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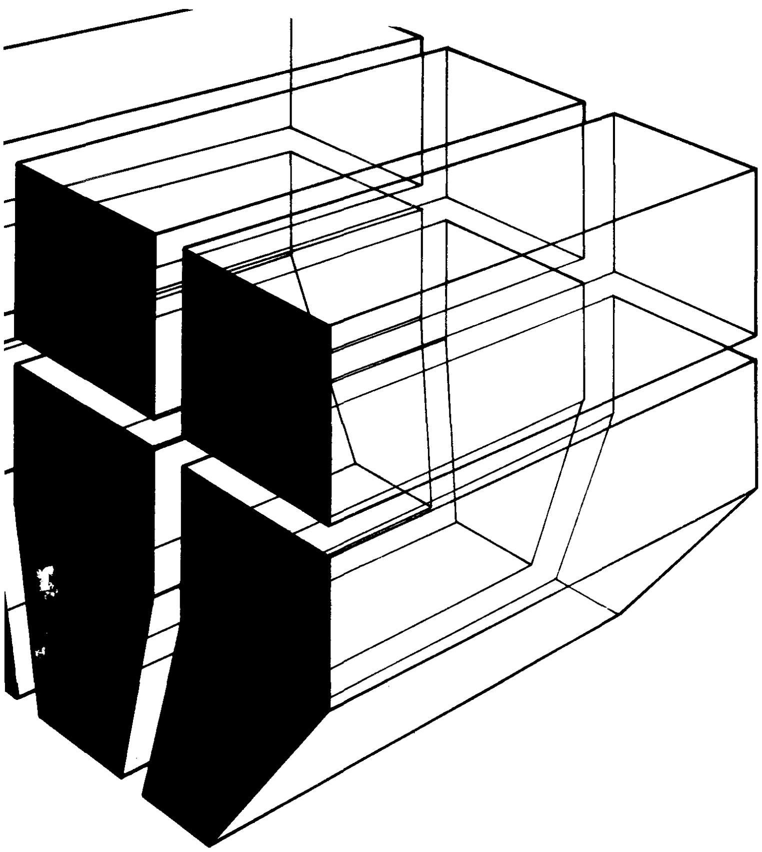
Integrated Installation Noise Contour System

OPERATIONAL NOISE DATA FOR UH-60A AND CH-47C ARMY HELICOPTERS



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The objectives of this study were to develop sound exposure level (SEL) versus distance curves for the UH-60A and CH-47C Army helicopters, to investigate the variation of SEL with aircraft speed, and to confirm the validity of the measurement procedures by comparing data obtained for UH-1H helicopters at Forts Campbell and Rucker.

Sound levels produced by the helicopters were measured for heavily and lightly loaded aircraft which were hovering and traveling at various speeds and distances.

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The data show that a heavily loaded UH-60A is about 2 dB louder than a lightly loaded one. Landing noise with the UH-60A and CH-47 is substantially greater than for level flyover. The variation of SEL with speed is rather modest, except for aircraft at very low or very high speeds. The results for the UH-1H at Forts Campbell and Rucker did not compare as favorably as expected. Various factors, including maintenance procedures and the surface of the test area, may have contributed to the discrepancies.

FOREWORD

This study was performed for the Directorate of Military Programs, Office of the Chief of Engineers (OCE) under Project 4A762720A896, "Environmental Quality Technology"; Technical Area A, "Installation Environmental Management Strategies"; Work Unit 011, "Integrated Installation Noise Contour System." The OCE Technical Monitor was Gordon Valesco, DAEN-MPE-I.

This investigation was performed by the Environmental Division (EN), U.S. Army Construction Engineering Research Laboratory (EN). Dr. R. K. Jain is Chief of EN.

COL L. J. Circeo is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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OPERATIONAL NOISE DATA FOR UH-60A AND CH-47C 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 Noise Zone Program (ICUZ).[1] Like the Department of Defense's (DOD) *Construction Criteria Manual* and *Air Installation 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 (CERL's) integrated noise contour system (INCS). This system can produce joint noise zone maps for blast noise and fixed- and rotary-wing aircraft operations. Noise zone maps are produced using the CERL-developed BNOISE-3.2 computerized prediction procedure; helicopter noise zone maps are developed using a CERL-modified Air Force 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 CERL research has addressed, to some degree, these sets of data for rotary-wing aircraft and for blast noise prediction. In particular, CERL Technical Report N-38 defines the noise emission characteristics for rotary-wing aircraft operating in the Army fleet during the late 1970s.[4] Since then, the new UH-60A and CH-47C helicopters have been introduced; their emissions data are required by the Army for ICUZ and for environmental assessment.

Objective

The objectives of this study were: (1) to develop sound exposure level (SEL) versus distance curves for the new Army aircraft, (2) to investigate the variation of SEL with aircraft speed, and (3) to confirm the validity of the measurement procedures.

Approach

To accomplish these objectives, the basic approach was to use as much as possible the microphone types and layout, recording method, and analysis procedures employed in April 1974 at Fort Rucker.[5] Chapter 2 details the collection of data and specifically highlights changes from the 1974 procedures; Chapter 3 describes the data analysis.

To help confirm the validity of the measurement procedures, data were also gathered on the UH-1H at Fort Campbell for comparison with the 1974 measurements for this aircraft at Fort Rucker. Similar results from the two studies would show that the measurement procedures were independent of site, or that the operational/pilot technique or other factors had not changed in the 6 years between the two measurement periods. Chapter 4 discusses this comparison and presents the basic results.

Mode of Technology Transfer

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

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[1] "Installation Compatible Noise Use Zones" (Department of the Army, Office of the Adjutant General, 20 May 1981).

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

[3] Lincoln L. Little, Violetta I. Pawlowska, and David L. Effland, *Blast Noise Prediction Volume II: BNOISE 3.2 Computer Program Description and Program Listing*, Technical Report N-98/ADA099335 (U.S. Army Construction Engineering Research Laboratory [CERL], 1981); R. D. Horonjeff, R. R. Kandukuri, and N. H. Reddingius, *Community Noise Exposure Resulting From Aircraft Operation: Computer Program Description*, Air Force Report AMRL TR-73-109/ADA004821 (1974).

[4] B. Homans, L. Little, and P. Schomer, *Rotary Wing Aircraft Operational Noise Data*, Technical Report N-38/ADA 051999 (CERL, 1978).

[5] B. Homans, L. Little, and P. Schomer, *Rotary Wing Aircraft Operational Noise Data*, Technical Report N-38/ADA 051999 (CERL, 1978).

2 COLLECTION OF DATA

Helicopter Operations

At Fort Rucker, one set of data was 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 co-pilot. Table 2 lists the aircraft types and conditions employed. The Fort Rucker study indicated that level flyover data and landing data adequately characterized the noise emissions of all other dynamic operations. Therefore, the study at Fort Campbell concentrated only on level flyovers and landings.

At Fort Rucker, cargo and utility aircraft were flown lightly loaded and fully loaded. At Fort Campbell, this condition varied with aircraft type. The UH-1H and CH-47C were flown lightly loaded only. Table 3 lists the operations performed by these helicopters. The aircraft began by flying level flyovers with headings of either 100 degrees or 280 degrees at 300 ft above ground level (AGL). In the middle of the test, they performed two hover operations, and then resumed level flyovers, but this time at an altitude of 1000 ft AGL. Two aircraft of each type were used, each with a different pilot. The aircraft performed the 300-ft-AGL operations, the landing, the two hovers, and as many of the 1000-ft-AGL operations as they could before returning to base for fuel. The operations and procedures (as well as the measurement equipment described below) were designed to investigate the change in SEL with speed and distance, and to establish noise emissions data for the CH-47C and the UH-60A.

The tests with the UH-60A were different in that the aircraft was flown both lightly loaded and more fully loaded. To load the UH-60A, its sling was used to carry a full 500-gal water buffalo. Two UH-60A aircraft performed only operations 1 through 17 from Table 3—once lightly loaded and once heavily loaded. The UH-60A aircraft were not flown at 1000 ft AGL.

The level flyovers at Fort Campbell were flown similarly to those at Fort Rucker. 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 the 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 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. Operation 15, a normal landing (Figure 2), began at 300 ft AGL on a ground track of 280 degrees. The aircraft landed 800 ft west of the east end of the microphone array (Figure 3).

Static operations consisted of in-ground and out-of-ground effect hovers. These measurements were performed largely over a grassy surfaced area (Figure 4). In-ground effect hovers were performed with the aircraft at a stabilized position between 0 and 5 ft above the ground. The aircraft maintained the stabilized position by always facing into the wind. Out-of-ground hovers were performed at an altitude of 1 rotor diameter.

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

Microphone Placement

A basic array of six microphones was used at Forts Rucker and Campbell (Figure 3). (Four additional sideline microphones were located at Fort Campbell for a future analysis of helicopter sound exposure level attenuation with distance [Figure 5].)

Hover measurements were performed at point H on Figure 4. The hover measurement positions formed a 400-ft-radius curve around the hover position. Measurements were made at eight equally spaced points on the hover circle. Three points were part of the six-microphone array, and five points were special manned stations used only during the hover operation.

Measurement Instrumentation

As at Fort Rucker, the main acoustic instrumentation at Fort Campbell consisted of six B&K 4149 ½-in. quartz-coated microphones. Newer B&K 4921 outdoor microphone systems with silk windscreens were used in place of the older B&K 141 field amplifiers used at Fort Rucker. The six microphones were wired to an equipment van. As at Fort Rucker, each microphone signal was received, amplified by a Neff 119 DC amplifier, split, and recorded on a 14-channel FM tape recorder. At Fort Campbell, Ampex PR 2200 recorders were used in place of the older FR 1300 recorders. Rather than split the signal at 707 Hz as was done at Fort Rucker (a procedure which gained no more than 6 dB in dynamic range of the high frequencies), it was decided to split the recording into a high gain and low gain channel to increase the dynamic range.

Time synchronization was handled by a Systron Donner 8350 time code generator which occupied one tape recorder channel. The remaining data channel on the Ampex recorder was used for wind speed and wind direction information.

The recordings for hover measurements were made simultaneously by using three of the six permanent microphones and five identical portable systems manned by five individuals. Each of the portable systems consisted of a B&K 4145 1-in. condenser microphone powered by a B&K 2209 sound level meter. These systems recorded from the AC output of the sound level meter onto a Nagra DJ full-track portable scientific tape recorder which was set to run at 7-½ ips. In a departure from the Fort Rucker procedures, no recordings at Fort Campbell were made at the 1.5 ips speed.

Ground Tracking System

The tracking system used at Fort Campbell was very similar to that at Fort Rucker. Two cameras and a theodolite (Figure 3) marked the position of an aircraft flying over the middle of the microphone array. Camera 1 was placed 500 ft south of microphone array, and camera 2 was placed at the east end of the runway next to microphone 4. Stator poles in front of the camera positions were marked with uniform graduations. By examining photographs from both cameras, one could ascertain position information in three dimensions at the moment the pictures for the 300-ft-AGL test were taken. For the 1000-ft-AGL operations, only camera 2 was used. Two additional stator poles were used to determine the lateral deviation of the aircraft (north or south) from the desired flight line. Pictures were taken remotely by an operator who could see when the aircraft were precisely over the east-west middle of the measurement array. The helicopters' altimeters guaranteed that the aircraft were close enough to 1000 ft AGL for this study.

A bus system connected the cameras with the van and the theodolite. When a picture was taken from either camera, both cameras were fired and wind direction information on the Ampex 14 track tape recorder was interrupted momentarily. A push button activator at the theodolite interrupted wind speed information on the Ampex recorder and sounded a bell at the test control center. Photographs were taken when the aircraft was over the center of the microphone array, except during landings. In this case, photographs were taken when the aircraft reached the east end of the landing lane.

Calibration

At the beginning of each reel of 14-track 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 K factor for each actuator.)

The instrumentation for the hover operation measurements was calibrated using B&K 4220 pistonphones. The calibration tone was recorded on the Nagra recorders.

3 DATA REDUCTION AND ANALYSIS

Raw Data

Each reel of tape from the 14-track Ampex PR-2200 tape recorder contained 12 channels of acoustical data; one channel of time code information; one channel onto which wind speed, wind direction, and signals from the cameras and theodolite were recorded; and one edge track onto which voice information was placed.

The 12 channels of acoustical data originated from the six microphones in the dynamic operations array. Each microphone signal was split: one part recorded linearly on one channel and the other sent through a 14 to 24 dB amplifier and recorded on another channel. The object was to increase the recorded dynamic range.

Time code information was supplied by a Systron Donner model 8350 time code generator. Day of the year, hours, minutes, and seconds were recorded on one channel of the Ampex recorder in digital format.

The remaining data channel contained the outputs of two voltage-controlled oscillators. These units were set up to form a discrete frequency band for each. The voltage-controlled oscillators were driven by an R. M. Young wind speed and direction measurement apparatus. Thus, this tape channel could be read by a spectrum analyzer, and wind speed and direction components determined. The edge track contained a vocal running diary of events.

Each helicopter run was photographed when the aircraft passed over the center of the landing lane. For 300-ft-AGL runs, two cameras, 90 degrees apart, focused on a point above the center of the runway where it was anticipated that the helicopter would fly. In the foreground of each photograph was a stator rod marked with uniform divisions. When the helicopter passed over the appropriate spot, an operator triggered one of the cameras. A wire bus system triggered the other camera, and at the same time momentarily interrupted the wind direction signal, as described in Chapter 2. Each photograph carried information about latitude and side-to-side variation. The time at which the photographs were shot was noted on the analog recording.

In addition, a written record was kept by the theodolite operator. Since the theodolite was fixed in place for each run, the operator could record the relative altitude of the helicopter in the field of view when the cameras were fired (and a Sonalert near the theodolite sounded). The theodolite was only used to check results from the cameras.

Reduction of Dynamic Operation Data

A Nova 1200 minicomputer sampled the spectrum analyzer every 0.5 sec, summed the spectra into one-third octaves, and stored the contents on disks. Since each microphone signal was split while recording (one high-gain and one low-gain channel), four passes were performed for each of the six microphones. (The spectrum analyzer requires a high- and low-frequency pass to properly constitute one-third octave bands over the total range.)

The procedure for the analysis system was as follows. When a helicopter was first detected, the tape and analysis equipment were started. The first two passes were made on the high-gain channel for high and low frequencies. Some overloading of the spectrum analyzer was expected, and these portions were flagged by the minicomputer. For record-keeping purposes, the minicomputer was used interactively; that is, information was requested from the operator before and after each pass.

After the helicopter being analyzed was no longer detectable, analysis stopped, the tape was rewound, and gain to the analyzer was lowered in preparation for a second set of passes. For these two low-gain passes, the analysis was started at the same time on tape by using the time code channel to insure synchronization between the passes. The two sets of passes were meshed by incorporating data from the second low-gain pass whenever the high-gain pass was overloaded. The results were fitted together to form the full spectrum per 0.5 sec for each microphone.

Reduction of data from the two cameras was handled differently. The graduated stator rod in the foreground of each photograph allowed calculation of altitude and lateral variation over the center of the landing lane because the camera angle, distance to the stator rod, and distance between graduations on the stator rod were known. Corrections were made for aberrations in the lens.

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 the minicomputer for further calculation and analysis. Given the information supplied by the two pictures, algorithms were written that located the helicopter in three dimensions at the time both cameras were fired. 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.

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. In this study, three methods were used to determine the combined noise level.

