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JAN 79 W J GALLOWAY F33615-76-C-0528
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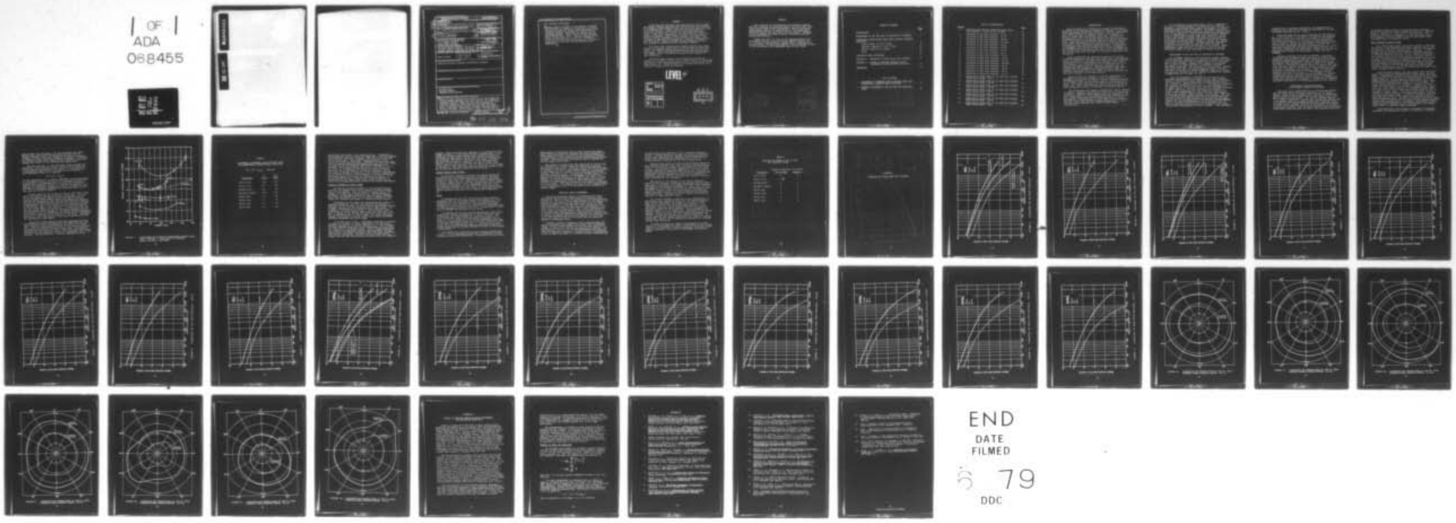

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Acoustical data obtained from helicopters in level flight and during 6 degree approaches are used to obtain the variation of A-weighted sound exposure level and effective perceived noise level with distance. These functions are normalized to a reference airspeed which differs for individual helicopter types. Sound level functions at airspeeds different from the reference airspeed, either higher or lower, are obtained by

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20. Abstract (continued)

adding a decibel increment to the reference functions. This increment is obtained by multiplying a constant, different for each helicopter, times the square of the difference between the airspeed of interest and the reference airspeed. These data are provided for the following aircraft: CH-3C, CH-47C, CH-54B, HH-53B/C, OH-6A, TH-55A, UH-1N, UH-13. Maximum A-weighted sound levels and perceived noise levels at a distance of 76 meters (250 feet) are also provided as a function of angle around the aircraft during stationary hover conditions.

SUMMARY

Acoustical data obtained from helicopters in level flight and during 6 degree approaches are used to obtain the variation of A-weighted sound exposure level and effective perceived noise level with distance. These functions are normalized to a reference airspeed which differs for individual helicopter types. Sound level functions at airspeeds different from the reference airspeed, either higher or lower, are obtained by adding a decibel increment to the reference functions. This increment is obtained by multiplying a constant, different for each helicopter, times the square of the difference between the airspeed of interest and the reference airspeed.

The sound level functions are computed without any consideration of "impulse adjustments" for the effect of blade slap noise. Recommended impulse adjustments are provided for each helicopter. These adjustments were derived from psychoacoustical judgment tests of recorded helicopter noise signals for each helicopter.

Acoustical data obtained for helicopters hovering at a height of 1.5 meters (5 feet) over a fixed location on the ground are used to obtain maximum A-weighted sound levels and perceived noise levels, at a fixed distance of 76 meters (250 feet), as a *function of* angle around the aircraft.

PREFACE

This research was performed for the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base, Ohio under Project/Task 723107, Technology to Define and Assess Environmental Quality of Noise From Air Force Operations. Technical monitor for this effort was Mr. Jerry D. Speakman of the Biodynamic Environment Branch, Biodynamics and Bioengineering Division.

Thanks are due H. C. True of the Systems Research and Development Service, Federal Aviation Administration, and E. J. Rickley, Transportation Systems Center, Department of Transportation, for providing magnetic tape recordings of most of the helicopter noise signatures used in this study.

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INTRODUCTION

Noise produced in a community as a result of helicopter operations is not generally a primary contribution to the total noise environment around USAF facilities. However, helicopters can be major sources of community noise in the vicinity of some U.S. Army, Navy, and Marine facilities. Further, the growing size of the civilian helicopter fleet has caused an increased interest in the general ability to predict helicopter noise. Many military helicopters have civil aircraft derivatives whose characteristics are identical to their military counterparts under equivalent operating modes. Incorporation of helicopter noise and performance data within the datafile for NOISEMAP would provide the ability to utilize NOISEMAP for DOD installations where helicopter noise may be significant as well as for joint civil/military use facilities and other civil facilities.

Major controversy has existed for years on the proper acoustical measures to describe helicopter noise, with emphasis on how to account for the subjective qualities of the impulsive characteristics of a helicopter noise signature when "blade slap" exists. With the exception of the need and form of an "impulse adjustment" there is essential agreement that the conventional time-integrated, frequency-weighted sound level measures such as A-weighted sound exposure level (SEL) and effective perceived noise level (EPNL) adequately describe the subjective response to helicopter noise.

Putting aside the question of "impulse adjustments" for the moment, a helicopter datafile can be incorporated in NOISEMAP utilizing SEL and EPNL in a manner completely parallel and consistent with the procedures used for conventional aircraft. This report describes the formulation of functions of sound level versus slant distance and the variation of source power levels as a function of aircraft operating condition.

The controversy over "impulse adjustments" cannot, however, be ignored. Numerous laboratory and field tests of subjective response to impulsive noise signals have been conducted in the past several years to derive psychoacoustical information for use in developing noise certification procedures for civil helicopters. Interpretation of these data is still equivocal with the result that proposed "impulse adjustments" to conventional noise measures such as SEL and EPNL remain controversial.

It is proposed in this report that, until a consensus on the form for such adjustments is achieved in the technical community, psychoacoustically judged "adjustments" for specific helicopters may be used as offsets to the normal sound level functions if the increased subjective response to impulse noise is to be accounted for. Not all helicopters produce impulsive noise of significant severity under most conditions; others produce very impulsive sounds under any operating condition. On the basis of the technical information now available an arbitrarily determined fixed constant to account for "impulse adjustment" is not warranted. Instead, specific adjustments in decibels are provided for each helicopter and mode of operation for which data are included in this report. These adjustments range from zero to 7 decibels, with 3 decibels being most typical if any adjustment is called for at all.

DEVELOPMENT OF SEL AND EPNL AS FUNCTIONS OF DISTANCE

The NOISEMAP community noise prediction program requires a noise data base consisting of functions of single event sound level versus distance from an observation point to the flight path of each aircraft, together with a means of specifying the variation of these functions for different aircraft operating conditions. The collected set of such data, together with noise level data for ground runup operations, for all aircraft of interest, is termed NOISEFILE. Data for 59 fixed wing military aircraft that now comprise NOISEFILE are reported in AMRL-TR-73-110, Volumes 1-6, ref. 1.

Data for development of NOISEFILE are acquired from systematic measurements and analysis of the noise characteristics of individual aircraft types obtained during controlled test conditions. Basic procedures for performing the tests are outlined in AMRL-TR-73-107, ref. 2. The analysis procedures for producing the sound level data files are implemented in the OMEGA series of acoustical data reduction programs developed at AMRL. Basically, the test procedures for aircraft in flight require measurements of the acoustical signature produced by the aircraft under a series of level over flights, at specified heights, power settings, and airspeeds. The USAF test procedure also requires that test site and weather conditions, as well as data acquisition and reduction equipment, comply with the specifications of the Federal Aviation Administration for noise certification of civil aircraft, ref. 3. Thus the measured acoustical data are compatible with noise certification measurements for civil aircraft. Data averaging, normalization to reference conditions, and extrapolation to distances other than test distances are performed by uniform procedures described in ref. 1 and 2.

Acoustical data for the fixed wing aircraft described in ref. 1 were acquired by the USAF in a series of test programs. Data have not yet been obtained by the USAF for helicopters. Acoustical measurements for a series of 8 helicopters have been obtained by FAA and the DOT Transportation Systems Center (TSC) as part of studies being performed to develop noise certification procedures for civil helicopters (ref. 4). These data were obtained with instrumentation and controlled test conditions consistent with those used by AMRL, and thus provide measured data suitable for development of input data for NOISEMAP.

Through cooperation from FAA and DOT/TSC, a suitably calibrated copy of magnetic tape recordings of various noise signatures produced by the different helicopters was obtained. The data included measurements below the flight path as the helicopters flew overhead at a nominal height of 150 meters (500 feet) at different airspeeds, and at 120 meters (400 feet) under different approach angles at approach speeds of 60 knots or 60 mph, depending on the aircraft. These recordings were analyzed in one-third octave frequency bands, in 0.5s time intervals, as specified in ref. 2. The results of these analyses were used in conjunction with the OMEGA 6.6 program to generate various sound level versus distance functions. Graphs depicting SEL and EPNL versus distance are provided for the various helicopters in Appendix A, normalized to reference conditions described in the following section of this report.

VARIATIONS OF HELICOPTER NOISE WITH AIRCRAFT OPERATING CONDITIONS

The basic noise characteristics of a fixed wing aircraft are controlled by the acoustical properties of its engine design. Under different engine power settings the acoustical power radiated by the aircraft will usually vary both in level and in spectral distribution. For jet and turbofan engines it is usually sufficient to assume that the spectral distribution of acoustical power at different engine power settings can be accounted for by assuming different spectral shapes for takeoff and other power settings, using as few as possible to describe a particular aircraft. Each of these spectra is used to generate sound level versus distance functions. The absolute sound level at different power settings is accounted for by shifting reference sound level versus distance functions by a specific amount of decibels as a function of slant distance. The reference functions are defined for a specific engine power and airspeed. In the NOISEMAP system the adjustment factor *for engine power* is symbolized as Δ"6.

SPEED EFFECTS IN LEVEL FLIGHT

For a fixed engine power and distance between flight path and observer, time integrated acoustical measures such as SEL and EPNL will vary with aircraft speed. That is, the duration of the event is directly proportional to airspeed. In the NOISEMAP system differences in aircraft operating speed and a reference speed are accounted for by a decibel adjustment to the reference sound level versus distance functions equal to 10 times the logarithm of the reference airspeed to the actual airspeed. This adjustment is symbolized as Δ'6. Thus the noise produced on the ground by fixed wing aircraft in flight are described by an appropriate sound level versus distance function, offset by Δ'6 for any deviation in airspeed from reference conditions and by Δ"6 for differences in engine power from a reference power condition.

In an analogous fashion, one would expect that helicopter noise should vary with operating mode, engine power, and airspeed. A fundamental difference between helicopters and fixed wing aircraft is the ability of the helicopter to sustain level flight from zero, or even negative forward speed, up to its maximum airspeed, whereas the fixed wing aircraft has a relatively narrow airspeed range available in level flight. For fixed wing aircraft where an increase in airspeed in level flight is proportional to an increase in engine power (thrust), over most of the useful portion of its operating speed range, the sound level in level flight will increase directly with an increase in engine power. In contrast, helicopters utilize a tradeoff in direct vertical lift and forward speed to operate over their wide speed range. In order to operate at very low airspeeds or at hover, a helicopter uses more power than at some intermediate speed. As speed is increased above this intermediate speed increased power is required until maximum speed is reached with *maximum power*. Accordingly, helicopters in level flight produce a minimum level at some airspeed, with higher sound levels at lower and higher airspeeds.

Considering only level flight at reasonable (non-hover) airspeeds, and ignoring any effects of variation in aircraft gross weight, one can expect, for any particular helicopter design, that engine power and resulting airspeed will be uniquely related. With this assumption it should be possible to develop a single operating condition adjustment, in decibels, for reference sound level versus distance functions that would combine the effects of both airspeed and engine power.

The data from ref. 4, and other data in Bolt Beranek and Newman Inc. files have been used to develop $\Delta 6$ functions for the helicopters considered in this report. It was found that a generalized format for $\Delta 6$ in decibels could be applied to each helicopter, where $\Delta 6$ is given by

$$\Delta 6 = a(V - V_{ref})^2 .$$

In this expression a is a constant dependent on each helicopter, V is airspeed in knots, and V_{ref} is the airspeed in knots for minimum noise, also variable with the particular helicopter. Data for the variation of EPNL as a function of airspeed at a distance of 150 meters overhead are plotted in Figure 1, along with the $\Delta 6$ adjustments calculated by using the values for a V_{ref} that are listed in Table 1.

In most cases the fit of the $\Delta 6$ curves to the data is very good, with that for the UH-13 being the worst case. For most of the helicopters the measured levels are matched over the entire airspeed range usually within less than one decibel. Although the $\Delta 6$ equations were derived from EPNL data, examination of the difference between EPNL and SEL values at different airspeeds shows that these differences are essentially constant at 150 meters. Thus it is proposed that the $\Delta 6$ adjustment be used for either EPNL or SEL functions. It should be noted that the same values cannot be used for acoustical measures that do not incorporate time integration, for example maximum A-weighted sound level, since the formulation for $\Delta 6$ given here incorporates the effect of airspeed on the duration of the event. Adjustment factors for level only measures could also be derived, but are not considered in this report.

