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Operational Noise Data for CH-47D and AH-64 Army Helicopters

by Paul D. Schomer Aaron J. Averbuch Richard Raspet Richard K. Wolf

The objectives of this study were to develop sound exposure level (SEL) versus distance curves for flight operations and time-average sound level (LEQ) contours versus distance for static operations for two new Army aircraft. Sound levels produced by the helicopters were measured for the aircraft both hovering and traveling at varoius speeds. The CH-47D was operated in both a heavily and a lightly loaded configuration; the heavy load was achieved by sling-loading a 10-ton Army truck.

The data show that the aircraft are quieter than the types they are replacing; the CH-47C and the AH-1G. Except at the highest speeds, sound variation with speed is not a large factor. In terms of sound variation with load, the CH-47D actually made less sound during level flight at full load than it did lightly loaded, although the sound did increase with load during takeoff and landing. As with other aircraft, the CH-47D makes more sound during landing than it does during level flight or takeoff, but the sound levels for the AH-64 are virtually independent of operation.

Only two of each aircraft were supplied. Both types of aircraft exhibited sound levels which were a little higher than expected, and more aircraft would have enhanced the statistical reliability of the data. In the future, a minimum of four aircraft of any type should be supplied. They should be measured in two gropus of two, separated by at least 1 month in time to better insure the statistical reliability of the data.

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distance for static operations for two new Army aircraft; the CH-47D and the AH-64. Sound levels produced by the helicopters were measured for the aircraft both hovering and traveling at various speeds. The CH-47D was operated in both a heavily and a lightly loaded configuration; the heavy load was achieved by sling-loading a 10-ton Army truck.

The data show that the aircraft are quieter than the types they are replacing; the CH-47C and the AH-1G. Except at the highest speeds, sound variation with speed is not a large factor. In terms of sound variation with load (because of possible changes in cyclic trim), the CH-47D actually made less sound during level flight at full load than it (cont'd)

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did lightly loaded, although the sound did increase with load during takeoff and landing. As with other aircraft, the CH-47D makes more sound during landing than it does during level flight or takeoff, but the sound levels for the AH-64 are virtually independent of operation.

Only two of each aircraft were supplied. Both types of aircraft exhibited sound levels which were a little higher than expected, and more aircraft would have enhanced the statistical reliability of the data. In the future, a minimum of four aircraft of any type should be supplied. They should be measured in two groups of two, separated by at least 1 month in time to better insure the statistical reliability of the data.

Unclassified

FOREWORD

This work was performed for the U.S. Army Materiel Command (AMC), Aviation Systems Command, under IAO AAH 676-86, dated April 1986, and IAO 19-5-BK092, dated November 1986, as part of their responsibilities under Army Regulation (AR) 200-1 and the AMC Supplement to AR 200-1. The Technical Monitors were MAJ James O'Connor and Jim Pliml for the CH-47D and the AH-64, respectively.

The investigation was conducted by the Environmental (EN) Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. R. K. Jain is Chief, EN. The Technical Editor was Gloria J. Wienke, Information Management Office.

COL Norman C. Hintz is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

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OPERATIONAL NOISE DATA FOR CH-47D AND AH-64 ARMY HELICOPTERS

1 INTRODUCTION

Background

In recent years, residential development has occurred near military and civilian airfields--areas subject to high noise levels from aircraft and airfield operations. To control this development, the U.S. Army has instituted the Installation Compatible Use Zone (ICUZ) Program.¹ Like the Department of Defense's (DOD) Construction Criteria manual and Air Installations Compatible Use Zone program (AICUZ), the ICUZ program defines land uses compatible with various noise levels and establishes a policy for achieving such uses.² Each document describes three noise zones which restrict land use in varying degrees to ensure compatibility with military operations. The ICUZ program stresses Army-unique noise sources such as blasts (e.g., artillery, armor, demolition) and rotary-wing aircraft.

Noise zone maps for the ICUZ program are developed by the Army Environmental Hygiene Agency (AEHA) using U.S. Army Construction Engineering Research Laboratory's (USA-CERL's) integrated noise contour system (INCS). This system can produce integrated noise zone maps for blast noise and fixed- and rotary-wing aircraft operations. Noise zone maps are produced using the USA-CERL-developed BNOISE-3.2 computerized prediction procedures; helicopter noise zone maps are developed using a USA-CERL-modified Air Force (AF) NOISEMAP Computer Prediction Program.³ Each of these computerized prediction procedures relies on three separate data sources: (1) source emissions data, (2) data detailing sound propagation from source to receiver, and (3) data defining the human and community response to the received noise.

Previous USA-CERL research has addressed these sets of data for then current rotary-wing aircraft and for blast noise prediction. In particular, USA-CERL Technical Report N-38 defines the noise emission characteristics for rotary-wing aircraft operating in the Army fleet during the late 1970s⁴ and USA-CERL Technical Report N-131 defines the noise emissions of the CH-47C and the UH-60A from testing conducted at Forts

¹Army Regulation (AR) 200-1, Environmental Protection and Enhancement, Chapter 7 (U.S. Army Corps of Engineers [USACE], 15 June 1982).

²DOD 4270.1-M, Construction Criteria (Department of Defense [DOD], 1972); DOD Instruction 4165-57, Air Installations Compatible Use Zones (DOD, 1973).

³Lincoln L. Little, Violetta I. Pawlowska, and David L. Effland, Blast Noise Prediction Volume II: BNOISE 2.3 Computer Program Description and Program Listing, Technical Report N-98/ADA099335 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], 1981); R. D. Horonjeff, R. R. Kandurkuri, and N. H. Reddinghius, Community Noise Exposure Resulting From Aircraft Operation: Computer Program Description, Aerospace Medical Research Laboratory Report AMRL-TR-73-109 (Bolt Beranek and Newman, 1974).

⁶B. Homans, L. Little, and P. Schomer, Rotary Wing Aircraft Operational Noise Data, Technical Report N-38/ADA051999 (USA-CERL, 1978).

Rucker and Campbell.⁵ Since then, the new CH-47D and AH-64 helicopters have been introduced; their emissions data are required by the Army for ICUZ and for environmental assessment.

