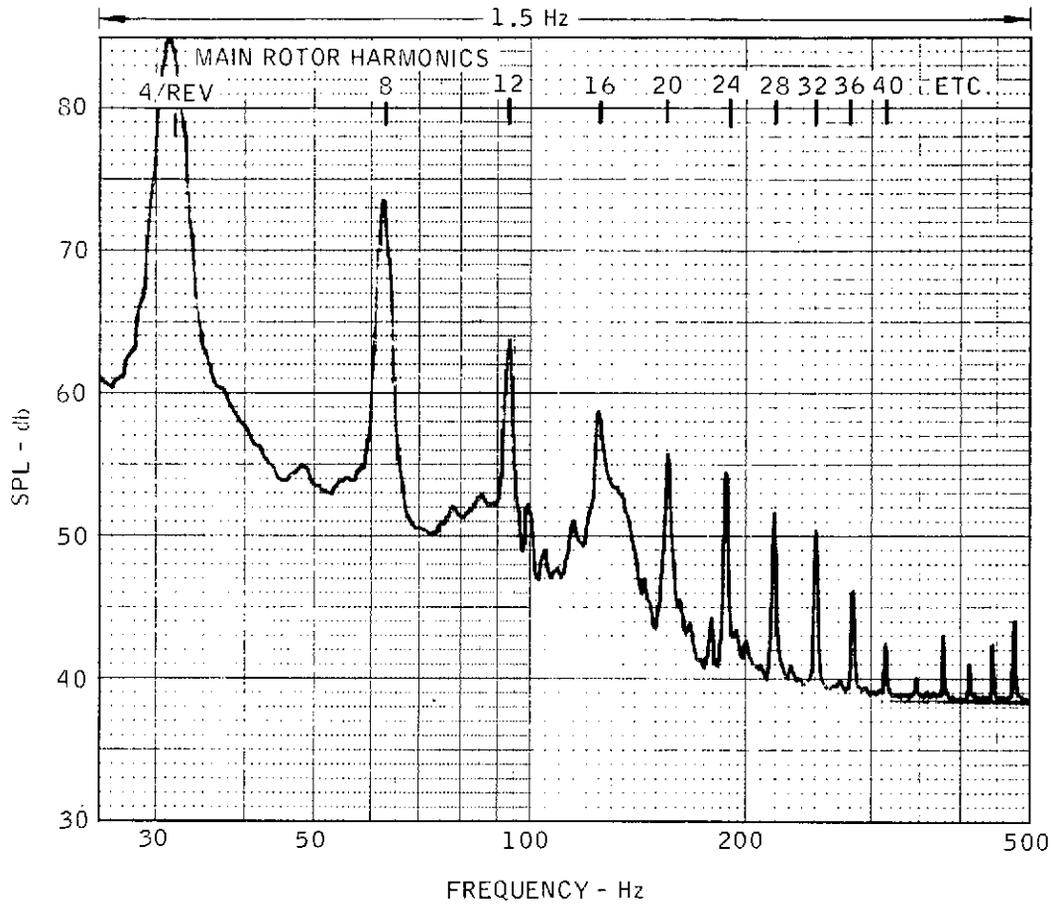
OVERALL NOISE LEVEL

Linear: 65.0
"A": 48.0
"D": 55.0
PNdB: 59.4

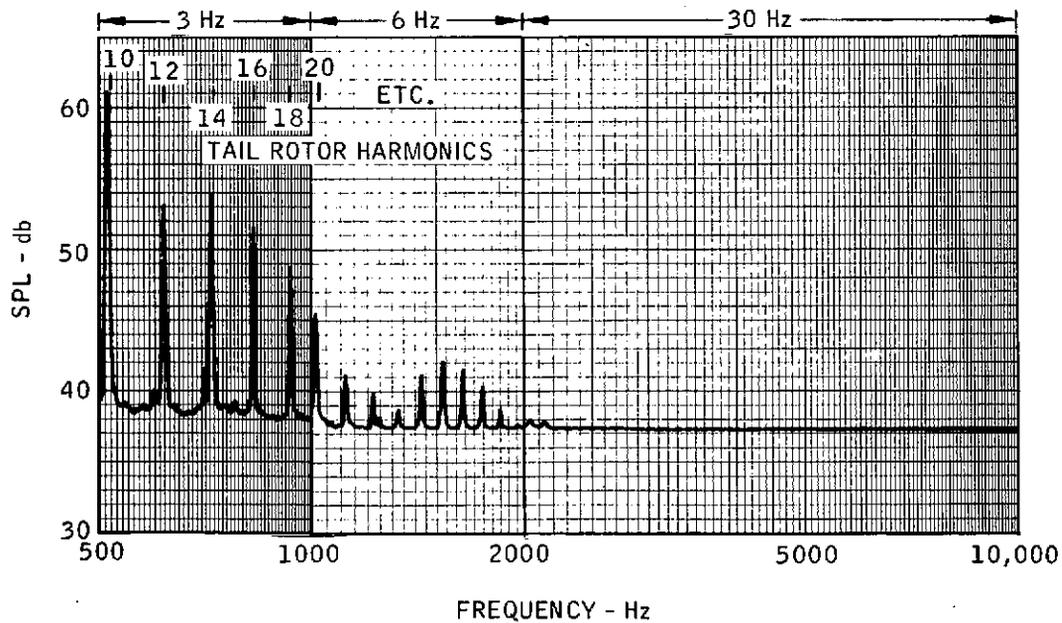
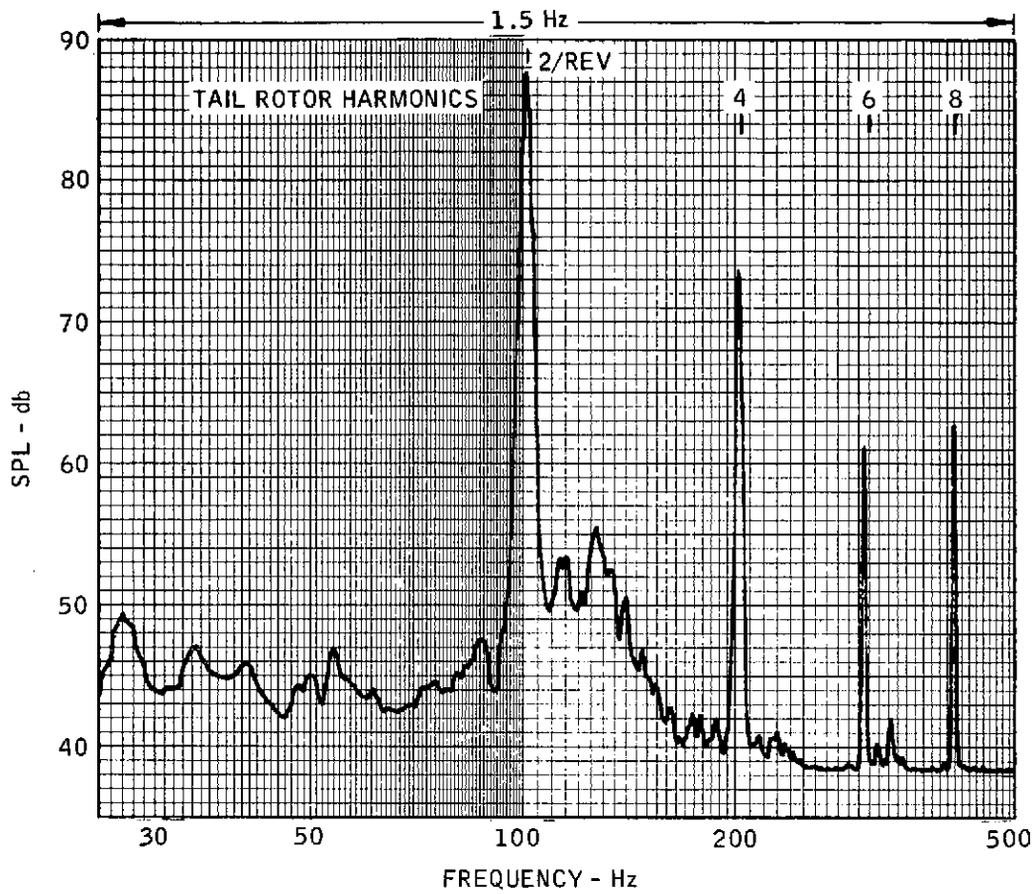
(Recorded at: 60 dB)



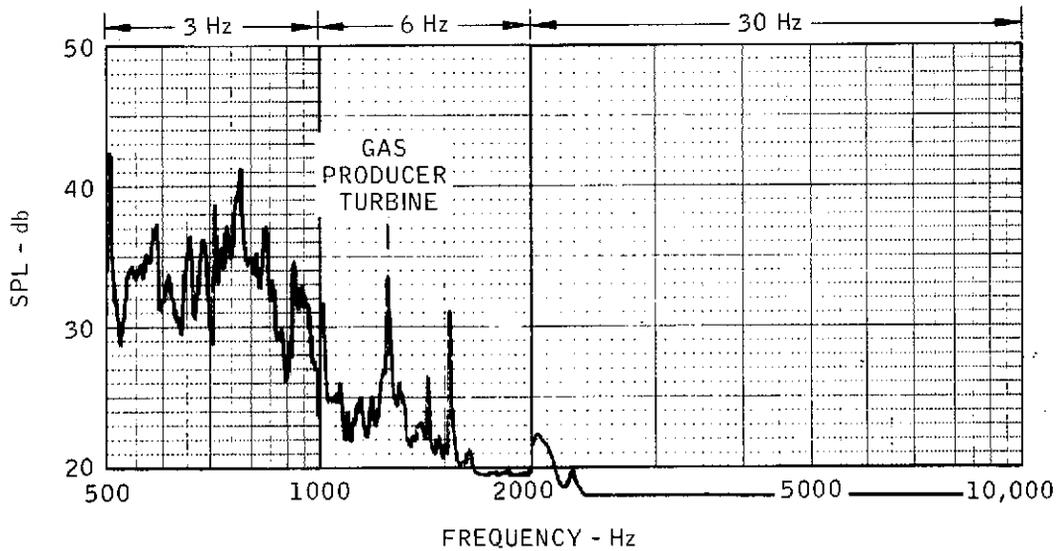
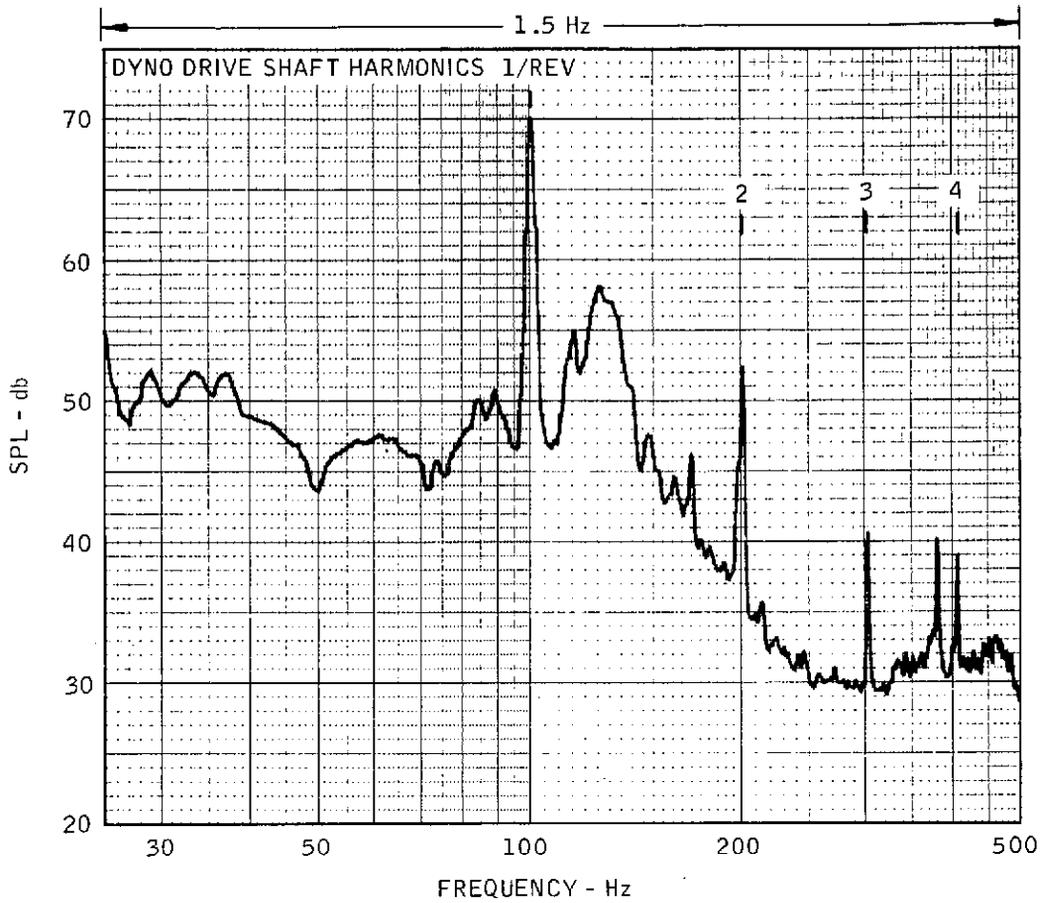
Run 128. Narrow Band Spectra Plot, Complete OH-6A Helicopter
Free Hover At 6-Foot Skid Height