Sound level versus distance functions developed for fixed wing aircraft at positions underneath the flight path are also used to predict noise at positions to the side of the flight path. This use assumes that the sound field around the aircraft is symmetrical around the aircraft flight path. Helicopters, particularly those with tail rotors, have acoustical directivity patterns that are asymmetric around the longitudinal axis of the aircraft. The data from ref. 4 allow an examination of how

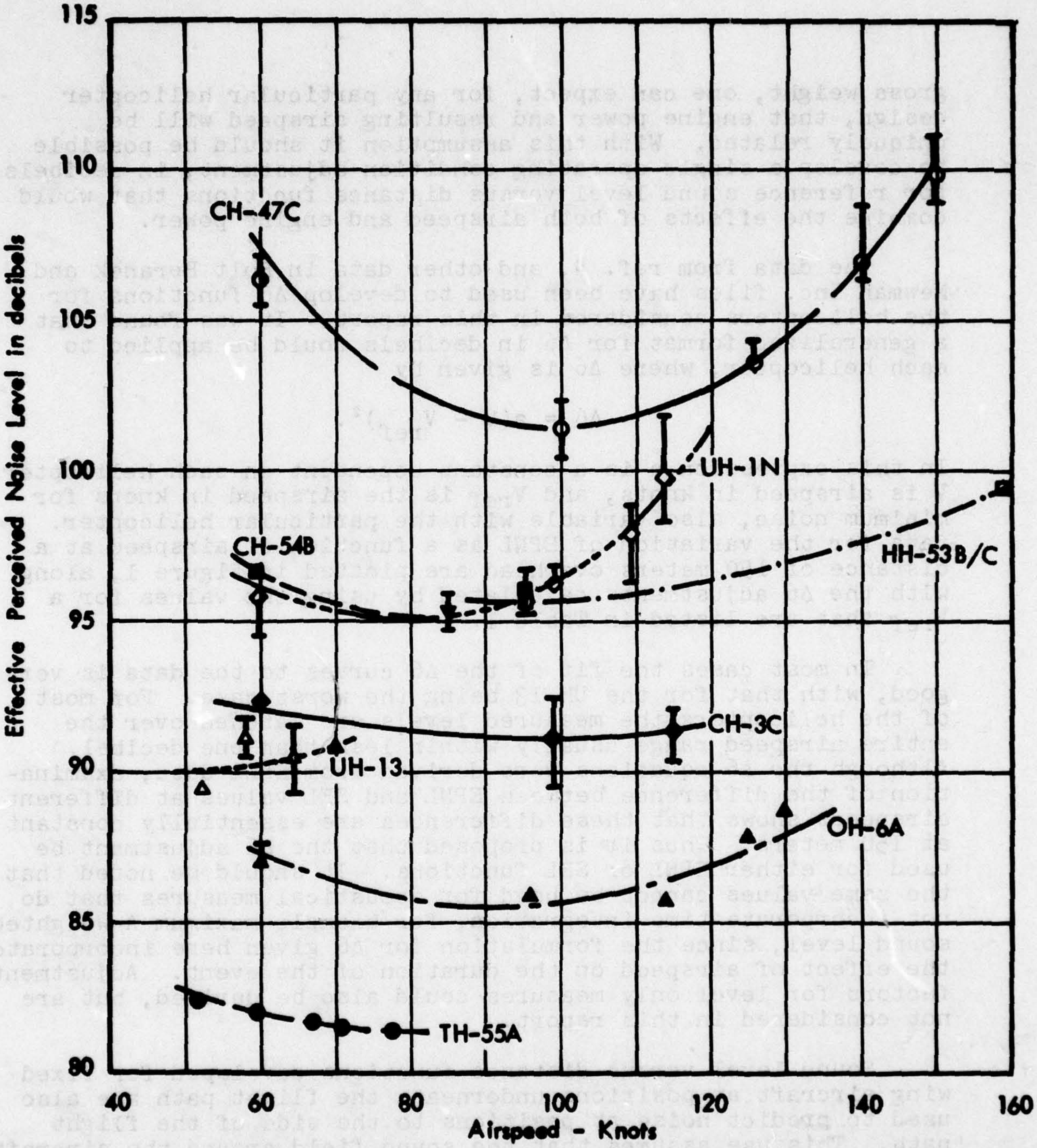

FIGURE 1. VARIATION OF EFFECTIVE PERCEIVED NOISE LEVEL WITH AIRSPEED - 150M (500 FT) FLYOVER
[Data from Ref.4 and BBN]

TABLE 1

ADJUSTMENT TO REFERENCE SOUND EXPOSURE LEVEL FOR NONREFERENCE AIRSPEED/POWER CONDITIONS

$$\Delta 6 = a(V - V_{ref})^2 \text{ decibels}$$

Helicopter	a $x10^{-3}$	V_{ref} knots
CH-3C (S-61)	0.63	100
CH-47C (114)	3.4	100
CH-54B (S-64)	3.8	80
HH-53 B/C (S65A)	0.83	100
OH-6A (500)	2.2	90
TH-55A (300)	1.7	80
UH-1N (212)	4.1	80
UH-13 (47G)	2.5	50

significant this effect is on sideline noise. In addition to the microphones directly under the flight path, other microphones were placed at positions 150 meters (500 feet) on either side of the flight path. Test flights included passes in both directions along the centerline. Comparison of acoustical data from the opposite sideline microphone positions allow the effects of asymmetry in the helicopter directivity patterns to be assessed. While some effects were noted in the data of ref. 4, the effect on integrated sound levels on opposite sideline positions was of the order of one decibel, typically within the normal experimental variation in the acoustical measurements. On this basis it does not seem warranted to derive asymmetrical adjustment factors to account for directivity effects. It is our recommendation that sideline noise from helicopters be predicted from the sound level versus distance functions derived from overhead measurements without any further adjustments.

APPROACH COMPARED TO LEVEL FLIGHT

Differences in spectrum shape of noise produced during approach, as compared with level flight at the same airspeed, occur in helicopters. Part of these differences result from changes in "blade slap" characteristics. During approach a helicopter is descending through its own main rotor downwash. Even those helicopters that do not exhibit bladeslap in level flight will produce some degree of bladeslap during descent.

Postponing for the moment the psychoacoustical effects of impulses themselves, the fact that impulses are produced is reflected in the customary one-third octave sound pressure level analyses, and thus in the calculated SEL or EPNL values. For a number of helicopters the effect of these spectral level differences on SEL or EPNL is small, with the result that the rate of change of SEL or EPNL with distance is the same as the SEL or EPNL functions for level flight. For others the shape changes sufficiently to warrent sound level versus difference functions different from level flight.

In the FAA tests of ref. 4 approaches were made at constant airspeed of 60 knots or 60 mph, depending on the aircraft's airspeed calibration, at descent angles of 3, 6, and 9 degrees. The data indicate relatively little differences in sound level as a function of the descent angle. Since 6 degrees approaches are likely to be adopted by FAA and internationally for helicopter noise certification purposes, data from these approaches were used in this study. The test data were again used to compute SEL and EPNL versus distance functions with the OMEGA 6.6

program. These functions were compared to the appropriate level flight functions. An arbitrary decision was made that, if the difference in sound level between level flight and approach conditions at 3000 meters (10,000 feet) was less than one decibel different from that at 150 meters (500 feet), a separate approach function was not required. If the difference was greater than one decibel, separate functions of sound level versus distance were retained. This is reflected in the figures of Appendix A. Note that for some helicopters an approach curve may be required for SEL or EPNL but not the other.

TAKEOFF VERSUS LEVEL FLIGHT

No data were obtained by FAA/TSC for takeoff operations. Acoustical data for various helicopter operations have been obtained by the Construction Engineering Research Laboratory of the U.S. Army (ref. 5). Data in this report indicate little difference between takeoff and level flight noise for a variety of military helicopters. It is recommended here that until more data are available that the USAF utilize the sound level versus distance curves for level flight in computing noise from takeoff operations adjusted for the appropriate airspeed by $\Delta 6$.

HOVER

A complete data file for fixed wing aircraft includes acoustical data for stationary ground runup operations. This information is used for actual runups, or transition from a standing start in a takeoff roll. The analogous helicopter operation is a hover in which the helicopter is stationary, but is supported above ground by rotor lift. Incorporation of hover data in NOISEMAP was explored in this study.

In addition to the level flyover and approach noise tests conducted by FAA/TSC, measurements of sound level were made during hover at a wheel height of 1.5 meters (5 feet). For most of the hover tests the sound levels fluctuated over a range of 5 to 10 decibels in a 19 second measurement interval. Acoustical measurements during hover were also obtained by CERL in the Army tests described in ref. 5. Fluctuation in sound levels up to 10 decibels were again observed and attributed to either variability in aircraft position in hover or fluctuations in wind speed.

The variability in acoustical data obtained during hover in ref. 4 or 5 is partially attributed to variability in wind conditions during the measurements. Experience with acoustical measurements of helicopter noise by Bolt Beranek and Newman under calm wind conditions indicates that this variability in sound levels will still occur due to the piloting difficulty in maintaining a fixed position without altering the helicopter controls. Such sound level fluctuations may be regarded as typical rather than unusual.

The purpose of sound level data specified for use in land use planning is to provide means for predicting long term mean-square sound levels. A suitable source specification can be derived by taking the mean-square average of a fixed ensemble of measurements as an estimate of the long term mean-square average. The data in ref. 5 provide two separate sets of data, each containing 38 samples, at increments of 45 degrees in azimuth, at a fixed distance of 76 meters (250 feet). The 76 samples of sound level obtained at each angular position were averaged on a mean-square basis to define the source sound levels for hover conditions provided in the figures of Appendix A of this report. All figures are plotted with 0 degrees being on the longitudinal axis of the aircraft in the direction of forward flight.

IMPULSIVE NOISE ADJUSTMENTS

The psychoacoustical effects of bladeslap noise from helicopters has received a great amount of attention internationally. While a number of publications have addressed this subject over the years, accelerated interest in the response to helicopter impulsive noise has taken place since 1974 when serious discussion of international noise certification for civil helicopters began to take place in the Committee on Aircraft Noise of the International Civil Aviation Organization. At the same time Working Group 2 (WG2) on Aircraft Noise of the International Standardisation Organization's Subcommittee on Noise of Technical Committee 43-Acoustics were asked by ICAO to propose an appropriate acoustical measure for helicopter noise, including the ability to account for the subjective response to impulsive noise.

Numerous studies of impulsive noise using simulated and actual helicopter noise signals have taken place in England, France, and the United States over the last four years in an attempt to arrive at a suitable psychoacoustical measure. The preponderance, but not all, of the experimental data indicate that the subjective response to impulsive noise is understated by SEL or EPNL by as much as 6 or more decibels, depending upon the particular noise signature, with 3 decibels being most typical. Several methods to measure the physical differences in the noise signatures that generate these psychoacoustical effects have been proposed, including one from ISO that is being evaluated in mid-1978 by the ICAO working group.

Unfortunately, while the ISO or other proposed impulsiveness measures correlate quite well with some psychoacoustical tests, the correlation between these measures and other tests is poor. This situation leads opponents to the use of impulsiveness measures to argue that EPNL or SEL are sufficient to characterize helicopter noise, with advocates of impulsiveness adjustments equally adamant that their use is supported by sufficient data and that the non-supportive data are inconclusive, insufficient, or inaccurate.

The opinion of the author of this report, based on a review of the available literature and psychoacoustical judgment tests of a variety of recorded helicopter noise signatures performed at Bolt Beranek and Newman Inc. (ref. 6,7), is that the response to helicopter blade slap is underestimated by SEL and EPNL. Further, either the ISO proposal or similar proposals reasonably predict the judged acceptability of actual helicopter noise, although they do not predict acceptability very well for <u>all</u> impulsive noises.

If a better estimate is desired of the acceptability of helicopter noise containing blade slap than that provided by SEL or EPNL, adjustments in decibels to be added to SEL or EPNL can be derived from the judged data from ref. 6, in combination with the calculated ISO adjustments for those helicopter operations where judgments are not available but physical analyses of the signals are. Such adjustments are listed in Table 2 for the helicopters considered in this report. Separate values are given for level flight and approach conditions. No data are available for takeoff operations. It is not expected that impulse adjustments will apply to takeoff operations, however, since bladeslap is generally not produced during climb operations.

In order to assist the reader in assessing the current status for rating impulsive noise a brief review of the current status, as of mid-1978, of impulse adjustment proposals is provided in Appendix B along with a bibliography of pertinent papers.

TABLE 2

PROPOSED ADJUSTMENT TO SEL OR EPNL FOR IMPULSIVE NOISE

	Impulse Adjustment in Decibels	
Helicopter	**Level Flight**	**Approach**
CH-3C (S-61)	0	3
CH-47C (114)	$2 + \frac{\Delta 6}{2}$	5
CH-54B (S-64)	1	2
HH-53B/C (S-65A)	0	3
OH-6A (500)	0	1
TH-55A (300)	0	1
UH-1N (212)	3	3
UH-13 (47G)	0	3

