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NOISE LEVELS OF OPERATIONAL HELICOPTERS OF THE OH-6 TYPE DESIGNED TO MEET THE LOH MISSION

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NOISE LEVELS OF OPERATIONAL HELICOPTERS OF THE OH-6 TYPE DESIGNED TO MEET THE LOH MISSION

SUMMARY

A program of test and design was conducted with the following aims:

1. An investigation into possible effects of lack of instrumentation dynamic acoustic range at the higher frequency ranges of data reported in Reference 1 was conducted. This investigation consisted of repeats of selected tests of Reference 1 with two recording channels, one of which had a high pass filter to attenuate signals below 500 Hz, the other channel of which was unfiltered. The results showed no significant changes from earlier tests. The filtered channel should show more accurate values of SPL at high frequencies than the unfiltered channel. The test rig used was that described in Reference 1.

   Certain other tests were conducted attempting to determine whether any significant ground reflection waves existed. These tests consisted of comparing records from a microphone at 4 feet with those of a microphone at 9 inches off the ground. Substantial and consistent differences as a function of frequency were found. These differences are not explainable on the simple basis of lengths traveled by the direct wave and the reflected wave, and calculating whether the reflected wave augments or reduces the direct wave at the microphone position. In fact, the data seems the direct opposite of the simple theory.

   All tests were conducted in an open area, during the middle of the night with the wind and with all other known variables either eliminated, or kept as constant as possible.

2. A helicopter design program aimed at producing preliminary designs of operational helicopters of the OH-6 type which meet the LOH mission using the Allison C-20 engine. These designs were in two general areas.

   a. Helicopters designed for optimum performance, without regard to noise level.

   b. "Quieted" helicopters designed to meet the mission but at reduced payload as necessitated by the quieting provisions.

No less than 13 designs were investigated. Payload and noise levels are presented and a range of penalties for quietness in terms of reduced payload per dB of noise reduction was established. These penalties range from 6 to 30 pounds of payload per dB of overall sound pressure level (linear scale). The major single item affecting payload is the power-robbing aspect of the muffler.

Formulas relating OASPL to parameters such as horsepower required, tip speed, and thrust for main and tail rotors are presented for standard and "quieted" versions. Formulas relating OASPL to engine parameters such as horsepower output and percent power turbine rpm are presented for unmuffled and muffled engines. The linear scale was used in preference to any of the weighted scales because it resulted in more consistent agreement with the test data when the SPL is expressed in the usual parameters of tip speed, thrust generated and power required. It is recognized that the linear scale does not adequately reflect hearing response, and hence is not a good absolute measure for detection by humans. However, linear OASPL is believed to be useful as a relative means of comparing noise level variations of individual components in similar helicopters with reasonably modest design changes. Perhaps this is tantamount to assuming that there are no significant changes in the harmonic content of each noise source accompanying these design changes.

A simple autorotation parameter involving main rotor kinetic energy is presented to assure satisfactory emergency operational autorotation. A discussion is presented of a recommended method to achieve this satisfactory level of emergency autorotation if rotor kinetic energy is too low (due to reduced tip speeds).

Formulas are presented for estimating the weights of helicopters of this type being considered, including a brief discussion of weight of muffler for engine quieting.

INTRODUCTION

Previous programs conducted by this Contractor have resulted in substantial reduction of noise levels of an OH-6 helicopter (Reference 2). These modified OH-6 helicopters were not designed to be operational, and hence no rigorous assessment of the penalties for quietness could be derived.

The measurement program of Reference 1 resulted in a wide variety of data on the individual noise producing components of helicopters. This data has been used to derive formulas expressing the noise level of the noise producing components in terms of the parameters available to a designer in the preliminary design phase.

These machines are designed to be operational, and the requirements were selected as those met by the OH-6A in performing the light observation mission. The engine to be used is the Allison C-20 with a rating of 400 horsepower. The OH-6A is powered by the Allison C-18 with a rating of 317 horsepower.

Performance Requirements

The performance requirements given below are from Reference 3.

V_{NE}, CAS sea level standard	128 knots
Hover ceiling at mil power IGE 95°F	6240 feet
Range sea level including 2 minutes N_{RP} warm up and 10 percent reserve (61.5 gal fuel)	277 nautical miles
Endurance S. L. including 2 minutes N_{RP} warm up and 10 percent reserve (61.5 gal fuel)	3.3 hours
Hover ceiling, OGE standard day at alternate gross weight*	Sea level
Hover ceiling, IGE standard day at maximum structural weight**	3000 feet

*2609 pounds
**2700 pounds

Note:

1. Weights for the basic mission are as follows:

Crew	200 pounds
Fuel	400
Cargo	347
Useful	947
Weight empty	1219.5
Mission gross weight	2166.5 pounds

2. The OH-6A is certificated for a gross weight of 2400 pounds.

METHODOLOGY

General. - It is assumed that noise of a helicopter is generated by the following components: Main rotor, tail rotor, and engine and power train. The tests that are the basis of this report measured separately main rotor noise, tail rotor noise, and engine noise. The power train noise elements, i.e., main and tail rotor transmissions are included with the appropriate rotor system since that is the way the sound measurements were made.

Thus, it is theorized that the noise level of helicopters under consideration can be considered as being composed of main rotor, tail rotor, and engine noise. Formulas for expressing the OASPL of these components are derived from the test data.

These noise levels are then combined in the usual fashion, with a resultant OASPL.

Performance is derived on the basis of rotor tip speed and rotor radius. This establishes a mission gross weight based on the ability to hover at 6240 feet, 95°F, mil power IGE (power available is based on engine characteristics and atmospheric conditions).

Fuel weight for endurance and range are computed, and alternate gross weights computed for the hover OGE sea level standard conditions and for the hover IGE, 3,000 foot standard condition (maximum structural weight).

Component weights are computed based on powers, rotor size, solidity, etc., to arrive at empty weights. Use of these weights and the maximum gross weight based on performance permit determination of payload.

We are then in a position to compare payload with noise level, which is an aim of the study.

Performance. - Table I presents performance data for 9 "unquieted" versions and 2 "quieted" versions (with muffler and reduced rotor tip speed).

The OH-6A was used as baseline for performance analyses. The parasite area for the newly designed machines was assumed the same as the OH-6A. The Allison C-20 engine was used and the transmission rating was assumed sufficient to handle the full engine take-off rating of 400 horsepower. For cases 1 through 9, the blade aspect ratio was assumed equal to that of the OH-6A.

The tail rotor was sized to handle the full power of the C-20 engine on a standard day. It is assumed to be an all metal cambered, two-bladed tail rotor. Thus at a tail rotor tip speed of 692 feet per second, the tail rotor is the same size as that of the present Model 500C tail rotor which also uses the C-20 engine.

For all cases, the fuel capacity must be increased over that of the OH-6A in order to meet the 3.3 hours of endurance at sea level standard. As a consequence, the range with the fuel available is greater than the present 277 nautical mile.

Weight Data. - Table II presents component weight data for the basic OH-6A, nine "unquieted" versions (cases 1-9) and two quiet designs (cases 10 and 11).

The OH-6A was used as a baseline for weight analysis. The following formulas were used to calculate component weights:

1. Main rotor

(Blade) $$W_b = 0.2255(RC)^{1.144}\ V_T^{0.386}\ b = \text{Total blade weights}$$

(Hub and retention) $$W_{H+R} = 0.00166(W_b)^{0.844}\ R^{0.548}\ V_T^{0.805}$$

FOLDOUT FRAME

FOLDOUT FRAME

TABLE I

SUMMARY OF PERFORMANCE DATA

	Case No.	Main Rotor: Number of Blades	Main Rotor: Radius (ft)	Main Rotor: V_T (fps)	Mission Gross Weight Hover 4 ft Skid Height 6240' 95°F pounds	Fuel For 3.3 Hr** Endurance (Gal) Sea Level Std	Range (nm)** Sea Level Std	V_{MAX} T.O. HP (Knots) Sea Level Std	V_{MAX} at S.L. Maximum Continuous Power	V_{NE} (Knots)	Alternate Gross Weight Hover IGE at 3000 ft	Maximum Structural Gross Weight Hover OGE at Sl. Std.	Main Rotor Solidity	Main Blade Chord (ft)	Tail Rotor: Radius ft	Tail Rotor: Chord Inches	Tail Rotor: V_T fps	Tail Rotor: HP Hover 6240 ft 95°F
Standard	1	4	13.165	660	2534	71.2	303	146	140	108	3770	3570	0.0544	0.5625	2.125	5.3	692	26
Standard	2	4	14.0	660	2625	72.3	305	148	143	134	3581	3680	0.0544	0.5982	2.125	5.3	692	26
Standard	3	4	15.0	660	2737	74.0	308	150	143	$>V_{MAX}$	3743	3791	0.0544	0.6409	2.125	5.3	692	26
Standard	4	4	13.165	750	2505	76.8	308	150	140	$>V_{MAX}$	3424	3460	0.0544	0.5625	1.80	4.4	779	27
Standard	5	4	14.0	750	2590	78.5	303	148	138	$>V_{MAX}$	3548	3556	0.0544	0.5982	1.80	4.4	779	27
Standard	6	4	15.0	750	2706	80.7	299	144	134	$>V_{MAX}$	3709	3668	0.0544	0.6409	1.80	4.4	779	27
Standard	7	5	13.165	600	2594	71.2	304	143	136	115	3547	3540	0.068	0.5625	2.49	6.2	623	26
Standard	8	5	14.00	600	2713	72.9	306	144	139	129	3694	3680	0.068	0.5982	2.49	6.2	623	26
Standard	9	5	15.00	600	2815	74.0	307	146	140	$>V_{MAX}$	3846	3870	0.068	0.6409	2.49	6.2	623	26
Quieted	10	5	14.0	615	2490	75.2	279	>136	134	136	3470	3470	0.068	0.598	2.31	5.5	450	22
Quieted	11	5	14.0	550	2490	74.3	279	>130	129	130	3590	3565	0.0872	0.767	2.44	5.9	405	21
	OH-6A	4	13.165	660	2167	61.5	277	136	128	128	2700	2609	0.0544	0.5625	2.125	5.3	692	-

**Include 2 minute warmup and 10 percent reserve.

NOTES:
1) Rate of climb for all these machines is estimated to approximate 2200 ft/min at 60 kts
2) The muffler reduces engine power by35 H.P. at Sea Level and 29 H.P. at 6000' 95°
3) The muffler increases fuel flow 10 lbs per hour
4) OH-6A V_{MAX} based on derated engine power as follows:
   a) T.O. - 252 H.P.
   b) MAX. Cont - 221 H.P.
5) New designs with C-20 engine not derated
6) Tail rotors 1-9 are 2-bladed. 10 and 11 are 4-bladed.

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TABLE II

SUMMARY OF WEIGHT DATA

	Basic OH-6A	Standard									Quieted	
		Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11
Main Rotor	172.4	176.9	204.5	240.9	191.8	221.8	261.1	198.9	229.8	270.5	239.4	291.6
Tail Rotor	6.5	6.5	6.5	6.5	4.6	4.6	4.6	8.4	8.4	8.4	9.0	10.5
Tail Surfaces	16.3	16.3	16.8	17.5	16.3	16.6	17.3	16.6	17.3	18.0	16.3	16.3
Fuselage	247.9	247.9	264.9	286.3	247.9	263.4	284.9	249.3	268.1	289.2	247.9	247.9
Alighting Gear	66.2	66.2	68.1	71.1	66.2	67.2	70.2	67.3	70.4	73.1	66.2	66.2
Flight Controls	64.5	64.5	65.8	67.2	64.5	65.7	67.1	67.2	68.7	70.1	68.0	68.0
Engine & Mounts	154.0	172.0	172.0	172.0	172.0	172.0	172.0	172.0	172.0	172.0	172.0	172.0
Fuel System	35.2	39.1	39.5	40.2	41.3	42.0	43.0	39.1	39.8	40.2	38.5	38.0
Drive System	113.3	144.5	151.3	159.5	132.3	138.6	145.8	156.2	163.8	172.5	150.0	163.0
Misc. Fixed Propulsion	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	51.4	91.4*	91.4*
Fixed Equipment	291.8	291.8	291.8	291.8	291.8	291.8	291.8	291.8	291.8	291.8	291.8	291.8
Weight Empty	1219.5	1277.0	1333.0	1404.0	1280.0	1335.0	1409.0	1318.0	1383.0	1457.0	1391.0	1457.0
Crew	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0	200.0
Fuel	400.0	463.0	470.0	481.0	499.0	510.0	525.0	463.0	474.0	481.0	489.0	483.0
Cargo or payload	347.0	594.0	622.0	652.0	526.0	545.0	572.0	613.0	657.0	677.0	410.0	350.0
Mission Gross Weight (Hover IGE at 6240' 95°F)	2166.5 **	2534.0	2625.0	2737.0	2505.0	2590.0	2706.0	2594.0	2713.0	2815.0	2490.0	2490.0

*The quieted machines include a net increase of 40 lbs for the muffler

**Basic OH-6A is certificated for 2400 lbs. The commercial version is certificated for 2550 lbs.

2. Tail rotor

$$W_{TR} = 0.000179\ (RbC)^{1.305}\ V_T^{1.48}$$

3. Tail surfaces

$$W_{Ts} = 0.00643\ W_g$$

4. Fuselage

$$W_f = 0.959\ W_g^{0.422}\ R^{0.872}$$

5. Alighting gear

$$W_{LG} = 0.026\ W_g$$

6. Flight controls

$$W_{Fc} = 54.3 + 0.004\ W_g$$

a. Add 2.5# for 5-blade system

b. Add 1.0# per foot increase in blade radius over 13 feet

7. Drive system

$$W_{Ds} = 30.77 \left(\frac{HP}{\Omega}\right)^{0.748}$$

HP = 400 for "Standard"; 365 for Muffled

Ω = Main rotor speed (rad/sec)

8. Fuel system

$$W_{FS} = 10 + 0.063 \times (\text{lbs of fuel})$$

9. Muffler weight = 48 pounds

PERFORMANCE OPTIMIZED DESIGN

The OH-6A with the Allison C-18 gas turbine had strict and enforced requirements for light weight and high performance in its basic design. Literally, ounces were considered in comparing alternate configurations and parameters. As a result, the OH-6A was an excellent baseline from which to spring when investigating performance optimized designs with the C-20 engine.

The helicopters studied for the operational OH-6A type optimized for performance using the Allison C-20 engine had the following range of parameters:

Main rotor radius varied from 13.16 (OH-6A) to 15.0 feet

Main rotor tip speed varied from 600 to 750 feet per second

Tail rotor tip speed varied from 623 to 779 feet per second

These machines were required to meet the mission requirements previously given on page 3.

Initially, it had been planned to investigate main rotor tip speed as low as 550 feet per second for the performance optimized designs. It was also decided to keep the blade aspect ratio the same as that of the OH-6A to maintain as much similarity to OH-6A as possible. With these constraints, the 550 feet per second tip speed resulted in too high value of C_T when using the full power available at the design hover condition of 6240 feet and 95°F. This would result in excessive extrapolation of the OH-6A test data which is very sparse at these high values of C_T but it is likely that the implied nearness to stall would result in a hover performance reduction. Further, the vehicle could not reach the required V_{NE} because of retreating blade stall unless a substantial increase in rotor solidity was utilized. (Actually, the values of tip speed selected are greater than 600 feet per second, hence, the omission of the 550 values is academic.)

All of the helicopters of Table I, meet the OH-6A performance requirements except cases 1 and 7. These cases are for 13.16-foot rotor radius, at 660 and 600 feet per second tip speeds, respectively. These machines have a V_{NE} of 108 and 114.9 knots, respectively. Only at a higher tip speed can a rotor of this radius and solidity absorb the power of the C-20 without encountering retreating blade tip stall which in turn causes roughness which limits V_{NE}. In all other respects, all these machines meet or exceed the stated requirements. (Case 7 also fails to meet the autorotation criteria.) (See Figure 6.)

The pertinent data for the designs studied are given in Table I. Data for cases 1 through 9 are plotted on Figure 1, Payload versus Tip Speed. It can been seen that, as expected, payload increases with rotor radius, and with reduced rotor speed (within the ranges studied). Although the rotors shown for cases 1 through 6 are 4-bladed, and those of cases 7 through 9 are 5-bladed, the significant difference is not the number of blades, but rather the change in solidity necessitated by the lower tip speed of cases 7 through 9.

