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# Noise Certification Considerations for Helicopters Based on Laboratory Inve-tigations

Man-Acoustics and Noise Inc Seattle Wash

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# NOISE CERTIFICATION CONSIDERATIONS FOR HELICOPTERS BASED ON LABORATORY INVESTIGATIONS

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FINAL REPORT

JULY 1976



Prepared for

**U.S. DEPARTMENT OF TRANSPORTATION**
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**Washington, D.C. 20590**



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16. Abstract

This is the second part of a program concerning noise certification for V/STOL and helicopter aircraft. Aspects considered were: an engineering calculation procedure which validly and reliably reflects annoyance to helicopter operations; estimates of noise exposure levels which could be compatible with human activities in areas surrounding heliports; noise exposure modeling for helicopter noise; certification measurement approaches for helicopter noise certification.

The basics of the program involved human response evaluations of conventional takeoff and landing (CTOL) aircraft noise, simulations of helicopter noise emphasizing "slap" or pulsating noise effects, and recordings of a wide variety of helicopter operations.

The main conclusion is that PNdB with the FAR-36 duration correction reliably reflects annoyance to helicopter noise. No correction for "slap" or tone is required. Also, $dBA_D$ is almost as effective as $PNdB_D$ for measuring effects of helicopter noise (duration effects are included). Elimination of "heavy slap" is equivalent to a maximum of a 2 to 3 dBA reduction relative to annoyance response.


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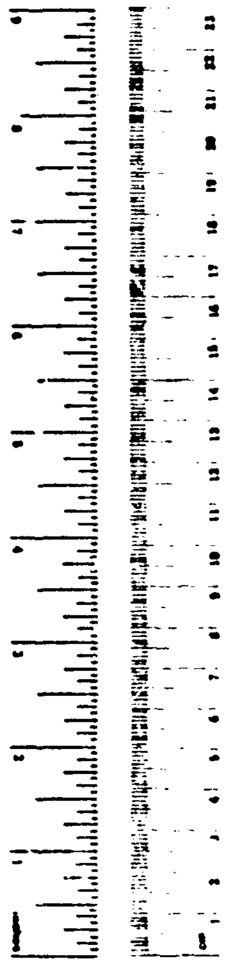
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

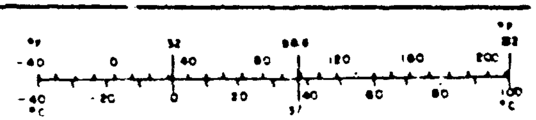
| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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## ACKNOWLEDGMENTS

A number of persons contributed to this study program. J. E. Mabry was the principal investigator and A. F. Emanuel the principal researcher. Acoustic analyses and development of signal presentation materials and equipments was completed by B. M. Sullivan, P. B. Oncley, and D. B. Shields. Design and fabrication of the helicopter simulator was performed by J. Bocek. T. L. Hughes performed the various statistical analyses and related the physical acoustical data to the human response results. In addition to these personnel, we want to thank Thomas H. Higgins of FAA Research and Development Service for his interest and valuable technical direction during the course of the study. We also want to thank the following for assisting MAN-Acoustics and Noise in obtaining various helicopter recordings.

The Bell UH-1H Huey and the Bell OH-58 Kiowa were recorded at Gray Army Air Base, Fort Lewis, Washington, with the helicopters operated by the personnel of the 10th Aviation Battalion and the 58th Signal Battalion respectively.

The Boeing/Vertol CH-47B Chinook recordings were made at Paine Field, Everett, Washington, under the auspices of the 124th Army Reserve Command Flight Facility, Paine Field, Everett, Washington.

Personnel of Air Operations, Whidbey Island Naval Air Station, Washington, provided the Boeing/Vertol CH-46 Sea Knight which was recorded at the Coupeville Auxiliary Landing Field, Coupeville, Washington.

Olympic Helicopters of Seattle, Washington flew the Hughes 269B which was recorded at Cedar Grove Airport, Washington.

# NOISE CERTIFICATION CONSIDERATIONS FOR HELICOPTERS BASED ON LABORATORY INVESTIGATIONS

## 1.0 INTRODUCTION

Noise certification has played and will continue to play an important role in reducing noise exposure impact from aircraft operations. Aircraft type noise certification is presently in effect for both commercial transport and general aviation aircraft (FAR-36, Appendix C and F respectively) but no noise certification rules have been implemented for the helicopter, which is a widely used and versatile aircraft type. The aim of this research program is to investigate various significant elements of a helicopter noise certification program. The work is accomplished utilizing laboratory studies involving human response to helicopter and other aircraft noise signals, review of work completed by other investigators, consideration of helicopter noise certification measurement schemes, and consideration of community response studies to noise from other aircraft such as CTOL types. The elemental objectives are:

- Determine an engineering calculation procedure or weighting network that validly reflects annoyance response to helicopter aircraft.

- Estimate noise exposure levels that will be compatible with activities surrounding heliports and airports at which helicopters are based.

- Determine the feasibility of incorporating noise exposure effects from helicopter aircraft into existing airport noise exposure modeling approaches.

- Provide essential aspects of a certification measurement approach for helicopter noise certification.

Since, due to "blade slap", helicopter noise has such distinctive characteristics, prior to presentation of the main aspects of this study program, a general discussion of the problem, some findings of previous studies, and a brief study rationale are provided.

## 1.1 Discussion of the Problem

The considerable subjective acoustic work examining the effects of conventional takeoff and landing (CTOL) aircraft, both jet and propeller powered, has provided useful information, but the applicability of this information to distinctively different aircraft noises such as impulsive helicopter rotor noise has yet to be established. There is a requirement to determine the relationship between annoyance and impulsive helicopter noise as a means of implementing noise certification of new helicopter types, as well as to facilitate helicopter operations noise modeling and noise reduction technology. In addition to the ability to produce the distinctive impulse or blade slap noise, the helicopter can hover, fly at very slow speeds, and operate through a greater range of takeoff and approach profiles than CTOL aircraft, with the attendant production of different and more widely varying noise-time signatures. It is the existence of these distinct noise characteristics, particularly the blade slap, which has motivated much of the investigation into the physical nature and psychological effects of helicopter noise.

Blade slap generation has been variously attributed to main rotor blade/vortex interaction, blade stall, compressibility drag rise, the interaction of the main rotor downwash with the tail rotor, and the interactions of one main rotor downwash with the blades of the other main rotor in tandem rotor helicopters. In some helicopters, blade slap can occur in virtually all flight regimes, while in others it may occur in only limited regimes such as hover and slow flight, or high speed flight, or increased gravitation loading such as in turns. Some helicopters produce no significant slap at all. Even among the same helicopter type, individual differences - presumably manufacturing tolerances, trim, or main rotor rigging - can change the slap generation character.

The prevailing state-of-the-art does not assure that new helicopter types will not produce blade slap, so that a noise certification scheme must be able to account for the presence of blade slap. Also, since many existing helicopters generate impulsive noise, noise modeling methods must include the effects of slap.

## 1.2 Findings of Previous Studies

Virtually no basic data are available which relate human response to the type of repetitive impulse noise generated by helicopter rotors.

Work has been done, for example, with sonic booms and with small numbers of impulses, but findings of these studies do not necessarily pertain to blade slap effects. The results from studies utilizing fly-over-type helicopter noises are not entirely helpful. These studies have, in general, used existing noise rating schemes such as dBA, dBB, dBC, dB(linear), and the Noy and Loudness Level based units. The weighting networks and calculation procedures have been investigated with and without tone and duration corrections. Leverton (Ref. 1-1) found that existing rating methods are inadequate for helicopters with impulsive noise, and on the basis of a small study (Ref. 1-2) tentatively proposed a 12 dBA penalty for such noises. Ollerhead (Ref. 1-3) also concludes that existing scales do not adequately reflect annoyance to helicopter noise, and that subjective effects of low frequency pulsatile sounds in conjunction with possible revision in the low frequency portions of the Noy curves should be investigated. Munch and King (Ref. 1-4) suggest that it may be necessary to add a penalty of from 5 to 10 dBA to impulsive aircraft noise: their conclusion was based on a study which correlated annoyance with the crest factor effect of the helicopter signal. Sternfeld, et al (Ref. 1-5) report that impulsive helicopter noise is underestimated by about 4.5 PNdB, inferring a 4.5 PNdB penalty. According to Hinterkeuser, et al (Ref. 1-6), PNdB and dBA are good units for helicopter noise dominated by tail rotor noise (which is similar to propeller noise), but blade slap is overweighted in the low frequencies by PNL and dBA, implying a need for a change in the weighting curves or an associated penalty. Pearsons, (Ref. 1-7) reported that PNL, dBA and dBN all predicted helicopter noise reasonably well, with PNL performing the best. A study by MAN-Acoustics and Noise, Inc. (Ref. 1-8) found that PNdB <u>overestimated</u> helicopter noise annoyance relative to some other types of aircraft noise signals, i.e., in contradiction to some of the above mentioned studies, a <u>negative</u> penalty is indicated. However, if PNdB is duration corrected, it does a reasonably good job for helicopters with and without blade slap. Hinterkeuser, et al (Ref. 1-6), Ollerhead (Ref. 1-3), and MAN-Acoustics and Noise, Inc. (Ref. 1-8) all agree that a duration correction improves the annoyance correlation, but Pearsons, et al (Ref. 1-7) found that a combination of duration and tone correction did not improve the accuracy of the prediction (the duration correction was only examined in combination with the tone correction).

Based on Ollerhead's work (Ref. 1-3), several researchers have suggested modifying the tone correction procedure to exclude corrections below 500 Hz. However, Galloway (Ref. 1-9) contends that Ollerhead incorrectly applied the tone correction below 500 Hz and proposes that a re-analysis of the data be undertaken to verify Ollerhead's results. In their study, MAN-Acoustics and Noise, Inc. (Ref. 1-8) found the tone correction provided a slight improvement in the helicopter noise prediction when applied to PNL.

## 1.3 Study Rationale

A survey of the studies cited in the previous section by no means provides a definitive qualitative assessment of the effects of impulsive rotor noise, to say nothing of the quantitative information which would be needed for a convincing subjective noise model. While several studies do conclude that existing weighting scales underestimate the annoyance of slap, one study (Ref. 1-8) shows that PNdB overestimates the annoyance relative to some other aircraft sounds. There seems to be a case for the inclusion of the duration correction, but the utility of the tone correction is questionable.

Most of the above studies used sounds with complex spectral and temporal variables. Thusly, the effects of blade slap could have been interacting with other variables. In order to more effectively isolate the subjective impact and the significant variables of blade slap, the initial phase of this study (referred to as the pilot study) employed simulations in which the slap parameters were controlled, as well as actual helicopter recordings. The results of the pilot study helped to define a larger study which used more diverse and complex sounds.

## 1.4 References

1-1. Leverton, J. W., "Helicopter Noise - Are Existing Methods Adequate for Rating Annoyance or Loudness?", J. Am. Helicopter Society, April 1974.

1-2. Leverton, J. W., "Helicopter Noise - Blade Slap Part 2: Experimental Results", NASA CR-1983, March 1972.

1-3. Ollerhead, J. B., "Scaling Aircraft Noise Perception", J. Sound & Vib., Vol. 26, No. 3, 1973.

1-4. Munch, C. L.; King, R. J., "Community Acceptance of Helicopter Noise: Criteria and Application", NASA CR-132430, 1974.

1-5. Sternfeld, H.; Hinterkeuser, E.; Hackman, R.; and Davis, J., "Acceptability of VTOL Noise Determined by Absolute Subjective Testing", NASA CR-2043, June 1972.

1-6. Hinterkeuser, E. G.; Sternfeld, H., "Civil Helicopter Noise Assessment Study, Boeing/Vertol Model 347", NASA CR-132420, May 1974.

1-7. Pearsons, K. S., "Noisiness Judgments of Helicopter Fly-overs", FAA DS-67-1, January 1967.

1-8. MAN-Accustics and Noise, Inc., "Noise Certification Criteria and Implementation Considerations for V/STOL Aircraft", FAA-RD-75-190, November 1975.

1-9. Galloway, W. J., "Community Noise Exposure Resulting from Aircraft Operations: Technical Review", AMRL-TR 73-106, November 1974.

## 2.0 PILOT STUDY

### 2.1 Objectives

The main objective involves obtaining results concerning extent of annoyance associated with "blade slap". The aim is to design a study which provides a wide opportunity for "blade slap" annoyance to surface. In conjunction with investigating the possibility of increased annoyance due to "blade slap", an evaluation of the extent that the crest factor correction (CFC) is associated with annoyance response will also be investigated. Finally, due to the fact that that helicopter noise contains considerable low frequency acoustic energy, recording and reproduction approaches that provide realistic presentations of low frequency noise will be examined.

### 2.2 Experiment Description

The pilot study essentials are a magnitude estimation experiment involving twelve subjects, judging sixteen signals at four different levels.

#### 2.2.1 Signals

A general description of the sixteen signals is presented in Table 2-1, while a detailed technical discussion concerning rationale for selection is given in the next section, "2.3 Signal Recording and Presentation Considerations". As can be seen from Table 2-1, the first seven signals are concerned with "slap" effects. Comparisons among signals 1 to 4 (no to heavy slap) will permit comparisons involving slap amplitude while comparisons among signals 3, 5, and 6 provide comparisons concerning frequency of slap. Comparison between signals 2 and 7 will show differences concerning slap rise time. Signals 9 through 16 are concerned with recording and presentation considerations of the low frequency noise.

Each signal was presented at peak levels of 61, 67, 73, and 79 dBA and the standard signal was at 70 dBA; as shown in Table 2-1, signal 1 was used as the standard. Thusly, each subject evaluated the sixteen noises at four levels for a total of sixty-four evaluations.

#### 2.2.2 Subjects

Persons evaluating the sixteen noises included MAN-Acoustics and Noise personnel plus persons from a subject pool established for previous studies. No subject who was aware of study aims

Table 2-1. Pilot study noise signals.

| No. | DESCRIPTION |
|---|---|
| 1 | Tail rotor noise simulation with no slap (Standard Signal). |
| 2 | Tail rotor noise with light slap at 10 beats/sec. |
| 3 | Tail rotor noise with moderate slap at 10 beats/sec. |
| 4 | Tail rotor noise with heavy slap at 10 beats/sec. |
| 5 | Tail rotor noise with moderate slap at 6 beats/sec. |
| 6 | Tail rotor noise with moderate slap at 18 beats/sec. |
| 7 | Tail rotor noise with moderate slap at 10 beats/sec. and fast rise time. |
| 8 | +Chinook level flyby - direct and FM recording. |
| 9 | " " " - direct and rolled-off FM recording. |
| 10 | " " " - direct recording only (no FM). |
| 11 | Chinook hover - direct and FM recording |
| 12 | " " - direct and rolled-off FM recording. |
| 13 | " " - direct recording only (no FM). |
| 14 | Chinook shallow turn - direct and FM recording. |
| 15 | " " " - direct and rolled-off FM recording. |
| 16 | " " " - direct recording only (no FM). |

+See section 2.3 for rationale of signals 8 through 16.

participated and they covered a wide range of ages ranging from the early twenties to late sixties, both sexes were represented. The following magnitude estimation instructions were utilized.

Pilot Study Instructions

We are asking you to help answer the question, "How annoying are various kinds of sounds?" We will ask you to listen to some sounds and rate them in terms of annoyance. The sounds you are to rate will be presented to you one-at-a-time. Listen to all of each sound before making your judgment. In a moment, we will have you listen to a sound with an annoyance score of 10. Use that sound as a standard, and judge each succeeding sound in relation to that standard. For example, if a sound seems twice as annoying as the standard, you will write "20" in the space for that sound on the answer sheet. If it seems three times as annoying, write "30". If slightly more than twice as annoying, you may choose to write "21" or "22" or "23", whatever is appropriate. If it seems only one-quarter as annoying, write 2-1/2. If slightly less annoying than the standard, use the number that best expresses the difference, such as "7" or "8", and so on.

Your ratings should reflect only your own opinion of the sounds: that is what we want. Each sound is numbered to correspond to the numbers on your answer sheet.

You will now hear the standard sound with an annoyance rating of 10.

### 2.2.3 Dependent Measures

The "subjective dB" method as described in References 2-1, 2-2, and 2-3 is used to evaluate response to the sixteen signals. The essentials of this magnitude estimation method is that signals are compared to a standard by the judges, plus there is also a comparison among the various signals. Results provide the answer to the question, "Utilizing a particular engineering calculation procedure or weighting network, at what level do the subjects place the noise for a particular calculated value?" For example, a noise event could have a calculated value of 70 dBA while the judged level is 75 dBA. This means that the dBA weighting network under-evaluates that noise event by 5 dBA.

## 2.3 Signal Recording and Presentation Considerations

Recordings of the helicopter signals utilized in both the pilot and main studies were made with the helicopters performing the following maneuvers:

(1) Normal takeoff and climb-out.
(2) Maximum performance takeoff and climb-out.
(3) Level flybys at various speeds and altitudes.
(4) Shallow and steep turns with the microphone at the center of the turn.
(5) Normal approach with touchdown.
(6) Steep approach with touchdown.
(7) Hover, with recordings made from forward, aft, port and starboard.

The Bell UH-1H Huey and the Bell OH-58 Kiowa are single-rotor, single-engine, turbine-powered helicopters. The Huey produces slap in most flight regimes, while the Kiowa produces very little slap, with the tail rotor noise dominating.

The Boeing/Vertol CH-46 Sea Knight and CH-47B Chinook are both turbine-powered tandem-rotor types. The Sea Knight has one turbine engine, the Chinook two. Both generate significant slap.

The Hughes 269B is light, single-rotor, and powered by a single reciprocating engine, producing almost no slap, with exhaust and tail rotor noise dominating.

Since one of the distinguishing characteristics of helicopter noise is the low frequency impulsive content, it is important that recording techniques used to acquire these signals be capable of capturing low frequency noise. The helicopter noises were recorded on a two-track Uher 4200 Report Stereo portable tape recorder. One track of the recorder was fed by an auxiliary frequency-modulation system, providing a recording capability of from 3 Hz (the lower limit of the microphone) to 600 Hz (the upper limit of the FM system). On the second recording track, the signal was first encoded by the compressor section of a dbx compressor/expander, a system capable of virtually doubling the dynamic range of the tape recording process to more than 70 dB by compressing the signal as it is recorded, and expanding during playback. The dbx-processed signal was recorded using the direct mode of the tape recorder. The frequency response of the second track recording was limited by the frequency response of the tape recorder itself to from about 40 Hz to 15 kHz. Both tracks were recorded simultaneously to produce time-synchronized spectral coverage from 3 Hz to 15 kHz. A calibrated tone was recorded on both channels to enable equalization of gains during playback.

For presentation in the study, the FM and direct tracks were mixed to provide the total audible spectrum. Mixing was accomplished by playing the decoded FM output through a low-pass filter, and the decoded dbx output through a high-pass filter, with both filters having 3 dB down points at 100 Hz. The outputs of the filters were fed to a two-channel amplifier and then to respective speakers in the listening chamber for acoustic mixing.

The dbx system was not used to process the signal recorded on the FM track because of the lower limiting frequency of the dbx system of about 20 Hz. The dynamic range of the FM track was therefore less than the direct track and thus limited the effective dynamic range of the presentation. However, the recording noise floor problems are generally of less significance in the lower frequencies than in the upper part of the audible spectrum. Since the FM signals were played back through a low-pass filter with a 100 Hz cutoff, the noise floor was considerably lowered, thereby minimizing the intersignal noise during presentation, and producing high quality, low noise signals.

Three recordings of the Boeing/Vertol CH-47B tandem rotor helicopter were used in the construction of noises presented in the pilot study. One of the recordings is of a 1000 feet level flyover at [illegible] knots. Of the other two recordings, one is a ten-second excerpt from a shallow turn at 400 feet above the ground with the microphone at the center of the turn; the other is a ten-second portion of a hover at [illegible] feet horizontal distance. The latter two noises were chosen as relatively steady-state specimens of actual noises.

The low frequency content of the three real noises was manipulated to test for the significance of the energy below the 50 Hz 1/3-octave band, the present lower spectral limit for Noy-based calculations. Each of the three recordings was presented in three modes, resulting in nine conditions.

In Mode 1, the simultaneous low frequency (FM) and high frequency (direct) recordings were passed through the low/high-pass filter and acoustically mixed in the listening chamber. This condition presented the complete spectrum to the subject, but contained the effects of mixing the FM and direct recordings.

Mode 2 was produced by decoding the FM signal, re-recording it direct so that the tape recorder limited the low frequency response to about 40 Hz, then FM encoding and re-recording was completed. The resulting recording, when mixed with the direct recording, had the same frequency response as the direct recording alone, but also contained the effects of mixing, if any. The direct channel was also re-recorded twice to preserve the simultaneity of the two channels.

Mode 3 consisted of the direct channel of Mode 2 (i.e., re-recorded twice), but with nothing on the FM channel. This, when presented without the use of the high-pass filter, produced a signal that had useable energy down to 40 Hz as in Mode 2, but because of the multiple generations, rolled off faster than the Mode 2 signal from about 60 Hz down. Mode 3 contained no mixing effects.

Thus, Mode 1 had response down to about 5 Hz (the lower limit of the speaker/listening chamber), Mode 2 to about 40 Hz, and Mode 3 to 60 Hz with reduced energy to 40 Hz.

Each of the three real signals was used in all three modes, making nine real conditions.

The aim of this aspect of the pilot study (Noise No's. 8 to 16) was to determine if low frequency noise (40 Hz and below) made a significant contribution to the annoyance judgments. Also, there was interest in whether or not recording technique influenced the judgments.

A special "blade slap" simulator was built which generated repetitive impulsive waveforms with variable amplitude, rise and fall time, and repetition rate. The simulator also has the capability of triggering, in synchronism with each impulse, shaped broad band noise, with adjustable onset and offset time. With proper manipulation, very realistic main rotor simulations with blade slap were created.

In addition to the main rotor simulations, a facsimile of tail rotor noise was synthesized, patterned after the acoustic signature of the Bell OH-58 Kiowa helicopter which is dominated by tail rotor noise with a fundamental frequency of about 100 Hz. This tail rotor noise was constructed to be completely devoid of any low frequency impulsive content, and was used in the study as the "standard noise", against which all other noises were compared.

Seven simulations were used to provide a well-controlled examination of the effects of repetitive impulsive noise. Simulation 1 was the same noise as the "standard noise" with no slap content. Simulations 2 through 7 were made by mixing the output of the blade slap simulator with Simulation 1 (the "standard noise"), with the resultant noise composed of tail rotor noise and main rotor noise with blade slap.

Simulations 2, 3, and 4 contained the same blade slap wave form at a 10 beats/sec. repetition rate, but with the blade slap proportionately adjusted to give what was judged by experienced observers to be "light slap", "moderate slap", and "heavy slap" respectively.

Simulations 5 and 6 used the same slap waveform and amplitude as Simulation 3 (moderate slap), with the repetition rate at 6 beats/sec. (slow) for Simulation 5, and 18 beats/sec. (fast) for Simulation 6.

Simulation 7 had the same repetition rate and peak slap amplitude as Simulation 3 (moderate slap), but with a distinctly perceptible faster rise time giving the effect of a sharper slap. These are the seven simulations ( No. 1 to 7) of Table 2-1.

These simulations were selected to test for degree of slap, slap rate and slap rise time.

For the pilot study, the nine "real" signal conditions, combined with the seven simulations, were faded in and out to create a smooth onset and offset.

## 2.4 Tape Construction

As described above, it was necessary to construct the pilot study experimental tapes with both the FM and direct tracks used in the same way as the original recordings to preserve the entire spectral content for presentation to the subjects. Peak dBA values of 61, 67, 73, and 79 were chosen as presentation levels. The 16 signals were adjusted relative to each other so they all produced equal peak dBA in the listening chamber, then re-adjusted and re-recorded in a randomized order at the four levels used in the study. The 64 noises were recorded on four tapes, with 16 noises on each tape. The order of the presentation of four tapes was balanced over the twelve subjects.

A calibration signal recorded on both tracks of each tape provided the means for equalizing the two tracks and adjusting for absolute listening levels in the chamber.

Voice cues for identifying the noises were recorded at a comfortable listening level on the direct track only.

A tape recording of the experiment instructions was constructed for presentation to the subjects at the beginning of the test.

## 2.5 Listening Environment

The listening environment was designed to provide a non-distracting setting with low ambient noise, thus avoiding any possible complications resulting from background noise effects.

The listening chamber internal walls are lined with acoustic wallboard which produce a semi-reverberant response. The subject was seated in a comfortable armchair located directly under two Speakerlab 2 acoustic suspension speakers used to acoustically mix the direct and decoded FM signals.

At the left and to the rear of the subject, approximately one foot from the ear, was a shock-mounted Bruel & Kjaer Type 2205 sound level meter feeding a Bruel & Kjaer Type 2307 level recorder, thus providing a simultaneous dBA trace of the signals as they were presented in the chamber.

To the right, and to the rear of the subject, about one foot from the ear, was a shock-mounted General Radio one-inch electret microphone with a General Radio Type 1560-P42 microphone preamplifier which was used to record, for later analysis, the signals representing what the subject actually heard.

The entire chamber is mounted on springs and lined with 1/64-inch lead sheet and absorbent 1-inch fiberglass blanket to provide acoustic and vibration isolation.

## 2.6 Signal Presentation

On the experimental tape, both data tracks were encoded, one track by the FM system, the other by the dbx compressor. During playback, the FM signal passed through the FM decoder, into a Kenwood stereo preamplifier, to a low-pass filter with a 100 Hz cut-off, then to one channel of a McIntosh Model 250 stereo amplifier, and finally into one of two Speakerlab 2 acoustic suspension speakers in the listening chamber. The direct signal was first decoded by the dbx expander, then to the preamplifier, to a high-pass filter with a 100 Hz cut-off, into the amplifier and to the other speaker in the listening chamber where acoustic mixing of the two signals took place.

Throughout the experiment, the sounds in the listening chamber were monitored by a Bruel & Kjaer Type 2205 sound level meter, in the A-weighting mode, and were fed into a Bruel & Kjaer level recorder, thus providing a simultaneous dBA record. The level recorder trace also provided a readout used to adjust the tape presentation level, employing the 1 kHz calibration tones recorded at the beginning of each tape reel.

Prior to the beginning of the study, the experimental tapes were played in the chamber (with no subject present) and recorded on a Teac 7030 tape recorder via a General Radio 1-inch electret microphone and preamplifier. This tape was analyzed to provide the objective data used in the calculations representing the signals the subject actually heard (see Section 2.7).

## 2.7 Physical Data Analysis

### 2.7.1 Analysis for Conventional Noise Units Calculations

Analysis of the 50 Hz to 10 kHz frequency range as specified in FAR Part 36 was performed by placing a 1-inch General Radio electret microphone in the listening chamber at the approximate position of the subject's head, with no subject present. The microphone fed a General Radio 1933 sound level meter used as a step attenuator/amplifier which drove the G. R. 1921 real time analyzer interfaced with a PDP-11 computer. Calculations were made, using 1/3-octave 1/2-second spectral analyses, of dBA, $dBA_T$, $dBA_D$, EdBA, PNdB, $PNdB_D$, EPNdB, dBD, dBE, and dBA corrected using a "crest" factor.

For the 25 Hz to 10 kHz frequency range analysis, the same instrumentation as above was used to analyze only the "steady-state" noises. These were the seven simulations and the three conditions for each of the "turn" and "hover" noises for a total of 13 signals at 4 levels each. Signals 8, 9, and 10 were based on a flyby so were not "steady-state" noises. For these 13 conditions, an 8-second integration time was used which included most of the steady signal, but eliminated the onset and offset portions.

Since the G. R. 1921 analyzer used in the physical analysis is limited in low-frequency response to the 25 Hz one-third octave band, a method of analysis which measures the energy down to the 0.3 Hz 1/3-octave band was developed. (The lowest blade slap frequency used in the pilot study was 6 beats/sec.)

To measure the levels between 6.5 Hz and 100 Hz, the "steady-state" signals were recorded at a tape speed of 1-7/8 inches per second using the FM recording system in conjunction with the same microphone and position as above. When this recording is replayed at 7-1/2 inches per second (a factor of 4 speed increase), the spectral content is shifted upward two octaves, ranging from 25 Hz to 400 Hz, and can be accurately analyzed as confirmed by a previous test with pure tones. Eight-second signals were used, and the speed-shifted analysis, when corrected for the level increase due to the increased speed, compared accurately with the conventional analysis in the overlap region of 25 Hz to 100 Hz.

A composite 1/3-octave spectrum extending from 6.3 Hz to 10 kHz was assembled for each of the conditions. These spectra were used to calculate dBA, dBB, dBC, dBD, dBE, and dB(linear), extrapolating the weighting curves to 6.3 Hz where necessary. The noise unit values were computed for each condition using three energy ranges: 6.3 Hz to 10 kHz, 25 Hz to 10 kHz, and 50 Hz to 10 kHz.

### 2.7.2 Analysis for Crest Factor Calculation

Munch and King, in Reference 2-4, suggested that the crest factor might be used as an objective impulse noise quantifier. The crest factor is equal to $20 \log_{10}$(Peak SPL/RMS SPL). They conducted preliminary subjective tests indicating that corrections from 8 to 13 dBA might typically be required to be added directly to the calculated or measured dBA levels with a 10 dB down duration correction, depending on the degree of blade slap present, and therefore, presumably, the crest factor.

A test of this method was made in the present study. The peak and RMS values used in the crest factor calculations were obtained using a General Radio 1933 sound level meter on the impact (rise time < 200 nanoseconds) and meter-slow functions respectively. The "average" peak and RMS values were read from the meter directly and used to calculate the crest factor.

## 2.8 Engineering Calculation Procedures

For the pilot study, ten engineering calculation procedures were investigated. Since both PNdB according to FAR-36 and dBA are in wide use, these two procedures with various corrections to them are emphasized. Also, two other weighting networks were examined, dBD and dBE, and the "crest" factor which is defined as

$$20 \log \frac{\text{Peak SPL}}{\text{RMS SPL}}$$

was applied to uncorrected dBA. The ten engineering calculation procedures and weighting networks investigated are:

| | |
|---|---|
| dBA | PNdB |
| + $dBA_T$ | $PNdB_T$ |
| $dBA_D$ | EPNdB |
| EdBA | dBD (calculated at peak PNdB) |
| dBA (with "crest" factor correction) | dBE (calculated at peak PNdB) |

+ "T" is tone correction according to FAR-36.
"D" is duration correction according to FAR-36.
"E" is both tone and duration correction applied according to FAR-36.

## 2.9 Results and Conclusions

### 2.9.1 Results

As indicated above under section 2.2 which describes the essentials of the PILOT STUDY, the various engineering calculation procedures were evaluated utilizing the subjective dB approach as described in References 2-1, 2-2, and 2-3. The subjective dB approach is concerned with the relationship between calculated and judged values. For the range of levels investigated, a noise is calculated at a particular level utilizing an engineering calculation procedure and compared to the level at which the subjects place the noise. The results for the ten engineering calculation procedures evaluated are given in Table 2-2. The essential information begins with the column headed "Range of Differences", the first value in column "3" provides the difference between the calculated and judged level for the signal that was judged least annoying while the second value is for the signal that was judged most annoying. Column "4" identifies those signals that were least and

Table 2-2. Subjective dB* (dBW(S)) summary results for ten engineering calculation procedures.

| 1<br>Procedure | 2<br>Mean of Standard | 3<br>+Range of Differences | 4<br>Signals Contrib. to Range | 5<br>Absolute Range |
|---|---|---|---|---|
| dBA | 70.2 | -3.2 to +6.5 | 7 and 9 | 9.7 |
| $dBA_T$ | 73.3 | -3.1 to +6.9 | 4 and 9 | 10.0 |
| $dBA_D$ | 71.1 | -3.4 to +5.1 | 14 and 9 | 8.5 |
| EdBA | 74.2 | -3.2 to +4.9 | 14 and 9 | 8.1 |
| dBA (crest) | 75.9 | -7.2 to +7.2 | 1 and 9 | 14.4 |
| PNdB | 81.6 | -3.9 to +6.1 | 7 and 9 | 10.0 |
| $PNdB_D$ | 82.5 | -3.3 to +5.5 | 7 and 9 | 8.8 |
| EPNdB | 85.6 | -3.1 to +5.3 | 7 and 9 | 8.4 |
| dBD | 75.6 | -4.1 to +7.3 | 5 and 9 | 11.4 |
| dBE | 75.0 | -3.8 to +7.4 | 5 and 9 | 11.2 |

+ Differences are obtained utilizing Subjective dB less Mean of Standard.

* dBW(S) means a subjective or judged level utilizing a particular engineering calculation procedure. For example, dBA(S) refers to a judged level utilizing dBA.

most annoying and the absolute range for the differences is given in column "5". The engineering calculation procedure with the smallest absolute range best reflects the subjects' evaluation of the 16 noises.

The calculation procedure which best reflects the judgment results is EdBA although it is not significantly superior to EPNdB; EdBA has a range of differences of 8.1 EdBA while EPNdB has a range of differences of 8.4 EPNdB, a small difference of 0.3 dB. The aim of the pilot study was to determine various effects of "slap", so differences (Subjective dB less Calculated dB) for the sixteen signals are given in Figure 2-1 utilizing EdBA and dBA with the "crest" factor correction.