APPENDIX A

VARIATION OF SOUND LEVEL WITH DISTANCE

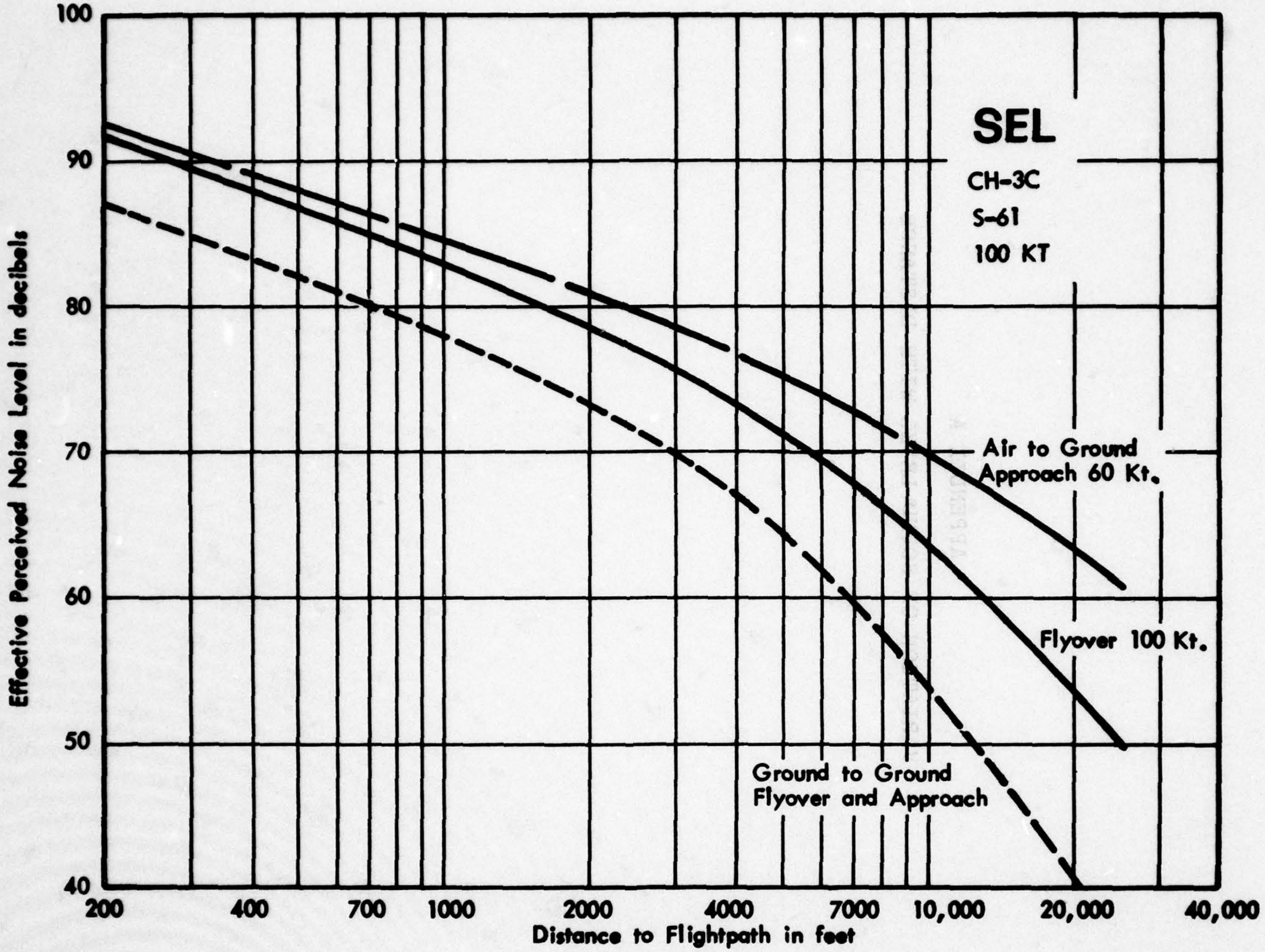

FIGURE 2. VARIATION OF SEL WITH DISTANCE - CH-3C

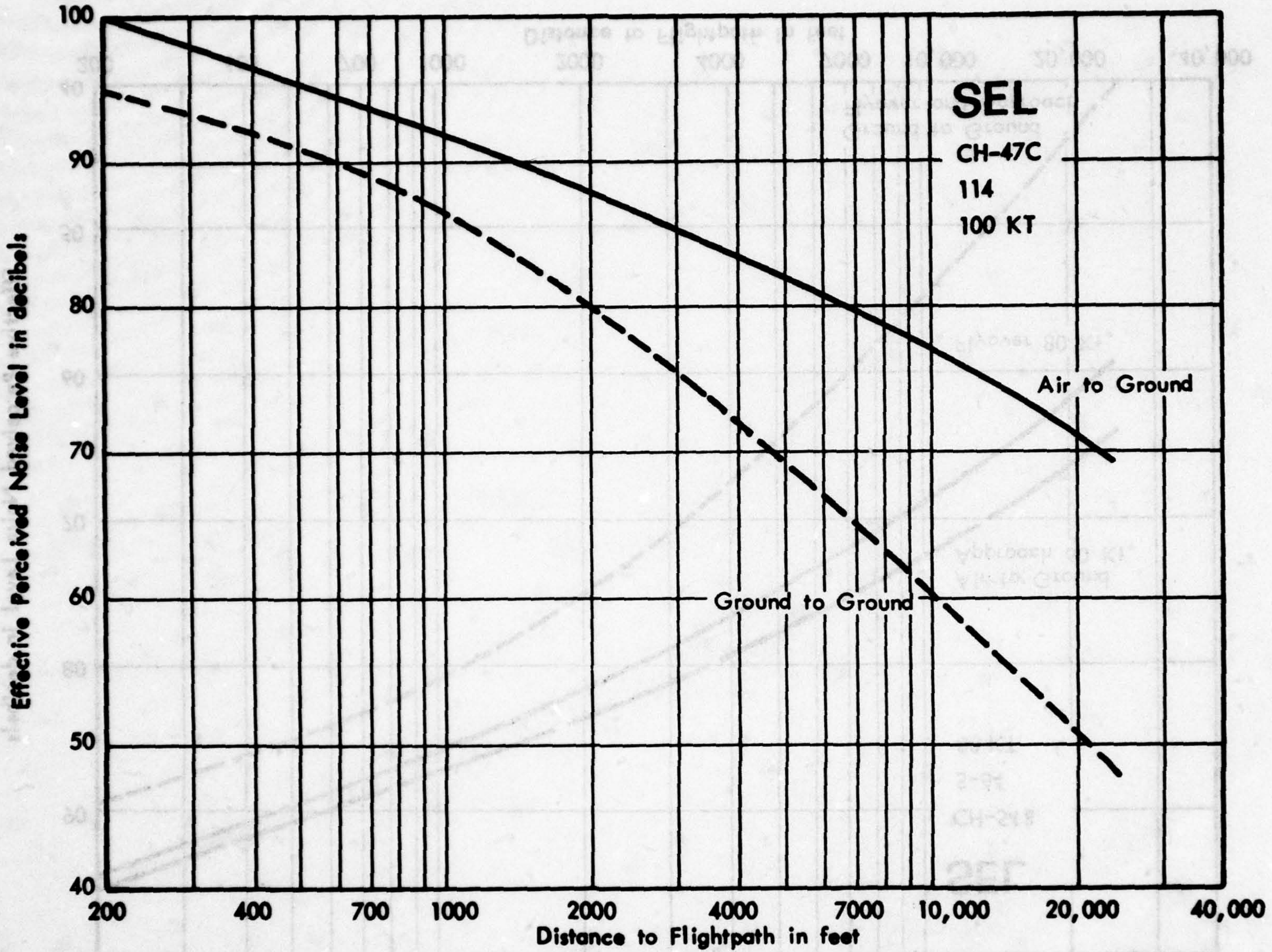

FIGURE 3. VARIATION OF SEL WITH DISTANCE - CH-47C

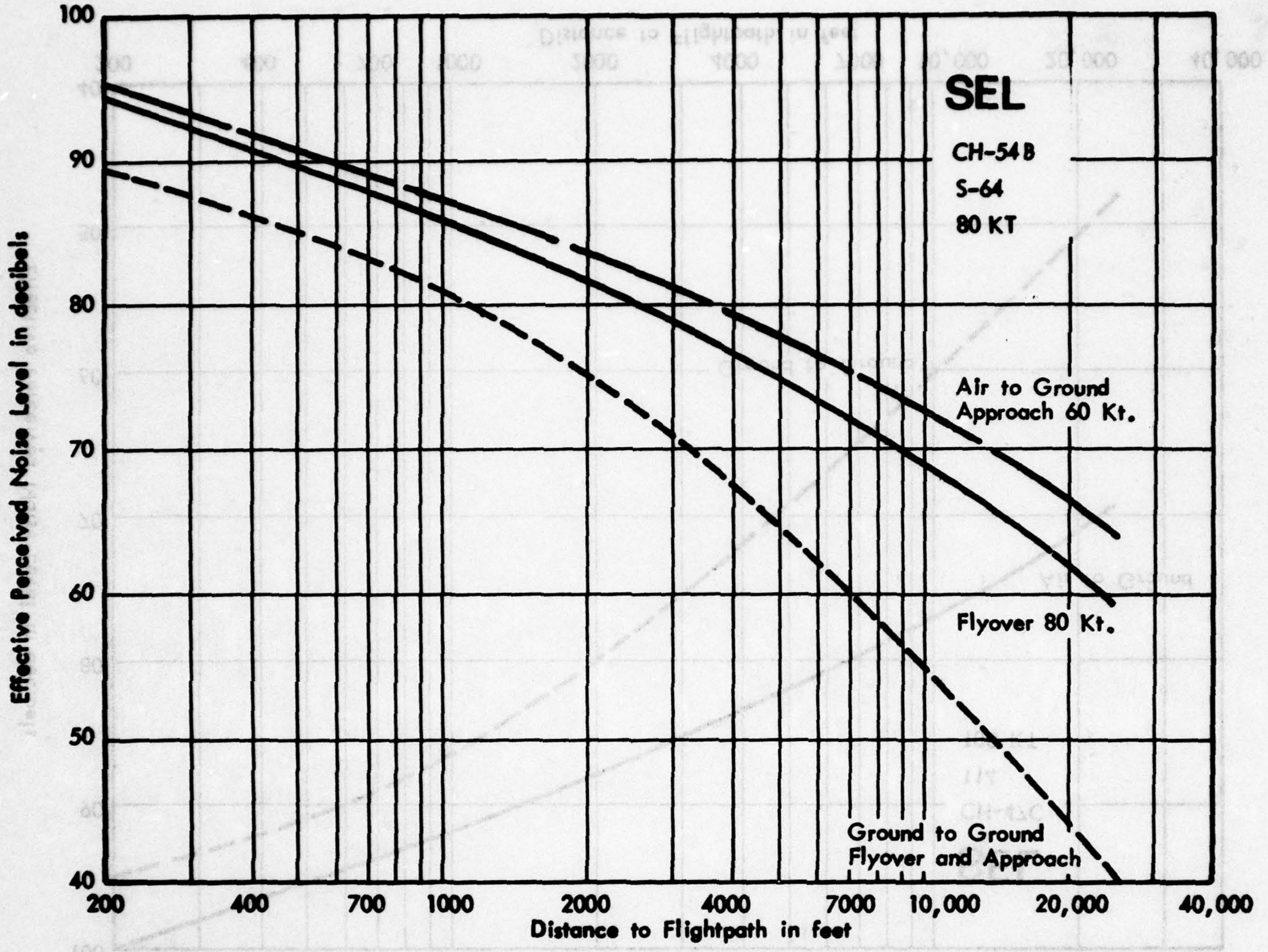

FIGURE 4. VARIATION OF SEL WITH DISTANCE - CH-54B

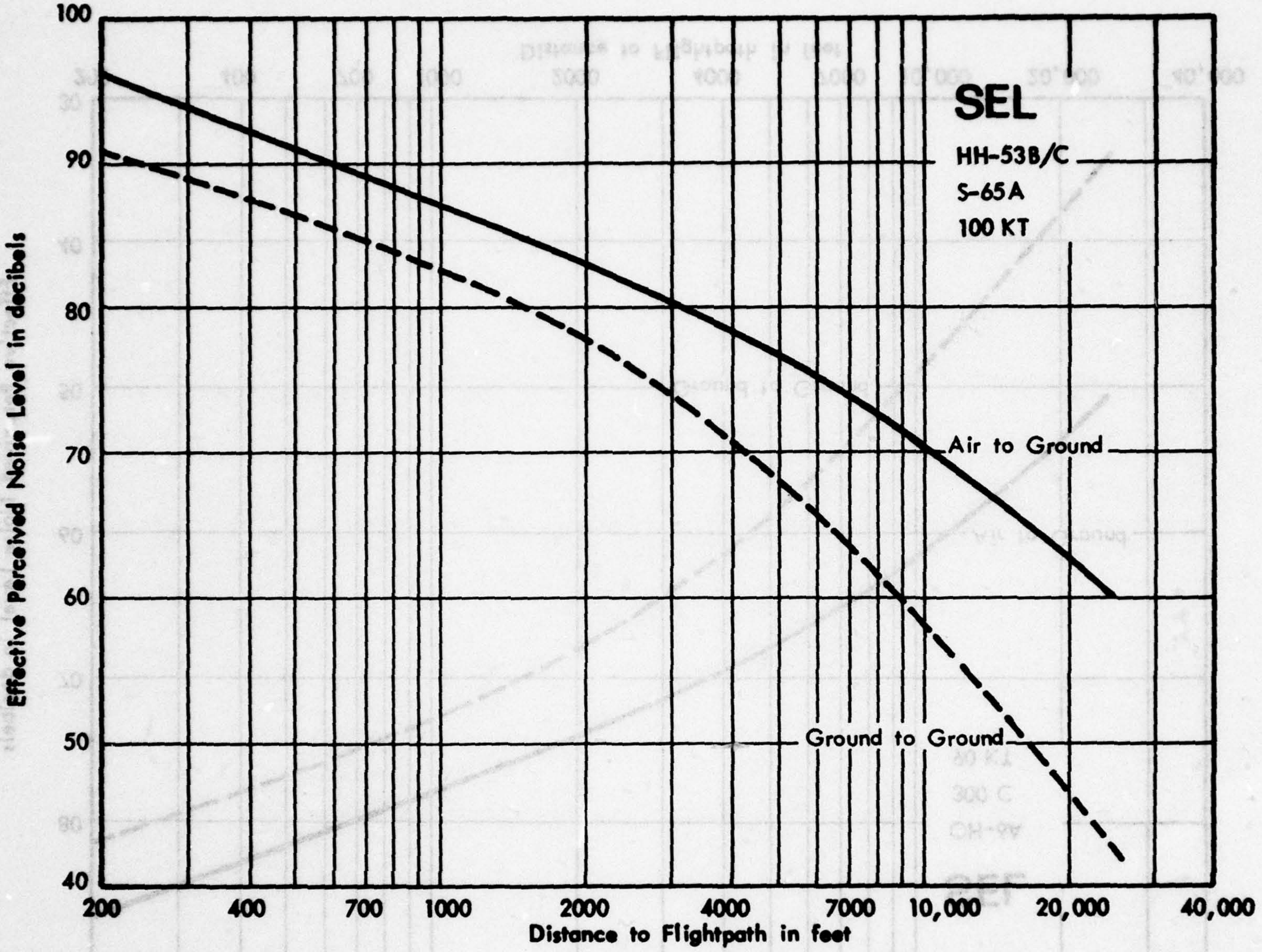

FIGURE 5. VARIATION OF SEL WITH DISTANCE - HH-53B/C

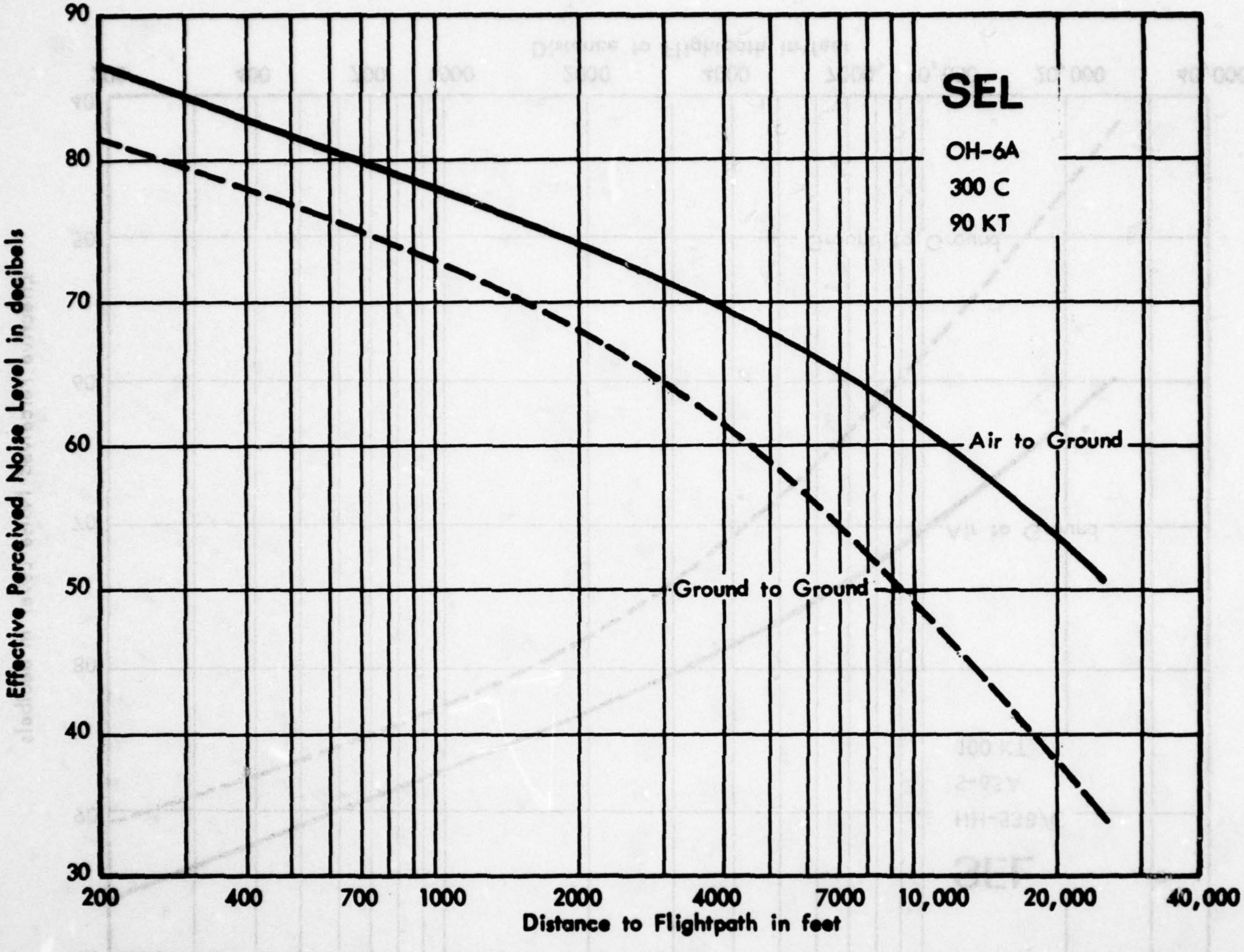

FIGURE 6. VARIATION OF SEL WITH DISTANCE - OH-6A

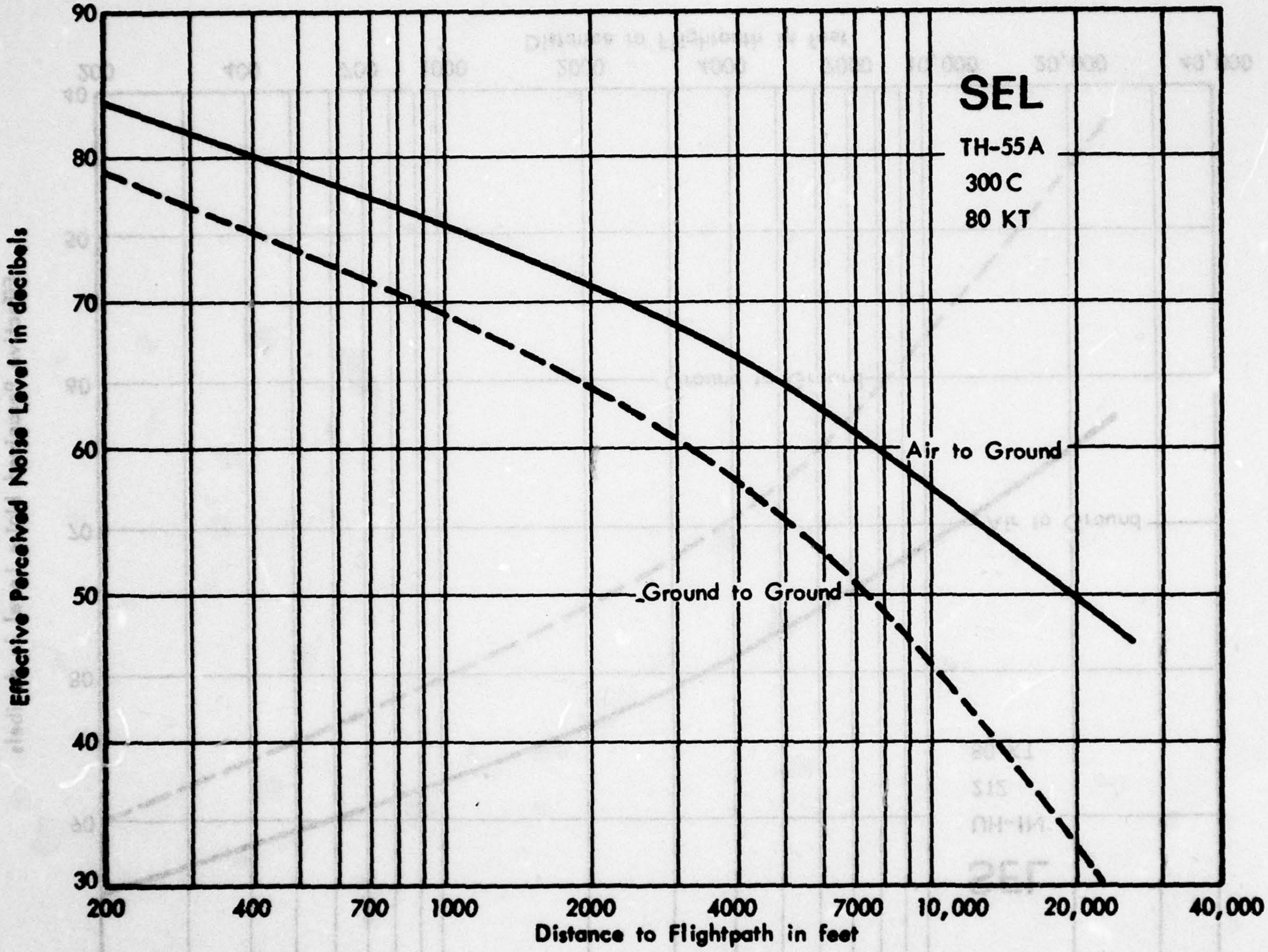

FIGURE 7. VARIATION OF SEL WITH DISTANCE - TH-55A

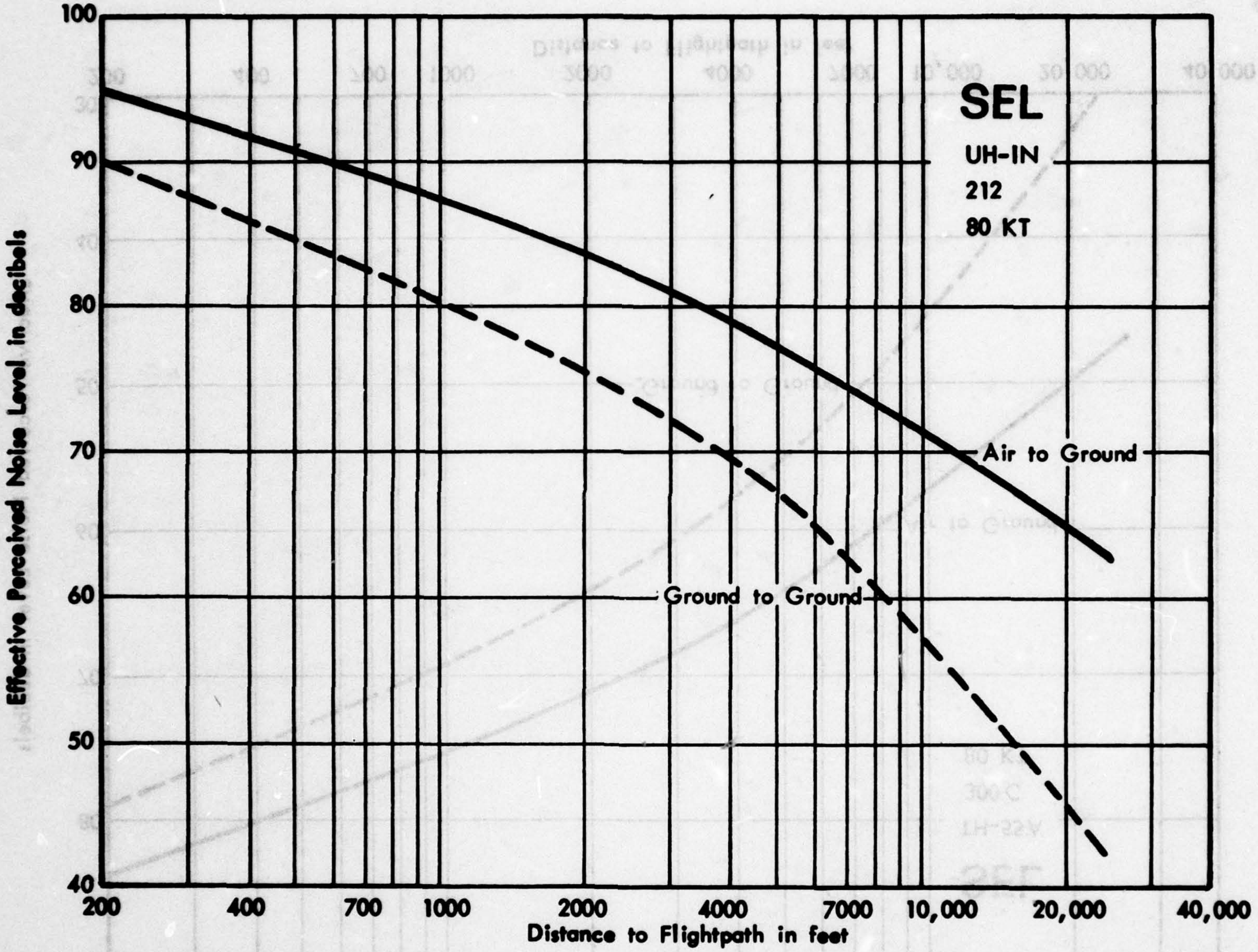

FIGURE 8. VARIATION OF SEL WITH DISTANCE - UH-IN

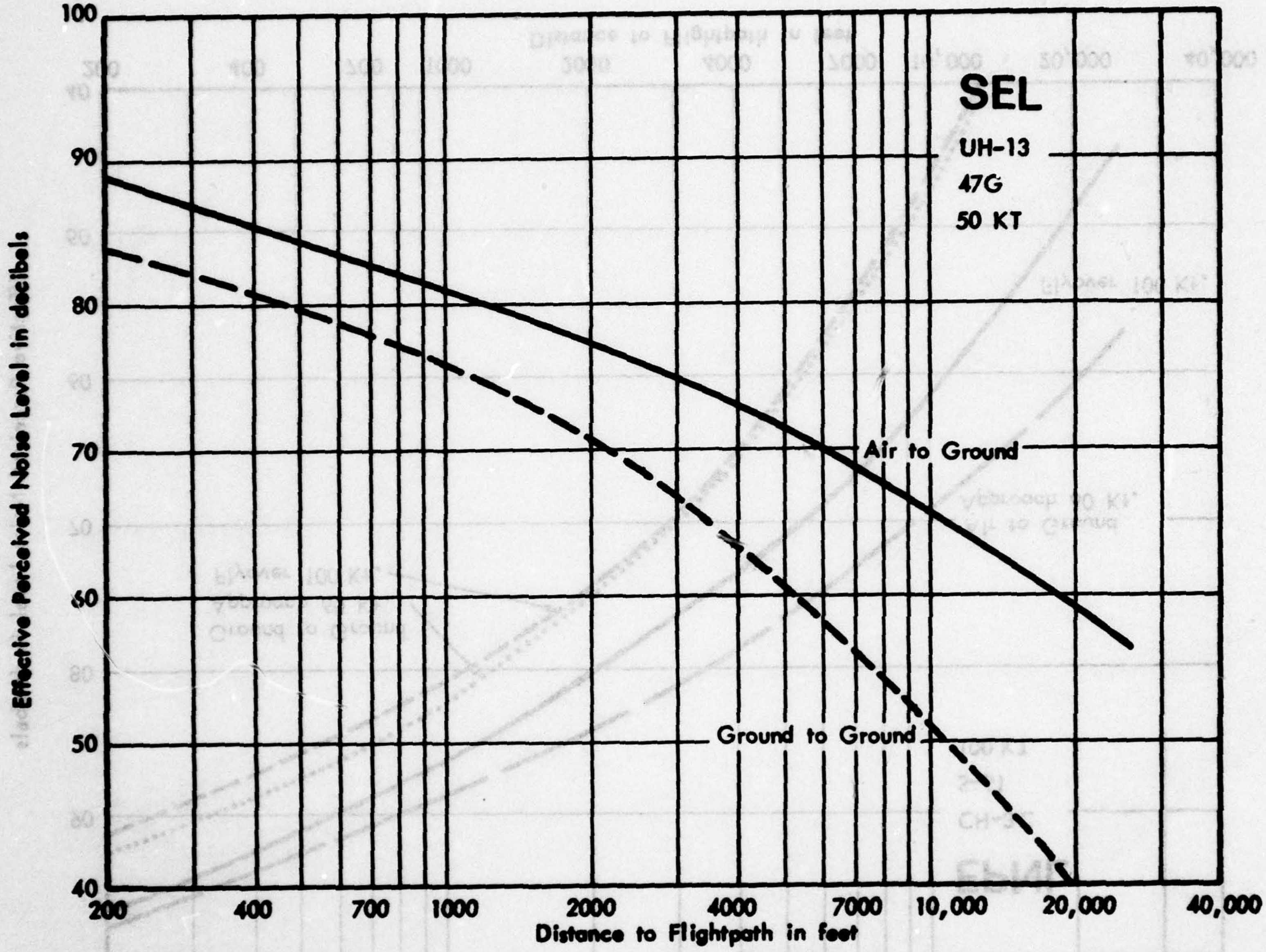

FIGURE 9. VARIATION OF SEL WITH DISTANCE - UH-13

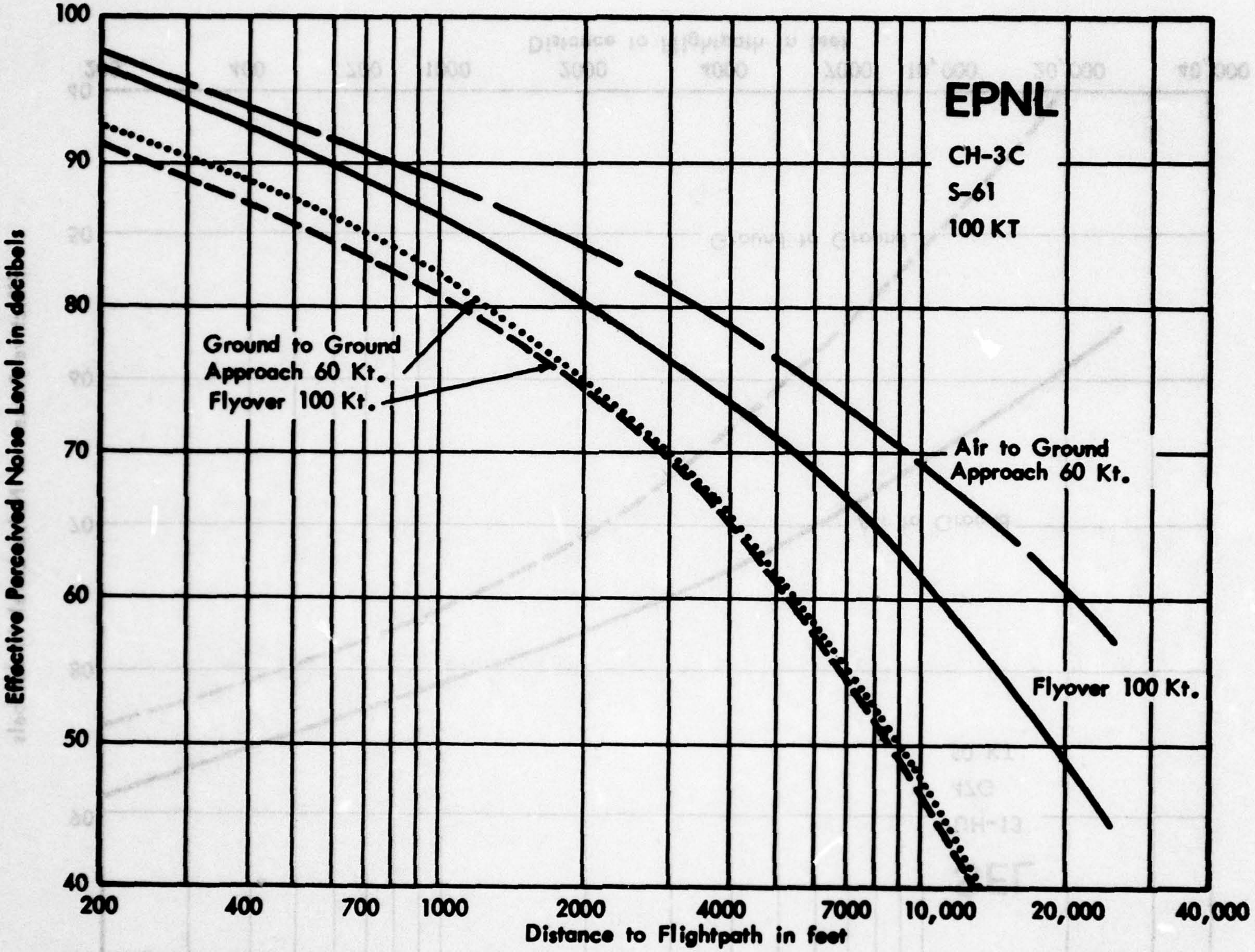

FIGURE 10. VARIATION OF EPNL WITH DISTANCE - CH-3C

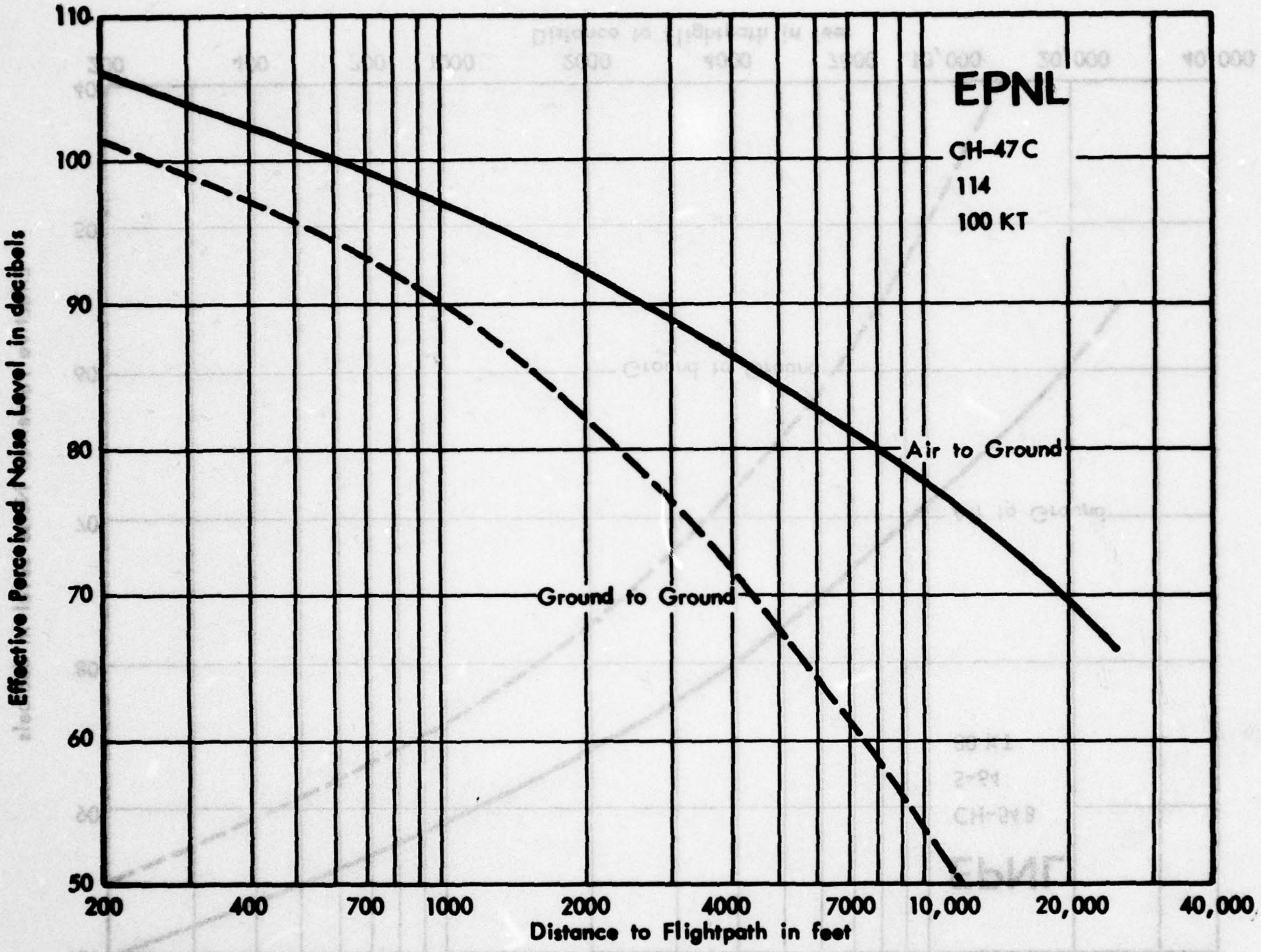

FIGURE 11. VARIATION OF EPNL WITH DISTANCE - CH-47C

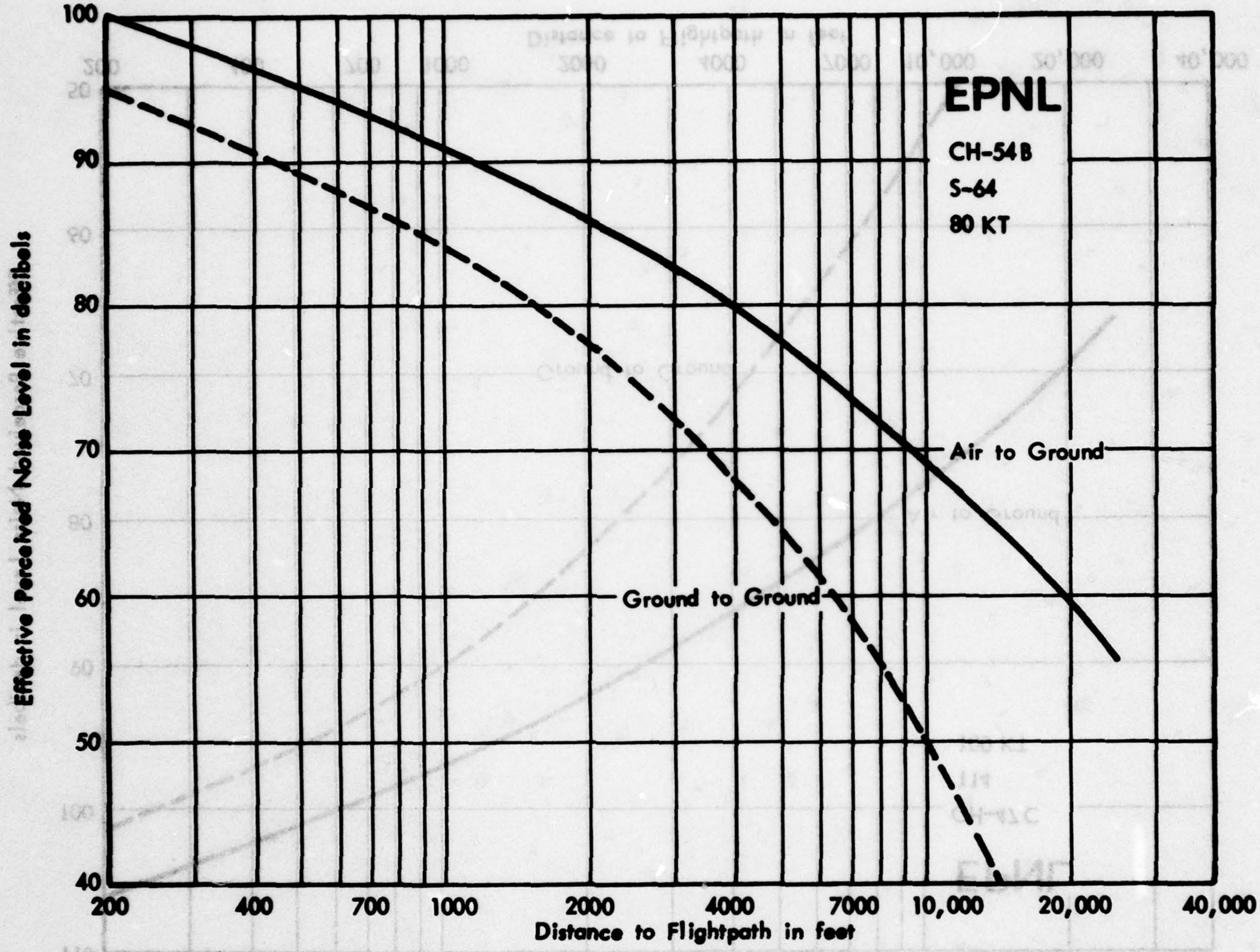

FIGURE 12. VARIATION OF EPNL WITH DISTANCE - CH-54B

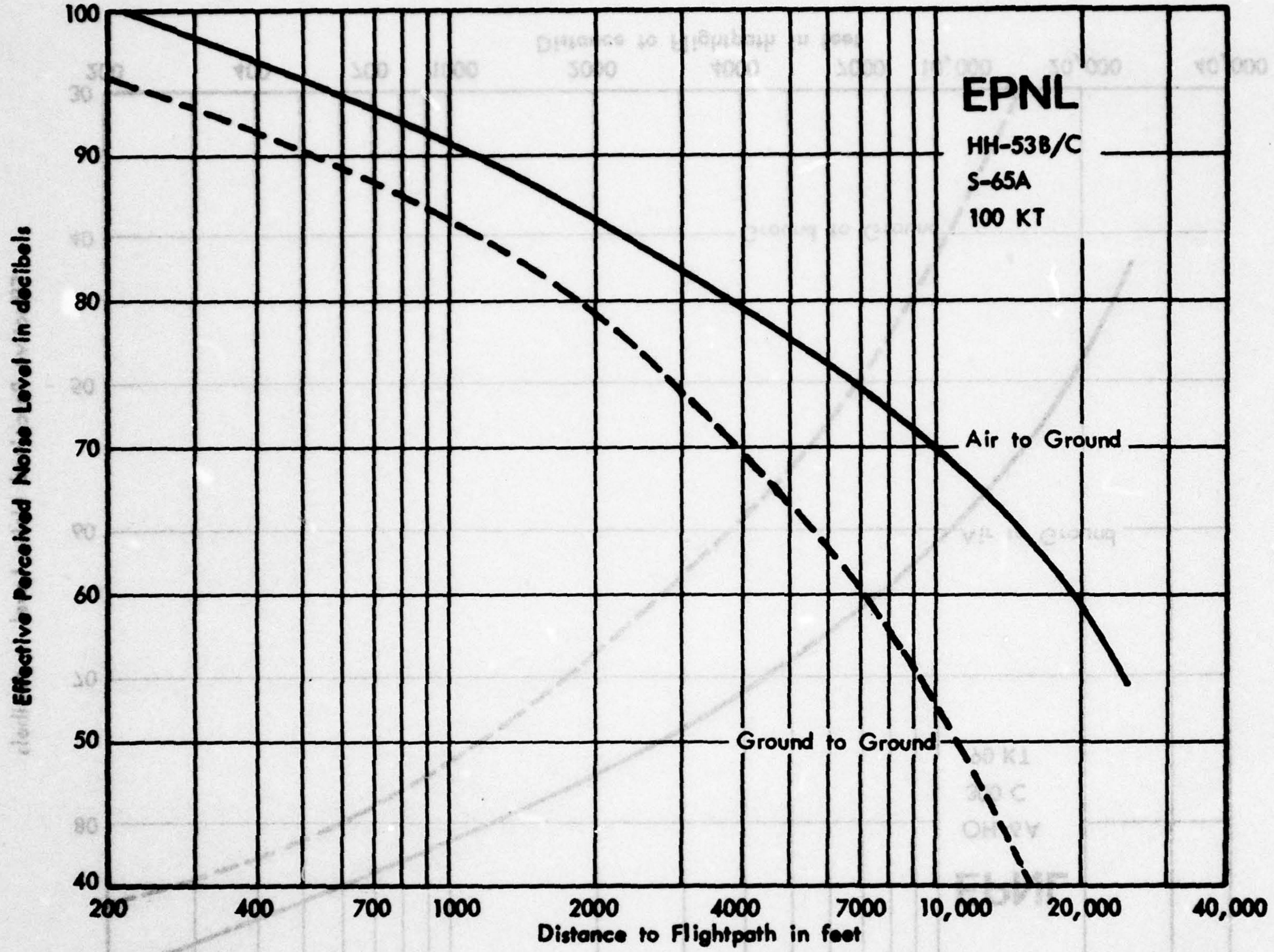