Figure 2, Payload/Empty Weight Ratio Versus Tip Speed shows that the 14.0 foot rotor at 615 feet per second tip speed has the maximum value of the

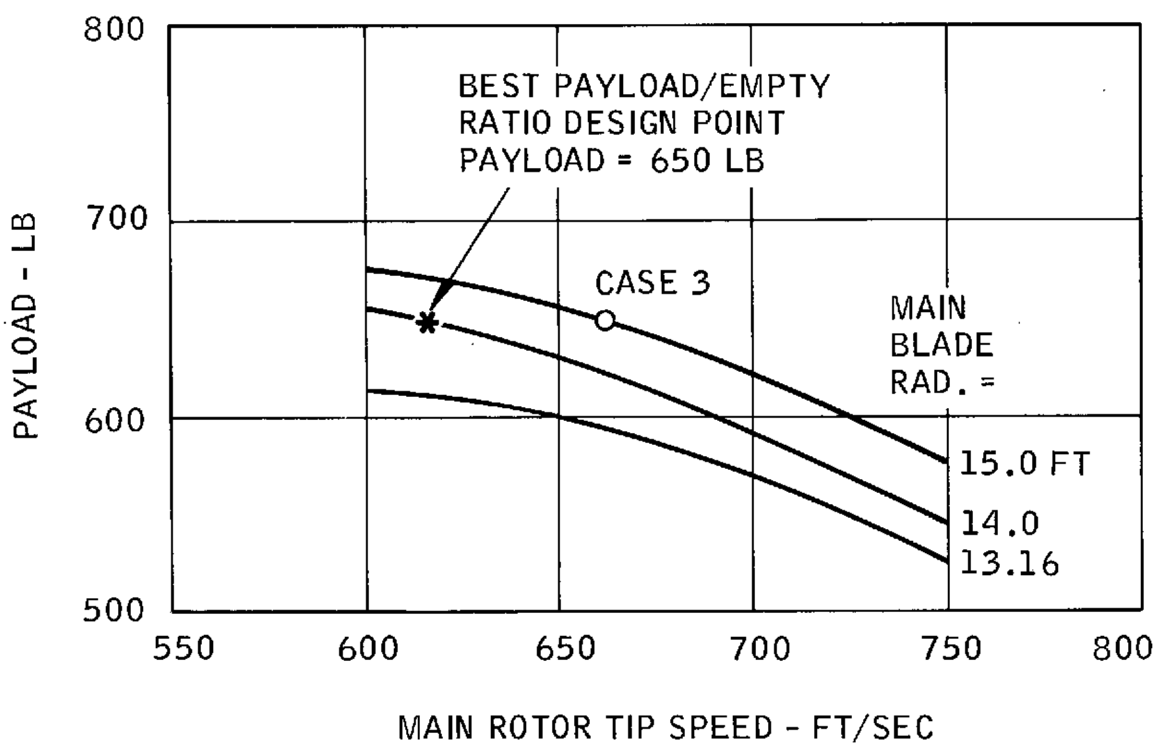

Figure 1. Payload Versus Tip Speed Standard Designs

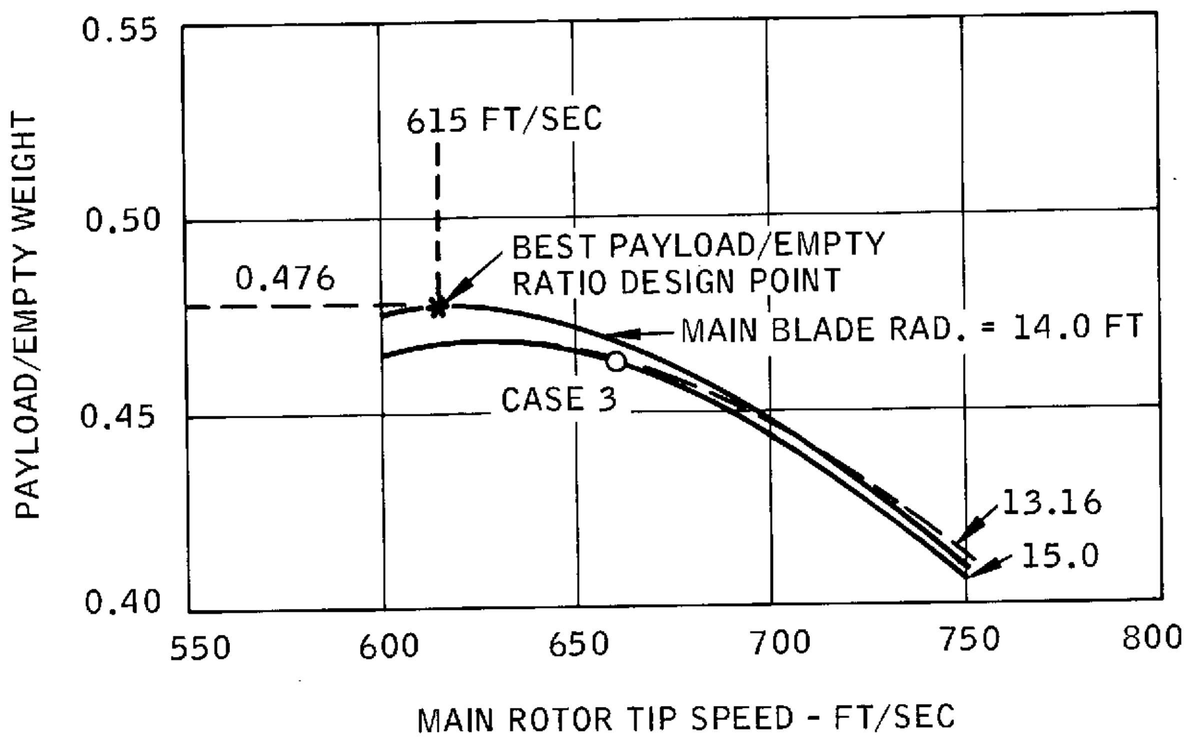

Figure 2. Payload/Empty Weight Ratio Versus Tip Speed Standard Designs

ratio. This indicates that, since first cost is proportional to empty weight, this machine will have the greatest value of payload per dollar of first cost. This design point is therefore selected as one of the performance optimized designs. The other parameters of the design as shown in Table III are interpolations from other specific design points.

This design has a mild anomaly in that the never exceed speed V_{NE} (130 knots) is less than the speed at maximum continuous power (141 knots). Thus, the vehicle is not able to attain the potential speed given by the power available. V_{NE} is determined as being 0.9 V_R where V_R is defined as roughness speed, and is assumed as occurring when the retreating blade tip angle of attack reaches a certain value. The value of V_{NE} can be raised by 1) increasing tip speed, or 2) by increasing blade area, or 3) by a combination.

Rather than "fine tune" the design around this point, it is more practical to consider case 3 which has essentially the same payload as the above design, but which has a V_{NE} greater than the V_H of 143 knots, and hence can realize the full potential of the engine.

These two designs are compared in Table III.

TABLE III

COMPARISON OF THE CASE FOR
BEST PAYLOAD/EMPTY WEIGHT RATIO
WITH CASE 3

	Best Ratio Payload/Empty	Case 3
Rotor Radius (ft)	14.0	15.0
V_T (ft/sec)	615	660
Payload (lb)	650	652
Empty Weight (lb)	1365	1404
Fuel weight (lb)	473	481
Mission gross (lb)	2688	2737
Altitude gross hover IGE 3000 ft (lb)	3650	3743
Altitude gross hover OGE SL (lb)	3690	3791
V_{NE} (kt)	130	>143
V_{MAX} (max cont) (kt)	141	143
V_{MAX} (T. O. Power) (kt)	145	150

As can be seen from Table I, all of the tail rotors studied had 26-27 horsepower required. From Table II, it can be seen that all tail rotor weights were within a range of ±1.9 pounds. Neither of these terms vary enough to be significant over the range of values studied.

DISCUSSION OF NOISE FORMULAS FOR DESIGN PURPOSES

The presentation of data in Reference 1 is satisfactory for showing the variation of noise levels when a single parameter is varied. For example, Table I of Reference 1 displays the component noise source, along with the partial derivative or explanation. This presentation is useful when evaluating the effect of a change in a single parameter, e.g., tip speed, in an existing vehicle.

Several parameters a designer has at his disposal when designing a helicopter are important in defining the noise level. These parameters are:

1. Tip speed of main and tail rotors

2. Thrust of the main and tail rotors

3. Power required of the main and tail rotors

4. Engine power and rpm

Initially, it had been planned to express the sound pressure level of the rotors as

$$SPL = K_1 + K_2 (V_T) + K_3 (H.P.) + K_4 (T)$$

In conducting the tests, when, for example V_T is held constant, horsepower and thrust are both changing. When comparing constant thrust points, tip speed and horsepower are both varying. As a result, determination of the values of the constants is ambiguous, and different values can be derived without a clear way of deciding which set is the best to describe the actual data.

On the basis of the tests reported in Reference 1, the noise levels of the main and tail rotors, and the engine were separately displayed. It has been a relatively simple matter to express these separate noise levels in following form (for the main and tail rotors):

$$OASPL = K_1 + K_2 (V_T) + K_3 \sqrt{HP \times T}$$

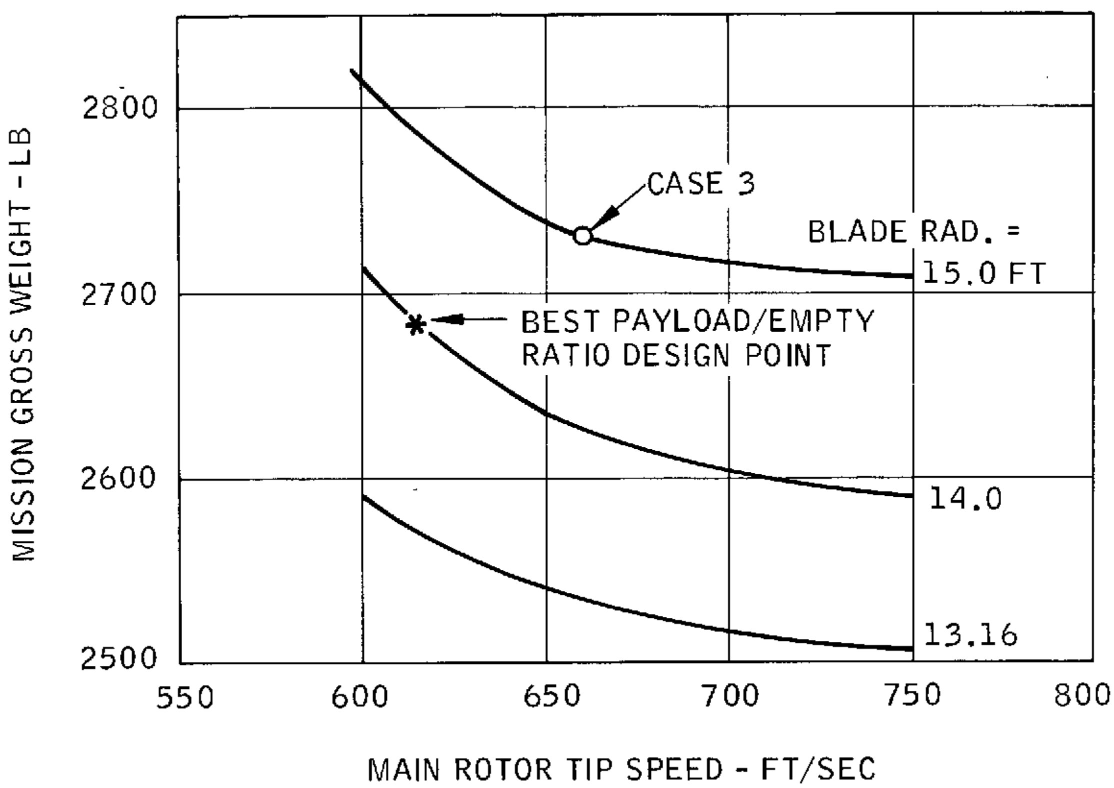

Figure 3. Mission Gross Weight Versus Tip Speed Standard Designs

and for the engine:

$$\text{OASPL} = K_1 + K_2\,(\text{HP}) + K_3\,(\%N_2)$$

where the K's are constants to be determined by the test data

V_T = tip speed (feet per second)

HP = horsepower

T = thrust (pounds)

$\%N_2$ = engine rpm expressed as a percentage of normal rated speed.

Intuitively, noise will increase as both horsepower and thrust increase, and since thrust will generally increase as horsepower increases, the square root of the product of horsepower and thrust seems a not unreasonable parameter against which to plot noise level. Using the square root retains the semblance of "linearity" of parameters. Although this "artificial" quantity is not correct if the thrust goes to zero (as it can in some of the tail rotor tests), we are really not interested in this extreme case, since in our application, both main rotor and tail rotor thrusts are confined to a comparatively narrow range of hovering values.

Of course, the data as presented in Reference 1 and this report can be used to express noise levels in terms of torque, or thrust, or any other quantity that may be available to the designer at a given time.

This presentation is valid only for an OH-6 type vehicle, although the variation in noise levels with variation in parameter could be used as the basis for checking theory, or making corrections to theory.

No attempt was made in this program to relate the noise levels to any theory, or method of calculating noise levels. The effort here is to present the test data in a convenient form for a designer to estimate the noise levels of an OH-6 type helicopter when tip speeds, thrust and power are known.

The derived formulas follow:

Standard Helicopter - Square tipped, 4-blade main rotor
2-blade tail rotor

Main rotor only

$$\text{OASPL} = 45.9 + 0.051\ V_T + 0.0077 \sqrt{\text{HP} \times \text{T}}$$

(Test runs 148-161, Table II, page 29)

Tail rotor only

$$\text{OASPL} = 65.0 + 0.024\ V_T + 0.094 \sqrt{\text{HP} \times \text{T}}$$

(Test runs 162-178, Table II, page 31)

Engine only

$$\text{OASPL} = 68.9 + 0.051\ (\text{HP}) + 0.036\ (\%N_2)$$

(Test runs 200-204 Table II, page 33)

Quieted Helicopter - Tapered tip 5-blade main rotor
4-blade tail rotor
muffled engine exhaust

Main rotor only

$$OASPL = 38.9 + 0.054 V_T + 0.0086 \sqrt{HP \times T}$$

(Test runs 90-103, Table III, page 55 and test runs 242-255 Table III, page 57, averaged)

Tail rotor only

$$OASPL = 60.5 + 0.021 V_T + 0.081 \sqrt{HP \times T}$$

(Test runs 65-77, Table III, page 57)

Engine only

$$OASPL = 57.9 + 0.033 (HP) + 0.118 (\%N_2)$$

(Test runs 20-34, Table III, page 59)

(All test runs cited above are from Reference 1.)

(All the above OASPL's are linear dB referenced to 0.0002 dyne per square centimeter)

(Note: In the data for the quiet tail rotor only, runs 65 to 77, there are no values of power required. To obviate this omission, the relationship between thrust and power was determined from other "quiet" tests where both thrust and power values were given. The appropriate values of power were then used in the determination of the constant terms.)

Although the noise levels of the engine gear box and main and tail rotor transmissions are not separately determined nor displayed, these components were present and their influence was present when the tests were run. Thus, we can synthesize the noise level of any OH-6 type helicopter by estimating the noise levels of the main and tail rotor, and the engine separately, and combining as shown in Figure 3.7, page 59 of Reference 4.

This has been done for the 9 "unquieted" designs and the data is shown in Table IV. This data shows that, as expected, when designs are made using essentially constant power, the noise level is a function only of the tip speed. (The estimated OASPL's for designs of the same tip speed vary only ±0.1 dB with the smaller rotor always the less noisy.)

TABLE IV

COMPUTED OASPL'S FOR "STANDARD" HELICOPTERS
HOVERING AT MISSION GROSS WEIGHT

	Main Rotor				Tail Rotor				Engine			
Case	V_T	HP	Thrust	OASPL	V_T	HP	Thrust	OASPL	HP	$\%N_2$	OASPL	Estimated Helicopter OASPL
1	660	192	2534	84.9	692	24	139	87.1	221	100	83.8	90.2
2	660	192	2625	85.0	692	24	140	87.1	220	100	83.7	90.3
3	660	192	2737	85.1	692	24	141	87.1	220	100	83.7	90.4
4	750	192	2505	89.5	779	24	122	88.8	220	100	83.7	92.8
5	750	192	2590	89.6	779	24	122	88.8	220	100	83.7	92.9
6	750	192	2706	89.8	779	24	122	88.8	220	100	83.7	93.0
7	600	192	2594	81.9	623	24	152	85.7	220	100	83.7	88.9
8	600	195	2713	82.1	623	24	156	85.8	224	100	83.9	89.0
9	600	196	2815	82.2	623	24	159	85.8	226	100	84.0	89.1

Figure 4 shows OASPL versus tip speed for the 14.0 foot rotor radius helicopter selected for the best payload/empty ratio.

QUIETED DESIGNS

Figure 2 illustrates the small change in payload/empty weight ratio occasioned by rotor radius change from 13.16 feet to 15 feet. This same small effect will be present in a "quieted" version since a major part of the quieting comes from the tail rotor.

Therefore, the same radius rotor as used in the best payload/empty ratio vehicle is used in the quieted version.

Basic vehicles studied are as shown in Tables I and II. Case 10 has a 5-bladed main rotor with tip speed of 615 feet per second (the same as the best payload/empty ratio design) but has tapered tips, and has a 4-bladed tail rotor with tip speed of 450 feet per second, and the engine is muffled.

Case 11 has the main rotor tip speed slowed down to 550 feet per second, increased blade chord, a 4-bladed tail rotor at 450 feet per second tip speed (slightly larger in blade radius and chord compared with Case 10 to achieve higher thrust necessitated by the lower tip speed main rotor), and the engine is muffled.

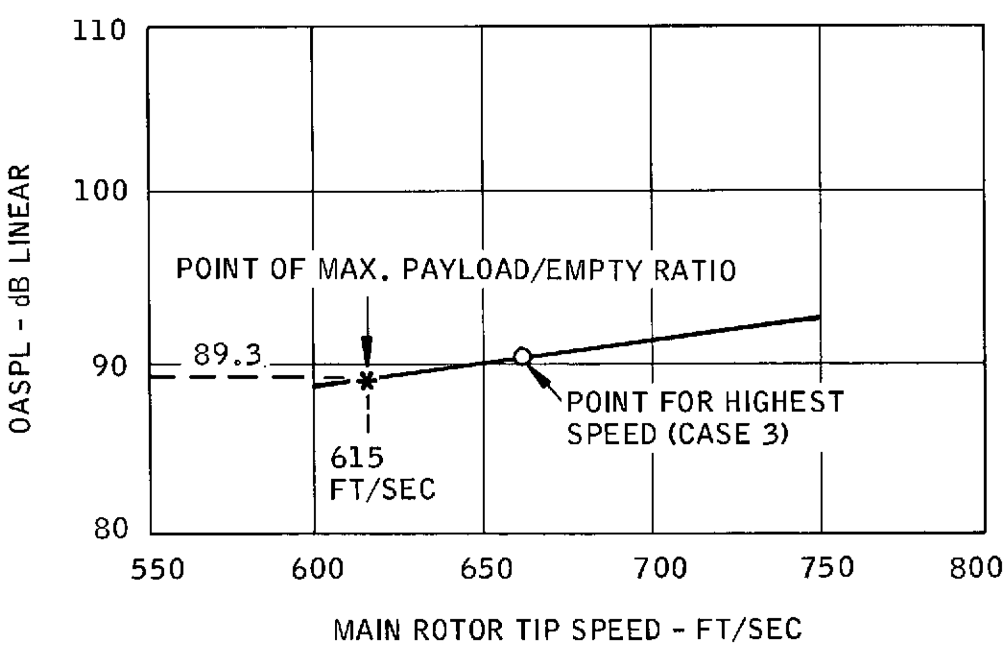

Figure 4. OASPL Versus Tip Speed for Standard Designs. SPL for Sea Level Hover IGE at Mission Gross Weight

In selecting the details of Case 10, the following was considered:

a. Use a rotor that yields a high payload/empty ratio, but make it quieter by using tapered tips and five blades. This assures good performance and still moves in the direction of quieting.

b. Use a quieted (4-blade) tail rotor at reduced tip speed. This reduces the tail rotor SPL to a value about 2 dB under that of the muffled engine. Although the SPL of this main rotor is about 3 dB higher than that of the tail rotor, the lower frequency of the main rotor harmonics indicate that, on a perceived noise level basis, the main rotor will not be the prime noise producer.

c. Muffling the engine reduces the SPL by about 7.5 dB (linear) and by 9 to 10 PNdB. Thus, although the engine is still the "noisiest" single element, the overall design represents a good compromise of performance and noise reduction.

In going from Case 10 to Case 11, an arbitrary reduction of main rotor tip speed to 550 feet per second was made, simply to get the main rotor SPL (linear) down to that of the tail rotor. Although, the OASPL (linear) of Case 11 is reduced by 1.3 dB below that of Case 10, the PNdB values of Case 11 would show substantially no change, since engine and tail rotor, with their higher harmonic content are about the same as Case 10.

Table V shows estimated noise levels for the quieted design.

Other combinations are possible as follows:

Consider the helicopter of Case 3 with a "quieted" tail rotor as in Case 10. Call this Case 12. The increase in empty weight due to larger tail rotor, lengthened tail boom, etc., amounts to about 8 pounds. The estimated linear OASPL of the "hybrid" is 87.6 dB. This is 2.8 dB less than that of Case 3. The payload penalty is about 3 pounds per dB of quieting for this modest reduction of noise.