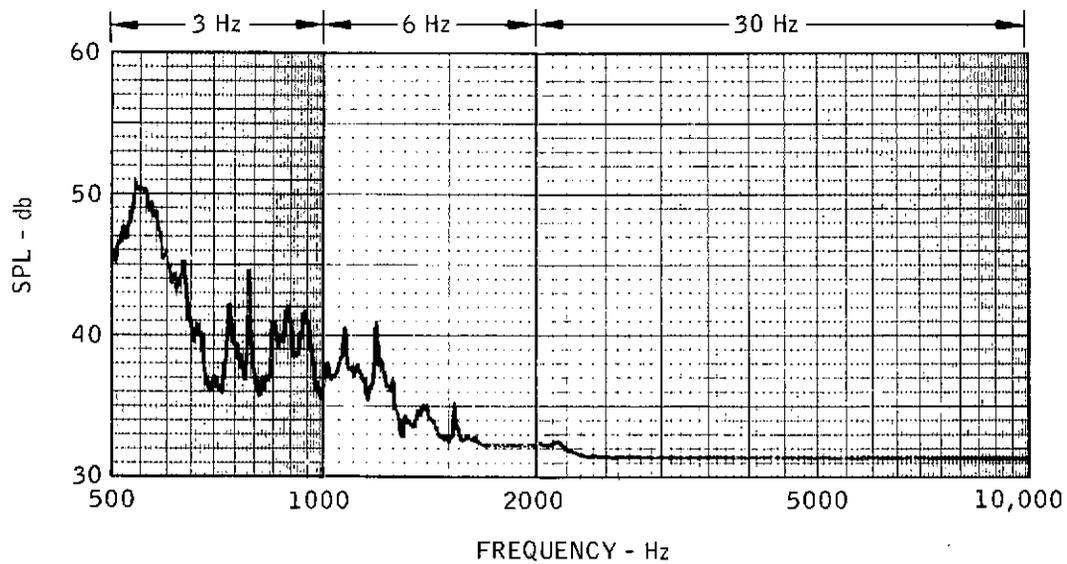
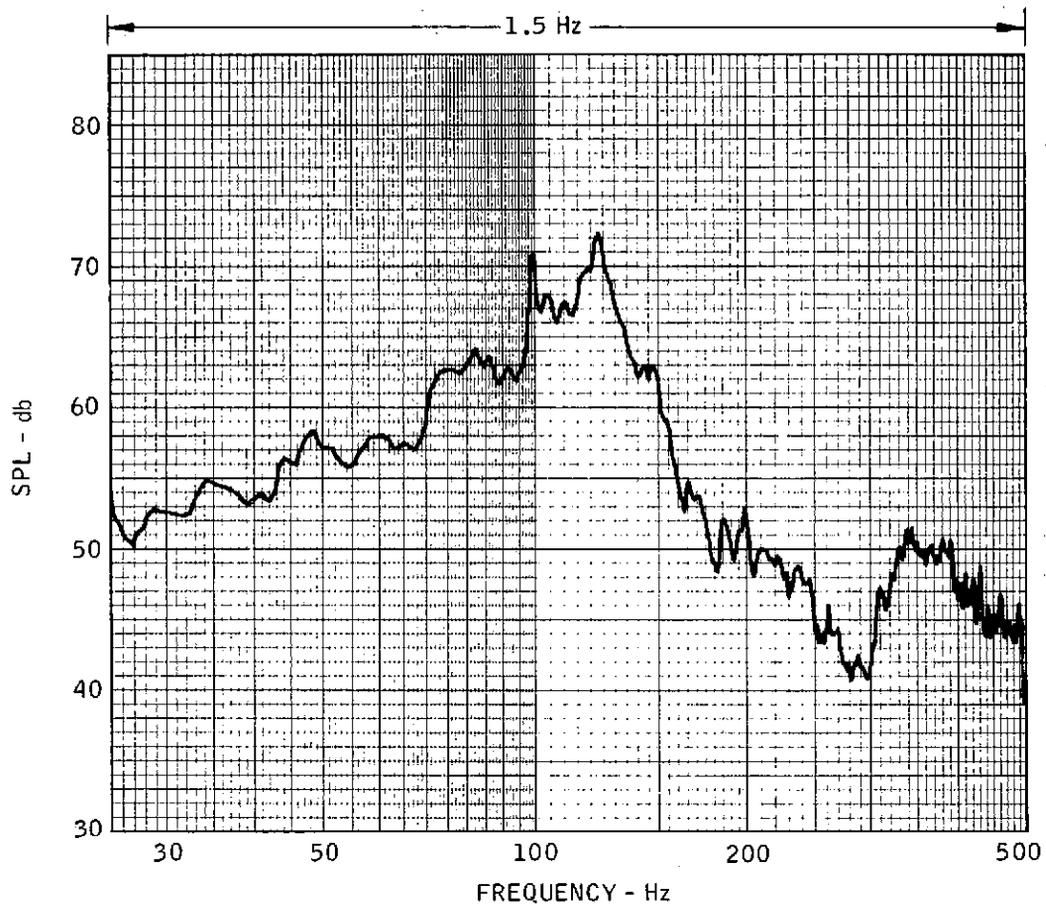
Run 149. Narrow Band Spectra Plot. OH-6A Helicopter - Main Rotor Only (4-Bladed)



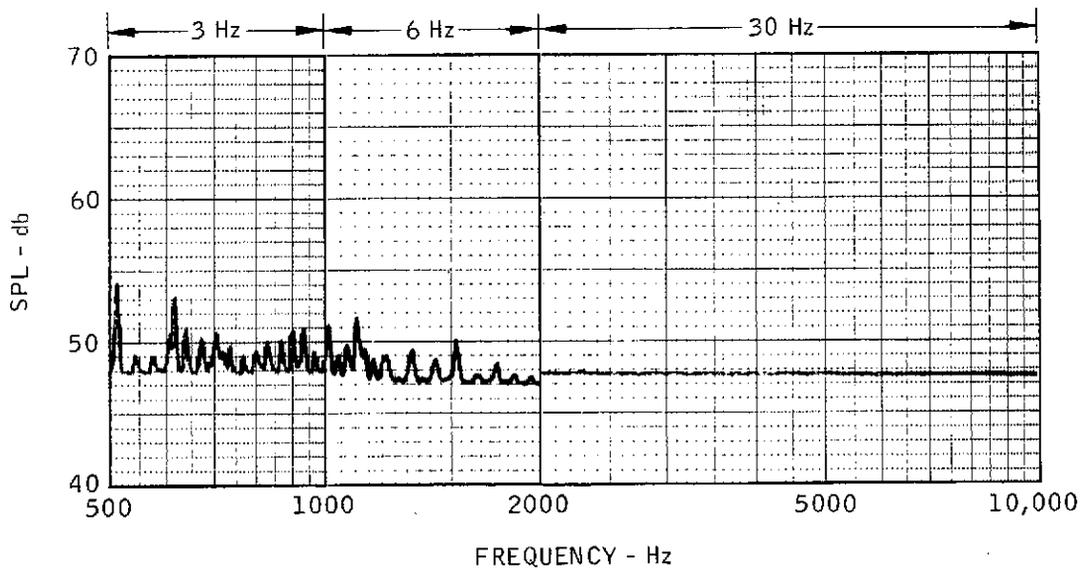
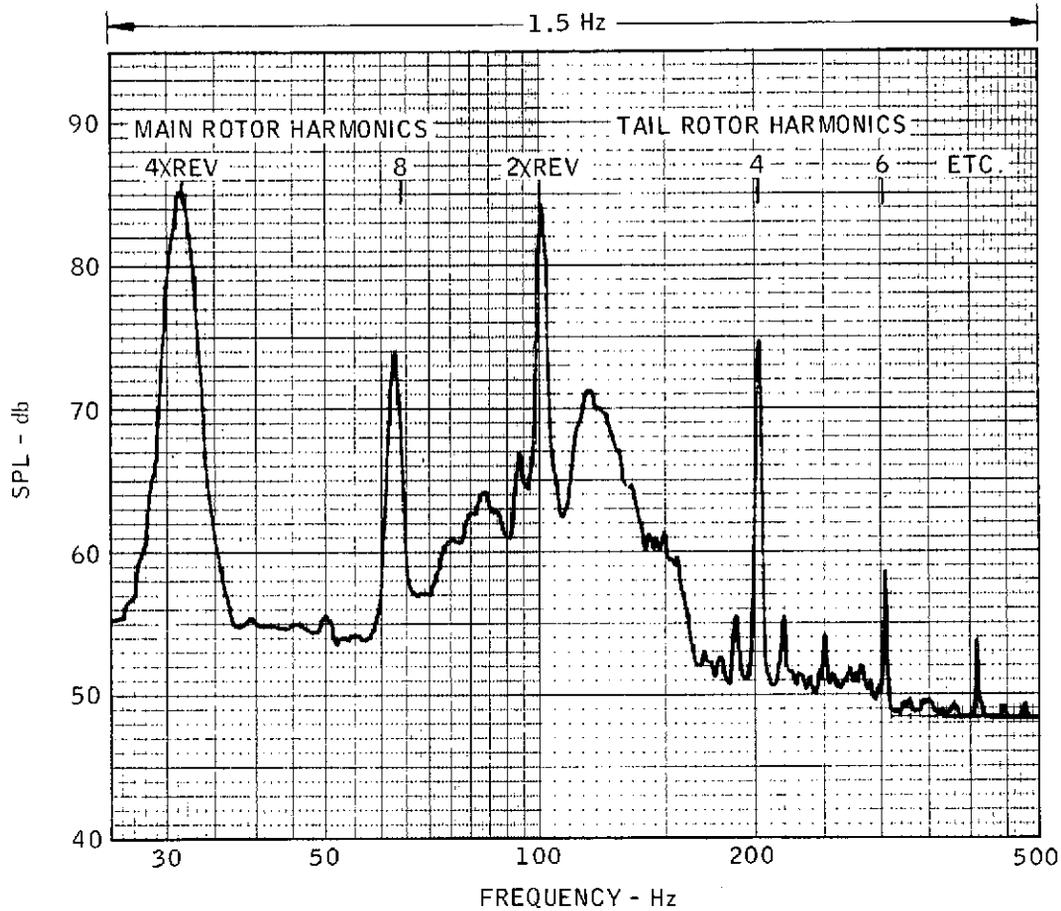
Run 165. Narrow Band Spectra Plot, OH-6A Helicopter - Tail Rotor Only (2-Bladed)



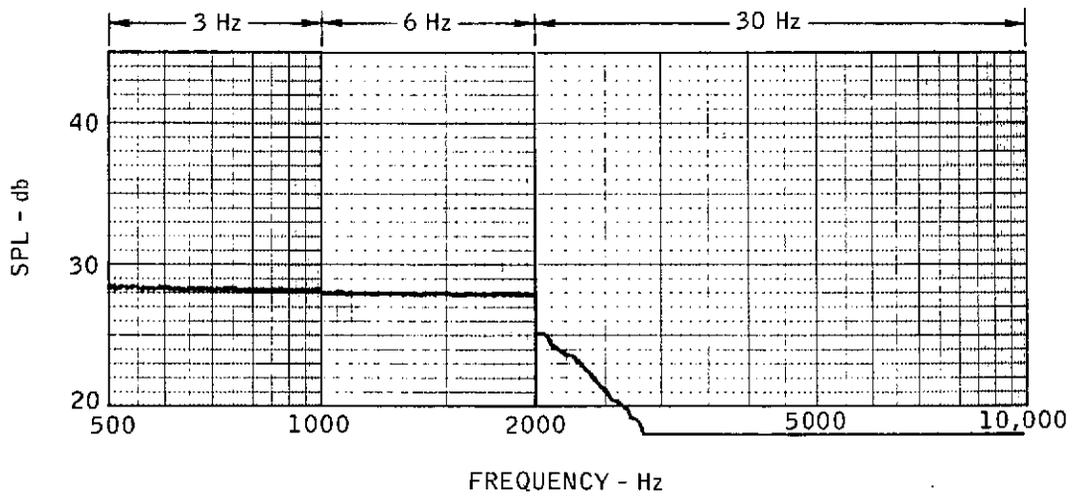
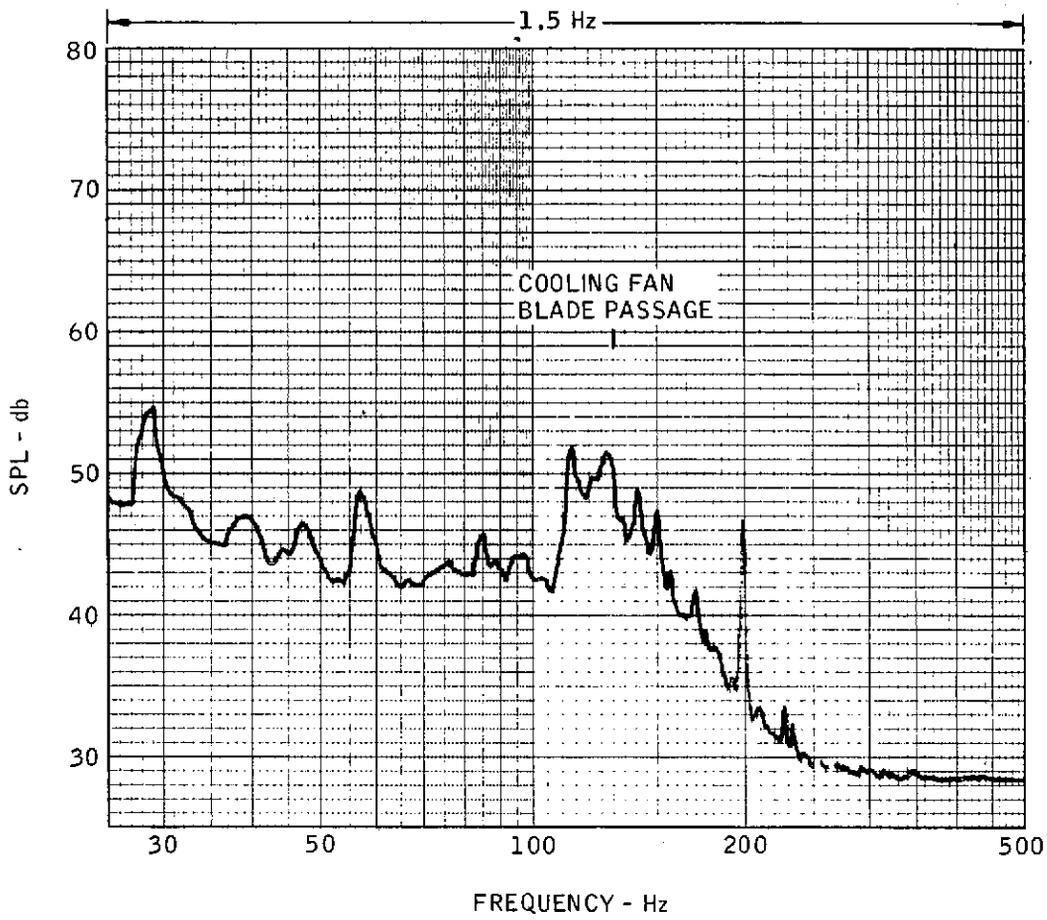
Run 180. Narrow Band Spectra Plot, OH-6A Helicopter Engine Only With Inlet And Exhaust Muffled, Insulated Cowl Door Installed