FIGURE 13. VARIATION OF EPNL WITH DISTANCE - HH-53B/C

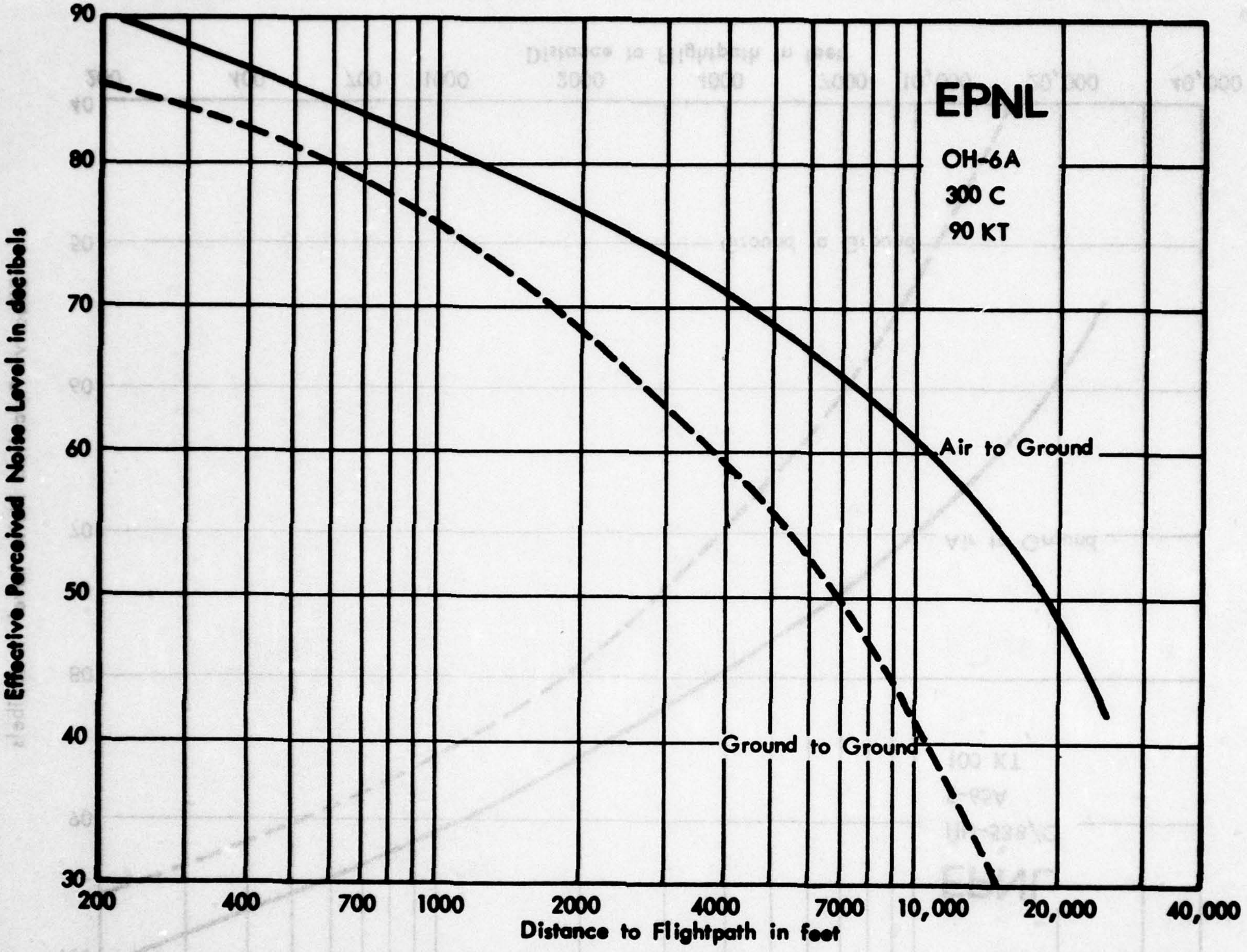

FIGURE 14. VARIATION OF EPNL WITH DISTANCE - OH-6A

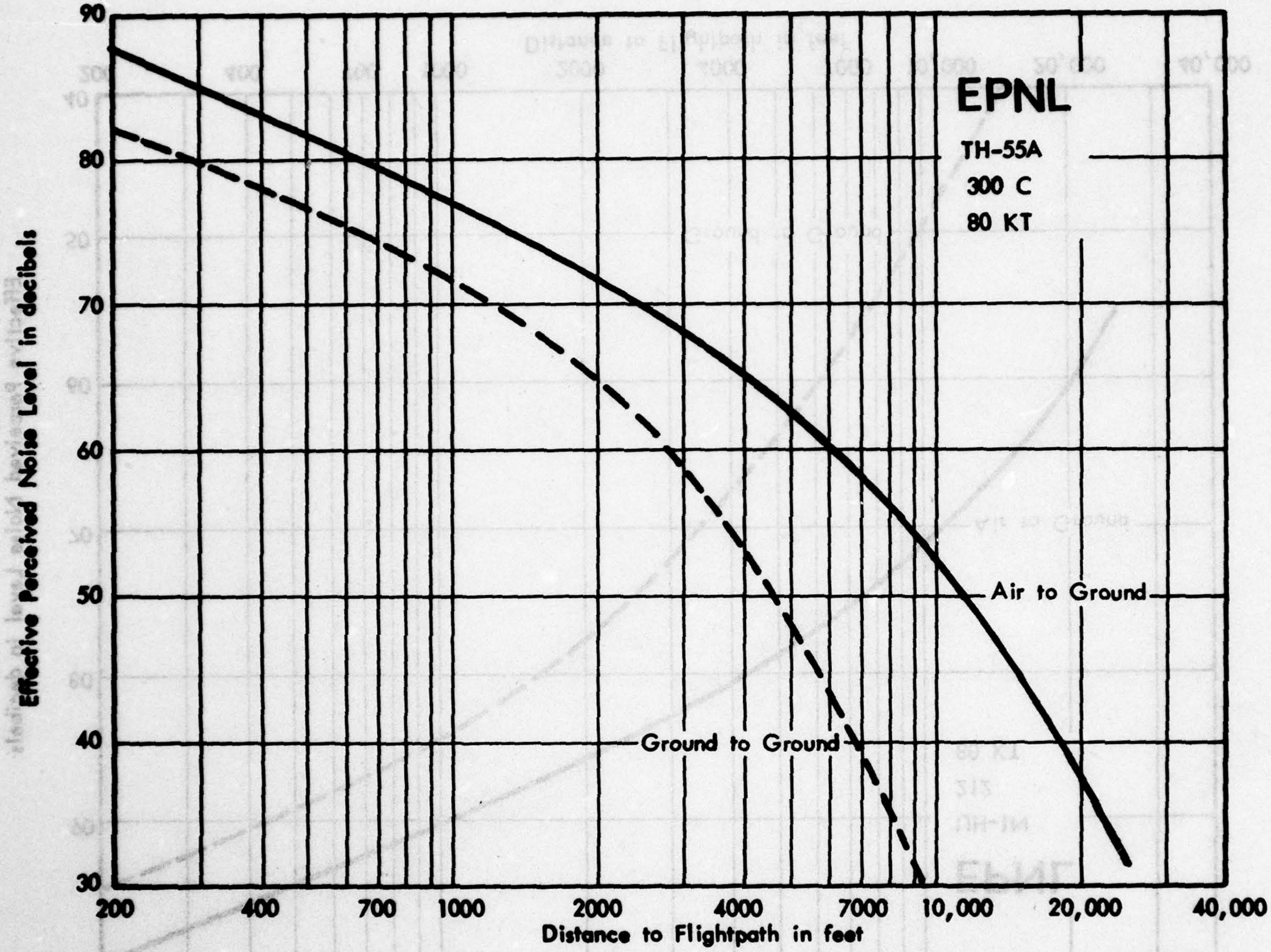

FIGURE 15. VARIATION OF EPNL WITH DISTANCE - TH-55A

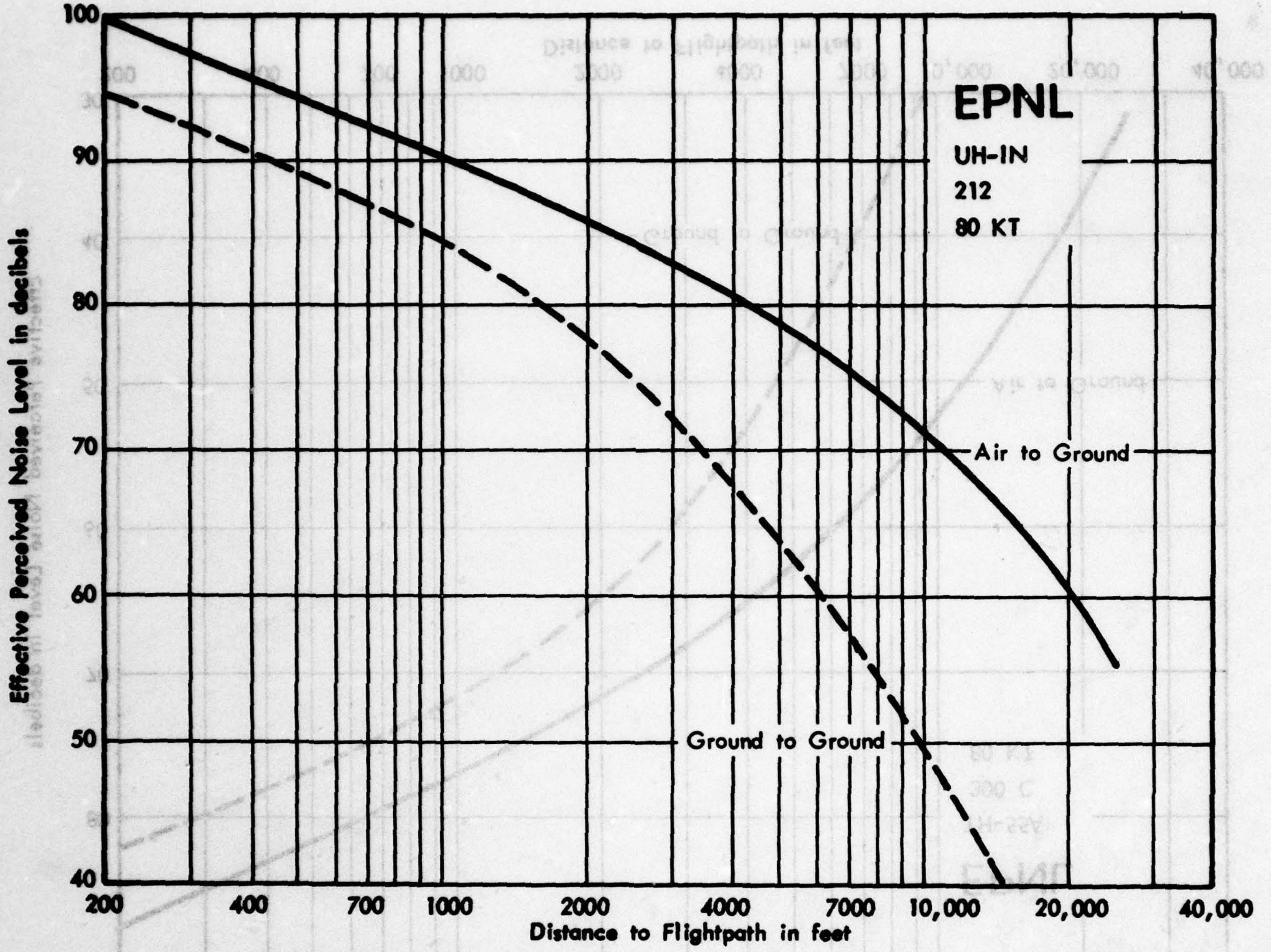

FIGURE 16. VARIATION OF EPNL WITH DISTANCE - UH-IN

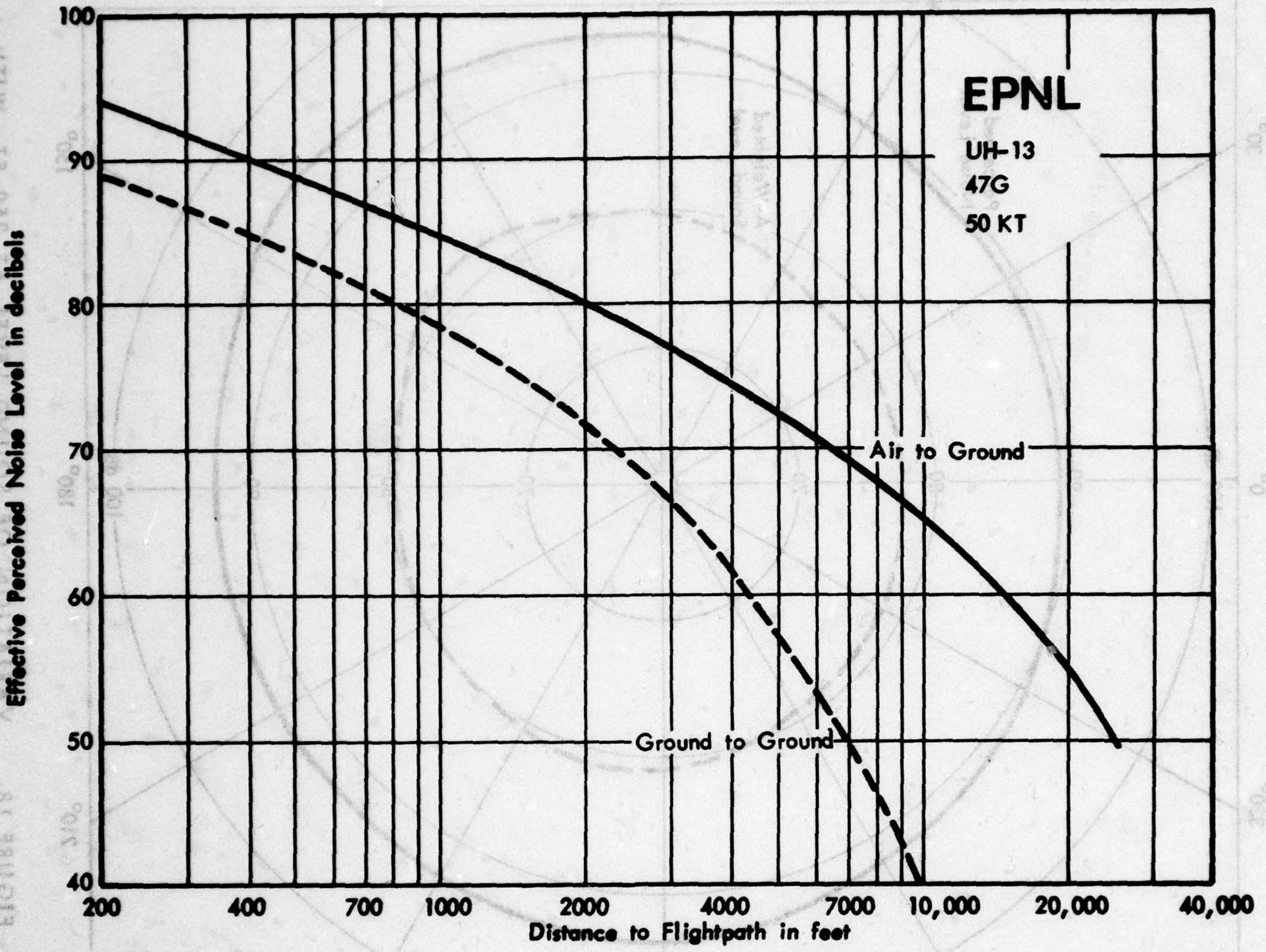

FIGURE 17. VARIATION OF EPNL WITH DISTANCE - UH-13

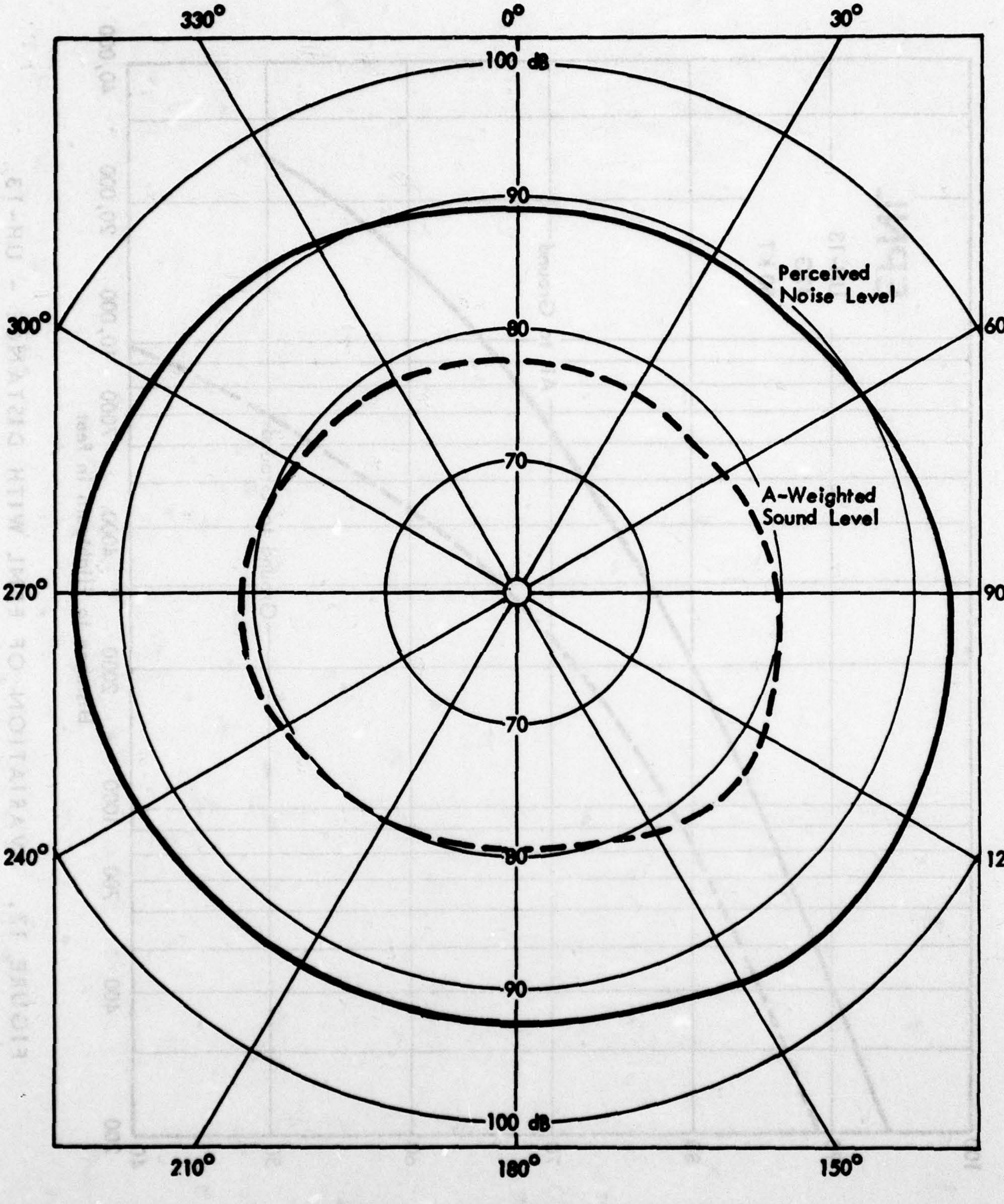

FIGURE 18. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - CH-3C

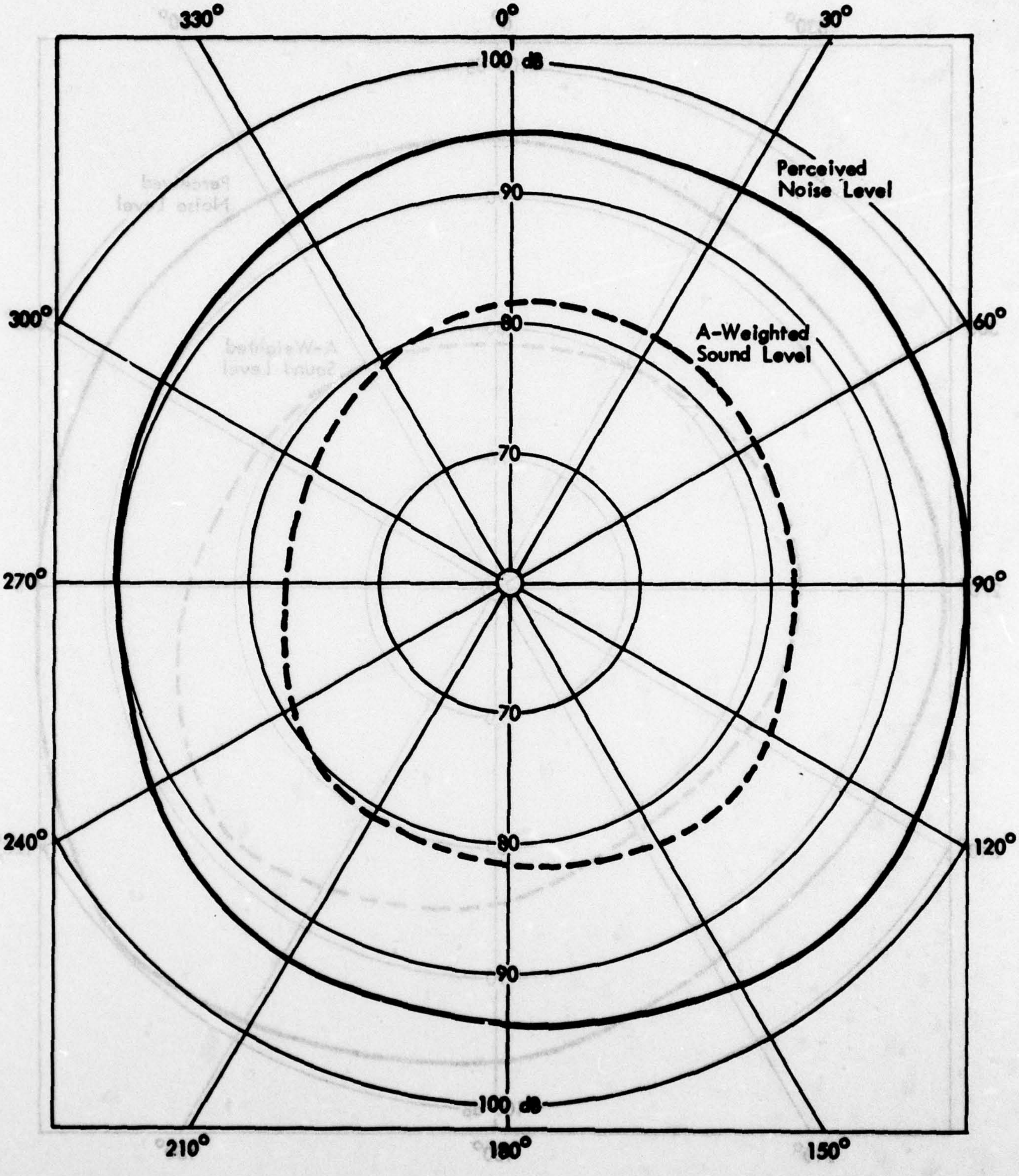

FIGURE 19. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - CH-47C

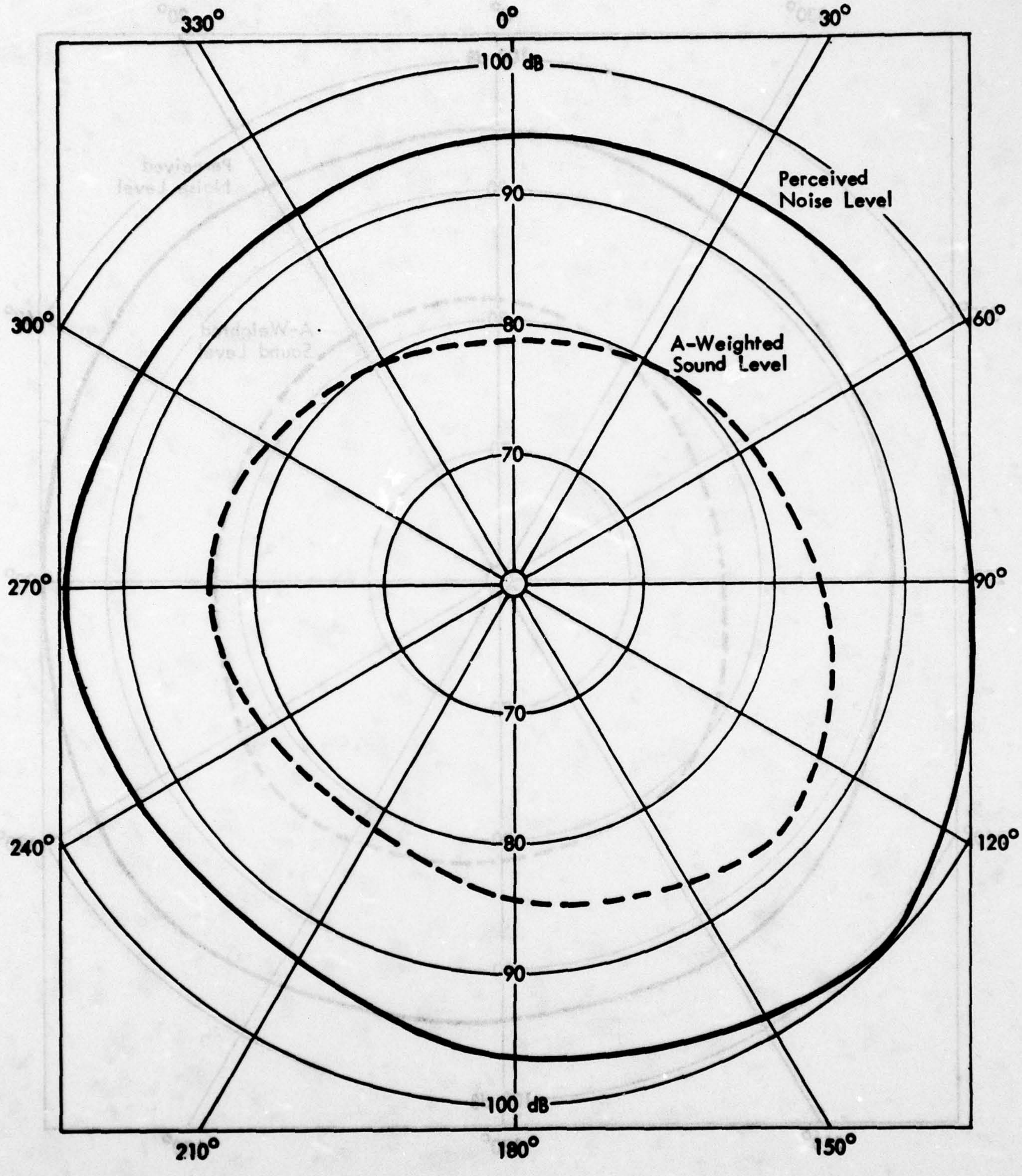

FIGURE 20. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - CH-54B

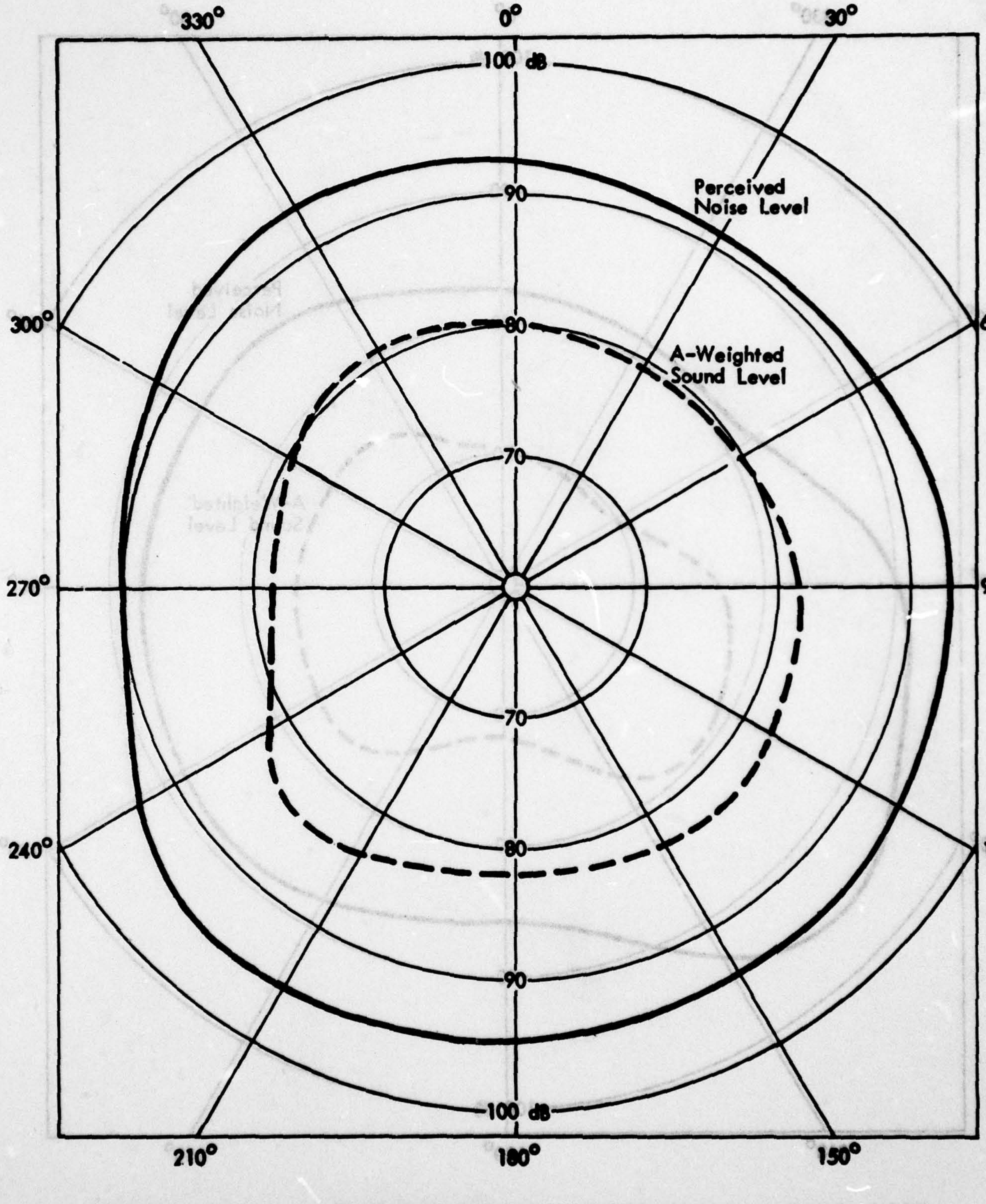

FIGURE 21. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - OH-6A

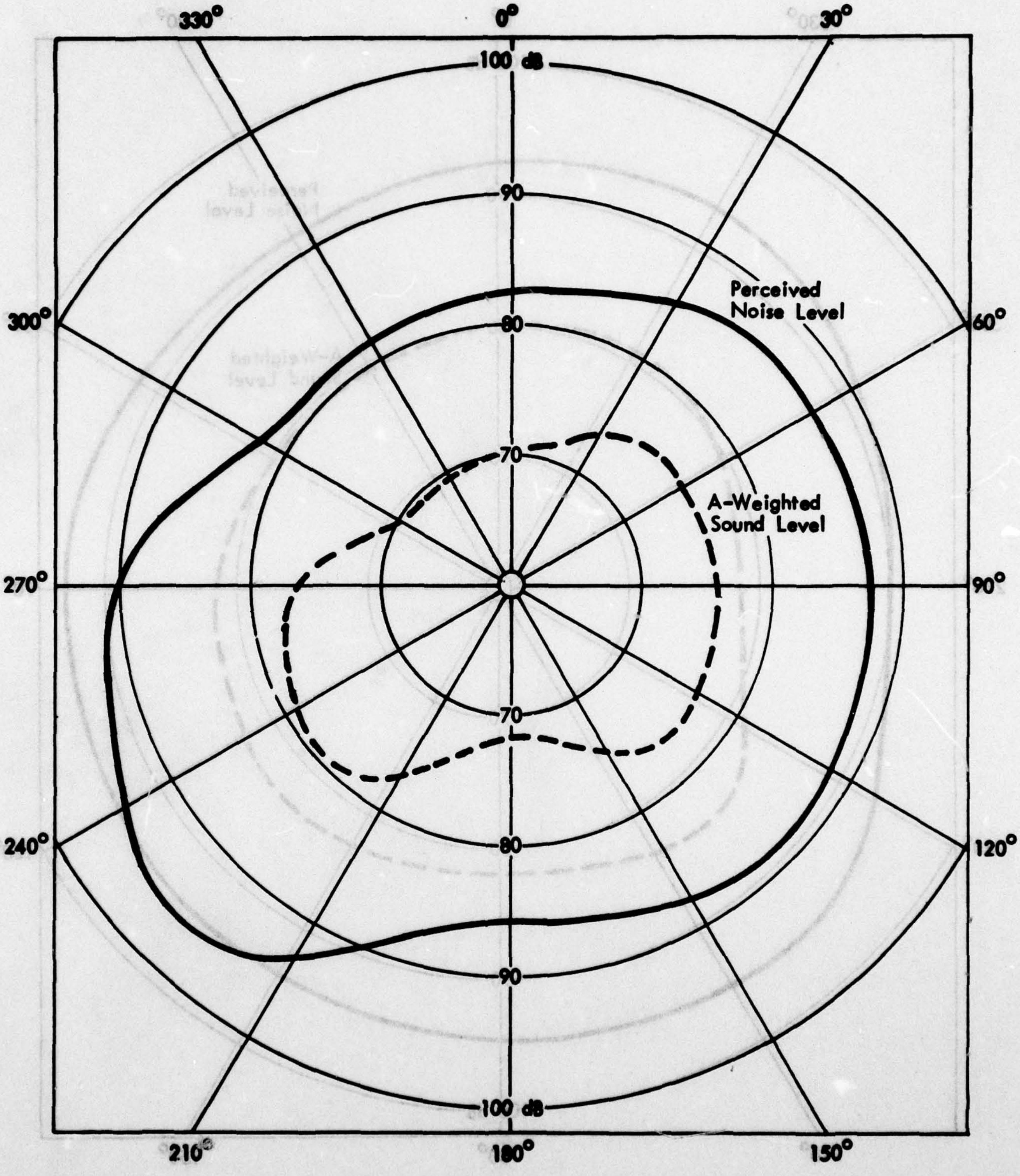

FIGURE 22. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - TH-55A

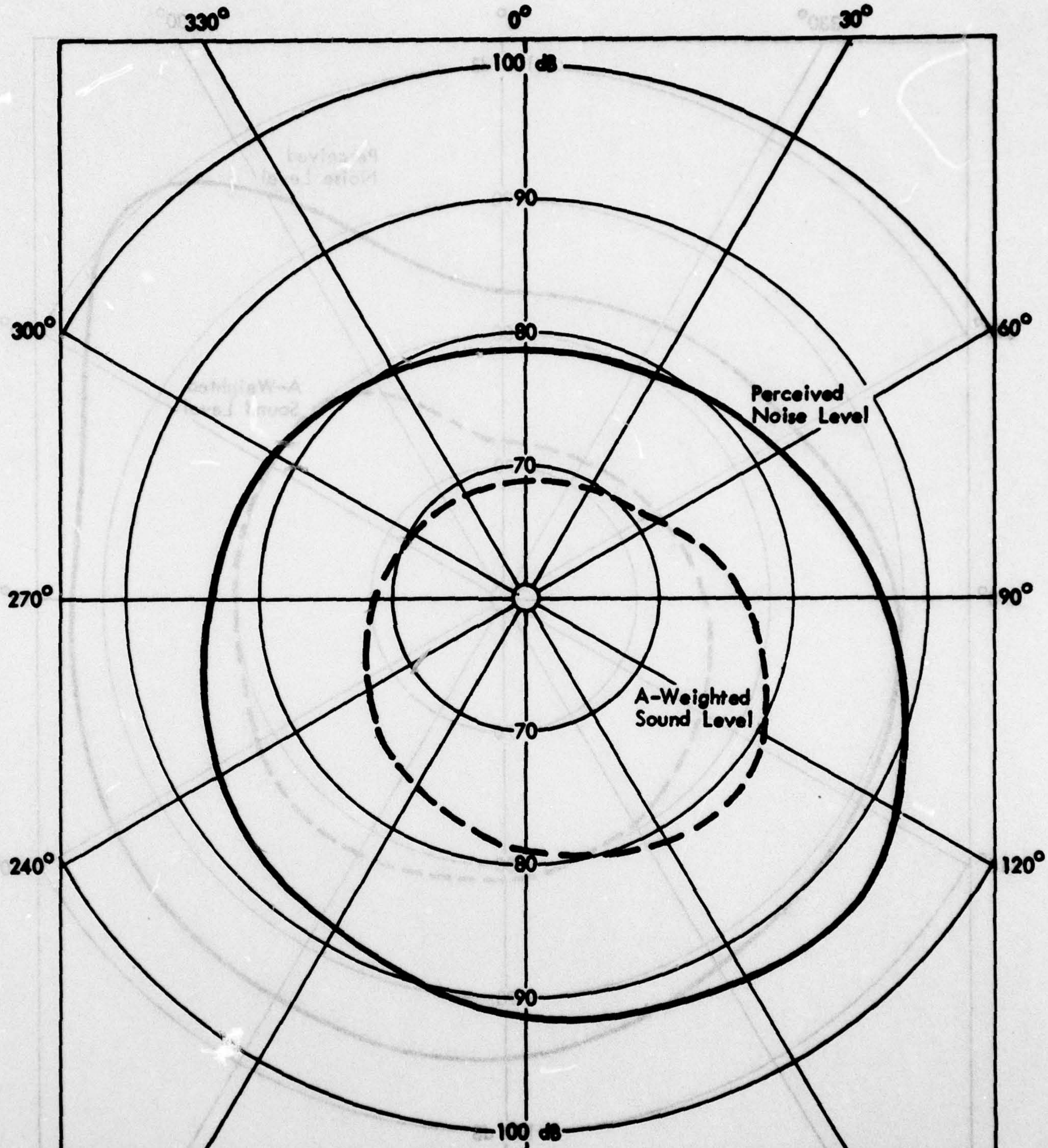

FIGURE 23. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - UH-1N