For the first reading—ambient noise—a recording was made immediately after the helicopter left the area following a set of passes. This reading reflected ambient sounds (such as 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 one of the stations and measuring the resultant level on playback from tape.

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

These three readings were summed to calculate a composite noise level (CNL) by one-third octaves for each gain setting used. The correct CNL was compared to the resultant one-third octave spectra for each 0.5 sec, and those 0.5-sec intervals were flagged if their levels came within 3 dB of the CNL value. For all noise readings taken, gain settings throughout the system were held the same as they were when the helicopter data were recorded.

Data Analysis

In addition to the reduction of dynamic operation data into one-third octave spectra for each 0.5 sec of recording, the SEL of each flyover was directly measured in the field using the CERL-developed True Integrating Noise Monitor and SEL Meter. The 0.5-sec spectra and the overall field-measured SEL were combined to produce A-weighted SEL versus distance relations.

These relations were developed in four steps. First, the A-weighted SEL for the microphone flyover was entered. Essentially, this calculation involved forming the integral of the A-weighted pressure squared received by the microphone. The CERL monitor performed this operation automatically. Second, the 0.5-sec time interval having the maximum A-weighted value was determined, and the entire one-third octave spectrum for that 0.5-sec interval was recorded. Third, from the positional information on the photographs, the closest approach of aircraft to microphone for each individual flyover recording at each microphone was determined and synchronized to the magnetic tape recording. 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 59°F and relative humidity of 70 percent.

During this final step, A-weighted SEL versus distance relations were established. The data used were the SEL at the microphone corrected to the standard day conditions, the distance of closest approach from aircraft to microphone, and the maximum one-third octave spectra during the 0.5 sec having the maximum A-weighted reading. 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 constant speed. Appendix A of CERL Technical Report N-38 contains a detailed description of this analysis procedure, which is structured similarly to the Air Force procedure that was written in part to describe the reduction of fixed-wing aircraft data.[6] The primary difference between the Air Force and Army data reductions is that the Air Force used tone corrections and effective perceived noise level (EPNdB) as well as A-weighted levels. The Joint Services (in conjunction with DOD) subsequently agreed to eliminate EPNdB and replace it with A-weighted levels, and to eliminate the tone corrections. Additionally, it was found that the concept of tone correction did not apply to helicopters since the primary noise source over most of a flyby is the rotor rather than the engines.

Analysis of the hover data was quite simple. It should be recalled that a 30-sec recording was made at 45-degree increments around the hovering helicopter at a distance of 400 ft from the center of the aircraft. Analysis consisted of direct measurement of the equivalent A-weighted levels (L_{eq}) for each recording. This L_{eq} measurement was performed using the CERL True Integrating Noise Monitor and SEL Meter (which employs a true integrating detector).

4 RESULTS AND DISCUSSION

This chapter explains the results of the operational measurements performed at Fort Campbell on the UH-60A, CH-47C, and UH-1H. SEL versus distance data are discussed, variations in SEL with aircraft speed are examined, and Fort Campbell data are compared with the earlier results at Fort Rucker.

In analyzing the data, it was found that for dynamic operations microphone 5 consistently measured higher than the other five primary microphones. This systematic bias was about 5 dB or more. After intensive investigation, equipment malfunction or data analysis errors were eliminated as possible sources for the systematic variation.

Site-specific terrain features offered a potential explanation for the higher measurements at this position. Microphone 5 was placed near the bottom of a wash (drainage depression) and thus may have experienced effects of sound focusing. In other words, microphone 5 may have been near the center of a ground surface having a somewhat parabolic shape. If so, when a helicopter flew over, the ground surface would have acted as a reflector focusing the helicopter sound near the microphone.

However, the hover data, which include microphone 5, do not show the microphone to be any louder. This may have resulted from the height of the aircraft. If the terrain did reflect noise, the source had to be high enough to radiate into the reflector, which should have focused less on landings than on level flyovers. Examination of the data reveals exactly this trend. Microphone 5 was high by 5 dB or more on level flyovers

[6] D. E. Bishop and W. J. Galloway, *Community Noise Exposure Resulting From Aircraft Operations: Acquisition and Analysis of Aircraft Noise and Performance Data*, Report AMRL-TR-73-107 (Bolt, Beranek, and Newman, 1975).

(when the aircraft was 300 to 1000 ft AGL), and by about 3 dB on landings (when it was perhaps 50 to 100 ft AGL). On hovers, microphone 5 was not higher than the others.

The data show that the helicopter is a very directional source which can be loosely thought of as a dipole with respect to sideline microphones. The spacing of the dipole appears to be approximately the rotor diameter. Figures 6 and 7 illustrate the directivity effects of an ideal dipole for level flyovers at 300 ft AGL and 1000 ft AGL. The reader must note that Figures 6 and 7 apply only when the aircraft is at the point of closest approach to the microphone. The radiation directivity pattern of the helicopter in three dimensions can be more nearly thought of as a portion of a donut (radiation is also reduced from the trailing portion of the donut).

Because of this directivity, a helicopter passing directly overhead sounds the loudest when it forms an angle of perhaps 45 degrees between the observer and the helicopter, and has not yet reached the observer. By the time the helicopter passes over and is leaving the area, it is already much quieter because of the directivity effects. Similar helicopter forward motion effects are observed at the sideline microphones, but these are also very sensitive to helicopter altitude, as is shown in Figures 6 and 7.

The data indicate that the complicated partial donut directivity pattern of the helicopter produces the following effects. The microphones directly underneath the aircraft (microphones 1 and 4) consistently measure lower levels than the sideline microphones. At 300 ft AGL, the 200-ft sideline microphones measure higher levels than do the 400-ft sideline microphones. However, because of the directivity pattern (Figure 7) when the aircraft is at 1000 ft AGL, the 400-ft sideline microphones measure as great or greater levels than do the 200-ft microphones underneath the aircraft.

To develop average sound exposure level versus distance or speed relations, the data for microphone 5 were eliminated because they were consistently high. In addition, the data from the other five microphones were not simply averaged. More complicated calculations were done because microphones 1 and 4 could systematically bias the data by 0.1 or 0.2 dB. Since these microphones always measured lower than the sideline microphones because of the directivity of the source, the data were combined by applying a 4/3 multiplier to the data for microphones 2, 3, and 6, and a multiplier of 1 to the data for microphones 1 and 4.

Sound Exposure Level Versus Distance

Figure 8 illustrates the developed SEL versus distance for level flyovers at a speed of 100 knots (300 ft AGL) for the UH-60A. Figure 8 also contains the SEL versus distance curve developed for the UH-60A landings. (For the heavily loaded "landing," the UH-60A actually brought the sling-loaded water buffalo in to the landing point and hovered with the buffalo resting on the ground.) As with the 1974 Fort Rucker data, the heavily loaded aircraft is about 2 dB louder than the lightly loaded aircraft, and the landing creates substantially more noise than a level flyover.

Figure 9 illustrates the SEL versus distance data developed for the CH-47C for level flyovers at a speed of 100 knots. Two curves are for data gathered at 300 ft and 1000 ft AGL; the third is for data on CH-47C landing noise, which is substantially greater than for level flyover.

Hover Data

Table 4 lists the in- and out-of-ground effect hover data (L_{eq}) taken at the eight measurement positions for the various aircraft. Raw data are in Appendix B.

CERL Technical Report N-38 included generalized hover contours and a table of parameters to be used for individual aircraft. The data gathered at Fort Campbell have been combined with the original data from Fort Rucker to form a revised set of generalized hover contours and individual aircraft parameters. Table 5 lists the amounts by which these generalized hover contours depart from a purely omnidirectional source. Table 6 contains the energy average hover emission value produced by each aircraft, if treated as an omnidirectional source. Together, these tables yield a generalized hover emissions pattern scaled to each aircraft. To form these composites, the 400-ft data for Fort Campbell were converted to 200 ft for the UH-60A and UH-1H, and to 300 ft for the CH-47C using a factor of 7 dB attenuation for doubling of distance. (The discrepancy between the measured UH-1H data at Forts Campbell and Rucker is discussed on p. 15.)

Variation of Sound Exposure Level With Speed

Figure 10 illustrates the measured variation of SEL with speed for the CH-47C at a slant distance of 500 ft. The data are shown separately for the 300-ft and 1000-ft-AGL flyovers. Figure 11 presents the same type of data for the UH-1H. Figure 12 illustrates the variation of sound exposure level with speed for the UH-60A—again at a slant distance of 500 ft. In this case, the data are presented for heavily and lightly loaded aircraft rather than for 300-ft- and 1000-ft-AGL flyovers. The data in Figures 10 through 12 are largely independent of aircraft altitude, slant distance, or load. Thus, composite curves can be constructed. Figure 13 illustrates the composite variation of SEL with distance for the three aircraft studied. Figure 13 is a generalized curve normalized to 0 dB at a speed of 100 knots.

Direct measurement of SEL versus aircraft speed is one way to determine the speed relation. Another approach is to measure the variation of the ½-sec maximum L_{eq} with speed. The variation should be equal to that of the ½-sec maximum minus 10 log (aircraft speed). Figures 14, 15, and 16 present data for the ½-sec maximum L_{eq} of the aircraft operations and slant distances shown in Figures 10, 11, and 12. Again, the data and curves are largely independent of aircraft height or load. Figure 17 illustrates the composite curves for the three aircraft; these curves were developed using maximum L_{eq} plus the theoretical variation of flyover duration with speed.

To compare the variation with speed of SEL and maximum ½-sec L_{eq}, the quantity 10 log (velocity/100) was added to the curves of Figures 12, 14, and 15 to form Figures 18, 19, 20, and 21. The data in Figure 21 were then compared with those in Figure 17 by plotting the difference (Figure 22). Table 7 lists the data in Figures 17, 21, and 22. The differences are small, showing that the variation of SEL with speed can be approximated by the variation of L_{eq} with speed minus 10 log (velocity) plus a constant. The tables in Appendix C list the data from Figures 8 through 22.

Comparison of Fort Campbell and Fort Rucker Results for the UH-1H Aircraft

Figure 23 presents the SEL versus distance curve developed for level flyovers (lightly loaded) at 80 knots and 300 ft AGL. The values at Fort Campbell are 3 to 4 dB lower than those at Fort Rucker. Figure 24 provides a similar comparison for landings. Again the values are 3 to 4 dB lower at Fort Campbell than at Fort Rucker. Table 8 presents the maximum ½-sec L_{eq} for several microphones at Forts Rucker and Campbell. These differ by 4 dB or more. The table also compares the 200-ft corrected average (energy) hover L_{eq} for in-ground and out-of-ground effects at the two forts. Table 8 also shows that the L_{eq} values for the in-ground effect hover are about 3 to 4 dB lower at Fort Campbell than at Fort Rucker. However, the L_{eq} values for the out-of-ground effect hover are similar.

The UH-1H aircraft measured at Forts Rucker and Campbell are essentially the same. There have been no modifications to blades, transmissions, or engines. The only known change is the installation of dynamic blade balancing hardware during 1974. For level flyovers, a dynamically balanced UH-1H aircraft exhibits blade slap in the speed range of 65 to 80 knots. Without dynamic balancing, this range may be slightly wider because the region of tip/wake vortex interaction increases. Thus, the 80-knot data from Fort Rucker could well be 3 to 4 dB louder than the same measurements at Fort Campbell. A similar effect may occur for landings.

Why are the out-of-ground effect data similar while Fort Rucker's in-ground effect data are higher than Fort Campbell's? Here, blade/vortex interaction is not a factor. However, the answer may lie in the measurement surface. The hover area used at Fort Rucker was the installation's helicopter parking, and hence was almost entirely paved; the area at Fort Campbell was grass. Theoretical computer analysis[7] shows the hard surface increases measured in-ground effect readings (at 200 ft) by about 4 dB, but only increases out-of-ground effect readings by about 1-½ dB. Thus, the measurement surface may contribute to the differences in hover levels.

Other reasons for the difference in levels might include changes in flight procedures, environmental factors affecting the measurement, or errors in measurement. At both installations, Army pilots flew the same type of aircraft 300 ft AGL at a speed of 80 knots, maintaining constant altitude. In both cases, the pilots performed in-ground and out-of-ground effect hovers. In both cases, measurements were made during warm weather, and the flyovers were performed in a grass-covered area with some trees nearby. (However, at Fort Campbell, the forests surrounding the clear area were much thicker than at Fort Rucker.) In both cases, independently operated and calibrated measurement systems were used. The two systems at Fort Rucker produced internally consistent measurements, as did the two at Fort Campbell. While environmental factors may have affected the total integrated exposure level,

[7]This analysis is based on R. J. Donato, "Propagation of a Spherical Wave Near a Plane Boundary With a Complex Impedance," *Journal of the Acoustical Society of America*, Vol 60, No. 1 (July 1976), pp 34–39.

it seems unlikely that they could have affected the maximum ½-sec L_{eq}, or the hover data measured at distances of 200 to 400 ft. Also, the two independent measurement systems used at each installation tend to rule out the possibility of measurement error. Thus, the only known plausible explanations for the large variations recorded are the dynamic blade-balancing procedure and the "hard" hover surface area at Fort Rucker.

5 CONCLUSIONS AND RECOMMENDATIONS

SEL versus distance curves for the UH-60A and CH-47C were developed. For the UH-60A, the data show that a heavily loaded aircraft is about 2 dB louder than a lightly loaded one. Landing noise with the UH-60A and CH-47C is substantially greater than for level flyover.

The variation of SEL with speed is rather modest, except for aircraft at very low or very high speeds. The variation of SEL with speed data will be incorporated in CERL's INCS system and, thus, 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.

The measurements at Fort Rucker showed great internal consistency. Four aircraft of the same type measured during the same testing period at the same site and with the same equipment yielded similar results. The measurements at Fort Campbell also showed great internal consistency--except for microphone 5. However, the bias of microphone 5, and the discrepancy between the data gathered at Forts Campbell and Rucker, indicate problems that will have to be solved before the gathering of helicopter noise emissions data can be standardized. Better methods need to be developed to control site terrain and environmental factors, and to account for the effects of variations in maintenance procedures and pilot techniques. To begin understanding such discrepancies, it will be useful to replicate the measurements from Forts Campbell and Rucker with the UH-1H aircraft.

Table 1
Dynamic Operations Performed at Fort Rucker

Operation	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 Normal
TH-55	Normal

Table 3
Dynamic Operations Performed at Fort Campbell
by CH-47C and UH-1H

	Operation*	Altitude (ft)	Speed (knots)	GT (degrees)
1	LF	300	80	280
2	LF	300	80	100
3	LF	300	40	280
4	LF	300	40	100
5	LF	300	100	280
6	LF	300	100	100
7	LF	300	60	280
8	LF	300	60	100
9	LF	300	120	280
10	LF	300	120	100
11	LF	300	80	280
12	LF	300	80	100
13	LF	300	100	280
14	LF	300	100	100
15	Landing	—	—	280
16	IGE Hover			
17	OGE Hover			
18	Takeoff	—	—	280
19	LF	1000	80	100
20	LF	1000	80	280
21	LF	1000	100	100
22	LF	1000	100	280
23	LF	1000	120	100
24	LF	1000	120	280
25	LF	1000	60	100
26	LF	1000	60	280
27	LF	1000	100	100
28	LF	1000	100	280
29	LF	1000	80	100
30	LF	1000	80	280

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

Table 4
Average (Energy) Measured Data (dB)

Aircraft	Hover	Position (degrees)* 0	45	90	135	180	225	270	315	Average
UH-1H (Unloaded)**	IGE	74.1	80.6	75.8	75.1	75.5	75.3	77.9	74.2	76.7
	OGE	78.8	81.5	84.4	86.0	85.0	85.5	80.5	78.7	83.4
UH-60-A (Unloaded)**	IGE	77.1	75.5	76.9	76.3	77.2	78.0	74.8	77.5	76.8
	OGE	80.4	79.5	86.4	81.6	83.4	81.4	81.9	79.9	81.9
UH-60-A (Loaded)**	OGE	81.0	80.6	86.1	88.2	85.5	82.0	78.0	81.6	84.0
CH-47C (Unloaded)†	IGE	84.3	86.5	86.9	83.2	80.3	75.8	75.5	80.7	83.3
	OGE	84.7	88.1	88.3	87.3	81.9	81.6	82.2	84.9	85.6

*Front of aircraft is 0°.
**From Table B5.
†From Table B8.