USA-CERL Technical Report N-184 studied repeatability of rotary-wing aircraft source emissions and concluded with recommendations for statistical validity and a slightly revised microphone layout.⁶

Objectives

The objectives of this study were to develop (1) sound exposure level (SEL) versus distance curves for flight operations and (2) time-average sound level (LEQ) contours versus distance for static operations for two new Army aircraft; the CH-47D and the AH-64.

Approach

In the past, helicopter noise emissions were measured by going to locations where the aircraft were based. The measurements require a flat, open field (650 ft radius) with no extraneous noise. Because this method of obtaining measurements presented a significant coordination problem and travel expense, it was decided to permanently install microphone positions, equipment housing, a grass landing pad, and weather sensing equipment for testing at the Bondville Field Station of the University of Illinois. Measurements for the CH-47D and AH-64 were performed at this site in accordance with the recommendation set forth in USA-CERL Technical Report N-184.

Mode of Technology Transfer

Data developed for helicopter SEL versus distance or speed and static operations LEQ versus distance will be entered in the INCS data base and will be immediately available for use by AEHA and other DOD organizations.

⁵P. D. Schomer, Aaron Averbuch, and Richard Raspet, Operational Noise Data for UH-60A and CH-47C Army Helicopters, Technical Report N-131/ADA118796 (USA-CERL, June 1982).

⁶Paul D. Schomer, Rotary-Wing Aircraft Noise Measurements: Analysis of Variations and Proposed Measurement Standard, Technical Report N-184/ADA146207 (USA-CERL, September 1984).

2 DATA COLLECTION

Helicopter Operations

At Fort Rucker, one set of data had been based on the dynamic operations listed in Table 1.* Forty helicopters took part in that study; each aircraft flew the series of operations twice: once with the pilot and once with the copilot. Table 2 lists the aircraft types and loading conditions employed. The Fort Rucker study indicated that level flyover data adequately characterized the noise emissions of all other dynamic operations except landings. Therefore, for the study at Fort Campbell and this new study, concern centered only on level flyovers, landings, and static operations. Takeoffs are also measured separately since a takeoff must precede each landing.

At Forts Rucker and Campbell, cargo and utility aircraft were flown lightly loaded and fully loaded. Table 3 lists the operations performed by the helicopters at Fort Campbell. At both forts, the aircraft began by flying level flyovers at 300 ft above ground level (AGL). In the middle of the test, they performed static operations, and then resumed level flyovers. Four aircraft of each type were requested; each with a different crew.

For testing at the Bondville site, USA-CERL researchers requested four CH-47D and four AH-64 sizeraft; only two of each could be obtained. Each CH-47D was flown twice fully loaded and twice partially loaded. Each condition was flown by the pilot and the copilot. To load the CH-47D, its sling was used to carry a 10-ton Army truck. The AH-64 were flown only with a fuel load and only twice each: once by the pilot and once by the copilot. Table 4 lists the operations performed at these tests.

The level flyovers were flown similarly to those at Forts Rucker and Campbell. The pilots were instructed to maintain straight, level, steady flight for at least 1.5 nautical miles before and after each dynamic operation. All teardrop turns, other ancillary maneuvers, and preparations for actual dynamic operation were performed beyond 1.5 nautical miles. Flying this distance allowed the pilot to stabilize the aircraft and provided enough time for 10-decibel (dB) down-sound-level points to be recorded on magnetic tape when the operation was flown at 300 ft AGL. Figure 1 illustrates the level flyover flight path. Landings began at 300 ft AGL on a ground track of 180 or 360 degrees and terminated at the center of the microphone array (Figure 2).

Static operations consisted of 0-pitch engine idle, in-ground and out-of-ground effect hovers. These measurements were performed over a grassy area in the center of the array (Figure 2). In-ground effect hovers were performed with the aircraft at a stabilized position between 0 and 5 ft above the ground. Out-of-ground hovers were performed at an altitude of 1 1/2 rotor diameters.

The pilots logged information about each operation flown. Typical entries from a pilot's log are shown in Appendix A.

^{*}Tables and figures appear at the end of this report, beginning on p 15.

Microphone Placement

Figure 2 shows the layout for six microphones. With this arrangement, any flight alignment from Figure 1 (18-36, 6-24, 12-30) can be used depending on winds. The remaining four microphones are the sideline microphones. Landings and takeoffs are to the center of the array and static operations are performed at the array center. With operations at 300 ft AGL, the sideline microphones are 433 ft to the side, the slant distance (distance of the aircraft's closest approach to the microphone) is 527 ft.

Measurement Instrumentation

As at Fort Campbell, the acoustical instrumentation consisted of six B&K 4149 quartz-coated microphones on B&K 4921 outdoor microphone systems with silk windscreens. Each microphone channel was recorded on a Nagra SJ channel (A.M.; 7-1/2 inches per second [ips], 60 dB dynamic range) and analyzed in the field for overall A-weighted SEL using a USA-CERL True Integrating Noise Meter. The six microphones were wired underground to the mobile Acoustics Field Laboratory.

Ground Tracking System

The tracking system used at Forts Campbell and Rucker consisted of two cameras and a theodolite to mark the position of an aircraft flying over the middle of the microphone array. At the Bondville Field Station, three cameras were used as shown in Figures 2 and 3. Stator poles in front of the camera positions were marked with uniform graduations. By examining photographs from those cameras, one could ascertain position information in three dimensions at the moment the pictures for the 300-ft-AGL test were taken. The thoedolite used in earlier tests, was not needed since these modern aircraft with their radar altimeters are always close to the correct altitude.

Calibration

At the beginning of each reel of tape, the 1000-Hz electrostatic actuator built into the 4921 microphone systems was used to set a known level on the tape. The electrostatic actuators were tested with B&K 4220, 124-dB pistonphones before and after the entire measurement program. (Calibration of the electrostatic actuator with the B&K 4220 allows one to establish an absolute calibration value for each actuator.) Calibration was checked at the end of each measurement period.

3 DATA REDUCTION AND ANALYSIS

Camera Data

The graduated stator rod in the foreground of each photograph allowed calculation of altitude and lateral variation over the center of the flight track because the camera angle, distance to the stator rod, and distance between graduations on the stator rod were known (Figure 3).