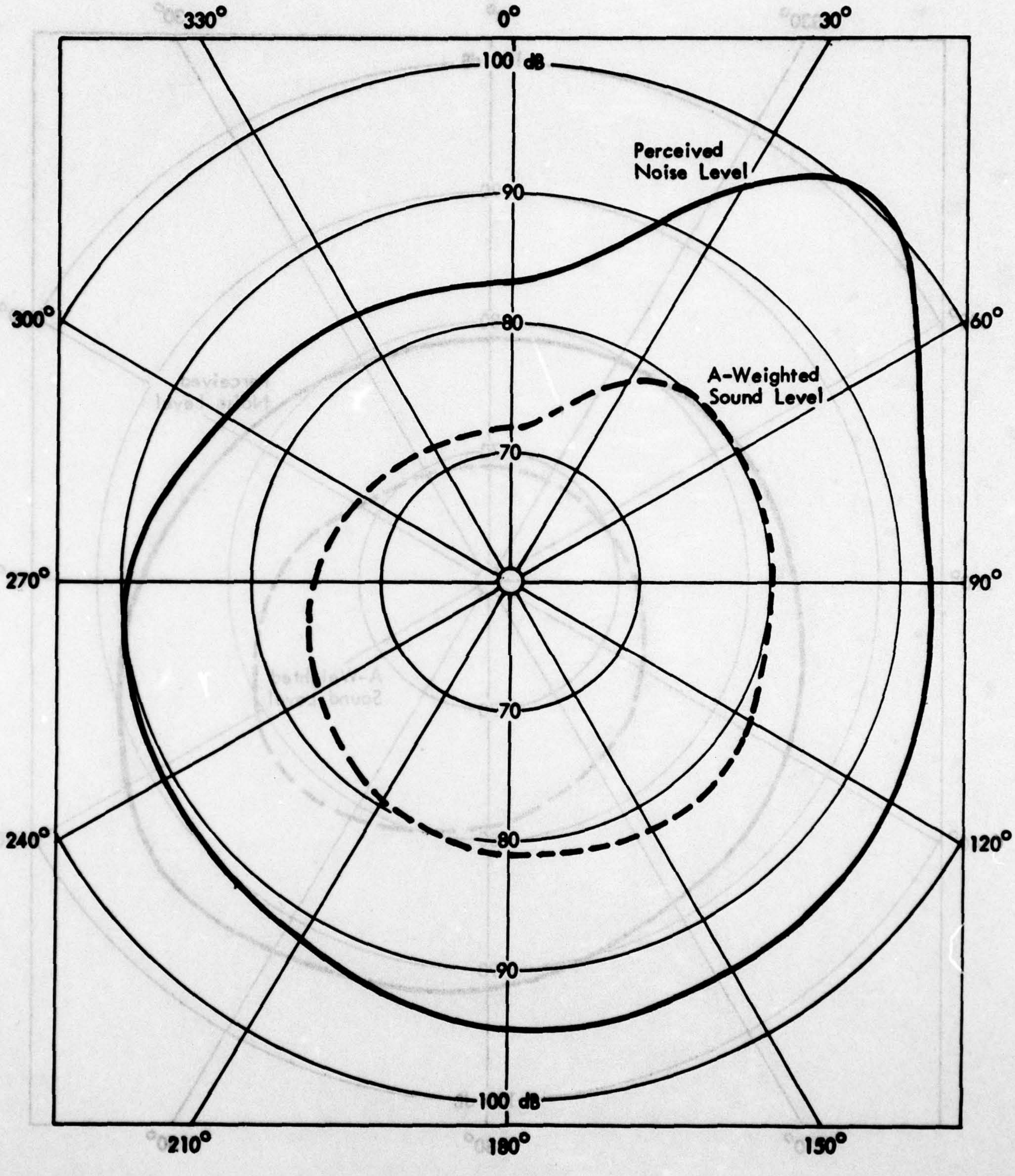

FIGURE 24. VARIATION OF SOUND LEVEL AT 250 FT, WITH AZIMUTH ANGLE DURING HOVER - UH-13

APPENDIX B

STATUS OF PROPOSED IMPULSIVE NOISE ADJUSTMENTS FOR HELICOPTER BLADE SLAP

Numerous studies have been made in which subjects have judged the acceptability of helicopter noise and experimenters have examined various physical descriptors to account for the judged responses (ref. 6 to 27). Activities of Working Group B of the ICAO Committee on Aircraft Noise (ICAO/CAN/WG B), and those of ISO TC 43, SC1, Working Group 2, "Aircraft Noise," (ISO/TC43/SC1/WG2) at the request of ICAO, have led to several proposals for physical descriptors for impulsiveness and methods for applying these descriptors to derive an adjustment to EPNL to account for its underestimation of judged response to blade-slap (ref. 23-27). The proposals call for computation of an adjustment to be applied to *tone-corrected perceived noise* level (PNLT) in each 0.5 second interval, just as is done for the adjustment for tones, prior to the summation to obtain EPNL. A synthesis of the British and French positions was issued as a draft ISO proposal in January 1978 (ref. 28).