Table 5
Hover Directivity Versus Position (dB)
(0° Is Front of Aircraft)

Position	Single Rotor (Overall Average, Table B7)	Dual Rotor (Overall Average, Table B10)
0	−2.7	+0.2
45	−1.6	+2.8
90	−0.6	+2.5
135	+1.4	0
180	+1.1	−2.1
225	+2.2	−3.0
270	−0.4	−3.3
350	−2.4	−1.1

Table 6
Energy Average A-Weighted Hover Sound Levels (dB)
(To Be Used With Table 5)

Aircraft	Surface	Distance (feet)	IGE	OGE
AH-1G	Hard	200	88.3	87.8
OH-58	Hard	200	81.4	83.7
UH-1B*	Hard	200	85.9	90.1
UH-1H*	Hard	200	88.4	91.8
UH-1H**	Soft	400	76.7	83.4
UH-1M	Hard	200	86.2	89.9
UH-60A*	Soft	400	81.7	83.1
CH-47A/B*	Hard	300	90.2	91.8
CH-47C**	Soft	400	83.3	85.6
TH-55	Hard	200	84.8	–

*Dual load.
**Light load.

Table 7
Difference, in Decibels, Between Composite Speed Variation Functions
(L_{eq} vs Speed as Compared to the Function SEL Plus 10 log [v/100] vs Speed)*

Speed (knots)	Figure 17 Composite, L_{eq} vs Speed**			Figure 21 Composite, SEL + 10 log (v/100 knots) vs Speed***			Difference, Figure 22†		
	CH-47C	UH-1H	UH-60A	CH-47C	UH-1H	UH-60A	CH-47C	UH-1H	UH-60A
40	3.6	0.4	−4.3	3.7	−3.7	−4.7	0.0	4.1	0.4
60	2.2	−4.0	−2.6	2.8	−4.0	−2.8	−0.6	0.0	0.2
80	0.9	−2.3	−1.6	0.7	−2.3	−1.5	0.2	0.0	−0.1
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
120	0.2	4.9	2.1	1.3	6.1	2.3	−1.1	−1.2	−0.2
140	1.8		3.7	3.9		4.0	−2.1		−0.3

*Data for 300-ft and 1000-ft AGL are combined.
**From Table C3.
***From Table C4.
†From Table C5.

Table 8
Comparison of Fort Campbell and Fort Rucker UH-1H Data

	Fort Rucker	Fort Campbell	Difference
IGE hover–200 ft (Fort Campbell corrected +7 dB for distance and +2 dB for light load)	88.4	85.7	+2.7
OGE hover–200 ft (Fort Campbell corrected +6 dB for distance and +2 dB for light load)	91.8	91.4	+0.4
Max. ½-sec L_{eq}			
Mikes 1&4*	91.7	85.2	+6.5
Mikes 2&5	88.2	84.0	+4.2
Mike 3	84.9	80.7	+4.2

*The 6 dB difference (high reading at Fort Rucker) may be caused by the very loud noise during the few seconds just before the aircraft went overhead. This may result from retreating blade/vortex interaction. Since it was a short-lived effect, it does not influence the SEL greatly.

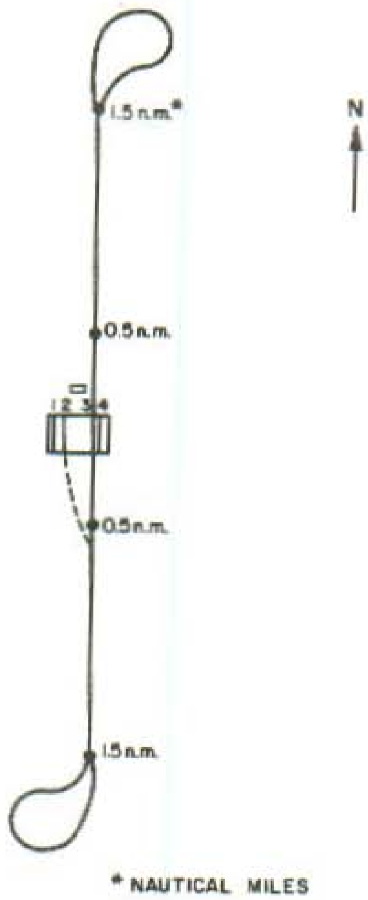


Figure 1. Flight path for level flyovers.

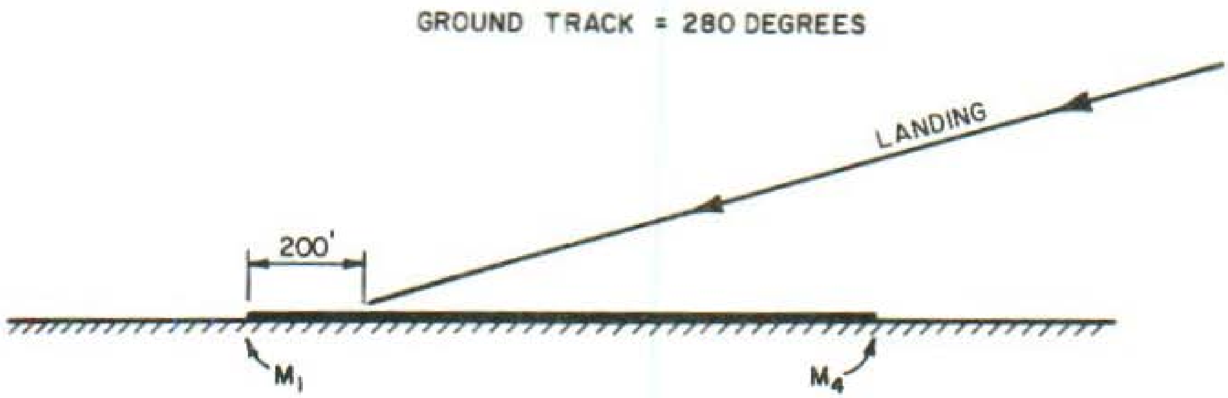


Figure 2. Flight path for landing.

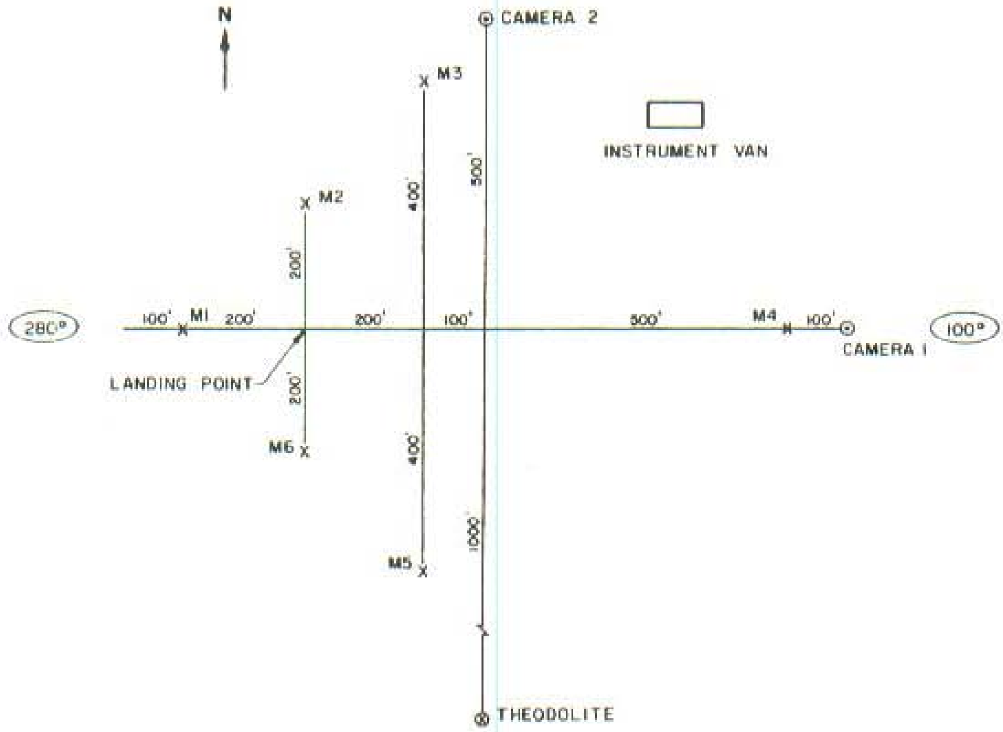


Figure 3. Microphone/camera layout at Fort Campbell.

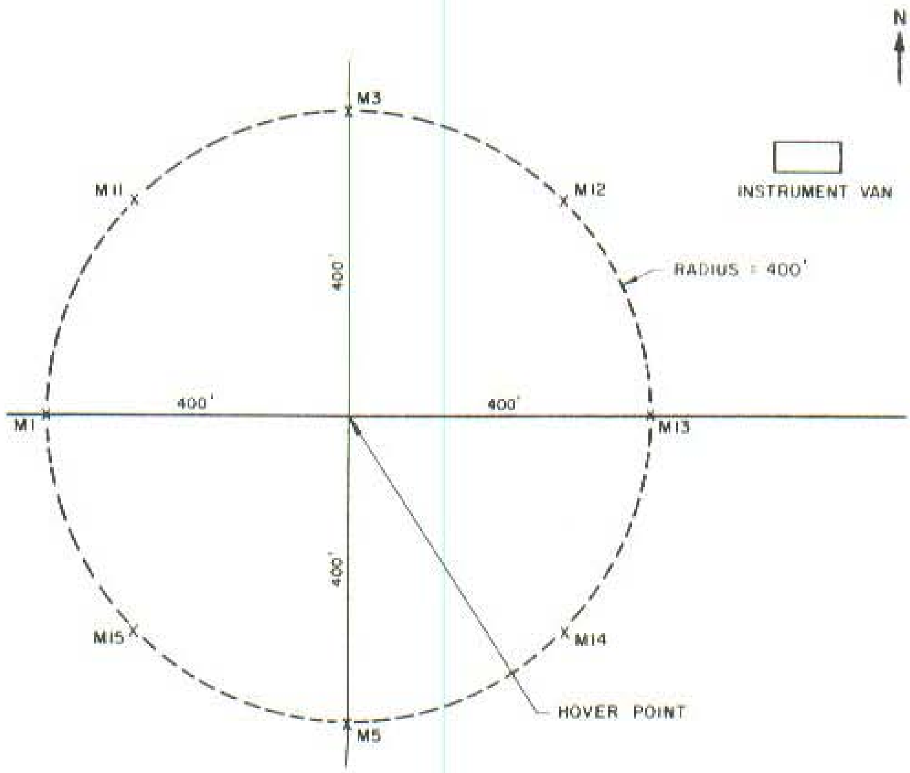


Figure 4. Hover microphones at Fort Campbell.

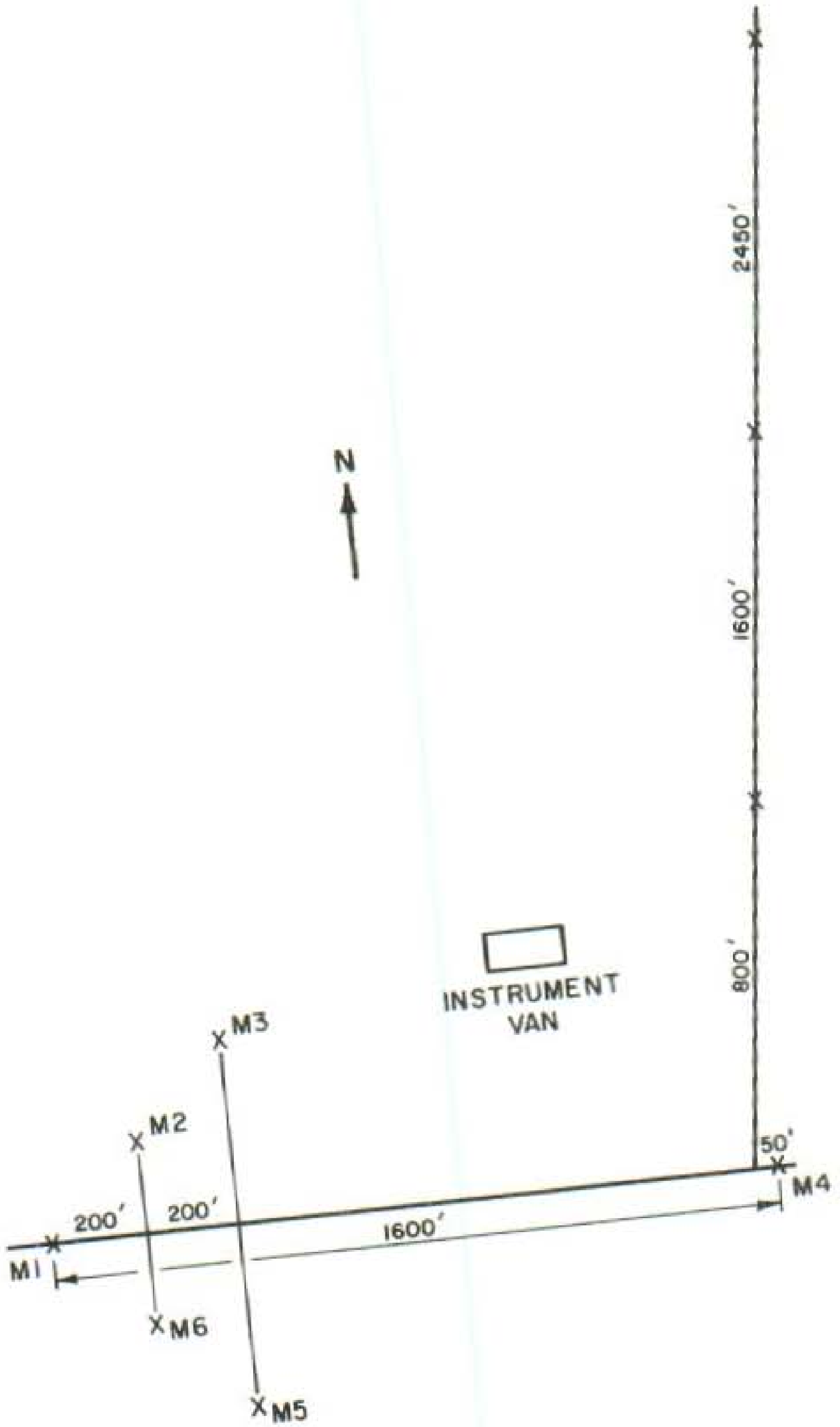


Figure 5. Sideline microphones at Fort Campbell.