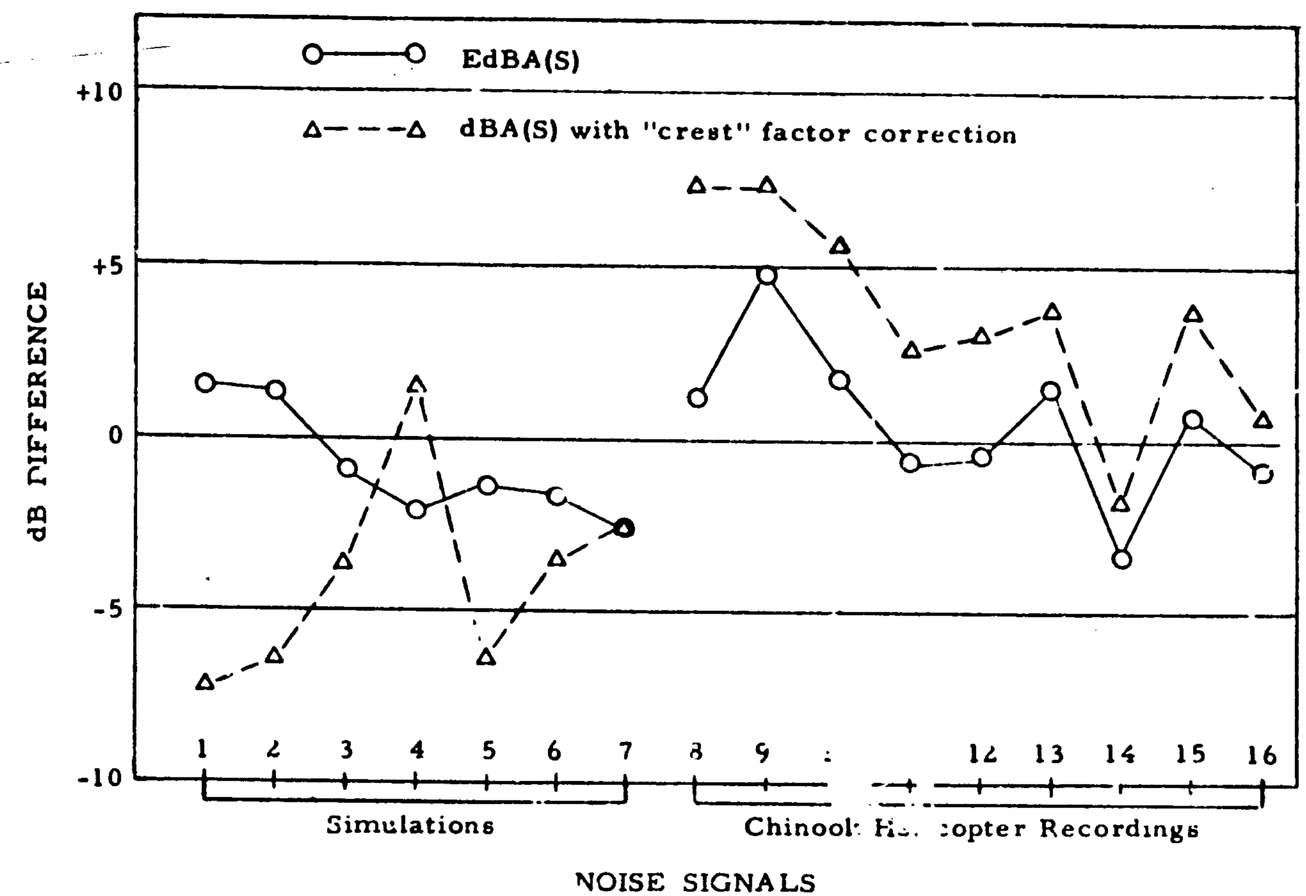



Figure 2-1. Differences between calculated and judged values utilizing two engineering calculation procedures.

Utilizing the calculation procedure (EdBA(S) and EdBA) that has the best relationship to the judgment results, the effect of "slap" can be evaluated by comparing differences between the calculated and judged levels for signals "1" through "4" which involved no, light, moderate, and heavy "slap" respectively. The no "slap" signal is judged 1.5 EdBA(S) greater than the mean of the standard, the light "slap" signal is 1.3 EdBA(S) greater than its calculated level, the moderate "slap" signal 1.0 EdBA(S) less than its calculated value, and the heavy "slap" signal is judged 2.2 EdBA(S) less than its calculated value. Utilizing this calculation procedure, the anncyance effects are fully accounted for; if the subjects were to have been adversely affected by the "slap", the differences would have moved in the direction of increasing "slap" producing increasing differences (an increasing function) instead of the decreasing function obtained. Also, the range of differences for these four signals (-2.2 to 1.5 EdBA) of 3.7 EdBA(S) is small enough to indicate that the calculation procedure validly reflects annoyance to these four signals. There is no evidence that a special correction for "slap" is required. Note that when utilizing the "crest" factor correction to dBA, annoyance does increase as "slap" increases but the range of differences is so great (absolute range of 8.8 dBA (crest) for the four signals) that it can be concluded that this calculation procedure does not validly reflect annoyance response. It is most difficult to apply the crest factor correction (CFF) to EdBA or EPNdB. Since duration and tone corrections reduce the absolute range by 2.6 EdBA(S) for dBA(S), applying these corrections to dBA (crest)(S) where the absolute range is 14.4 dBA(crest)(S) would not have been worthwhile.

Signals 5, 3, 6 all contained moderate slap but impulse noise was at 6, 10, and 18 beats/sec. Thusly, all variables are held constant and number of beats per second is allowed variation. Figure 2-2 provides the results and shows that number of beats per second is not related to annoyance. Subjects' evaluations of the three noises show no consistent relationship of annoyance to number of beats per second and that all three noises are judged slightly less annoying than if calculated utilizing EdBA.

Figure 2-2 also provides a comparison between a slower and faster rise time for beats utilizing the EdBA(S) less EdBA calculation procedure. This comparison is based on evaluations of signals "3" and "7" which permit only rise time to vary. The faster rise time signal is judged 1.5 EdBA(S) less annoying than the slower rise time signal which is a small enough difference to be considered experimental error. The dBA weighting network adequately accounts for the higher frequency content produced by the faster rise time.

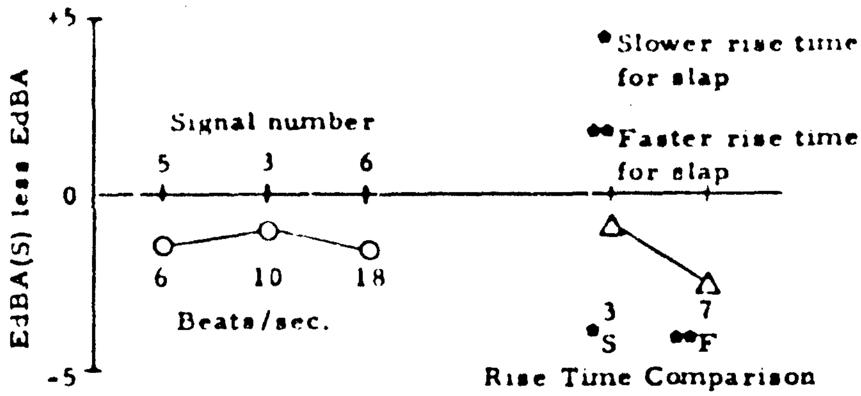



Figure 2-2. Difference between judged (EdBA(S)) and calculated (EdBA) values as a function of beats per second and rise time.

Other than the "crest" factor correction, a final consideration involves sound recording and reproduction capability associated with low frequency content. Examining the three Chinook recordings in groups of three (signals 8, 9, and 10 which is a level flyby utilizing the three recording methods as an example), shows that recording and reproduction methods do not consistently affect the annoyance judgments (Figure 2-1).

### 2.9.2 Conclusions

Pilot study conclusions are:

- No special correction is required for "slap" effect over and above the calculated EdBA or EPNdB which reflects the subjective reaction within less than ±2 dB.

- For the range of beats per second expected from helicopter operations, number of beats per second does not influence annoyance response to helicopter noise.

- Rise time effects for the impulse part of the helicopter noise are accounted for by engineering calculation procedures such as PNdB and dBA which are significantly improved by the FAR-36 duration correction.

- The low frequency content (from approximately 5 to 40 Hz) of helicopter noise does not increase annoyance effects at the levels investigated which were 61 to 79 dBA.

## 2-10. References


2-1. Society of Automotive Engineers, "An Evaluation of Psycho-acoustic Procedures for Determining Human Response to Aircraft Noise, Vol. I - Specifications for Four Experiments", FAA-RD-72-51, I, October 1973.

2-2. Mabry, J. E., and Parry, H. J., "An Evaluation of Psycho-acoustic Procedures for Determining Human Response to Aircraft Noise, Vol. II - Demonstrated Examples", FAA-RD-72-51, II, October 1973.

2-3. MAN-Acoustics and Noise, Inc., "Noise Certification Criteria and Implementation Considerations for V/STOL Aircraft", FAA-RD-75-190, November 1975.

2-4. Munch, C. L., and King, R. J., "Community Acceptance of Helicopter Noise: Criteria and Application", NASA CR-132430, 1974.

# 3.0 MAIN STUDY

## 3.1 Experiment Description

### 3.1.1 Approach

Twenty-four persons made both magnitude estimation and absolute acceptability judgments to both actual and simulated recordings of helicopter noise signals, and to recordings of CTOL aircraft flyovers using the following instructions:

INSTRUCTIONS

> We are asking you to help us answer the question, "How annoying are various kinds of sounds?" We will ask you to listen to some sounds and rate them in terms of annoyance. The sounds you are to rate will be presented to you one-at-a-time. Listen to all of each sound before making your judgment. In a moment, we will have you listen to a sound with an annoyance score of 10. Use that sound as a standard, and judge each succeeding sound in relation to that standard. For example, if a sound seems twice as annoying as the standard, you will write "20" in the space for that sound on the answer sheet. If it seems only one-quarter as annoying, write 2-1/2. If it seems three times as annoying, write "30". If one-half as annoying, write "5", and so on.
>
> We will also ask you to judge if each sound you hear would be acceptable to you if you experienced it in your home four or five times an hour during your waking hours. This requires a simple "yes" or "no" answer in the space provided on the answer sheet.
>
> Your ratings should reflect only your own opinion of the sounds; that is what we want. Each sound is numbered to correspond to the numbers on your answer sheet.
>
> You will now hear the standard sound with an annoyance rating of 10, followed by five more sounds. Rate each of the sounds following the standard as previously instructed; a score of 20 if twice as annoying, 5 if half as annoying, and so on. Be sure to listen to all of each sound before making your judgment. Also, indicate your judgment of the acceptability of each sound.

Each subject evaluated twenty-four noises of which seven were the simulations used in the pilot study, six were takeoff and landings of CTOL aircraft, and eleven were recordings of operational helicopters. Subjects were individually tested in a small semi-reverberant chamber so that spectral characteristics and level could be controlled. All twenty-four noises were presented at five different levels and order of signal and tape presentation was randomized. Total testing time for each subject was two to two and one-half hours. So that the subjects would not become fatigued by evaluating too many noises without rest, signals were presented in groups of twelve with each grouping followed by rest periods. Thusly, each of the twenty-four persons evaluated 120 individual noise events for a total of 2880 noise evaluations. Essentials of the main study experiment are:

-- Noise signals were twenty-four in number.

-- Noise evaluations involved both magnitude estimation and absolute acceptability methods.

-- Twenty-four persons each evaluated 120 distinct noise events.

-- Twelve different engineering calculation procedures were evaluated leading to 34, 560 evaluations of the data points.

### 3.1.2 Flyover Signals

The noise signals used in the main study are given in Table 3-1. The seven simulations used in the Pilot Study were again investigated in the main study as a means of checking on the findings from the pilot study but utilizing a larger and different sample of subjects. Signals 8 through 13 are of CTOL aircraft and are included for comparative purposes. The remaining eleven signals are quality dbx recordings of operational helicopters performing various operations.

### 3.1.3 Dependent Measures

As provided in the instructions, the subject's task involved two evaluations of each of the 120 noises presented. They first used magnitude estimation as a noise rating approach and then made an absolute acceptability judgment as to whether or not they could accept that particular noise if experienced four or five times an hour during their waking hours. A description of these two methods for evaluating the noise is given in Reference 3-1, pp 2-6 to 2-9. Briefly, the magnitude estimation results are used to evaluate the effectiveness of various

Table 3-1. Listing of noise signals.

| No. | Flyover/Simulation | Description |
|---|---|---|
| 1 | Simulation | Tail rotor noise with no slap (standard). |
| 2 | Simulation | Tail rotor noise w/ light slap at 10 b/s.* |
| 3 | Simulation | Tail rotor noise w/ moderate slap at 10b/s. |
| 4 | Simulation | Tail rotor noise w/ heavy slap at 10 b/s. |
| 5 | Simulation | Tail rotor noise w/ moderate slap at 6 b/s. |
| 6 | Simulation | Tail rotor noise w/ moderate slap at 18b/s. |
| 7 | Simulation | Tail rotor noise w/ moderate slap at 10b/s. and fast rise time. |
| 8 | Boeing 747 | Takeoff |
| 9 | DC-8 | Takeoff |
| 10 | Boeing 747 | Approach |
| 11 | DC-8 | Approach |
| 12 | Britten-Norman Islander | Takeoff of small commuter reciprocating. |
| 13 | Convair 640 | Takeoff of medium sized turboprop. |
| 14 | Chinook CH 47-A | Level flyover at 500 ft. altitude. |
| 15 | Chinook CH 47-A | Routine Approach |
| 16 | Chinook CH 47-A | Routine takeoff |
| 17 | Bell UH-1H (Huey) | Level flyover at 500 ft. altitude. |
| 18 | Kiowa OH-58 | Level flyover at 500 ft. altitude. |
| 19 | Kiowa OH-58 | Routine approach |
| 20 | Sea Knight | Level flyover at 500 ft. altitude. |
| 21 | Sea Knight | Shallow turn operation. |
| 22 | Hughes 300 | Steep turn operation. |
| 23 | Bell UH-1H (Huey) | Routine takeoff |
| 24 | Hughes 300 | Level flyover at 500 ft. altitude |

* beats/second

engineering calculation procedures while the absolute acceptability data involve predictions concerning acceptability of helicopter noise in the community.

### 3.1.4 Engineering Calculation Procedures

Twelve engineering calculation procedures were evaluated, including OASPL. Both PNdB and dBA were emphasized due to the wide use of these approaches. Procedures evaluated are:

| | | |
|---|---|---|
| PNdB | dBA | Mark VII |
| + $PNdB_T$ | $dBA_T$ | Mark $VII_D$ |
| $PNdB_D$ | $dBA_D$ | dBE |
| EPNdB | EdBA | OASPL |

+ "T" is tone correction according to FAR-36.

"D" is duration correction according to FAR-36.
EPNdB and EdBA means that the basic procedure is corrected for both tone and duration according to FAR-36.

### 3.1.5 Data Analysis Considerations

There are two sets of dependent measures that are to be related to twelve engineering calculation procedures. The first set involves the magnitude estimation approach which is basic to the question, "Which engineering calculation procedure best defines or reflects annoyance to a diverse group of noises?" The second set of dependent measures involves the level at which persons would find a particular flyover "acceptable" if experienced four to five times per hour during usual daytime living activities.

A productive approach for investigating the effectiveness of various engineering calculation procedures is to relate the mean of the log-magnitude estimations (log of the geometric means) to the various measured values as determined by each engineering calculation procedure. The engineering calculation procedure that provides the smallest range of determinations based on judgment results would thusly have the widest application to a diverse set of noises and would be accepted as the "best" procedure. However, this approach does not quantify from a statistical interence point of view whether or not there are real (not chance) differences among the noises as evaluated by the judges. A statistical model which permits an evaluation of the extent that the various noises differ reliably utilizes analysis of variance. Instead of relating the mean of the log-magnitude estimations of the twenty-four subjects to measured levels for each engineering calculation procedure, results are first obtained for each individual subject. For the present study, each subject judged twenty-four noises at five different levels. To obtain results for individual subjects, the following is completed for each subject:

(1) Obtain equation for best-fitting line using all levels of all noises investigated for each individual subject. This would involve 5 levels x 24 noises for 120 pairs of points.

(2) Obtain equation for best-fitting line for each individual noise. Each individual noise determination is based on five pairs of points.

(3) Using the mean for the particular engineering calcu-

lation procedure under investigation, for each noise, determine the subjective response score determined by this grand mean.

(4) Using this subjective response score (obtained from (3) above), calculate the engineering calculation procedure value via best-fitting line based on all observations ((1) above).

Applying this approach on a subject by subject basis means that subjective dB's are obtained for each of the twenty-four noises but based only on the judgments of one person. Consequently, subjective dB's for one subject are independent of those obtained from a second, third, or fourth subject. Thusly, they are used as the dependent measure in a randomized block design with subjects conceptualized as the blocks and the noises as randomly assigned within a particular subject or block. Such an approach provides a 24 subjects x 24 noises matrix and the interaction between subjects and noises is the appropriate error term. Thusly, the extent of real (not chance) differences among subjects or noises can be determined. Each of the twelve engineering calculation procedures will be investigated utilizing this analysis of variance approach.

### 3.1.6 Absolute Acceptability Analysis

The main interest is the extent that persons predict that they would accept flyovers at a particular level. This is important relative to establishing noise levels around airports with which communities would and could live. These results are based on "0-1" datum (not accept or accept) which can also be evaluated using analysis of variance.

### 3.1.7 Subjects

There were thirteen females and eleven males taking part in the study. They were selected from a subject pool that had been accumulated for previous studies. The main requirements were that none of them had serious hearing deficiencies and that they had not taken part in a previous comparable study (Ref. 3-1). This last requirement permits an independent comparison between the two studies. Each subject was examined audiometrically. Prior to taking part in the study, a noise oriented questionnaire was administered to each; there was particular interest in determining that the group could be considered representative of an adult population in general. Following are summaries of pertinent characteristics of persons taking part. The question or characteristic investigated is provided along with the response information.

(1) How do you like living in this neighborhood? Do you rate it as an excellent, good, fair, poor, or very poor place to live?

| | Female | Male |
|---|---|---|
| Excellent | 31% | 36% |
| Good | 46% | 46% |
| Fair | 23% | 0% |
| Poor | 0% | 9% |
| Very Poor | 0% | 9% |

Some 75-80% for both females and males rate their neighborhood as an excellent or good place to live.

(2) Do you like many things, just a few things, hardly anything, or nothing at all about living around here?

| | Female | Male |
|---|---|---|
| Many things | 100% | 82% |
| A few things | --- | --- |
| Hardly anything | --- | --- |
| Nothing at all | --- | 18% |

Again the group is quite positive concerning their neighborhood. With the exception of two males, all persons like many things about where they live.

(3) What are some of the things you don't like about living in your neighborhood?

This open-ended question was examined for whether or not noise was mentioned. Only one female (8%) mentioned traffic noise as a dislike about her neighborhood while four of the males (36%) reported that noise was one of the things that they disliked about their neighborhood. Noisy cars, motorcycles, barking dogs, and traffic noise were given by the males.

(4) How noisy or quiet do you think this neighborhood is? Very noisy, somewhat noisy, somewhat quiet, very quiet?

| | Female | Male |
|---|---|---|
| Very noisy | 8% | 0% |
| Somewhat noisy | 23% | [illegible]% |
| Somewhat quiet | 54% | 27% |
| Very quiet | 15% | 27% |

As with question (3), the females perceive their neighborhood as being more on the quiet side than do the males. Almost one-half of the males rate their neighborhood as being "somewhat" noisy.

(5) When you're inside your house, does noise in the neighborhood bother or annoy you very much, moderately, very little, or not at all?

| | Female | Male |
|---|---|---|
| Very much | 0% | 9% |
| Moderately | 23% | 27% |
| Very little | 54% | 46% |
| Not at all | 23% | 18% |

There is little difference between females and males on this item; 3 females and 3 males are moderately bothered by neighborhood noise while one male is very much bothered.

(6) When you're inside your house, which is the MOST bothersome noise from the neighborhood that you hear?

| Category | F | M | Category | F | M |
|---|---|---|---|---|---|
| Cars | 20% | 47% | General noise (night) | 7% | 0% |
| Motorcycles | 33% | 20% | | | |
| Barking dogs | 13% | 13% | Neighbors | 7% | 7% |
| Sirens | 0% | 13% | Garbage collec. | 7% | 0% |
| Nothing | 13% | 0% | | | |

The responses to this question do not mean that the persons are unusually disturbed by the noises since they were directly asked to give the, "MOST bothersome noise from the neighborhood?" As can be seen, the majority of persons select some form of surface transportation as the most bothersome noise with barking dogs as second.

(7) Each participant responded to a ten item noise sensitivity test which has been utilized in a number of previous studies (Ref. 2-3). Subjects responded using the following category scale:

a. Extremely annoying
b. Moderately annoying
c. Slightly annoying
d. Not annoying

The ten items were scored as 0, 1, 2, or 3 with "0" for Not annoying and "3" for Extremely annoying. This means that scores could range from 0 to 30. The mean and range of scores to the noise sensitivity test are:

| | Females | Males |
|---|---|---|
| MEAN | 21.9 | 20.5 |
| RANGE | 17 - 27 | 10 - 27 |

Both the females and males scored relatively high on this noise sensitivity test. Earlier work (Ref. 3-1, p 2-13) shows mean scores of approximately 15. These persons either see themselves as being more sensitive to noise than others or with the high interest of late in reducing noise levels, perhaps persons are more willing to rate themselves as being noise sensitive.

(8) Compared to other people, are you more aware of noise than others, about the same as others, or less aware of noise than other persons?

| | Female | Male |
|---|---|---|
| More aware | 46% | 36% |
| Same | 46% | 46% |
| Less aware | 8% | 18% |

More persons in this group feel that they are more aware of noise than those in the group who feel that they are less aware of noise than others.

(9) Some people have said that, "pollution is one of the biggest problems of modern times." Would you agree strongly, agree somewhat, disagree somewhat, or disagree strongly with that statement?

| | Female | Male |
|---|---|---|
| Agree strongly | 69% | 82% |
| Agree somewhat | 31% | 18% |
| Disagree some | -- | -- |
| Disagree strongly | -- | -- |

All of the subjects agree to some extent that pollution is a serious problem with the males feeling more strongly that it is a problem than the females.

(10) This section provides characteristics relative to socio-economic level such as number of years of schooling completed, income, and occupation plus age of the participants.

## SCHOOLING COMPLETED

| | Female | Male |
|---|---|---|
| AVERAGE YEARS Schooling Completed | 13.9 | 16.4 |
| RANGE OF YEARS Completed | 12 - 17 | 11 - 22 |

The subjects were, for the most part, above average in respect to education. All of the females were high school graduates and many of them had some college experience. Educational range for the males was wider than for the females but their educational level was higher on the average.

## YEARLY FAMILY INCOME

| | Female | Male |
|---|---|---|
| Under $5,000 | 8% | 18% |
| 5,000 - 9,999 | 23% | 9% |
| 10,000 - 14,999 | 46% | 37% |
| 15,000 - 19,999 | 8% | 27% |
| 20,000 or more | 15% | 9% |

There is a wide range of yearly incomes with more persons falling in the middle income (10,000 - 14,999) group than for the other five income classifications.

## SUMMARY OF AGES FOR PARTICIPANTS

| Age Category | Female | Male |
|---|---|---|
| 20 - 24 | 0% | 18% |
| 25 - 29 | 8% | 9% |
| 30 - 34 | 23% | 9% |
| 35 - 39 | 15% | 27% |
| 40 - 49 | 31% | 27% |
| 50 - 59 | 15% | 9% |
| 60 & over | 8% | 0% |

Median age for the females was approximately 42 years while it was approximately 37 years for the males. Both groups covered a wide range of ages.

(11) Results from the attitudinal items have more meaning when compared to those obtained from a random sample of persons that are representative of a larger population. Responses to these same questions were obtained from adult respondents residing in 659 randomly selected households (Ref. 3-2). Results from this study follow, along with those for the females and males of the present study. The Paragraph Number (Para. No.) heading in the first column corresponds to the numbered paragraph of this section in which more detailed results are presented. Under "Item", a synopsis of the question is given while the third column gives the "Category" that was studied for comparison.

COMPARISON OF SOME ATTITUDINAL RESULTS TO THOSE FROM A PREVIOUS STUDY

| Para. No. | Item | Category | Prev. Study | F | M |
|---|---|---|---|---|---|
| (1) | Rate neighborhood? | Excellent | 28% | 31% | 36% |
| (2) | How many things like? | Many things | 54% | 100% | 82% |
| (3) | Things don't like? | +Open-end ques. | 28% | 8% | 36% |
| (4) | How noisy or quiet? | Somewhat quiet | 42% | 54% | 27% |
| (5) | Awareness of noise? | More aware | 24% | 46% | 36% |
| (9) | Pollution question | Agree strongly | 66% | 69% | 82% |

+Percent is for those who stated some noise event not liked.

Using the results from the previous numbered paragraphs and the comparison data of paragraph (11), a profile of the subjects is provided.

(a) Both the females and males for this study are slightly more inclined to rate their neighborhood as "Excellent" than those from a larger random sample but not to a significant extent. However, there is a much stronger tendency for persons from this study to report that they like "Many things" about their neighborhood when compared to response from the larger random sample.

(b) Noise as a "dislike" to the open-ended question is not emphasized by the females of this study but the males are, on the average, more inclined to spontaneously give noise as a "dislike" than are persons in the larger sample. For this study, the females rate their neighborhood on the quiet side to a greater extent than do the males. However, the average rating of males and females (41%) is very close to the 42% rating of "Somewhat quiet" for the larger random sample.

(c) Both females and males rate themselves as being more sensitive to noise than others and report that they are more aware of noise than does a large, random sample of respondents.

(d) In summary, the subjects represent a wide range of ages and income, tend to like their neighborhood, are fairly highly educated, the females perceive their neighborhood as being more on the quiet side than do the males and both females and males appear to have higher sensitivity to noise than other groups of persons who were tested some five to seven years ago.

## 3.2 Physical Acoustic Considerations

There are three main aspects involving the physical acoustics of psychophysical studies. These are:

(1) Recordings and simulations of the signals of interest.

(2) Signal presentation.

(3) Signal analysis.

Approaches utilized for the main study were identical to those used for the pilot study with the exception that no FM recording and presentation activities were employed as the pilot study results had demonstrated that this approach was not essential. Also, methods employed were identical to those used in Reference 3-1 where complete details are provided in Sections 3.0 and 4.0. Recording and signal presentation involved dbx techniques which provide extremely low or no "noise" tapes. All signals were monitored as they were presented to make certain that levels did not vary. Again, as in Reference 3-1, all signal analysis was performed via a GR 1921 Real Time Analyzer in conjunction with a PDP 11/10 computer. Calculated levels utilized are given for all 24 signals and the 12 engineering calculation procedures in Appendix A.

## 3.3 Results

### 3.3.1 Magnitude Estimation

The magnitude estimation judgments are related to the 12 engineering calculation procedures using two different approaches. One approach is the subjective dB method which provides a comparison of a judged level vs a calculated level while the second approach involves obtaining equally annoying point solutions as described in Reference 2-1 and 2-2. A third approach uses the absolute acceptability results to obtain equally annoying point solutions. For all three methods, the best engineering calculation procedure provides the smallest mean difference and variability (variance or standard deviation) based on judgment results to the five levels of the twenty-four noises. Table 3-2 gives the mean of differences between judged and calculated values and standard deviations for the three methods. For all calculation procedures, the mean difference is significantly smaller for the subjective dB method and for all calculation procedures except OASPL, the standard deviations for the subjective dB method are less than for the other two methods. Thusly, results from the subjective dB approach are emphasized for further analyses.

As shown in the first column of Table 3-2, the mean difference for all 12 calculation procedures approaches zero as a limit. However, there are large differences among the standard deviations of these differences. Figure 3-1 provides plots of the standard deviations for the twelve calculation procedures. Mark $VII_D$ shows the least amount of variability although $PNdB_D$ does not show significant greater variability than Mark $VII_D$. Note that for both PNdB and dBA that the FAR-36 tone correction increases variability, indicating that the correction is not needed for these signals. The procedure that is least valid is OASPL with a standard deviation that is almost four times that of Mark $VII_D$. It is clear that OASPL does not adequately reflect annoyance to these twenty-four signals.

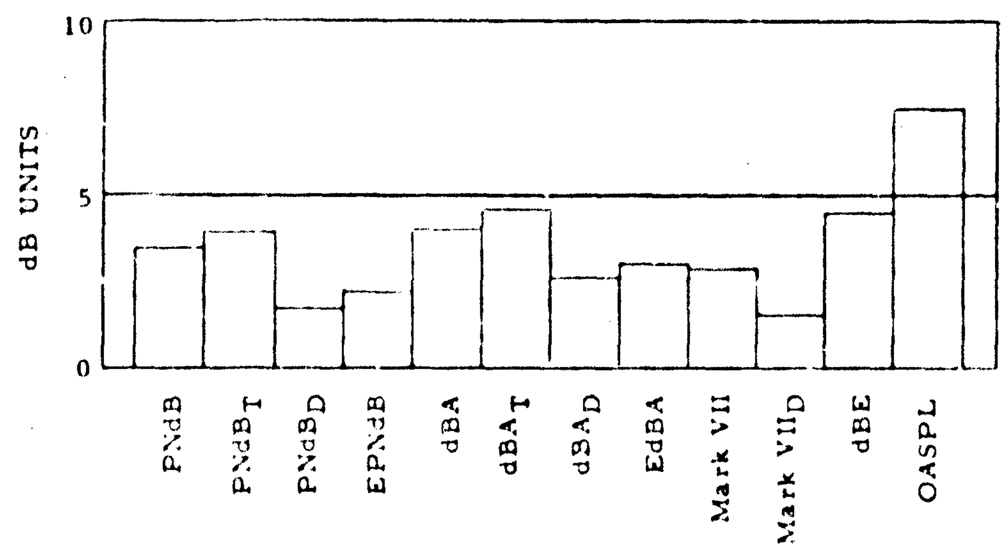



Figure 3-1. Standard deviations based on differences (calculated vs judged level) for 12 engineering calculation procedures.

Table 3-2. Mean of differences of judged levels from calculated levels utilizing three methods.

| | SUBJECTIVE dB | | EQUAL ANNOY. Pt. | | ACCEPTABILITY | |
|---|---|---|---|---|---|---|
| | Mean Difference | Stand. Dev. | Mean Difference | Stand. Dev. | Mean | Stand. Dev. |
| PNdB | -.02 | 3.55 | 1.65 | 4.22 | 0.09 | 5.31 |
| $PNdB_T$ | -.01 | 3.92 | 2.29 | 4.54 | 0.72 | 5.55 |
| $PNdB_D$ | -.11 | 1.90 | 3.47 | 2.53 | 1.87 | 3.34 |
| EPNdB | -.12 | 2.11 | 4.39 | 2.73 | 2.79 | 3.45 |
| dBA | 0.00 | 4.00 | 3.46 | 4.41 | 2.00 | 5.32 |
| $dBA_T$ | -.01 | 4.54 | 4.15 | 4.69 | 2.67 | 5.53 |
| $dBA_D$ | -.11 | 2.62 | 5.24 | 2.98 | 3.76 | 3.35 |
| EdBA | -.13 | 2.96 | 6.19 | 3.22 | 4.70 | 3.56 |
| Mark VII | 0.00 | 2.98 | 1.76 | 3.60 | 0.39 | 4.66 |
| Mark $VII_D$ | -.09 | 1.73 | 2.80 | 2.07 | 1.41 | 2.71 |
| dBE | 0.01 | 4.40 | 2.86 | 4.56 | 1.41 | 5.56 |
| OASPL | 0.26 | 7.27 | -.14 | 5.35 | -1.59 | 6.40 |

Since there is high interest in response to helicopter noise on its own, mean differences and standard deviations (S. D.) were obtained for the helicopter simulations and actual recordings of helicopters separately. These results are given in Table 3-3. For the recorded helicopter signals, $PNdB_D$ has the least variability (it is superior to Mark $VII_D$) and again the FAR-36 tone correction degrades the relationship between the judged and calculated levels.

Analysis of variance was also completed utilizing individual subjective dB's for all twelve calculation procedures. Analysis was completed for all twenty-four of the noises, the eleven recordings of helicopter noise, and the seven simulations separately. Summaries of these analyses of variance are given in Tables 3-4, 3-5, and 3-6. Results are that for all analyses, the noises, on the whole, are significantly different among themselves. No calculation procedure works perfectly. However, again $PNdB_D$ and Mark $VII_D$ stand out as being the most valid in that these calculation procedures provide the smallest F-ratios. For the separate analysis of the recorded helicopter noises, $PNdB_D$ shows the smallest F-ratio. Also, the tone correction again reduces the relationship between the judged and calculated values.

Summary information for the magnitude estimation method is given in Table 3-7. Column (1) provides the range of subjective dB evaluations while the second column gives the absolute range of the subjective dB's. The smaller the range, the more valid the engineer-

Table 3-3. Mean of differences utilizing Subjective dB based on all noises, simulations, & helicopters.

| | ALL NOISES N = 24 | | SIMULATIONS N = 7 | | HELICOPTERS N = 11 | |
|---|---|---|---|---|---|---|
| | Mean Difference | Stand. Dev. | Mean Difference | Stand. Dev. | Mean Difference | Stand. Dev. |
| PNdB(S)+ | -.02 | 3.55 | -.06 | 1.77 | -.01 | 3.58 |
| $PNdB_T$(S) | -.01 | 3.92 | -.04 | 2.11 | .02 | 4.18 |
| $PNdB_D$(S) | -.11 | 1.90 | -.05 | 1.89 | -.18 | 1.92 |
| EPNdB(S) | -.12 | 2.11 | -.03 | 2.22 | -.18 | 2.00 |
| dBA(S) | .00 | 4.00 | -.03 | 2.77 | .00 | 4.82 |
| $dBA_T$(S) | -.01 | 4.54 | -.01 | 3.29 | .02 | 5.86 |
| $dBA_D$(S) | -.11 | 2.62 | -.01 | 2.92 | -.16 | 3.14 |
| EdBA(S) | -.13 | 2.96 | .01 | 3.43 | -.17 | 3.37 |
| Mark VII(S) | .00 | 2.98 | -.07 | 1.54 | .00 | 3.02 |
| Mark $VII_D$(S) | -.09 | 1.73 | -.06 | 1.61 | -.14 | 2.19 |
| dBE(S) | .01 | 4.40 | -.04 | 2.59 | -.02 | 4.76 |
| OASPL(S) | .26 | 7.27 | -.05 | 1.84 | .19 | 7.27 |

+ (S) means based on subjective or judged level.

ing calculation procedure. Utilizing the absolute range, Mark $VII_D$ (followed closely by $PNdB_D$) is the most valid engineering calculation procedure. Column (7) gives the product moment coefficients of correlation for mean judgment data vs the various engineering calculation procedures. PNdB, Mark $VII_D$, EPNdB, and $dBA_D$ are all above 0.90 with $PNdB_D$ and Mark $VII_D$ being the highest. Again, the correlations show that the tone correction reduces the relationship between judged and calculated values and is thusly not required for these noises. Correlations based on individual noises (column (8)) are higher than those based on all of the noises, indicating that there are unique reactions if only level is varied. Rates of change of annoyance range from approximately 11.5 to 12.5 dB (with the exception of Mark VII and OASPL) for doubling of annoyance effects instead of the expected 10 dB. Although OASPL was included for comparison purposes only, it is interesting that it is unusually poor as a predictor of noise effects in all respects. Its rate of change for doubling noise effects is almost 17 dB while rate of change for doubling utilizing Mark VII is 10.3 dB.