To illustrate the potency of the muffler, consider Case 10 with a "perfect" muffler, i.e., one that does not reduce engine power, does not increase fuel consumption, does not weigh anything, but which does reduce engine noise similar to that estimated for Case 10. Call this Case 13. The mission gross weight of 2490 pounds will then be increased to approximately the same as that of the vehicle having the best payload/empty ratio of Table IV, namely 2688 pounds (because the main rotor diameters and tip speeds are the same).

TABLE V

COMPUTED OASPL'S FOR "QUIETED" HELICOPTERS
HOVERING AT MISSION GROSS WEIGHT

	Main Rotor				Tail Rotor				Engine			
Case	V_T	HP	Thrust	Est OASPL	V_T	HP	Thrust	Est OASPL	HP	$\%N_2$	Est OASPL	Estimated Helicopter OASPL
10	615	175	2490	77.8	450	22	137	74.4	202	100	76.4	81.2
11	550	170	2490	74.2	450	22	149	74.5	196	100	76.2	79.9
12	660	192	2737	85.1	450	22	141	74.5	218	100	83.7	87.6
13	615	192	2688	78.3	450	24	150	74.8	220	100	77.0	81.7

The empty weight of this "ideal" machine, Case 13, grows to 1416 pounds and the new payload becomes 599 pounds. This indicates a payload penalty of 6 pounds per dB. This value represents a limit penalty line (for large reductions in noise) that may not be attainable.

Figure 5 shows payload versus OASPL for several of the designs considered. A line from the "standard" designs to Cases 10 and 11 shows a penalty of 30 pounds of payload per dB (linear) noise reduction. Practical values of the penalty for quieting would appear to be in the range of 6 to 30 pounds per dB, with the size of penalty largely a function of the basic quietness of the engine, and/or the all-around efficiency of the muffler.

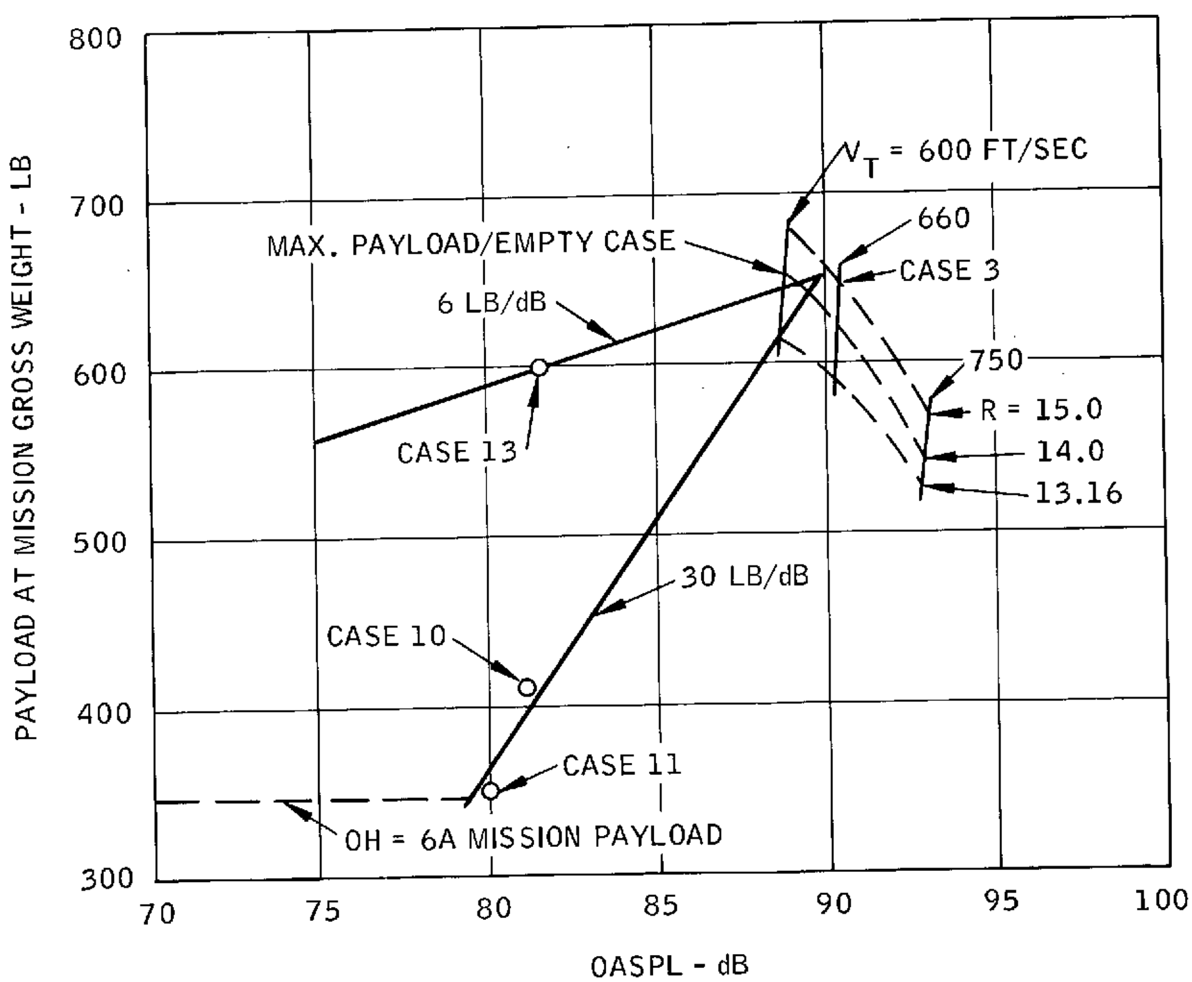

Figure 5. Payload Versus OASPL for Hover at Mission Gross Weight. Mission Gross Weight Based on Hover Ceiling of 6240 Feet IGE at Mil Power

RECOMMENDATIONS

Hughes Helicopter quiet helicopter program has demonstrated a "quiet vehicle", but one not totally suited to operational use because the quieting involved rotor speeds at which emergency autorotation was not satisfactory.

This study has identified the range of payload penalties in terms of pounds per dB (OASPL linear scale) if the vehicle is quieted and is operationally suitable.

Not demonstrated is the tactical significance of "quiet". It would appear that this demonstration is not particularly amenable to analytic determination. Even if PNdB had been used instead of linear OASPL as the reference, the aspects of directional effects, the effect of forward flight, the effects of modulation due to inter-rotor action (none of which were measured in this program), and the influence of ambient noise levels and ground cover are sufficiently complex as to render analytic conclusions difficult to arrive at, and perhaps more difficult to believe in.

Therefore, it is recommended that several OH-6A helicopters of an agreed upon quiet be procured, and appropriate field testing be conducted to assess the value of quiet in tactical situations. These machines could have, say, two levels of engine quieting and tail and main rotor quieting to permit assessment of the several ranges of frequencies represented by the three noise producing components.

It is recommended that development work be pursued leading to reduced engine noise. This work should be done both as part of the basic engine design, and as an add-on muffler. The object should be to reduce noise with the least penalties to power available.

CONCLUSIONS

1. A range of penalties of 6 to 30 pounds of payload per dB of OASPL is shown for an OH-6A type helicopter designed to meet the LOH mission. The efficiency of the muffler and the amount of quieting required determine where in the above range the actual penalty falls. Payload loss associated with weight of a muffler, and increased fuel required because of the effect of the muffler on engine fuel consumption are small compared to the loss of payload occasioned by reduced engine power available.

   Substantial reductions in noise can be accomplished by designing the tail rotor for reduced tip speed and muffling the engine without altering the main rotor characteristics of the OH-6A. This conclusion may not be valid for a helicopter with substantially higher main rotor tip speed.

2. Main rotor tip speed of 615 feet per second is found to give the greatest ratio of payload to empty weight for an OH-6A helicopter designed to meet the prescribed LOH mission.

3. The adverse effect of the present muffler on engine power available is the gravest single penalty in terms of payload when designing a quiet helicopter of the OH-6A type.

4. Emergency autorotation is not compromised when main rotor tip speed is reduced provided the blade area (rotor solidity) is appropriately increased to permit the same V_{NE} values as for a standard OH-6A.

5. There does not appear to be any problem of achieving proper weight and balance with the modifications proposed for quieting.

6. A repeat test of a 4-bladed tail rotor showed the same trends as the original tests for SPL versus azimuth displacement of the pairs of blades. Compared to the 90°/90° configuration, the 75°/105° is slightly quieter (less than 1 dB) and the 60°/120° configuration is slightly noisier (less than 2 dB).

7. Rotor blade resonances (both main and tail rotors) will be more difficult to avoid if wider-than-usual operating rpm ranges are specified in order to achieve quietness under certain quieting conditions. This should be obvious, but is mentioned here as a simple cautionary note.

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2. 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, Virginia. USAAMRDL Technical Report 72-29, September 1972.

3. Anon., Detail specification for a single engine, single main rotor LOH helicopter, Army model OH-6A, dated 29 December 1969. Hughes Report, HTC-AD-369Y-8003A.

4. Beranek, Leo, L., Editor: Noise Reduction - Prepared for a special program at the Massachusetts Institute of Technology. McGraw-Hill Book Co., Inc., 1960.

5. Anon. Preliminary Technical Proposal on emergency rotor spin up systems for HTC Quiet Helicopter (TP72-2191) Talley Industries.

6. Boeing-Vertol Division: An Investigation of Noise Generation on a Hovering Rotor, Report No. D210-10229-1, AD 721312, January 1971.

SYMBOLS

b	Number of blades
c	Blade chord (ft)
R	Blade radius (ft)
V_T	Tip speed (ft/sec)
W_b	Total weight of main rotor blades per rotor (lb)
W_{H+R}	Hub and retention weight (lb)
$W_R = W_b + W_{H+R}$	Rotor weight (lb)
W_{TR}	Total tail rotor weight (lb)
W_g	Gross weight (lb)
W_f	Fuselage weight (lb)
W_{LG}	Landing gear weight (lb)
W_{Fc}	Flight controls weight (lb)
W_{Ds}	Drive system weight (lb)
HP	Horsepower
Ω	Angular velocity (rad/sec)
W_{FS}	Fuel system weight (lb)
I_R	Main rotor moment of inertia (slug ft^2)
T	Rotor thrust (lb)
N_2	Power turbine speed

APPENDIX

AUTOROTATION

In designing an operational helicopter where tip speed is a parameter, we must keep in mind emergency autorotation. There are several methods of expressing the ability of the helicopter to perform satisfactory autorotation. A very simple expression, but deemed satisfactory for the present purpose, is the ratio of rotor kinetic energy to gross weight (foot pounds of energy per pound of gross weight). Obviously, the greater this quantity, the easier to perform an autorotation, as long as the two vehicles being compared are not too unlike as regards disc and power loading. This study shows that if the quieted design is such that the rotor has sufficient solidity and tip speed to meet the V_{NE} required of the OH-6A, the rotor has sufficient kinetic energy to perform an emergency autorotation safely.

The following applies to the standard OH-6A:

Rotor weight	= 172.4 lb
Rotor radius	= 13.16 ft
Rotor inertia	= 208 slug ft^2
Rotor tip speed	= 641 ft/sec (at N_2 = 100%)
Rotor kinetic energy	= 247,000 ft lb
Mission gross weight	= 2167 lb
Autorotation number	= AN = 114 ft lb/lb

The commercial version of OH-6 (Model 500) is certificated at 2550 pounds, and when operated at 103% N_2, AN (Model 500) = 103.

Any design having an AN value at least 100 will be considered operationally suitable for autorotation.

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Rotor moment of inertia (for similar rotors) is proportional to the product of weight of rotor by the square of the radius. Thus:

$$I_R = \frac{208 \times W_R}{172.4} \times \left(\frac{R}{13.16}\right)^2 = 0.007\ W_R\ R^2$$

where

I_R = Moment of inertia of a rotor similar to OH-6 (slug ft^2)

W_R = Weight of rotor being considered (lb)

R = Radius of rotor being considered (ft)

The kinetic energy of a rotor

$$K.E._R = \frac{I_R V_T^2}{2R^2}$$

where

V_T = tip speed (ft/sec)

Substituting the value of I_R yields

$$K.E._R = 0.0035\ W_R V_T^2 \text{ ft lb}$$

Figure 6 shows the performance designed helicopter with an AN = 109 which indicates that the design can autorotate satisfactorily. It also shows that as long as the main rotor has solidity sufficient to perform the required mission (i.e., reach the proper V_{NE}) the rotor will have enough kinetic energy to permit satisfactory autorotation.

If a helicopter is designed for a certain tip speed, and then operated at a substantially lower tip speed (perhaps to achieve a lower noise level at reduced

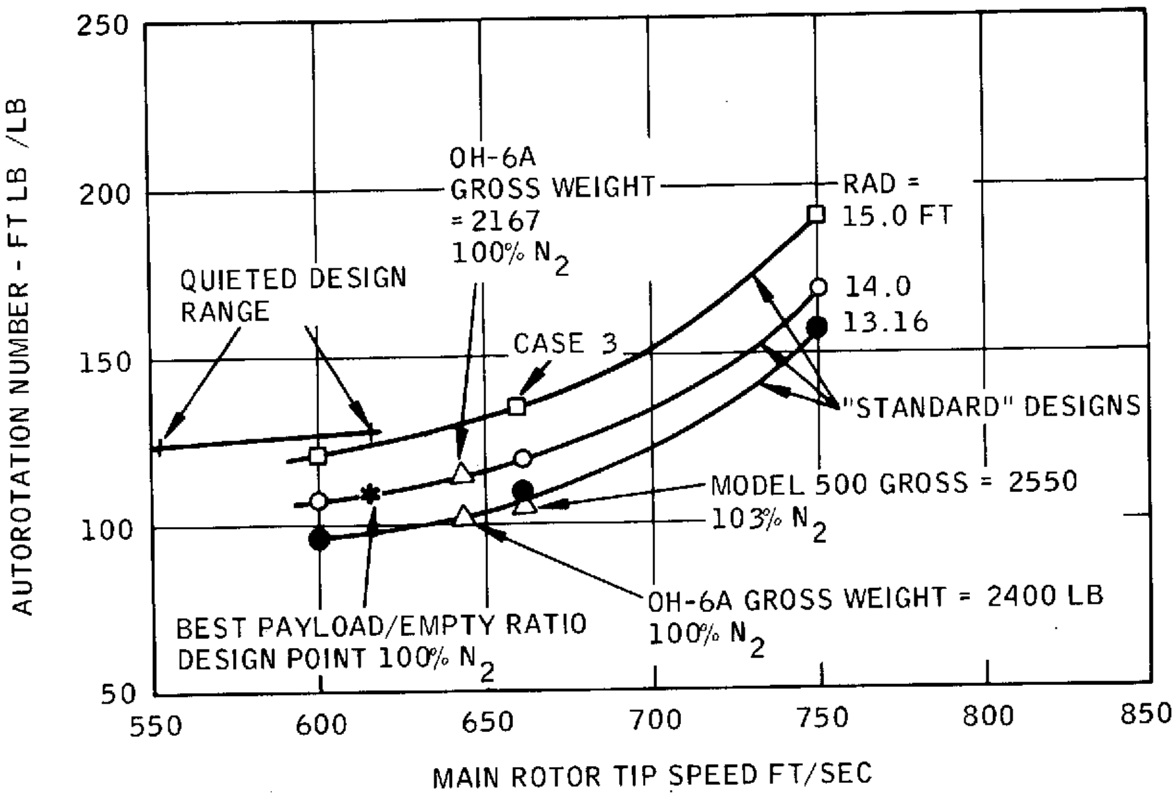


Figure 6. Autorotation Number Versus Tip Speed for a Variety of Designs

gross weight), the autorotation number may decrease to an unsatisfactory level. An example of this is shown in Reference 2 where the "quieted" OH-6A was flown at 1600 pounds gross weight and 67% N_2. Compared to the standard OH-6A at 2400 pounds and 100% N_2, the "quieted" autorotation number is $(2400/1600) \times ((67\ N_2/100\ N_2))^2 = 67\%$ as great as standard, and obviously unsatisfactory for emergency autorotation.

Several methods have been investigated to eliminate this problem:

1. High speed fly wheels

2. Cartridge starter

3. Main rotor tip rockets

The weight and complexity of the first two above methods speak against their consideration. Both involve attachments to the mechanical drive system with dynamic problems implied. The weight penalty involved in either the flywheel or the cartridge starter mechanism is of the order of 100 pounds.

A more practical approach appears to be solid propellant rockets attached to the main rotor blade tips. The following will establish the general level of performance required of such rockets.

Take as baseline the standard OH-6A operated at 100% N_2 and 2400 pounds gross weight. The rotor kinetic energy = 247,000 foot-pounds.

Assume that in the quiet mode (or version) the rotor speed is reduced to 70% of the normal value. The rotor kinetic energy is now reduced to 247,000 x $(0.7)^2$ = 121,000 foot-pounds. Thus there is now a deficiency of 126,000 foot-pounds compared to the baseline case.

Assume the tip rockets will burn for 3 seconds at an average tip speed = 0.85 x 641 = 544 feet per second and at an average thrust per rocket = P. Assuming 4 blades, the indicated energy is:

$$P \times 4 \times 544 \times 3 = 126,000 \text{ foot-pounds}$$

or

$$P = 20 \text{ pounds}$$

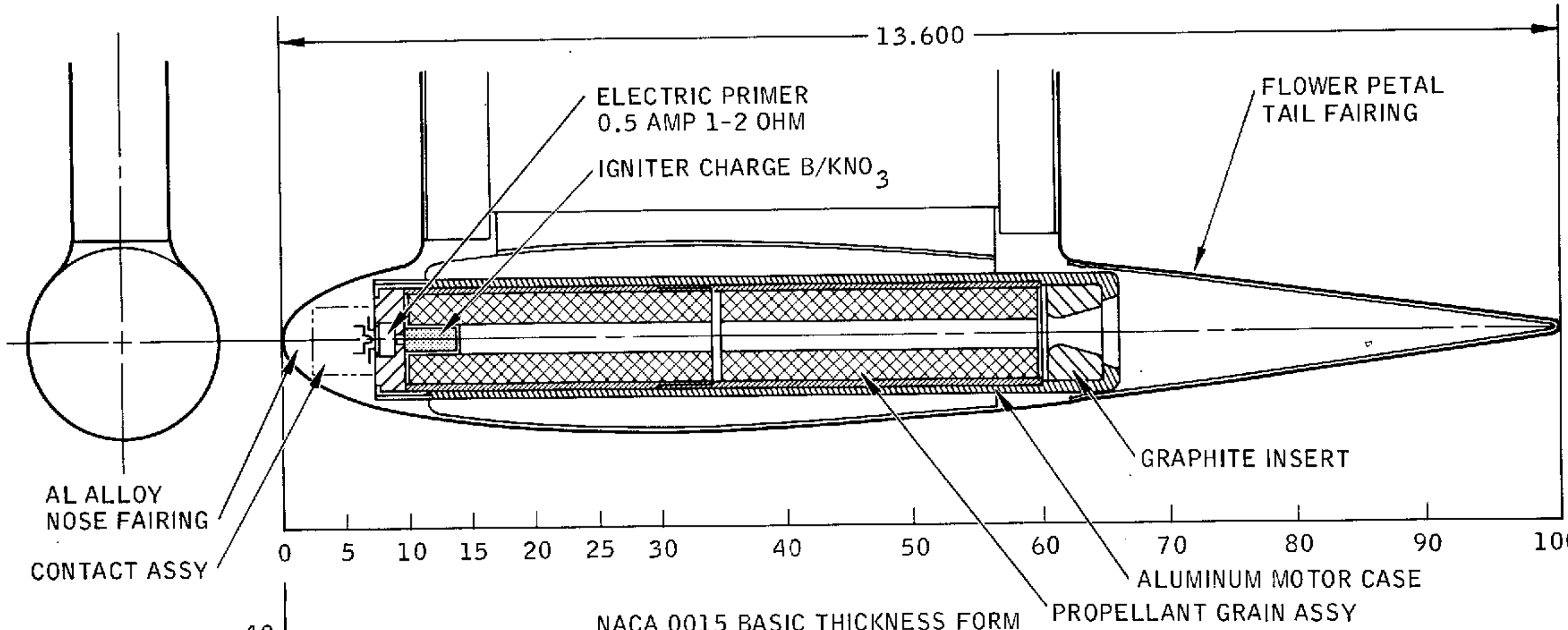
For the 4 rockets, the total impulse = 4 x 3 x 20 = 240 pound-seconds.