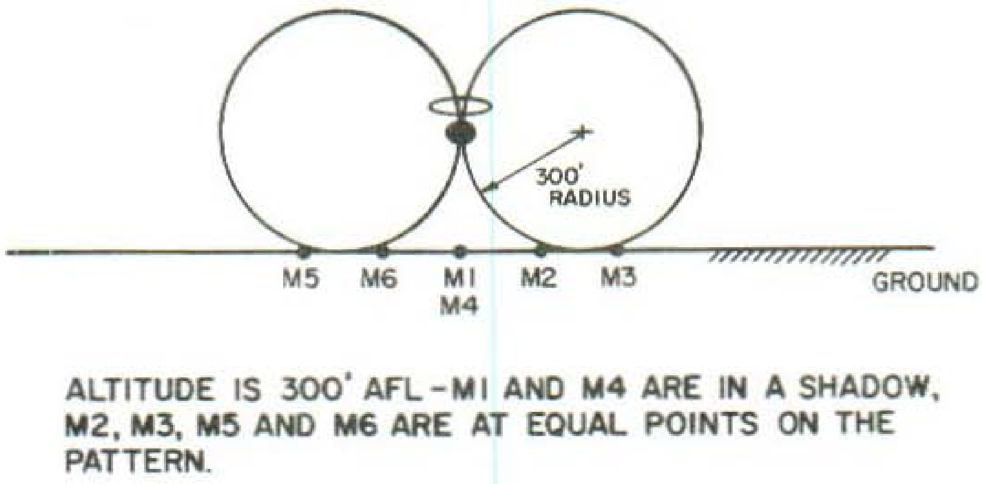


Figure 6. Directivity effects–300 ft AGL.

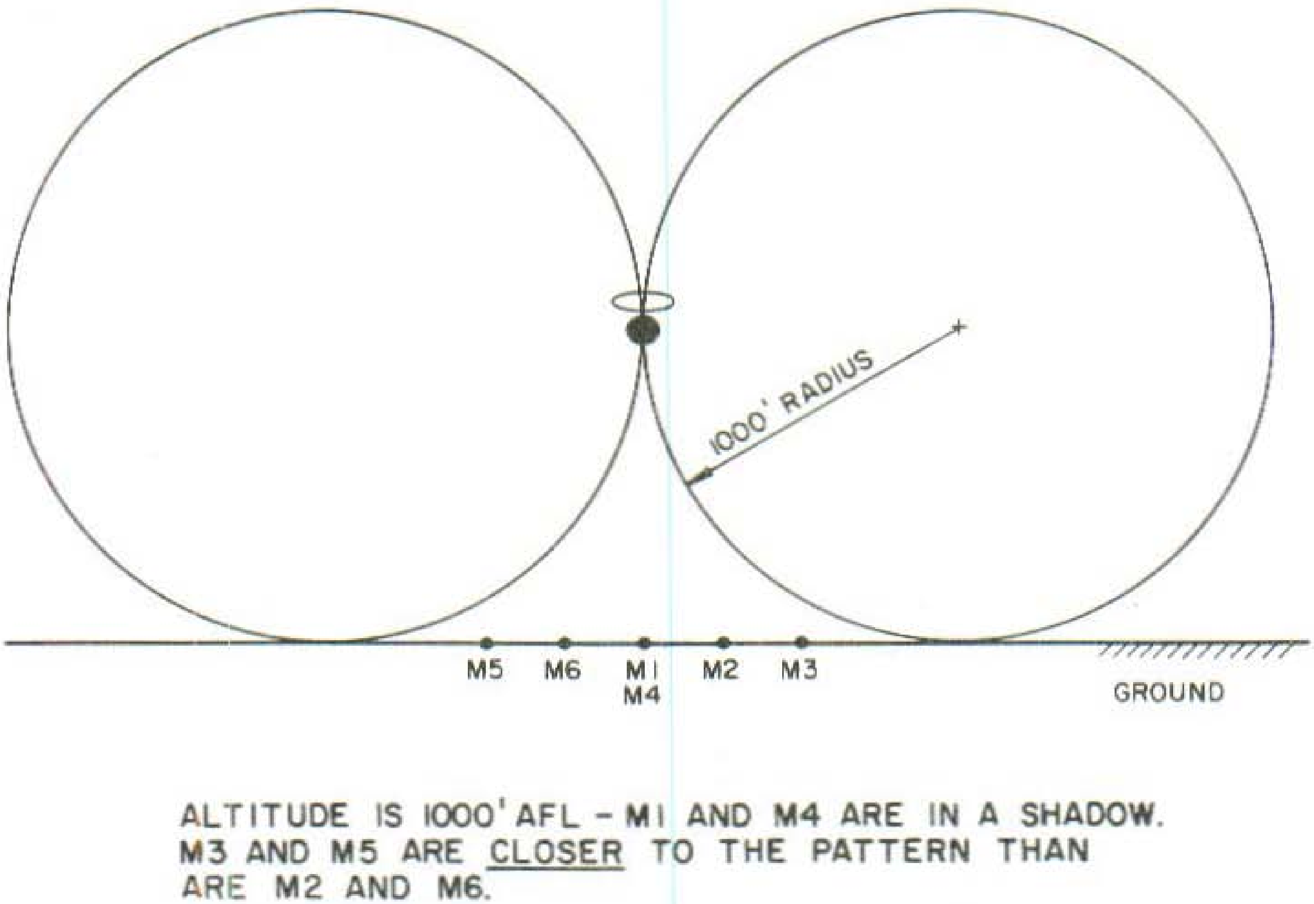


Figure 7. Directivity effects–1000 ft AGL.

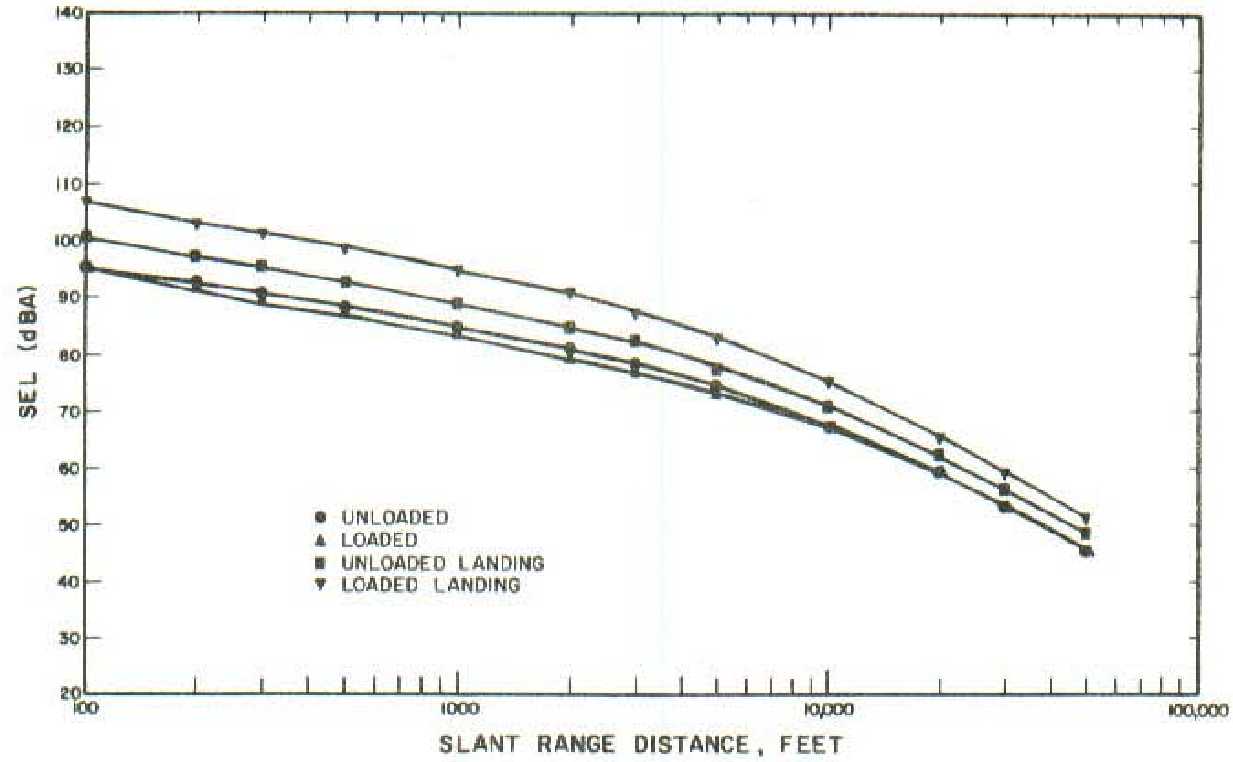


Figure 8. UH-60A–variation of SEL with distance, level flyover (100-knot data).

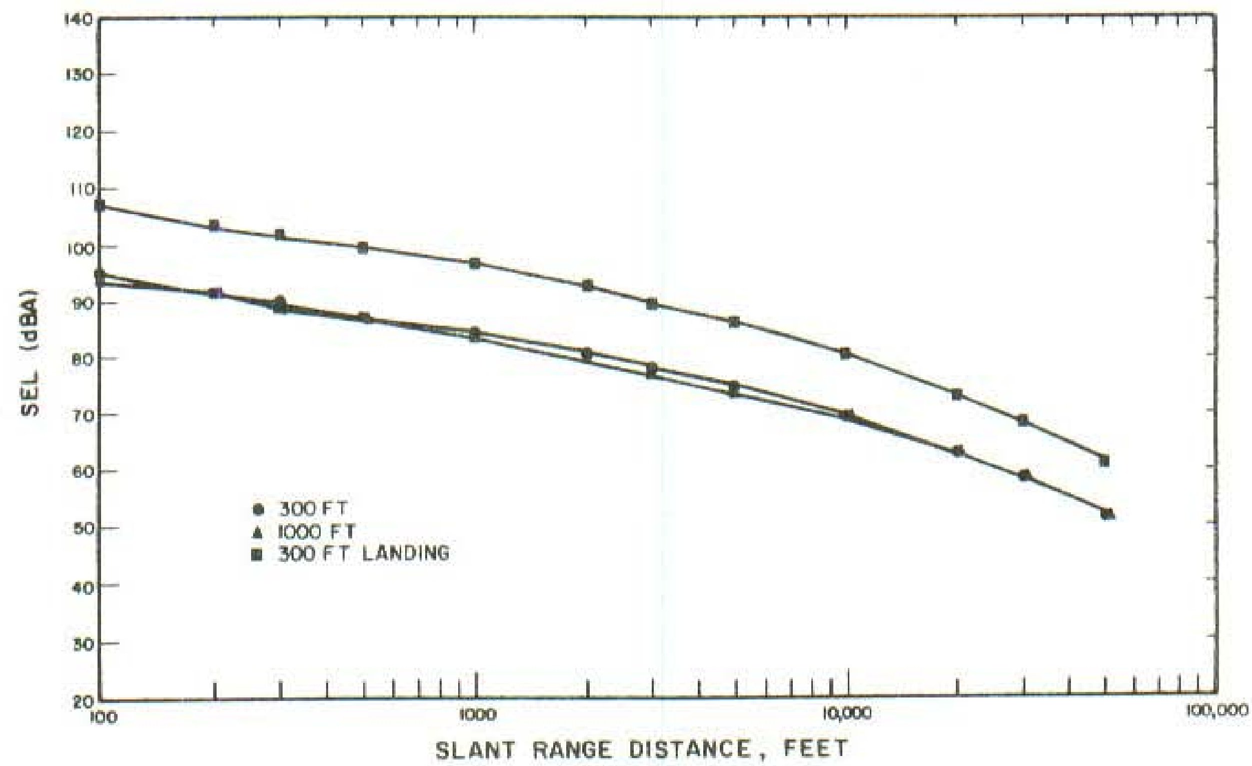


Figure 9. CH-47C–variation of SEL with distance, level flyover (100-knot data).

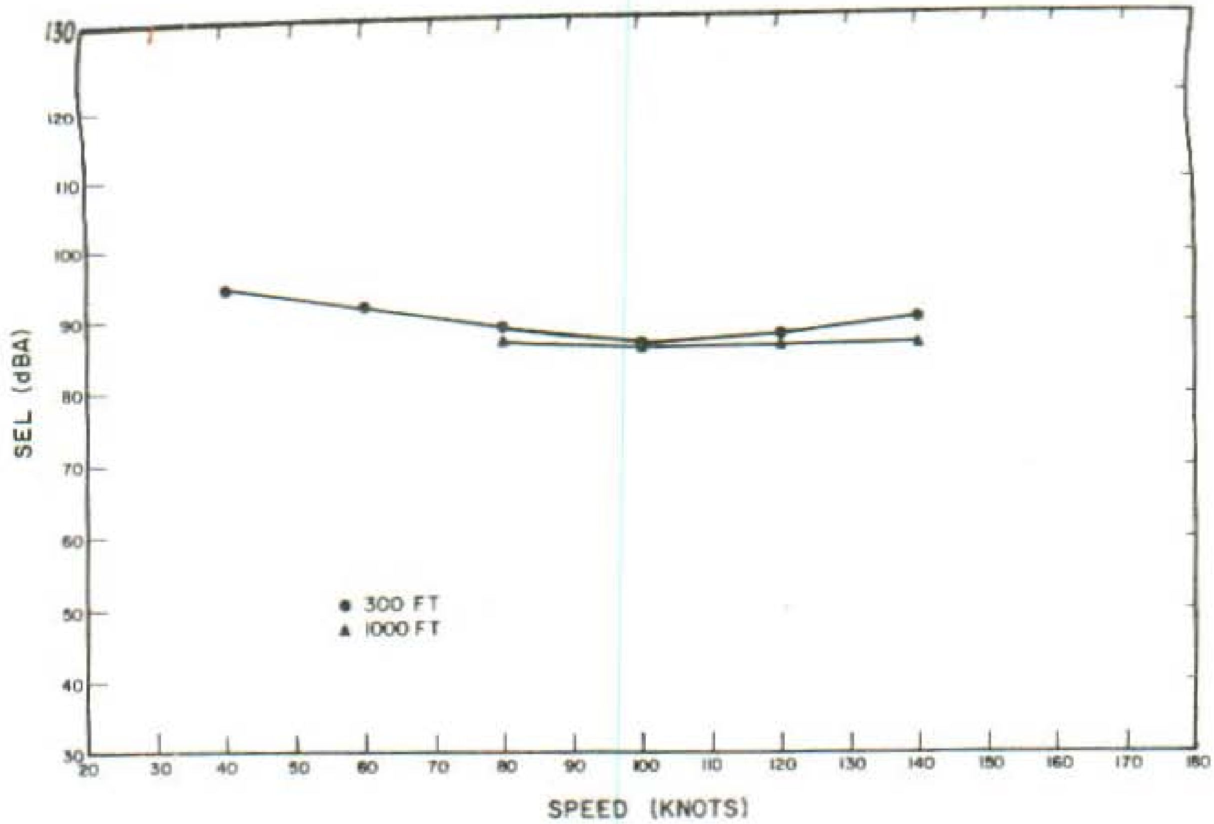


Figure 10. CH-47C–variation of SEL with speed at 500 ft (300- and 1000-ft flyovers).