A final statistical inference kind of comparison involves how large must a difference between ratings of two signals be for the difference to be accepted as a reliable (non-chance) difference? Duncan's Multiple Range Test was applied to the subjective dB results for the 24 signals utilizing EPNdB and the results are given in Figure 3-2. For this number of means, differences must be approximately 3 to 4 EPNdB for these differences to be reliable at the P<.01 level. Any two sig-

Table 3-4. Summary of analysis of variance for individual subjective dB's based on 12 engineering calculation procedures. (All 24 Signals)

| ENGINEER. CALC. PROC. | SOURCE OF VARIANCE | SUM OF SQUARES | df | MEAN SQUARE | F-ratio | SIGNIF. POINT |
|---|---|---|---|---|---|---|
| PNdB(S) | Noises | 7672.88 | 23 | 333.60 | 18.07 | P<.005 |
| | Subjects | 3.86 | 23 | .17 | .01 | ------ |
| | Error | 9767.80 | 529 | 18.46 | | |
| $PNdB_T(S)$ | Noises | 9466.16 | 23 | 411.57 | 20.04 | P<.005 |
| | Subjects | 3.39 | 23 | .15 | .01 | ------ |
| | | 10861.66 | 529 | 20.53 | | |
| $PNdB_D(S)$ | Noises | 2225.56 | 23 | 96.76 | 5.52 | P<.005 |
| | Subjects | 20.48 | 23 | .89 | .05 | ------ |
| | Error | 9274.42 | 529 | 17.53 | | |
| EPNdB(S) | Noises | 2753.25 | 23 | 119.71 | 6.63 | P<.005 |
| | Subjects | 21.58 | 23 | .94 | .05 | ------ |
| | Error | 9553.53 | 529 | 18.06 | | |
| dBA(S) | Noises | 9871.06 | 23 | 429.18 | 22.92 | P<.005 |
| | Subjects | 1.36 | 23 | .06 | ----- | ------ |
| | Error | 9907.70 | 529 | 18.73 | | |
| $dBA_T(S)$ | Noises | 12742.38 | 23 | 554.02 | 24.25 | P<.005 |
| | Subjects | 5.19 | 23 | .23 | .01 | ------ |
| | Error | 11605.17 | 529 | 21.94 | | |
| $dBA_D(S)$ | Noises | 4351.75 | 23 | 189.21 | 10.22 | P<.005 |
| | Subjects | 33.33 | 23 | 1.45 | .08 | ------ |
| | Error | 9790.92 | 529 | 18.51 | | |
| EdBA(S) | Noises | 5556.88 | 23 | 241.60 | 12.22 | P<.005 |
| | Subjects | 40.42 | 23 | 1.76 | .09 | ------ |
| | Error | 10463.56 | 529 | 19.78 | | |
| Mark VII(S) | Noises | 5484.31 | 23 | 238.45 | 16.86 | P<.005 |
| | Subjects | 3.02 | 23 | .13 | .01 | ------ |
| | Error | 7483.19 | 529 | 14.15 | | |
| Mark $VII_D(S)$ | Noises | 1977.02 | 23 | 85.96 | 5.39 | P<.005 |
| | Subjects | 30.08 | 23 | 1.31 | .08 | ------ |
| | Error | 8432.52 | 529 | 15.94 | | |
| dBE(S) | Noises | 11849.88 | 23 | 515.21 | 26.39 | P<.005 |
| | Subjects | 4.06 | 23 | .18 | .01 | ------ |
| | Error | 10327.98 | 529 | 19.52 | | |
| OASPL(S) | Noises | 32065.17 | 23 | 1394.14 | 37.89 | P<.005 |
| | Subjects | 73.58 | 23 | 3.20 | .09 | ------ |
| | Error | 19464.33 | 529 | 36.80 | | |

Table 3-5. Summary of analysis of variance for individual subjective dB's based on 12 engineering calculation procedures. (11 Helicopters)

| ENGINEER. CALC. PROC. | SOURCE OF VARIANCE | SUM OF SQUARES | df | MEAN SQUARE | F-ratio | SIGNIF. POINT |
|---|---|---|---|---|---|---|
| PNdB (S) | Noises | 3083.91 | 23 | 134.08 | 9.09 | P<.01 |
| | Subjects | 2.61 | 10 | .26 | .02 | ----- |
| | Error | 3393.52 | 230 | 14.75 | | |
| $PNdB_T$ (S) | Noises | 4194.04 | 23 | 182.35 | 11.02 | P<.01 |
| | Subjects | 2.27 | 10 | .23 | .01 | ----- |
| | Error | 3807.19 | 230 | 16.55 | | |
| $PNdB_D$ (S) | Noises | 882.43 | 23 | 38.37 | 2.20 | P<.01 |
| | Subjects | 44.01 | 10 | 4.40 | .25 | ----- |
| | Error | 4003.31 | 230 | 17.41 | | |
| EPNdB (S) | Noises | 960.80 | 23 | 41.77 | 2.34 | P<.01 |
| | Subjects | 45.48 | 10 | 4.55 | .26 | ----- |
| | Error | 4101.53 | 230 | 17.83 | | |
| dBA (S) | Noises | 5586.48 | 23 | 242.89 | 14.16 | P<.01 |
| | Subjects | 4.79 | 10 | .48 | .03 | |
| | Error | 3943.75 | 230 | 17.15 | | |
| $dBA_T$ (S) | Noises | 8227.97 | 23 | 357.74 | 16.02 | P<.01 |
| | Subjects | 10.63 | 10 | 1.06 | .05 | ----- |
| | Error | 5135.36 | 230 | 22.33 | | |
| $dBA_D$ (S) | Noises | 2359.83 | 23 | 102.60 | 5.05 | P<.01 |
| | Subjects | 65.44 | 10 | 6.54 | .32 | ----- |
| | Error | 4676.34 | 230 | 20.33 | | |
| EdBA (S) | Noises | 2723.13 | 23 | 118.40 | 5.45 | P<.01 |
| | Subjects | 70.54 | 10 | 7.05 | .33 | ----- |
| | Error | 4999.06 | 230 | 21.74 | | |
| Mark VII (S) | Noises | 2184.67 | 23 | 94.99 | 8.80 | P<.01 |
| | Subjects | 1.38 | 10 | .14 | .01 | ----- |
| | Error | 2481.27 | 230 | 10.79 | | |
| Mark $VII_D$ (S) | Noises | 1149.98 | 23 | 50.00 | 2.88 | P<.01 |
| | Subjects | 68.11 | 10 | 6.81 | .39 | ----- |
| | Error | 3998.06 | 230 | 17.38 | | |
| dBE (S) | Noises | 5428.37 | 23 | 236.02 | 14.23 | P<.01 |
| | Subjects | 8.70 | 10 | .87 | .05 | ----- |
| | Error | 3815.63 | 230 | 16.59 | | |
| OASPL (S) | Noises | 12669.50 | 23 | 550.85 | 14.90 | P<.01 |
| | Subjects | 122.13 | 10 | 12.21 | .33 | ----- |
| | Error | 8502.63 | 230 | 36.97 | | |

Table 3-6. Summary of analysis of variance for individual subjective dB's based on 12 engineering calculation procedures. (7 Simulations)

| ENGINEER. CALC. PROC. | SOURCE OF VARIANCE | SUM OF SQUARES | df | MEAN SQUARE | F-ratio | SIGNIF. POINT |
|---|---|---|---|---|---|---|
| PNdB(S) | Noises | 449.34 | 23 | 19.54 | 3.62 | P<.01 |
| | Subjects | 2.20 | 6 | .37 | .07 | ----- |
| | Error | 745.29 | 138 | 5.40 | | |
| $PNdB_T(S)$ | Noises | 639.75 | 23 | 27.82 | 4.77 | P<.01 |
| | Subjects | .71 | 6 | .12 | .02 | |
| | Error | 804.31 | 138 | 5.83 | | |
| $PNdB_D(S)$ | Noises | 516.20 | 23 | 22.44 | 4.03 | P<.01 |
| | Subjects | 1.83 | 6 | .31 | .06 | |
| | Error | 768.51 | 138 | 5.57 | | |
| EPNdB(S) | Noises | 710.81 | 23 | 30.91 | 5.13 | P<.01 |
| | Subjects | .63 | 6 | .10 | .02 | ----- |
| | Error | 831.45 | 138 | 6.02 | | |
| dBA(S) | Noises | 1103.00 | 23 | 47.96 | 7.39 | P<.01 |
| | Subjects | 1.23 | 6 | .21 | .03 | ----- |
| | Error | 895.97 | 138 | 6.49 | | |
| $dBA_T(S)$ | Noises | 1562.90 | 23 | 67.95 | 8.62 | P<.01 |
| | Subjects | 4.52 | 6 | .75 | .10 | ----- |
| | Error | 1087.55 | 138 | 7.8[illegible] | | |
| $dBA_D(S)$ | Noises | 1228.14 | 23 | 53.40 | 7.77 | P<.01 |
| | Subjects | 1.32 | 6 | .22 | .03 | ----- |
| | Error | 948.31 | 138 | 6.87 | | |
| EdBA (S) | Noises | 1695.25 | 23 | 73.71 | 8.82 | P<.01 |
| | Subjects | 4.71 | 6 | .79 | .09 | ----- |
| | Error | 1153.10 | 138 | 8.36 | | |
| Mark VII(S) | Noises | 342.84 | 23 | 14.91 | 3.40 | P<.01 |
| | Subjects | 2.88 | 6 | .48 | .11 | ----- |
| | Error | 604.95 | 138 | 4.38 | | |
| Mark $VII_D(S)$ | Noises | 371.57 | 23 | 16.16 | 3.63 | P<.01 |
| | Subjects | 2.70 | 6 | .45 | .10 | ----- |
| | Error | 613.99 | 138 | 4.45 | | |
| dBE (S) | Noises | 963.08 | 23 | 41.87 | 7.07 | P<.01 |
| | Subjects | .48 | 6 | .08 | .01 | ----- |
| | Error | 817.06 | 138 | 5.92 | | |
| OASPL(S) | Noises | 489.46 | 23 | 21.28 | 3.52 | P<.01 |
| | Subjects | 21.72 | 6 | 3.62 | .60 | ----- |
| | Error | 833.91 | 138 | 6.04 | | |

Table 3-7. Summary information for magnitude estimation method - all 24 signals.

| ENGINEERING CALCULATION PROCEDURE | RANGE Subjective dB's | ABSOLUTE RANGE | F-ratio | MEAN CALCULATION PROCEDURE | STANDARD | NOISE NUMBER FOR RANGE | CORRELATION BASED ON ALL NOISES | RANGE OF CORRELATION FOR INDIVIDUAL NOISES | SLOPES BASED ON ALL NOISES | RANGE OF SLOPES FOR INDIVIDUAL NOISES |
|---|---|---|---|---|---|---|---|---|---|---|
| **PNdB(S)** | 67.18 - 82.30 | 15.11 | 18.07 | 76.91 | 75.24 | 13-21 | .836 | .922 - .999 | .025 | .020 - .033 |
| **$PNdB_T$(S)** | 74.01 - 85.66 | 16.65 | 20.04 | 79.42 | 78.38 | 14-21 | .810 | .821 - .999 | .024 | .020 - .034 |
| **$PNdB_D$(S)** | 71.79 - 79.40 | 7.61 | 5.52 | 75.90 | 76.02 | 13-16 | .940 | .933 - .999 | .026 | .020 - .033 |
| **EPNdB(S)** | 73.68 - 82.04 | 8.36 | 6.63 | 78.10 | 79.13 | 13-16 | .932 | .928 - .999 | .025 | .020 - .033 |
| **dBA(S)** | 55.36 - 70.31 | 14.95 | 22.92 | 64.52 | 64.90 | 13-21 | .790 | .921 -1.000 | .025 | .022 - .035 |
| **$dBA_T$(S)** | 56.86 - 73.60 | 16.74 | 25.25 | 66.96 | 68.02 | 13-21 | .763 | .922 -1.000 | .024 | .022 - .036 |
| **$dBA_D$(S)** | 59.45 - 69.28 | 9.83 | 10.22 | 63.50 | 65.63 | 1-16 | .903 | .932 -1.000 | .026 | .022 - .035 |
| **EdBA(S)** | 60.57 - 72.37 | 11.80 | 12.22 | 65.71 | 68.77 | 1-23 | .889 | .926 - .999 | .025 | .022 - .036 |
| **MarkVII(S)** | 61.20 - 72.80 | 11.60 | 16.86 | 68.69 | 67.57 | 13-21 | .846 | .927 -1.000 | .029 | .023 - .037 |
| **$MarkVII_D$(S)** | 65.76 - 72.20 | 6.44 | 5.39 | 68.33 | 68.24 | 9-16 | .939 | .933 -1.000 | .028 | .023 - .039 |
| **dBE(S)** | 58.63 - 76.29 | 17.66 | 26.39 | 69.95 | 69.75 | 13-21 | .766 | .920 -1.000 | .025 | .022 - .035 |
| **OASPL(S)** | 58.25 - 85.36 | 27.11 | 37.89 | 74.79 | 71.56 | 13-22 | .698 | .916 - .999 | .018 | .023 - .036 |

| RANK | EPNdB(S) | FLYOVER NUMBER | *CODE |
|---|---|---|---|
| 1 | 73.68 | 13 | TP |
| 2 | 75.21 | 1 | S |
| 3 | 76.21 | 2 | S |
| 4 | 76.46 | 9 | J |
| 5 | 76.56 | 20 | H |
| 6 | 76.76 | 12 | P |
| 7 | 76.81 | 18 | H |
| 8 | 77.01 | 11 | J |
| 9 | 77.07 | 14 | H |
| 10 | 77.34 | 8 | J |
| 11 | 77.45 | 3 | S |
| 12 | 77.62 | 5 | S |
| 13 | 78.08 | 6 | S |
| 14 | 78.51 | 22 | H |
| 15 | 78.75 | 15 | H |
| 16 | 79.04 | 17 | H |
| 17 | 79.25 | 21 | H |
| 18 | 79.43 | 24 | H |
| 19 | 79.75 | 4 | S |
| 20 | 80.75 | 7 | S |
| 21 | 80.87 | 10 | J |
| 22 | 80.88 | 19 | H |
| 23 | 81.79 | 23 | H |
| 24 | 82.04 | 16 | H |

Any two means not bracketed by the same line are significantly different at the P<.01 level.

Any two means bracketed by the same line are NOT significantly different at P<.01 level.

* H - Helicopter
J - Jet
P - Propeller
TP - Turboprop
S - Simulation

Figure 3-2. **Significant differences for EPNdB(S) among 24 noises at P<.01 level utilizing Duncan's Multiple Range Test.**

nals that are not judged to be at least 3 EPNdB different, are both adequately evaluated by that particular calculation procedure.

Figure 3-3 provides a plot of the judged values less their calculated values utilizing the four PNdB based engineering calculation procedures. As mentioned previously, if a calculation procedure were to work perfectly for all noises, all differences would be zero. We begin by examining the uncorrected PNdB differences and observe how the tone and duration correction affects the differences. Notice that tone correction never markedly improves PNdB but for the most part keeps the difference approximately the same or degrades PNdB slightly. However, for the most part, the duration correction decreases the difference between the judged and calculated values; this is particularly apparent for signals 11, 12, 13, 14, 20, 21, and 22. The only signal that involves an increase in the difference between the judged and calculated value is noise number 19. It is clear that the duration correction is very effective while the tone correction is not needed.

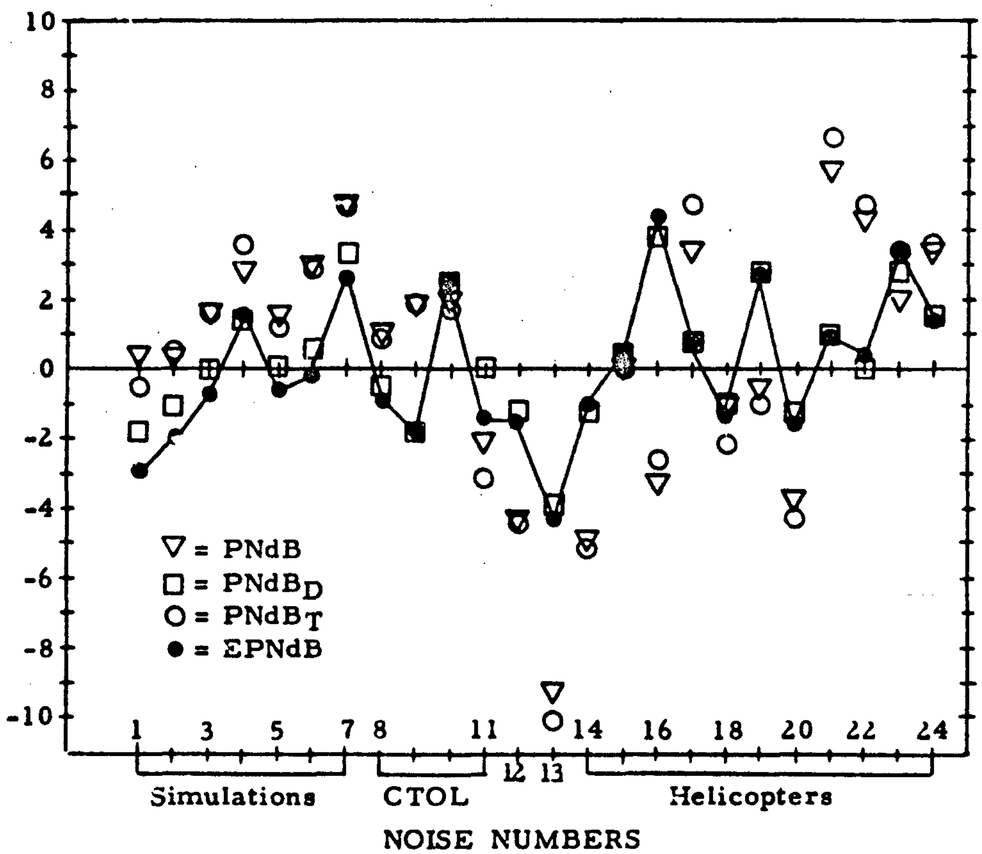



Figure 3-3. PNdB, $PNdB_T$, $PNdB_D$, and EPNdB Subjective dB's based on mean individual response.

Results as provided in Figure 3-3 can also be used to substantiate findings from the pilot study concerning "slap" effects. Remembering that signals with noise numbers 1, 2, 3, and 4 contained no, light, moderate, and heavy "slap" respectively, results based on these four signals are examined. Using $PNdB_D$, annoyance does increase as expected with increased "slap". However, none of the differences is significant (ranging from 1 to 3 $PNdB_D$). Thusly, it is concluded that all of these differences belong to the same set and are not reliably different.

### 3.3.2 Absolute Acceptability

An analysis of variance was also performed on the absolute acceptability data. A summary of the results are given in Table 3-8. As expected, differences based on noise levels (4 dBA increments) were highly significant providing an F-ratio of 45.55. Differences among noises averaged over level were also significant as were differences based on the first order interaction of noises times levels. This interaction finding means that differences are both a function of noise and level or that level differences for some noises are greater at one level than at other levels.

Table 3-8. Summary of analysis of variance for absolute acceptability data.

| SOURCE OF VARIANCE | Sum of Squares | df | Mean Square | Error Source | F-ratio | Signif. Point |
|---|---|---|---|---|---|---|
| Subjects (S) | 258.20 | 23 | 11.22 | ------ | ----- | ------ |
| Noises (N) | 40.83 | 23 | 1.78 | S x N | 10.93 | P<.005 |
| Level (L) | 87.40 | 4 | 21.85 | S x L | 45.55 | P<.005 |
| S x N | 85.89 | 529 | .16 | ------ | ----- | ------ |
| S x L | 44.13 | 92 | .48 | ------ | ----- | ------ |
| N x L | 13.33 | 92 | .14 | SxNxL | 1.74 | P<.005 |
| S x N x L | 176.74 | 2116 | .08 | ------ | ----- | ------ |

Percent "accept the noises" are given in Table 3-9. Even for the lowest level (nominal dBA of 57), the predictions of accepting the noises if heard in their homes 4 to 5 times per hour during waking hours are not considered high. The range is from 50.0% acceptability for signals 21 and 24 to 87.5% acceptability for signal number 13 which was a recording of a turboprop CTOL aircraft. Average acceptability for the eleven helicopter recordings at 57 dBA is 65.1% while it is at 66.7% for the four jet aircraft signals. This also provides some additional evidence that calculation procedures utilized to measure

Table 3-9. Percent absolute acceptability for 5 levels of 24 noise signals.

| | Noise No. | Nominal dBA Level | | | | |
|---|---|---|---|---|---|---|
| | | 73 | 69 | 65 | 61 | 57 |
| SIMULATIONS | 1 | 16.7 | 37.5 | 50.0 | 58.3 | 70.8 |
| | 2 | 16.7 | 25.0 | 45.8 | 62.5 | 70.8 |
| | 3 | 8.3 | 25.0 | 37.5 | 54.2 | 62.5 |
| | 4 | 4.2 | 25.0 | 33.3 | 41.7 | 58.3 |
| | 5 | 20.8 | 25.0 | 20.8 | 62.5 | 66.7 |
| | 6 | 8.3 | 4.2 | 25.0 | 54.2 | 66.7 |
| | 7 | 12.5 | 4.2 | 33.3 | 33.3 | 58.3 |
| JETS | 8 | 16.7 | 37.5 | 54.2 | 66.7 | 58.3 |
| | 9 | 20.8 | 29.2 | 41.7 | 58.3 | 62.5 |
| | 10 | 25.0 | 33.3 | 33.3 | 66.7 | 66.7 |
| | 11 | 33.3 | 29.2 | 62.5 | 66.7 | 70.8 |
| | 12 | 54.2 | 58.3 | 54.2 | 75.0 | 79.2 |
| | 13 | 54.2 | 70.8 | 70.8 | 66.7 | 87.5 |
| HELICOPTER RECORDINGS | 14 | 29.2 | 58.3 | 62.5 | 70.8 | 79.2 |
| | 15 | 12.5 | 33.3 | 50.0 | 54.2 | 58.3 |
| | 16 | 12.5 | 29.2 | [illegible].7 | 70.8 | 70.8 |
| | 17 | 4.2 | 16.7 | 33.3 | 45.8 | 58.3 |
| | 18 | 12.5 | 54.2 | 62.5 | 58.3 | 79.2 |
| | 19 | 25.0 | 29.2 | 45.8 | 66.7 | 75.0 |
| | 20 | 29.2 | 41.7 | 54.2 | 66.7 | 79.2 |
| | 21 | 4.2 | 16.7 | 16.7 | 20.8 | 50.0 |
| | 22 | 4.2 | 20.8 | 20.8 | 41.7 | 54.2 |
| | 23 | 4.2 | 12.5 | 37.5 | 54.2 | 62.5 |
| | 24 | 8.3 | 20.8 | 29.2 | 50.0 | 50.0 |

annoyance to jet aircraft flyovers can also be utilized for helicopter noise evaluations. That the absolute acceptability levels are considered on the low side will be emphasized in section 4.0 Community Acceptability Considerations.

### 3.3.3 "Slap" Detection Study

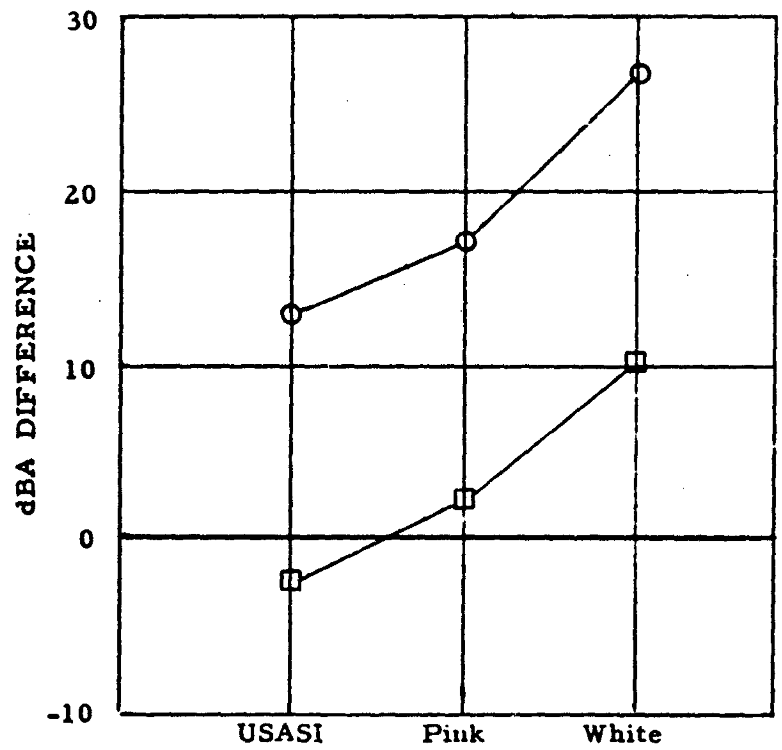
The high interest in "slap" effects led to the question of the level above or below the steady state noise at which "slap" is just perceptible. Since "slap" primarily contains low frequency components, this could have significance for indoor noise effects due to the fact that low frequency noise is more difficult to attenuate than higher frequency noise. It was expected that "slap" detection would be a function of the spectral content of the non-impulse noise and the spectral characteristics (sharpness) of the slap. A study utilizing three steady state noises which were white, pink, and USASI noise and two impulse noises representing "slap" was completed. Both a normal slap and sharp slap were introduced at a 10 Hz rate during presentation of the individual steady state noises. Ten persons took part in the experiment utilizing the following instructions:

> We are looking for the level at which a pulsating noise becomes clearly perceptible against a steady noise background.
>
> We will present you with a short burst of noise and we want you to tell us when you can clearly hear the pulsating noise. Press the intercom call button when you hear this pulsating noise.
>
> First we will present the pulsating noise alone. Then we will present a mixture of pulsating and steady noise, in which the pulsating noise is clearly audible. After that, the pulsating noise may or may not be audible in the steady noise. Press the button whenever you are sure it is there.

The results are given in Table 3-10 utilizing both RMS and Peak dBA as measures of slap and, of course, RMS dBA as a measure of the steady state noises. Detection of pulsating noise is very much a function of the steady state noise with which it is presented. Using peak dBA as a measure in white noise, it can be detected almost 12 dBA below the steady state noise level; but for USASI noise which has more low frequency content, it must be 2 dBA above USASI steady state noise to be detected. Note that the difference between the "sharp" and "normal" slap detection is always less than 1 dB and is not a significant difference. Figure 3-4 plots the difference between the steady state noise and slap for the sharp pulsating noise utilizing both RMS dBA and Peak dBA. As high frequency content in the steady state noise increases (USASI to Pink to White noise), "slap" detection increases. For this study, the audibility of slap in either USASI or Pink noise is achieved at the level at which the "slap" energy barely contributes to the measured RMS dBA (slow) level. While in White noise, "slap" is audible at considerably lower levels than can be measured. It can be concluded that "slap" is unusually easy to detect but this does not necessarily mean that it increases annoyance significantly.

Table 3-10. dBA differences between steady state noises and point at which "slap" is just perceptible (steady state value less slap value).

| | | Steady State Noises | | |
|---|---|---|---|---|
| | | White | Pink | USASI |
| Sharp Slap | RMS | 26.9 | 17.4 | 13.1 |
| | Peak | 11.7 | 2.2 | - 2.1 |
| Normal Slap | RMS | 27.0 | 16.9 | 12.7 |
| | Peak | 11.8 | 1.8 | - 2.4 |




O = RMS dBA of slap
□ = Peak dBA of slap

Figure 3-4. dBA difference for sharp slap to be audible for 3 steady state noises (steady state value less slap value).

3.3.4 Additional "Slap" Effects Considerations

Since there is considerable difference of expert opinion concerning whether or not there is increased annoyance as a function of helicopter blade slap (see pp 1-2 to 1-4 of this report), some of the intentions that were basic to this study along with empirical findings are reviewed.

The intent in developing the simulations for the pilot study was to provide every opportunity for "slap" to show an effect on the annoyance judgments. As the pilo study results of Figure 2-1, p. 2-12 show, increased "slap" did not increase annoyance but slightly decreased annoyance (within the bounds of experiment error) when engineering calculation procedures such as dBA with a tone and duration correction were applied. In addition, when a crest factor correction [CFC = 20(log Peak SPL/RMS SPL)] was applied to dBA, the relationship between the subjective evaluations of the noises and the calculated values was decreased. Crest factor corrections for the 16 pilot study signals are provided in Table 3-11. These results show that crest factor corrections for the simulations were of the same magnitude as those obtained from recordings of the Chinook helicopter. The aim in obtaining recorded signals from this helicopter was to obtain maximum "slap" (compare CFC of 10.0 and 10.1 for signals 4 and 5 to CFC of 10.1 for signal 9). Conclusions from the pilot study were that a correction for "slap" is not required and that the CFC is not effective.

From a statistical inference standpoint, results from the main study are in agreement with those from the pilot study, i.e., engineering calculation procedures such as PNdB and dBA corrected for duration adequately reflect annoyance. However, if we examine annoyance value results (subjective dB), utilizing $PNdB_D(S)$ for no, light, moderate, and heavy slap (signals 1, 2, 3, and 4), the effect of slap does progress in the expected direction. $PNdB_D(S)$ values for signals 1, 2, 3, and 4 are 74.0, 74.8, 75.7, and 77.1 respectively while each was calculated at 75.7 $PNdB_D$. There is some evidence for a slight slap effect.

As a means of further investigating this slight slap effect, the following investigation was completed. In order to assess the contribution to the dBA and dBlinear levels of the different blade slaps used in the simulation signals, a 1/2" GR electret microphone was set up in the listening chamber in the approximate position of the subject's head; no subject was present. The signal from the microphone was fed to a GR 1933 Precision Sound Level Meter and to a Telequipment D66 oscilloscope.

Table 3-11. Pilot study noise signals with crest factor correction (CFC) for highest level of each signal.

| No. | DESCRIPTION | CFC |
|---|---|---|
| 1 | Tail rotor noise simulation with no slap (Standard sig.) | 5.5 |
| 2 | Tail rotor noise with light slap at 10 beats/sec. | 6.9 |
| 3 | Tail rotor noise with moderate slap at 10 beats/sec. | 9.0 |
| 4 | Tail rotor noise with heavy slap at 10 beats/sec. | 10.0 |
| 5 | Tail rotor noise with moderate slap at 6 beats/sec. | 10.1 |
| 6 | Tail rotor noise with moderate slap at 18 beats/sec. | 5.8 |
| 7 | Tail rotor noise with moderate slap at 10 beats/sec. and fast rise time. | 9.0 |
| 8 | Chinook level flyby - direct and FM recording | 8.8 |
| 9 | " " " - direct & rolled-off FM recording | 10.1 |
| 10 | " " " - direct recording only (no FM) | 9.4 |
| 11 | Chinook hover - direct and FM recording | 6.5 |
| 12 | " " - direct and rolled-off FM recording | 7.7 |
| 13 | " " - direct recording only (no FM) | 9.4 |
| 14 | Chinook shallow turn - direct and FM recording | 8.4 |
| 15 | " " " - direct & rolled-off FM recording | 9.2 |
| 16 | " " " - direct recording only (no FM) | 7.7 |

Using the steady state (tail rotor) noise, simulation 1, at its highest presentation level, the intensity was adjusted to give a suitable peak-to-peak reading on the oscilloscope screen and the maximum dBA and dB lin (RMS) levels were measured on the sound level meter. Then, using the highest presentation level of simulation 2 (tail rotor plus light slap), which pictorially consisted of the steady state noise with a superimposed slap pattern, the intensity again was adjusted so that the steady state portion of the signal had the same peak-to-peak measurement on the oscilloscope screen as had simulation 1 (see Figure 3-5). The dBA and dB lin levels of the signal at this intensity were measured. The steady state tail rotor noise being the same in both simulation 1 and 2, the difference between the dBA (or dB lin) levels of the two signals is due to the contribution of the slap component.

This procedure was repeated for the other simulation signals, 3 through 7, and a table calculated of the additional effect on dBA and dB lin of the different types of slap used (Table 3-12) over the levels for simulation 1. The accuracy of measurement was taken to be ±0.4 dBA (or dB lin), this being the repeatability of levels for simulation 1. As Table 3-12 shows, the increase in dB lin with additional slap intensity (simulations 2, 3, and 4) is marked, and with dBA the

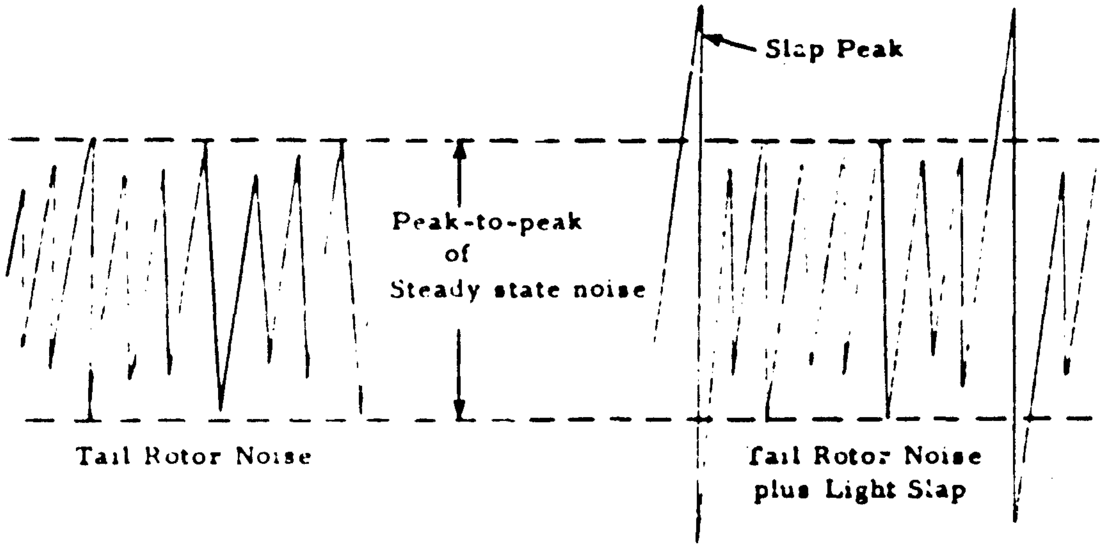



Figure 3-5. Schematic of slap measurement approach.

Table 3-12. Contribution of slap.

| Noise No. | DESCRIPTION | Additional level over tail rotor noise of Sim. 1 | |
|---|---|---|---|
| | | dBA | dBA linear |
| 2 | Tail rotor noise plus light slap | 0.9 | 1.3 |
| 3 | Tail rotor noise plus moderate slap | 1.4 | 4.3 |
| 4 | Tail rotor noise plus heavy slap | 2.5 | 12.9 |
| 5 | Tail rotor noise plus moderate slap, slow repetition rate | 0.9 | 3.1 |
| 6 | Tail rotor noise plus moderate slap, fast repetition rate | 1.0 | 6.0 |
| 7 | Tail rotor noise plus moderate slap with sharp waveform | 0.8 | 3.5 |

trend, though also increasing, is much less. This is due to the increase in energy due to slap being mainly in the low frequencies, which are weighted out by dBA. Even though simulation 4 has considerably more slap than simulation 2, the additional effect on dBA is only 1.6 dB.

Although there is but slight evidence (Main Study results only) that increases in "slap" increase annoyance response to helicopter flyovers, there are two additional considerations involving applied problems relative to "slap". These are considerations involving a possible penalty for slap and an operational definition of slap.