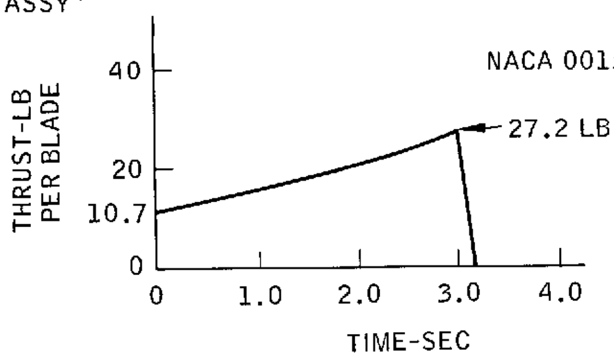
For propellant I_{sp} = 200 seconds, the total propellant weight = 240/200 = 1.2 pounds.

The estimated weight per rocket is less than 1.0 pound as shown on Figure 7 which also shows a sketch of the device. This is data from Reference 5. The tip weight now in OH-6A blades weighs approximately 3 pounds. Hence, the rocket weight would not add to blade weight, and stresses, but would substitute for part of the existing weight.

Six horsepower per rotor is estimated as due to drag of the rockets. This extra power required would necessitate a reduction in gross weight of about 50 pounds in those hover cases where full engine power is required. No reduction in mission weight at sea level is implied.

It is believed there will be no increase in noise due to the installation of the rocket pods outside of that implied by the additional power which is negligible.





WEIGHT ESTIMATE

PROPELLANT	0.300
IGNITER	0.003
MOTOR HARDWARE	0.250
CONTACT	0.010
FAIRING	0.020
STRUCTURE	0.257
TOTAL (LB)	0.840

Figure 7. Rotor Tip Thruster to Improve Emergency Autorotation

No detailed autorotation analysis will be undertaken for any of the quieted versions, it being considered that the above discussion will suffice.

MUFFLER DESIGN

There are several aspects of muffler design to be discussed.

The single largest penalty in using a muffler as designed for the OH-6A quiet program is the adverse effect of back pressure on power available of the turbine engine. This reduces power available in the C-20 engine by about 35 horsepower at sea level and 29 horsepower at altitude. If the machine is delivering lift at say, 10 pounds per horsepower, there is an immediate penalty of 290 pounds out of payload.

An additional penalty is in extra fuel required. The muffled engine requires about 10 pounds of fuel more per hour, for an increase of 33 pounds of fuel.

The net weight increase of the muffler for the OH-6A program as discussed below is about 40 pounds. It can clearly be seen that more development work is needed in reducing the back pressure in terms of amount of silencing. The weight penalties are minor -- the power loss is not.

The basis for muffler weight is the muffler described in Reference 2.

This is a double expansion, reactive type muffler which in the final configuration was shaped to fit the aircraft. This shaping resulted in "kidney" shaped chambers contoured to fit the engine and remain inside the basic aircraft lines.

If we disregard the requirement to fit inside the existing OH-6A contour, we can make the muffler cylindrical and reduce the surface metal area from 2408 square inches for the kidney shape to 1750 square inches for the cylindrical shape while maintaining the same volumes.

In changing from the kidney to the cylindrical shape, better utilization of material properties is possible, and reduction of material thickness of one gage is assumed. Thus, "kidney" skin thickness was 0.020 inch, cylindrical skin thickness = 0.015 inch.

The above applied to the C-18 engine. Assume the volumes required are in proportion to the rated horsepower. C-18 is rated at 317; C-20 at 400 horsepower.

Hence, volume of C-20 muffler = 400/317 x (Vol C-18).

For the cylindrical shape, the volume is proportioned to the square of the diameter, hence the surface area is proportional to the square root of the volumes.

The shell weight of the "kidney" mufflers for the C-18 ≈30 pounds.

The insulation weight of the "kidney" mufflers ≈40 pounds.

Taking the above into account, cylindrical mufflers for the C-20 engine will weigh 48 pounds per engine. The net increase in weight due to mufflers equals 40 pounds because the standard OH-6A has 8 pounds of exhaust collector which is removed when the mufflers are installed.

ROTOR POWER REQUIRED

The helicopters being tested were instrumented with torsion reading strain gages on the main drive shaft, and the tail rotor drive shaft. The output of these gages, together with knowledge of the rotational speed of these shafts allow computation of the power required by each rotor.

Strain gages on the tail boom yielded lateral bending moment of the boom which allows direct determination of the thrust of the tail rotor. The thrust of the main rotor was determined by hovering at several known gross weights, and determining the power required and the collective pitch setting for several values of rotor speed. These values of collective setting and rotor speed were then prescribed by the test engineer and were maintained during the tests on the rig.

Engine power and speed were determined by a torque gage and rpm indicator on the instrument panel.

DISCUSSION OF DATA REDUCTION
(Supplied by Wyle Laboratories)

The following paragraphs briefly describe the equipment and procedures utilized to perform the required analyses of the tapes.

All data charts are presented with the Sound Pressure Level (SPL) in dB (reference 0.0002 μbar) indicated on the vertical axis. In each case, the level was normalized to the calibration level contained on the tape as accurately as possible.

Weighted Data Analysis

The following equipment was used to obtain the weighted values of each run.

Precision Instruments PS 200A Recorder
Bruel & Kjaer 3347 Real Time Analyzer
Digital Equipment Corporation PDP-8 Computer

Each run was played back on the PI recorder and with the RTA set to a slow random response. The 1/3 octave levels from 25 to 20 kHz were stored in the RTA. These 1/3 octave levels were transferred from the RTA through the PDP-8 to a punched tape. The punched tape was subsequently used as a source to obtain the Linear, A-weighted, D-weighted, and PNdB values. Each weighted value was computed by the PDP-8 with appropriate level corrections applied to each 1/3 octave as required. Standard corrections were applied and, in the case of the PNdB calculation, the procedure outlined in FAR part 36 was utilized. See Table VI.

One Third Octave Data Analysis

The 1/3 octave analysis was performed using the following equipment:

PI PS 200A Recorder
B&K 3347 Real Time Analyzer
B&K 2305 Level Recorder

This data was actually obtained simultaneously with the storage of the 1/3 octave values by the PDP-8. The charts are shown on pages 57 to 60.

Narrow Band Data Analysis

Narrow Band Analysis of the data was performed utilizing the following equipment:

PI PS 200A Recorder
Nagra IV SJ Recorder
Spectral Dynamics SD301C Real Time Analyzer
Spectral Dynamics SD302C Ensemble Averager
Hewlett Packard XY Plotter

The narrow band analysis requires a data sample with a time duration between 1 and 2 minutes. Several of the data runs had a usable time duration of only 30 seconds, so it was necessary to rerecord the data, duplicating the sample 2 to 3 times. For this purpose the Nagra recorder accurately retains the

TABLE VI. OASPL COMPARISON

Run No.		LINEAR		"A"		"D"		PNdB		
Later	Earlier	Later	Earlier	Later	Earlier	Later	Earlier	Later	Earlier	
347	150	83.4	84.5	72.8	70.0	76.6	74.5	83.7	78.5	Main Rotor Only
348	149	84.8	86.0	71.4	68.0	78.2	74.0	85.3	79.5	
349	154	81.6	83.0	70.2	67.0	75.1	72.0	81.8	77.8	
350	156	78.2	80.5	69.8	68.5	75.7	73.0	82.4	78.4	
384	202	81.2	81.0	75.4	72.0	79.2	77.5	86.9	84.1	Engine Only
385	201	82.4	83.5	72.8	73.0	79.7	80.0	87.3	86.0	
386	203	84.2	83.5	76.4	74.5	81.4	80.0	89.4	86.4	
387	204	85.0	83.0	77.2	77.0	81.9	80.5	89.8	87.7	
388	200	85.8	85.0	77.8	75.0	82.8	81.0	90.7	88.9	
389	213	88.6	88.0	85.2	78.0	89.8	85.0	97.0	92.1	Simulated Hover
390	212	88.2	88.5	81.2	78.0	86.0	83.0	93.4	90.5	
391	215	86.2	91.0	78.2	77.0	84.9	82.0	91.7	91.4	
392	217	86.4	85.0	79.8	74.0	84.9	81.0	91.7	88.7	
393	211	89.0	91.0	82.0	85.0	88.0	89.0	95.2	94.5	
394	164	83.8	86.0	75.4	73.0	81.2	81.5	89.0	88.0	Tail Rotor Only
395	165	84.8	86.0	78.0	74.0	82.3	81.0	90.3	88.8	
398	166	85.8	87.5	77.2	75.0	82.8	83.0	90.9	90.6	

original data content. All runs recorded on the Nagra were checked by obtaining a 1/3 octave analysis, using the B&K RTA, and comparing them to the original analyzed from the PI playback. Agreement within ±0.5 dB in each 1/3 octave was obtained to confirm the accuracy of the procedure.

The following table gives the pertinent analysis bandwidths utilized for each frequency band and the number of ensembles required for the averaging process.

Frequency Band	Bandwidth	Number of Ensembles
10 - 500 Hz	1.5 Hz	64
10 Hz - 1 kHz	3.0 Hz	128
100 Hz - 2 kHz	6.0 Hz	256
100 Hz - 5 kHz	15.0 Hz	512 (not required)
100 Hz - 10 kHz	30.0 Hz	1024

Charts of the narrow band analyses are shown on pages 61 to 65.

DISCUSSION OF TEST DATA

The question of accuracy of test data is always present. Perhaps the matter is similar to that of dynamics analysis versus test results:

> Everyone believes the analysis except the person who wrote it, and no one believes the test data except the one who ran the test.

As part of this program, several tests were run repeating configurations tested in the earlier part of the program. These relevant repeat tests were main rotor only, tail rotor only, engine only, and entire helicopter in simulated hover on the test rig. Table VI presents the OASPL for linear, "A", "D" and PNdB scales.

Figures 8 through 11 are plots of the data of Table VI.

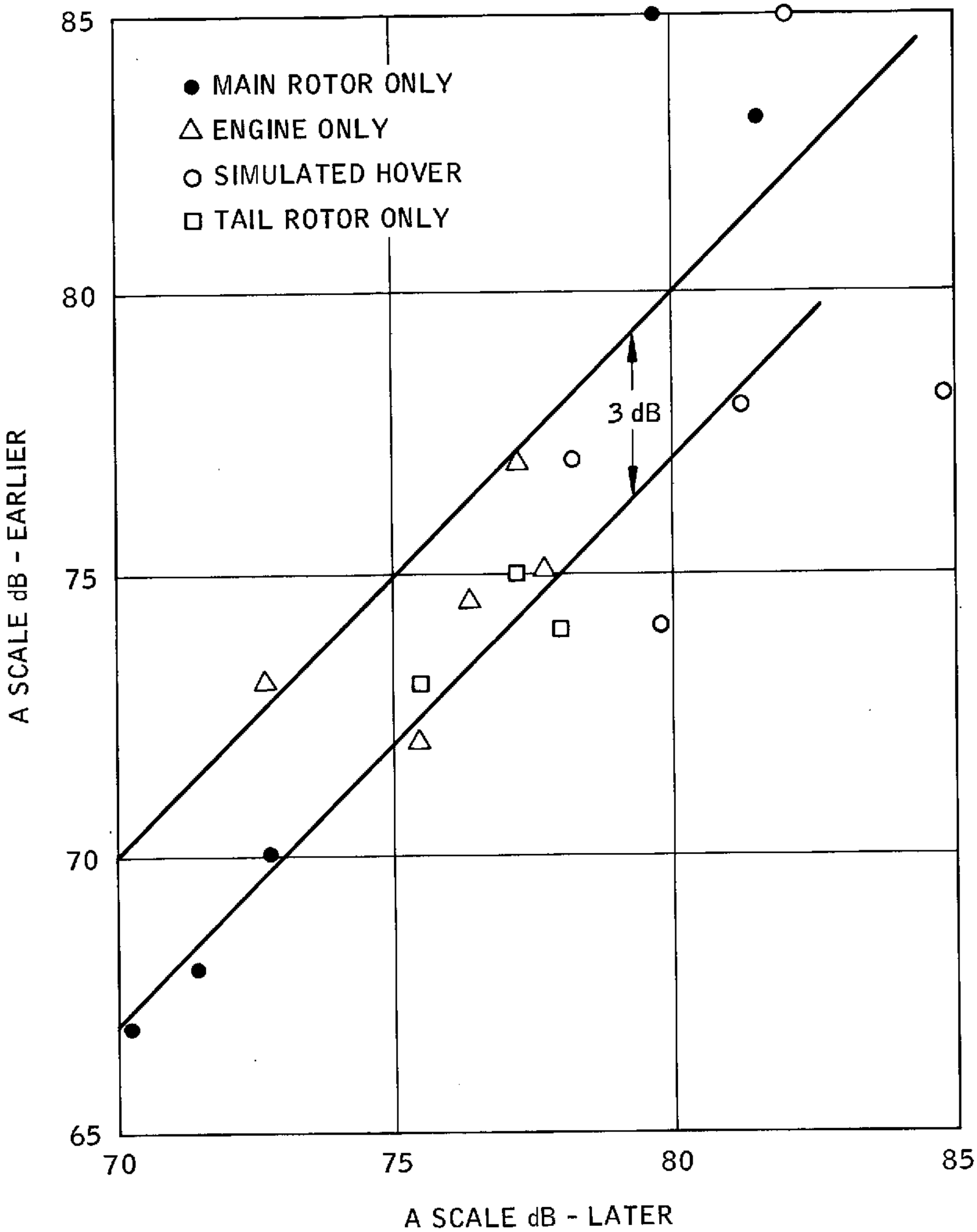


Figure 8. OASPL Comparison Between "Earlier" and "Later" Runs (A Scale)

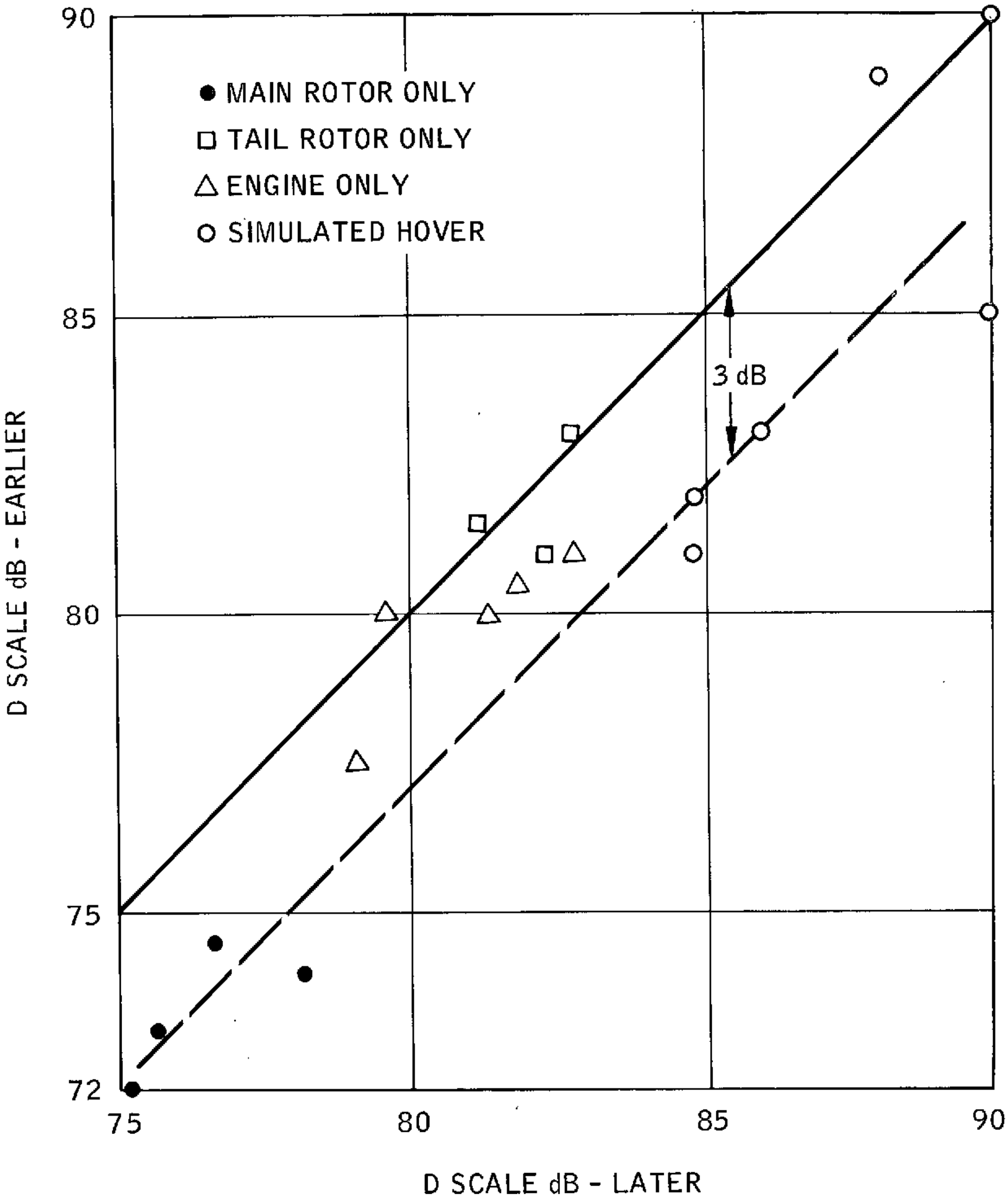


Figure 9. OASPL Comparison Between "Earlier" and "Later" Runs (D Scale)