Negatives of each helicopter were projected on the screen of a microfiche reader; measurements were taken in relation to the stator rod, and data were encoded into a microcomputer for further calculation and analysis. Given the information supplied by the pictures, algorithms were written that located the helicopter in three dimensions at the time the cameras were activated. The slant distance to each of the six microphones in the array was calculated based on the position of the helicopter in space and its forward speed.

Acoustical Data Reduction

A B&K 2131 Digital Frequency Analyzer or a Larson Davis 3100 Real Time Analyzer (LD) interfaced to a Hewlett Packard (HP) 9816 computer was used for data reduction. The procedure for the analysis system was as follows. When a helicopter was first detected, the analysis equipment was started. After the helicopter being analyzed was no longer detectable, analysis stopped. The full one-third octave spectrum for each microphone for each 0.5 sec (with a "slow" time response) was stored in the HP computer or the LD analyzer depending on the analyzer used.

The problem of different types of noise being present is inherent in any analysis procedure. However, noise from different sources only becomes significant when it approaches the signal level. The sources of noise include: (1) background acoustical, (2) electrical, and (3) recording tape. In this study, three respective methods were used to determine the combined noise level.

For the first type of noise--ambient noise--a recording was made either immediately before or after the helicopter arrived or departed the area. This reading reflected wind, vehicles, birds, and other environmental sounds that occurred during the tests.

Electrical noise--the noise of the system that is constant at different gain settings--was measured by attaching a dummy microphone to the input amplifier at a microphone station and measuring the resultant level on playback from tape.

The third noise--tape noise--was measured by shorting the input to one channel and recording. On playback, the level was measured.

These three noise measurements were summed to calculate a composite noise level (CNL). This was developed in one-third octaves for each gain setting used. This "correcting" CNL was compared to the resultant one-third octave spectra for each 0.5 sec. One-third octave bands in any 0.5-sec interval were flagged if their level came within 10 dB of the corresponding CNL value. If the difference was 3 dB or more, the one-third octave band was "corrected" on an energy base; otherwise it was deleted. For all noise readings taken, gain settings throughout the system were held the same as they were when the helicopter data were recorded, or the changes were noted and accounted for.

Acoustical Data Analysis

The final data were developed in four steps. First, the 0.5-sec time interval having the maximum A-weighted value (slow) was determined, and the entire one-third octave spectrum for this 0.5-sec interval was stored as a separate record. Second, the Aweighted SEL was calculated for the time-interval during which the A-weighted level sound was within 10 dB of the maximum level (determined in first step). Third, from the positional information on the photographs, the closest approach of the aircraft to each microphone for each individual flyover was determined. Finally, the maximum spectrum and distance of closest approach were used to convert the raw field-measured SEL (A-weighted) to an equivalent SEL for a day with a standard temperature of 15 °C (59 °F) and relative humidity of 70 percent.

During this final step, A-weighted SEL versus distance relations were established. Distance causes three factors to vary: air absorption (the one-third octave spectrum was used to determine the effect of air absorption), the $1/r^2$ amplitude change of a point acoustical source, and the apparent durational change of a source moving in a straight line at various constant speeds. Appendix A of USA-CERL Technical Report N-38 contains a detailed description of this analysis procedure, which is structured after the AF procedure that was developed to reduce similar fixed-wing aircraft acoustical data.⁷ As with current practice of the Federal Aviation Administration (FAA) and AF, the durational factor is constrained to also account for excess ground attenuation. So SEL versus distance curves include air absorption and a -13 log d/d₀ term which accounts for distance, duration and excess absorption where: (1) $1/r^2$ is proportional to -20 log d/d₀, (2) duration is proportional +10 log d/d₀, and (3) excess attenuation is proportional to -3 log d/d₀.

Static Operations Acoustical Data Analysis

Hover and engine idle data were analyzed by finding the time-average one-third octave spectra at each microphone. These were energy-averaged and time-average sound level (LEQ) versus distance data developed using detailed propagation models for ground-to-ground sound propagation.⁸

⁷Bishop, D. E., and W. J. Galloway, Community Noise Exposure Resulting From Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data, Aerospace Medical Research Laboratory Report AMRL-TR-73-107 (Bolt Beranek and Newman, 1975).

⁸R. K. Wolf and R. Raspet, "Investigation of the Dependence of Excess Attenuation of Aircraft Noise on Distance," J. Acoust. Soc. Am., Suppl. 1, Vol 80 (1986), pp S8-S9.

4 RESULTS

Sound Exposure Level Versus Distance

Figures 4, 5, and 6 illustrate the developed SEL versus distance curves for level flyovers at a speed of 130 knots (300 ft AGL), landings, and takeoffs respectively for the CH-47D; 130 knots is reported since this is the typical cruise speed of the CH-47D and the AH-64. For the heavily loaded "landing," the CH-47D actually brought the sling-loaded truck to the landing pad and hovered with the truck resting on the ground. As with the earlier CH-47 data, a landing creates substantially more noise than does a level flyover at all but the highest speed.

The noise from the heavily loaded aircraft (44,000 versus 31,000 lbs) should have been about 1.5 dB louder. However, the change in weight results in a change in centerof-gravity and cyclic trim. This apparently reduces the blade-vortex interaction noise such that the loaded aircraft is actually quieter during level flyover, although it is noisier during takeoff or landing.

Figure 7 illustrates similar SEL versus distance data developed for the AH-64 for level flyovers at a speed of 130 knots, landings, and takeoffs. Appendix B contains tabular summaries of these AH-64 and CH-47D data and other similar results. There is little difference between operations and the increase in noise evident for other aircraft during landings is not present in the case of the AH-64.

Hover Data

Figures 8 and 9 illustrate time-average A-weighted sound level for in- and out-ofground effect hover and for engine idle for the lightly and heavily loaded CH-47D and for the AH-64, respectively. The data are developed for both a hard surface such as a heliport in a paved, built-up area and for a soft surface such as the typical airport with its large expanses of open grass fields. These data are derived by averaging the timeaverage one-third octave level at each microphone and using the procedures described by Wolf and Raspet to determine the decay of these levels with distance.