Slap Penalty Considerations. As shown in Table 3-12, increase in slap as measured by dBA is not pronounced due to the fact that the slap results from low frequency acoustic energy. Thusly utilization of a weighting network such as dBA would not provide precision. However, dB in unweighted SPL does provide some meaningful differences (dB linear column of Table 3-12). Therefore, if there is interest in providing a penalty for slap, it is proposed that unweighted SPL be utilized as shown in Table 3-13. As an example, if a helicopter flyover was measured at 80 dBA and increase in SPL due to slap was 14 dB, this particular helicopter flyover would be assigned a dBA level of 83 dBA.

Table 3-13. Penalty for slap in dBA.

| SPL Increase Due to Slap | Penalty |
|---|---|
| 0 to 5.9 dB | 0 dBA |
| 6 to 11.9 dB | 2 dBA |
| 12 and greater | 3 dBA |

Operational Definition of Slap. As was shown in the "slap" detection study of Section 3.3.3, detection of slap is a function of both slap level and spectral content of the "steady state" noise. In addition, the pilot study results show that the crest factor correction (CFC) is not adequately related to the annoyance judgments. Thusly, the search for an operational definition of "slap" is elusive. Comparing the peak 1/3-octave band spectra for signals 1 through 4 does suggest an accurate measurement approach (See Appendix B). The slap is clearly based on low frequency noise so the following measurement approach is suggested.

(1) Measure peak SPL based on all 24 1/3octave bands.

(2) Measure peak SPL based only on 1/3-octave bands from 250 to 10,000 Hz (Bands 24 to 40).

(3) The difference between (1) and (2) (measurement (1) less measurement (2)) is a measure in dB of the slap.

Table 3-14 provides a hypothetical example of this suggestion. This suggestion for operationally defining slap is based on the assumption that most of the low frequency energy is contributed by "slap". Thusly, for broad application, peak spectra from a number of different types of helicopters under various operating conditions should be examined.

Table 3-14. Hypothetical measurement of slap.

| Signal Description | SPL Based on 24 1/3 Octave | SPL Based on Bands 24-40 | Measurement of Slap |
|---|---|---|---|
| No Slap | 81.3 dB | 81.1 dB | 0.2 dB |
| Heavy Slap | 93.7 dB | 81.2 dB | 12.5 dB |

## 3.4 References


3-1. MAN-Acoustics and Noise, Inc., "Noise Certification Criteria amd Implementation Considerations for V/STOL Aircraft", FAA-RD-75-190, November 1975.

3-2. MAN-Acoustics and Noise, Inc., "City of Portland and Multnomah County System Noise Management Program", Contract No. USE-OR-10-00-0003, April 1975.

## 4.0 COMMUNITY ACCEPTABILITY CONSIDERATIONS

There are two main aspects concerning community acceptability for both helicopters and V/STOL aircraft noise exposure. One aspect involves various kinds of residential living around airports out of which these aircraft operate, and in many situations in conjunction with CTOL aircraft. A second aspect of community acceptability is concerned with various kinds of business activities around heliports since many of them are located in business areas. Noise exposure criteria are discussed in respect to both of these aspects of community acceptability.

### 4.1 Residential Living and Noise Exposure

As shown by the results of this study, both PNdB and dBA corrected for duration adequately reflect annoyance effects from helicopters. This result is also confirmed by a previous study which included evaluations of both V/STOL and helicopter noise (Ref. 4-1). Thusly, work involving effects of CTOL aircraft noise exposure can be utilized for predicting effects of both helicopter and V/STOL noise exposure as both PNdB and dBA are utilized in measuring CTOL noise effects. For residential living activities, the main concerns are a generalized annoyance response to aircraft noise plus emphasis on sleep and speech interference which contribute to this generalized annoyance response. Although energy summation approaches such as CNR and NEF could be used to measure V/STOL or helicopter noise exposure, a meaningful approach involves a limit on peak level that would provide noise exposure compatible with residential living. In a recent study involving spontaneous "Dislike" of airport noise, 51.4% of the respondents who lived in areas exposed to aircraft noise at 85 dBA or greater reported "Dislike" of airport noise. However, for those who lived in the airport influence area who were not exposed to aircraft noise greater than 85 dBA, 11.1% reported "Dislike" of airport noise (Ref. 4-2). This leads to the criterion for V/STOL and helicopter noise as follows: if there is outdoor noise at 85 dBA or greater, a problem area relative to noise exposure exists, while residential areas that are exposed to noise below 85 dBA are not significantly impacted by the noise. Depending on the types and frequency of operations for various aircraft, using a time-level limit of no noise equal-to-or-greater than 85 dBA is equivalent to a NEF value of 26 to 32.

Although there is need for caution in respect to the attenuation of the pulsating aspect of helicopter noise for indoor activities, this upper limit of no noise equal-to-or-greater than 85 dBA should not markedly interfere with sleep. As shown in a review of sleep interference studies involving behavioral awakening, many persons do not awake with flyover noise peaking at 70 dBA (Ref. 4-3). If 20 dBA attenuation is obtained from the structure, peaks will be below 65 dBA. Also, this level of 65 dBA will not markedly interfere with speech and listening activities (Refs. 4-4 and 4-5).

A final comment involves the validity or accuracy of the absolute acceptability results obtained from this study. These results are predictions based on hearing a particular noise on one occasion in an austere laboratory environment. For most of these noises to have been rated as 90% acceptable, it is estimated that the lowest noise level should be reduced from approximately 57 dBA to 48 to 50 dBA. Thusly, the predictions are much too low when compared to actual findings from the real life situations as shown in References 4-2 and 4-3. The main aim of the laboratory study was to evaluate engineering calculation procedures. Other methods are required to establish thresholds of community acceptability and other criteria.

## 4.2 Business Activities Around Heliports

Although there will be unique considerations concerning noise exposure around various heliports, an indoor activity that is expected to be quite prevalent involves speech communication activities associated with various kinds of "office" work. Since one study (Ref. 4-6) has shown that flyover levels peaking at 66 to 67 dBA are compatible with classroom activities where speech communication is an important factor, utilizing no indoor noise equal-to-or-greater than 65 dBA as an upper limit can be considered as a standard. Thusly, the criterion is a function of both peak noise levels and the attenuation properties of the building. Earlier studies emphasizing office noise effects have shown that annoyance tends to increase as the noise reaches 55 dBA and greater (Ref. 4-7). However, the concern was with steady state (almost continuous) noise as opposed to intrusions which come and go as will the helicopter noise.

## 4.3 References


4-1. MAN-Acoustics and Noise, Inc., "Noise Certification Criteria and Implementation Considerations for V/STOL Aircraft", FAA-RD-75-190, November 1975.

4-2. Hughes, T. L., and Mabry, J. E., "The Relationship between Noise Annoyance and Duration Above Specified Noise Levels", FAA-EQ Report in Publication, August 1976.

4-3. MAN-Acoustics and Noise, Inc., "Review of Studies Investigating Human Response to Commercial Aircraft Noise", FAA-RD-75-182 (page 6-2). November 1975.

4-4. Williams, C. E.; Stevens, K.; and Klatt, M., "Judgments of the Acceptability of Aircraft Noise in the Presence of Speech", J. Sound Vib. (1969) 9 (2) 263-275.

4-5. MAN-Acoustics and Noise, Inc., "Establishing Noise Criteria for Residential Living in Areas Surrounding Commerical Aviation Airports", FAA-RD-75-211, November 1975.

4-6. Anon., "Aircraft Noise Study - Remedial Construction - Schools", Highline Schools, District No. 401, 15675 Ambaum Blvd. SW, Seattle, WA.

4-7. Beranek, L. L., "Revised Criteria for Noise in Buildings", Noise Control, Vol. 3, 1957, pp. 19-27.

## 5.0 CERTIFICATION IMPLEMENTATION

There are two noise certification schemes now in effect under Federal Aviation Regulations Part 36: Appendix C which covers all aircraft in the transport category, and all jet-powered aircraft; and Appendix F which pertains to small propeller-driven aircraft up to 12,500 pounds maximum takeoff gross weight.

### 5.1 Appendix C

For Appendix C certifications, the EPNL calculation procedure requires peak noise measurements and corrections for duration and tone content. The locations of the microphones used for noise measurement are shown in Figure 5-1. The microphones are located to measure noise on takeoff, both under and to the side of the flight path, and also under the approach path. The specified takeoff and approach flight paths are approximations of the way the aircraft actually fly in normal operations and the measurement locations are somewhat representative of typical airport/community interfaces around major airports.

For an Appendix C certification, the so-called "weather window" defines atmospheric limits within which the applicant may conduct the certification tests, provided the noise and aerodynamic data are corrected to atmospheric standard day conditions. The procedure specified for making the corrections to standard day conditions requires precision tracking of the aircraft position during the certification tests. An Appendix C certification requires complex instrumentation and a very high degree of technical competence.

### 5.2 Appendix F

Appendix F provides for the noise certification of propeller-driven small CTOL aircraft of up to 12,500 pounds maximum takeoff gross weight. The measurement scheme used for Appendix F certification is shown in Figure 5-2. The peak dBA is measured for a level flyover at 1,000 feet above the ground at maximum continuous power. No corrections for duration or tone are applied. Aircraft position tracking requirements are minimal, and no correction to standard day conditions is necessary when the test is conducted within specified atmospheric limits. To augment the level flyby noise measurement, Appendix F includes a performance correction which allows aircraft with superior

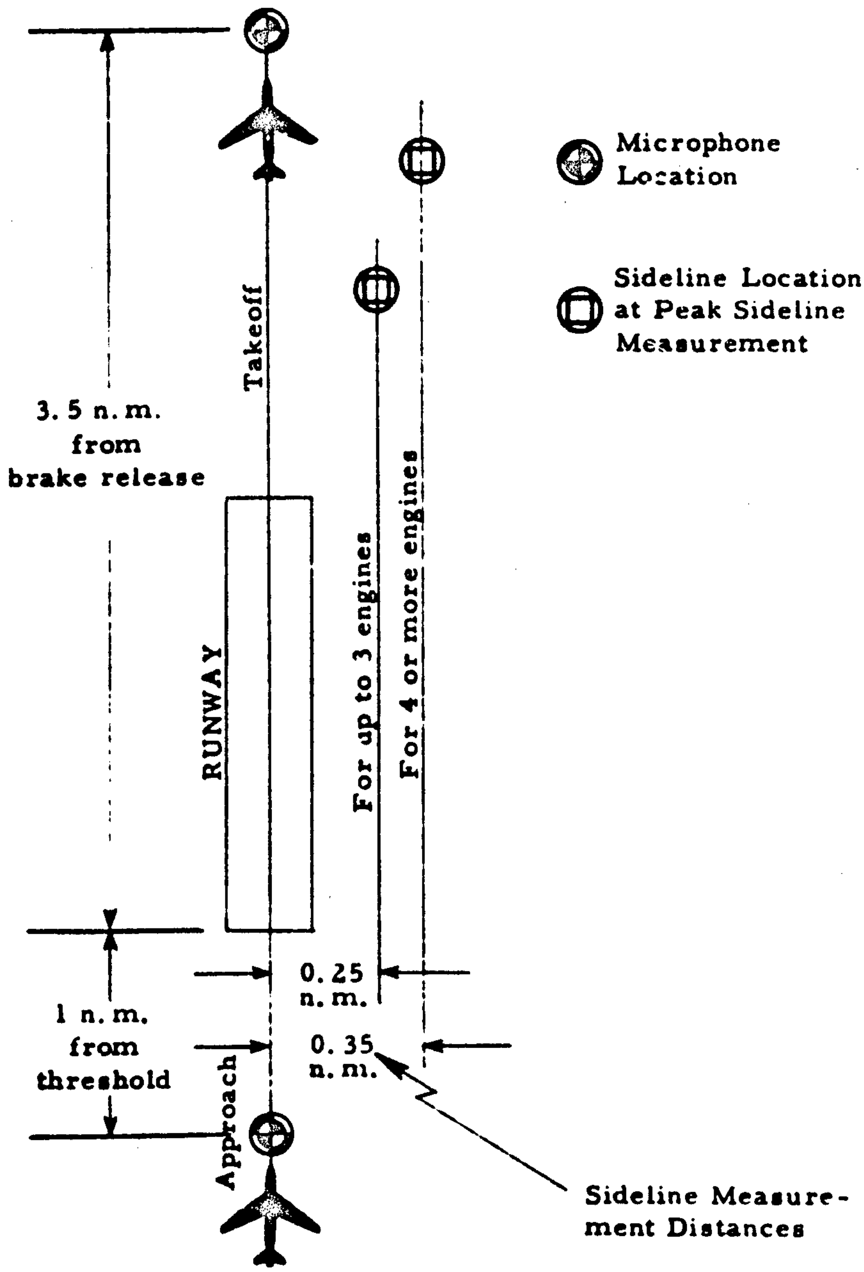



Figure 5-1. FAR Part 36, Appendix C measurement locations.

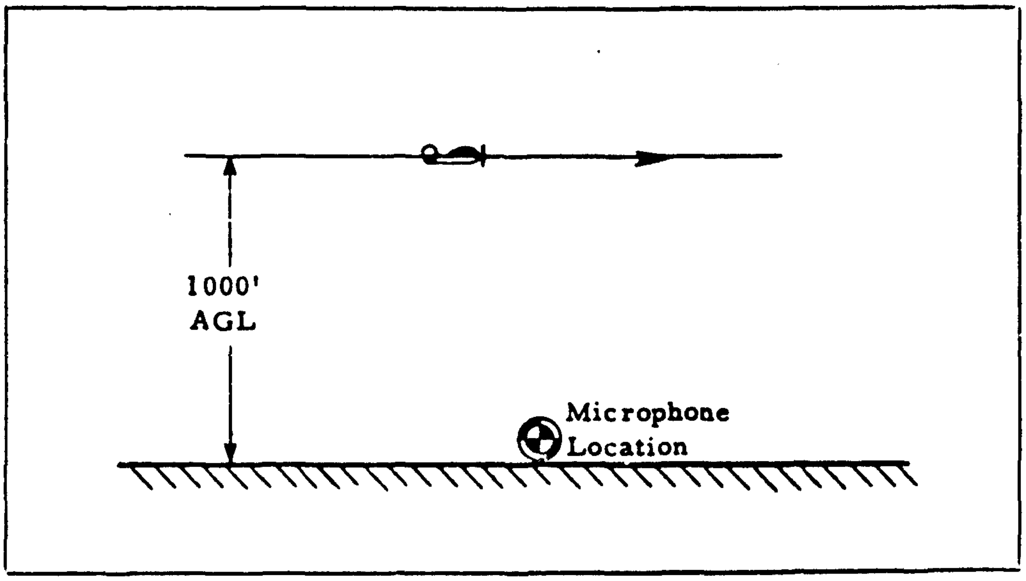



Figure 5-2. FAR Part 36, Appendix F measurement location.

climb performance an increased noise limit, thus tending to equalize the community noise exposure potential during takeoff.

Appendix F is clearly intended to be a simpler procedure than Appendix C, permitting the use of less complex instrumentation and reducing the demands on the technical skills of certification personnel. Moreover, in proportion to the total aircraft certification costs, an Appendix C type requirement is much more reasonable for a transport class aircraft than for many small propeller-driven aircraft. In fact, for some small aircraft manufacturers, and certainly for many small aircraft supplemental type certificate applications, an Appendix C type requirement could be prohibitively expensive. In view of the economics, and the less critical nature of the small aircraft noise problem, it is reasonable that a simplified procedure is used.

Appendices C and F both relate the maximum allowable noise to the maximum takeoff gross weight of the aircraft, with the heavier aircraft (which would normally require more power) permitted to make more noise at the measuring points. Appendix F focuses on noise measurement at high power settings, whereas Appendix C is concerned with both takeoff and approach noise levels.

It is important to note that the motive for requiring both takeoff and approach measuring points for Appendix C is not only to reflect community noise exposure at those points, but to also account for the differences in character of jet engine noise at the different power settings. This character does not significantly change with changing atmospheric conditions, so that measurements made at one atmospheric condition can reasonably be extrapolated to another. For the helicopter, however, it is possible for the character of the noise to change with, among other things, changing atmospheric conditions, a complication which is discussed in the following section.

## 5.3 Helicopter Certification Considerations

For the purpose of noise certification, the helicopter differs in three important respects from the conventional fixed-wing aircraft covered by Appendices C and F: (1) it is capable of a greater range of takeoff and approach trajectories, (2) it can hover, and fly at very slow speeds, (3) it can, under certain conditions, produce the low frequency impulsive noise referred to as bang or slap.

The results of this study indicate that annoyance due to helicopter noises, with or without blade slap, correlates well with peak PNdB when corrected for the effects of duration, with annoyance increasing as the peak and/or duration increase in value. The presence of blade slap not only increases the peak noise value, but, because of the relatively greater propagation of low frequency acoustic energy, the duration is also usually increased, thereby compounding the growth in annoyance. These findings corroborate the generally expressed intuition that helicopter noise with blade slap is more annoying than without.

It appears unlikely, in the near future at least, that all new helicopter types will be completely devoid of blade slap. However, for the wide variety of blade slap investigated, PNdB with a duration correction adequately reflects noise annoyance.

The generation of low frequency impulse noise for any particular helicopter type may be affected by one or more of the following parameters: forward speed, gross weight, main rotor rigging, gravitational (g) loading, atmospheric density, power setting, turbulence, climb or descent gradient, attitude and center of gravity location.

It is perhaps an impossibly difficult task to design a practical noise certification procedure which would insure the inclusion of the effects of blade slap wherever it existed in the range of possible operational conditions. This is especially true when one considers that the economics of the certification of many helicopters are more similar to those of the small propeller aircraft than to the transport category, with the attendant need to have a certification procedure less burdensome than Appendix C. On the other hand, it can be argued that if a helicopter type is capable of producing blade slap during normal operations, and the noise certification rule cannot properly account for the effects, then the rule will not be adequate to the job of limiting the noise emissions.

Because of the apparently conflicting requirements of practicality and effectiveness, a balanced approach seems called for. Such an approach might be to construct a rule which requires the use of representative operational maneuvers to demonstrate that, within the bounds of safety, the helicopter can conduct normal operations and meet required noise limits. The rule could include the following maneuvers: takeoff, approach, hover, and level flyover. The takeoff measuring point would reflect the ability to climb, and relate that ability to noise under the flight path, while the approach requirement would demonstrate typical qualities of approach noise. There will be possible interactions between takeoff or approach gradients and noise levels at the measuring points. However, to rigidly define the flight trajectory on takeoff or approach may not only prevent the demonstration of the most appropriate noise performance, but will probably significantly complicate the position tracking requirements for the certification procedure. It seems possible to allow the applicant to select the takeoff and approach trajectory, consistent with standard practice and safety, and still have meaningful takeoff and approach noise limits.

The hovering requirement is necessary because many helicopter operations will be conducted in high population density areas and the hovering noise could constitute an important portion of the noise exposure.

Helicopters are frequently used in ways which require cruising speeds at altitudes where the noise exposure impact on the ground is significant. Also, some helicopters are more likely to produce slap at higher speeds. Providing a certification requirement for a high speed level flyover condition will thus help define the noise performance of the helicopter.

The four flight conditions discussed here are not necessarily sufficient for completely circumscribing the maximum noise radiation of a helicopter. Increasing the "g" load as in a turn, for example, can increase slap or produce it where it might not otherwise occur. Furthermore, slap is sometimes more likely to occur or increase on colder days when the air is more dense, a phenomenon which can make extrapolation of ... atmospheric condition uncertain. To require ... helicopter noise over the entire range of operat... to insure that limits will not be exceeded ... burden on the applicant.

By ... in this section, and otherwise using ... relatively simple rule for helicopter ... formulated.

5.4 Measure...

The foll... certification measurement locations ...

(1) Distance ... with an aircraft noise weig... electrical system noise when ...

(2) Distance ... size requirements for ... terrain effects.

(3) Microphone ... field, a minimum of three, ... meters away.

(4) Microphone ... be unaffected by rotor ...

Using ... that some helicopters exhibit consid... radiation pattern, the authors of ... measurement layout shown in Figure 5-... hover or level flyover measurem... the simple modifications show... The two measurement locations ... touchdown point on the ... quadrant measurements to help ... dissymmetries in the radiation ... Any one of the microphone locat... level flyover noise under the flight path

The ... the ground cushion, with light ... translational lift effects, microphone wind noise, ... The takeoff and approach should ... the approved height/velocity per-

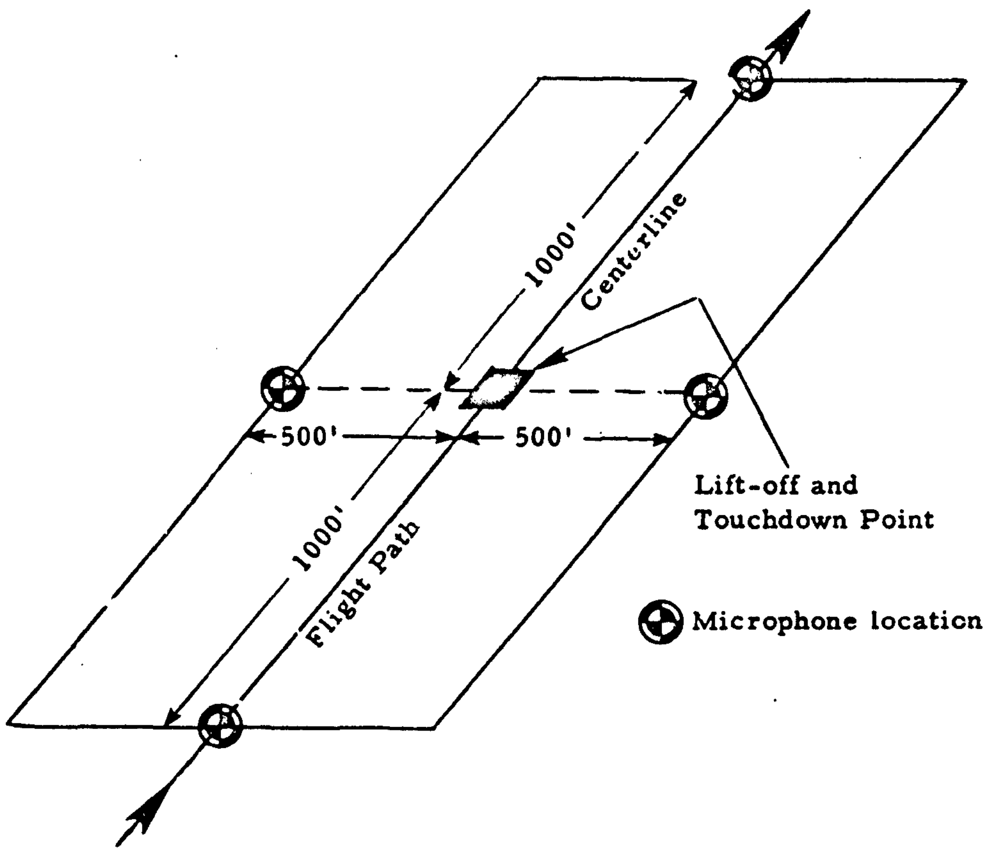



Figure 5-3. Boeing/Vertol-proposed helicopter measurement locations.

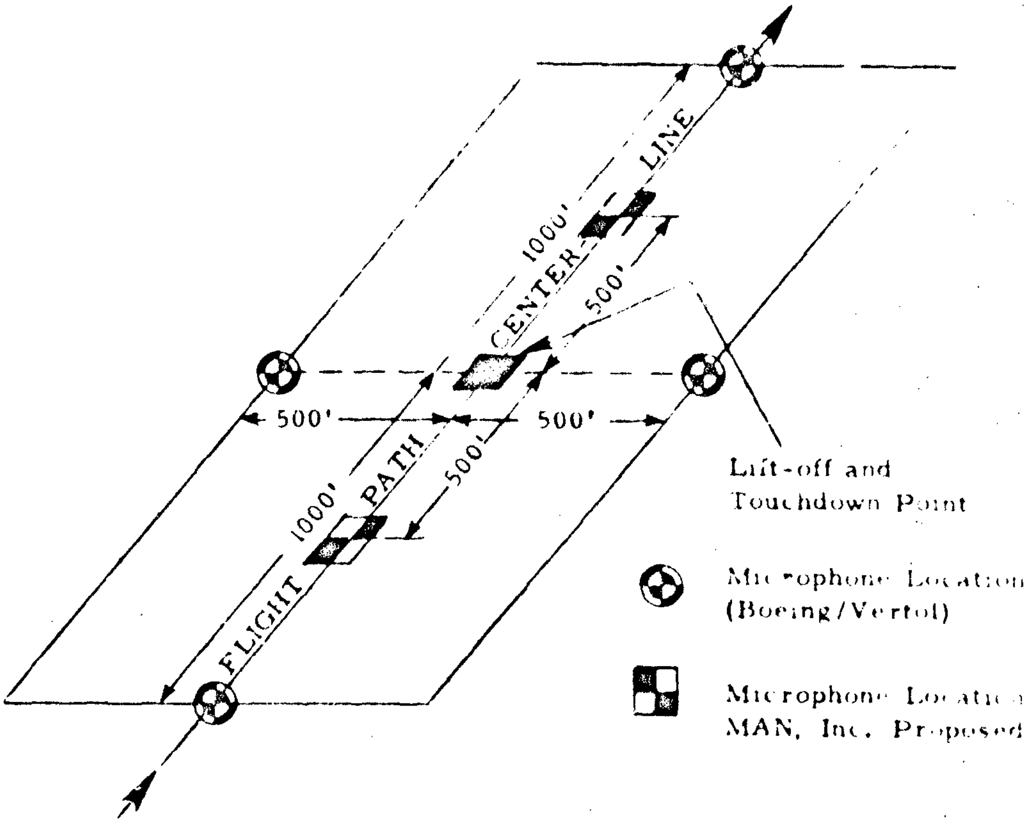



Figure 5-4. Modified Boeing/Vertol-proposed helicopter measurement locations.

formance envelope. The level flyby altitude of 300 feet was chosen to meet the criteria recommended in the previous paragraph and should be stabilized at maximum continuous power long enough to ensure valid 10 dB down points for the purpose of calculating the duration correction. All certification measurements should be made at maximum rotor RPM and maximum gross weight.

The PNL measurements and limits for hover should be specified without a duration correction since the hovering duration is undefined.

## 5.5 A-weighted Measurements and Calculations

Since much community noise exposure data, and some common community noise exposure models are based on A-weighted measurements and extrapolations, it would be useful to require that all noise data acquired during the helicopter certification be expressed in A-weighted as well as Noy-weighted values, thus providing additional basis for community noise evaluation.

## 5-6. Determination of Certification Noise Limits

Explicit in FAR Part 36 is the stipulation that noise certification requirements must be economically reasonable and technologically practicable. In the determination of Appendix C and F limits, this has been assured by basing noise limits on the existing aircraft which best combine performance and noise reduction technology. In the case where existing aircraft do not employ optimum noise reduction technology, an adjustment in the limit was made based on the estimate of possible improvement. This same approach seems appropriate for helicopters.

## 5-7. References


5-1. Hinterkeuser, E.G. et al, "Civil Helicopter Noise Assessment Study, Boeing Vertol Model 347," Boeing Vertol Co., May 1974, N74-25563.

## 6.0 CONCLUSIONS

As indicated in the introduction, this program involved four objectives. The three psychoacoustic experiments contribute directly to objective "1" and somewhat indirectly to objectives "2", "3", and "4", which also involve consideration of results from other studies. Each objective is listed and conclusions and comments relative to that objective are provided.

(1) Determine an engineering calculation procedure or weighting network that validly reflects annoyance response to helicopter aircraft.

It is concluded that PNdB according to FAR-36 and corrected for duration ($PNdB_D$) validly reflects annoyance to a wide variety of helicopter noises. No correction for "slap" or tone is considered essential. Also, dBA corrected for duration is not significantly different from $PNdB_D$ and thusly can be used as a basis for community noise exposure models.

(2) Estimate noise exposure levels that will be compatible with activities in areas surrounding heliports and airports at which helicopters are based.

Based on other studies and the fact that dBA (including duration) adequately reflects annoyance to CTOL, V/STOL, and helicopters, it is concluded that no outdoor noise levels equal-to-or-greater than 85 dBA can be considered as being compatible with residential living around airports at which helicopters operate. For indoor activities involving speech communication, no indoor noise equal-to-or-greater-than 65 dBA is proposed as an upper limit.

(3) Determine the feasibility of incorporating noise exposure effects from helicopter aircraft into existing noise exposure modeling approaches.

Since both PNdB and dBA along with a duration factor, validly reflect annoyance to helicopter noise, energy summation models such as CNR, NEF, and $L_{DN}$ could be used to model helicopter noise on its own or in conjunction with operations of other aircraft. Also, the amount of time that the noise exceeds specified levels of dBA can be utilized.

(4) Provide essential aspects of a certification measurement approach for helicopter noise certifications.

Meeting this objective involved engineering considerations of the many facets of noise certification. These are presented in Section 5.0 of this report. However, a valid engineering calculation procedure is basic to the certification process. The results of this study lead to the conclusion that PNdB corrected for duration ($PNdB_D$) according to FAR-36 should be used as the engineering calculation procedure for helicopter certification.

It is also concluded that elimination of "heavy slap" is equivalent to a maximum of a 2 to 3 dBA reduction relative to annoyance response.

## APPENDIX A

Engineering calculation procedure values for the five levels of the twenty-four noise signals investigated and their corresponding subjective dB values. Table A-13 provides means for the log magnitude estimation results.

TABLE A- 1 PHYSICAL ANALYSIS OF NOISE
SIGNALS - RMS UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | [illegible] |
|---|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 5 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE A-[illegible] PHYSICAL ANALYSIS OF NOISE
SIGNALS - PNLD UNITS

| NOISE | LEVEL 1 | LEVEL [illegible] | LEVEL [illegible] | LEVEL [illegible] | LEVEL [illegible] | [illegible] |
|---|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 15 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 16 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE A- 2 PHYSICAL ANALYSIS OF NOISE
SIGNALS - PNLT UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJUDG |
|---|---|---|---|---|---|---|
| 1 | [illegible] | 74.[illegible] | 79.8 | 82.6 | 83.8 | 78.[illegible] |
| 2 | 71.[illegible] | 75.8 | 79.8 | 81.0 | 86.[illegible] | 7[illegible].2 |
| 3 | 7[illegible].7 | 74.[illegible] | 78.4 | 82.2 | 86.4 | 80.[illegible] |
| 4 | 71.8 | [illegible] | 79.8 | 82.5 | 8[illegible] | 82.[illegible] |
| 5 | 70.[illegible] | 74.5 | 79.5 | 82.6 | 8[illegible] | 80.2 |
| 6 | 7[illegible].2 | 74.6 | 79.2 | 82.1 | 8[illegible].5 | 82.0 |
| 7 | [illegible] | 7[illegible].6 | 79.2 | 82.8 | 8[illegible] | 82.6 |
| 8 | 71.8 | [illegible] | 79.[illegible] | 82.7 | 8[illegible] | 7[illegible].2 |
| 9 | 71.[illegible] | [illegible].1 | 79.1 | 82.5 | 8[illegible].2 | 81.9 |
| 10 | 71.8 | 74.[illegible] | 7[illegible].7 | 8[illegible] | 87.8 | 80.8 |
| 11 | 74.4 | 7[illegible].8 | 81.1 | 8[illegible].2 | 8[illegible].4 | 7[illegible].8 |
| 12 | [illegible] | [illegible] | [illegible] | 81.[illegible] | [illegible] | 74.4 |
| 13 | 71.[illegible] | 76.6 | 81.[illegible] | 82.5 | 8[illegible] | 6[illegible].1 |
| [illegible] | [illegible] | 7[illegible].8 | 80.7 | [illegible] | 86.[illegible] | 74.8 |
| [illegible] | [illegible] | [illegible].7 | [illegible] | [illegible].7 | [illegible] | 7[illegible].1 |
| 15 | [illegible] | [illegible].7 | 81.4 | 8[illegible].2 | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE A-4 PHYSICAL ANALYSIS OF NOISE
SIGNALS - EPNL UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 71.0 | 75.1 | 79.9 | 82.4 | 86.4 | 75.2 |
| 2 | 71.3 | 75.6 | 79.7 | 84.6 | 87.1 | 76.2 |
| 3 | 71.1 | 76.[illegible] | 79.1 | 82.9 | 87.0 | 77.4 |
| 4 | 72.6 | 74.7 | 80.5 | 82.1 | 86.5 | 79.8 |
| 5 | 70.7 | 74.6 | 76.6 | 82.6 | 85.6 | 77.6 |
| 6 | 70.9 | 74.9 | 79.6 | 82.9 | 86.2 | 78.1 |
| 7 | 72.7 | 73.6 | 79.4 | 81.9 | 87.7 | 80.7 |
| 8 | 70.6 | 71.9 | 79.7 | 82.7 | 87.4 | 77.3 |
| 9 | 72.6 | 78.[illegible] | 81.5 | 85.1 | 89.5 | 76.5 |
| 10 | 66.6 | 71.6 | 71.7 | 81.0 | 84.3 | 80.9 |
| 11 | 70.0 | 74.0 | 76.5 | 82.1 | 86.4 | 77.0 |
| 12 | 64.5 | 66.7 | 72.2 | 76.1 | 80.6 | 76.8 |
| 13 | 64.9 | 69.6 | 74.5 | 77.6 | 82.4 | 72.7 |
| 14 | 66.4 | 72.4 | 73.4 | 79.8 | 82.6 | 77.1 |
| 15 | 69.5 | 71.1 | 76.7 | 81.0 | 83.4 | 78.7 |
| 16 | 64.5 | 66.7 | 74.6 | 77.8 | 81.2 | 82.0 |
| 17 | 72.3 | 76.[illegible] | 81.2 | 86.3 | 85.6 | 79.0 |
| 18 | 70.0 | 71.2 | [illegible] | 81.1 | 84.6 | 76.8 |
| 19 | 67.6 | 71.4 | 74.9 | 79.2 | 81.5 | 80.9 |
| 20 | 66.[illegible] | 72.[illegible] | 72.4 | 79.2 | 84.1 | 76.6 |
| 21 | [illegible] | 76.1 | 82.[illegible] | 86.2 | 91.3 | 79.2 |
| 22 | 74.5 | 76.[illegible] | 81.[illegible] | 81.[illegible] | 88.8 | 76.5 |
| 23 | 67.[illegible] | 72.1 | 76.9 | 82.1 | 86.5 | 81.8 |
| 24 | 72.[illegible] | 77.[illegible] | 81.[illegible] | 86.2 | 89.1 | 79.4 |