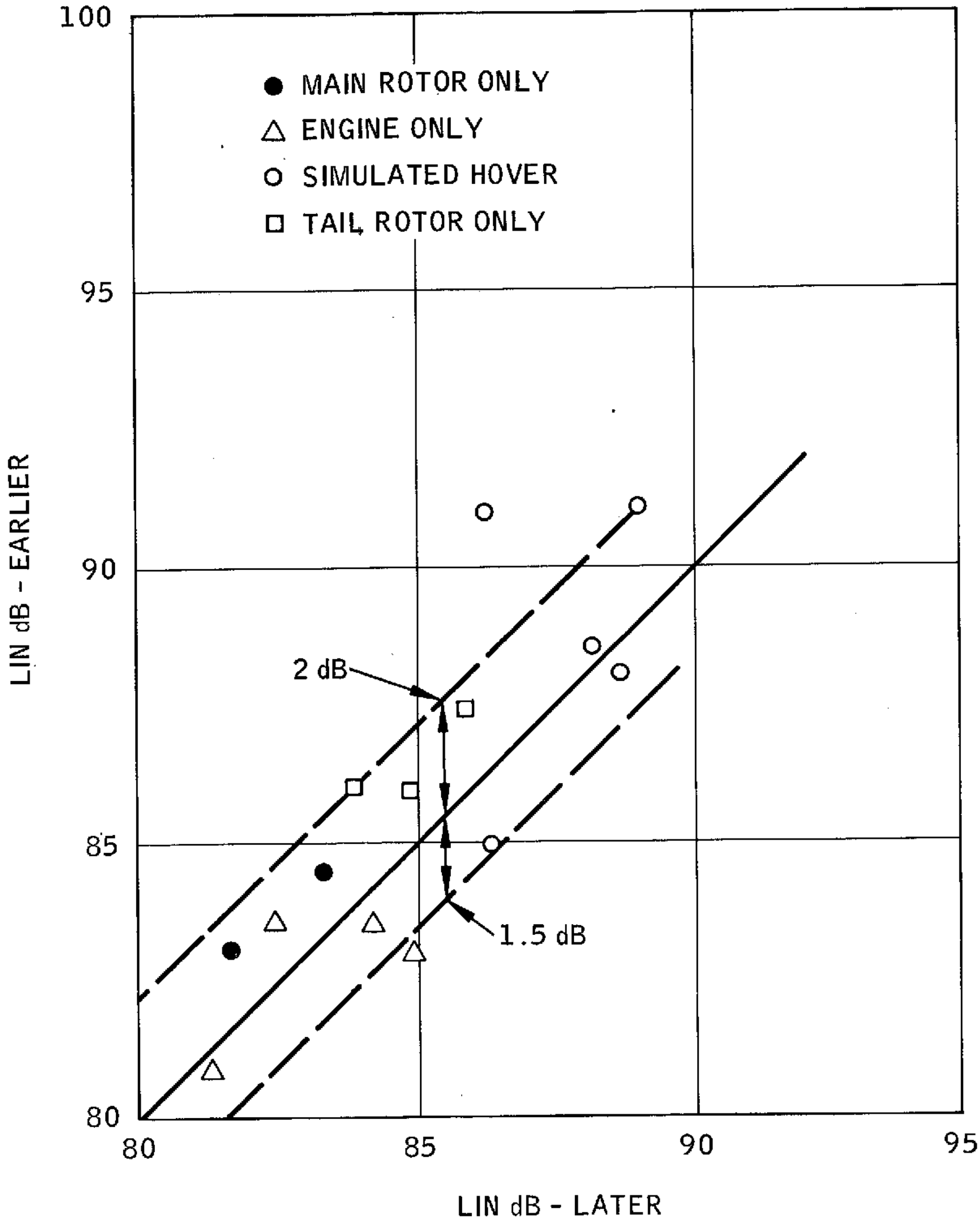


Figure 10. OASPL Comparison Between "Earlier" and "Later" Runs (Linear Scale)

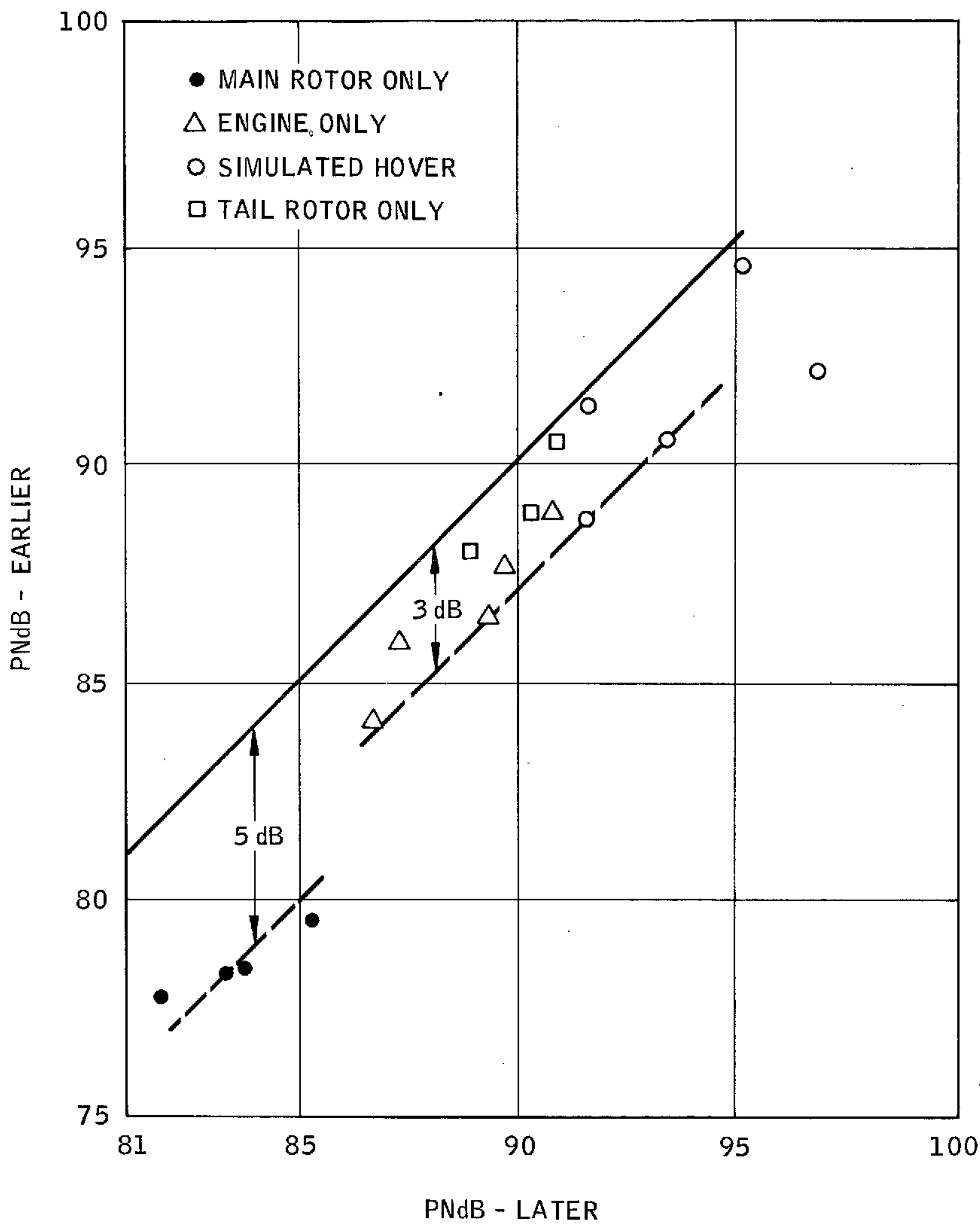


Figure 11. OASPL Comparison Between "Earlier" and "Later" Runs (PNdB)

The linear scale plot shows scatter on each side of the equality line, with the earlier readings slightly higher (on average) than the later ones.

The A and D scale plots show later readings generally running about 3 dB higher than the earlier ones.

The PNdB plot shows the "main rotor only" later readings about 5 dB greater than the earlier values, while the remainder of the later readings are only about 3 dB greater.

It is probably futile to attempt a closer assessment of the probable accuracy of the test results. Both the earlier and later tests were run largely by the same people, with the same amount of care being taken, and the data was reduced by the same people.

Figure 12 shows microphone locations for the test.

INFLUENCE OF HIGH PASS FILTER IN CHANNEL 3

In an effort to improve the recording of higher frequency noises, a high pass filter was installed in Channel 3 as shown in Figure 13. This filter has the characteristics as shown in Figure 14. By reducing or eliminating much of the low frequency main rotor noise signal, the filter permits a lower record setting to more accurately measure the higher frequency engine noise levels.

When Channels 1 and 3 are set at the same record level, Channel 3 has a record range 10 dB below that of Channel 1. Thus, at the reduced SPL's of the higher frequencies, Channel 1 will get into the "floor" of the instrumentation sooner than Channel 3. Thus, Channel 3 will continue to show reductions of SPL after Channel 1 has reached its low limit and is in the "mud" noise area of the tape machine. Hence the value of Channel 1 minus Channel 3 will continue to increase positively as frequency increases. See Figure 15. The values of SPL of Channel 3 are, therefore, more correct than those of Channel 1 at frequencies above, say 3000 Hz.

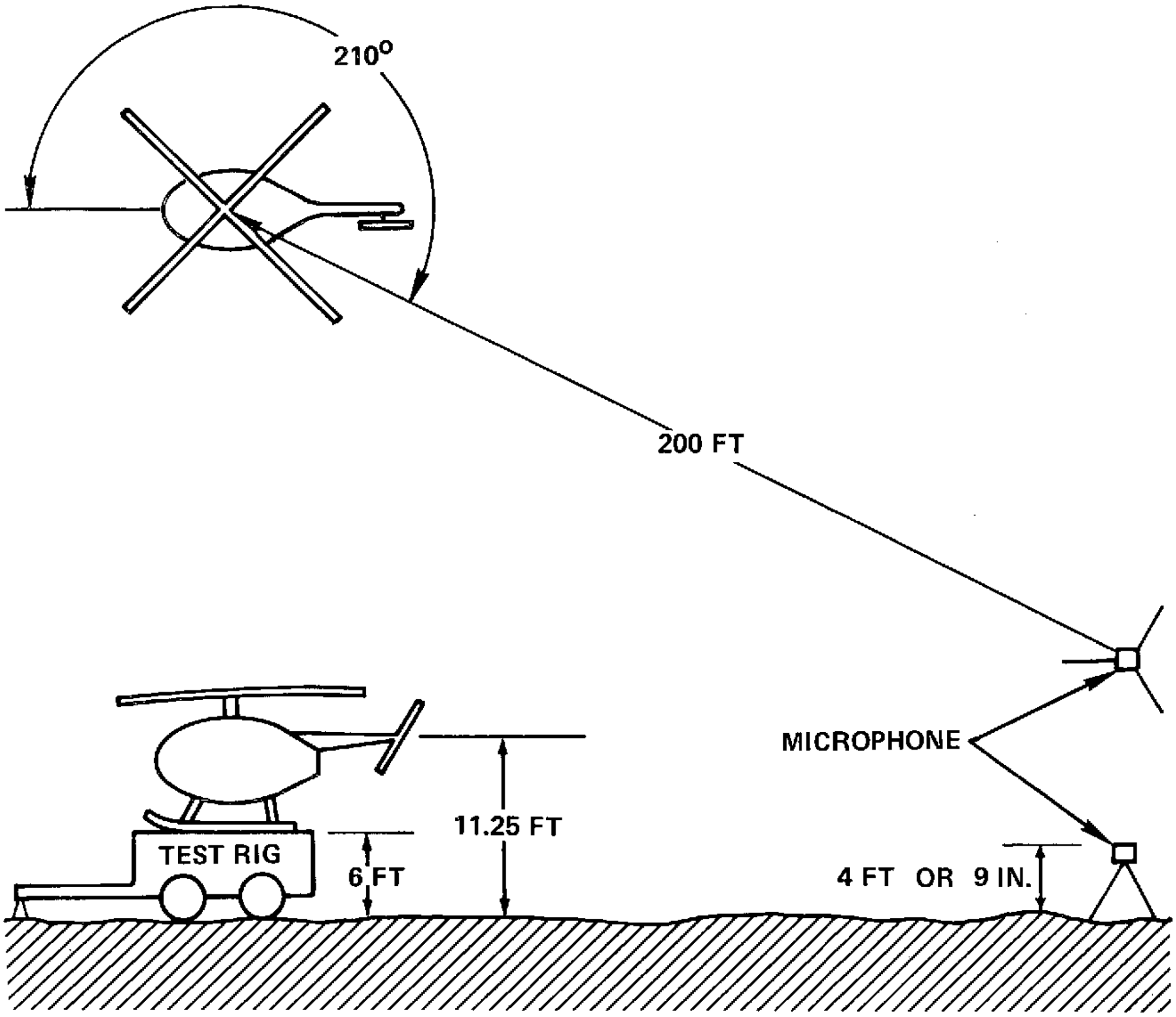


Figure 12. Microphone Locations

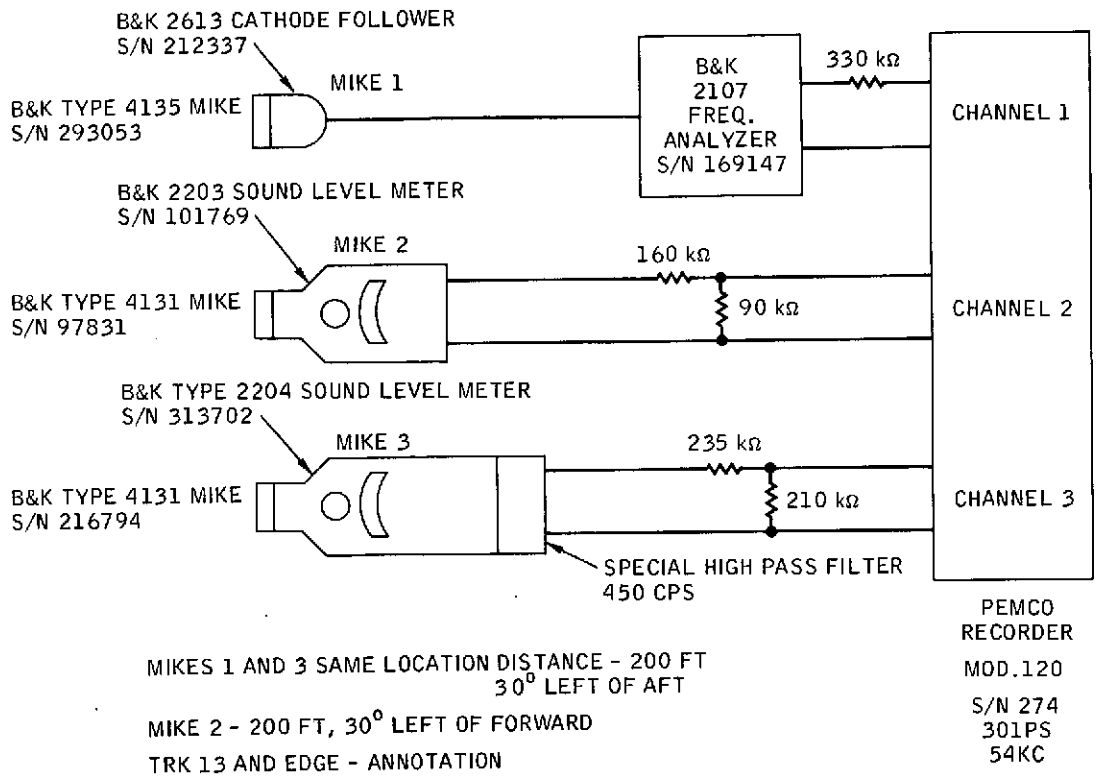


Figure 13. Sound Recording System

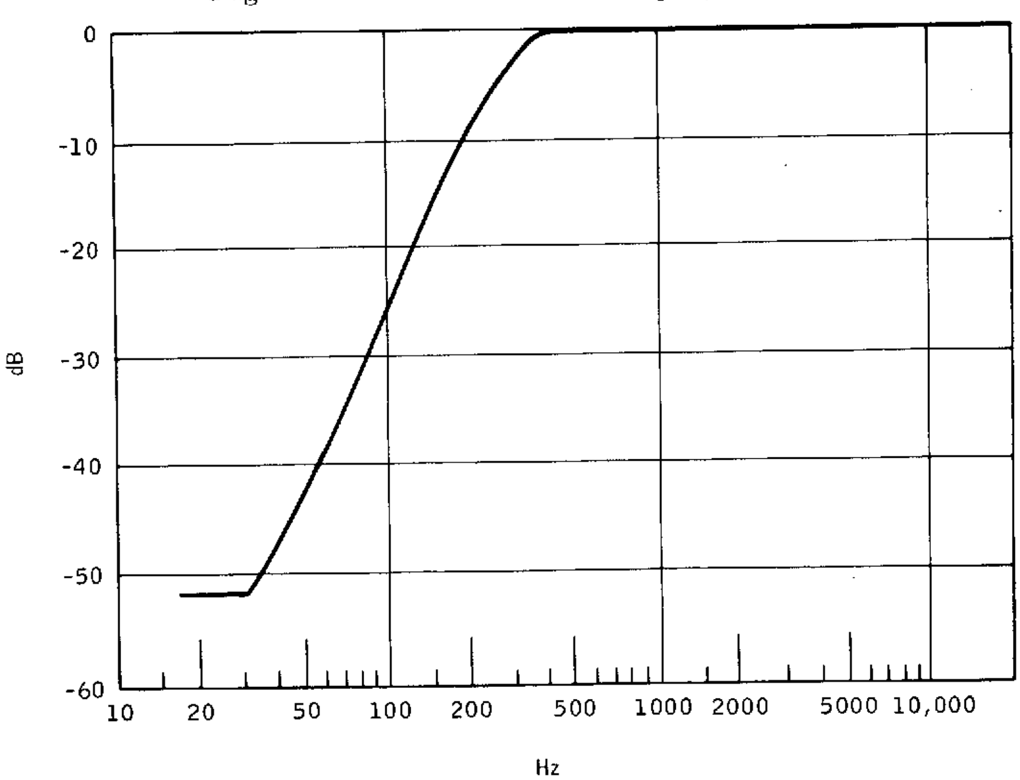


Figure 14. High Pass Filter Characteristics (Channel 3)