Variation of Sound Exposure Level With Speed

Figure 10 illustrates the measured variation of SEL with speed for the CH-47D and AH-64 at a slant distance of 200 m. These data are also tabulated in Appendix B.

5 CONCLUSIONS AND RECOMMENDATIONS

SEL versus distance curves for the CH-47D and AH-64 were developed. These particular data for the CH-47D show that a heavily loaded aircraft is actually quieter than a lightly loaded one. For this reason, the data curves for a lightly loaded aircraft are recommended for general use. As with all other Army rotary-wing aircraft, landing noise of the CH-47D and AH-64 is substantially greater than is cruise speed level flyover noise, but the increase is only marginal for the AH-64.

As was found with earlier studies, the variation of SEL with speed is rather modest, except for aircraft at very high speeds. The variation of SEL with speed data will be incorporated into a planned new version of the helicopter noise contour program which will be based on FAA work. So, in the future, this capability will be available when (1) aircraft speeds differ significantly from the typical speeds, (2) the situation warrants this precision, and (3) the aircraft operational data are accurate enough to reliably indicate aircraft position, altitude, and speed as a function of time.

Noise data from both of these aircraft are a little higher than expected. In the future, a minimum of four of each aircraft is recommended. The measurements should be done in two groups at least 1 month apart to better ensure statistical reliability.

The control of blade-vortex noise by cyclic trim offers a potential means to mitigate CH-47D noise and should be the subject of further study.

Table 1

Dynamic Operations Peformed at Fort Rucker

Ор	eration	Beginning Ground Track (GT) (degrees)
1.	Level	360
2.	Level	180
3.	NOE*	360
4.	NOE	180
5.	Ascent	360
6.	Descent	180
7.	Descent	360
8.	Ascent	180
9.	Left turn	315
10.	Right turn	45
11.	Right turn	225
12.	Left turn	135
13.	Landing	180
14.	Takeoff	180

*Nap of the earth (NOE) operations were not used in the analysis because of the inability to predict aircraft position.

Table 2

Helicopter Types and Loading Conditions Measured at Fort Rucker

Helicopter Model	Loading Condition					
OH-58	Normal					
AH-1G	Normal					
UH-1M	Normal					
UH-1H	Maximum or Normal					
UH-1B	Maximum or Normal					
CH-47B	Maximum or Normal					
CH-54	Maximum or Norma					
TH-55	Normal					

Table 3

Dynamic Operations Performed at Fort Campbell by CH-47C and UH-1H

Operation *	Altitude (ft)	Speed (knots)	GT (degrees)
LF	300	80	280
LF	300	80	100
LF	300	40	280
LF	300	40	100
LF	300	100	280
LF	300	100	100
LF	300	60	280
LF	300	60	100
LF	300	120	280
LF	300	120	100
\mathbf{LF}	300	80	280
LF	300	80	100
LF	300	100	280
LF	300	100	100
Landing	-	-	280
IGE Hover			
OGE Hover			
Takeoff	-	-	280
\mathbf{LF}	1000	80	100
LF	1000	80	280
LF	1000	100	100
LF	1000	100	280
LF	1000	120	100
LF	1000	120	280
LF	1000	60	100
LF	1000	60	280
LF	1000	100	100
LF	1000	100	280
LF	1000	80	100
LF	1000	80	280

*LF = level flyover; IGE = in-ground effect; OGE = out-of-ground effect.

Table 4

Typical Order of Operations Performed at Bondville

	Operation ¹	Speed (Knots)	Heading ²
A	Calibration	-	
В	Background Noise	-	
1	Takeoff ³	-	360
2	LF	130	180
3	LF	130	360
4	LF	70	180
5	LF	70	360
6	LF	100	180
7	LF	100	360
8	LF	MAX	180
9	LF	MAX ⁴	360
10	LF	40	180
11	LF	40	360
12	LF	130	180
1 3	LF	130	360
14	Land ³		180
15	Eng. Idle ⁵		180
16	IGE-Hover ⁵		Into Wind
17	OGE-Hover		Into Wind
18	Takeoff ³		180
	Background		
19	LF	70	360
20	LF	70	180
2 1	LF	MAX ⁴	360
22	LF	MAX4	180
23	LF	130	360
24	LF	130	180
25	LF	100	360
26	LF	100	180
27	LF	40	360
28	LF	40	180
20	LF	130	360
30	LF	130	180
3 1	Land ³		
	Background		

¹All level flyovers (LF) flown at 300 ft AGL.

"Maximum speed that the aircraft could fly that day (recorded in pilot's log).

⁵Could not be performed for sling-loaded CH-47D.

²These measurements began using a heading of 180 or 360. If 180 was chosen, then all the headings were the reverse of those shown in the table. These tests only used the 18-36 alignment, but the other two (12-30, 06-24) could have been used had the winds required it.

³The CH-47D, sling-loaded, "took off" and "landed" from and to an OGE hover such that the load just touched the ground in the center of the array.



Figure 1. Flight track for level flyovers. The solid path shows the tear-drop turn and the alignment (18-36) used for these tests. The dashed lines show the alternate alignments (06-24, 12-30) which could have been used had winds required one of them.



Figure 2. Test site layout. The pair of microphones (06-24, 18-36, or 12-30) most aligned with the wind are used as the flyover microphones. The other four microphones are the sideline microphones. With a flight altitude of 300 ft AGL, the sideline microphones are at a slant distance of 527 ft. Hovers, takeoffs and landings are to the center of the array. The cameras are wired together and fired electronically when the aircraft (flyover) is in the center of the array.



Figure 3. Typical camera site. Elevation through center of array. Aircraft height is determined by distance from camera to array center and to stator pole, and height of helicopter in picture (in stator pole markings).



Figure 4. SEL vs slant distance for lightly and heavily loaded CH-47D aircraft performing 300-ft AGL level flyovers at 130 knots indicated air speed.



Figure 5. SEL vs slant distance for lightly and heavily loaded CH-47D aircraft performing landings. The heavy load is a sling-loaded 10-ton truck so the landing is to a 35 ft hover.