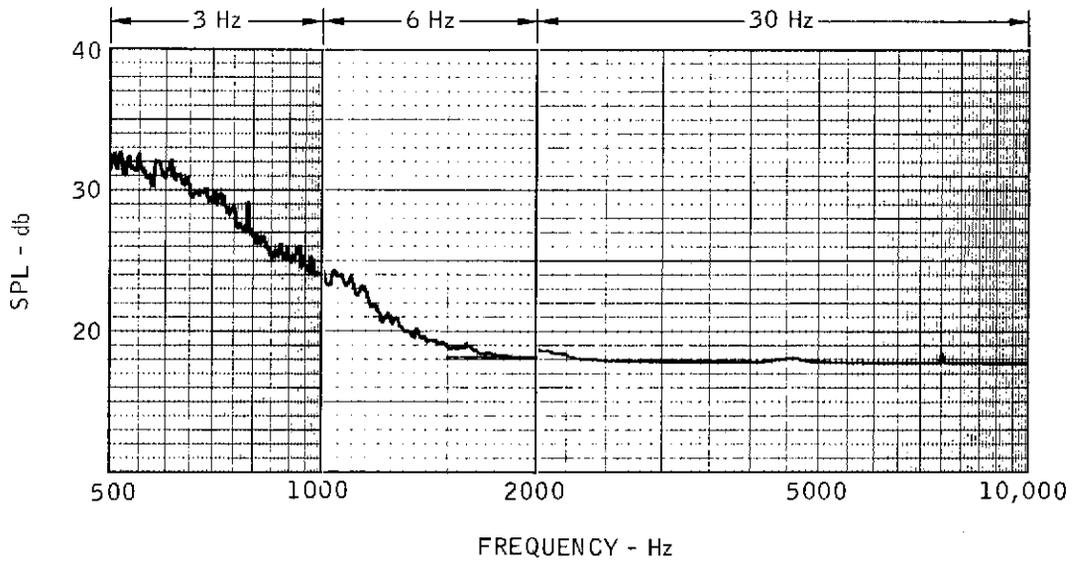
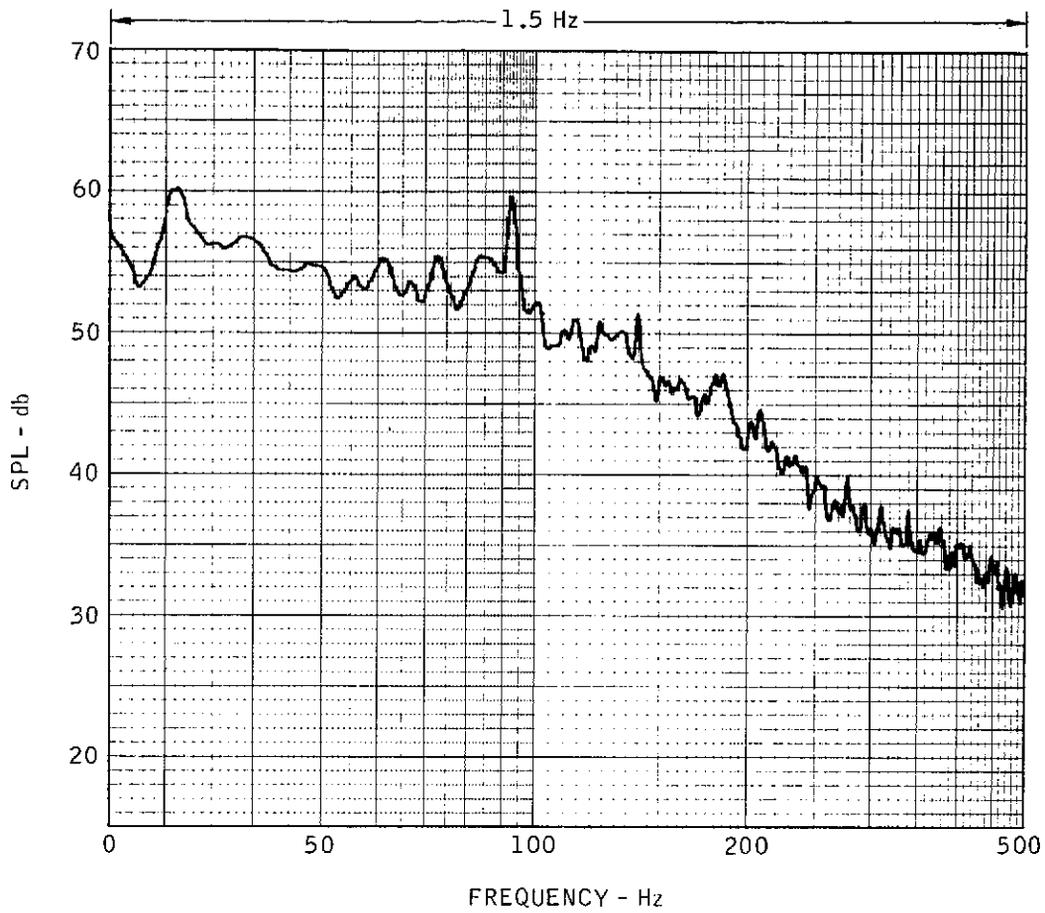
Run 201. Narrow Band Spectra Plot, OH-6A Helicopter - Engine Only



Run 212. Narrow Band Spectra Plot, Complete OH-6A Helicopter Simulated Hover



Run 238. Narrow Band Spectra Plot
Dyno Cooling System Only



Run 35. Narrow Band Spectra Plot
Dyno Cooling System Only

TABLE III

TEST DATA - "QUIET" HELICOPTER

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
<u>Free Hover - 6 ft. Skid Height</u>																	
Baseline "Quiet" Helicopter	1	666	495	On	-	On	-	103	250	2700	165	20.0	*	*	*	*	1
	2	615	457	On	-	On	-	95	243	2700	168	21.0	*	*	*	*	2
In Free Hover	3	666	495	On	-	On	-	103	222	2400	149	18.2	81.0	71.5	75.1	84.8	3
	4	615	457	On	-	On	-	95	207	2400	149	19.0	77.8	70.0	74.2	80.0	4
	5	550	409	On	-	On	-	85	198	2400	158	18.5	76.1	70.0	73.6	79.6	5
	6	666	495	On	-	On	-	103	187	2000	130	*	81.0	76.0	75.7	84.5	6
	7	615	457	On	-	On	-	95	172	2000	126	*	79.0	74.7	76.3	82.7	7
	8	550	409	On	-	On	-	85	158	2000	130	*	75.8	70.0	72.3	79.8	8
	9	485	360	On	-	On	-	75	150	2000	161	*	74.7	67.5	72.5	78.5	9
	10	666	495	On	-	On	-	103	159	1700	107	*	80.3	75.0	76.0	84.3	10
	11	615	457	On	-	On	-	95	144	1700	105	*	79.0	73.0	77.0	83.7	11
	12	550	409	On	-	On	-	85	129	1700	105	*	78.2	73.2	77.0	83.8	12
	13	453	336	On	-	On	-	70	112	1700	114	*	75.4	65.6	72.0	78.5	13
<u>Simulated Hover - 6 ft. Skid Height</u>																	
Baseline "Quiet" Helicopter	14	666	495	On	-	On	-	103	250	2700	165	*	82.7	72.2	77.0	84.7	14
	239(1)	666	495	On	-	On	-	103	222	2400	149	18.5	83.5	71.0	76.0	82.5	15
	240	615	457	On	-	On	-	95	207	2400	149	19.6	82.0	*	*	*	16
	241	550	409	On	-	On	-	85	198	2400	158	21.0	75.0	71.0	73.0	81.6	17
	18	666	495	On	-	On	-	103	187	2000	130	*	80.0	70.2	76.5	81.3	18
	19	666	495	On	-	On	-	103	159	1700	107	*	79.4	65.5	74.7	81.9	19
	20	615	457	On	-	On	-	95	144	1700	105	*	77.1	69.0	73.4	80.2	20
	21	550	409	On	-	On	-	85	129	1700	105	*	73.4	67.0	70.8	79.4	21
	22	453	336	On	-	On	-	70	112	1700	114	*	72.0	63.5	68.1	75.6	22
Main Rotor Only	90	666	-	-	On	On	-	103	244	2700	-	-	82.0	67.0	73.5	80.2	90
	91	666	-	-	On	On	-	103	215	2400	-	-	81.5	67.0	73.2	79.6	91
(This configuration was rerun - see runs 242 thru 255)	92	666	-	-	On	On	-	103	180	2000	-	-	81.0	66.0	74.0	78.8	92
	93	666	-	-	On	On	-	103	153	1700	-	-	80.0	70.0	74.3	80.9	93
	94	615	-	-	On	On	-	95	232	2700	-	-	77.5	67.0	73.2	79.4	94
	95	615	-	-	On	On	-	95	198	2400	-	-	77.5	67.0	72.9	77.7	95
	96	615	-	-	On	On	-	95	165	2000	-	-	76.0	67.0	72.0	79.1	96
	97	615	-	-	On	On	-	95	140	1700	-	-	80.5	67.0	72.7	78.1	97
	98	550	-	-	On	On	-	85	190	2400	-	-	72.0	62.0	67.5	75.3	98
	99	550	-	-	On	On	-	85	151	2000	-	-	69.0	60.0	65.8	72.1	99
	100	550	-	-	On	On	-	85	124	1700	-	-	70.0	62.0	67.0	73.7	100
	101	518	-	-	On	On	-	80	189	2400	-	-	72.5	65.0	69.7	76.2	101
	102	453	-	-	On	On	-	70	141	2000	-	-	69.0	59.0	64.5	71.0	102
	103	453	-	-	On	On	-	70	102	1700	-	-	67.5	58.0	62.8	69.2	103

TABLE III

TEST DATA - "QUIET" HELICOPTER (Continued)

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
Main Rotor Only (Rerun of runs 90 thru 103)	242	666	-	-	On	On	-	103	244	2700	-	-	83.6	65.0	74.0	84.0	242
	243(1)(2)	666	-	-	On	On	-	103	215	2400	-	-	83.0	66.8	80.8	86.7	243
	244	666	-	-	On	On	-	103	180	2000	-	-	80.7	61.5	73.5	80.9	244
	245	666	-	-	On	On	-	103	153	1700	-	-	80.8	65.0	78.8	83.4	245
	246	615	-	-	On	On	-	95	232	2700	-	-	79.0	62.0	76.1	83.2	246
	247	615	-	-	On	On	-	95	198	2400	-	-	78.0	62.0	75.8	82.3	247
	248	615	-	-	On	On	-	95	165	2000	-	-	77.8	62.8	76.8	83.0	248
	249	615	-	-	On	On	-	95	140	1700	-	-	77.5	63.0	76.8	82.5	249
	250	550	-	-	On	On	-	85	190	2400	-	-	74.0	57.5	72.0	77.4	250
	251	550	-	-	On	On	-	85	151	2000	-	-	72.0	55.2	67.5	74.3	251
	252	550	-	-	On	On	-	85	124	1700	-	-	70.2	53.5	68.0	73.3	252
	253(1)	518	-	-	On	On	-	80	189	2400	-	-	70.6	53.5	66.5	72.6	253
	254	453	-	-	On	On	-	70	141	2000	-	-	67.2	52.8	63.8	70.6	254
	255	453	-	-	On	On	-	70	102	1700	-	-	*	*	*	*	255
	Baseline Less Main Rotor	23	-	495	On	-	On	On	103	250	-	165	*	83.0	74.5	78.8	85.3
24(1)		-	495	On	-	On	On	103	222	-	149	*	81.4	74.0	77.8	84.5	24
25		-	457	On	-	On	On	95	207	-	149	*	78.7	70.0	74.5	81.7	25
26		-	409	On	-	On	On	85	198	-	158	*	78.0	69.3	74.3	80.7	26
27		-	495	On	-	On	On	103	187	-	130	*	79.8	69.5	76.6	82.3	27
28		-	495	On	-	On	On	103	159	-	107	*	79.5	70.2	79.5	82.2	28
Main Rotor Only w/Stnd OH-6A main rotor blades (no tapered tips)	104	666	-	-	On	On	-	103	250	2700	-	-	85.0	78.0	82.4	88.8	104
	105(1)	666	-	-	On	On	-	103	222	2400	-	-	84.0	78.5	80.8	88.6	105
	106	666	-	-	On	On	-	103	187	2000	-	-	84.0	76.0	78.0	84.1	106
	107	666	-	-	On	On	-	103	159	1700	-	-	83.0	76.0	80.2	86.6	107
	108	615	-	-	On	On	-	95	207	2400	-	-	80.5	73.0	76.7	83.9	108
Tail Rotor Only w/baseline 4 blade tail rotor installed (75° - 105° blade spacing)	109	550	-	-	On	On	-	85	198	2400	-	-	75.0	70.0	74.0	83.0	109
	65	-	495	-	On	On	On	103	116	-	191	*	76.0	57.0	71.2	78.0	65
	66	-	495	-	On	On	On	103	116	-	165	*	75.0	65.0	71.3	77.8	66
	67(1)(2)	-	495	-	On	On	On	103	116	-	149	*	76.0	66.0	70.9	78.0	67
	68	-	495	-	On	On	On	103	116	-	130	*	75.0	66.0	70.2	76.7	68
	69(1)	-	495	-	On	On	On	103	116	-	107	*	73.0	64.0	69.5	75.8	69
	70	-	495	-	On	On	On	103	116	-	0	*	73.0	64.0	69.2	75.5	70
	71	-	457	-	On	On	On	95	125	-	0	*	71.0	63.0	67.3	75.3	71
	72	-	457	-	On	On	On	95	124	-	48	*	72.0	63.0	67.0	73.7	72
	73	-	457	-	On	On	On	95	124	-	96	*	73.0	63.0	68.1	75.7	73
	74	-	457	-	On	On	On	95	135	-	143	*	73.0	64.0	68.1	75.0	74
	75	-	409	-	On	On	On	85	96	-	0	*	70.5	63.0	67.6	74.1	75
	76	-	409	-	On	On	On	85	96	-	48	*	70.0	65.0	67.0	74.3	76
77	-	409	-	On	On	On	85	97	-	96	*	71.5	65.0	68.7	75.5	77	

TABLE III

TEST DATA - "QUIET" HELICOPTER (Continued)