TABLE A- 5 PHYSICAL ANALYSIS OF NOISE SIGNALS - DBA UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 57.5 | 61.1 | 63.3 | 69.0 | 72.1 | 62.3 |
| 2 | 57.7 | 61.5 | 63.4 | 70.0 | 72.5 | 62.3 |
| 3 | 56.7 | 60.5 | 63.9 | 68.6 | 71.6 | 65.3 |
| 4 | 57.0 | 59.5 | 64.6 | 67.0 | 70.2 | 68.0 |
| 5 | 56.6 | 60.2 | 64.1 | 68.1 | 70.5 | 65.0 |
| 6 | 55.9 | 59.8 | 64.3 | 68.1 | 70.2 | 67.1 |
| 7 | 57.8 | 60.7 | 64.1 | 68.3 | 71.8 | 68.8 |
| 8 | 57.1 | 61.1 | 63.9 | 69.4 | 72.3 | 64.2 |
| 9 | 58.1 | 63.1 | 63.4 | 69.3 | 72.2 | 65.0 |
| 10 | 56.3 | 59.6 | 63.6 | 68.4 | 71.6 | 66.1 |
| 11 | 56.8 | 60.3 | 64.4 | 67.5 | 72.7 | 63.6 |
| 12 | 56.7 | 60.6 | 63.7 | 66.4 | 71.3 | 58.9 |
| 13 | 56.1 | 61.0 | 65.4 | 67.7 | 71.3 | 55.4 |
| 14 | 58.9 | 62.4 | 67.2 | 71.7 | 73.0 | 58.0 |
| 15 | 57.8 | 60.8 | 63.9 | 68.2 | 72.5 | 61.1 |
| 16 | 56.5 | 60.4 | 65.4 | 69.7 | 71.7 | 63.1 |
| 17 | 56.4 | 59.8 | 63.9 | 68.2 | 70.4 | 68.9 |
| 18 | 59.2 | 62.[illegible] | 66.6 | 69.8 | 72.9 | 60.4 |
| 19 | 57.8 | 61.0 | 64.3 | 68.3 | 72.8 | 63.3 |
| 20 | 56.8 | 62.5 | 65.1 | 67.8 | 73.0 | 60.0 |
| 21 | 55.7 | 59.7 | 63.6 | 67.7 | 72.1 | 70.3 |
| 22 | 57.2 | 59.7 | 63.6 | 67.4 | 71.1 | 69.0 |
| 23 | 56.0 | 59.0 | 63.6 | 67.4 | 70.7 | 69.9 |
| 24 | 56.4 | 60.1 | 64.3 | 68.4 | 70.7 | 68.9 |

TABLE A- 6 PHYSICAL ANALYSIS OF NOISE
SIGNALS - DBAD UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 58.3 | 61.7 | 66.3 | 69.[illegible] | 72.7 | 59.5 |
| 2 | 58.2 | 62.0 | 65.7 | 70. | 72.0 | 60.9 |
| 3 | 57.2 | 61.1 | 64.7 | 69.1 | 72.3 | 62.6 |
| 4 | 57.2 | 59.9 | 65.3 | 67.6 | 70.9 | 65.6 |
| 5 | 56.6 | 60.6 | 64.1 | 68.0 | 70.8 | 62.9 |
| 6 | 56.6 | 60.4 | 65.0 | 68.9 | 70.8 | 63.7 |
| 7 | 58.0 | 60.8 | 64.2 | 68.4 | 72.1 | 66.6 |
| 8 | 56.9 | 60.9 | 65.3 | 68.2 | 72.5 | 62.4 |
| 9 | 59.9 | 64.7 | 67.3 | 70.8 | 74.6 | 61.3 |
| 10 | 54.4 | 57.9 | 61.7 | 66.7 | 70.0 | 65.7 |
| 11 | 52.7 | 56.5 | 60.7 | 64.2 | 68.5 | 65.1 |
| 12 | 51.1 | 55.1 | 59.1 | 62.2 | 65.8 | 62.0 |
| 13 | 50.4 | 54.8 | 59.2 | 62.2 | 66.7 | 60.1 |
| 14 | 51.5 | 56.8 | 61.6 | 66.0 | 67.9 | 61.9 |
| 15 | 56.4 | 59.6 | 62.8 | 66.9 | 70.7 | 63.4 |
| 16 | 49.4 | 53.3 | 58.0 | 61.6 | 64.8 | 69.3 |
| 17 | 57.2 | 61.0 | 64.8 | 69.5 | 71.5 | 65.6 |
| 18 | 57.8 | 60.7 | 64.5 | 68.2 | 71.7 | 60.1 |
| 19 | 54.6 | 58.1 | 61.2 | 65.3 | 69.5 | 65.1 |
| 20 | 53.4 | 58.8 | 61.2 | 64.6 | 69.3 | 61.8 |
| 21 | 60.4 | 64.0 | 68.0 | 71.3 | 76.4 | 64.3 |
| 22 | 60.4 | 62.9 | 66.7 | 70.7 | 74.4 | 63.1 |
| 23 | 54.7 | 57.7 | 62.5 | 65.7 | 67.2 | 69.2 |
| 24 | 58.7 | 62.7 | 66.7 | 71.1 | 71.6 | 64.8 |

TABLE A- 7 PHYSICAL ANALYSIS OF NOISE
SIGNALS - DEAT UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 60.7 | 64.2 | 68.7 | 72.1 | 75.2 | 63.8 |
| 2 | 60.8 | 64.5 | 68.5 | 73.0 | 75.6 | 65.0 |
| 3 | 59.4 | 63.0 | 66.7 | 71.4 | 74.4 | 67.4 |
| 4 | 58.6 | 61.1 | 66.3 | 68.6 | 71.9 | 71.4 |
| 5 | 59.4 | 62.0 | 68.5 | 71.0 | 72.3 | 66.7 |
| 6 | 58.5 | 62.7 | 67.0 | 70.7 | 72.7 | 69.3 |
| 7 | 60.5 | 62.6 | 66.8 | 71.3 | 74.8 | 71.0 |
| 8 | 59.5 | 62.6 | 68.3 | 70.8 | 75.4 | 66.5 |
| 9 | 59.9 | 65.5 | 67.6 | 71.6 | 75.2 | 67.8 |
| 10 | 59.0 | 62.5 | 66.5 | 71.4 | 74.6 | 68.1 |
| 11 | 60.3 | 64.0 | 68.0 | 70.6 | 76.2 | 65.1 |
| 12 | 58.0 | 62.0 | 65.4 | 68.2 | 73.1 | 61.8 |
| 13 | 58.9 | 63.8 | 68.3 | 70.4 | 76.4 | 56.9 |
| 14 | 62.1 | 65.0 | 69.7 | 74.2 | 75.4 | 59.7 |
| 15 | 59.9 | 62.1 | 66.2 | 70.7 | 74.7 | 66.7 |
| 16 | 58.2 | 62.2 | 67.1 | 70.4 | 73.5 | 66.3 |
| 17 | 57.4 | 61.2 | 64.9 | 69.4 | 71.4 | 72.0 |
| 18 | 62.6 | 65.4 | 70.0 | 72.5 | 76.2 | 61.5 |
| 19 | 60.2 | 64.0 | 66.8 | 70.9 | 74.8 | 65.5 |
| 20 | 59.1 | 64.7 | 67.1 | 70.8 | 73.1 | 62.2 |
| 21 | 57.4 | 61.6 | 66.0 | 69.4 | 72.9 | 72.6 |
| 22 | 59.1 | 61.9 | 65.9 | 69.5 | 72.2 | 72.0 |
| 23 | 57.3 | 60.5 | 65.1 | 69.0 | 72.1 | 72.9 |
| 24 | 58.6 | 62.3 | 66.5 | 70.6 | 72.2 | 71.7 |

TABLE A- 8 PHYSICAL ANALYSIS OF NOISE SIGNALS - EDBA UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 61.4 | 64.8 | 69.4 | 72.0 | 75.8 | 60.6 |
| 2 | 61.3 | 63.0 | 68.8 | 72.6 | 76.0 | 62.3 |
| 3 | 59.8 | 62.7 | 67.2 | 71.8 | 74.9 | 64.4 |
| 4 | 58.8 | 61.3 | 66.9 | 69.2 | 72.6 | 68.3 |
| 5 | 59.4 | 63.3 | 67.0 | 70.8 | 72.6 | 64.4 |
| 6 | 59.2 | 62.9 | 67.6 | 71.5 | 72.2 | 65.4 |
| 7 | 60.8 | 62.7 | 66.9 | 71.2 | 73.0 | 68.2 |
| 8 | 59.0 | 62.2 | 67.6 | 70.4 | 74.6 | 64.5 |
| 9 | 61.7 | 66.3 | 69.2 | 72.7 | 76.3 | 67.8 |
| 10 | 56.1 | 59.[illegible] | 62.4 | 68.3 | 71.8 | 68.5 |
| 11 | 55.9 | 59.[illegible] | 64.1 | 67.5 | 71.9 | 66.2 |
| 12 | [illegible] | 57.[illegible] | 61.2 | 64.2 | 66.0 | 64.2 |
| 13 | [illegible] | 57.1 | 61.8 | 64.6 | 69.2 | 61.9 |
| 14 | 55.[illegible] | 58.3 | 62.1 | 67.3 | 69.[illegible] | 64.6 |
| 15 | [illegible] | 61.3 | [illegible] | [illegible] | 72.3 | 66.1 |
| 16 | 51.[illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 72.[illegible] |
| 17 | [illegible] | [illegible] | [illegible] | 71.[illegible] | 72.4 | [illegible] |
| 18 | [illegible] | [illegible] | [illegible] | 70.[illegible] | [illegible] | 62.0 |
| 19 | 56.[illegible] | 61.1 | [illegible] | [illegible] | 71.[illegible] | [illegible] |
| 20 | 55.[illegible] | [illegible] | [illegible] | [illegible] | 71.[illegible] | [illegible] |
| 21 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 22 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 67.1 |

TABLE A- 9 PHYSICAL ANALYSIS OF NOISE SIGNALS - PLL-VII UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJOB |
|---|---|---|---|---|---|---|
| 1 | 60.1 | 63.5 | 68.1 | 70.8 | 72.8 | 68.7 |
| 2 | 60.7 | 63.9 | 68.9 | 71.9 | 74.4 | 68.9 |
| 3 | 60.4 | 64.1 | 67.2 | 71.5 | 74.4 | 70.2 |
| 4 | 62.8 | 65.3 | 69.8 | 72.3 | 75.1 | 70.6 |
| 5 | 60.2 | 63.7 | 67.2 | 70.7 | 72.4 | 70.2 |
| 6 | 60.3 | 63.9 | 68.1 | 71.6 | 72.9 | 71.3 |
| 7 | 62.4 | 63.1 | 68.3 | 72.3 | 75.3 | 72.4 |
| 8 | 61.7 | 65.4 | 69.5 | 71.8 | 75.4 | 68.8 |
| 9 | 62.4 | 65.9 | 69.2 | 72.0 | 76.2 | 69.5 |
| 10 | 61.7 | 64.8 | 68.1 | 72.3 | 75.8 | 69.7 |
| 11 | 61.9 | 65.0 | 68.5 | 71.8 | 73.8 | 67.9 |
| 12 | 61.6 | 65.0 | 68.1 | 70.5 | 75.0 | 63.7 |
| 13 | 59.8 | 64.6 | 68.8 | 71.3 | 77.2 | 61.3 |
| 14 | 62.2 | 65.8 | 70.0 | 74.0 | 75.6 | 64.1 |
| 15 | 61.8 | 65.1 | 67.8 | 72.1 | 73.7 | 68.6 |
| 16 | 63.9 | 65.7 | 71.2 | 74.4 | 77.3 | 65.4 |
| 17 | 61.9 | 64.9 | 69.3 | 72.7 | 75.1 | 71.5 |
| 18 | 61.5 | 64.5 | 68.2 | 71.3 | 74.2 | 67.5 |
| 19 | 62.8 | 65.7 | 68.6 | 72.2 | 76.3 | 67.2 |
| 20 | 61.3 | 66.[illegible] | 68.[illegible] | 72.[illegible] | 76.2 | 65.0 |
| 21 | 61.7 | 63.[illegible] | 68.9 | 72.5 | 76.2 | 72.8 |
| 22 | 62.6 | 63.3 | 68.[illegible] | 72.[illegible] | 73.[illegible] | 71.7 |
| 23 | 63.[illegible] | 65.0 | 70.1 | [illegible] | 77.5 | 70.4 |
| 24 | 62.7 | 66.1 | 70.0 | 73.7 | 76.[illegible] | 71.1 |

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | [illegible] |
|---|---|---|---|---|---|---|
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

TABLE A-12 PHYSICAL ANALYSIS OF NOISE
SIGNALS - DBSPL UNITS

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 | SUBJDB |
|---|---|---|---|---|---|---|
| 1 | 64 1 | 67 7 | 72 1 | 73 6 | 78 7 | 77 2 |
| 2 | 64 5 | 66 4 | 72 2 | 77 1 | 79 6 | 77 1 |
| 3 | 65 8 | 69 7 | 72 7 | 77 7 | 80 3 | 77 6 |
| 4 | 71 7 | 74 2 | 79 3 | 81 8 | 83 2 | 74 0 |
| 5 | 64 8 | 68 7 | 72 4 | 76 2 | 79 1 | 79 1 |
| 6 | 67 2 | 71 2 | 73 4 | 79 2 | 81 6 | 76 2 |
| 7 | 66 6 | 69 3 | 72 2 | 77 3 | 81 2 | 82 1 |
| 8 | 66 8 | 70 8 | 73 2 | 78 1 | 82 0 | 75 2 |
| 9 | 65 9 | 71 0 | 74 8 | 77 2 | 81 1 | 78 4 |
| 10 | 61 6 | 67 1 | 68 8 | 72 7 | 77 2 | 82 7 |
| 11 | 58 4 | 62 1 | 66 6 | 67 7 | 72 7 | 84 2 |
| 12 | 67 9 | 71 7 | 76 2 | 77 8 | 82 3 | 69 2 |
| 13 | 69 2 | 71 0 | 78 6 | 82 4 | 86 6 | 78 3 |
| 14 | 66 3 | 71 9 | 76 8 | 81 2 | 82 7 | 66 9 |
| 15 | 68 8 | 72 1 | 73 0 | 79 6 | 82 1 | 72 9 |
| 16 | 69 4 | 74 2 | 78 1 | 82 0 | 87 0 | 68 0 |
| 17 | 75 5 | 79 7 | 82 4 | 88 2 | 90 0 | 67 5 |
| 18 | 66 2 | 69 2 | 72 6 | 76 7 | 79 6 | 74 5 |
| 19 | 67 7 | 71 2 | 74 0 | 78 7 | 82 6 | 72 4 |
| 20 | 67 4 | 72 9 | 77 8 | 78 8 | 82 7 | 68 0 |
| 21 | 65 1 | 68 1 | 71 8 | 76 4 | 80 6 | 61 9 |
| 22 | 64 6 | 66 8 | 71 2 | 77 1 | 78 6 | 80 4 |
| 23 | 76 6 | 79 8 | 81 4 | 87 6 | 90 5 | 62 5 |
| 24 | 69 6 | 72 4 | 77 8 | 81 4 | 82 5 | 77 2 |

TABLE A-11 AVERAGE OF LOGARITHMS OF MAGNITUDE ESTIMATION RATINGS FOR EACH NOISE SIGNAL

| NOISE | LEVEL 1 | LEVEL 2 | LEVEL 3 | LEVEL 4 | LEVEL 5 |
|---|---|---|---|---|---|
| 1 | [illegible] | [illegible] | * 1 [illegible] | 1 11[illegible] | 1 201 |
| [illegible] | [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | 1 11[illegible] | 1 11[illegible] | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 11[illegible] | 1 [illegible] | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | 1 11[illegible] | 1 1[illegible]1 | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | 1 1[illegible]1 | 1 [illegible] | 1 20[illegible] |
| [illegible] | 1 [illegible]11 | 1 [illegible] | 1 1[illegible]1 | 1 [illegible] | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 [illegible] | 1 [illegible] | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 11[illegible] | 1 [illegible] | 1 [illegible]1[illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 1[illegible] | 1 200 |
| 11 | [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible]1 |
| [illegible] | [illegible] | [illegible] | 1 [illegible] | [illegible] | 1 0[illegible]6 |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 1 0[illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] |
| [illegible] | [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible] |
| 16 | [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 [illegible] | 1 [illegible] | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | 1 [illegible] | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | 1 [illegible]1 | 1 [illegible]11 | 1 [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | 1 11[illegible] | 1 1[illegible] |
| [illegible] | [illegible] | 1 1[illegible] | 1 [illegible] | 1 [illegible]1 | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible]1 | 1 [illegible] |
| [illegible] | [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible] | 1 11[illegible] |
| [illegible] | 1 [illegible] | 1 [illegible] | 1 1[illegible] | 1 [illegible] | 1 [illegible] |

* Standard Signal

## APPENDIX B

Peak 1/3-octave spectra for PNdB calculations for highest level of twenty-four noises utilized in the Main Study.

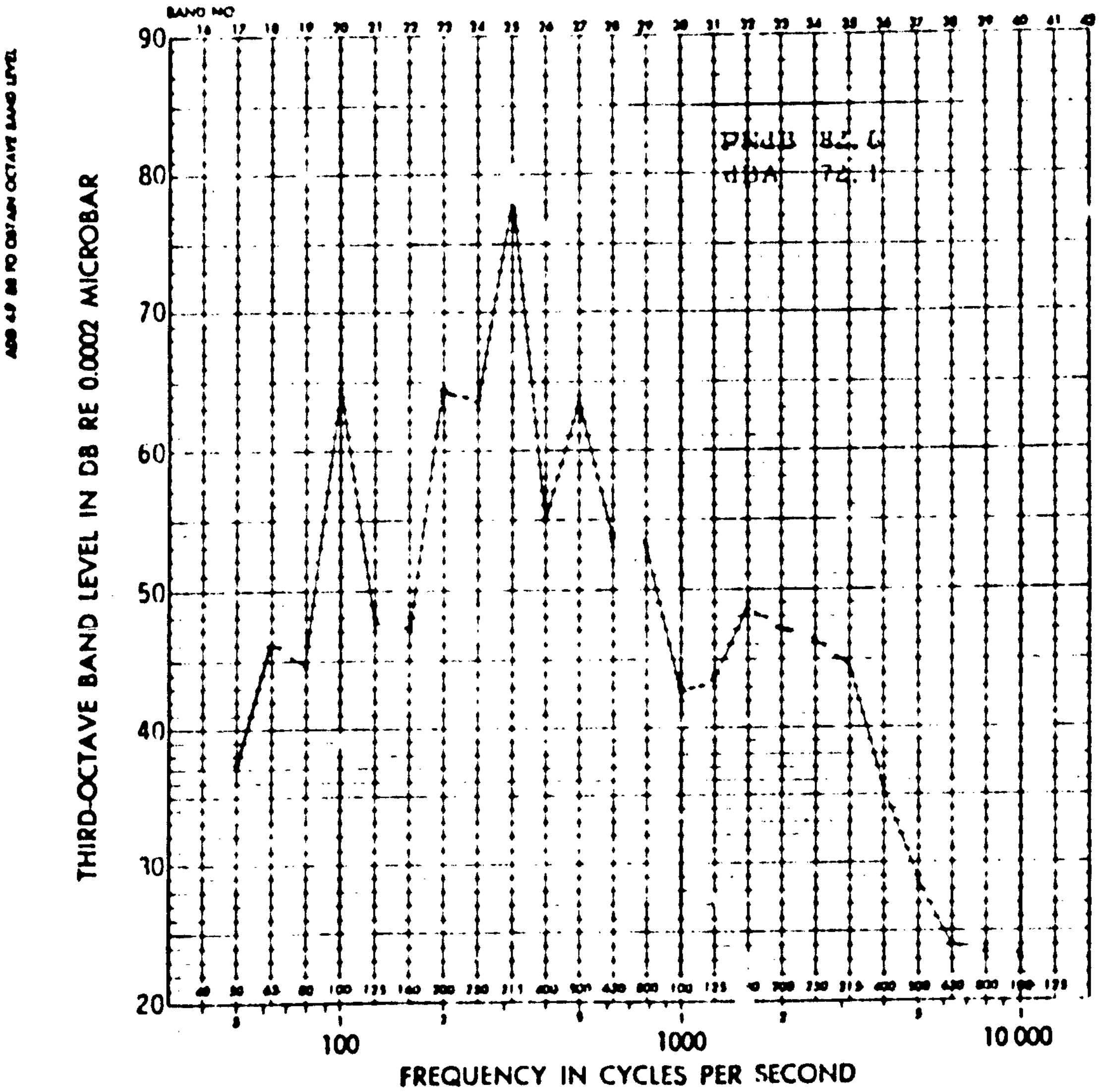



Figure B-1. Peak 1/3-octave band spectrum for Signal No. 1 - Simulation - Tail rotor noise with no slap (Standard)

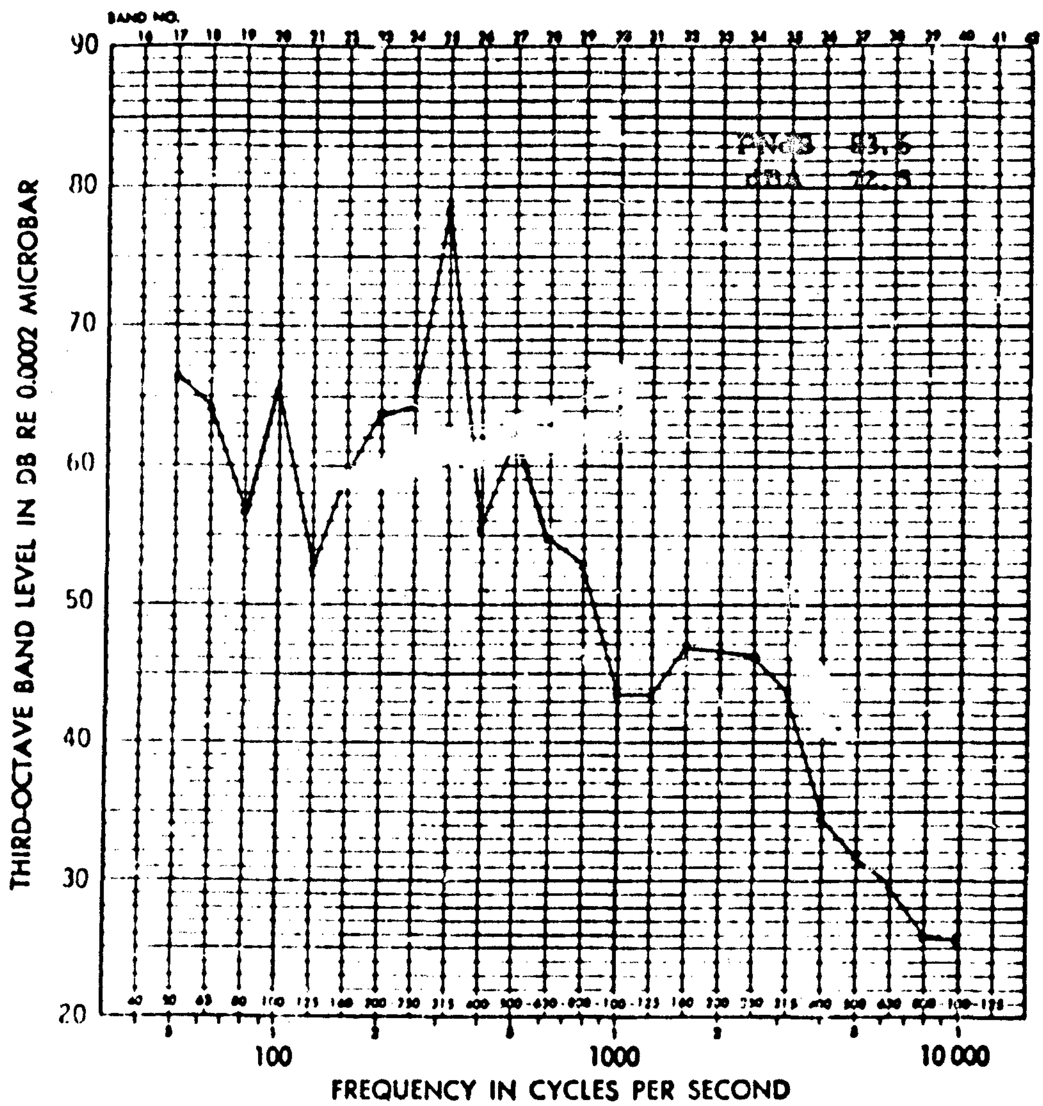


Figure B-2. Peak 1/3-octave band spectrum for Signal No. 2 - Simulation - Tail rotor noise with light slap at 10 beats/sec.

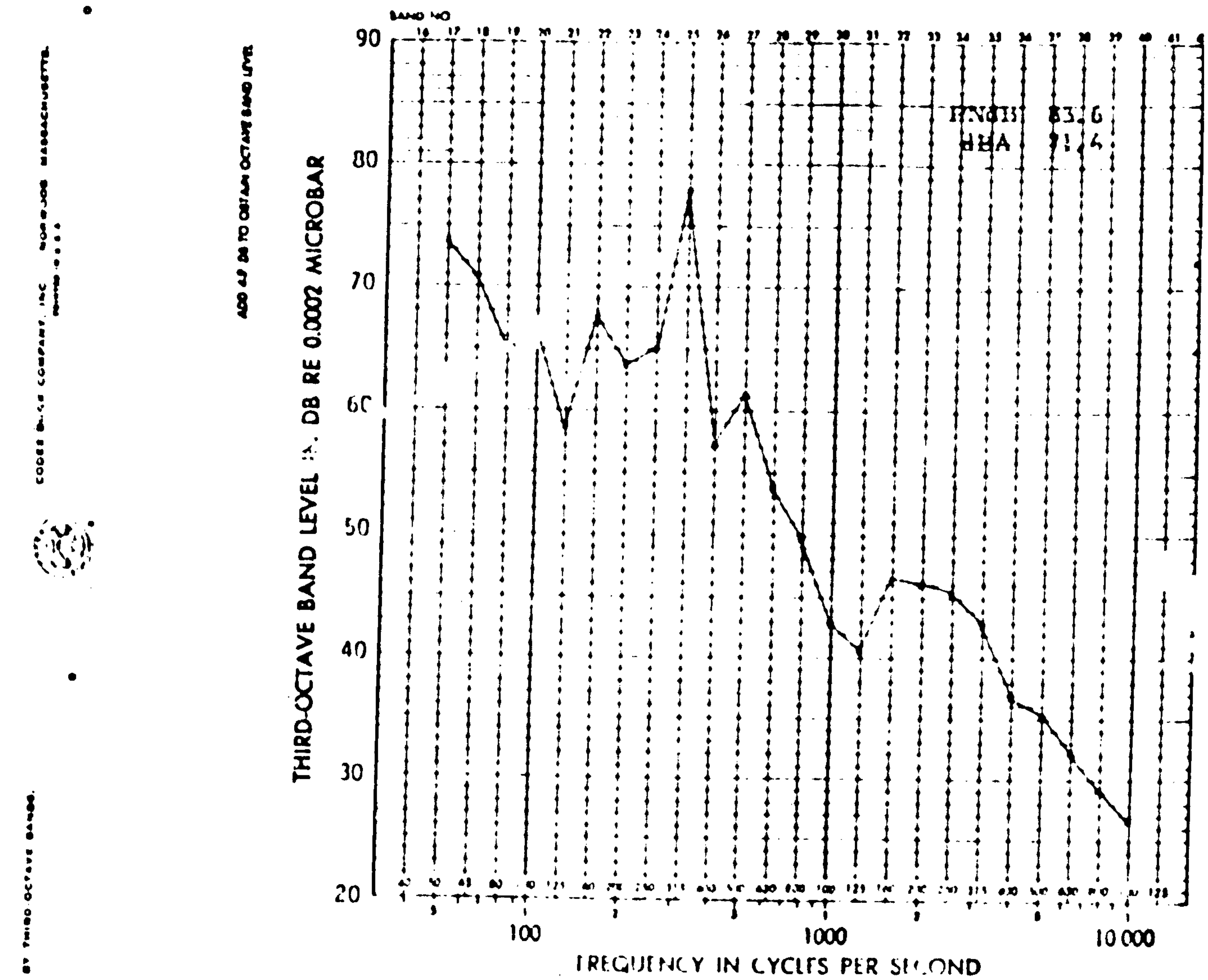



Figure B-3. Peak 1/3-octave band spectrum for Signal No. 3 - Simulation - Tail rotor noise with moderate slap at 10 beats/sec.

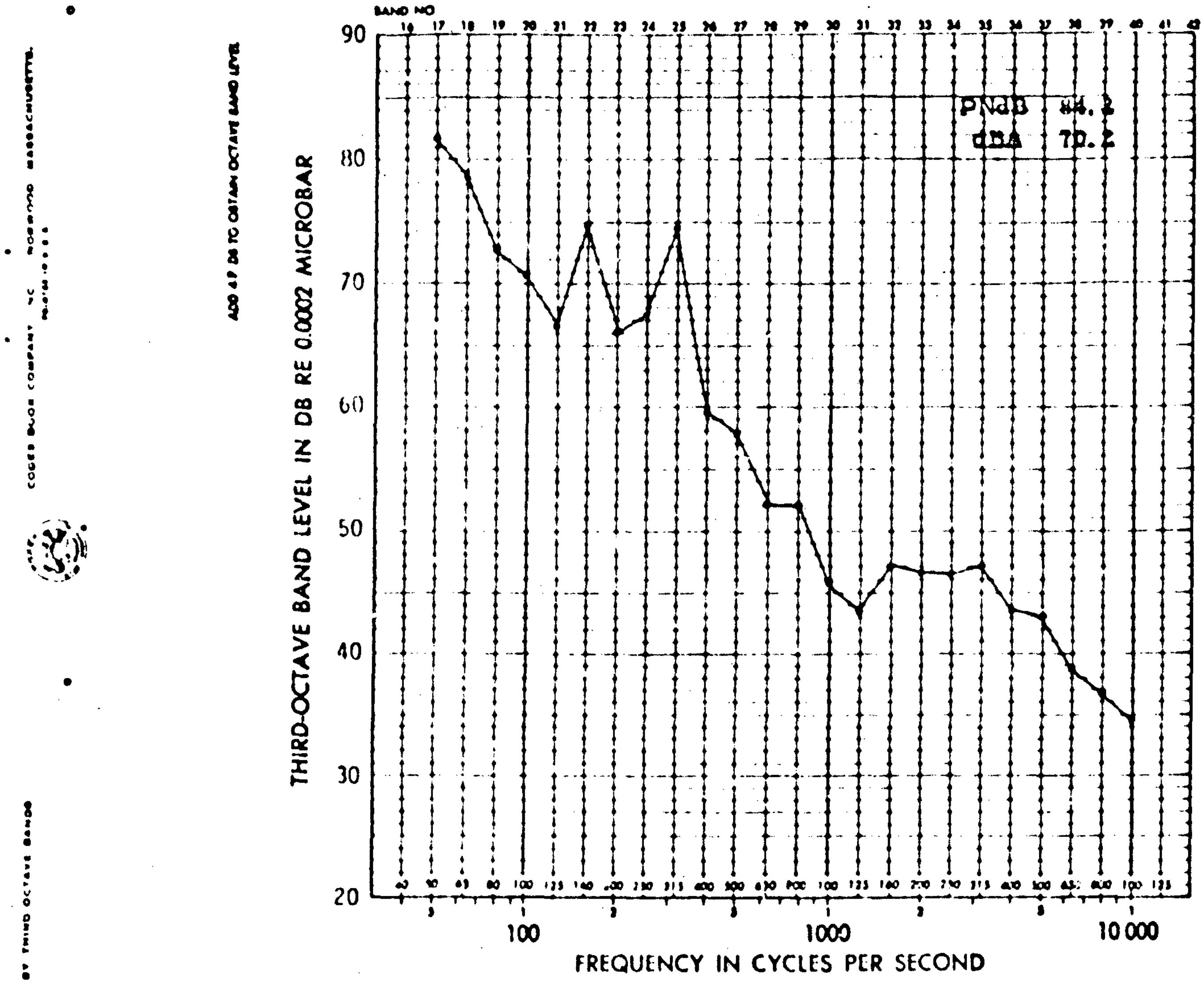



Figure B-4. Peak 1/3-octave band spectrum for signal No. 4 - Simulation - tail rotor noise with heavy slap at 10 beats/sec.

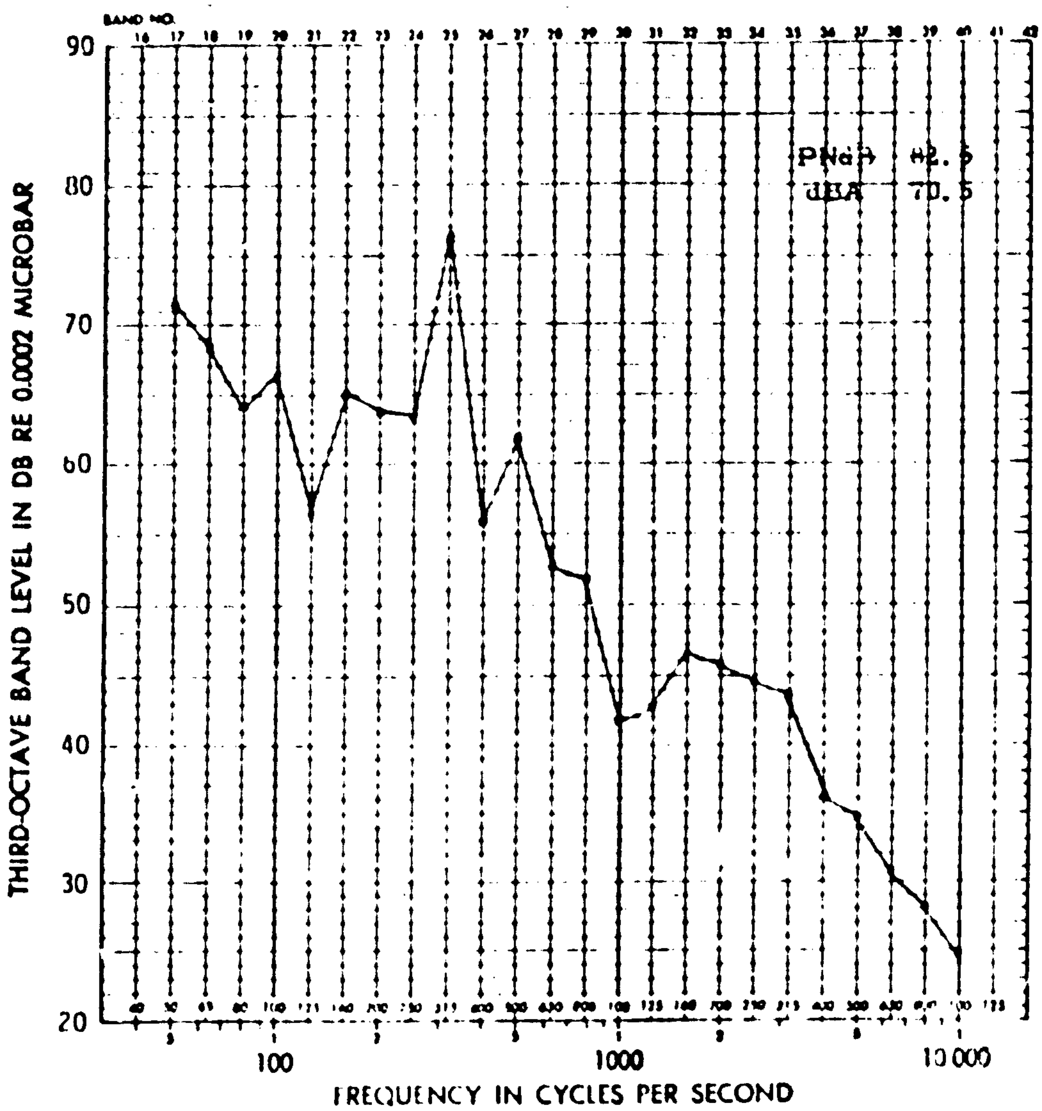



Figure B-5. Peak 1/3-octave band spectrum for Signal No. 5 - Simulation - tail rotor noise with moderate slap at 6 beats/sec.