Figure 6. SEL vs slant distance for lightly and heavily loaded CH-47D aircraft performing takeoffs. The heavy load is a sling-loaded 10-ton truck so the takeoffs are from a 35 ft hover.

فتعددوا



Figure 7. SEL vs slant distance for AH-64 aircraft performing 300-ft AGL level flyovers at 130 knots, takeoffs, and landings.



Figure 8a. Average (for all directions) A-weighted LEQ vs distance for lightly loaded CH-47D aircraft performing zero-pitch engine-idle, IGE hover, and lightly and heavily loaded aircraft performing OGE hover. The propagation is for over a hard surface.



Figure 8b. Average (for all directions) A-weighted LEQ vs distance for lightly loaded CH-47D aircraft performing zero-pitch engine-idle, IGE hover, and lightly and heavily loaded aircraft performing OGE hover. The propagation is for over a soft surface.



Figure 9a. Average (for all directions) A-weighted LEQ vs distance for AH-64 aircraft performing zero-pitch engine-idle, IGE hover, and OGE hover. The propagation is for over a hard surface.



Figure 9b. Average (for all directions) A-weighted LEQ vs distance for AH-64 aircraft performing zero-pitch engine-idle, IGE hover, and OGE hover. The propagation is for over a soft surface.



Figure 10. Variation of SEL with speed for CH-47D (lightly and heavily loaded) and AH-64 aircraft performing 300-ft AGL level flyovers at a slant distance of 200 m.

TYPICAL PILOT'S LOG

PILOT'S LOC	Run Number
Rotary Wing Aircraft Noise Measurements	TAKE OFF
Construction Engineering Research Lab	GT 6. 24. 12. 40 18 AS
August 1986	Radio call 10 eer minut
AH64 Test	"10 seconds"
Aircraft Identification 83.23789	Radio at Takeoff
Date 4 Auc 80	"Takeot f"
Set Number SET	Perform norma) climb and acceleration
Gross Weight 14287	10() Lt YT
	130 kts IAS
	Takeoff time 1/16
	Distance (ft) from takeoff
	to reach 300 ft AGL $\frac{403}{2}$
	(note terrain feature)
	Distance (ft) from start of -ru]]

\$

111

Rotor speed (average) (00%)

360

Fuel weight Heading <u>Z</u>

to reach kts IAS 500 0

(mqr d22 = 000 ₹ Undspeed 2.55.....kts (from Doppler) At 172 mile before colored ground marker, kts (1AS) 134 Fuel Ibs (total) 2480 Ibs. UT 6, 12, 18, 24, 30, (36) 1AS: 40, 70, 100, (130, max kts Heading 36 Pressure Alt 2,60, teet <u>)</u> _ feet Altitude: 300 ft. AGL or HAT 24 Alt speed 130 Herein Auf 300 Kotorspeed _____ A/C Heading 36 D Mark time 1113 radio "Mark" Kun Number Set Alt 29.92 LEVEL FLYOVER Kec or d, 7 (100 : 225 rpm) kts drum boppler) 2 At 1/2 mile before colored ground marker, Fuel Ibs (total) 22 Ibs. Kts (IAS) GT -- 6, 12, (18), 24, 30, 36 Altitude: 300 ft. AL or 705 IAS: 40, 70, 100, (130), max kts ן פינין tt. . E Engine Torque #1 67 A/C Heading 12.2 Undspeed Height ALL 30 7 Pressure Alt 68. Rotorspeed 120 Airspeed 130 FAT 25 Mark time 1110 Heading [80 radio "Mark" Run Number_____ LEVEL FLYOVER Set Alt 29.92 Record,

~

-- 7 (100 = 225 rpm) kts (from Doppler) 2 At 1/2 mile before colored ground marker, kts (IAS) 71 Engine Torque #1 39 7 #2 58 , lbs, CT -- 6, 12, 18, 24, 30, (36) IAS: 40, 207 100, 130, max kts Altitude: 300 ft. ACL or 300 _ feet feet Fuel lbs (total) /420 ပ Pressure Alt 650 Height AGL 30^{O} A/C Heading <u>360</u> Rotorspeed 100 Gndspeed 142 0 Mark time 1123 Heading 36 radio "Mark" FAT 24 LEVEL FLYOVER Set Alt 29.92 Airspeed Run Number Record, 7 (100 = 225 rpm) kts (from Doppler) ~ At 1/2 mile before colored ground marker, Engine Torque #1 40 ... 7 #2 39 kts (IAS) 72 Fuel lbs (total) /463 lbs. GT --- 6, 12, (B) 24, 30, 36 Altitude: 300 ft. A. or 200 IAS: 40, (79, 100, 130, max kts feet Pressure Alt 750 feet ဥ Height ACL 307 Roturspeed 100 - 20 0 A/C Heading 18 Mark time 1121 Heading 12 radio "Mark" FAT 24 Airspeed ____ Gndspeed ... LEVEL FLYOVER Set Alt 29.92 Kun Number Record,

7 (100 = 225 rpm) kts (from Doppler) ~ At 1/2 mile before colored ground marker, Engine Torque #1 70 7. #2 4/ kts (IAS) UT -- 6, 12, (18) 24, 30, 36 IAS: 40, 70, 400, 130, max kts Heading 1 20 Altitude: 300 ft. AGL or 300 Pressure Alt 680 feet feet ပ္ပ Height AG 300 A/C Heading $\underline{I}\underline{\mathcal{C}}\underline{\mathcal{O}}$ Fuel lbs (total) _ Rotorspeed 100 Airspeed 100 Gndspeed [7] Mark time 11 25 24 radio "Mark" LEVEL FLYOVER Set Alt 29.92 kun Number _____ FAT ____ Record,

7.(100 = 225 rpm)_kts (from Doppler) ~ At 1/2 mile before colored ground marker, _ kts (IAS) 99 - 7, #2 40 l bs. CT -- 6, 12, 18, 24, 30, (6) IAS: 40, 70, 600 130, max kts Altitude: 300 ft. AGL or 200 Pressure Alt 680 feet feet ၁ Fuel lbs (total) 1330Engine Torque #1 43 Rotorspeed 100 Height AGL 300 A/C Heading _363 Gndspeed 201 Airspeed 100 Heading 360 radio "Mark" 7 kun Number LEVEL FLYOVER Mark time _____ Set Alt 29.92 FAT Record,