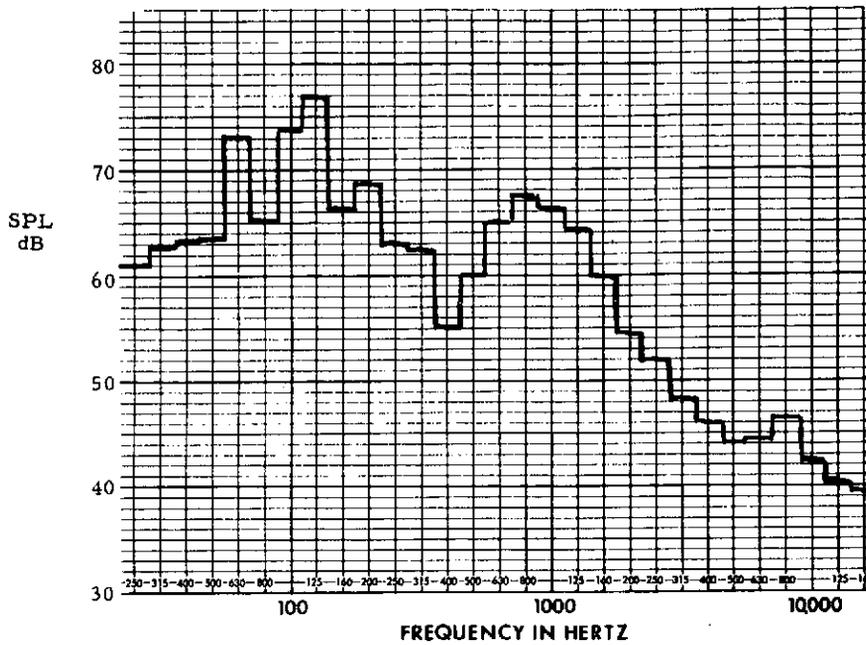
Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
(con't)	78	-	409	-	On	On	On	85	99	-	143	*	73.0	65.0	69.1	76.1	78
	79	-	336	-	On	On	On	70	80	-	0	*	71.0	64.0	67.5	73.9	79
	80	-	336	-	On	On	On	70	80	-	48	*	70.0	63.0	66.4	72.7	80
	81(1)	-	336	-	On	On	On	70	80	-	96	*	71.0	63.0	67.5	73.5	81
Baseline Less Tail Rotor	42	666	-	On	-	On	-	103	245	2700	-	-	*	*	*	*	42
	43(1)	666	-	On	-	On	-	103	214	2400	-	-	81.0	64.0	72.0	76.7	43
	44	666	-	On	-	On	-	103	180	2000	-	-	80.0	65.0	72.0	77.5	44
	45	666	-	On	-	On	-	103	155	1700	-	-	80.0	65.0	72.0	77.5	45
	46	615	-	On	-	On	-	95	202	2400	-	-	77.0	66.0	72.2	78.8	46
	47	550	-	On	-	On	-	85	189	2400	-	-	73.0	62.0	66.5	72.9	47
Tail Rotor Only w/only 2 of the 4 blades installed	60(1)	-	495	-	On	On	On	103	105	-	96	*	76.0	56.0	71.4	77.3	60
	61	-	495	-	On	On	On	103	104	-	48	*	75.5	56.0	71.4	77.1	61
	62	-	495	-	On	On	On	103	104	-	0	*	73.0	64.0	68.5	74.1	62
	63	-	457	-	On	On	On	95	92	-	48	*	74.0	63.5	68.0	73.5	63
	64	-	409	-	On	On	On	85	86	-	48	*	74.0	65.0	69.1	75.6	64
Tail Rotor Only w/60° - 120° blade spacing	110	-	495	-	On	On	On	103	104	-	0	3.6	77.2	68.2	74.2	82.7	110
	111	-	495	-	On	On	On	103	104	-	48	5.7	75.0	62.2	71.1	79.0	111
	112(1)	-	495	-	On	On	On	103	104	-	96	9.9	76.5	66.0	72.3	79.5	112
	113	-	457	-	On	On	On	95	96	-	48	4.9	74.2	66.3	72.7	78.0	113
	114	-	409	-	On	On	On	85	93	-	48	5.2	71.2	65.5	68.5	75.5	114
Tail Rotor Only w/90° - 90° blade spacing	115	-	495	-	On	On	On	103	105	-	0	3.6	75.0	65.7	71.1	76.9	115
	116	-	495	-	On	On	On	103	103	-	48	5.2	74.3	65.5	70.8	76.8	116
	117(1)	-	495	-	On	On	On	103	104	-	96	8.7	75.2	67.2	70.9	77.9	117
	118	-	457	-	On	On	On	95	97	-	48	4.8	73.4	64.3	69.6	76.5	118
	119	-	409	-	On	On	On	85	99	-	48	4.1	71.2	63.5	68.6	74.4	119
Engine Only	29	-	-	On	-	On	On	103	250	-	-	-	78.1	68.0	73.7	80.5	29
	30(1)(2)	-	-	On	-	On	On	103	222	-	-	-	77.4	69.0	74.0	81.7	30
	31	-	-	On	-	On	On	103	187	-	-	-	76.0	67.6	72.4	80.4	31
	32	-	-	On	-	On	On	103	159	-	-	-	75.2	66.7	71.8	79.4	32
	33	-	-	On	-	On	On	95	207	-	-	-	75.6	66.2	71.1	77.4	33
	34	-	-	On	-	On	On	85	198	-	-	-	75.5	65.5	71.1	77.2	34
Baseline Less Engine	82	666	495	-	On	On	-	103	250	2700	165	18.2	82.5	70.5	75.5	83.4	82
	83(1)	666	495	-	On	On	-	103	222	2400	149	14.9	82.0	74.5	77.1	85.2	83
	84	666	495	-	On	On	-	103	187	2000	0	2.7	82.0	70.0	75.0	82.4	84
	85	666	495	-	On	On	-	103	187	2000	96	7.8	81.5	73.5	78.0	84.9	85

TABLE III

TEST DATA - "QUIET" HELICOPTER (Continued)

Configuration	Run No.	Main Rotor Tip Speed FPS	Tail Rotor Tip Speed FPS	Engine Inlet Muffler	Ground Exhaust Silencer	Insulated Cowl Doors	Dyna-mometer	Engine RPM % N ₂	Engine Power HP	Main Rotor Thrust (approx) LB	Tail Rotor Thrust LB	Tail Rotor Power HP	Linear db	Overall Sound Pressure Level			Run No.
														"A" Weighted db	"D" Weighted db	PNdB	
(con't)	86	666	495	-	On	On	-	103	187	2000	191	24.6	81.0	71.0	76.3	82.9	86
	87	666	495	-	On	On	-	103	159	1700	107	9.9	80.0	70.5	76.0	84.2	87
	88	615	457	-	On	On	-	95	207	2400	149	14.9	77.5	66.0	72.4	79.3	88
	89	550	409	-	On	On	-	85	198	2400	158	17.0	74.0	66.5	71.7	78.7	89
Engine Only w/insulated cowl doors removed	48	-	-	On	-	-	On	103	250	-	-	-	79.0	72.0	76.0	84.2	48
	49(1)	-	-	On	-	-	On	103	222	-	-	-	77.0	69.0	73.8	80.6	49
	50	-	-	On	-	-	On	103	187	-	-	-	75.0	67.0	70.9	77.3	50
	51	-	-	On	-	-	On	103	159	-	-	-	76.0	67.5	71.6	77.6	51
	52	-	-	On	-	-	On	95	207	-	-	-	76.0	67.0	70.5	77.0	52
	53	-	-	On	-	-	On	85	198	-	-	-	75.5	66.0	70.2	76.2	53
Engine Only w/flight muffler and cowl doors removed	120	-	-	-	-	-	On	103	250	-	-	-	86.5	77.0	82.4	89.8	120
	121(1)	-	-	-	-	-	On	103	222	-	-	-	86.5	77.0	83.0	90.2	121
	122	-	-	-	-	-	On	103	187	-	-	-	83.9	73.0	79.2	86.8	122
	123	-	-	-	-	-	On	103	159	-	-	-	86.0	74.7	81.3	88.8	123
	124	-	-	-	-	-	On	95	207	-	-	-	85.5	74.2	80.6	88.5	124
	125	-	-	-	-	-	On	85	198	-	-	-	85.6	74.0	80.5	87.9	125
Engine Only w/Exhaust Silenced (This is the lowest power-on noise level)	54	-	-	-	On	On	On	103	250	-	-	-	71.0	57.0	64.2	69.0	54
	55(1)	-	-	-	On	On	On	103	222	-	-	-	71.0	54.0	68.0	74.9	55
	56	-	-	-	On	On	On	103	187	-	-	-	71.0	63.0	67.8	73.7	56
	57	-	-	-	On	On	On	103	159	-	-	-	73.0	65.0	69.0	75.3	57
	58	-	-	-	On	On	On	95	207	-	-	-	72.0	64.0	69.0	74.9	58
	59	-	-	-	On	On	On	85	198	-	-	-	72.0	63.0	68.9	74.2	59
Dyno Cooling System Only	35(2)	-	-	-	-	-	-	-	-	-	-	-	68.0	54.5	63.0	68.5	35

* Data not available or considered unreliable.
 (1) One-third octave spectra plot for this run is included.
 (2) Narrow band spectra plot for this run is included.



Baseline "Quiet" Helicopter - Less Main Rotor - 222 HP

Run No. 24
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

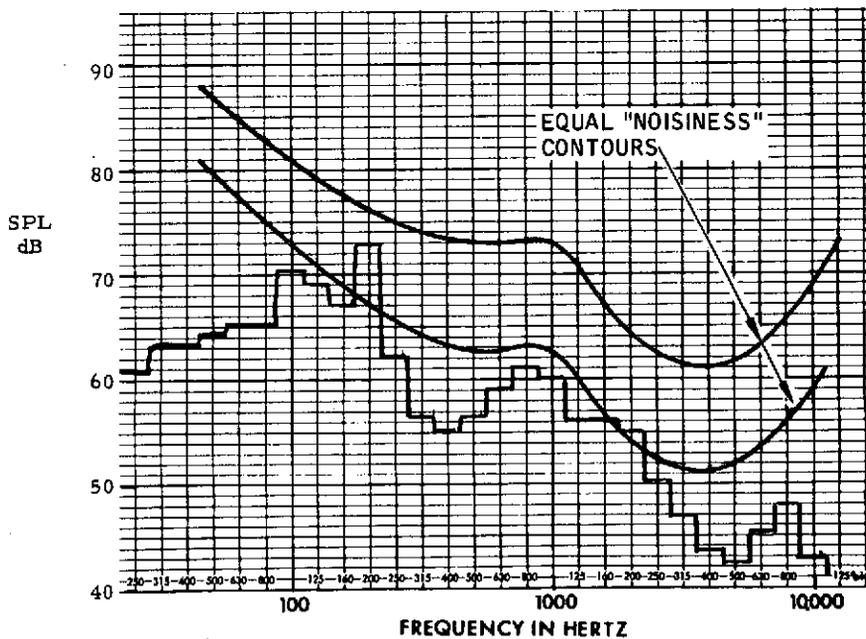
CONFIGURATION

Main Rotor: Off
 Tail Rotor: 495 fps
 Cowl Doors: Insulated
 Exhaust: Flt Muff
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 81.4
 "A": 74.0
 "D": 77.8
 PNdB: 84.5

(Recorded at: 80 dB)



"Quiet" Helicopter - Engine Only - 222 HP

Run No. 30
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

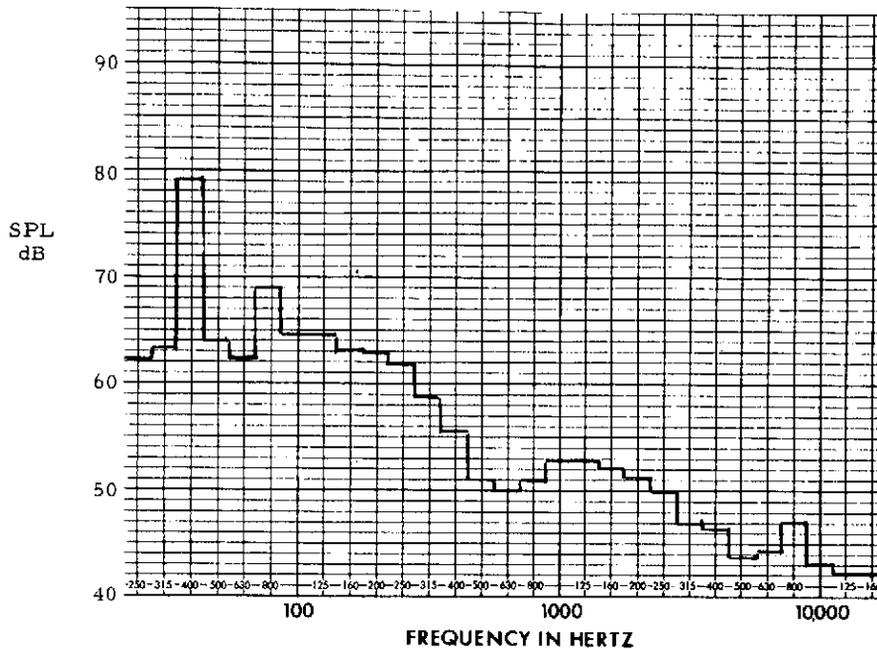
CONFIGURATION

Main Rotor: Off
 Tail Rotor: Off
 Cowl Doors: Insulated
 Exhaust: Flt Muff
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 77.4
 "A": 69.0
 "D": 74.0
 PNdB: 81.7

(Recorded at: 80 dB)



Baseline "Quiet" Helicopter - Less Tail Rotor - 2400 lbs

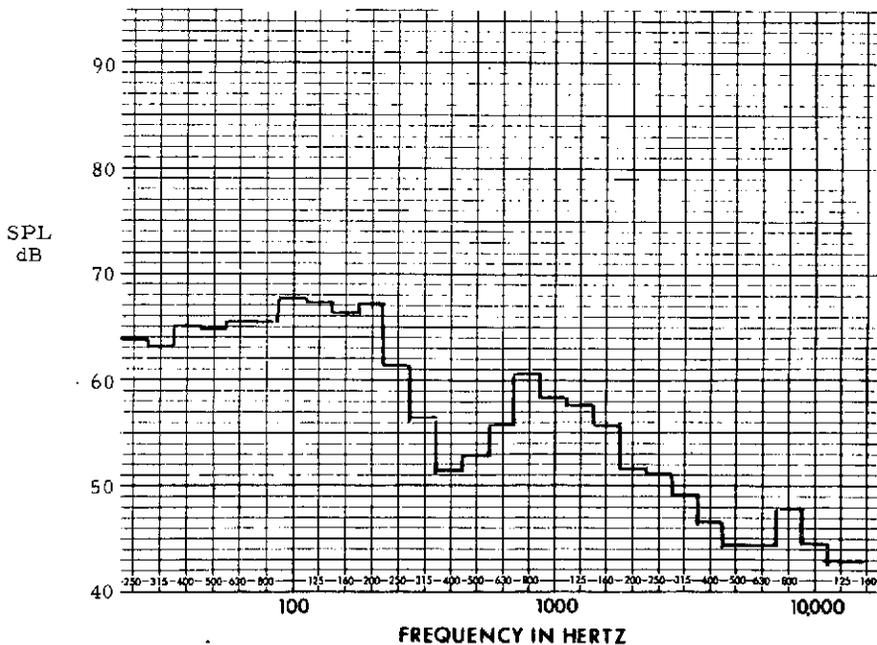
Run No. 43
"QUIET" HELICOPTER

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION
 Main Rotor: 666 fps
 Tail Rotor: Off
 Cowl Doors: Insulated
 Exhaust: Flt Muff
 Dynamometer: Off

OVERALL NOISE LEVEL
 Linear: 81.0
 "A": 64.0
 "D": 72.0
 PNdB: 76.7

(Recorded at: 80 dB)