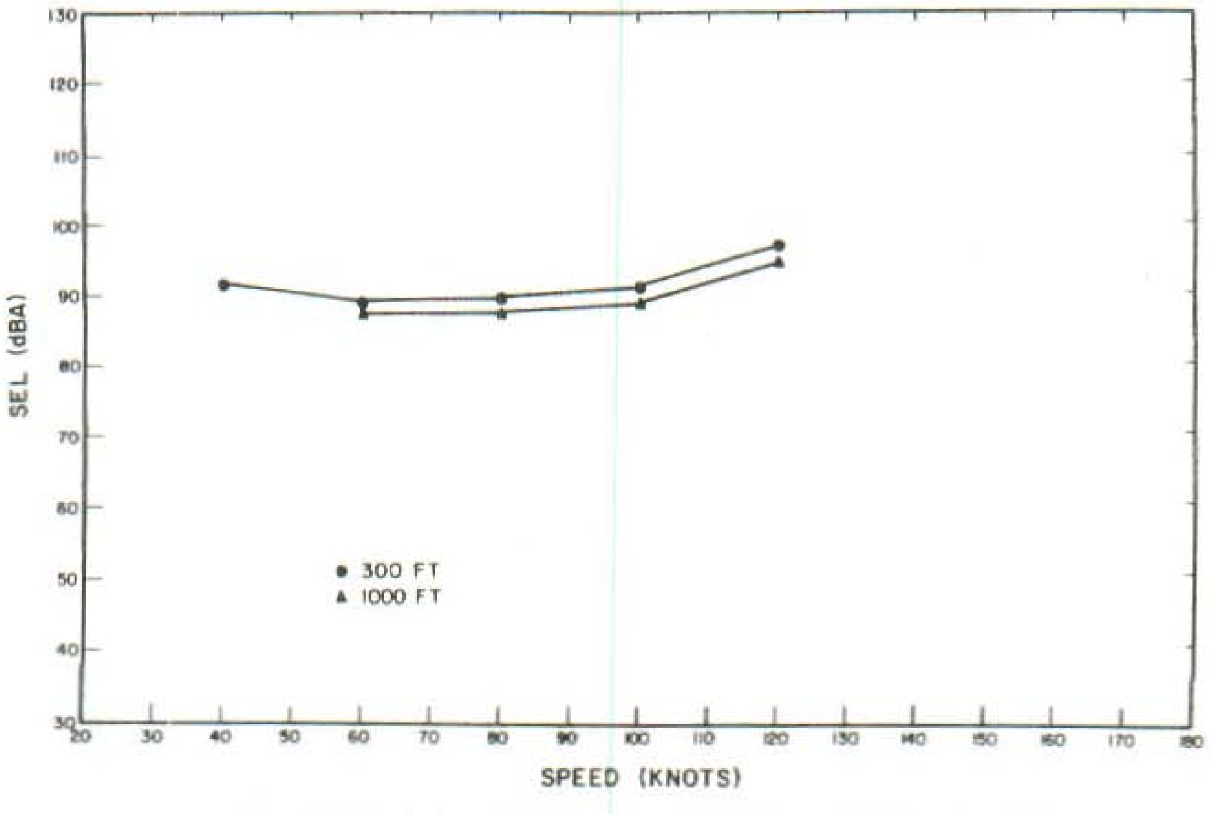


Figure 11. UH-1H–variation of SEL with speed at 500 ft (300- and 1000-ft flyovers).

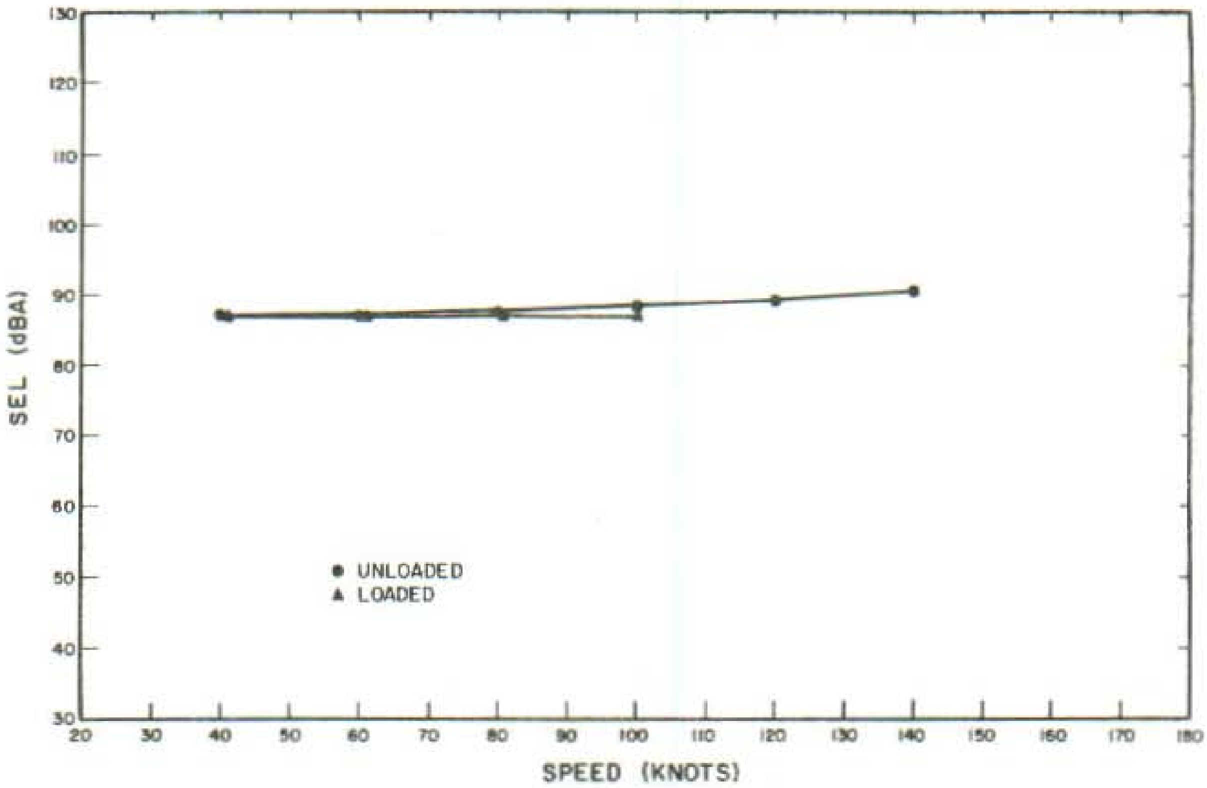


Figure 12. UH-60A–variation of SEL with speed at 500 ft (loaded and unloaded flyovers).

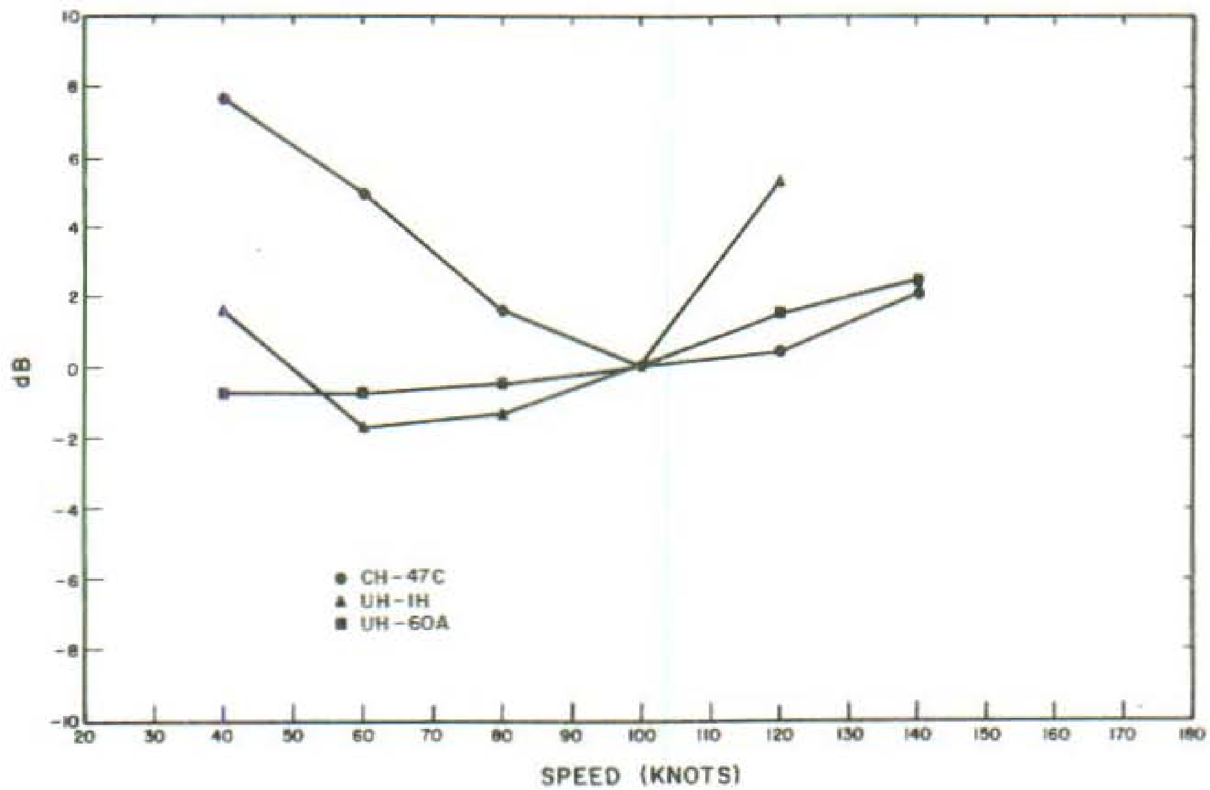


Figure 13. Composite curves of variation of SEL with distance at 500 ft (normalized to 0 dB at 100 knots).

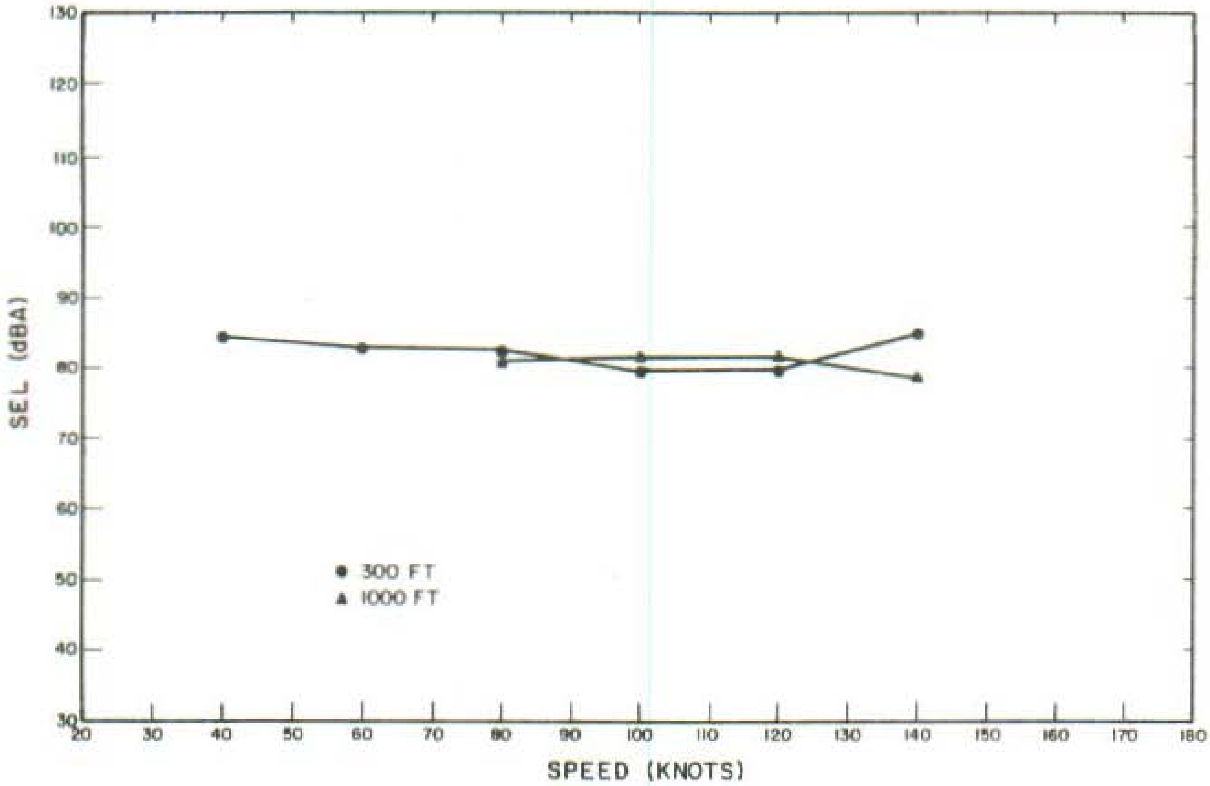


Figure 14. CH-47C–variation of L_{eq} with speed at 500 ft (300- and 1000-ft flyovers).

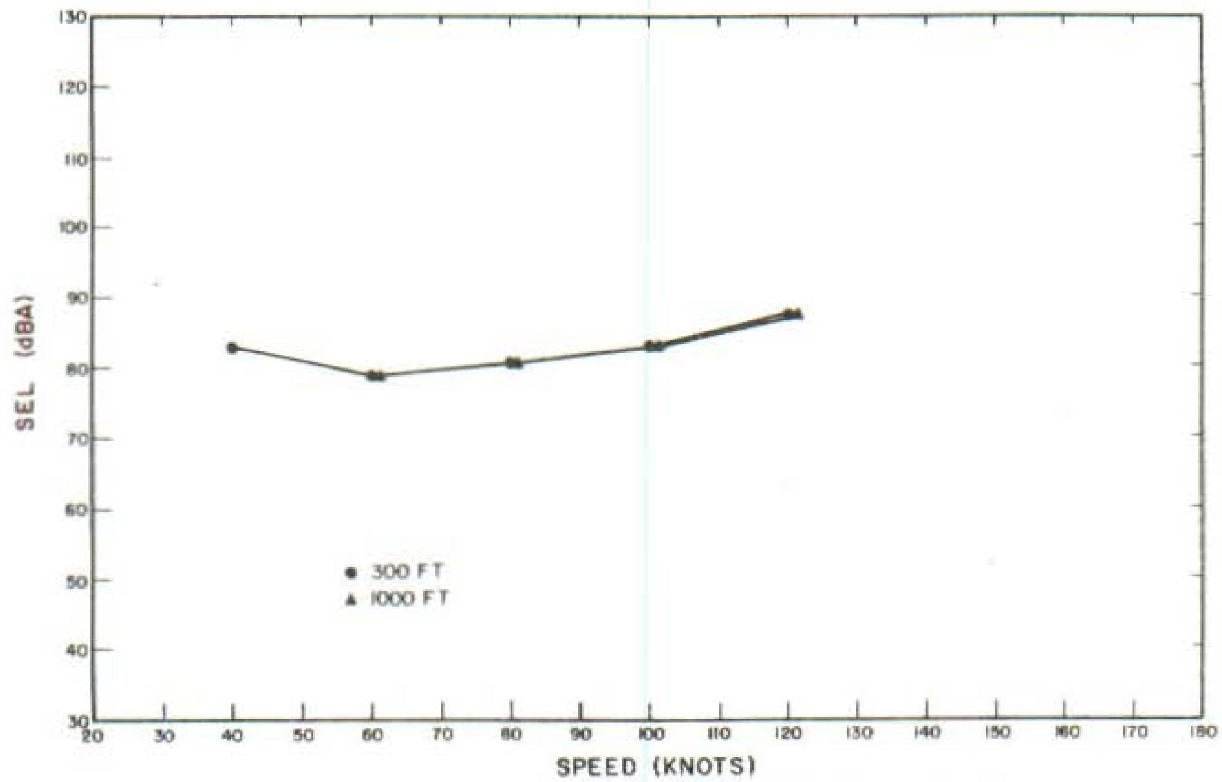


Figure 15. UH-1H–variation of L_{eq} with speed at 500 ft (300- and 1000-ft flyovers).