The psychoacoustical studies used to develop the British proposal for an impulse adjustment for EPNL used steady state signals having a background noise on which repeated sine wave pulses were superposed to simulate blade-slap (ref. 21). The first French proposal was based on similar experiments (ref. 25), while a later proposal (ref. 20,26,27) used time varying helicopter noise signals without blade-slap, superposing blade-slap signals to simulate actual helicopters. None of these studies applied the proposed impulse adjustment procedures to signals representing actual helicopter noise signatures as produced under the flyover and approach operating procedures being considered for certification. Other subjective response studies using simulated and actual helicopter recordings, while providing information of value in studying response to impulsive noise, employed signals again not representative of those obtained under proposed certification conditions (ref. 16-19).

The applicability of the different impulse adjustment measures to recorded helicopter noise signatures from the TSC/DOT test series was compared to judged psychoacoustical reponse, for eight helicopter noise signatures (ref. 6), as well as a variety of synthesized helicopter noise signals. It was found that the French (essentially the ISO) procedure accounted satisfactorily (i.e. within about one decibel) for the judged response to the eight helicopters, but did not work well on the synthesized signals. It was also found that an adjustment based on a combination of A-weighted sound level crest factor and blade repetition rate worked equally well for the eight helicopters.

The preponderance of evidence to date indicates that the psychoacoustical response to helicopter blade-slap is underestimated by SEL or EPNL. The underestimate varies from 0 to 7 decibels, depending upon the helicopter and its operating condition. In two military studies (ref. 18 and 29) the estimate is made that the underestimate in the regression of the judgments of helicopters against sound levels in these tests was 2 decibels, which may be indicative of the net effect over an aggregate of operations of an air facility.

SUMMARY OF DRAFT ISO PROCEDURE

The recorded noise signal is A-weighted, passed through a 2000 Hz low-pass anti-aliasing filter, then digitally sampled at 5000 (or an integer multiple of 5000) samples per second to obtain voltages V_i. The 2500 samples in each o.5s interval are combined to determine an impulsiveness coefficient, I.

$$I = \frac{1}{2500} \sum_{i=1}^{2500} \left[\frac{V_i^2 - s}{s} \right]^2$$

$$s = \frac{1}{2500} \sum_{i=1}^{2500} V_i^2$$

Note that s is the mean square A-weighted voltage in the 0.5s interval.

I is then transformed to a decibel value, Δ, which is added to the PNLT value in each 0.5 second. The "adjusted" PNLT values are then summed over the event as in the conventional EPNL analysis. The adjustment can equally well be made to A-weighted sound levels, in 0.5s intervals, and then summed to obtain an "impulse adjusted" EPNL. The transfer function from I to Δ is given by:

$$\Delta = -2.4 + 8 \log_{10} I$$

with Δ restricted to the range $0 \leq \Delta \leq 5.5$ decibels.

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