"Quiet" Helicopter - Engine Only w/Insulated Cowl Doors Removed - 222 HP

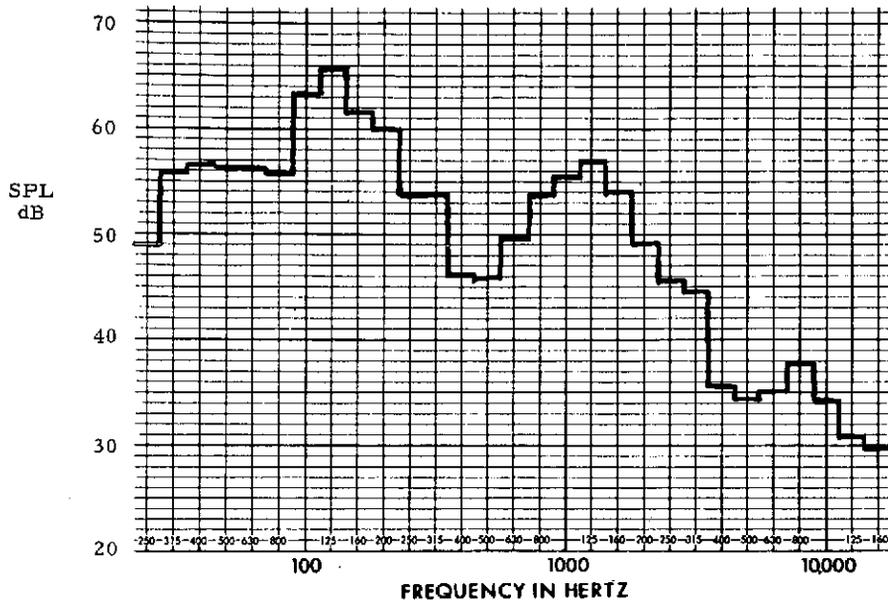
Run No. 49
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION
 Main Rotor: Off
 Tail Rotor: Off
 Cowl Doors: Off
 Exhaust: Flt Muff
 Dynamometer: On

OVERALL NOISE LEVEL
 Linear: 77.0
 "A": 69.0
 "D": 73.8
 PNdB: 80.6

(Recorded at: 80 dB)



Run No. 55
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

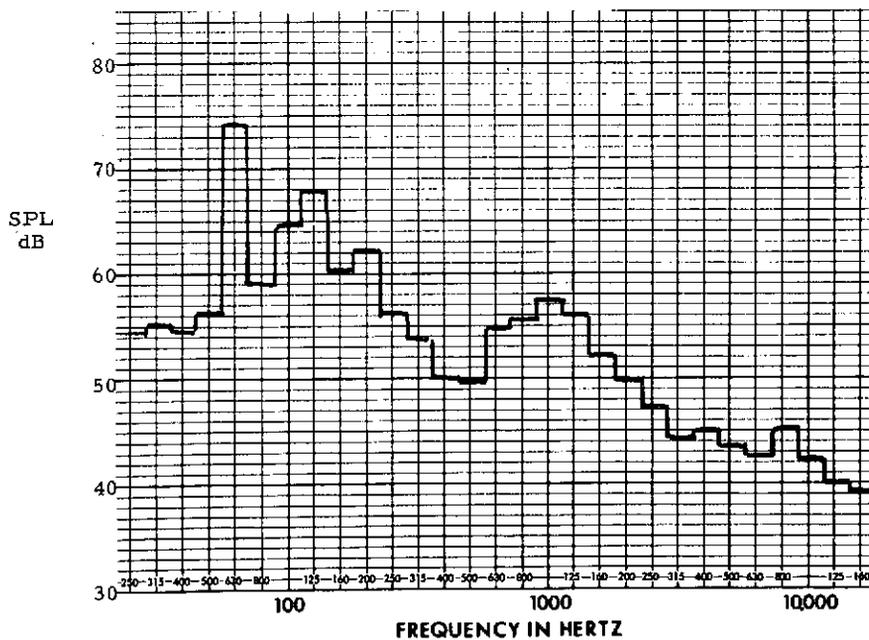
Main Rotor: Off
 Tail Rotor: Off
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 71.0
 "A": 54.0
 "D": 68.0
 PNdB: 74.9

(Recorded at: 70 dB)

"Quiet" Helicopter - Engine Only w/Exhaust Silenced - 222 HP



Run No. 60
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

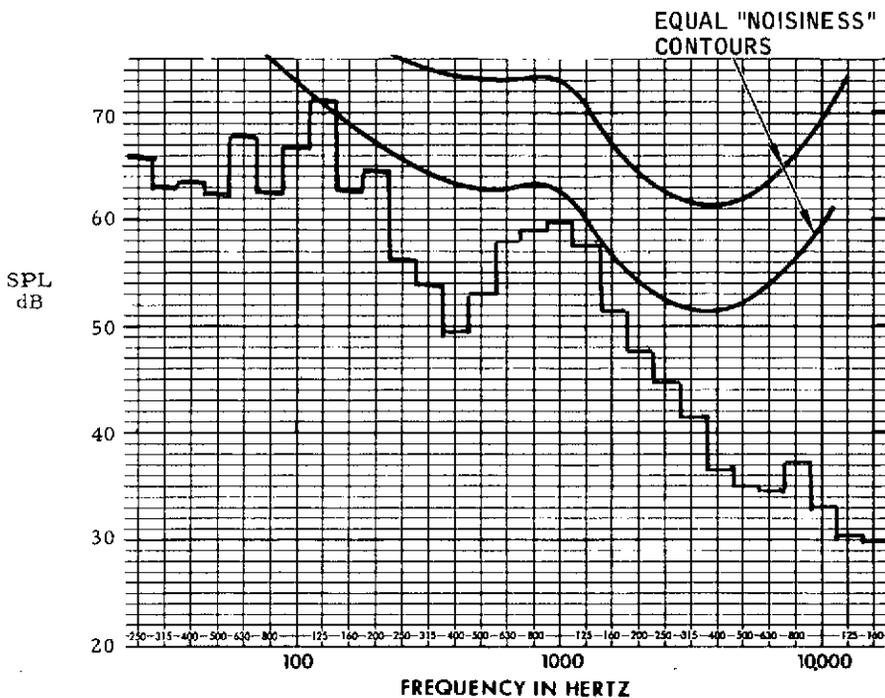
Main Rotor: Off
 Tail Rotor: 495 fps
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 76.0
 "A": 56.0
 "D": 71.4
 PNdB: 77.3

(Recorded at: 80 dB)

"Quiet" Helicopter - Tail Rotor Only w/Only 2 of 4 Blades Installed
 - 96 lb Thrust



Run No. 67
"QUIET" HELICOPTER

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

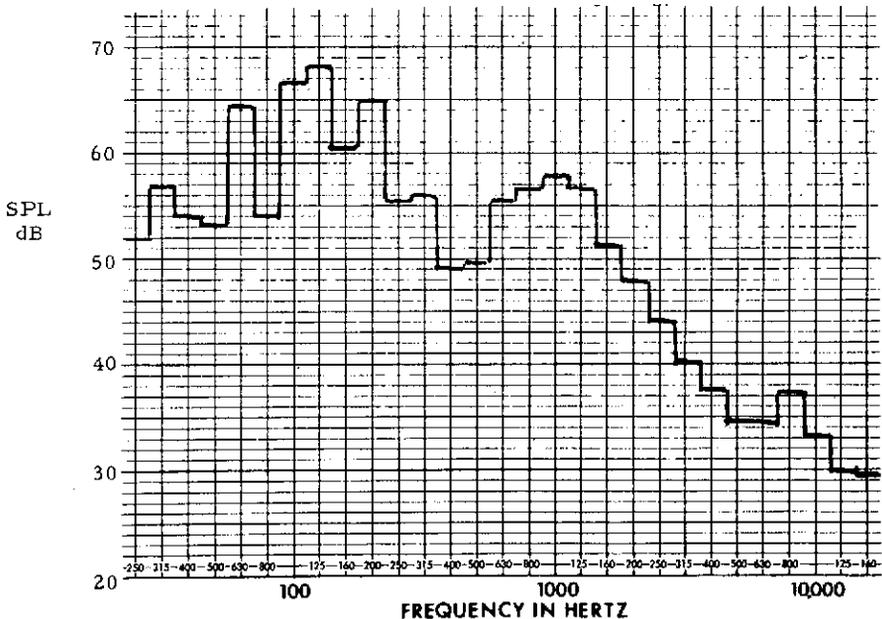
Main Rotor: Off
 Tail Rotor: 495 fps
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 76.0
 "A": 66.0
 "D": 70.9
 PNdB: 78.0

(Recorded at: 70 dB)

"Quiet" Helicopter - Tail Rotor Only w/Baseline 4 Blade Tail Rotor Installed (75°-105° Blade Spacing) - 149lb Thrust



Run No. 69
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

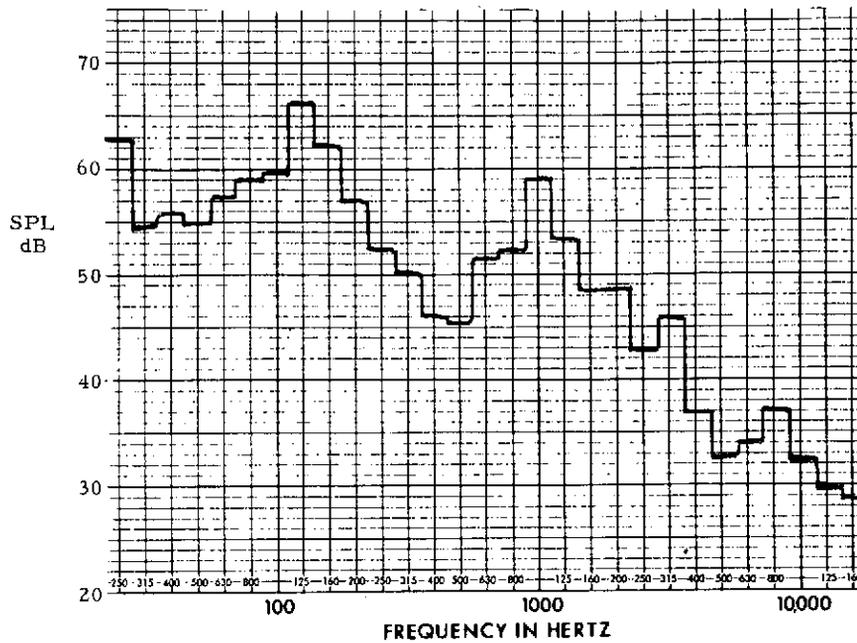
Main Rotor: Off
 Tail Rotor: 495 fps
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 73.0
 "A": 64.0
 "D": 69.5
 PNdB: 75.8

(Recorded at: 70 dB)

"Quiet" Helicopter - Tail Rotor Only w/Baseline 4 Blade Tail Rotor Installed (75°-105° Blade Spacing) - 107 lb Thrust



Run No. 81

"QUIET HELICOPTER"

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

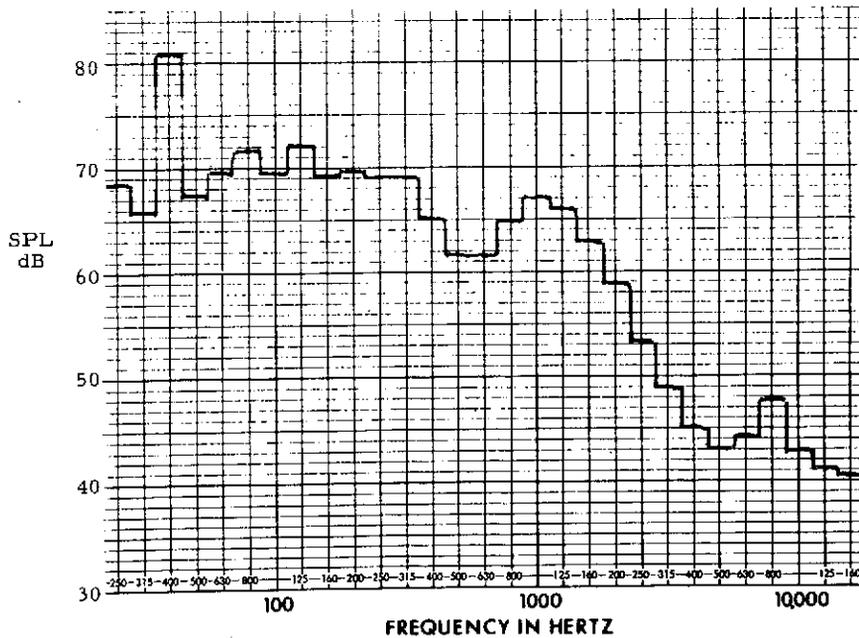
Main Rotor: Off
Tail Rotor: 336 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 71.0
"A": 63.0
"D": 67.5
PNdB: 73.5

(Recorded at: 70 dB)

"Quiet" Helicopter - Tail Rotor Only w/Baseline 4 Blade Tail Rotor Installed (75°-105° Blade Spacing) - 96 lb Thrust - 70% N₂



Run No. 83

"QUIET HELICOPTER"

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

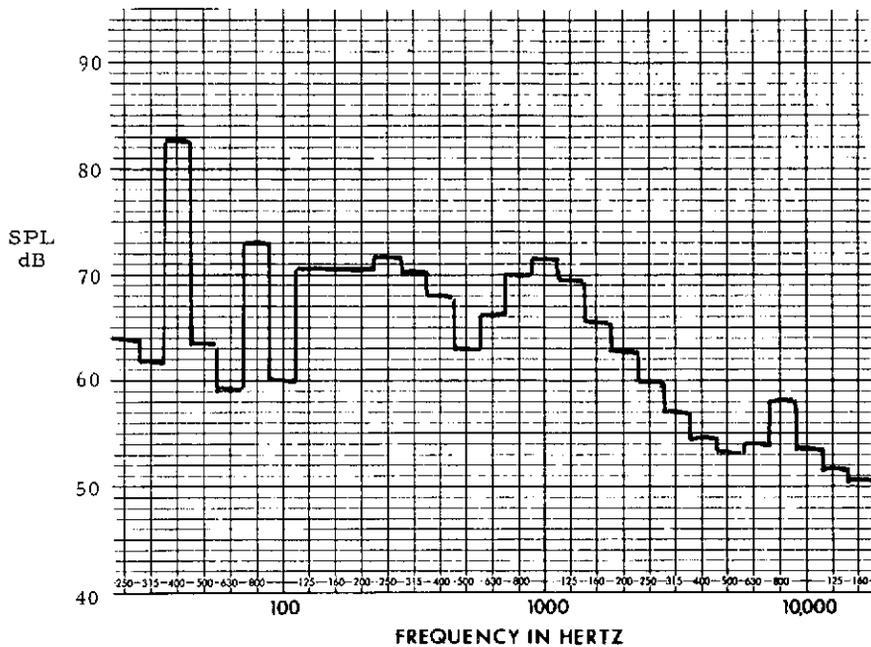
Main Rotor: 666 fps
Tail Rotor: 495 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 82.0
"A": 74.5
"D": 77.1
PNdB: 85.2

(Recorded at: 80 dB)

Baseline "Quiet" Helicopter - Less Engine - 2400 lb



"Quiet" Helicopter - Main Rotor Only w/Standard OH-6A
Main Rotor Blades (No Tapered Tips) - 2400 lb