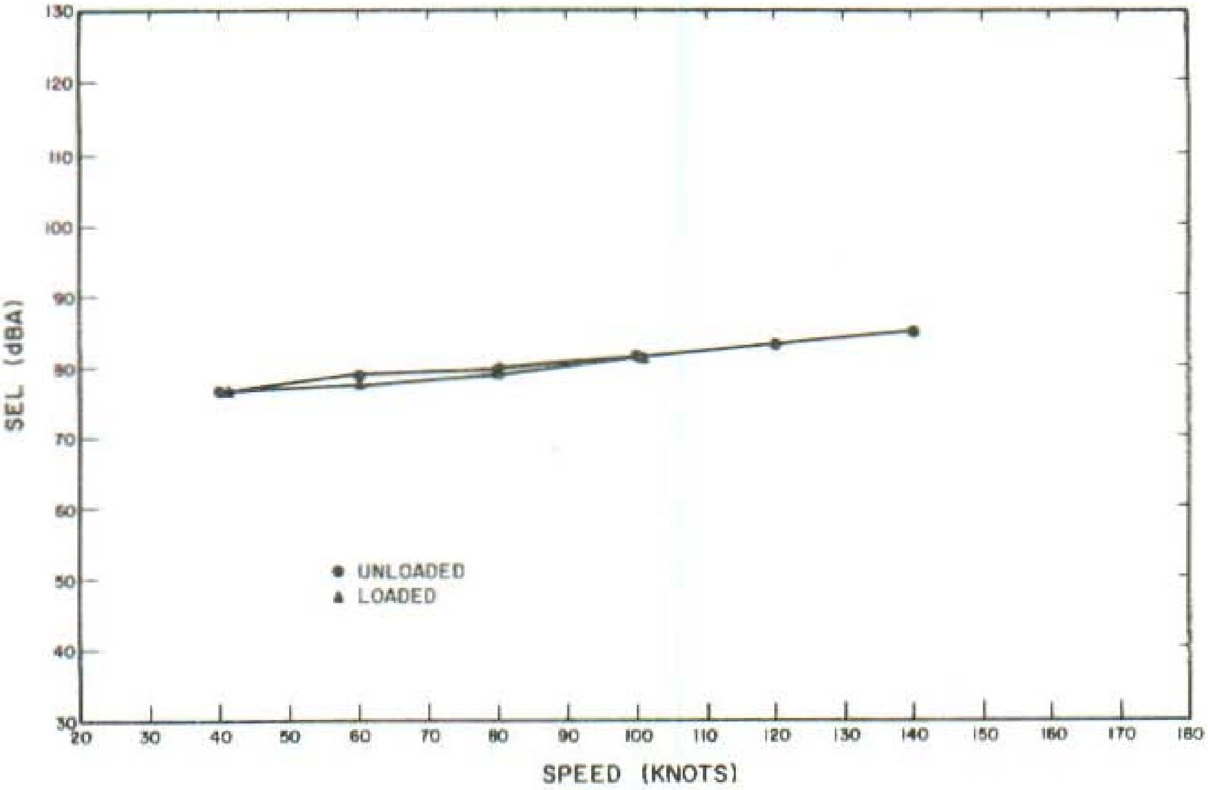


Figure 16. UH-60A—variation of L_{eq} with speed at 500 ft (loaded and unloaded flyovers).

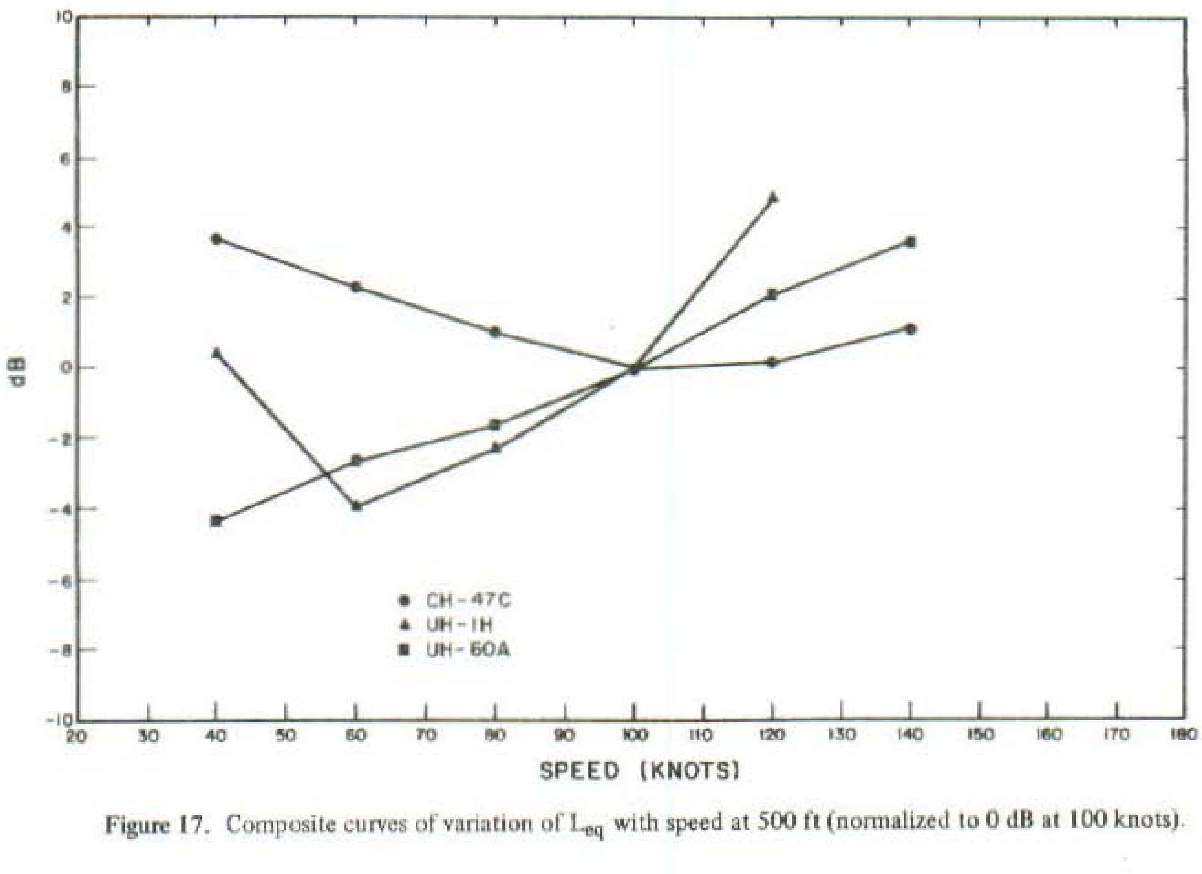


Figure 17. Composite curves of variation of L_{eq} with speed at 500 ft (normalized to 0 dB at 100 knots).

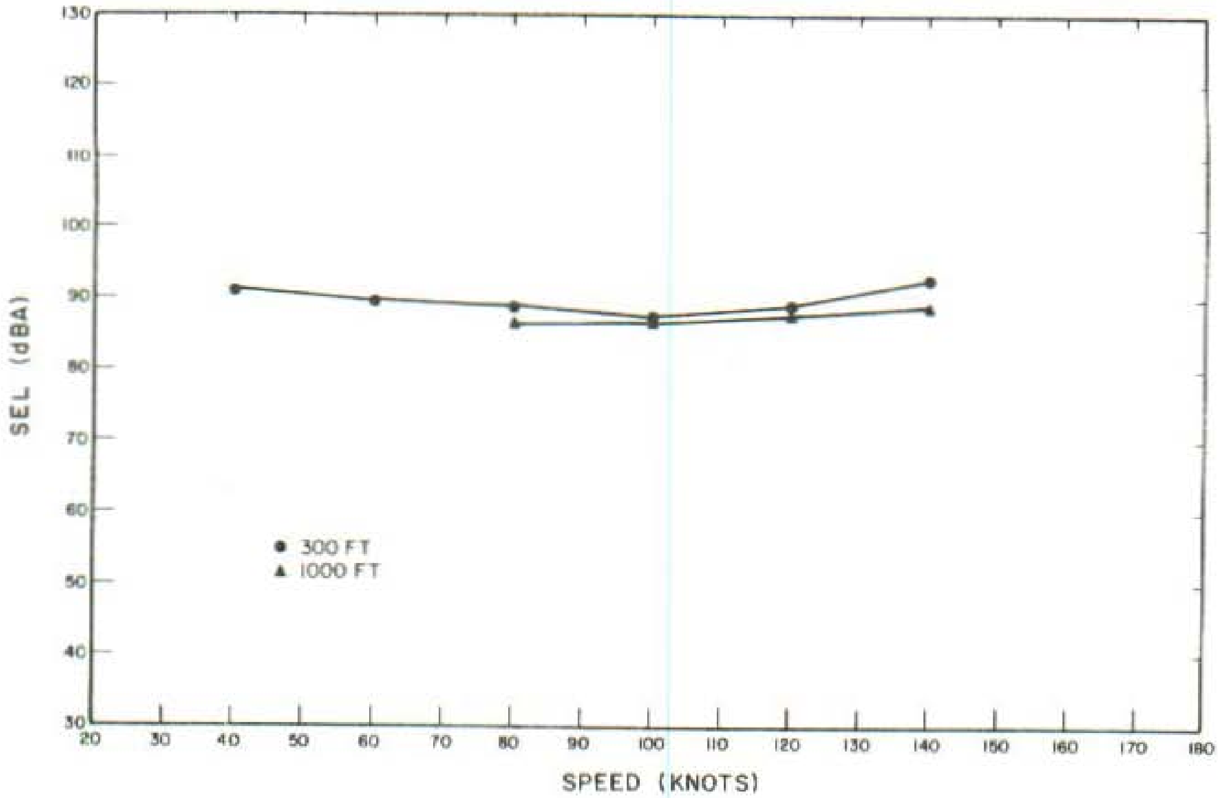


Figure 18. CH-47C–variation of SEL + 10 log (v/100 knots) with speed at 500 ft (300- and 1000-ft flyovers).

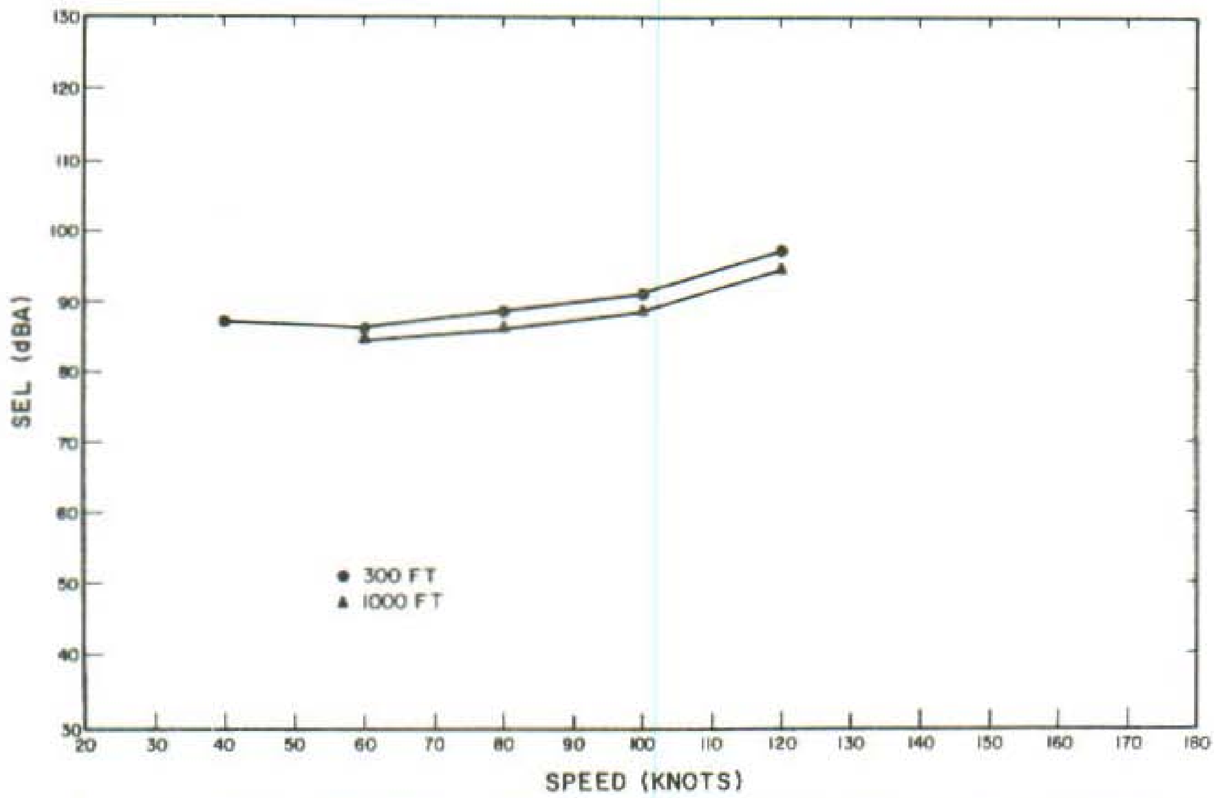


Figure 19. UH-1H–variation of SEL + 10 log (v/100 knots) with speed at 500 ft (300- and 1000-ft flyovers).

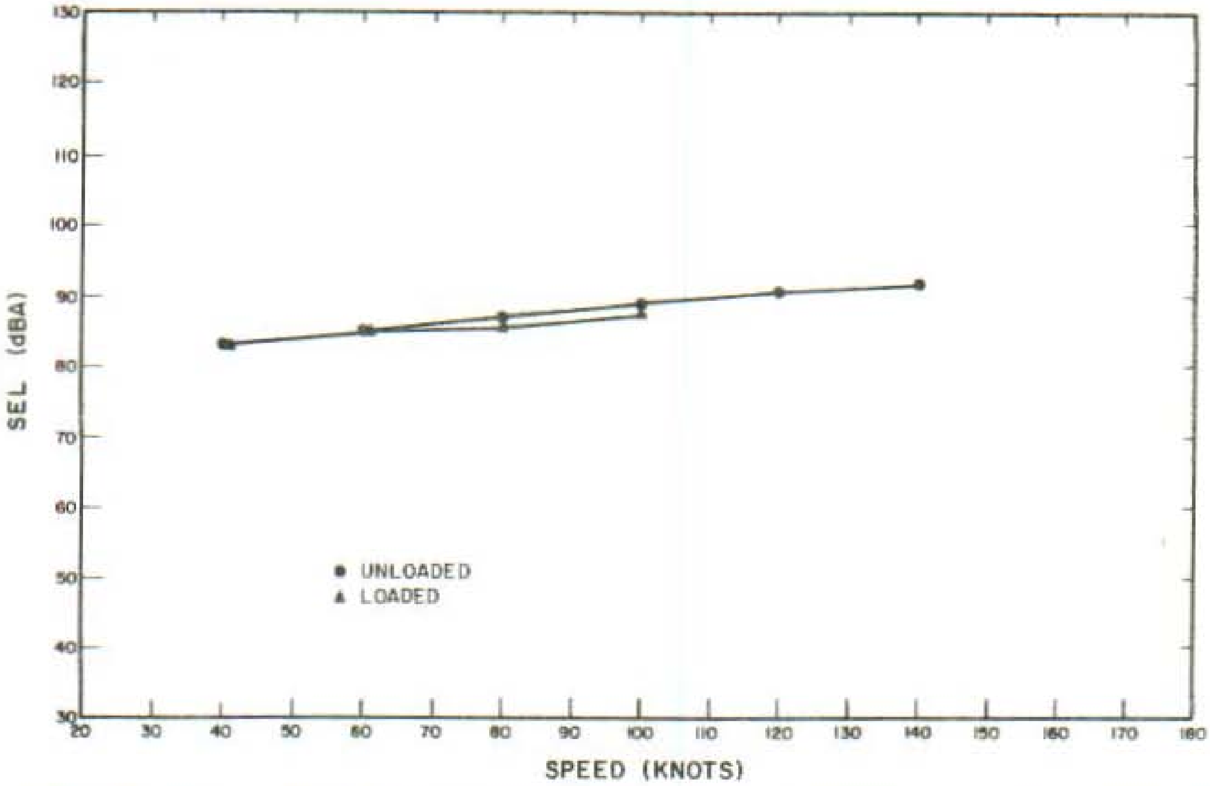


Figure 20. UH-60A–variation of SEL + 10 log (v/100 knots) with speed at 500 ft (loaded and unloaded flyovers).