Rotorspeed <u>100</u> 7 (100 = 225 rpm) __kts (from Doppler) 2 At 1/2 mile before colored ground marker, - kts (IAS) 149 Engine Torque #1 **22** 7, #2 **4**1 Fuel lbs (total) /2 '.0 lbs. GT -- 6, 12, (6) 24, 30, 36 Altitude: 300 ft. \overline{AGL} or 300IAS: 40, 70, 100, 130, man kts Pressure Alt <u>CS2</u> feet Height ACL 360 feet ပ္ပ A/C Heading 180 Airspeed 149 Gndspeed 279 Heading 140 Mark time 1135 FAT 24 radio "Mark" Set Alt 29.92 LEVEL FLYOVER Run Number Record,

7 (100 = 225 rpm) Gndspeed 285 kts (from Doppler) 2 At 1/2 mile before colored ground marker, Airspeed 149 kts (1AS) 143 Engine Torque #1 <u>14</u> ... #2 72 lbs. GT -- 6, 12, 18, 24, 30, (36) IAS: 40, 70, 100, 130, max kts Heading <u>36</u> Altitude: 300 ft. ACL or 200 Pressure Alt _6%0_ feet feet 3 Fuel lbs (total) 1/27 A/C Heading 360 Height ACL 300 Rotorspeed 10D Mark time 1/38 radio "Mark" FAT 25 LEVEL FLYOVER Set Alt 29.92 kun Number._______ Record,

Roturspeed 100 = 225 rpm) Gndspeed **62** kts (from Doppler) Engine Torque #1 40 7 #2 32 7 At 1/2 mile before colored ground marker, _____Kts (1AS) 44 Fuel lbs (total) 242.2 lbs. GT -- 6, 12, (18) 24, 30, 36 Altitude: 300 ft. ALL or 300IAS: (40, 70, 100, 130, max kts Heading <u>150</u> Pressure Alt 710 feet Height ALL 300 feet ပ္ပ A/C Heading 190 01 Mark time 16 49 radio "Mark" FAT 26 Airspeed ____ Kun Number LEVEL FLYOVER Set Alt 29.92 Record,

Rotorspeed 100 - 225 rpm) _kts (from Doppler) At 1/2 mile before colored ground marker, _kts (IAS) GT -- 6, 12, 18, 24, 30, (36) IAS: (40) 70, 100, 130, max kts Altitude: 300 ft. AGL or 30C Pressure Alt $\underline{-\mathcal{ILD}}$ feet _feet ວິ Height AGL 300 Airspeed 40 Gndspeed qu Mark time 1057 FAT 26 radio "Mark" Heading 36 LEVEL FLYOVER Set Alt 29.92 Run Number Record,

2

Engine Torque #1 $\frac{\mu}{2}$ 7 #2^{l_1} $\frac{1}{2}$ Fuel lbs (total) $\frac{\pi}{2}$ $\frac{1}{7}$ $\frac{1}{10}$ lbs.

A/C Heading 36

Kotorspeed 100 = 7.00 = 225 rpmkts (from Doppler) ~ At 1/2 mile before colored ground marker, _ kts (IAS) 123 Engine Torque #1 71 7 #2 7b Fuel Ibs (tutal) 2350 Ibs. $\mathbf{U}^{T} = \mathbf{b}, 12, (\mathbf{18}), 24, 30, 36$ Altitude: 300 ft. Ad. or 300 IAS: 40, 70, 100, 130, max kts Pressure Alt 21° leet ဥ feet Undspeed 242 FAT <u>26</u> Arrspeed 130 Height All 300 mark time 1650 Heading 18 Kun Number Set Alt 29.92 LEVEL FLYOVER Record.

% (100 = 225 rpm) ____kts (from Doppler) Engine Torque #1 12 7 #2 7 1 7 At 1/2 mile before colored ground marker, - kts (1AS) 135 Fuel lbs (total) 2.3/0 lbs. GT -- 6, 12, 18, 24, 30, 66 Altitude: 300 ft. ACL or 300 IAS: 40, 70, 100, (30, max kts _ feet Pressure Alt 710 feet ၁၀ Height ACL 300 A/C Heading _36 Rotorspeed Airspeed 130 Gndspeed 258 Mark time 1653 FAT 7 Heading 36 radio "Mark" Run Number.ZZ LEVEL FLYOVER Set Alt 29.92 Record,

Run Number 25

LANDI NC

GI == 6, 24, 12, 30, (18) 36

Begin from "tear drop" turn.

300 Ft ALL, 130 kts IAS,

At 1/2 mile before colored ground marker,

radio "Mark"

At touchdown, radio "Touchdown"

Mark time 1701

Distance from pad (ft)

when descent was initiated 3000 Fuel weight 2.3 D()

Kun Number

HERE'S I DIE

At pad center:

Len-ground 100%

in-ground effect

out-of-ground effect hover

Heading -- 6, 24, 12, 30, (18), 36 Altitude (wheels in ft A(L) \odot Start time 1504. Fuel weight 2250 Fuel weight 2250 Faine torque in 11 is 16FAT 25 oc

Rotor speed 100^{0}

Heading -- 6, 24, 12, 30, (18) 36 out-of-ground effect hover Engine torque #1 57 #2 58 Altitude (wheels in it ACL) 5 ပ္ပ win-ground effect on-ground 100% Rotor speed 100 % Fuel weight 2240 Start time 106 At pad center: Run Number 16 FAT 25 HOVER/HEE

Run Number 2.7 HOVER/ THE

At pad center:

on-ground 100% in-ground effect

Jout-of ground effect hover

Heading -- 6, 24, 12, 30, (3, 36)Altitude (wheels in ft AGL) $\underline{80}$ Start time $\underline{1107}$ Fuel weight $\underline{200}$ Engine torque #1 $\underline{70}$ #2.6 $\underline{2}$ HAT $\underline{25}$ oc