Run No. 105
"QUIET" HELICOPTER

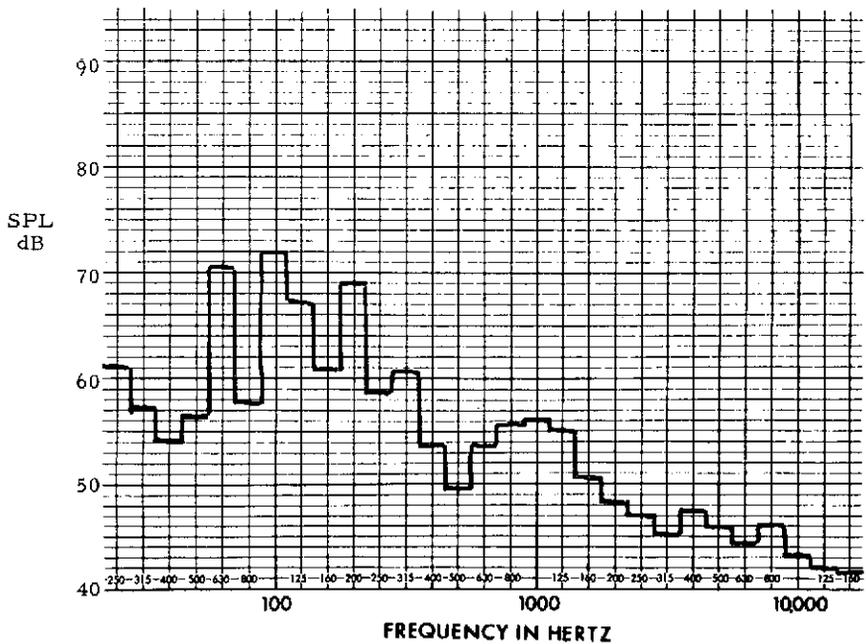
Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

Main Rotor: 666 fps
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 84.0
"A": 78.5
"D": 80.8
PNdB: 88.6
(Recorded at: 90 dB)



"Quiet" Helicopter - Tail Rotor Only w/60°-120° Blade Spacing
- 96 lb Thrust

Run No. 112
"QUIET HELICOPTER"

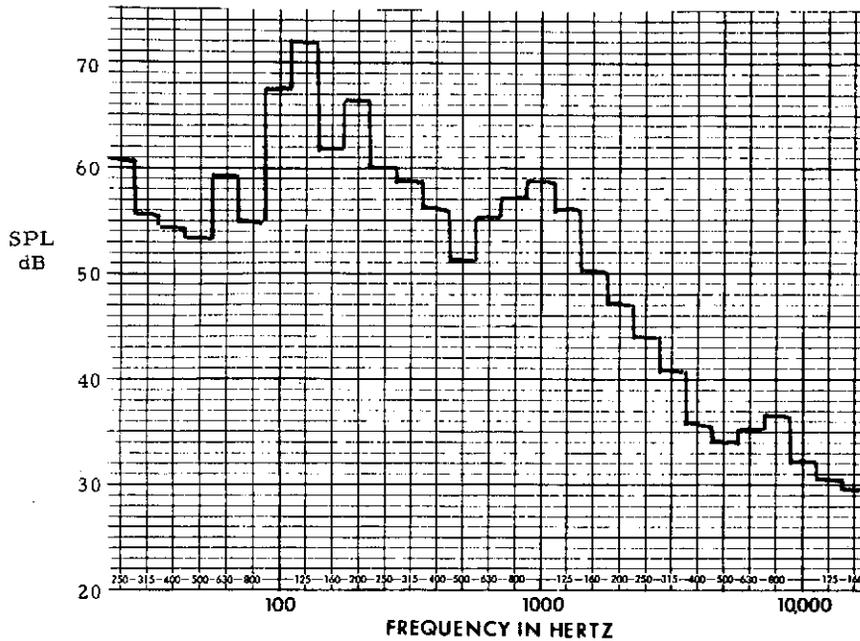
Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

CONFIGURATION

Main Rotor: Off
Tail Rotor: 495 fps
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: On

OVERALL NOISE LEVEL

Linear: 76.5
"A": 66.0
"D": 72.3
PNdB: 79.5
(Recorded at: 80 dB)



Run No. 117
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

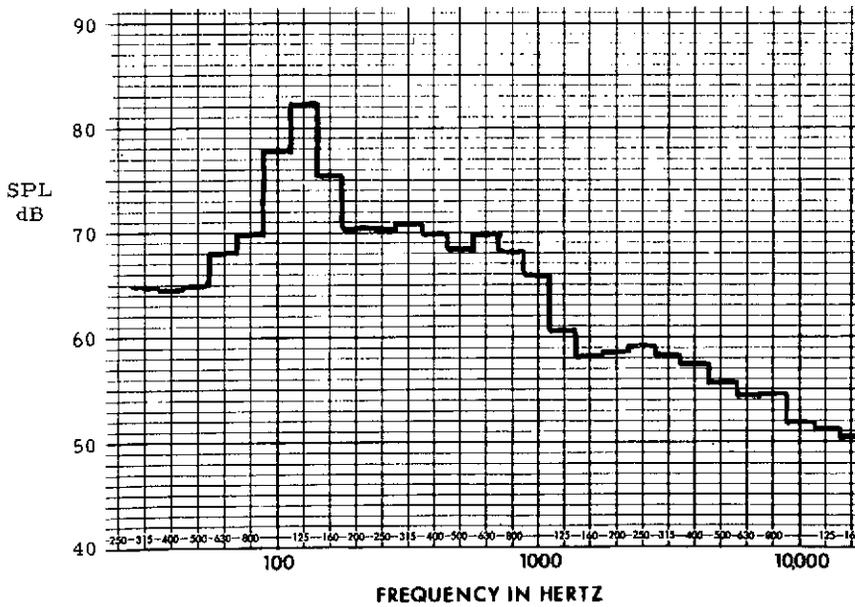
Main Rotor: Off
 Tail Rotor: 495 fps
 Cowl Doors: Insulated
 Exhaust: Silenced
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 75.2
 "A": 67.2
 "D": 70.9
 PNdB: 77.9

(Recorded at: 70 dB)

"Quiet" Helicopter - Tail Rotor Only w/90°-90° Blade Spacing
 - 96 lb Thrust



Run No. 121
"QUIET HELICOPTER"

Simulated Hover
 6' Skid Height
 (Microphone at 200 ft
 30° L of aft)

CONFIGURATION

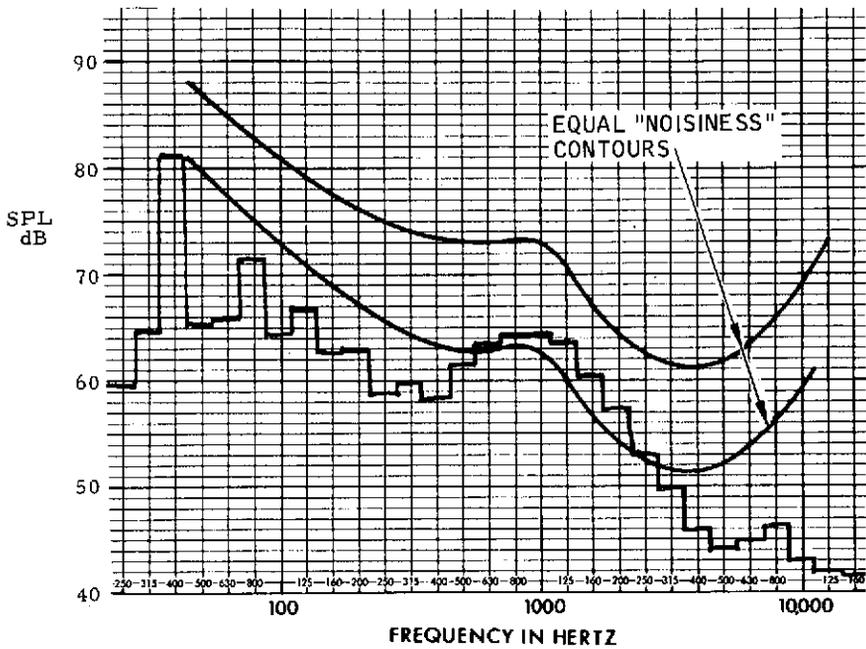
Main Rotor: Off
 Tail Rotor: Off
 Cowl Doors: Off
 Exhaust: Open
 Dynamometer: On

OVERALL NOISE LEVEL

Linear: 86.5
 "A": 77.0
 "D": 83.0
 PNdB: 90.2

(Recorded at: 90 dB)

"Quiet" Helicopter - Engine Only w/Flight Muffler &
 Cowl Doors Removed - 222 HP



Baseline "Quiet" Helicopter - 2400 lb

Run No. 239

"QUIET HELICOPTER"

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

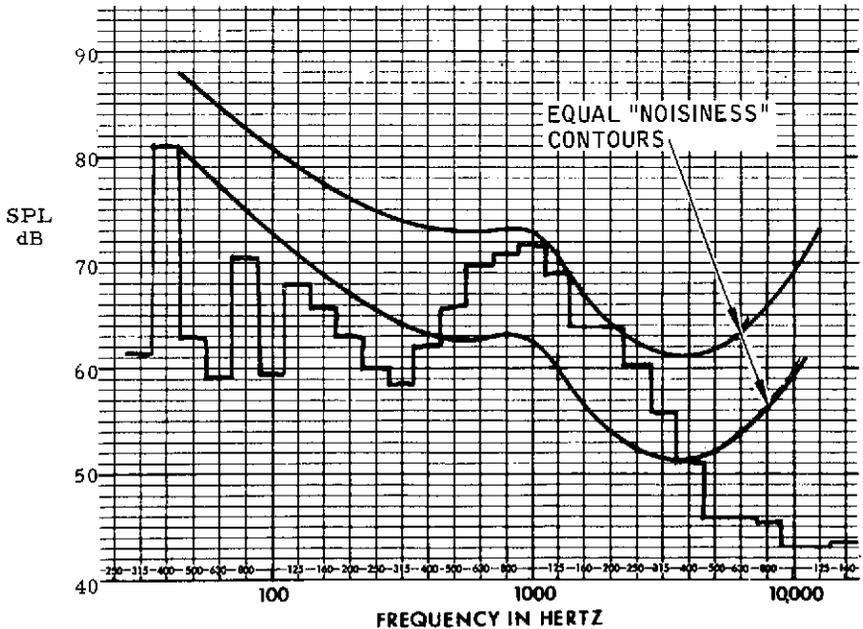
CONFIGURATION

Main Rotor: 666 fps
Tail Rotor: 495 fps
Cowl Doors: Insulated
Exhaust: Flt Muff
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 83.5
"A": 71.0
"D": 76.0
PNdB: 82.5

(Recorded at: 80 dB)



"Quiet" Helicopter - Main Rotor Only - 2400 lb - 103% N₂

Run No. 243

"QUIET" HELICOPTER

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

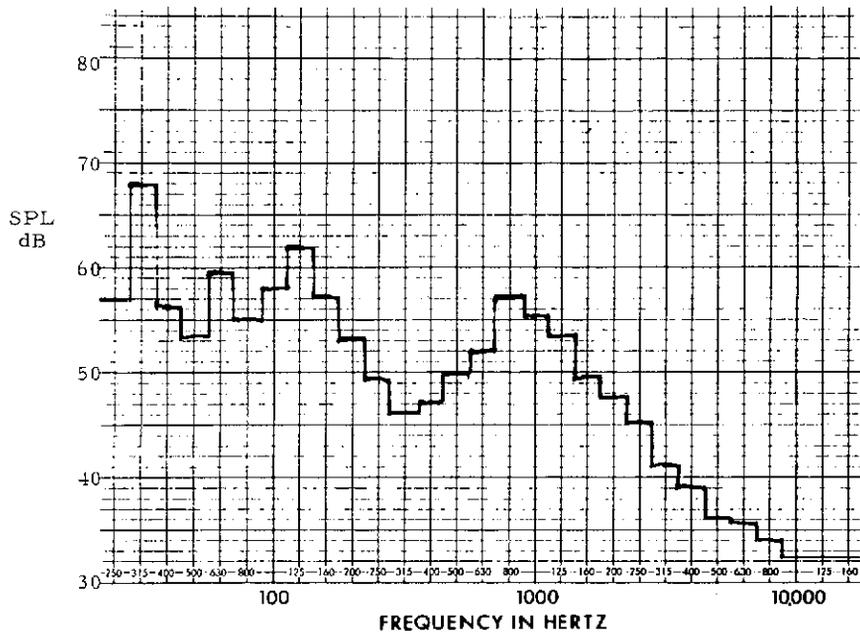
CONFIGURATION

Main Rotor: 666 fps
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

OVERALL NOISE LEVEL

Linear: 83.0
"A": 66.8
"D": 80.8
PNdB: 86.7

(Recorded at: 80 dB)



"Quiet" Helicopter - Main Rotor Only - 2400 lb - 80% N₂

Run No. 253

"QUIET HELICOPTER"

Simulated Hover
6' Skid Height
(Microphone at 200 ft
30° L of aft)