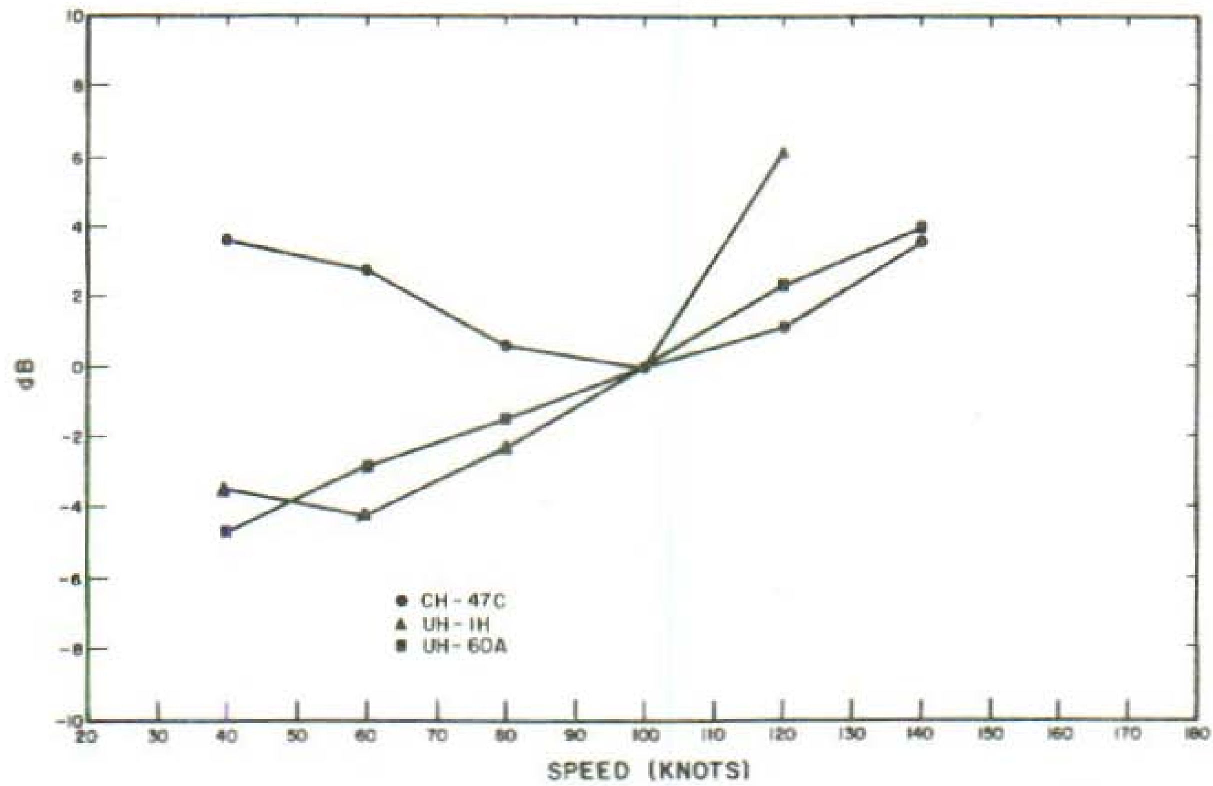


Figure 21. Composite curves of variation of SEL + 10 log (v/100 knots) with speed at 500 ft.

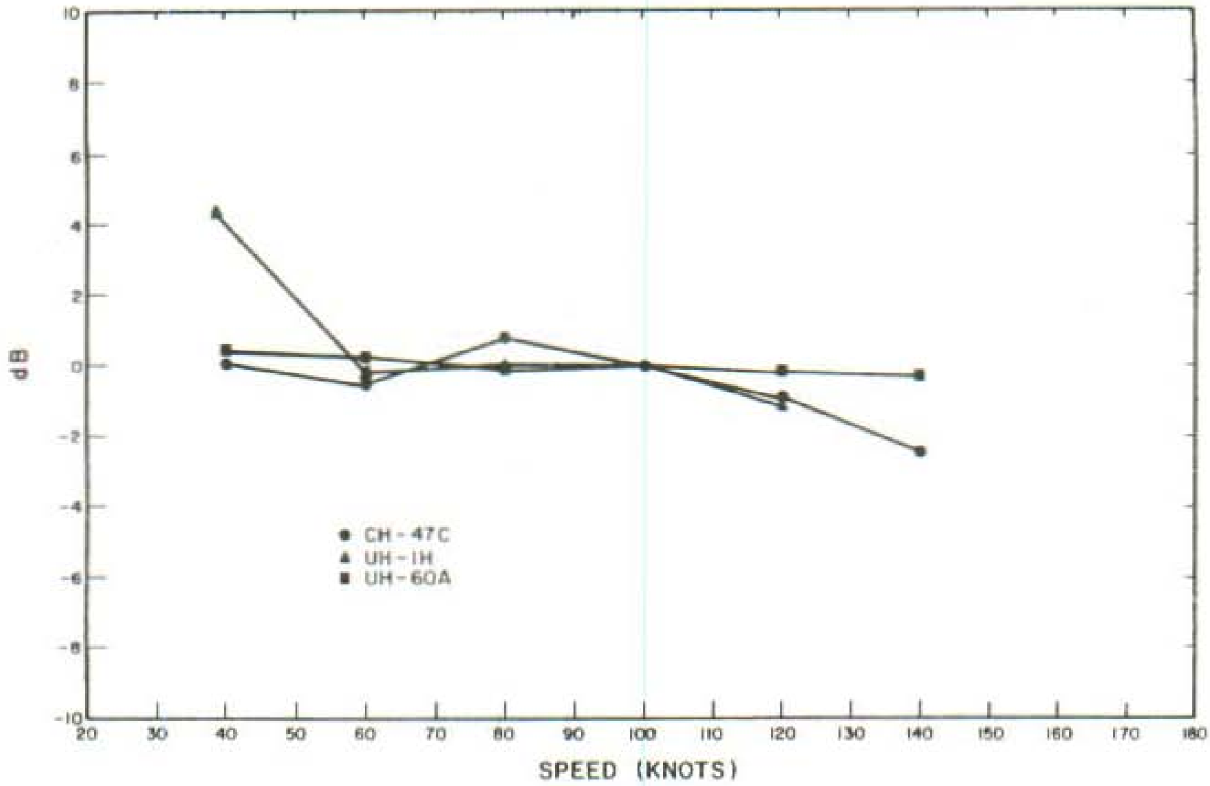


Figure 22. Difference of L_{eq} versus speed and SEL + 10 log (v/100 knots) at 500 ft.

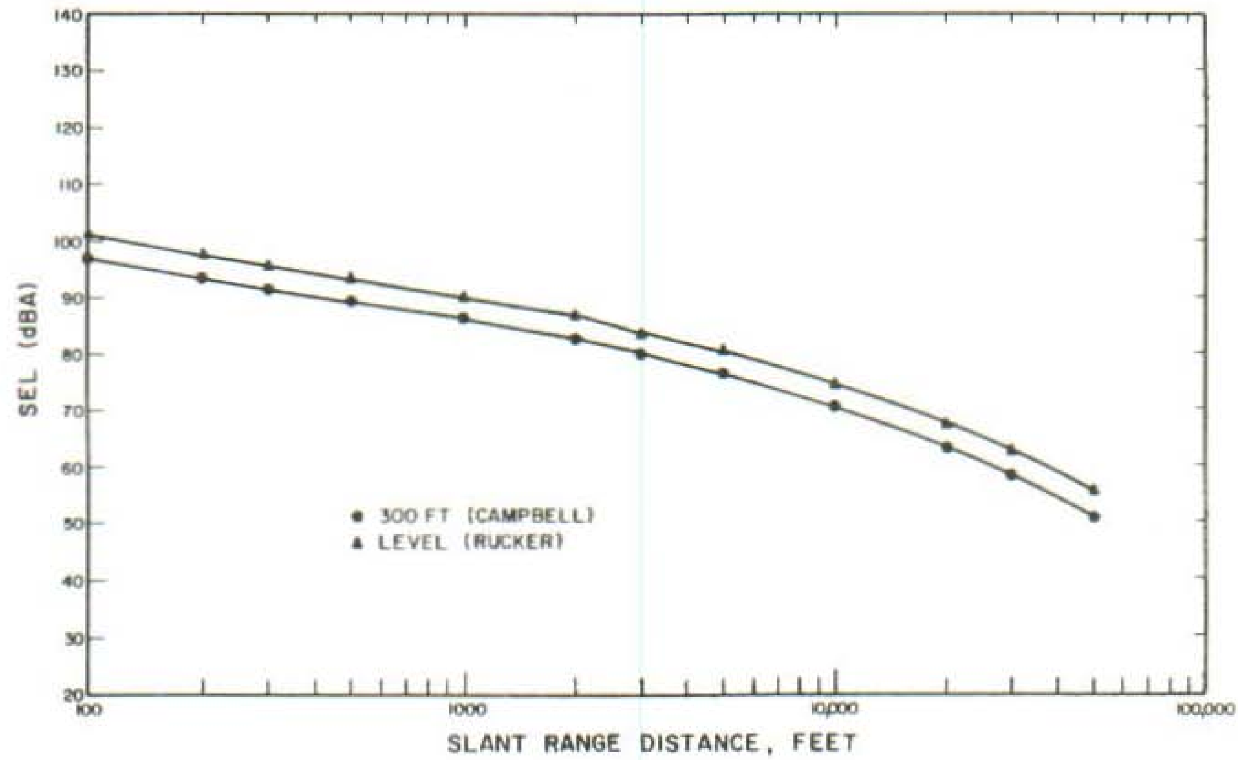


Figure 23. UH-1H–variation of SEL with distance at 80 knots (level flyovers).

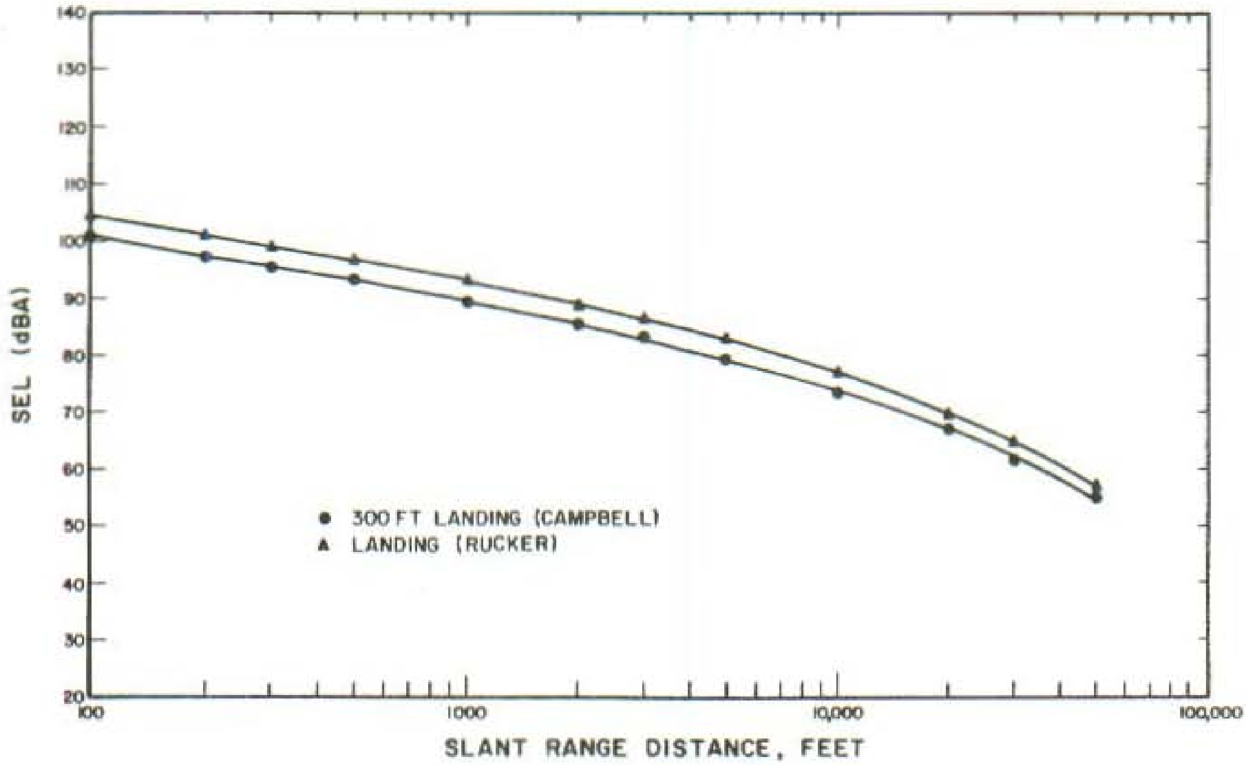


Figure 24. UH-1H–variation of SEL with distance at 80 knots (landings).