PAGES B-7, B-8
ARE
MISSING
IN
ORIGINAL
DOCUMENT

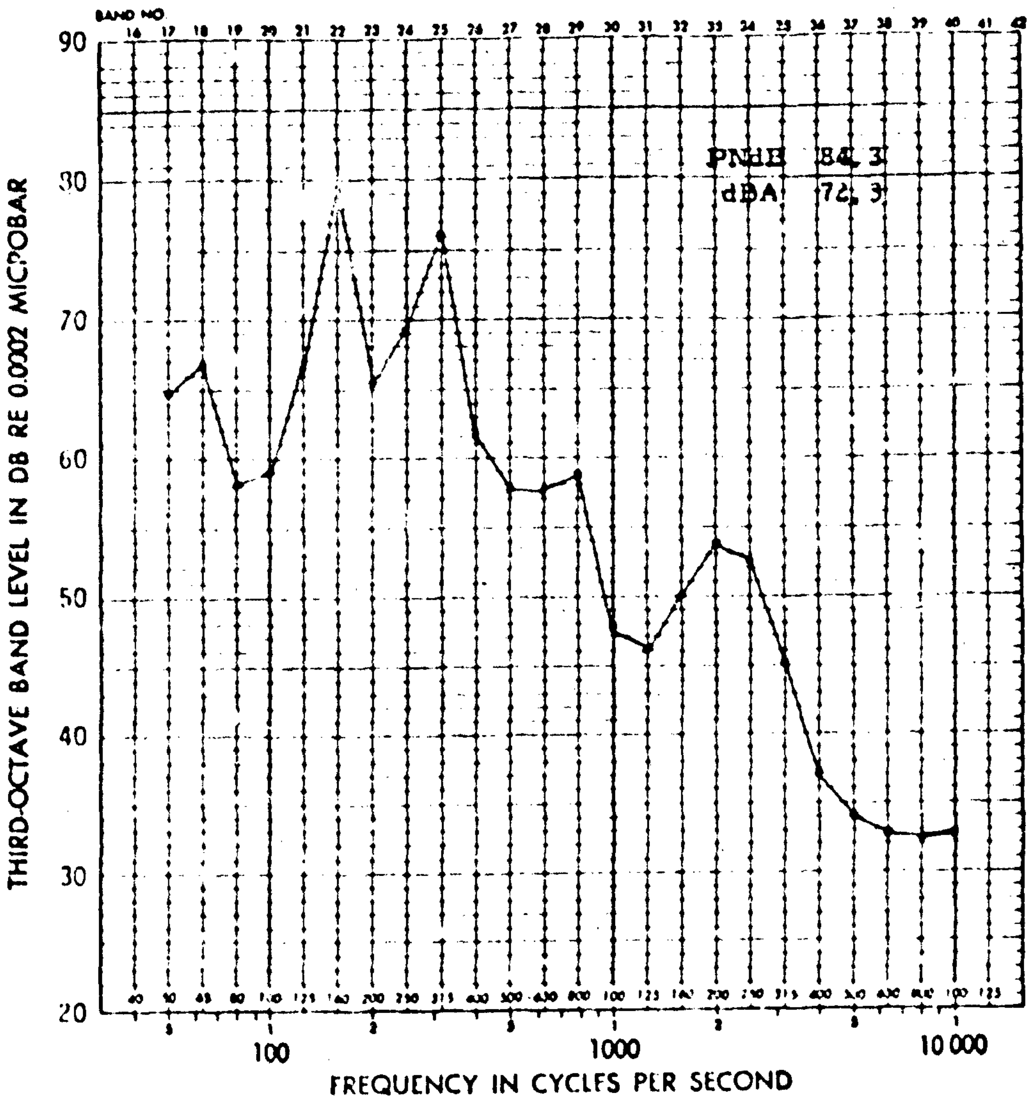



Figure B-8. Peak 1/3-octave band spectrum for Signal No. 8 - Boeing 747 - takeoff.

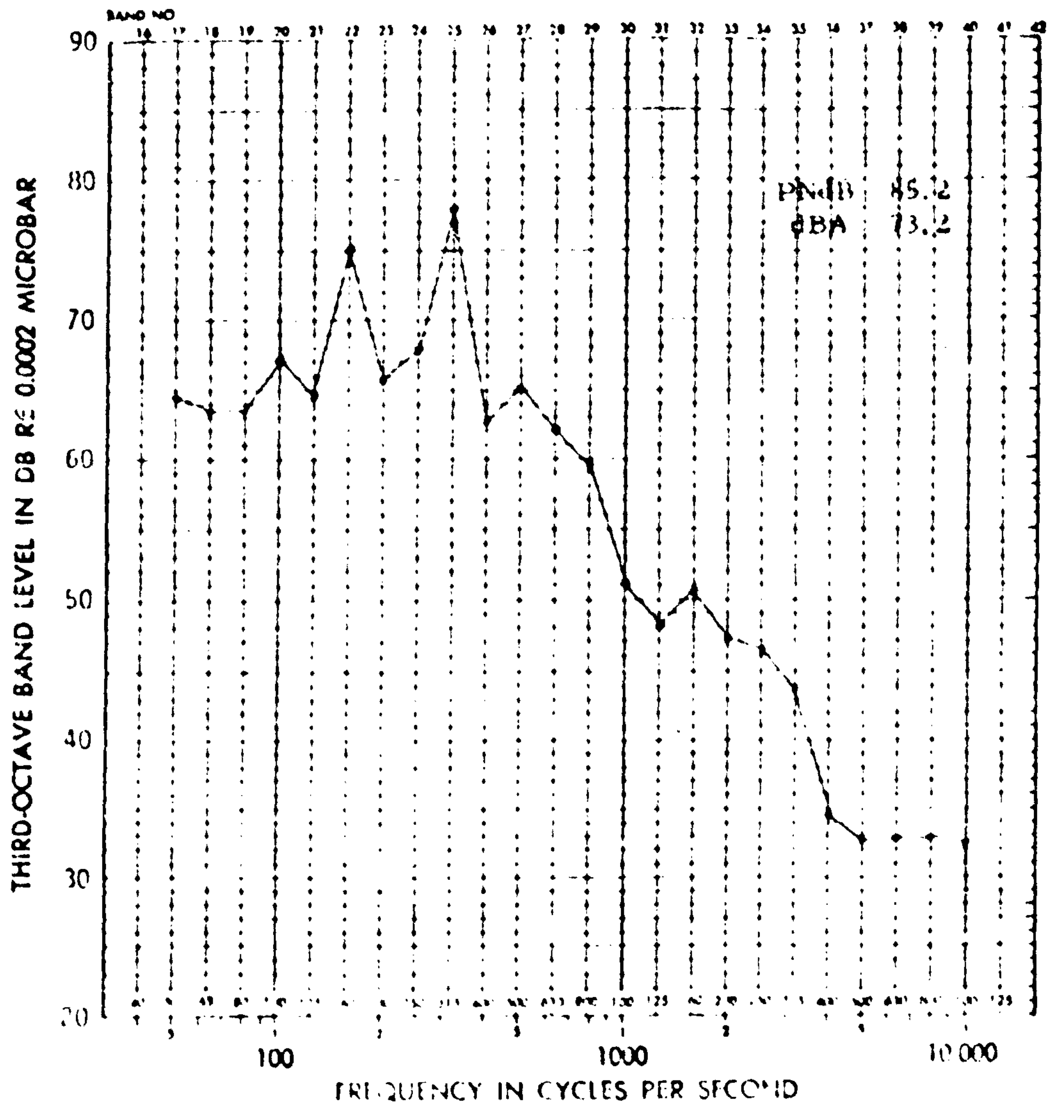



Figure B-9. Peak 1/3-octave band spectrum for Signal No. 9 - DC-8 - takeoff.

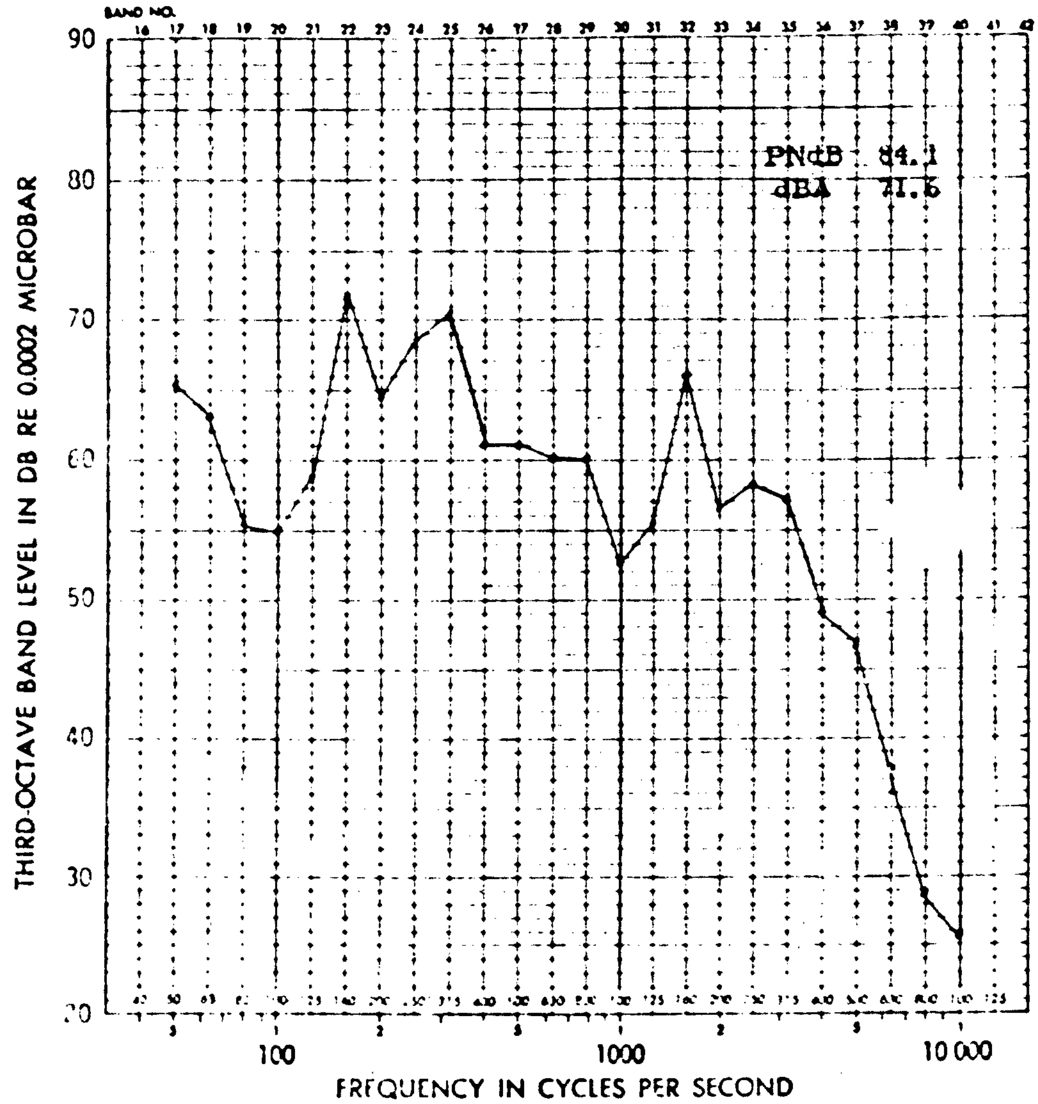



Figure B-10. Peak 1/3-octave band spectrum for Signal No. 10 - Boeing 747 - approach.

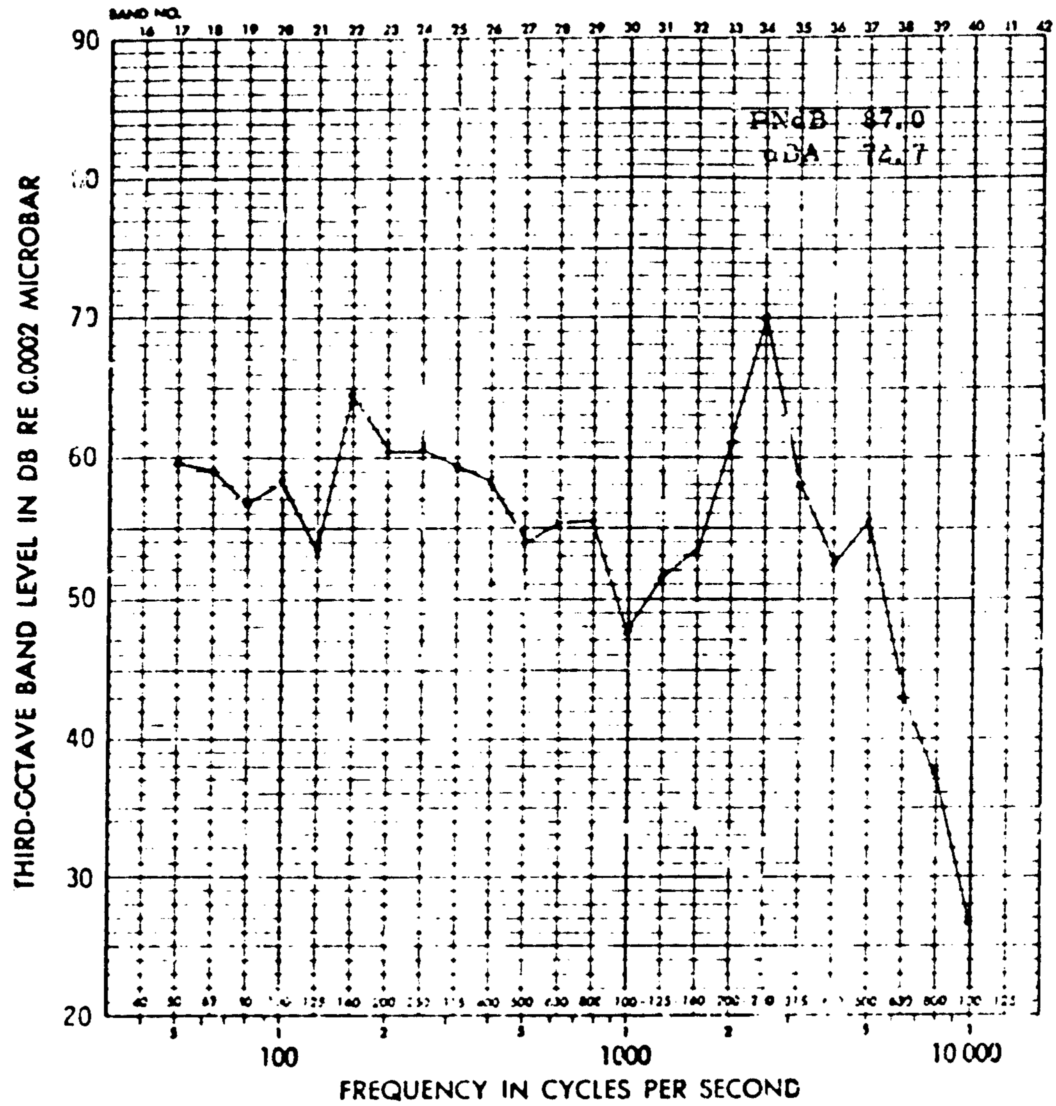



Figure B-11. Peak 1/3-octave band spectrum for Signal No. 11 - DC-8 - approach.

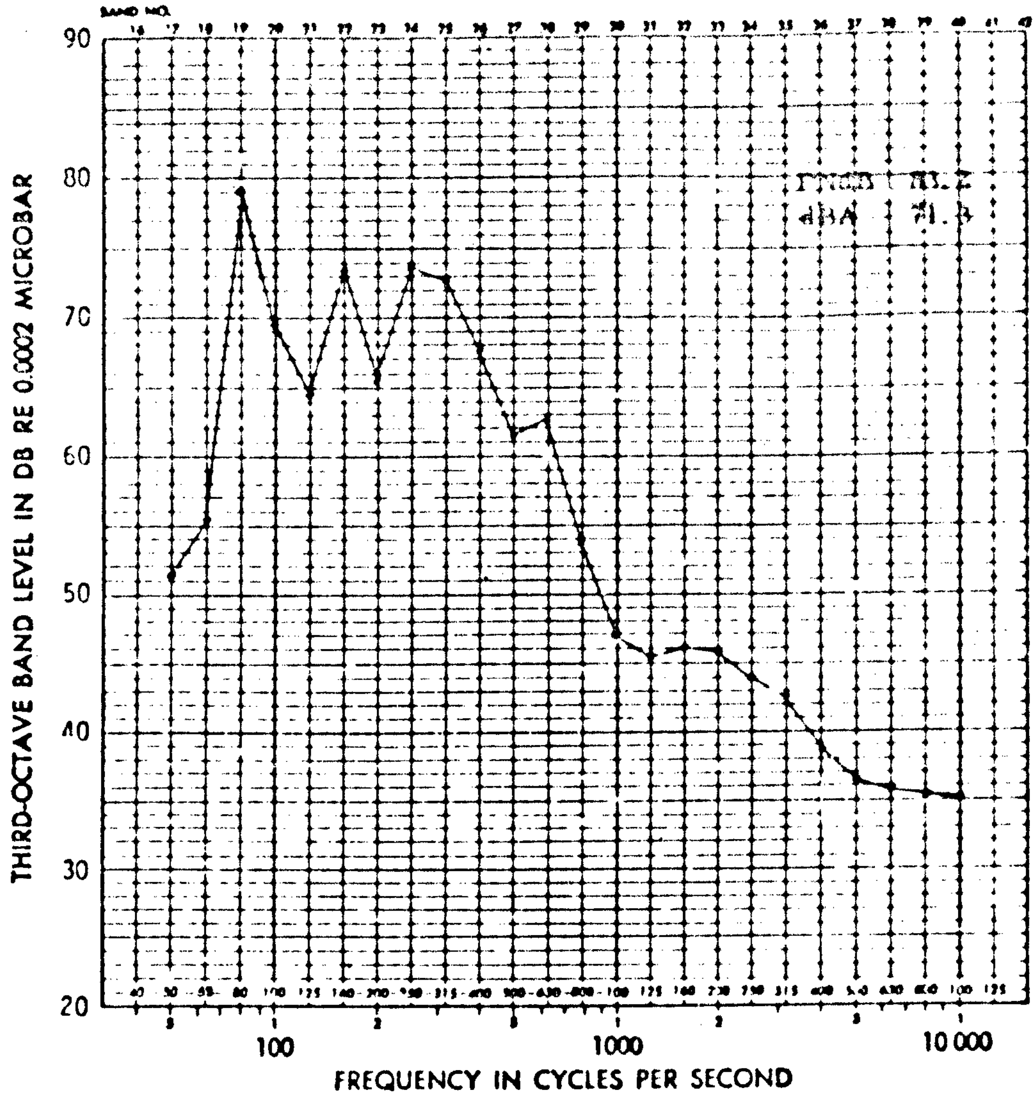



Figure B-12. Peak 1/3-octave band spectrum for Signal No. 12 - Britten-Norman Islander - Takeoff of small commuter reciprocating.

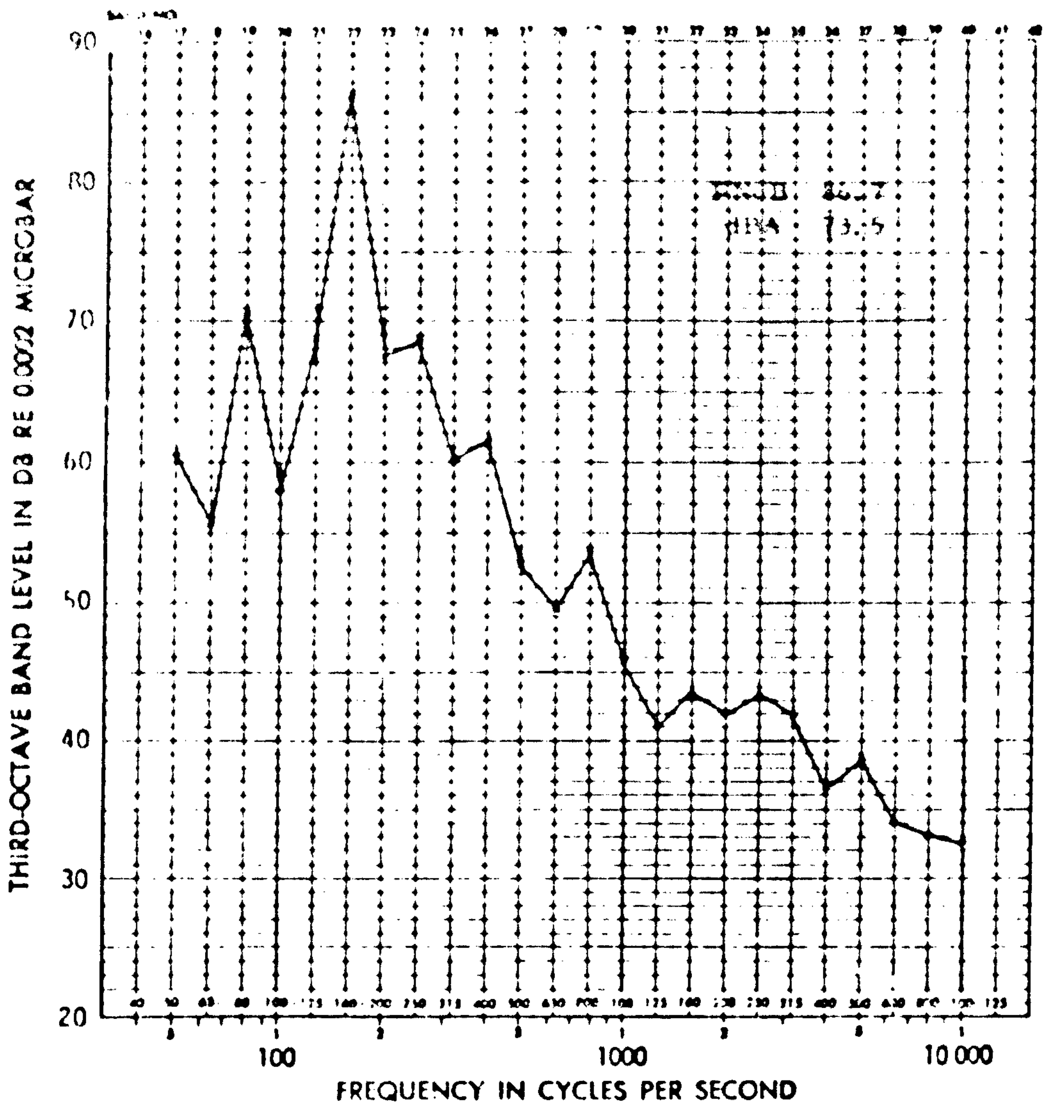



Figure B-13. Peak 1/3-octave band spectrum for Signal No. 13
Convair 640 - takeoff of medium sized turboprop.

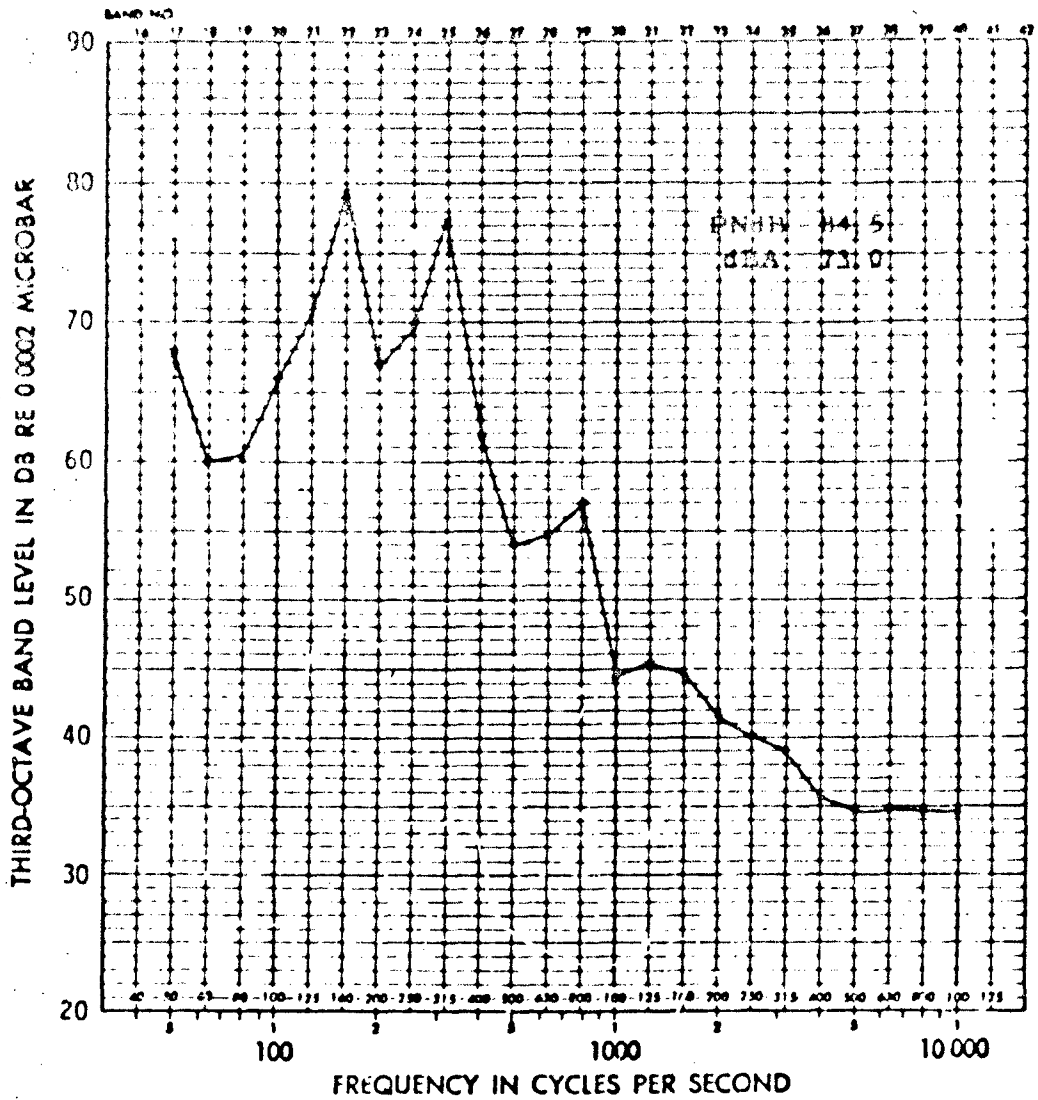



Figure B-14. Peak 1/3-octave band spectrum for Signal No. 14 - Chinook CH 47-A - level flyover at 500 ft. altitude.

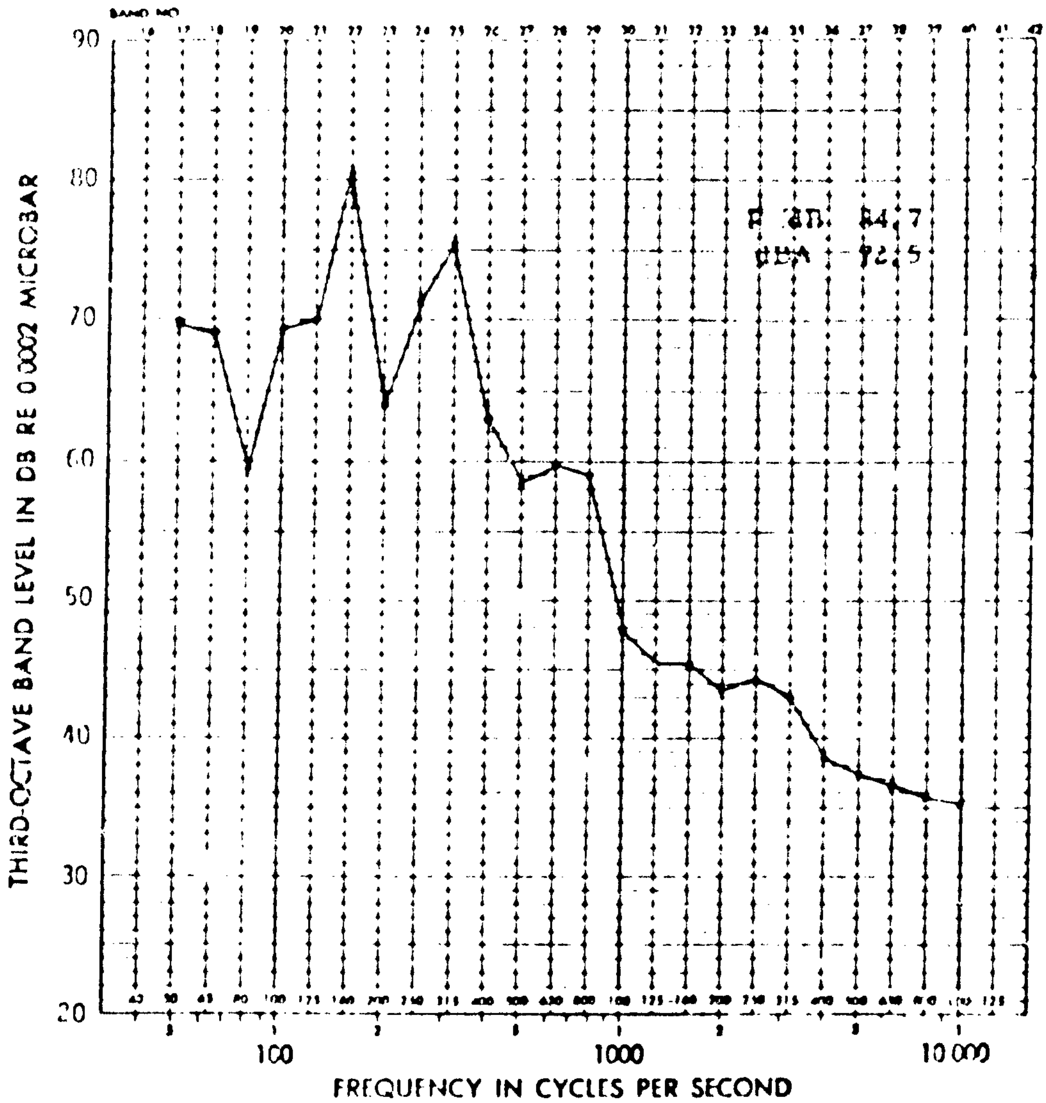



Figure B-15. Peak 1/3-octave band spectrum for Signal No. 15 - Chinook CH 47-A - routine approach.

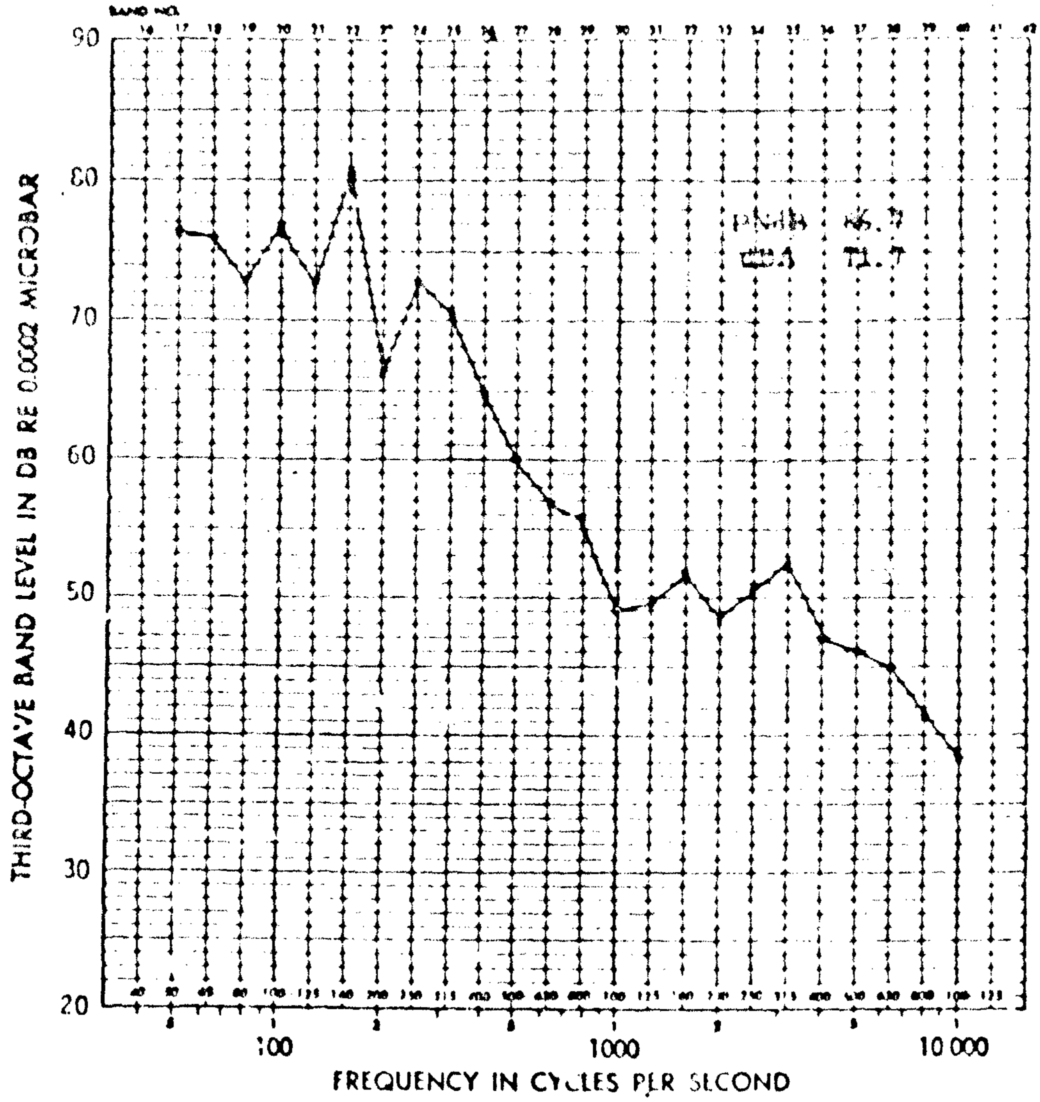



Figure B-16. Peak 1/3-octave band spectrum for Signal No. 16 - Chinook CH 47-A - routine takeoff.