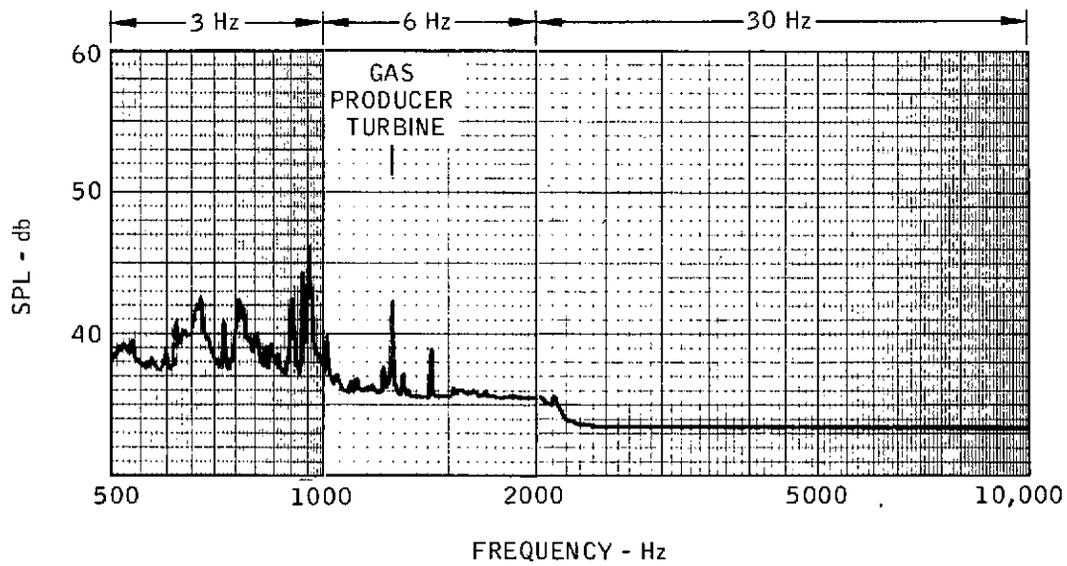
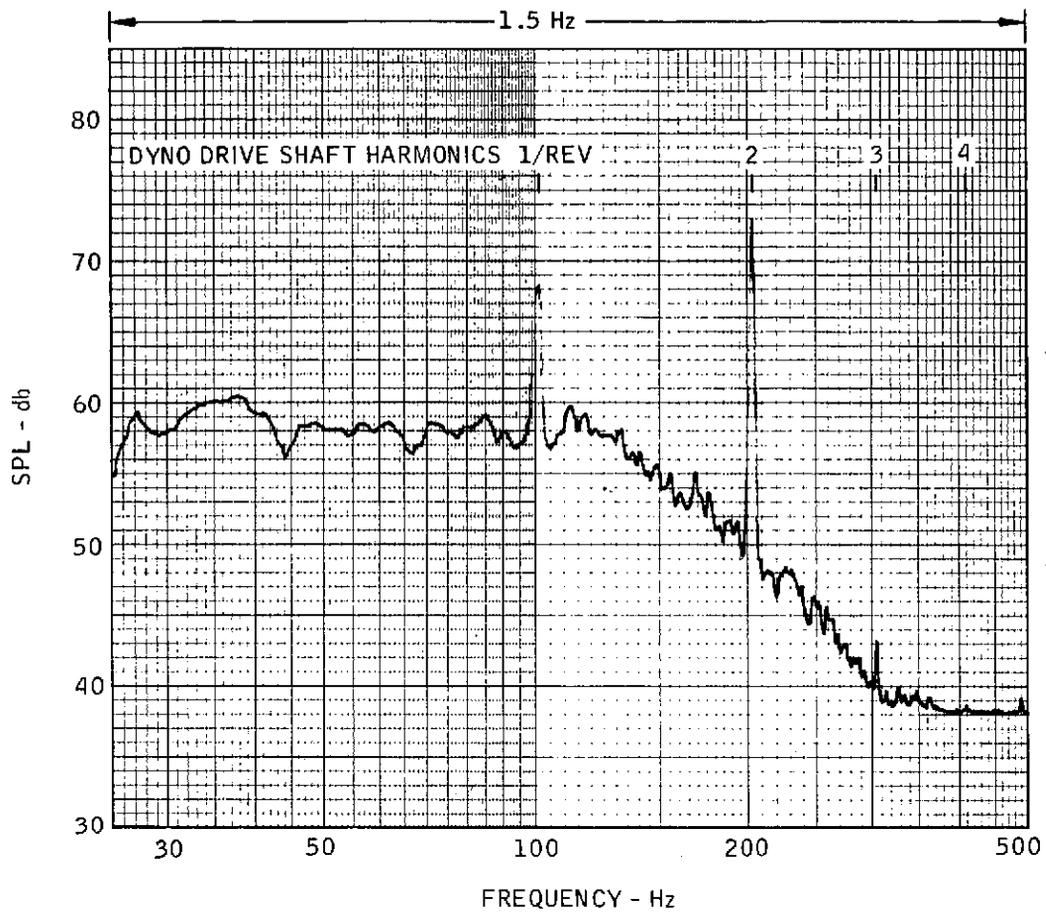
CONFIGURATION

Main Rotor: 518 fps
Tail Rotor: Off
Cowl Doors: Insulated
Exhaust: Silenced
Dynamometer: Off

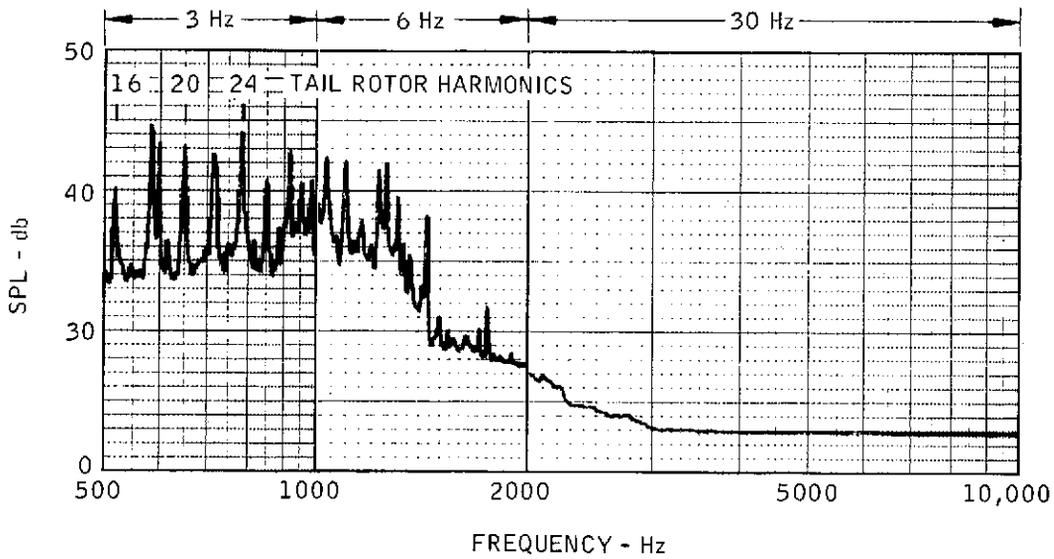
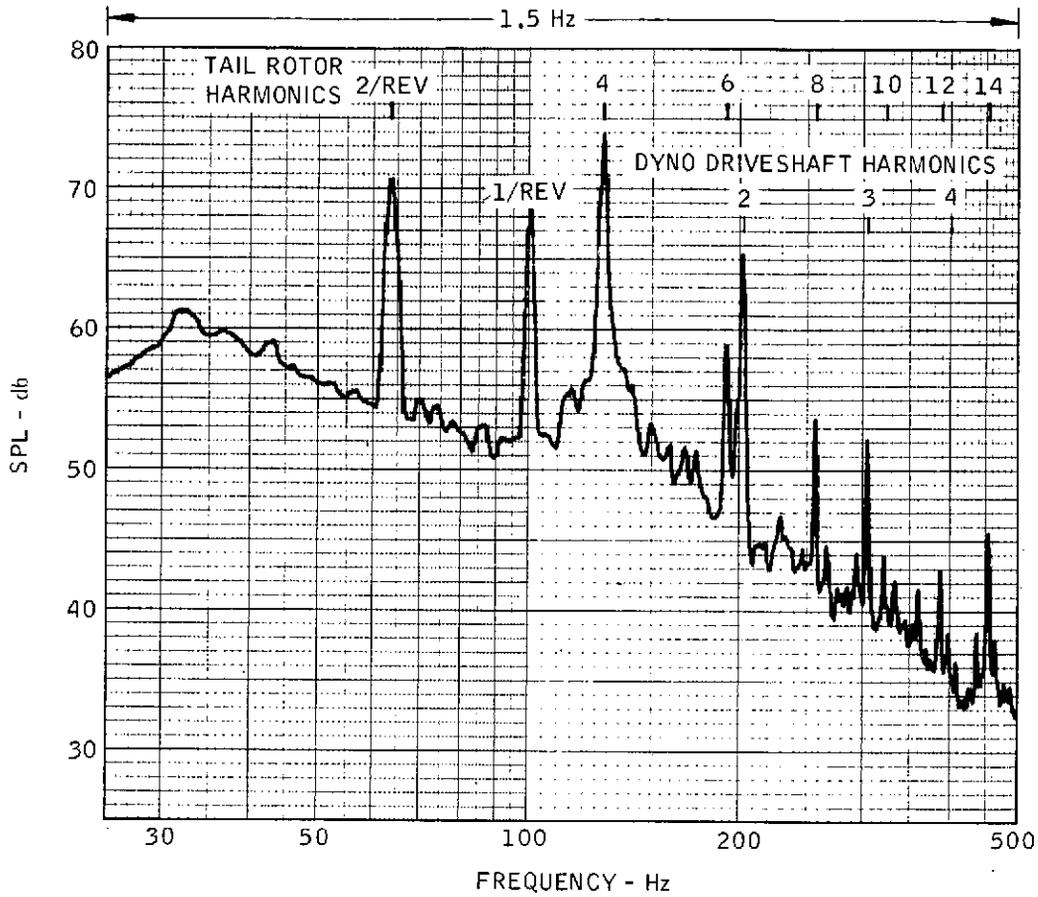
OVERALL
NOISE LEVEL

Linear: 70.6
"A": 53.5
"D": 66.5
PNdB: 72.6

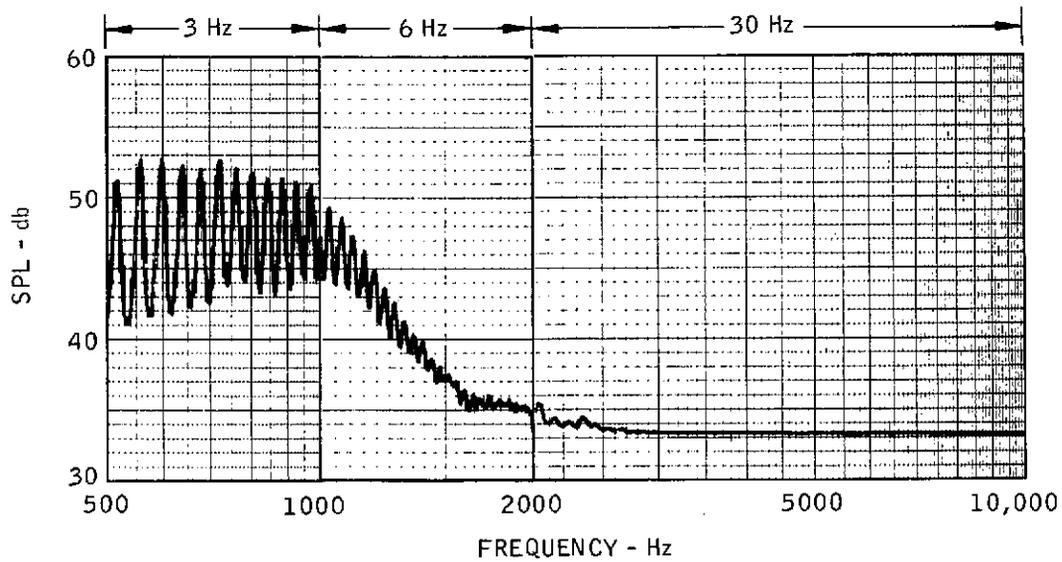
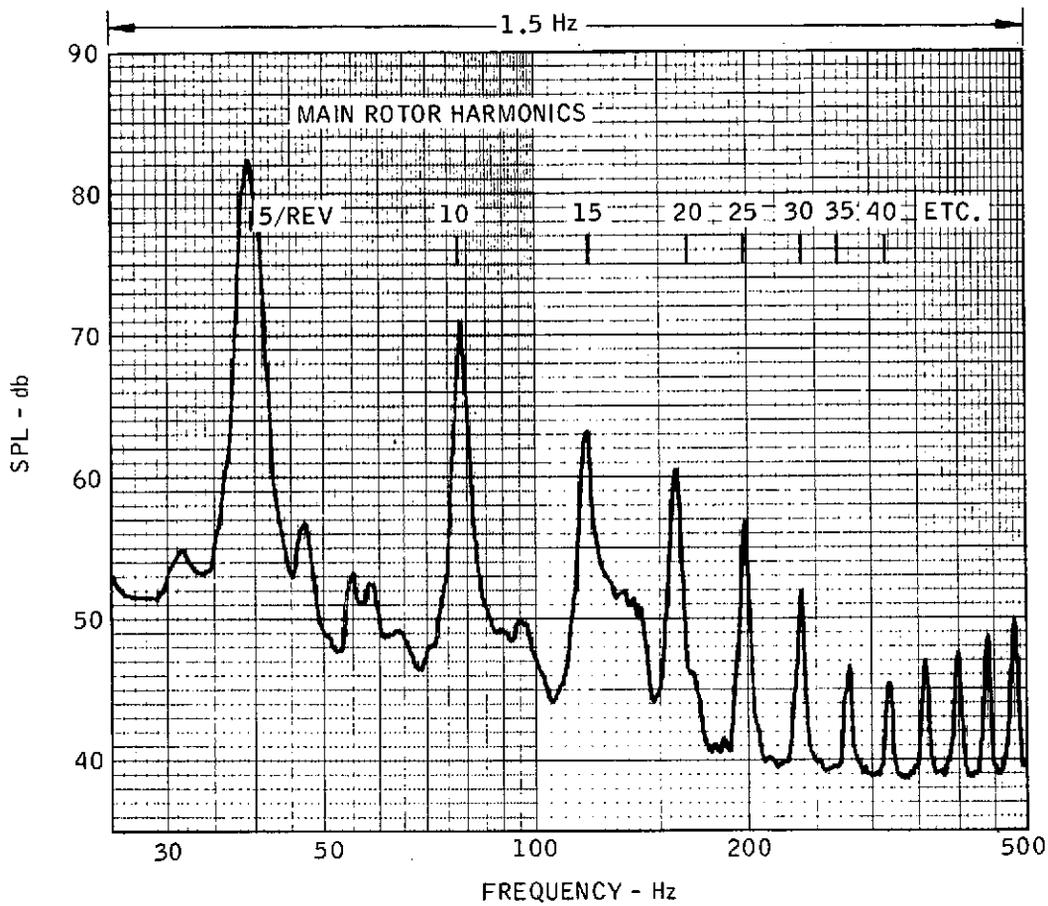
(Recorded at: 70 dB)