METRIC CONVERSIONS

1 ft = 0.3 m
1 in. = 25.4 mm
1 gal = 4.5 L
1 knot = 30.85 m/sec

$$\frac{°F-32}{1.8} = °C$$

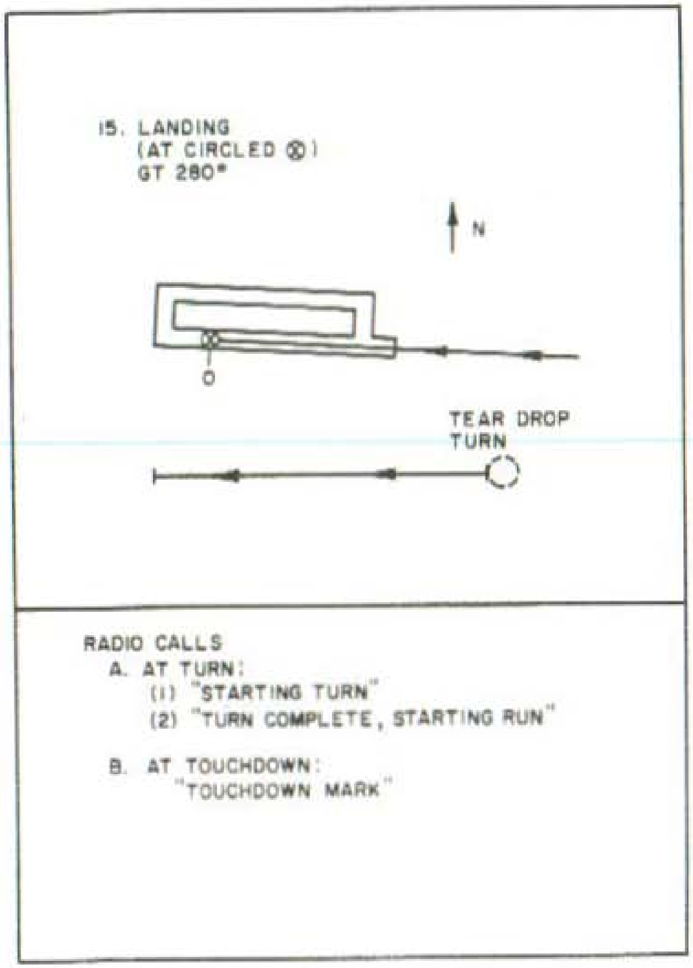


Figure A3. Instruction sheet for landing–Operation 15.

15. LANDING

Heading ___280___

At 1 1/2 miles before runway, after turn, radio "Mark"

At touchdown, radio another "Mark"

Touchdown Time ___1026___

Engine Exhaust Gas Temp ___560-600___

Fuel Weight ___3450___

Indicated Air Speed ___0___

Figure A4. Pilot's entries for landing.

APPENDIX A: PILOT'S LOG

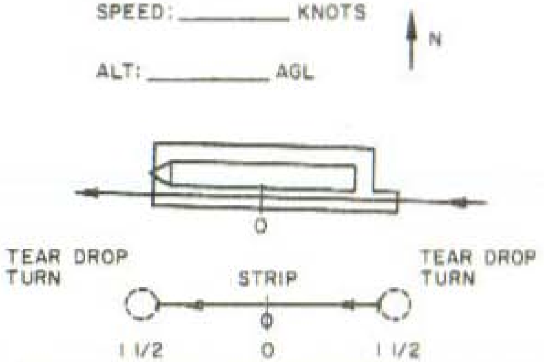
This appendix contains typical pilot's log pages for level flyover, landings, hovers, and takeoffs–operations 14, 15, 16, 17, and 18. (For a list of operations, see Table 3.)

LEVEL FLYOVER

GT ________

SPEED: ________ KNOTS

ALT: ________ AGL



RADIO CALLS AT EACH 1 1/2 NAUTICAL MILE TURN

(1) STARTING TURN

(2) TURN COMPLETE, STARTING RUN

Figure A1. Instruction sheet for a level flyover–Operation 14.

14. LEVEL FLYOVER - GT 100°

Altitude 300 feet AGL

Speed 100 knots

Heading ________

Run Initiation Time 1023

Rotor RPM 235

Torque 32 %

% N_1 85 – 8

Engine Exhaust Gas Temp 620 – 630

Indicated Air Speed 100

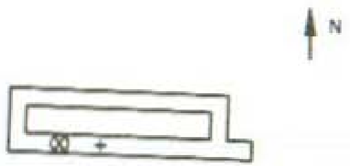
Fuel Weight 3650

Outside Air Temp 24 °C

Figure A2. Pilot's entries for level flyover.

16. IN-GROUND EFFECT HOVER

17. OUT-OF-GROUND EFFECT HOVER



A. MOVE 200 FT. ALONG RUNWAY FROM LANDING POINT, ⊗, TO PLUS SIGN, +

B. TOUCHDOWN WITH ENGINES ON

C. BEGIN IN-GROUND HOVER ON RADIO COMMAND

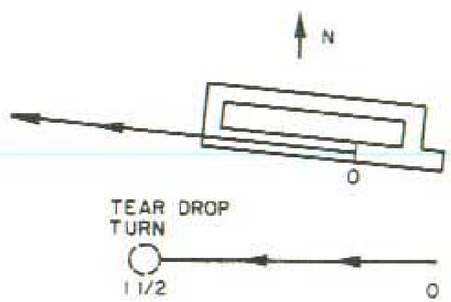
D. BEGIN OUT-OF-GROUND HOVER ON RADIO COMMAND

Figure A5. Instruction sheet for hovers–Operations 16 and 17.

	16. In-Ground Effect Hover	17. Out-of-Ground Effect Hover
Altitude	10'	50'
Heading	100	100
Rotor RPM	235	235
Torque	40 %	44 %
% N_1	87–86	88–87
Engine Exhaust Gas Temp	640–660	650–670
Fuel Weight	3400	3350
Time	1027	1030

Figure A6. Pilot's entries for hovers.

18. TAKE OFF
GT 280°



RADIO CALLS:

(1) "BEGIN TAKE-OFF MARK"

(2) AT 1/2 NAUTICAL MILES, "STARTING TURN"

Figure A7. Instruction sheet for takeoff–Operation 18.

18. TAKEOFF

Heading ____2____

Engine Exhaust Gas Temp ____630 – 660____

Fuel Weight ____3150____

Indicated Air Speed ____50____

Time ____1040____

Figure A8. Pilot's entries for takeoff.

APPENDIX B: HOVER DATA

Table B1
UH-1H Hover Data (dB)

Set	Heading (degrees)	Type	Microphone 1	11	3	12	13	14	5	15	2	6	4
1	100	IGE	73.2	69.6	80.2	71.4	70.2	–	73.9	71.5	85.6	75.4	62.6
1	100	OGE	87.3	87.4	81.3	77.0	76.2	–	86.4	87.1	91.6	88.7	71.1
2	50	IGE	77.7	72.6	75.9	76.1	80.6	77.1	77.8	77.0	79.3	80.9	71.7
2	50	OGE	81.9	79.5	79.9	80.4	81.5	80.5	84.5	80.1	83.9	82.8	75.0

Table B2
UH-60A Hover Data–Unloaded (dB)

Set	Heading (degrees)	Type	Microphone 1	11	3	12	13	14	5	15	2	6	4
3	95	IGE	78.1	–	70.7	75.0	77.4	74.7	77.8	74.3	81.2	81.1	70.7
3	95	OGE	82.9	–	79.4	80.3	82.5	77.8	86.8	82.7	83.1	88.3	75.4
4	280	IGE	76.7	76.2	75.7	77.6	76.0	78.0	76.8	79.1	81.1	80.9	72.2
4	280	OGE	76.3	80.7	78.3	80.1	83.8	81.4	83.5	79.4	81.6	81.2	74.0

Table B3
UH-60A Hover Data–Loaded (dB)

Set	Heading (degrees)	Type	Microphone 1	11	3	12	13	14	5	15	2	6	4
3	95	IGE	84.9	–	–	80.7	80.8	81.3	86.9	88.7	–	90.3	75.7
3	95	OGE	88.3	–	–	81.9	81.2	79.0	87.5	92.1	–	93.0	74.4
4	280	IGE	83.5	81.6	78.4	82.6	81.2	80.2	83.2	79.1	86.0	81.5	76.8
4	280	OGE	83.2	82.3	77.5	80.8	80.8	81.4	85.5	82.4	85.8	85.3	75.9

Table B4
CH-47C Hover Data (dB)

Set	Heading (degrees)	Type	Microphone 1	11	3	12	13	14	5	15	2	6	4
5	100	IGE	83.0	74.3	76.0	81.0	84.0	88.2	86.7	85.4	81.6	77.1	84.3
5	100	OGE	81.7	77.6	82.9	84.8	85.8	87.8	89.2	88.6	83.6	78.8	92.1
6	100	IGE	72.1	76.9	74.8	80.3	84.6	83.5	87.0	78.7	78.8	79.3	75.1
6	100	OGE	82.0	83.7	81.3	84.9	83.3	88.4	87.1	85.4	85.4	87.4	78.0

Table B5
Energy Averages of Fort Campbell Single-Rotor Aircraft by Degrees With Respect to the Aircraft (0° Is Front of Aircraft); Table B1 Through B3 Data

	Average	180	225	270	315	0	45	90	135
UH-1H									
IGE	76.7	75.5	75.3	77.9	74.2	74.1	80.6	75.8	75.1
OGE	83.4	85.0	85.5	80.5	78.7	78.8	81.5	84.4	86.0
UH-60A									
IGE	76.8	77.2	78.0	74.8	77.5	77.1	77.5	76.9	76.3
OGE	81.9	83.4	81.4	81.9	79.9	80.4	79.5	84.4	81.6
Loaded	84.0	85.5	82.0	78.0	81.6	81.0	80.6	86.1	88.2

Table B6
Difference From Average; Table B5 Data

	Average	180	225	270	315	0	45	90	135
UH-1H									
IGE	0.0	−1.2	−1.4	+1.2	−2.5	−2.6	+3.9	−0.9	−1.0
OGE	0.0	+1.6	+2.1	−2.9	−4.7	−4.6	−1.9	+1.0	+2.6
UH-60A									
IGE	0.0	+0.4	+1.2	−2.0	+0.7	+0.3	−1.3	+0.1	−0.5
OGE	0.0	+1.5	−0.5	0.0	−2.0	−1.5	−2.4	+2.5	−0.3
Loaded	0.0	+1.5	−2.0	−6.0	−2.4	−3.0	−3.4	+2.1	+4.2

Table B7
Weighted Average of Single-Rotor Aircraft Directivity Change

	Number of Aircraft	Average	180	225	270	315	0	45	90	135
Fort Rucker Data*	63	0.0	+0.9	+0.2	−1.3	−1.8	−2.0	−0.1	+1.1	+1.5
Fort Campbell Data**	12	0.0	+1.1	+2.5	−0.2	−2.5	−2.8	−1.9	−1.0	+1.4
Overall Average	75	0.0	+1.1	+2.2	−0.4	−2.4	−2.7	−1.6	−0.6	+1.4

*From p 39 of CERL Technical Report N-38.
**From Table B6.

Table B8
Energy Averages of Fort Campbell Dual-Rotor Aircraft by Degrees With Respect to the Aircraft (0° Is Front of Aircraft); Table B4 Data

	Average	180	225	270	315	0	45	90	135
CH-47C IGE	83.3	80.3	75.8	75.5	80.7	84.3	86.5	86.9	83.2
CH-47C OGE	85.6	81.9	81.6	82.2	84.9	84.7	88.1	88.3	87.3

Table B9
Difference From Average; Table B8 Data

	Average	180	225	270	315	0	45	90	135
CH-47C IGE	0.0	−3.0	−7.5	−7.8	−2.6	+1.0	+3.2	+3.6	−0.1
CH-47C OGE	0.0	−3.7	−4.0	−3.4	−0.7	−0.9	+2.5	+2.7	+1.7

Table B10
Weighted Average of Dual-Rotor Aircraft Directivity Change

	Number of Aircraft	Average	180	225	270	315	0	45	90	135
Fort Rucker Data*	4	0.0	−3.3	−5.4	−5.1	−1.5	+0.2	+2.9	+3.2	+0.9
Fort Campbell Data**	4	0.0	−1.1	−1.4	−2.0	−0.8	+0.1	+2.6	+1.6	−1.1
Overall Average	8	0.0	−2.1	−3.0	−3.3	−1.1	+0.2	+2.8	+2.5	0.0

*From CERL Technical Report N-38.
**From Table B9.

APPENDIX C:
DATA FOR FIGURES 8 THROUGH 22

Table C1
Variation of SEL With Distance at 100 Knots (Figures 8 and 9)

	100	200	300	500	1K	2K	3K	5K	10K	20K	30K	50K
UH-60A												
Unloaded	95.9	92.8	90.9	88.4	84.9	80.8	78.1	74.2	67.7	59.6	53.8	45.6
Loaded	94.5	91.5	89.5	87.1	83.5	79.6	76.9	73.1	66.8	58.8	53.2	45.2
Unloaded Landing	100.3	97.2	95.3	92.8	89.1	84.9	82.1	77.9	71.0	62.3	56.5	48.4
Loaded Landing	106.2	103.0	101.1	98.6	94.8	90.4	87.4	82.9	75.2	65.5	59.1	50.9
CH-47C												
300 ft	94.9	91.8	90.0	87.6	84.2	80.4	78.0	74.6	69.4	63.0	58.5	51.8
1000 ft	93.9	90.8	89.0	86.6	83.1	79.4	76.9	73.6	68.5	62.3	58.0	51.3
300 ft Landing	106.9	103.8	102.0	99.6	96.2	92.4	89.9	86.3	80.5	73.2	68.1	60.8

Table C2
Variation of SEL With Speed at 500 ft (Figures 10 Through 13)

	40	60	80	100	120	140
CH-47C						
300 ft.	94.8	92.1	89.8	87.6	88.1	90.9
1000 ft.			87.5	86.6	86.8	87.4
UH-1H						
300 ft.	91.5	88.9	89.6	90.9	96.3	
1000 ft.		87.4	87.5	88.8	94.1	
UH-60A						
Unloaded	87.1	87.2	87.7	88.4	89.3	90.3
Loaded	87.1	87.1	86.8	87.1		
Composite (Normalized to 100 Knots)						
CH-47C	7.7	5.0	0.0	0.4	2.4	
UH-1H	1.5	−1.8	−1.3	0.0	5.3	
UH-60A	−0.7	−0.6	−0.5	0.0	1.5	2.5

Table C3
Variation of L_{eq} With Speed at 500 ft (Figures 14 Through 17)

	40	60	80	100	120	140
CH-47C						
300 ft.	84.1	82.7	82.1	79.4	79.6	84.2
1000 ft.			80.6	81.3	81.6	78.9
UH-1H						
300 ft.	83.1	78.7	80.3	83.1	87.6	
1000 ft.		78.7	80.4	82.2	87.5	
UH-60A						
Unloaded	76.5	78.7	79.6	81.3	83.0	84.6
Loaded	76.6	77.9	78.9	80.4		
Composite (Normalized to 100 Knots)						
CH-47C	3.6	2.2	0.9	0.0	0.2	1.8
UH-1H	0.4	−4.0	−2.3	0.0	4.9	
UH-60A	−4.3	−2.6	−1.6	0.0	2.1	3.7

Table C4

Variation of SEL + 10 log (v/100 knots) With Speed at 500 ft (Figures 18 Through 21)

	40	60	80	100	120	140
CH-47C						
300 ft.	90.8	89.9	88.8	87.6	88.9	92.4
1000 ft.			86.5	86.6	87.6	88.9
UH-1H						
300 ft.	86.3	86.7	88.6	90.9	97.1	
1000 ft.		85.2	86.5	88.8	94.9	
UH-60A						
Unloaded	83.1	85.0	86.7	88.4	90.1	91.8
Loaded	83.1	84.9	85.8	87.1		
Composite (Normalized to 100 Knots)						
CH-47C	3.7	2.8	0.7	0.0	1.3	3.9
UH-1H	−3.7	−4.0	−2.3	0.0	6.1	
UH-60A	−4.7	−2.8	−1.5	0.0	2.3	4.0

Table C5

Difference of L_{eq} With Speed Versus SEL + 10 log (v/100 knots) With Speed at 500 ft (Figure 22)

	40	60	80	100	120	140
CH-47C	−0.1	−0.6	0.2	0.0	−1.1	−2.1
UH-1H	4.1	0.0	0.0	0.0	−1.2	
UH-60A	0.4	0.2	−0.1	0.0	−0.2	−0.3