Rotor speed 10572

33

ALL DESCRIPTION PARTICIPAL RECORDER PROVIDED IN

(morid 22 ± 001) % Cndspeed _____kts (from Doppler) 2 At 1/2 mile before colored ground marker, FAT 2G of Airspeed 7D kts (1AS) 74Fuel 1bs (total) 2095 144 GT --- 6, 12, 18, 24, 30, 36 IAS: 40, 70/ 100, 130, max kts Heading 36 Altitude: 300 ft. AGL or 300 Pressure Alt **75**£. feet Height All 300 feet kotorspeed 100 Engine Torque #1 38 A/C Heading 3C Mark time 17 (5 radio "Mark" Kun Number 12 LEVEL FLYOVEK Set Alt 29.92 Kecord,

Perform normal climb and acceleration to Radio call 10 sec. prior to takeoff Distance (ft) from start of -roll to reach 300 ft AGL 4bb 2 Rotor speed (average) $[00^{-3}]$ GT -- 6, 24, 12, 30, (18) 36 (note terrain feature) to reach kts IAS 500 3 Distance (ft) from takeoff Fuel weight 2130Heading $1\overline{8}$ Takeoff time 1710 "10 seconds" Radio at Takeoff 130 kts IAS "Takeoff" 300 ft AGL TAKE OFF Run Number

Roturspeed 10) 7 (100 = 225 rpm) Gndspeed 2-12 kts (from Doppler) Engine Torque #1 <u>6.1.</u> 7. #2 <u>2.0.</u> 7. At 1/2 mile before colored ground marker. Lkts (IAS) 140 Fuel lbs (total) 462 lbs. GT -- 6, 12, 18, 24, 30, (36) Altitude: 300 ft. Ad. or ... 30. IAS: 44, 70, 100, 101, 01, 01 SAI Pressure Alt $\frac{750}{1000}$ feet feet ၁၀ Height AG 393 A/C Heading 36 Airspea 141 Mark time 1722 FAT 26 Heading 36 radio "Mark" Set Alt 29.92 LEVEL FLYOVER kun NumberZZ Record, Rotorspeed 101 % (100 = 225 rpm) __kts (from Doppler) ▶. At 1/2 mile before colored ground marker, Engine Torque #1 7 #2 5Fuel lbs (total) 2O4O lbs. GT -- 6, 12, (18) 24, 30, 36 IAS: 40, (79, 100, 130, max kts Altitude: 300 ft. ACL or 302 feet Pressure Alt 75 P feet ວິ

Height AGL JCO

Mark time 1118

Set Alt 29.92

Record,

radio "Mark"

Heading 18

Run Number 20 LEVEL FLYOVER A/C Heading 15

Gndspeed 132 Airspeed 20

FAT 26

Kun Number 23	LEVEL FLYOVER	GT 6, 12, 18, 24, 30, (36)	Altitude: 300 ft. ACL or 300	IAS: 40, 70, 100, (30, max kts	Heading 36	At 1/2 mile before colored ground marker,	radio "Mark"	Mark time 172-6	Set Alt 29.92	Record,	Height AGL 300 feet	Pressure Alt 750 feet	FAT 26 OC	Airspeed 130 kts (IAS) 132	Gndspeed 25% kts (from Doppler)	Rotorspeed	A/C Heading _36	Engine Torque #1 70 7 #2 62 7	Fuel lbs (total) 1890 lbs.
kun Number ZZ	LEVEL FLYOVER	GT 6, 12, (8,) 24, 30, 36	Altitude: 300 ft. AGL or 300	1AS: 40, 70, 100, 130, (max kts	Heading 1.60	At 1/2 mile before colored ground marker,	radio "Mark"	Mark time 112.3	Set Alt 29.92	Record ,	Height ACL 200 feet	Pressure Alt 250 feet	FAT 26 ou	Airspeed $\frac{1+2}{2}$ kts (IAS), $2q$	Gndspeed 267 kts (from Doppler)	Rotorspeed $\frac{125}{100}$ 7 (100 = 225 rpm)	A/C Heading 12	Engine Torque #1 61 7 #2 7 <u>9</u> 7	Fuel lbs (total) 11.0 lbs.

ŝ

Roturspeed ± 30 7 (100 = 225 rpm) A/C Heading 36Gndspeed 205 kts (from Doppler) Engine Torque #1 50 7 #2 48 7 - kts (IAS) { 0.2. At 1/2 mile before colored ground marker, Huel Ibs (total) <u>/645</u> lbs. uT -- 6, 12, 18, 24, 30, (36) IAS: 40, 70, (100, 130, max kts Altitude: 300 ft. ACL or <u>300</u> feet Pressure Alt 750 feet ၁ Airspeed 100 Height ALL 300 Mark time (13/ FAT 2.6 Heading 36 radio "Mark" kun Number 25 LEVEL FLYUVER Set Ait 29.92 Record, (mtr c22 = 225 rpm) ____kts (from Doppler) Engine Torque #1 <u>6.7</u> 7 #2 (a.(7 At 1/2 mile before colored ground marker, Airspeed 132 kts (185) 132 Fuel lbs (total) Lich lbs. UT ~ 6, 12, (18,) 24, 30, 36 Altitude: 300 ft. ACL or 300 leet ____ Pressure Alt 260_ teet 00 Height Aul __________ Gudspeed 247 Kuturspeed 100 A/C Heading _[5_ Mark time 1728 Heading 13 HAT 26 radio "Mark" kun Number 2. Y LEVEL FLYUVER Set Alt 29.92

37

Record,

7 (100 = 225 rpm) kts (from Doppler) Engine Forque #1 48 7. #2 46 7. At 1/2 mile before colored ground marker. _kts (IAS) /b Fuel lbs (total) /232 lbs. UT -- 6, 12, (1) 24, 30, 36 Altitude: 300 ft. AGL or 307 IAS: 40, 70, (00, 130, max kts _feet Pressure Alt 750 feet ာ Height AG 300 Kotorspeed 100 A/C Heading 18 Airspeed 100 Gndspeed 194 Mark time 1737 FAT 26 Heading 15 radio "Mark" Run Number 26 LEVEL FLYOVER Set Alt 29.92 Record,