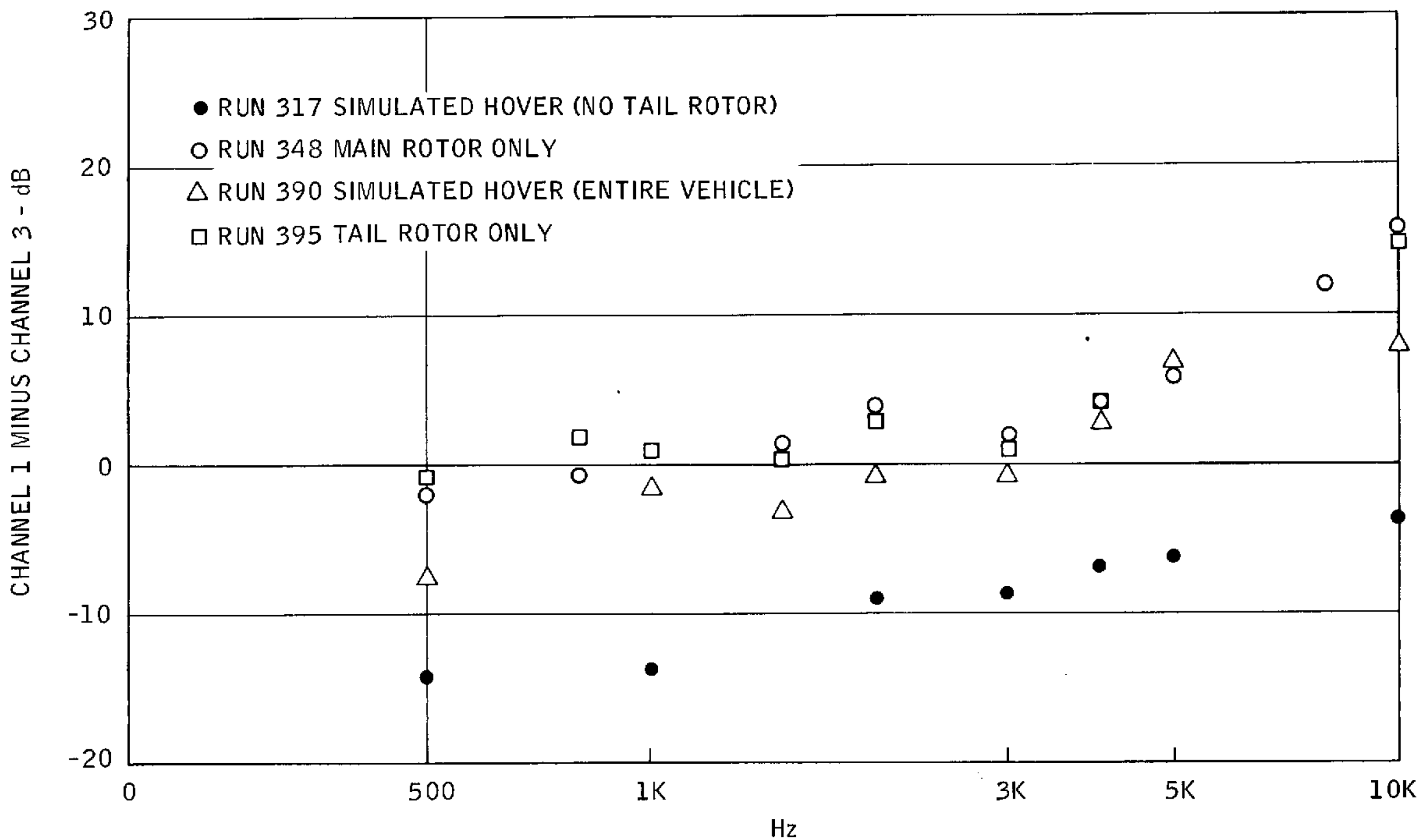


Figure 15. SPL of Channel 1 Minus SPL of Channel 3 Versus Frequency
(Based on 1/3 Octave Plots)

Effect of Microphone Height on Recorded Noise Levels

In an attempt to determine the effect of ground reflected waves on recorded noise levels, several tests were run with the microphones at 4.0 feet and at 9.0 inches off the ground at the same distance from the noise source. In these tests, the only significant noise source was the 4-bladed tail rotor with the blades set at 90°/90°. There was no main rotor installed, and the engine was silenced with the ground exhaust silencer.

Table VII shows the data from 1/3 octave plots for the range of frequencies of interest.

Figure 16 derived on the basis of Reference 6 shows that, up to about 200-300 Hz, the two microphones should read the same and Table VII shows that to be the case. However, at 600 Hz, the test data shows the 4-foot microphone to be reading 6-14 dB higher than the 9 inch location, whereas Figure 16 indicates that it should be reading about 2 dB lower. At 1000 Hz, Figure 16 indicates that the 4-foot microphone is getting its reflected wave at the first half-wave length away from the direct wave, and should be reading 9-10 dB lower than the 9-inch microphone. The test values show it to be 6-12 dB higher.

In the 2000 Hz region, Figure 16 indicates that both should be reading about the same, where the test data shows the 4-foot location to be indicating 3-7 dB higher.

Finally, in the 4000-5000 Hz region, where Figure 16 shows that the 4-foot position should be reading higher than the 9-inch microphone, the test data shows it to be 5-6 dB lower.

Thus, the data appears very consistent, but in the opposite sense to the prediction of simple reflection theory. There is no explanation available to the author at this time.

Effect of Tail Rotor Blade Azimuth Spacing

A repeat of earlier tests was performed with the 4-bladed tail rotor configured with the pairs of blades at 90°/90°; 75°/105°; and 60°/120° apart in azimuth.

TABLE VII

OASPL DATA FOR MICROPHONES
AT TWO HEIGHTS ABOVE THE GROUND

Frequency Hz	Run No. 374*	379	375*	380	376*	381	377*	382
60-65	67	65	66	65	**	**	62	62
120-130	70	70	70	71	**	**	66	68
300	58	56	54	55	**	**	54	57
600	64	50	60	50	64	56	58	52
800-1000	62	50	62	51	62	56	60	54
2500	56	52	58	53	56	49	58	55
4000-5000	58	64	58	63	50	56	60	66
OASPL	75	74	75	75	**	**	73	74
V_T (ft/sec)	495	495	495	495	457	457	408	408
Thrust (lb)	113	113	146	146	148	148	165	165

*Runs 374-377 Microphone 4.0 feet off the ground
Runs 379-382 Microphone 9.0 inches off the ground
**Runs 376 and 381 from Channel 3 which has the high pass filter - hence the frequencies less than 500 Hz are attenuated. All other runs on Channel 1. OASPL not appropriate for filtered data.

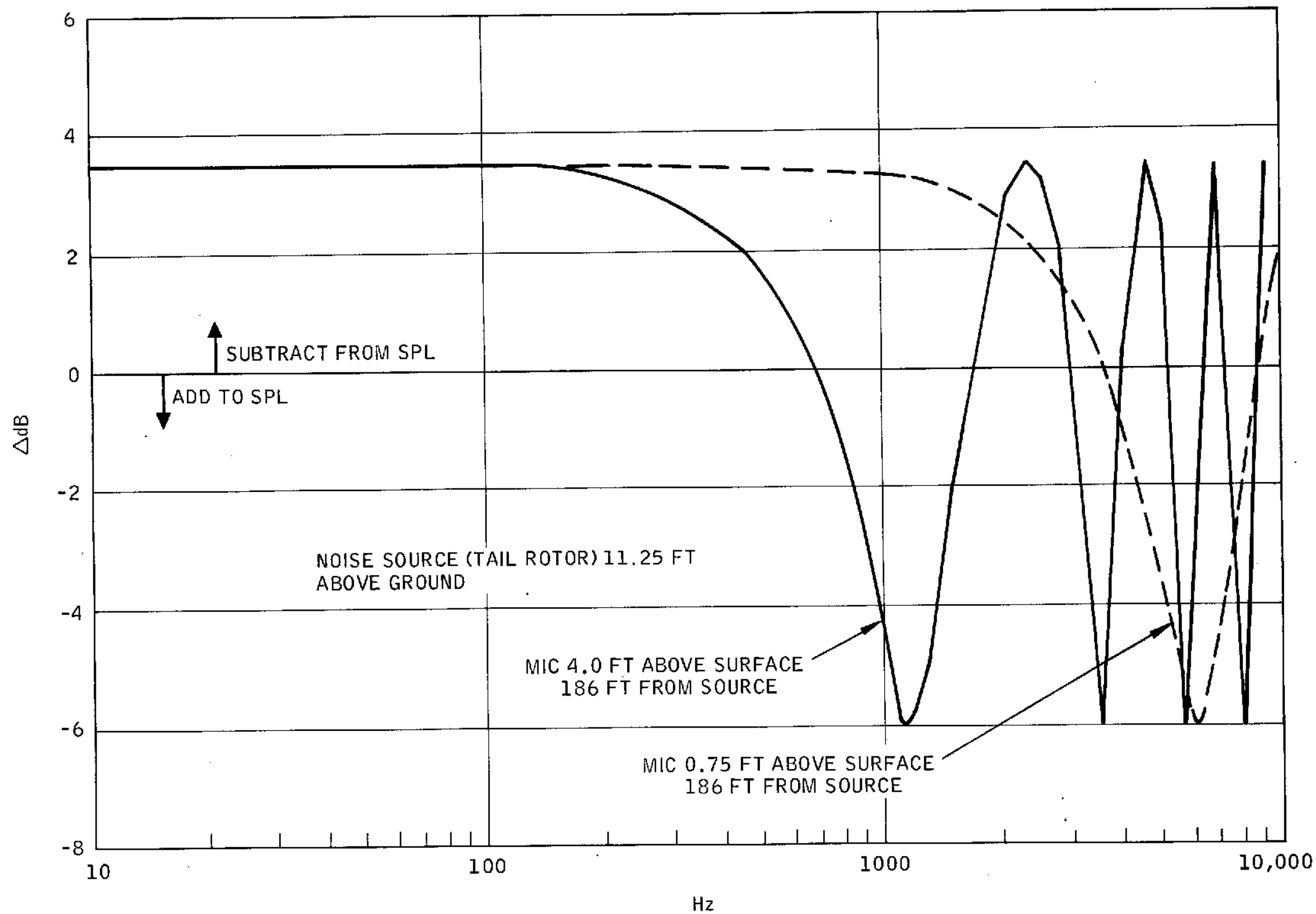


Figure 16. Calculated Effect of Microphone Height on Error Due to Ground Reflection Waves

The following shows the linear OASPL in dB for the several configurations:

Thrust lb	V_T fps	Configuration 90°/90°	75°/105°	60°/120°
146	495	75	74	75
148	457	73	74	76
165	408	73	72	74

These minor differences show the same trends as the original test, i.e., compared to the 90°/90° configuration, the 75°/105° is slightly quieter, and the 60°/120° is slightly noisier.

TABLE VIII. TEST DATA - QUIET HELICOPTER PHASE II

Configuration	Run No.	M/R Tip Speed fps	T/R Tip Speed fps	Ground Exhaust Silencer	Dynamometer	Engine rpm $\%N_2$	Engine Power hp	≈M/R Thrust lb	T/R Thrust lb	Microphone Azimuth deg	Overall Sound Pressure Level: Linear dB	Overall Sound Pressure Level: "A" Weighted dB	Overall Sound Pressure Level: "D" Weighted dB	Overall Sound Pressure Level: PNdB	Run No.
Free Hover 6' Skid H_T M/R on (4 blades tapered tips) T/R on (4 blades 75°/105°) 58" Dia.	300	666	495	---	---	103	≈215	2400	≈146	1/180	89.5	---	---	---	300
	300	666	495	---	---	103	≈215	2400	≈146	2/0	83.5	---	---	---	300
	301	666	495	---	---	103	≈215	2400	≈146	1/210	89.5	---	---	---	301
	301	666	495	---	---	103	≈215	2400	≈146	2/30	83.5	---	---	---	301
	302	666	495	---	---	103	≈215	2400	≈146	1/240	87.5	---	---	---	302
	302	666	495	---	---	103	≈215	2400	≈146	2/60	86.0	---	---	---	302
	303	666	495	---	---	103	≈215	2400	≈146	1/270	88.5	---	---	---	303
	303	666	495	---	---	103	≈215	2400	≈146	2/90	87.0	---	---	---	303
	304	666	495	---	---	103	≈215	2400	≈146	1/300	88.0	---	---	---	304
	304	666	495	---	---	103	≈215	2400	≈146	2/120	87.5	---	---	---	304
	305	666	495	---	---	103	≈215	2400	≈146	1/330	85.5	---	---	---	305
	305	666	495	---	---	103	≈215	2400	≈146	2/150	89.0	---	---	---	305
Simulated Hover 6' Skid H_T M/R on (4 blades tapered tips) No T/R	317	666	---	ON	---	103	192.5	2400	---	210	83.4	71.4	76.8	84.0	317
T/R Only (4 blades 75°/105°) 58" Dia. No M/R	322	---	495	ON	---	103	15.1	---	146	---	72	---	---	---	322
	323	---	457	ON	---	95	14.3	---	148	---	70	---	---	---	323
	324	---	408	ON	---	85	17.8	---	165	---	69	---	---	---	324

Note: Microphone azimuth location at 210° (i.e., 30° to left of straight aft) unless otherwise noted; 200 feet from main rotor center).

TABLE VIII. TEST DATA - QUIET HELICOPTER PHASE II (Continued)

Configuration	Run No.	M/R Tip Speed fps	T/R Tip Speed fps	Ground Exhaust Silencer	Dynamometer	Engine rpm $\%N_2$	Engine Power hp	≈M/R Thrust lb	T/R Thrust lb	Microphone Azimuth deg	Overall Sound Pressure Level Linear dB	"A" Weighted dB	"D" Weighted dB	PNdB	Run No.
T/R Only (4 blades	328	---	495	ON	ON	103	215.3	---	146	---	74	---	---	---	328
75°/105°) 58" Dia.	329	---	457	ON	ON	95	204.6	---	148	---	74	---	---	---	329
No M/R	330	---	408	ON	ON	85	198.7	---	165	---	72	---	---	---	330
T/R Only (4 blades	338	---	495	ON	ON	103	215.3	---	146	---	75	---	---	---	338
60°/120°) 58" Dia.	339	---	457	ON	ON	95	204.6	---	148	---	76	---	---	---	339
No M/R	340	---	408	ON	ON	85	198.7	---	165	---	74	---	---	---	340
M/R Only (4 Standard	347	666	---	ON	---	103	167.8	2000	---	---	83.4	72.8	76.6	83.7	347
Blades On)	348(1)	666	---	ON	---	103	213.6	2400	---	---	84.8	71.4	78.2	85.3	348
No T/R	(2)														
	349	615	---	ON	---	95	193.9	2400	---	---	81.6	70.2	75.1	81.8	349
	350	550	---	ON	---	85	197.1	2400	---	---	78.2	69.8	75.7	82.4	350
T/R Only (4 blades	374	---	495	ON	ON	103	164.9	---	113	---	75	---	---	---	374
90°/90°) 58" Dia.	375	---	495	ON	ON	103	215.3	---	146	---	75	---	---	---	375
No M/R	376	---	457	ON	ON	95	204.6	---	148	---	73	---	---	---	376
Microphones 4'	377	---	408	ON	ON	85	198.7	---	165	---	73	---	---	---	377
Above Ground															
T/R Only (4 blades	379	---	495	ON	ON	103	164.9	---	113	---	74	---	---	---	379
90°/90°) 58" Dia.	380	---	495	ON	ON	103	214.3	---	146	---	77	---	---	---	380
No M/R	382	---	408	ON	ON	85	198.7	---	165	---	74	---	---	---	382
Tail Microphones 9"	383	---	495	ON	ON	103	247.8	---	173	---	76	---	---	---	383
Above Ground															

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

FOLDOUT FRAME

TABLE VIII. TEST DATA - QUIET HELICOPTER PHASE II (Continued)

Configuration	Run No.	M/R Tip Speed fps	T/R Tip Speed fps	Ground Exhaust Silencer	Dynamometer	Engine rpm $\%N_2$	Engine Power hp	≈M/R Thrust lb	T/R Thrust lb	Microphone Azimuth deg	Overall Sound Pressure Level Linear dB	"A" Weighted dB	"D" Weighted dB	PNdB	Run No.
Engine Only No M/R or T/R	384	---	---	---	ON	103	164.9	---	---	---	81.2	75.4	79.2	86.9	384
	385 (1) (2)	---	---	---	ON	103	215.3	---	---	---	82.4	72.8	79.7	87.3	385
	386	---	---	---	ON	95	204.6	---	---	---	84.2	76.4	81.4	89.4	386
	387	---	---	---	ON	85	198.7	---	---	---	85.0	77.2	81.9	89.8	387
	388	---	---	---	ON	103	247.8	---	---	---	85.8	77.8	82.8	90.7	388
Simulated 6' Hover Std OH-6A with Metal 2 Blade T/R 51" Dia.	389	666	692	---	---	103	178.9	2000	106	---	88.6	85.2	89.8	97.0	389
	390 (1) (2)	666	692	---	---	103	218.5	2400	134	---	88.2	81.2	86.0	93.4	390
	391	615	638	---	---	95	207.3	2400	136	---	86.2	78.2	84.9	91.7	391
	392	550	571	---	---	85	198.7	2400	146	---	86.4	79.8	84.9	91.7	392
	393	666	692	---	---	103	268.7	2800	164	---	89.0	82.0	88.0	95.2	393
T/R Only (2 Blade Metal 51" Dia)	394	---	692	ON	ON	103	178.9	2000	106	---	83.8	75.4	81.2	89.0	394
	395 (1)	---	692	ON	ON	103	218.5	2400	134	---	84.8	78.0	82.3	90.3	395
	396	---	638	ON	ON	95	207.3	2400	136	---	83.0	77.0	80.2	88.1	396
	397	---	571	ON	ON	85	198.7	2400	146	---	81.0	72.0	77.3	84.5	397
	398	---	692	ON	ON	103	268.7	2800	164	---	85.8	77.2	82.8	90.9	398

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

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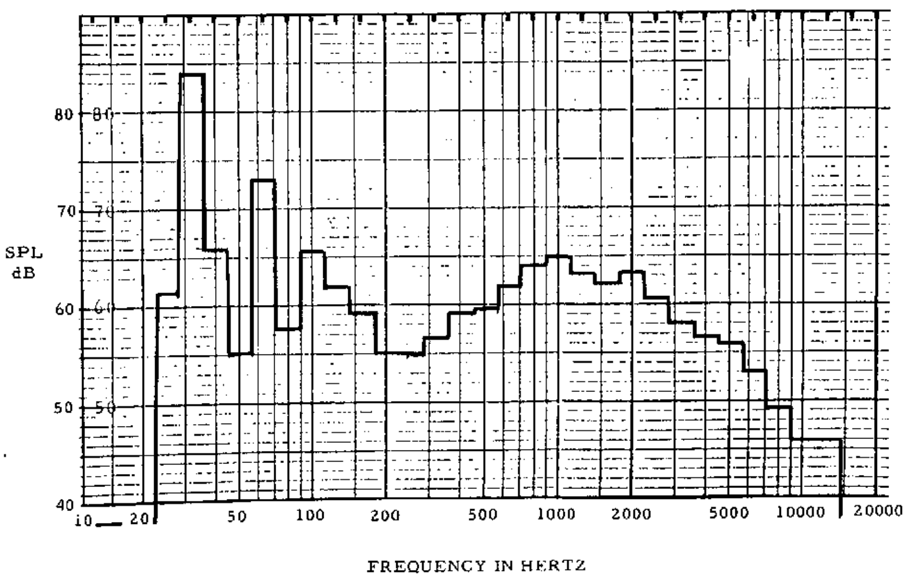