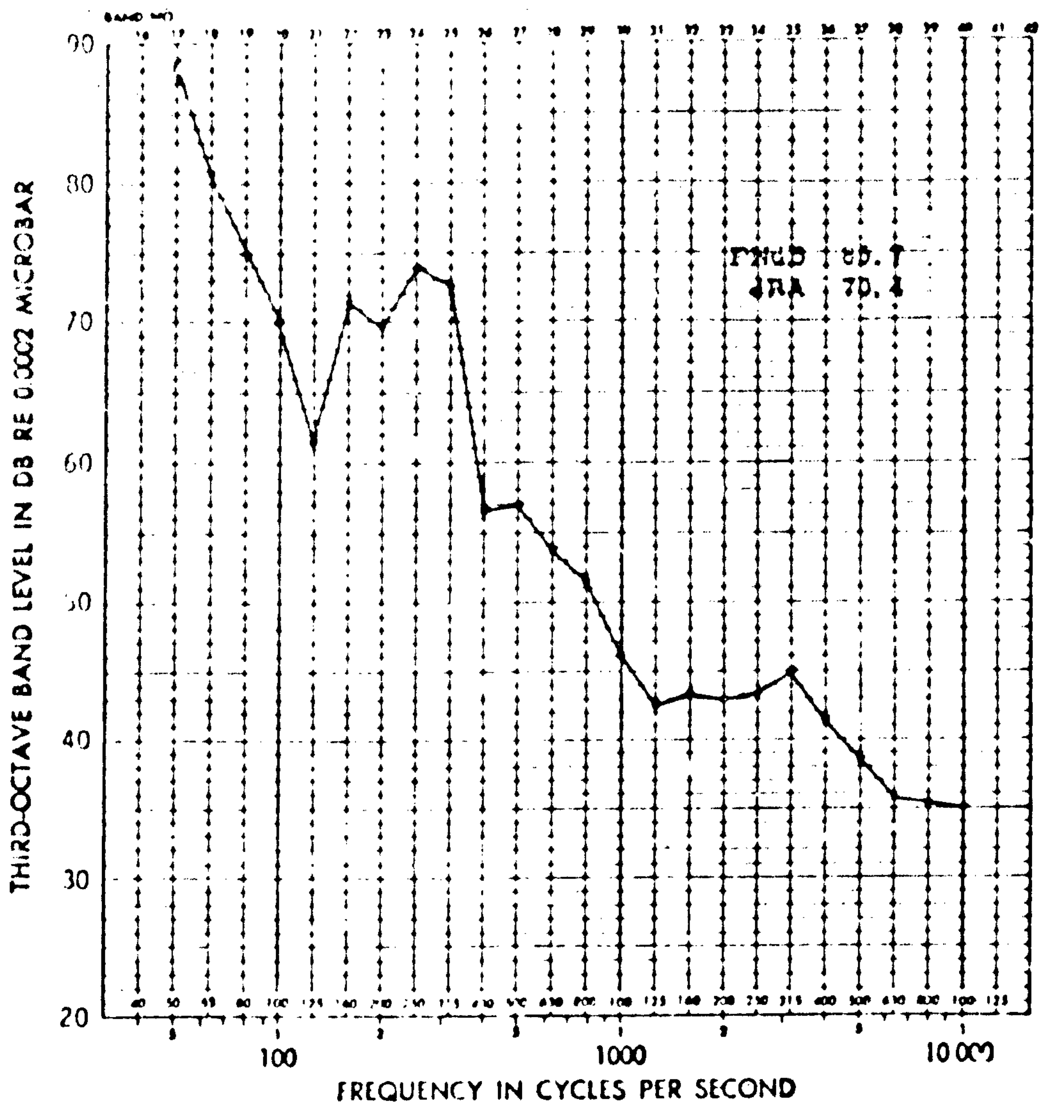



Figure B-17. Peak 1/3-octave band spectrum for Signal No. 17 - Bell UH-1H (Huey) - level flyover at 500 ft. altitude.

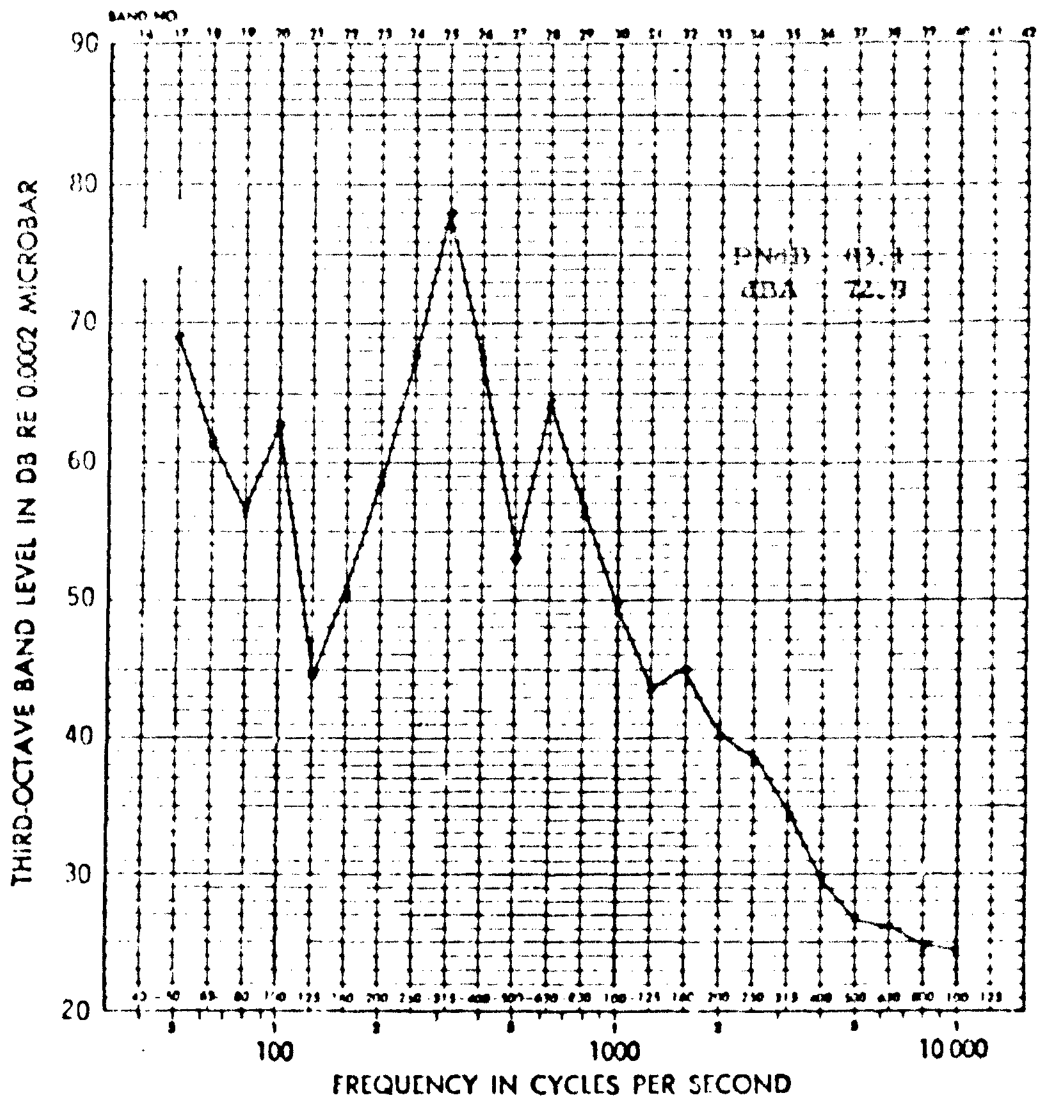



Figure B-18. Peak 1/3-octave band spectrum for Signal No. 18 - Kiowa OH-58 - level flyover at 500 ft. altitude.

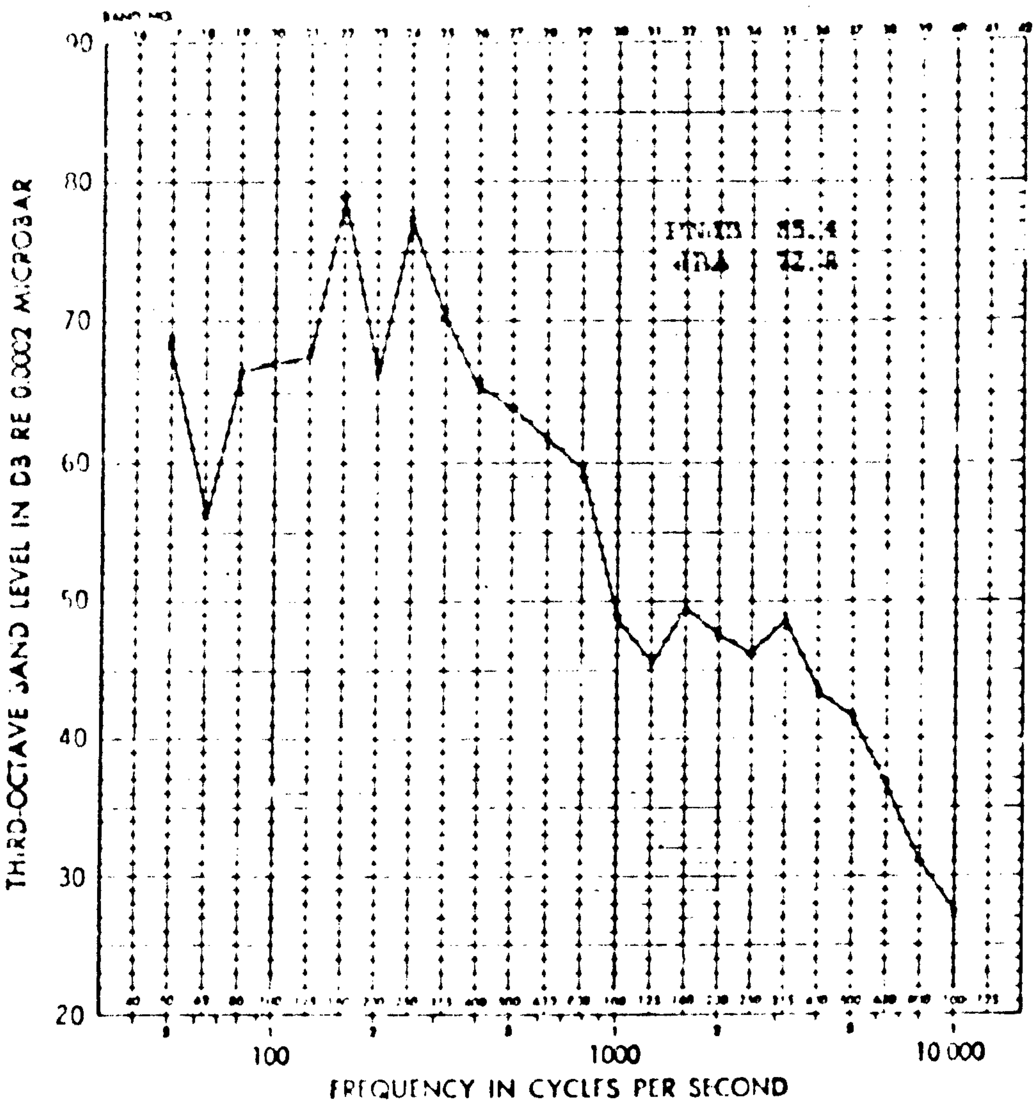



Figure B-19. Peak 1/3-octave band spectrum for Signal No. 19 - Kiowa OH-58 - Routine approach.

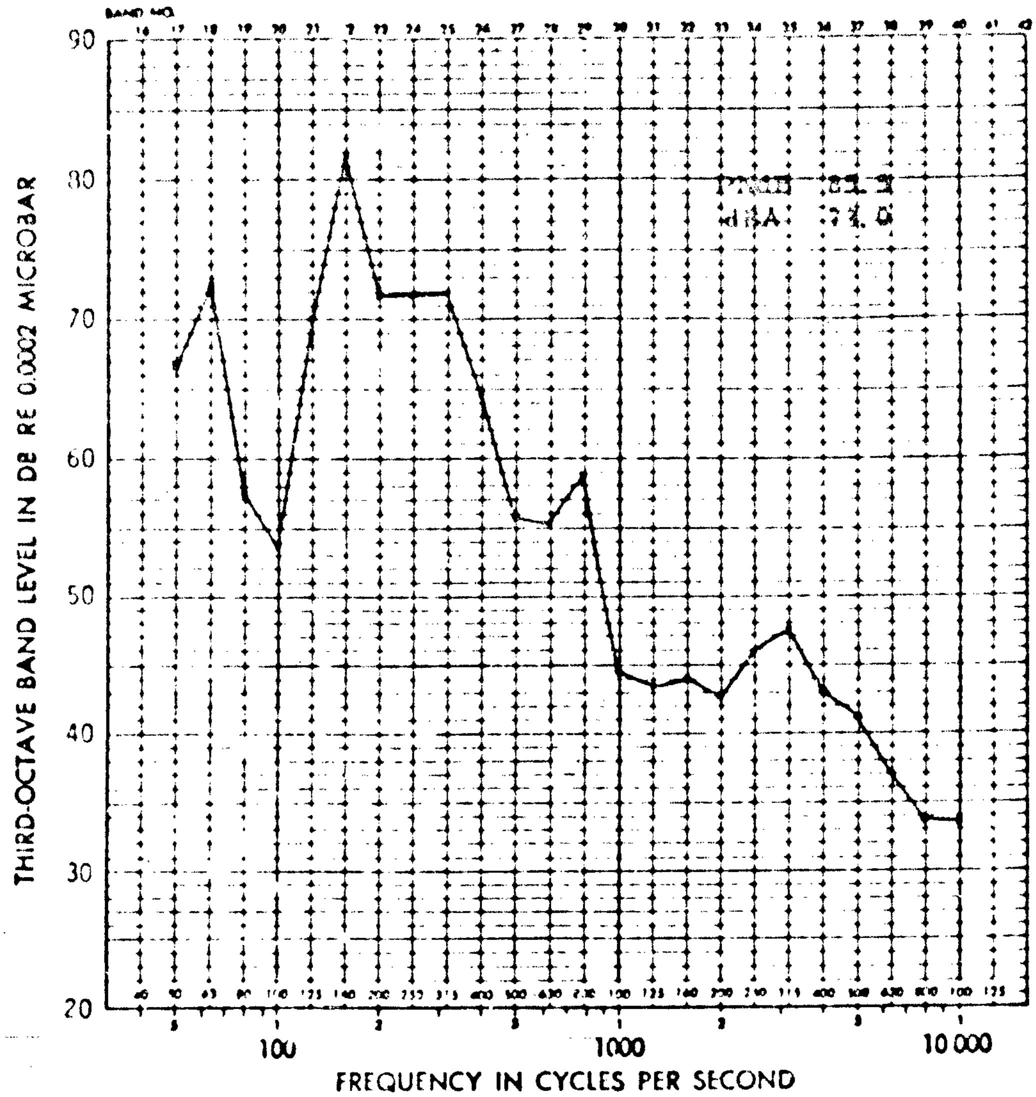



Figure B-20. Peak 1/3-octave band spectrum for Signal No. 20 - Sea Knight - level flyover at 500 ft. altitude.

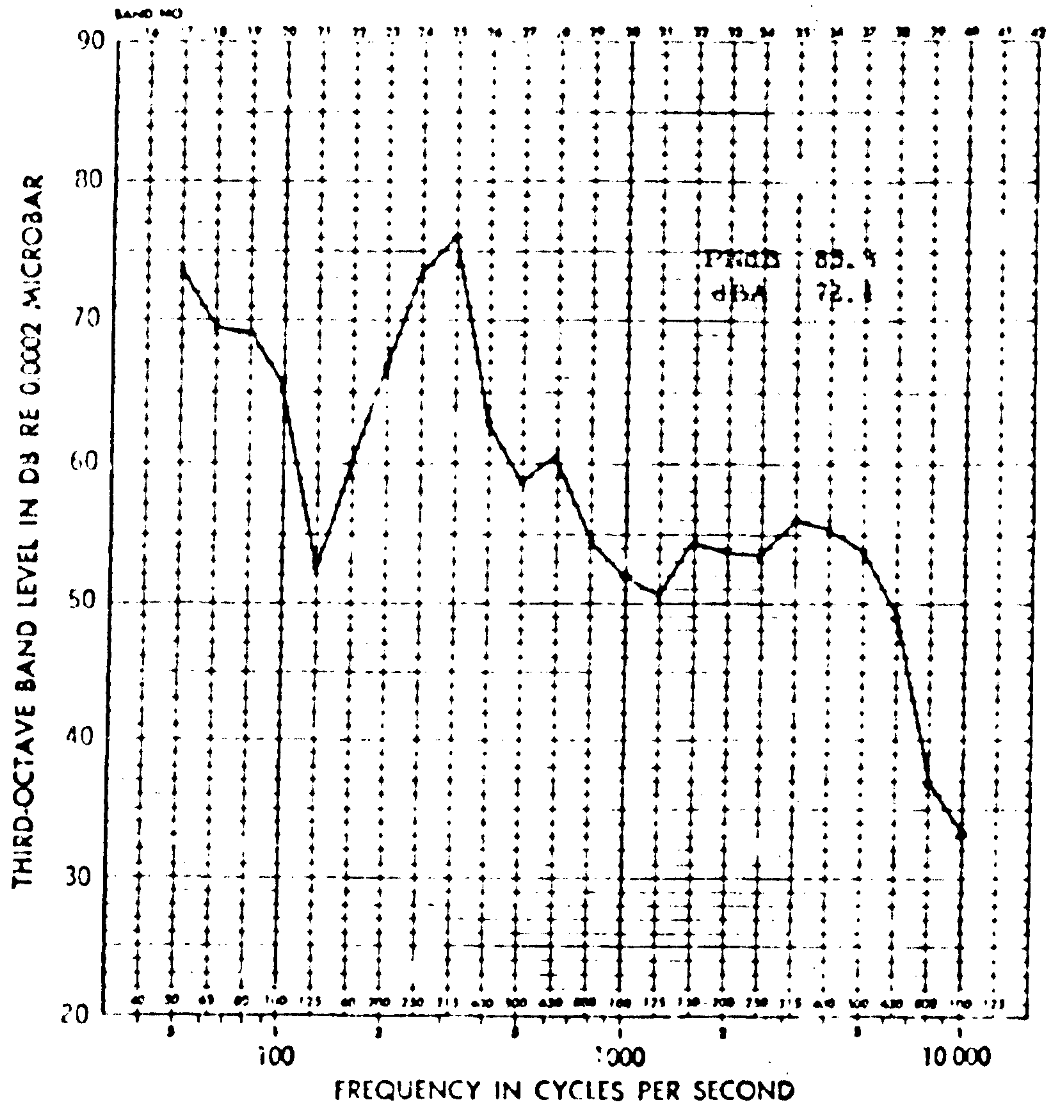



Figure B-21. Peak 1/3-octave band spectrum for Signal No. 21 - Sea Knight - shallow turn operation.

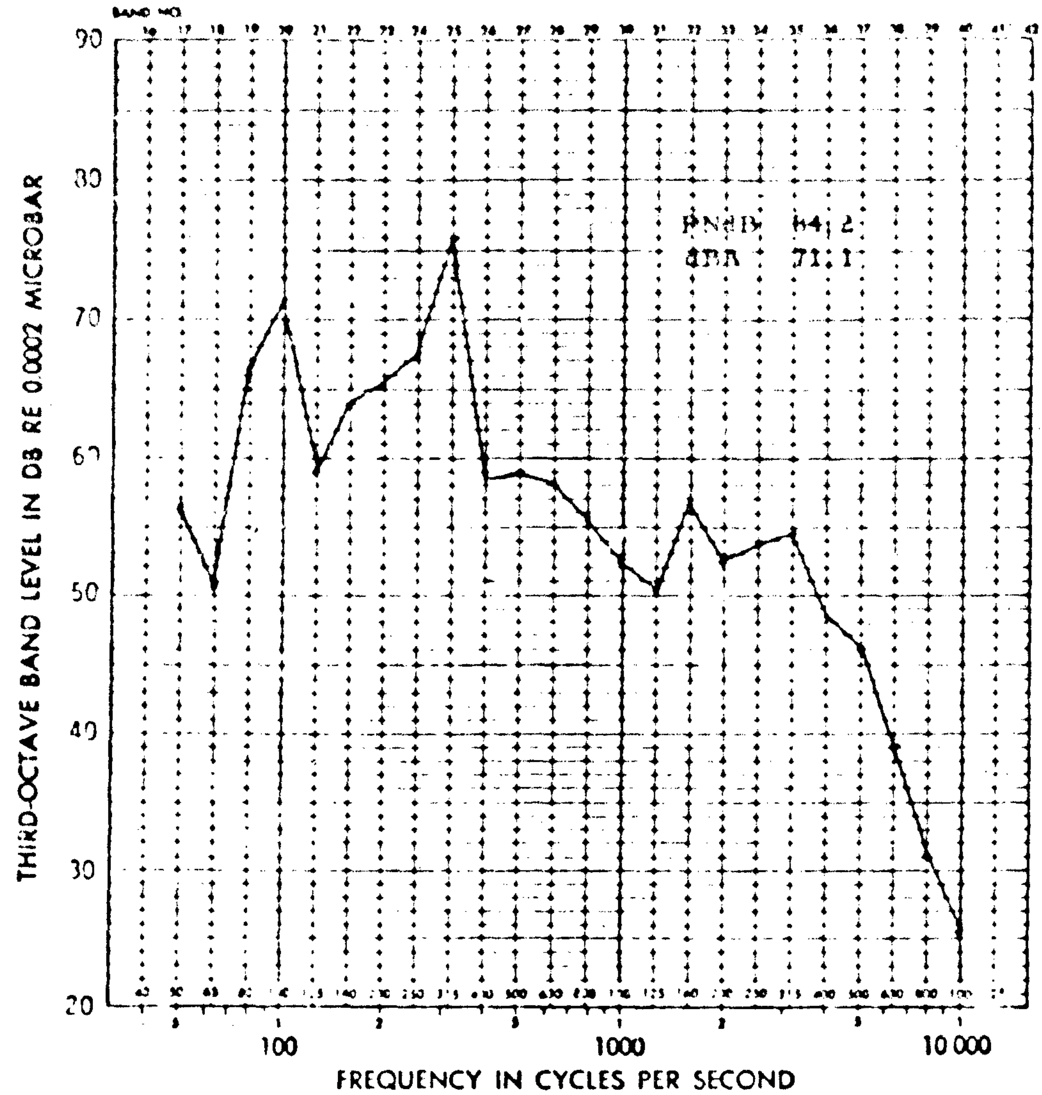



Figure B-22. Peak 1/3-octave band spectrum for Signal No. 22 - Hughes 300 - steep turn operation.

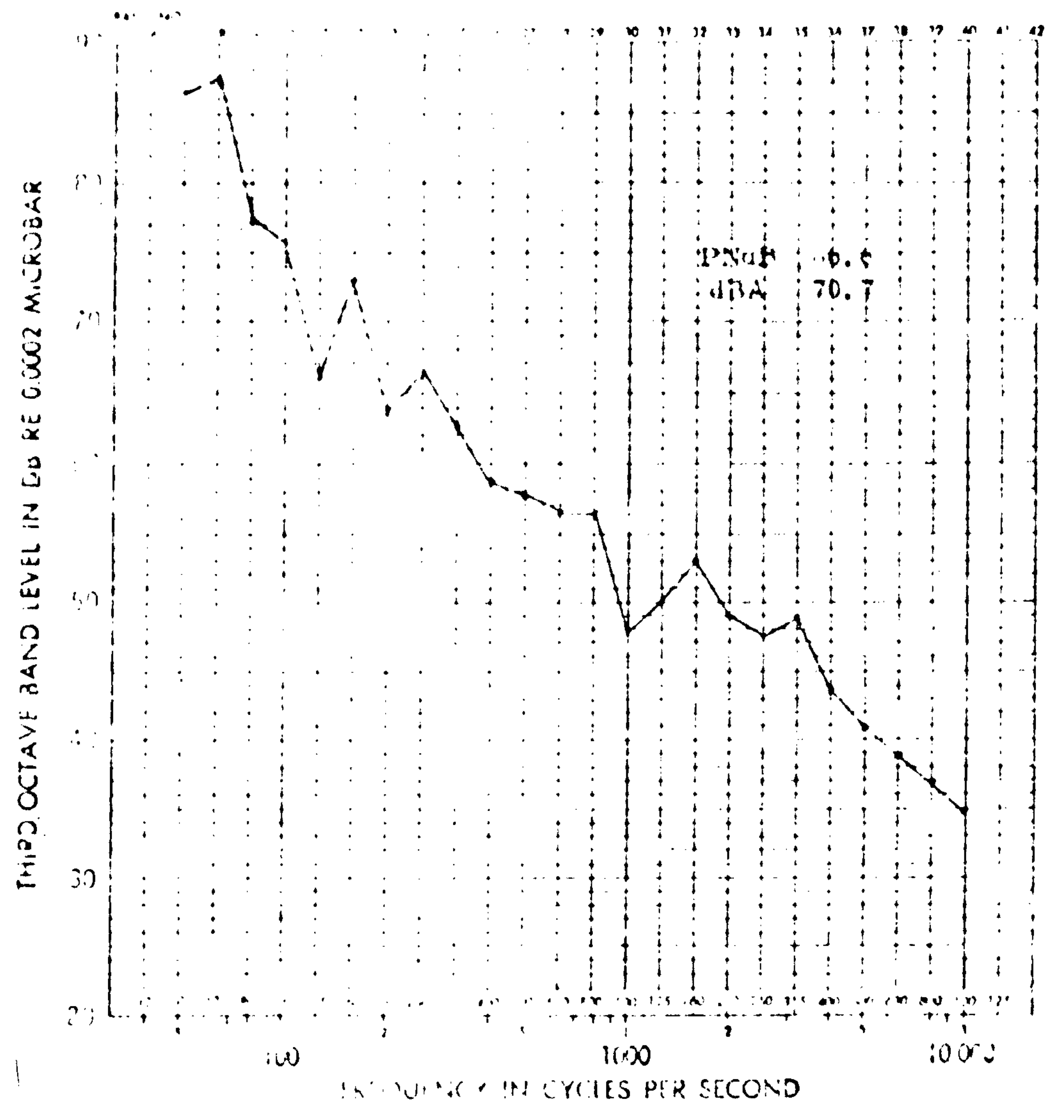



Figure B-23. Peak 1/3-octave band spectrum for Signal No. 23 - B 1 UH-1H (huey) - routine takeoff.

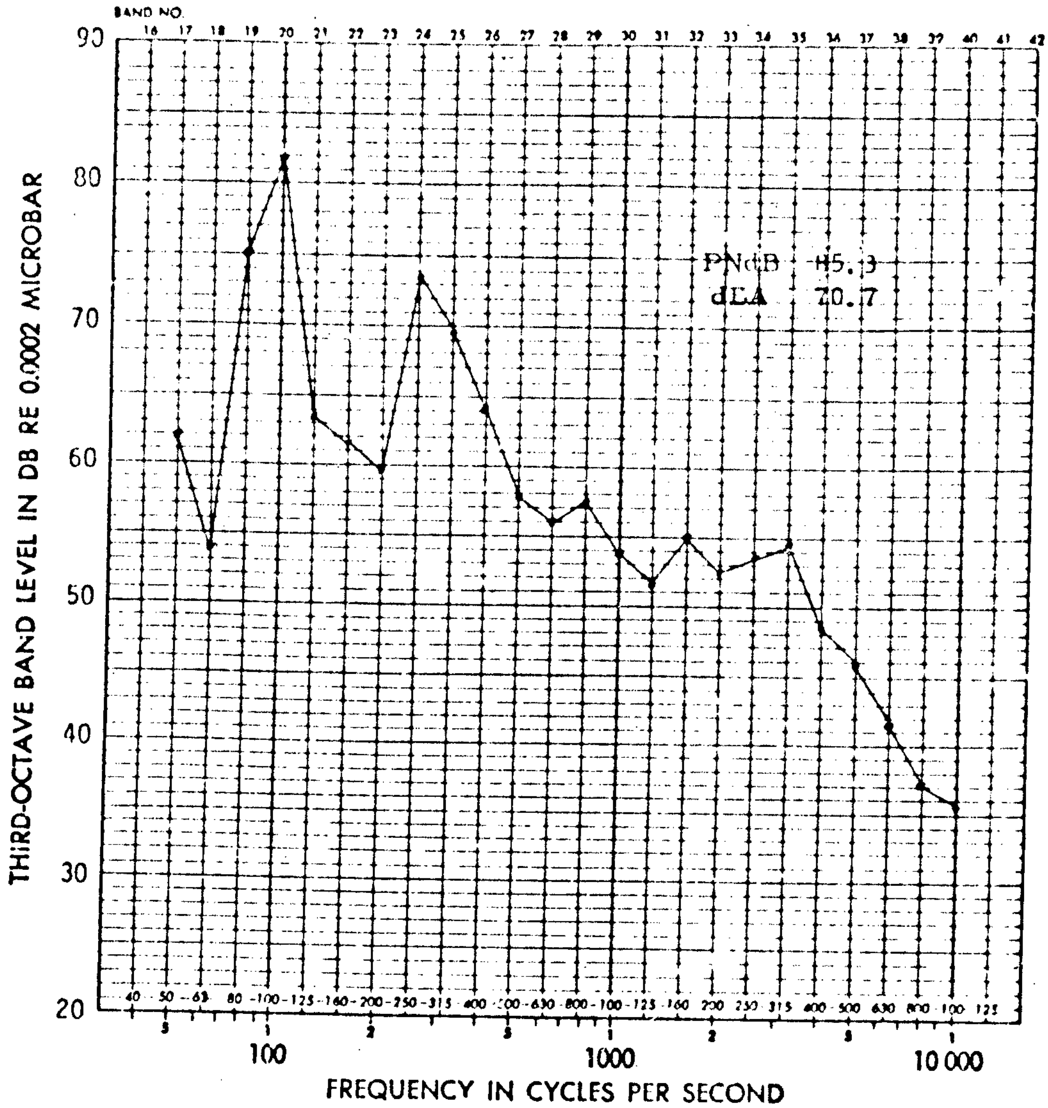



Figure B-24. Peak 1/3-octave band spectrum for Signal No. 24 - Hughes 300 - level flyover at 500 ft. altitude.

## APPENDIX C

Peak 1/3-octave spectra for PNdB calculations for highest level of twenty-four noises utilized in the Pilot Study.

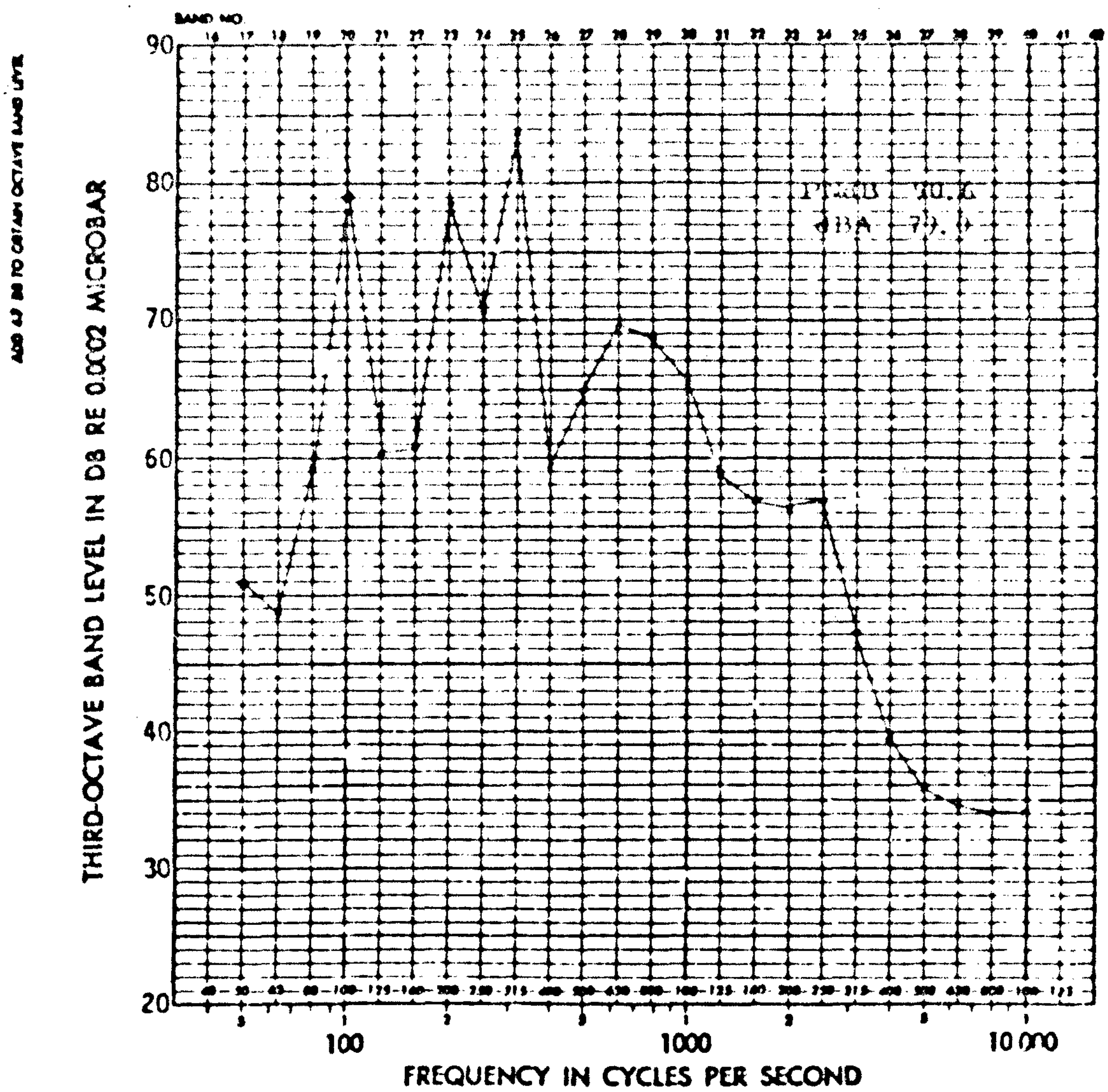



Figure C-1. Peak 1/3-octave band spectrum for Signal No. 1 - Tail rotor noise simulation with no slap (Standard Signal).