Rotorspeed $\frac{100}{100}$ 7. (100 = 225 rpm) _kts (from Doppler) ~ At 1/2 mile before colored ground marker, _ kts (IAS) '45 Engine Torque #1 40 7 #2 39 Fuel lbs (total) <u>1790</u> lbs. GT -- 6, 12, 18, 24, 30, (36) Altitude: 300 ft. AG. or 300 IAS: (40, 70, 100, 130, max kts Pressure Alt _____feet feet ာ Height ACL JOD A/C Heading 36 Heading 36 40 Mark time 17.36 98 FAT 26 radio "Mark" kuń Number 22 LEVEL FLYOVER Gndspeed .. Airspeed _ Set Alt 29.92 Record,

7 (100 = 225 rpm) _ kts (from Doppler) <u> 3':</u> 7, #2 <u>56</u> 7, At 1/2 mile before colored ground marker, _kts (IAS) 4 Fuel lbs (total) /755 lbs. GT -- 6, 12, 🕲 24, 30, 36 Altitude: 300 ft. ACL or 303IAS: (40, 70, 100, 130, max kts Heading 18 Pressure Alt 760_ feet feet ပ္ပ Height ACL 300 Engine Torque #1 Rotorspeed /0) Gndspeed 64 A/C Heading 12. Airspeed 40 Mark time 1739 FAT 26 radio "Mark" Kun Number 2£ LEVEL FLYOVER Set Alt 29.92 Record,

Rotorspeed 225 rpm) Gndspeed 248 (from Dopher) Engine Torque #1 <u>70</u> 7 #2 <u>57</u> 7 At 1/2 mile before colored ground marker, - kts (IAS) 129 Fuel lbs (total) <u>1700</u> lbs. CT -- 6, 12, 18, 24, 30, (36) IAS: 40, 70, 100, (190, max kts Pressure Alt 260 _ feet Height ACL $\frac{1}{200}$ feet ဥ Altitude: 300 ft. AGL or _ Airspeed 130 A/C Heading 3/C Mark time 1747 FAT 21 Heading 34 radio "Mark" LEVEL FLYUVER kun Number. 22 Set Alt 29.92 Record,

At 1/2 mile before colored ground marker, when descent was initiated 2.000At touchdown, radio "Touchdown" Mark time $\frac{1}{250}$ Begin from "tear-drop" turn, GT -- 6, 24, 12, 30, 18, (36) 300 ft ALL, 130 kts IAS, Distance from pad (ft) Fuel weight 1570 radio "Mark" Run Number _ LANDINC Koturspeed $\frac{100}{2}$ 7 (100 = 225 rpm) Gndspeed .252 kts (from Doppler) A/C Hedding 15 Engine Torque #1 70 7 #2 69 7 At 1/2 mile before colored ground marker, _ kts (IAS) 32 Fuel Its (total) 1600 Ibs. CT -- 6, 12, (18) 24, 30, 36 Altitude: 300 ft. AG or 300. IAS: 40, 70, 100, (130, max kts _feet Pressure Alt _760 feet ာ့ Height AG 300 Airspeed 120 Mark time <u>174</u>7 Heading 19 radio "Mark" Run Number 20 LEVEL FLYOVER Set Alt 29.92 FAT _ Record,

APPENDIX B:

TABULAR DATA FOR FIGURES IN REPORT

Table B1

Variation in SEL Vs Slant Distance

Aircraft		Operation	50	1 00 95.0	200 90.8	5000 84.8	1 000 79.9	2000 74.7	5000 67.0	1 0,000 60.4
Heavy	CH-47D	7D LF* 9								
Light	CH-47D	LF*	104.8	100.7	96.6	90.8	86.0	80.7	72.4	64.8
Heavy	CH-47D	Land	108.6	104.5	100.2	94.1	88.9	83.1	74.2	66.9
Light	CH-47D	Land	101.8	97.5	92.9	86.5	81.0	74.7	65.3	58.0
Heavy	CH-47D	Takeoff	102.6	98.4	94.0	87.8	82.5	76.7	68.1	61.2
Light	CH-47D	Takeoff	99.5	95.2	90.6	83.9	77.9	70.7	59.4	52.0
0	AH-64	Land	99.2	95.0	90.6	84.1	78.3	71.1	59.1	49.6
	AH-64	LF*	98.1	94.0	89.7	83.5	78.0	71.5	60.6	51.0
	AH-64	Takeoff	96.3	92.1	87.6	81.2	75.6	68.9	58.2	49.2

*LF is a level flyover at 300 ft AGL and 130 knots indicated air speed.

Table B2

Versions of Static Average LEQ With Distance Over Soft Ground (Yearly Average)

Aircraft	Operation	100*	200	300	500	700	1000	1200	1400
Heavy CH-47D	OGE Hover	91.0	82.6	76.1	68.2	63.8	59.1	57.2	55.4
Light CH-47D	OGE Hover	88.0	79.9	73.1	65.2	60.7	55.6	53.6	51.8
Light CH-47D	IGE Hover	84.9	75.8	70.0	64.0	60.9	56.7	55.0	53.8
Light CH-47D	Engine Idle	83.2	74.8	68.9	62.2	58.6	54.1	52.4	51.1
AH-64	OGE Hover	88.0	79.4	72.9	65.0	60.7	55.8	54.0	52.2
AH-64	IGE Hover	77.7	67.9	62.9	58.9	55.5	51.4	48.4	47.1
AH-64	Engine Idle	70.2	61.1	55.7	50.6	47.1	42.7	40.1	38.6

*Distance in meters.

Table B3

Variation of SEL Vs Speed (IAS) for 300-ft AGL Level Flyovers at a Slant Distance of 200 m

Indicated Air Speed (Knots)

		_			
Aircraft	40	70	100	130	MAX
AH-64	88.8	88.5	88.2	89.7	90.6 ¹
Light CH-47D	91.9	91.1	93.2	96.6	99.5 ²
Heavy CH-47D	94.6	90.3	88.7	-	90.8 ³

¹about 145 knots ²about 135 knots ³about 119-120 knots

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