RUN NO. 348

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

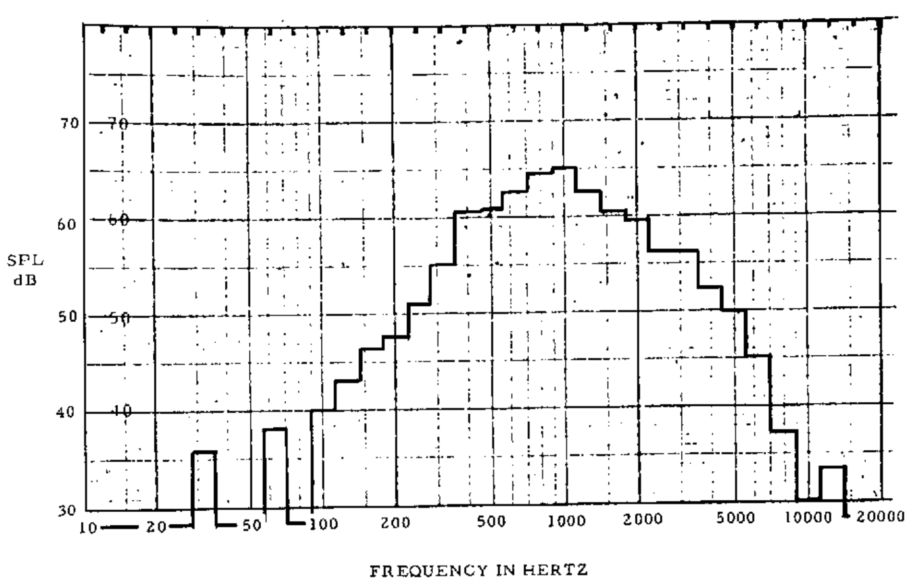
MAIN ROTOR 666 fps
TAIL ROTOR OFF
EXHAUST GROUND SILENCER
DYNAMOMETER OFF

OVERALL NOISE LEVEL

LINEAR	84.8
"A"	71.4
"D"	78.2
PNdB	85.3

(RECORDED AT: 70 dB)

OH-6A Helicopter - main rotor only
2400 Lb, 103% N_2 Track 1



RUN NO. 348

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

MAIN ROTOR 666 fps
TAIL ROTOR OFF
EXHAUST GROUND SILENCER
DYNAMOMETER OFF

OVERALL NOISE LEVEL

LINEAR
"A"
"D"
PNdB
} NOT APPROPRIATE

(RECORDED AT: 70 dB)

OH-6A Helicopter - main rotor only
2400 Lb, 103% N_2 Track 3

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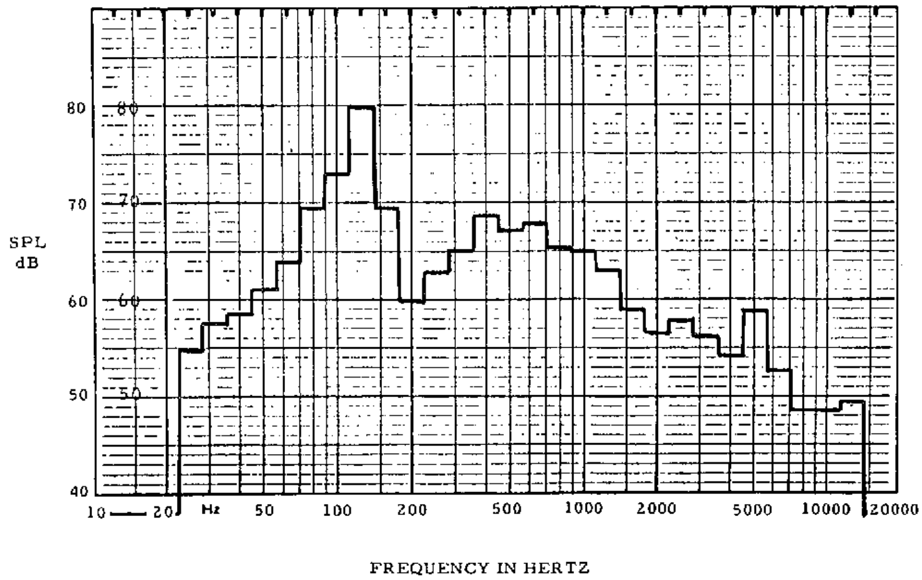


RUN NO. 385

OH-6A HELICOPTER

SIMULATED HOVER
6FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

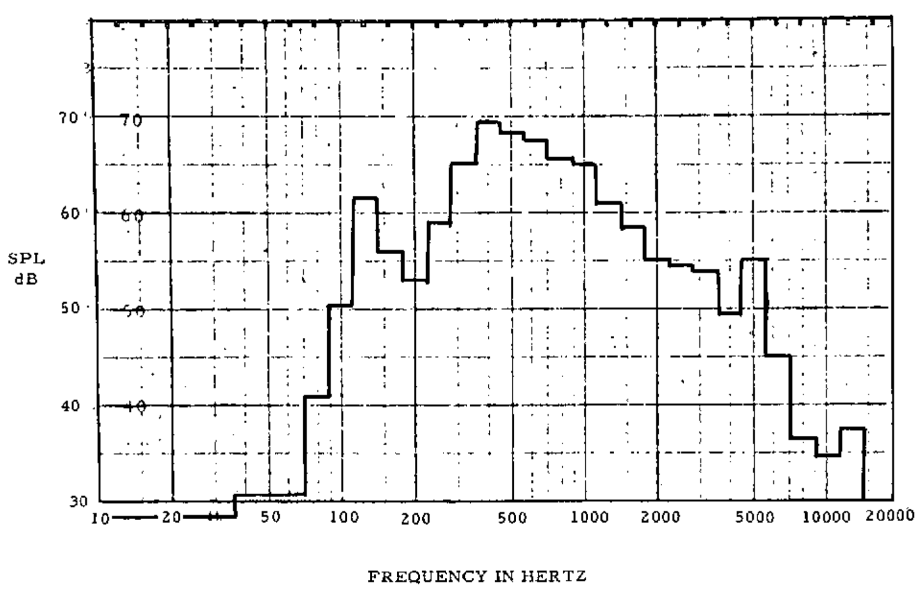
MAIN ROTOR	OFF
TAIL ROTOR	OFF
COWL DOORS	STANDARD
EXHAUST	OPEN
DYNAMOMETER	ON

OVERALL NOISE LEVEL

LINEAR	82.4
"A"	72.8
"D"	79.7
PNdb	87.3

(RECORDED AT 70 dB)

OH-6A Helicopter - engine only
Standard configuration 215 h.p. Track 1



RUN NO. 385

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

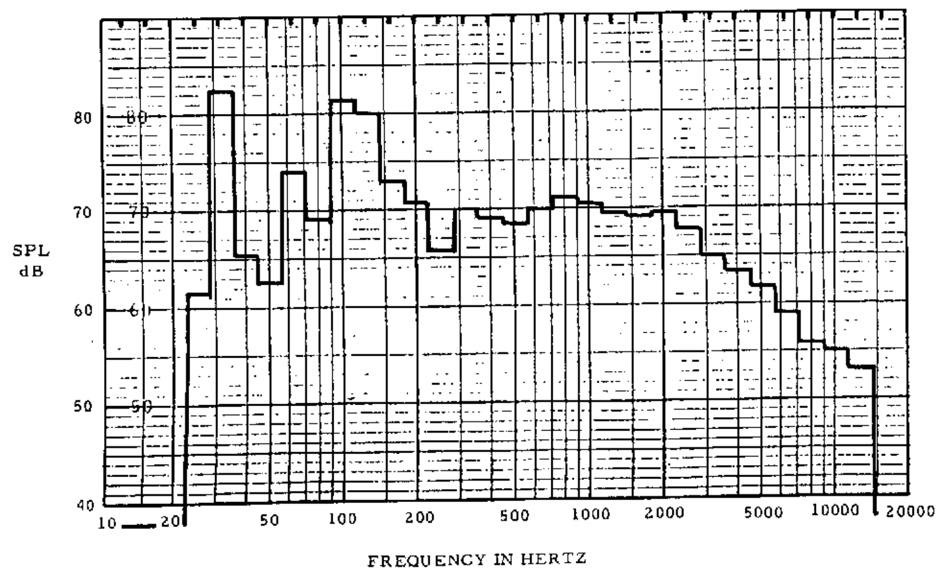
CONFIGURATION

MAIN ROTOR	OFF
TAIL ROTOR	OFF
COWL DOORS	STANDARD
EXHAUST	OPEN
DYNAMOMETER	ON

OVERALL NOISE LEVEL

LINEAR
"A"
"D"
} NOT APPROPRIATE
PNdB
(RECORDED AT 70 dB)

OH-6A Helicopter - engine only
Standard configuration 215 h.p. Track 3



RUN NO. 390

OH-6A HELICOPTER

SIMULATED HOVER
6FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

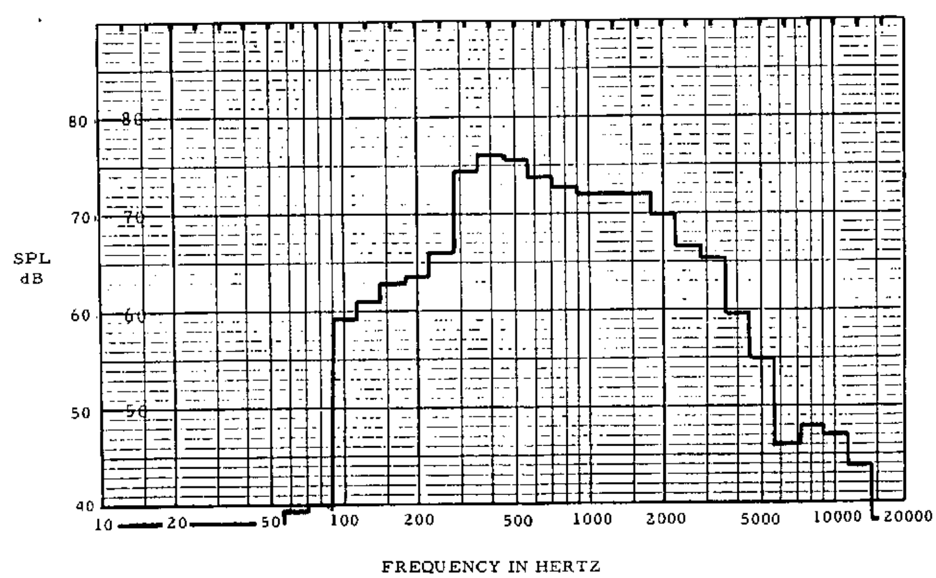
MAIN ROTOR	666 fps
TAIL ROTOR	666 fps
COWL DOORS	STANDARD
EXHAUST	OPEN
DYNAMOMETER	OFF

OVERALL NOISE LEVEL

LINEAR	88.2
"A"	81.2
"D"	86.0
PNdb	93.4

(RECORDED AT 70 dB)

OH-6A Helicopter complete aircraft
2400 Lb 103% N_2 Track 1



RUN NO. 390

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

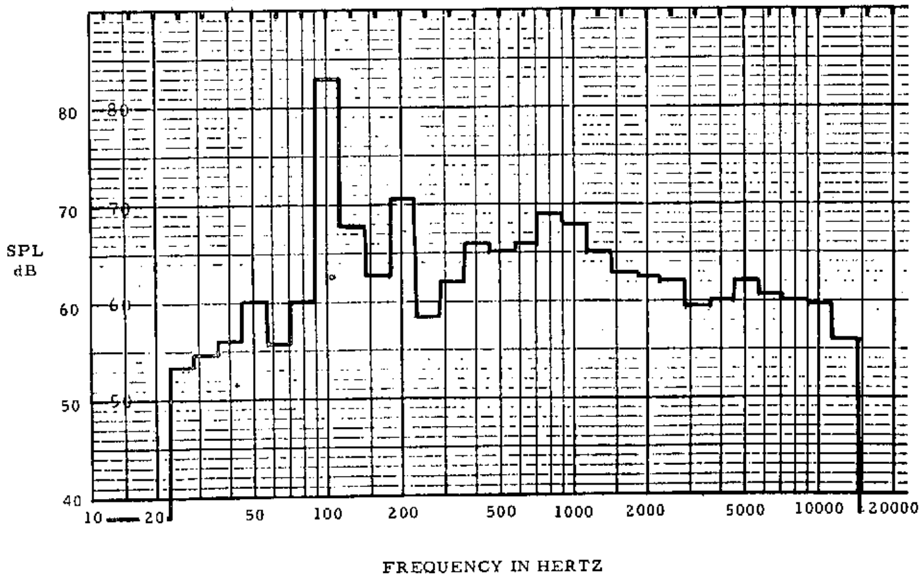
MAIN ROTOR	666 fps
TAIL ROTOR	666 fps
COWL DOORS	STANDARD
EXHAUST	OPEN
DYNAMOMETER	OFF

OVERALL NOISE LEVEL

LINEAR
"A"
"D"
PNdB
} NOT APPROPRIATE

(RECORDED AT 70 dB)

OH-6A Helicopter complete aircraft
2400 Lb 103% N_2 Track 3



RUN NO. 395

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

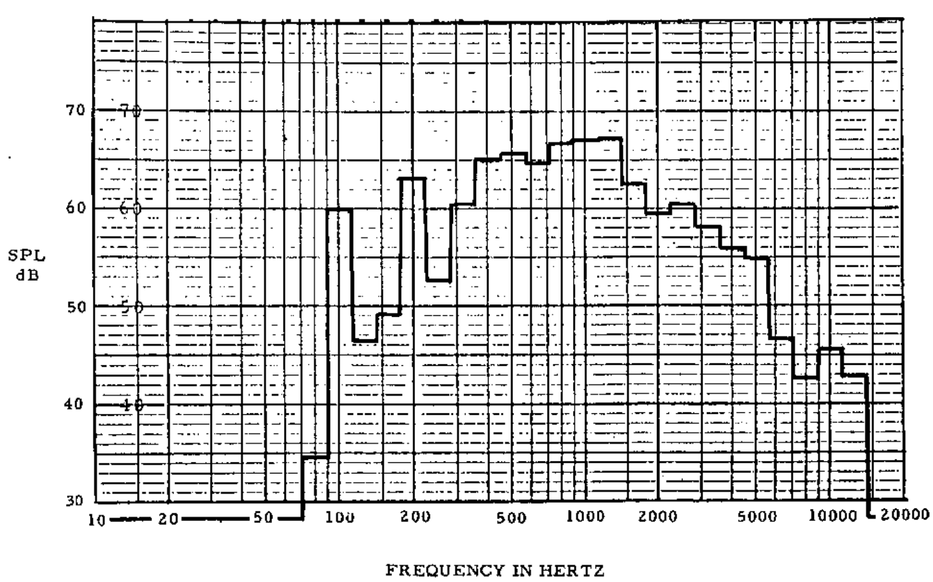
MAIN ROTOR OFF
TAIL ROTOR 692 fps
EXHAUST GROUND SILENCER
DYNAMOMETER ON

OVERALL NOISE LEVEL

LINEAR	84.8
"A"	78.0
"D"	82.3
PNdB	90.3

(RECORDED AT: 70 dB)

OH-6A Helicopter - tail rotor only - 134 Lb (Hover) thrust Track 1



RUN NO. 395

OH-6A HELICOPTER

SIMULATED HOVER
6 FT SKID HEIGHT
(MICROPHONE AT 200 FT
30° L OF AFT)

CONFIGURATION

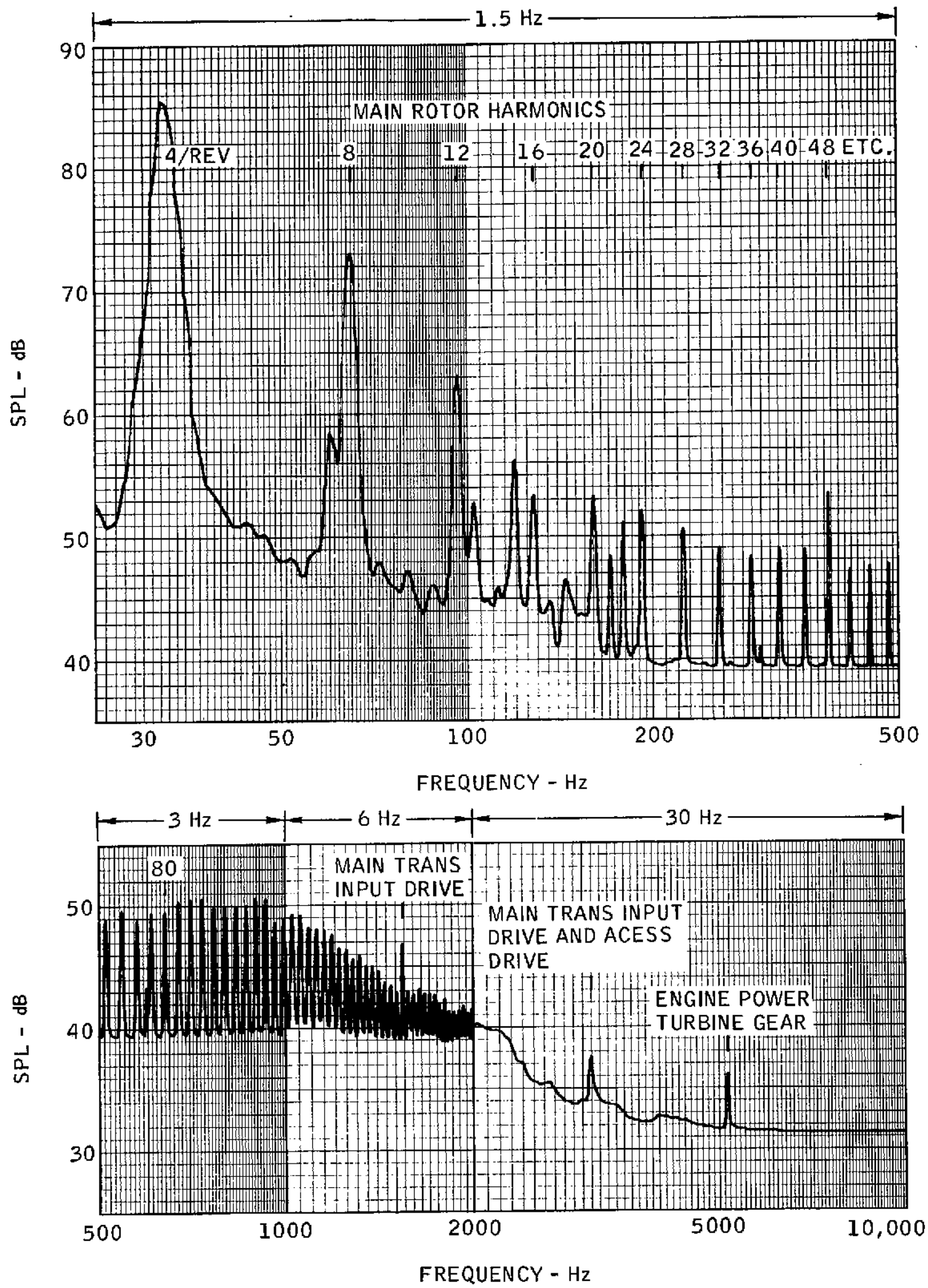
MAIN ROTOR OFF
TAIL ROTOR 692 fps
EXHAUST GROUND SILENCER
DYNAMOMETER ON