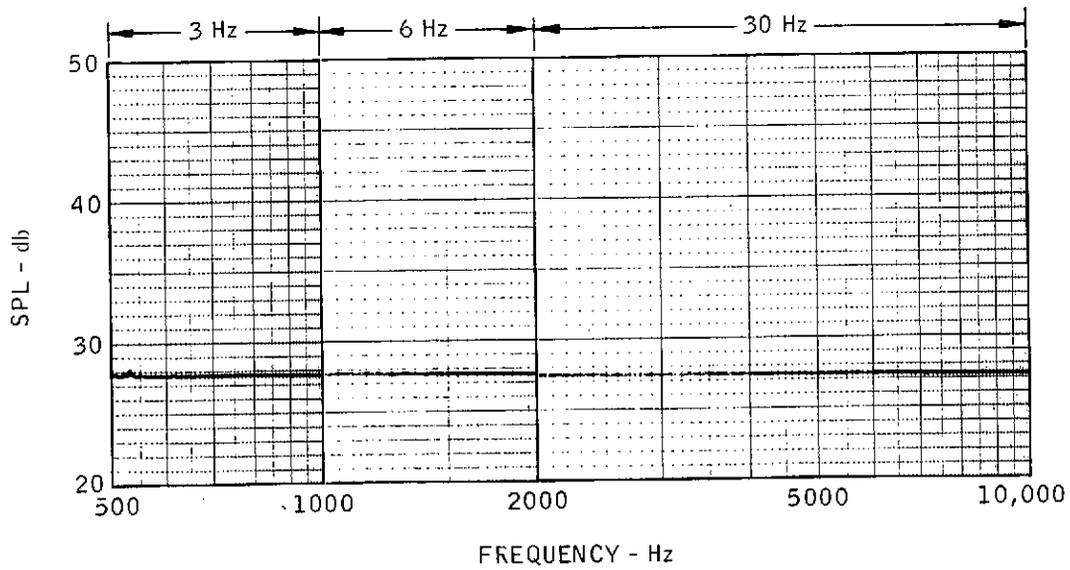
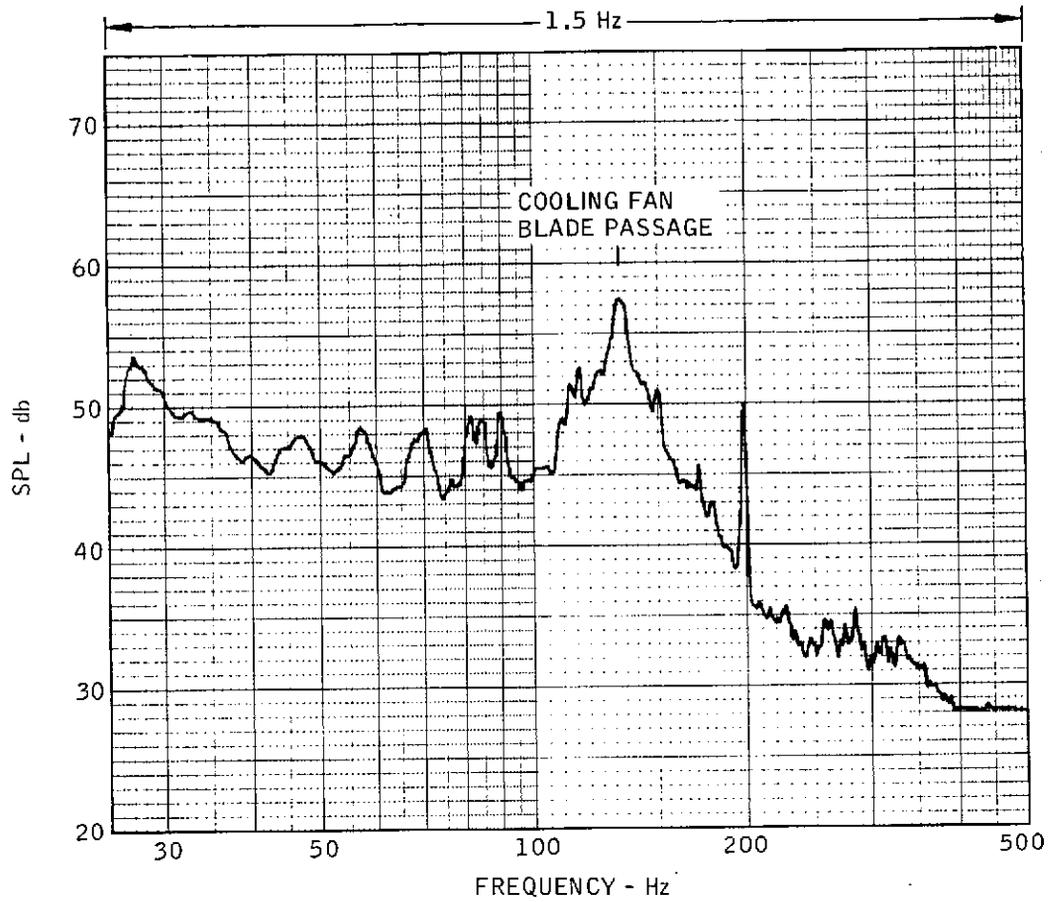
Run 30. Narrow Band Spectra Plot, "Quiet" Helicopter - Engine Only



Run 67. Narrow Band Spectra Plot, "Quiet" Helicopter - Tail Rotor Only (4-Bladed)



Run 243. Narrow Band Spectra Plot, "Quiet" Helicopter - Main Rotor Only (5-Bladed)



Run 35. Narrow Band Spectra Plot
Typical Ambient Record

APPENDIX II

POSSIBLE ERRORS IN TEST DATA RESULTING FROM GROUND REFLECTION WAVES

The tests were conducted in an open area with a grass surface at the reflection point between the test helicopter and the microphone. The grass surface was selected to reduce the ground reflection waves. Since all of the data was comparative, it was felt that no correction would be necessary for the ground reflection waves as they would exist in both runs being compared and would therefore cancel out.

In arriving at this assumption, two important factors were overlooked. First, the condition of the surface would not remain the same between comparative tests. In many cases, rain fell between the tests making the grass surface vary from very dry to very wet throughout the test program.

Second, the height of the noise source has a strong influence on the frequency at which the reflected wave will add or subtract from the primary wave. So, when comparing two different noise sources at the same frequency, but which originate at two different heights above the ground, the effect of the ground reflection waves will not be the same for both and therefore will not cancel out. For instance, a 1000 Hz noise originating at the main rotor which is 14 feet above the ground might have an error of -3 decibels, while a 1000 Hz noise coming from the tail rotor at 10 feet above the ground would only have an error of -1.5 decibels. This effect is shown in Figure 11, which was calculated by the method outlined in reference 2, using an estimated surface reflective constant.

To determine the effect of ground reflection waves, a number of test runs were repeated with the microphone raised to 8 feet instead of 4 feet. Figure 12 shows the theoretical error this should produce, again using the method given in reference 2. It will be noted that the maximum difference in recorded SPL between the two microphone heights should occur at 1000 Hz. Figure 13 (Run 214) shows one of the more severe variations in frequency spectra data with microphone height. The error indicated at 1000 Hz is in good agreement with the theoretical correction curve. However, throughout the rest of the spectrum there appears to be little, if any, correlation. Certainly any attempt to use the theoretical correction curve to improve the quality of the data would have been futile.

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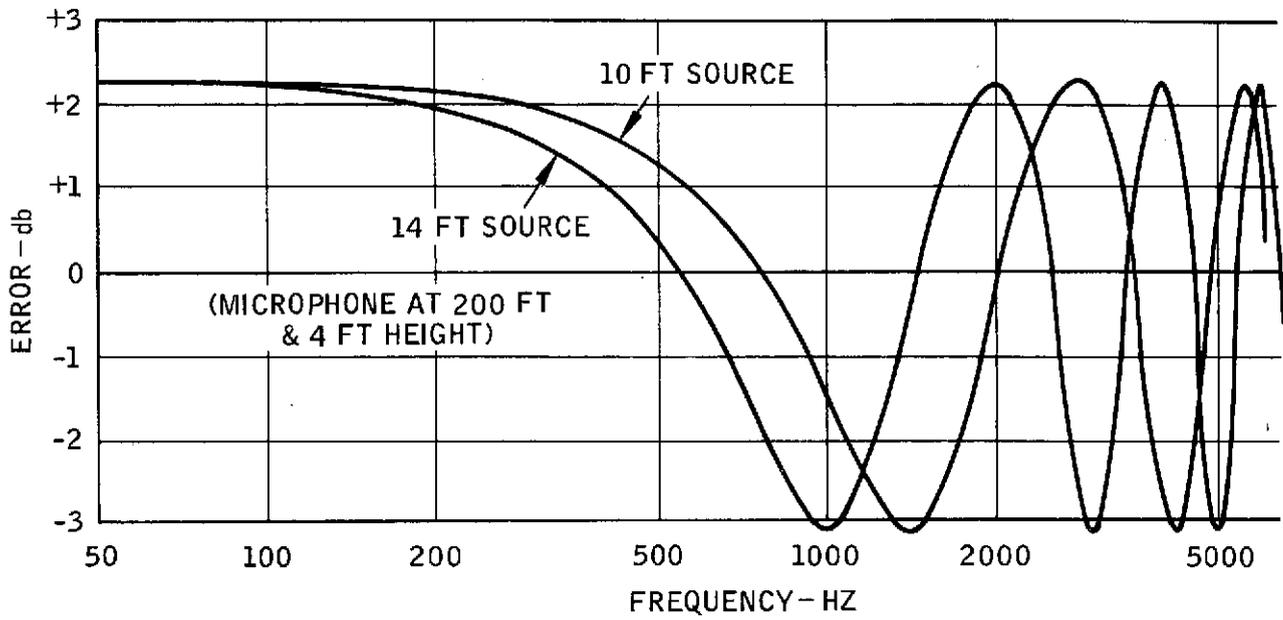


Figure 11. Effect of Noise-Source Height on Error Due to Ground Reflection Waves

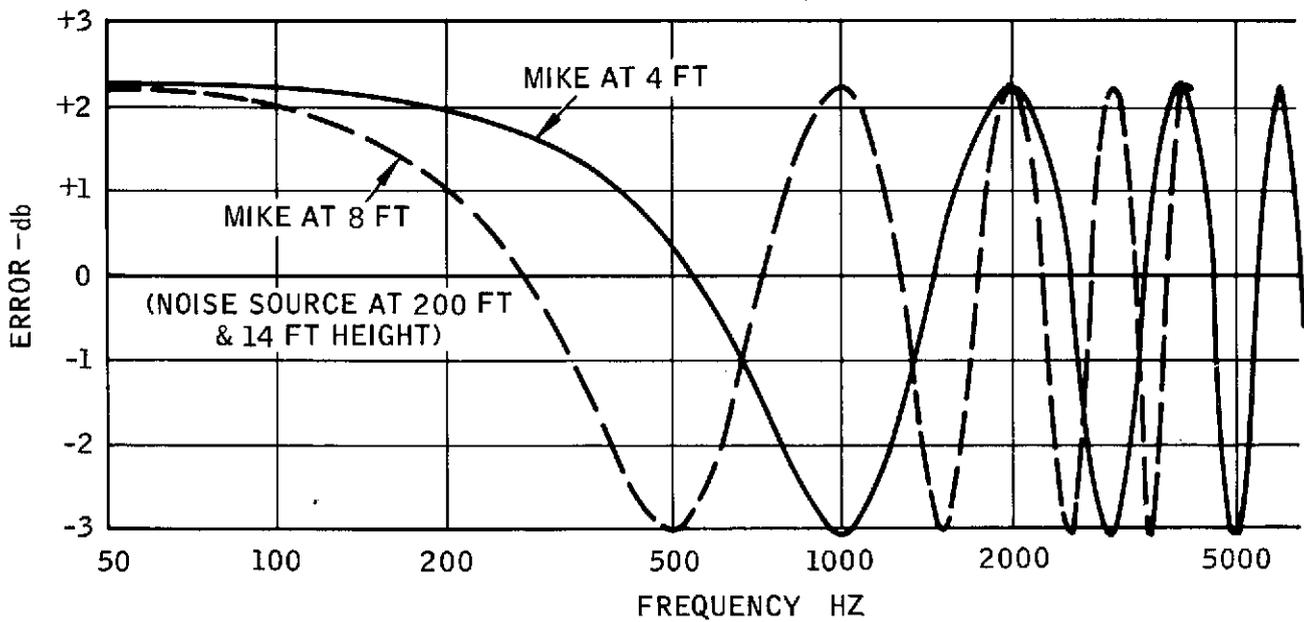


Figure 12. Effect of Microphone Height on Error Due to Ground Reflection Waves

Table IV shows the difference in OASPL for the runs when the microphone was raised to eight feet. The linear and PNdB values usually did not vary by more than 2 or 3 db. However, the "A" weighted readings varied by five or more db and for that reason were not used in the final evaluation of the data. The values shown in Table IV are not the error due to the ground reflection wave but rather, the error at 4 feet in one direction combined with the error at 8 feet in the other direction. The actual error in the data at 4 feet would only be approximately one-half or two-thirds of these values and most of this would cancel out in the comparative tests. In future tests, perhaps lowering the microphone height or erecting a physical barrier to intercept the ground reflection waves should be considered.

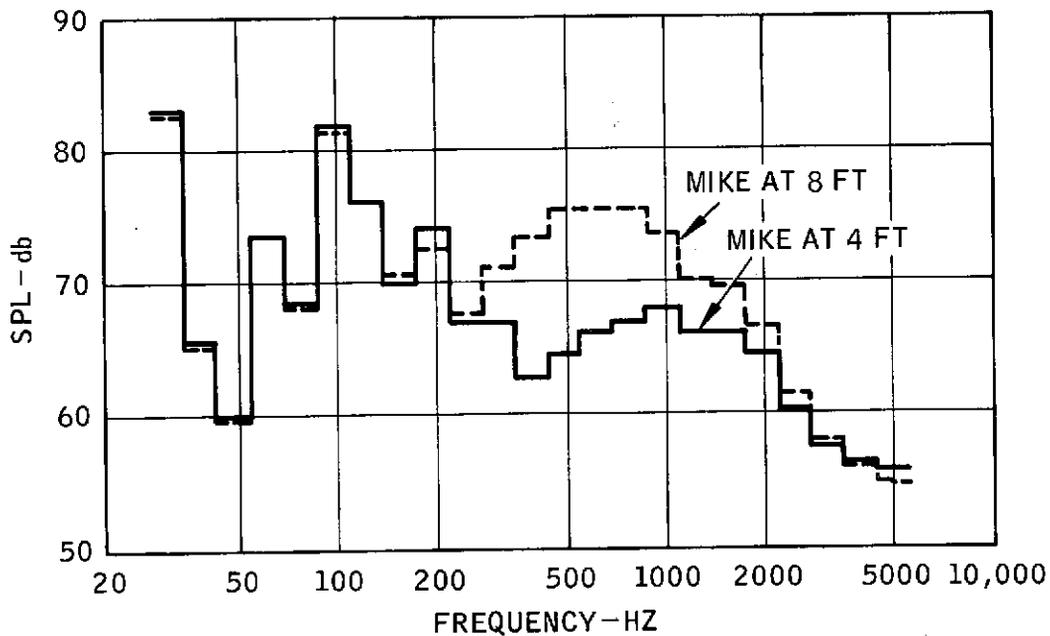


Figure 13. Spectra Plot of Complete OH-6A Helicopter Recorded at 200 Ft With Two Microphone Heights

Table IV. Effect of Ground Reflection Waves on OASPL Values

OASPL at 8 Ft Compared to 4 Ft Microphone Height				
Run No.	A Weighted db	D Weighted db	Linear db	PNdB
14	+3.3	+2.5	+0.3	+2.6
18	+1.3	+0.7	+0.2	+1.3
19	+7.7	+2.0	+0.3	+2.0
20	+1.0	+0.6	-1.7	+0.3
21	-0.7	-0.8	-0.4	-2.8
22	-1.0	-0.2	-0.7	-1.3
211	0	0	-0.5	+0.5
212	+5.0	+4.0	0	+3.1
213	+2.0	+0.5	0	-0.3
214	+5.0	+3.0	+0.5	+2.1
215	+2.0	+2.0	+0.3	-0.4
216	+2.0	+1.5	0	+2.1
217	+5.0	+2.0	+1.0	+2.8
218	+5.0	+3.0	+1.0	+1.2
219	+5.0	+3.0	+1.0	+2.5
240	+1.0	+0.5	0	+1.0
241	+4.0	+4.5	+3.0	+3.3