OVERALL NOISE LEVEL

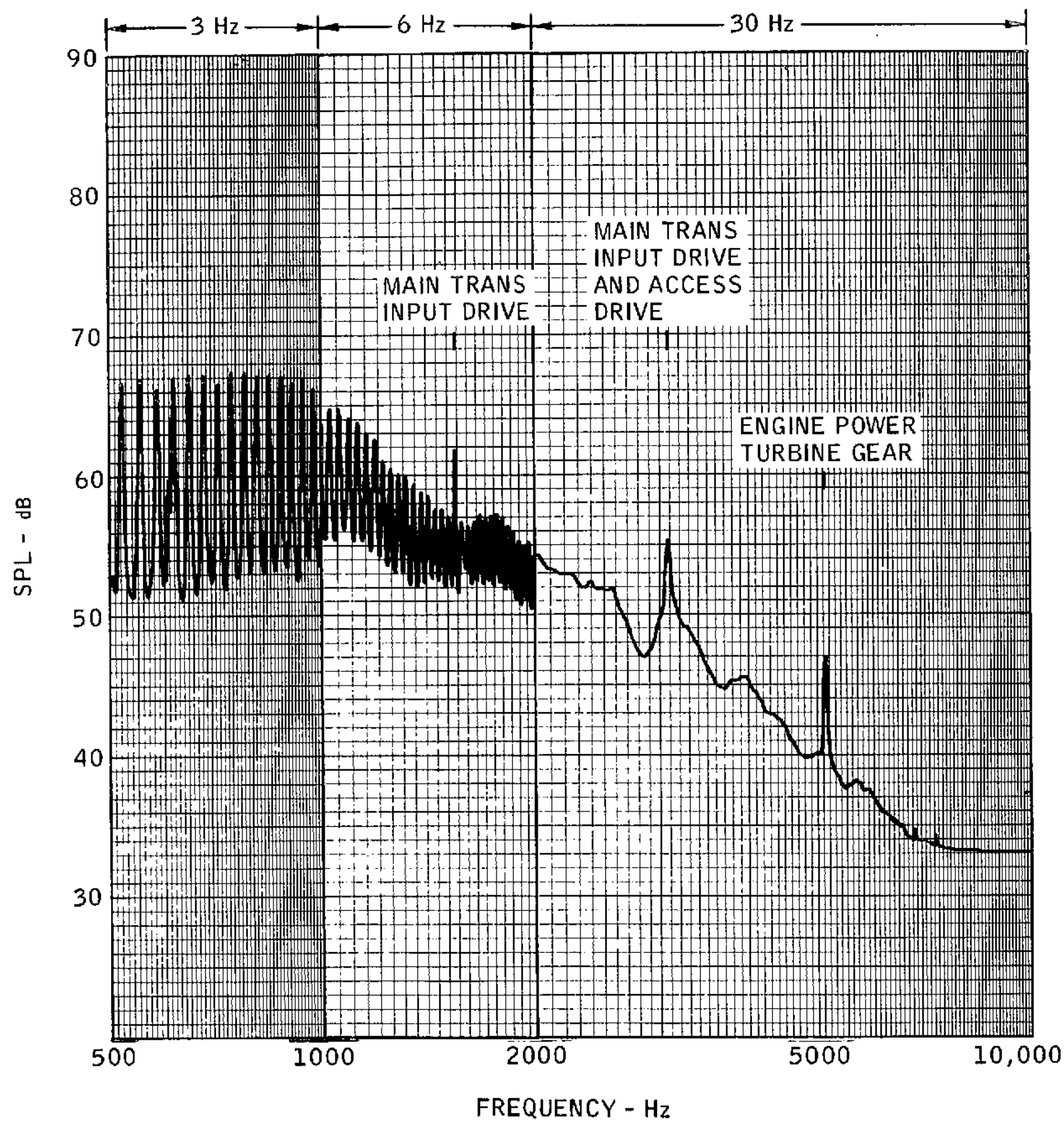
LINEAR
"A"
"D"
PNdB
} NOT APPROPRIATE

(RECORDED AT: 70 dB)

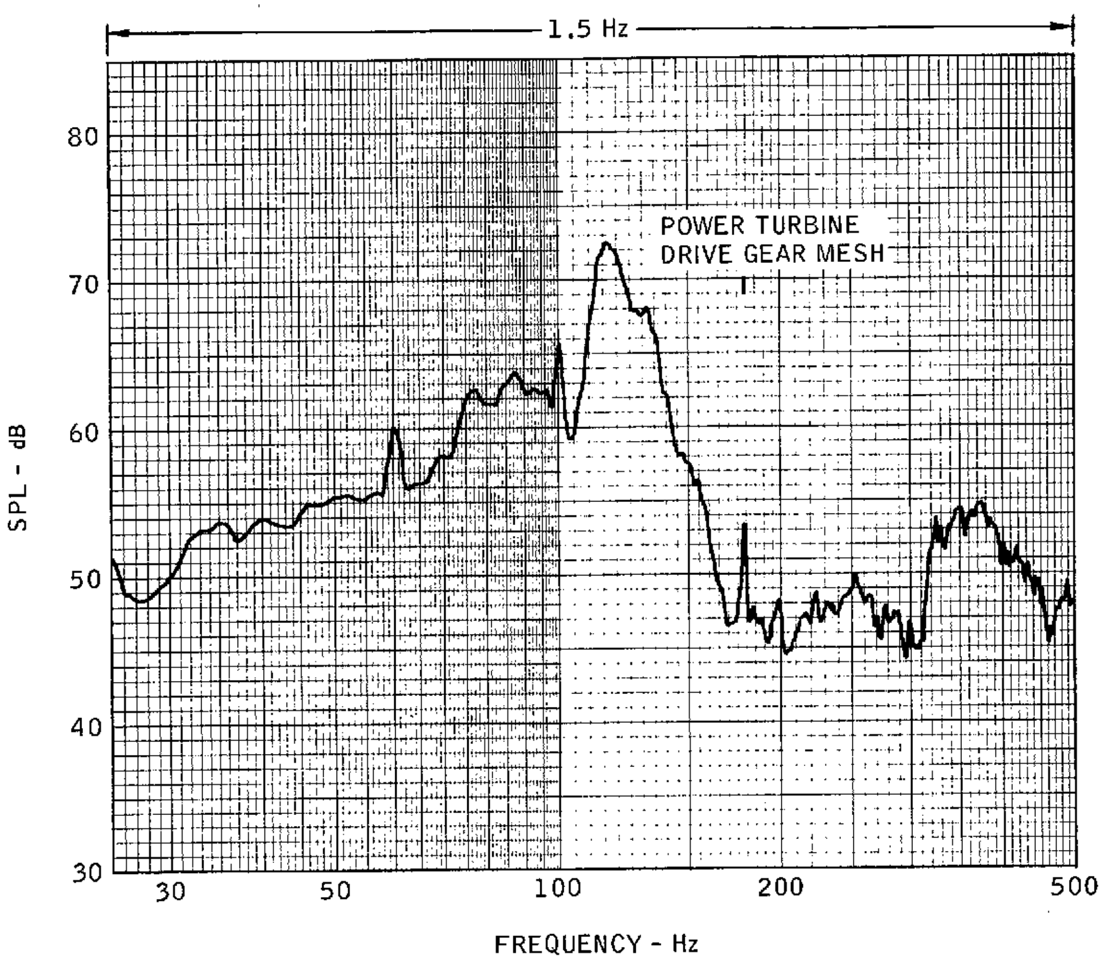
OH-6A Helicopter - tail rotor only - 134 Lb (Hover) thrust Track 3

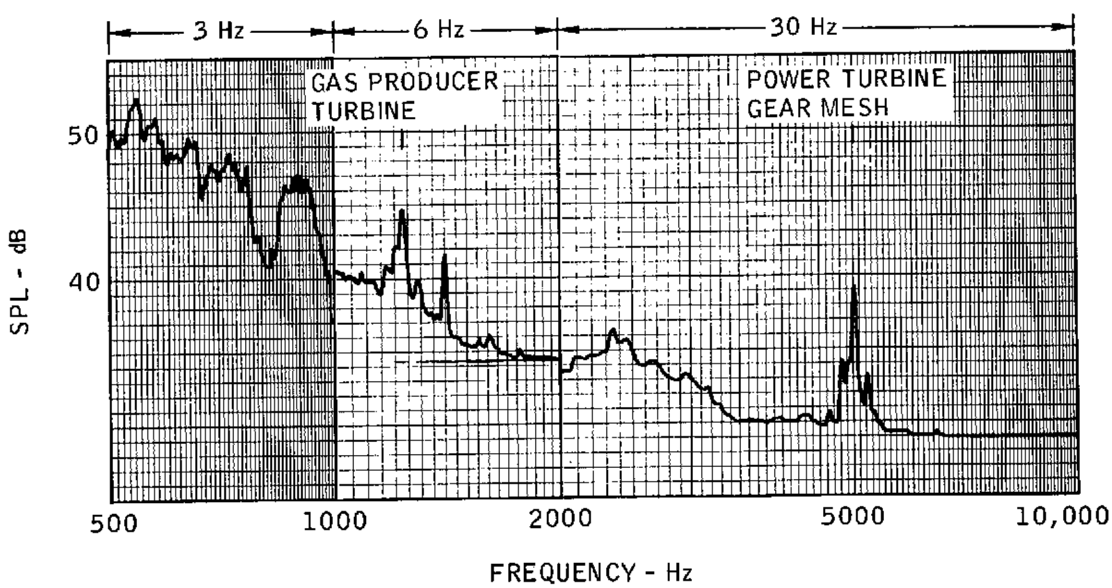


Run 348. Narrow Band Spectra Plot, OH-6A Helicopter
Main Rotor Only (4-Bladed) Track 1

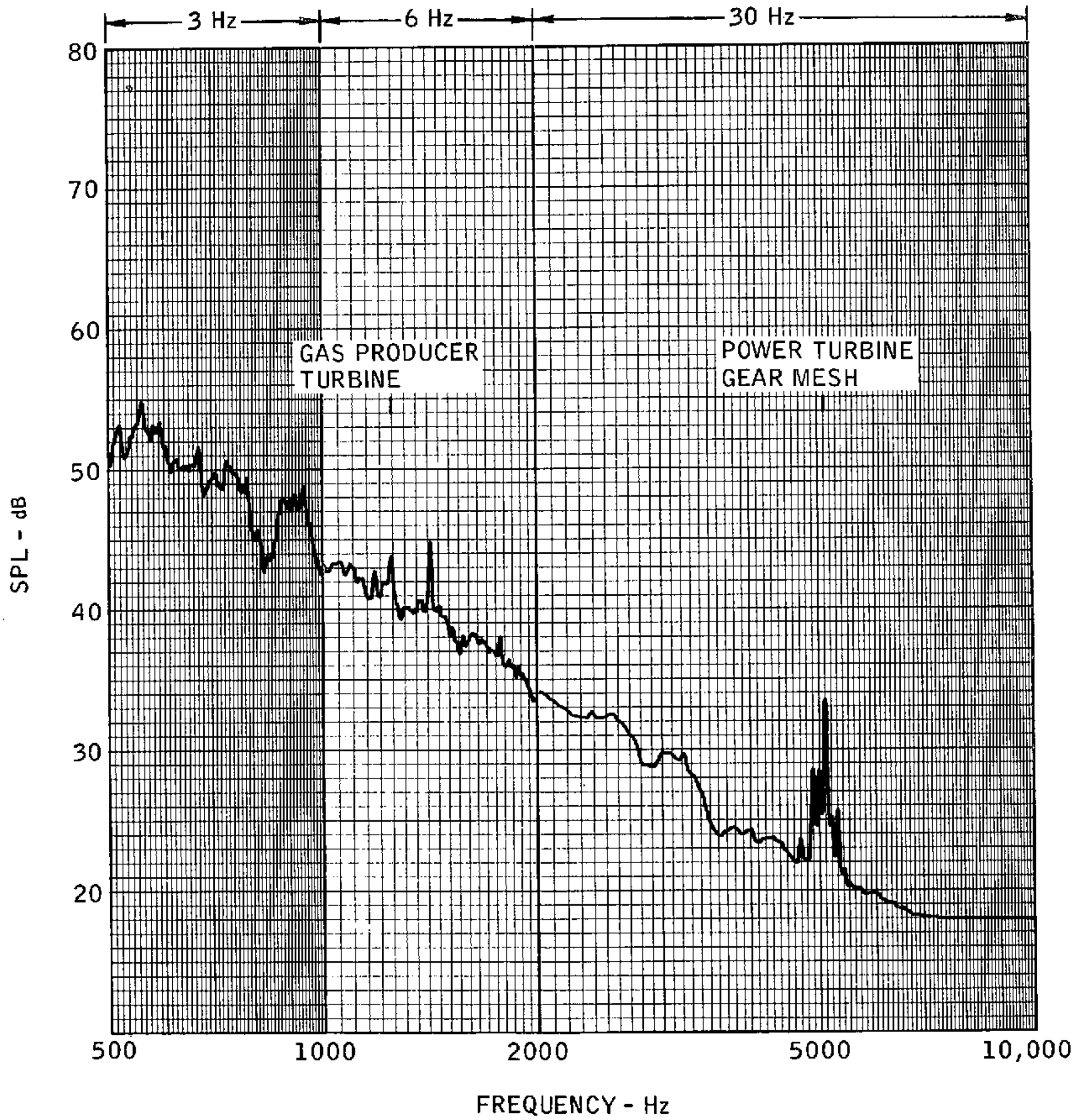


Run 348. Narrow Band Spectra Plot, OH-6A Helicopter Main Rotor Only (4-Bladed) Track 3

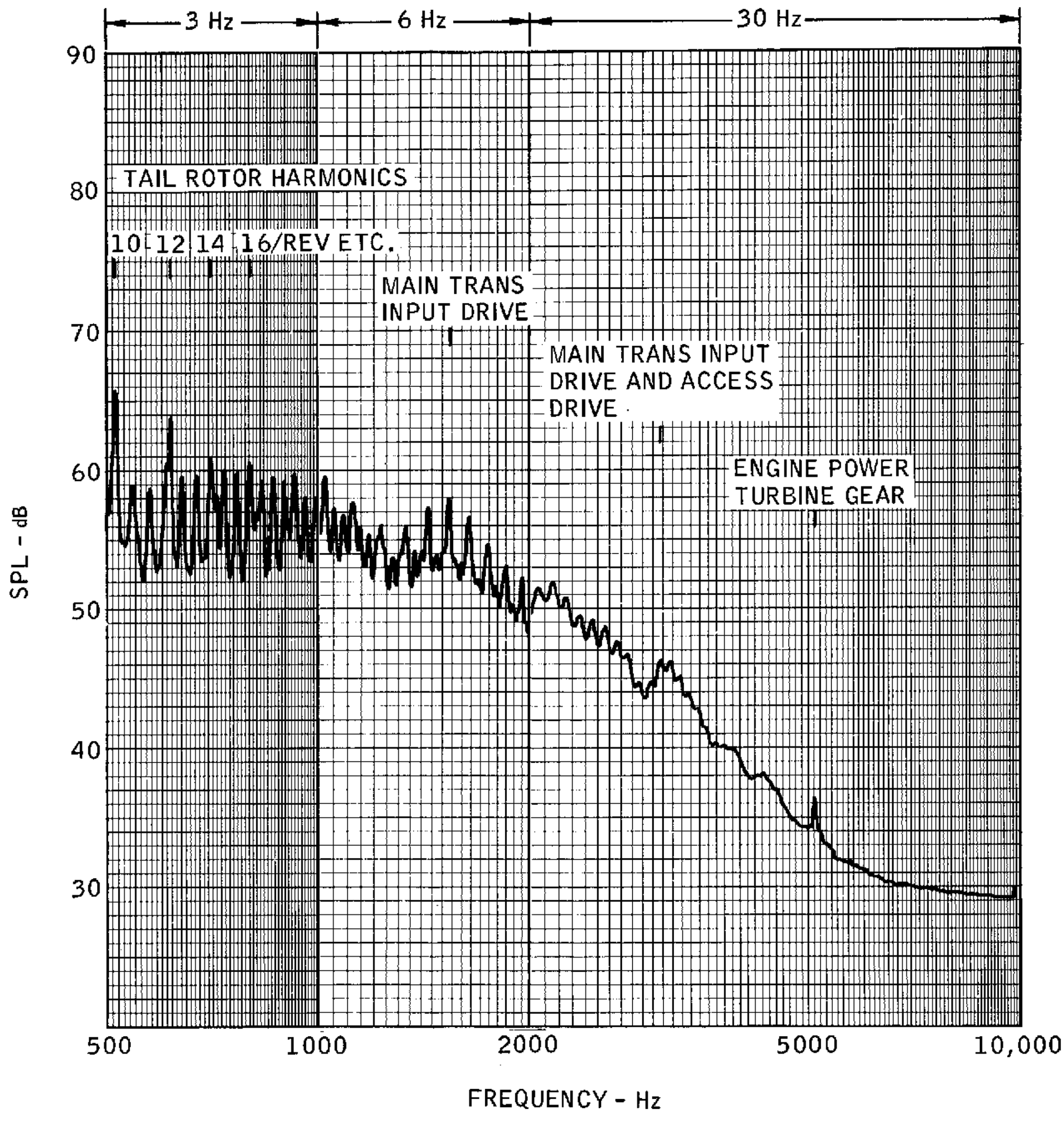




Run 385. Narrow Band Spectra Plot, OH-6A Helicopter
Engine Only Track 1



Run 385. Narrow Band Spectra Plot, OH-6A Helicopter
Engine Only Track 3



Run 390. Narrow Band Spectra Plot, Complete OH-6A Helicopter Simulated Hover Track 3