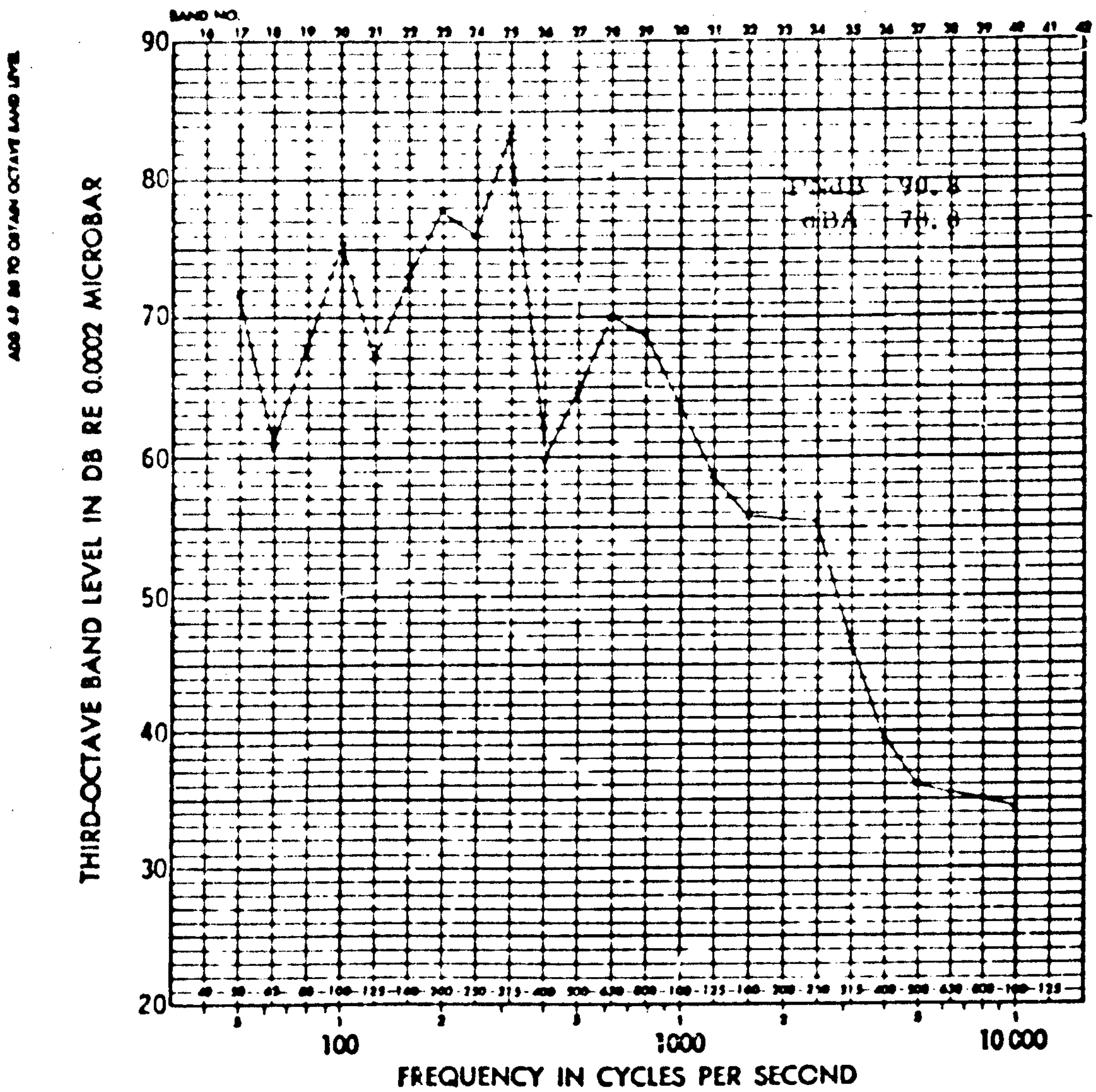



Figure C-2. Peak 1/3-octave band spectrum for Signal No. 2 - Tail rotor noise with light slap at 10 beats/sec.

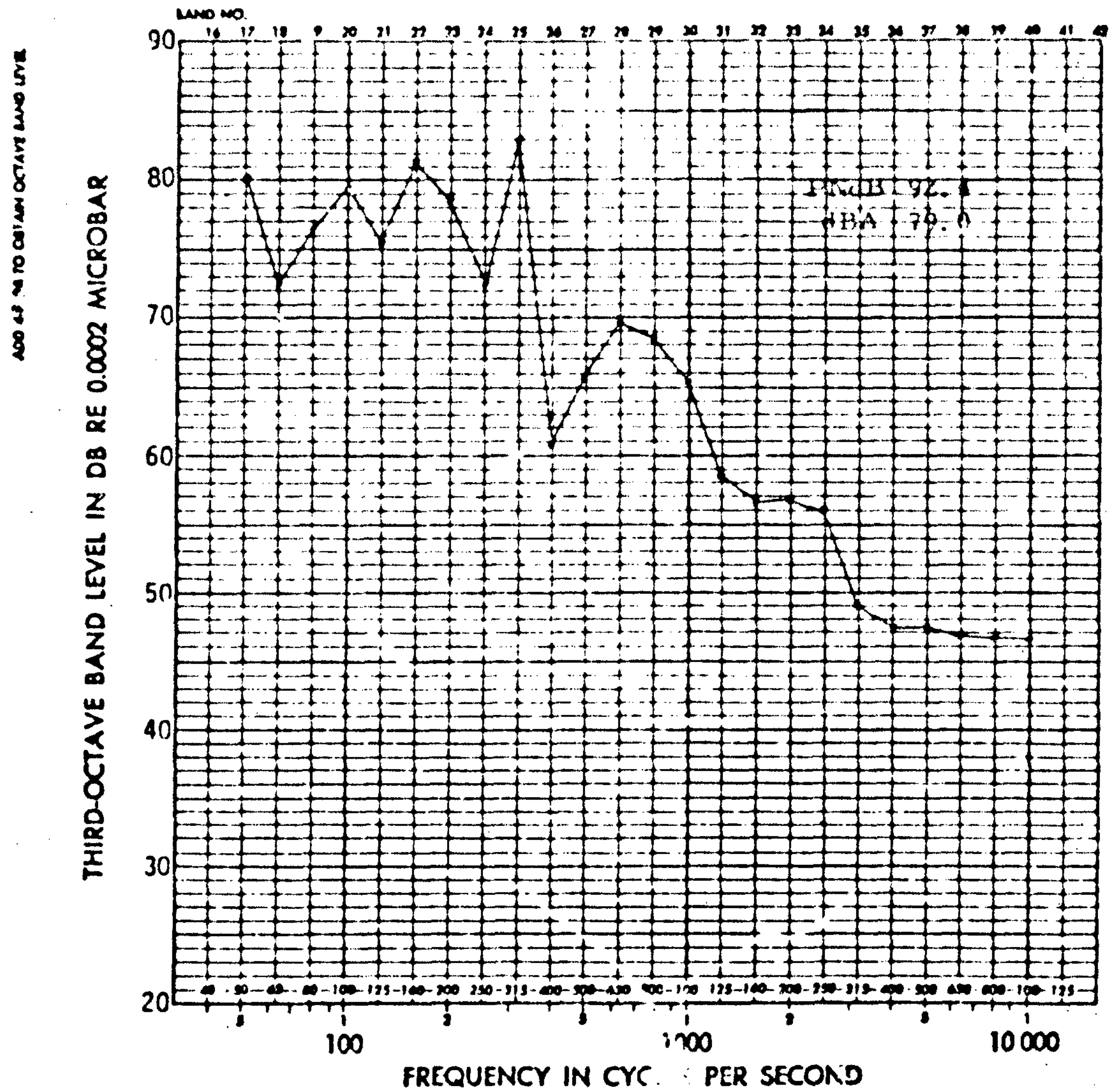



Figure C-3. Peak 1/3-octave band spectrum for Signal No. 3 - Tail rotor noise with moderate slap at 10 beats/sec.

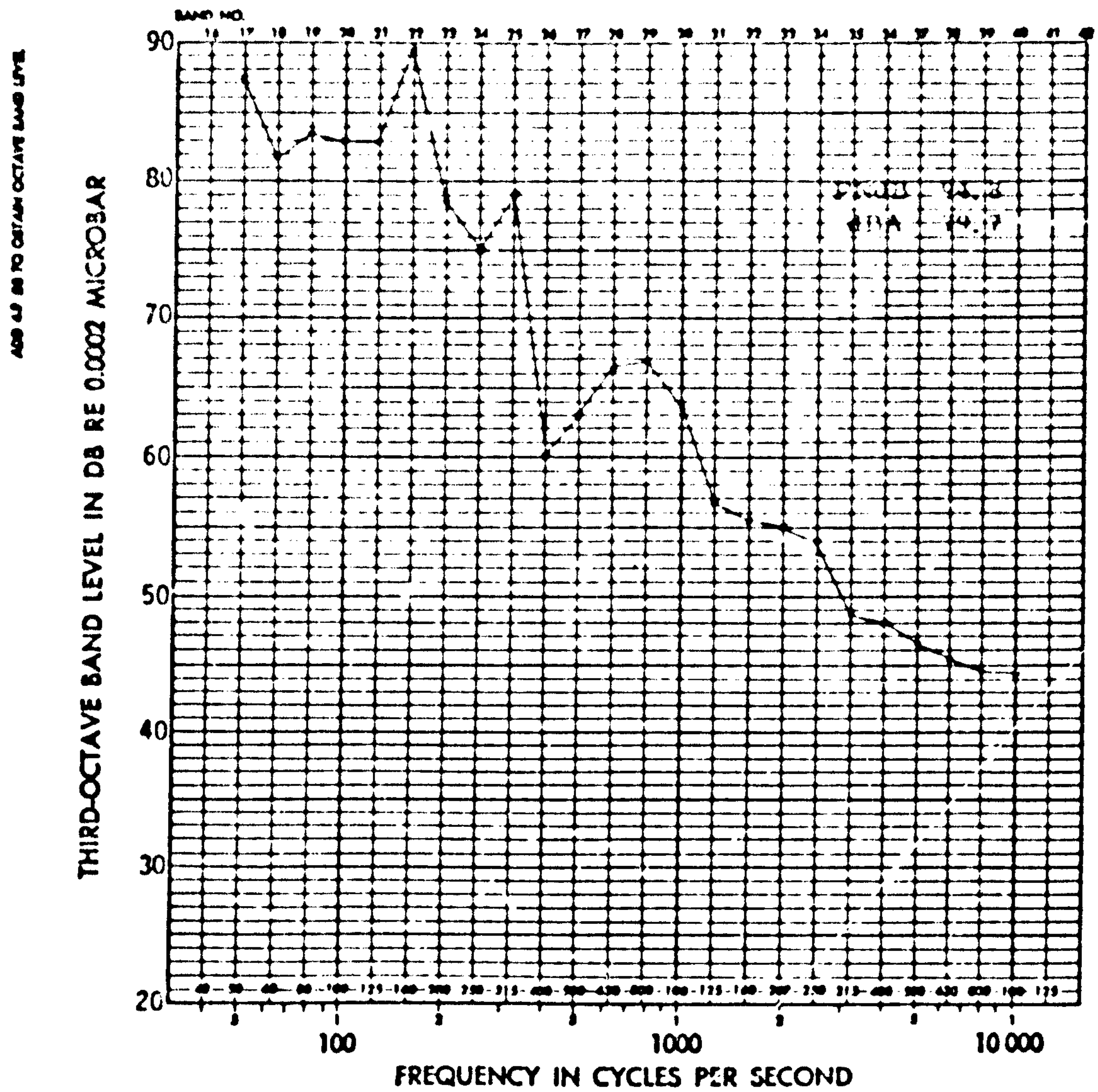



Figure C-4. Peak 1/3-octave band spectrum for Signal No. 4 - Tail rotor noise with heavy slap at 10 beats/sec.

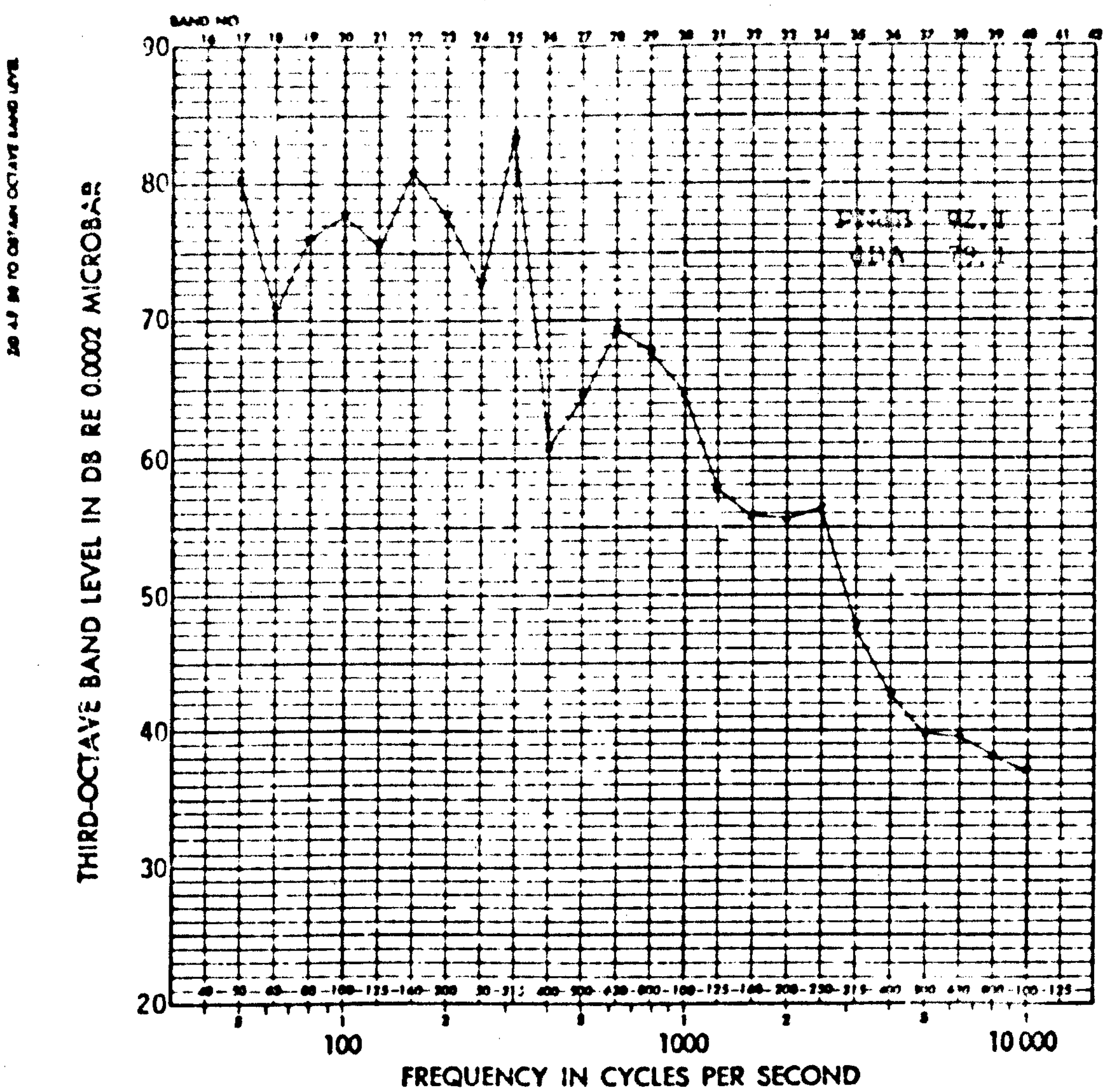



Figure C-5. Peak 1/3-octave band spectrum for Signal No. 5 - Tail rotor noise with moderate slap at 6 beats/sec.

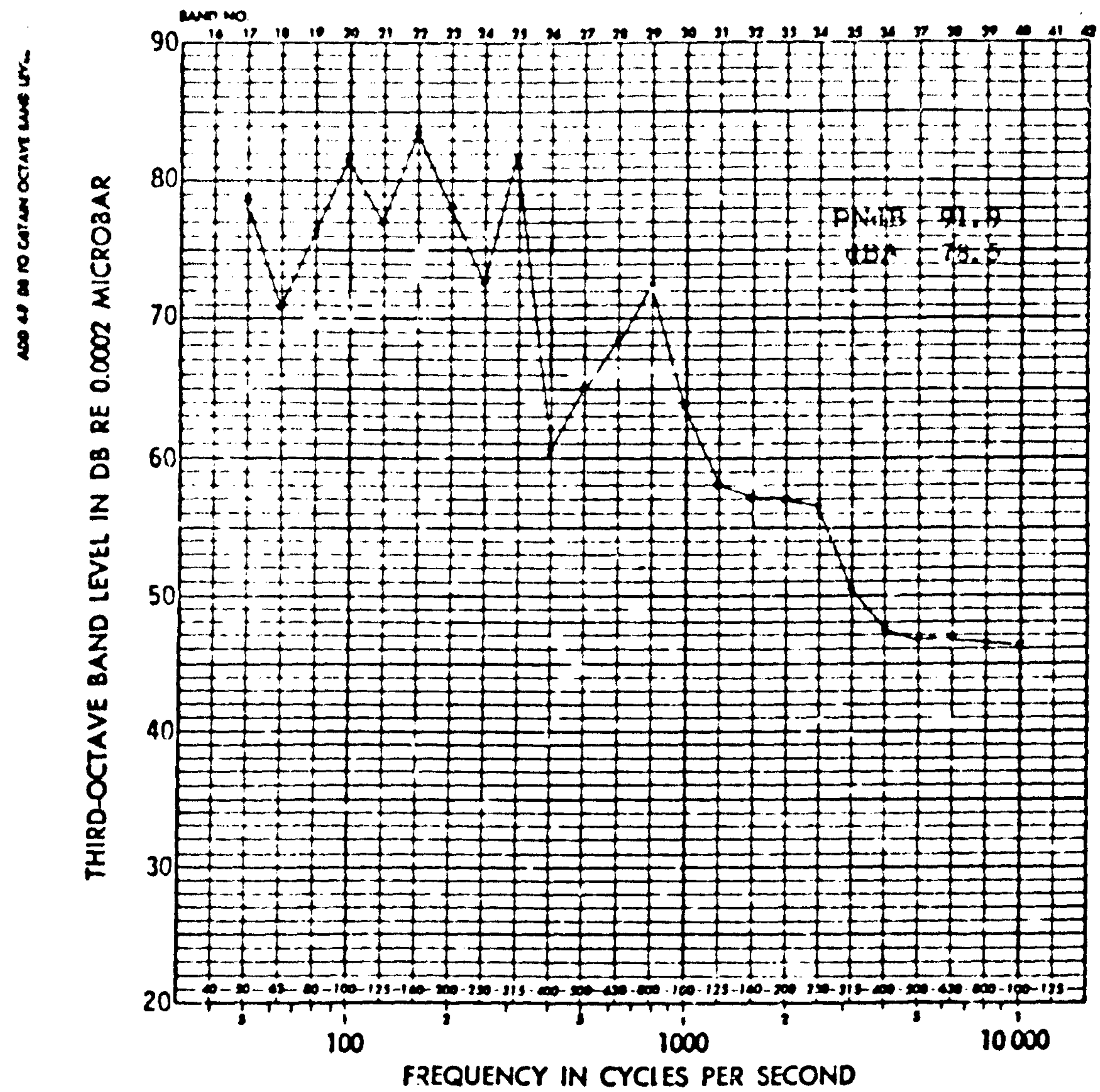



Figure C-6. Peak 1/3-octave band spectrum for Signal No. 6 - Tail rotor noise with moderate slap at 18 beats/sec.

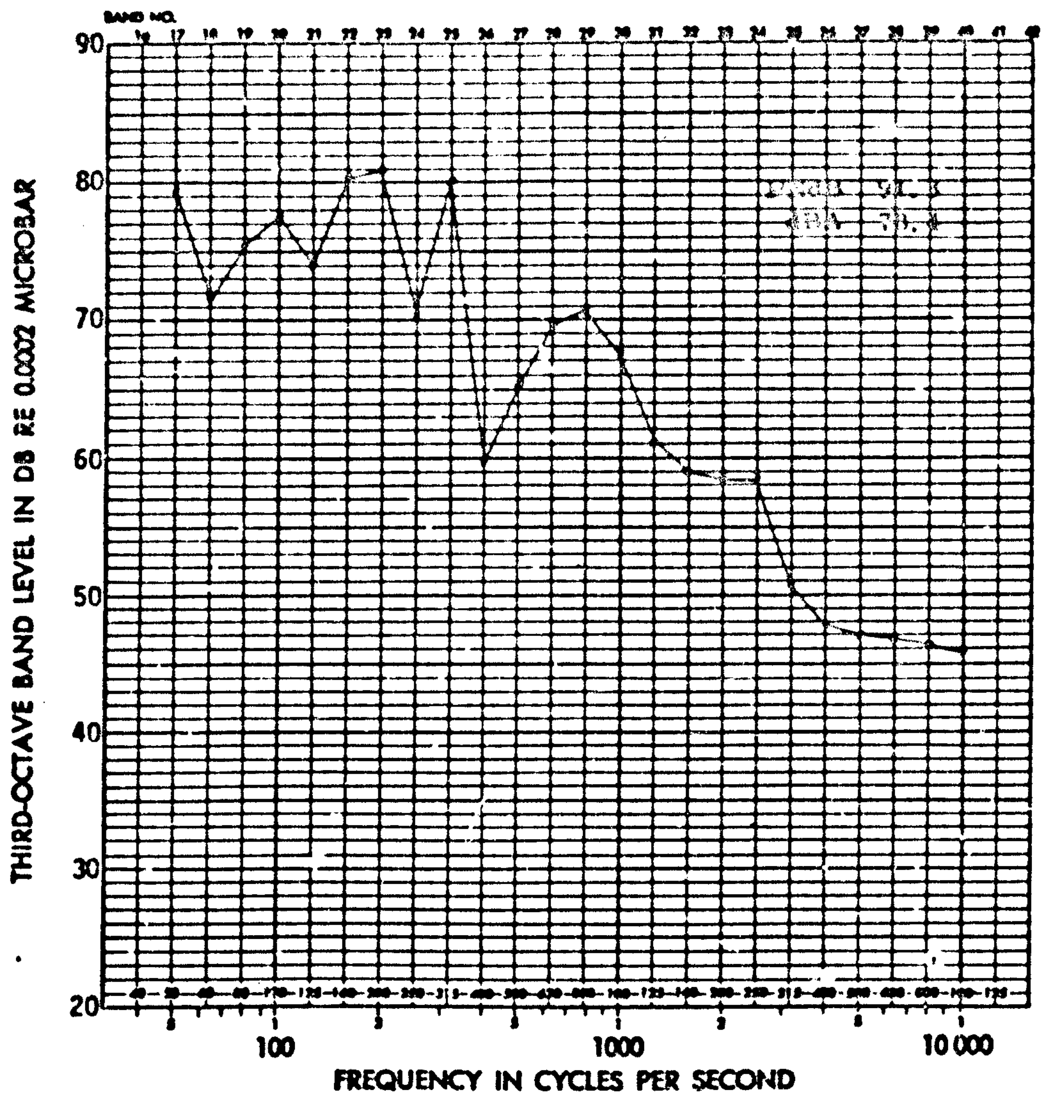



Figure C-7. Peak 1/3-octave band spectrum for Signal No. 7 - Tail rotor noise with moderate slap at 10 beats/ sec. and fast rise time.

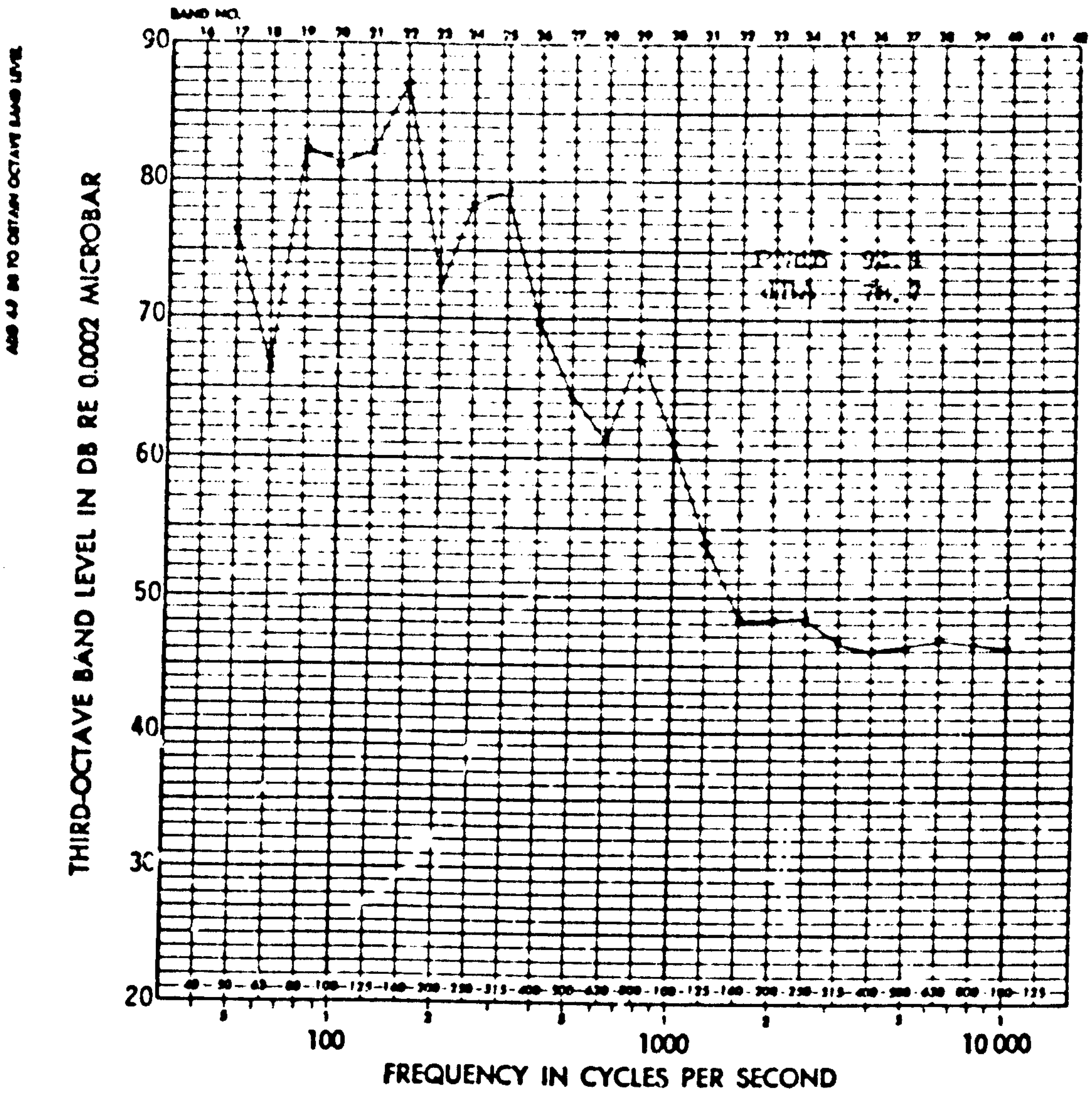



Figure C-8. Peak 1/3-octave band spectrum for Signal No. 8 - Chinook level flyby - direct and FM recording.

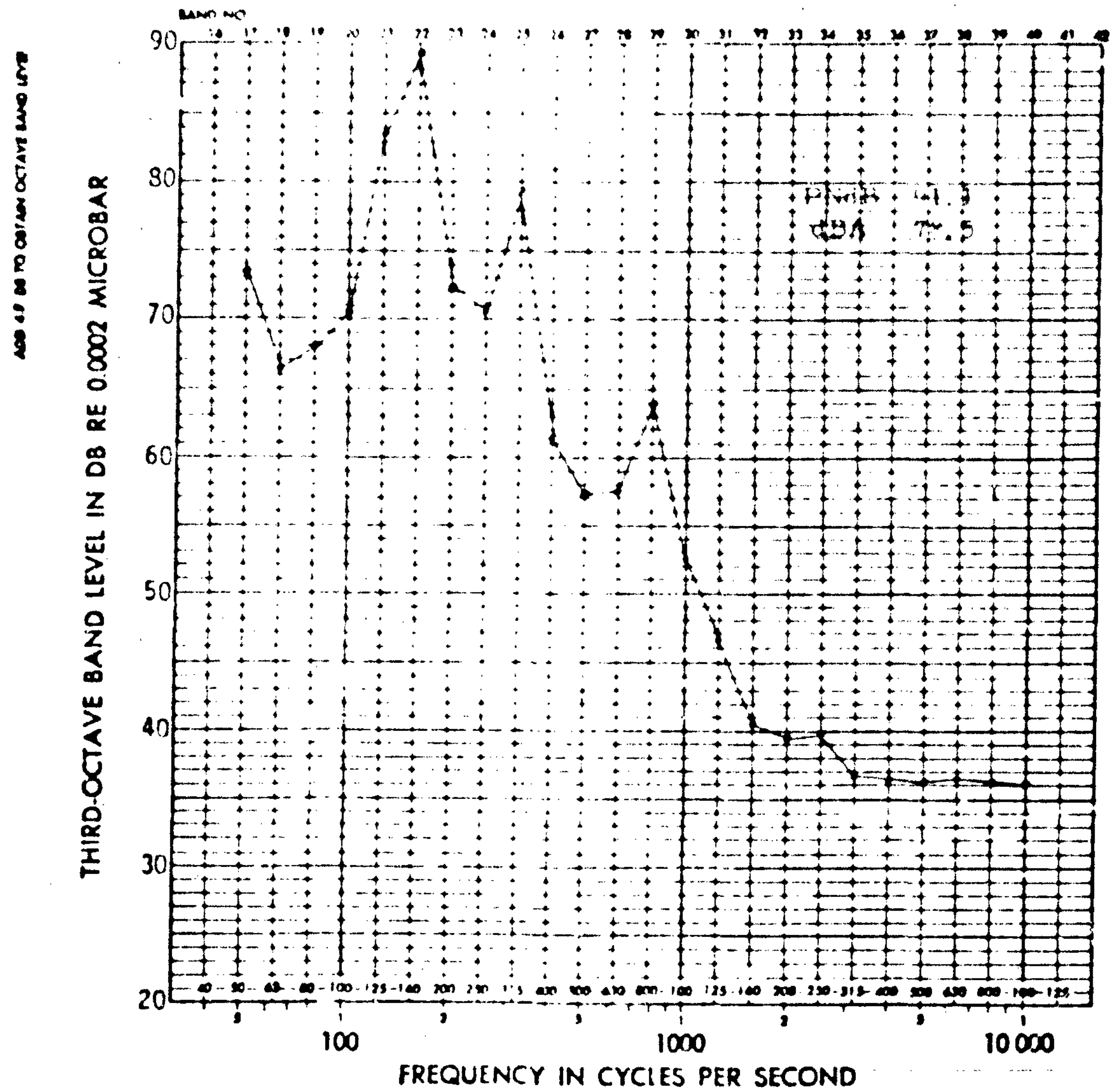



Figure C-9. Peak 1/3-octave band spectrum for Signal No. 9 - Chinook level flyover - direct and rolled-off FM recording.

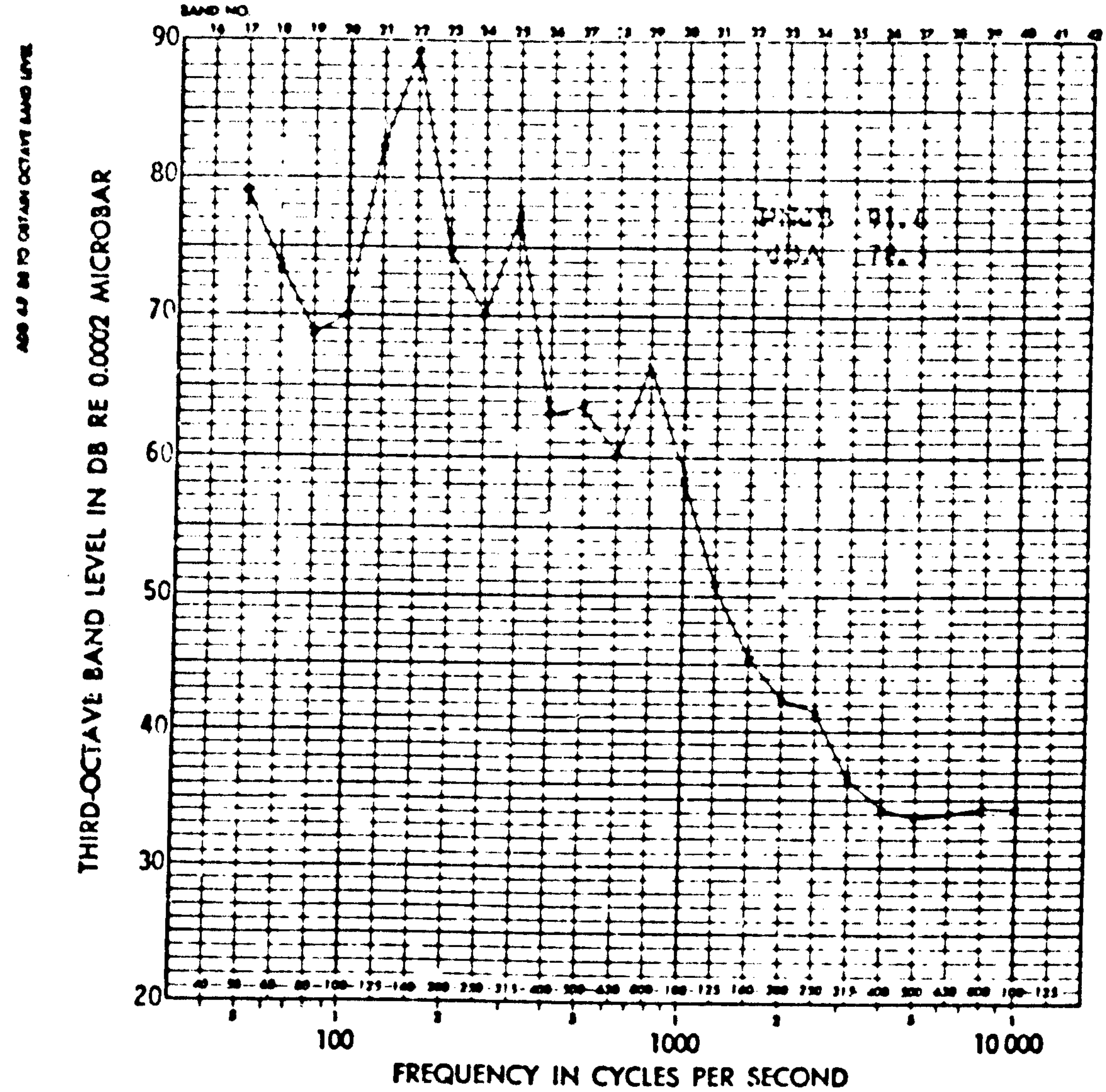



Figure C-10. Peak 1/3-octave band spectrum for Signal No. 10 - Chinook level flyby - direct recording only (no FM).

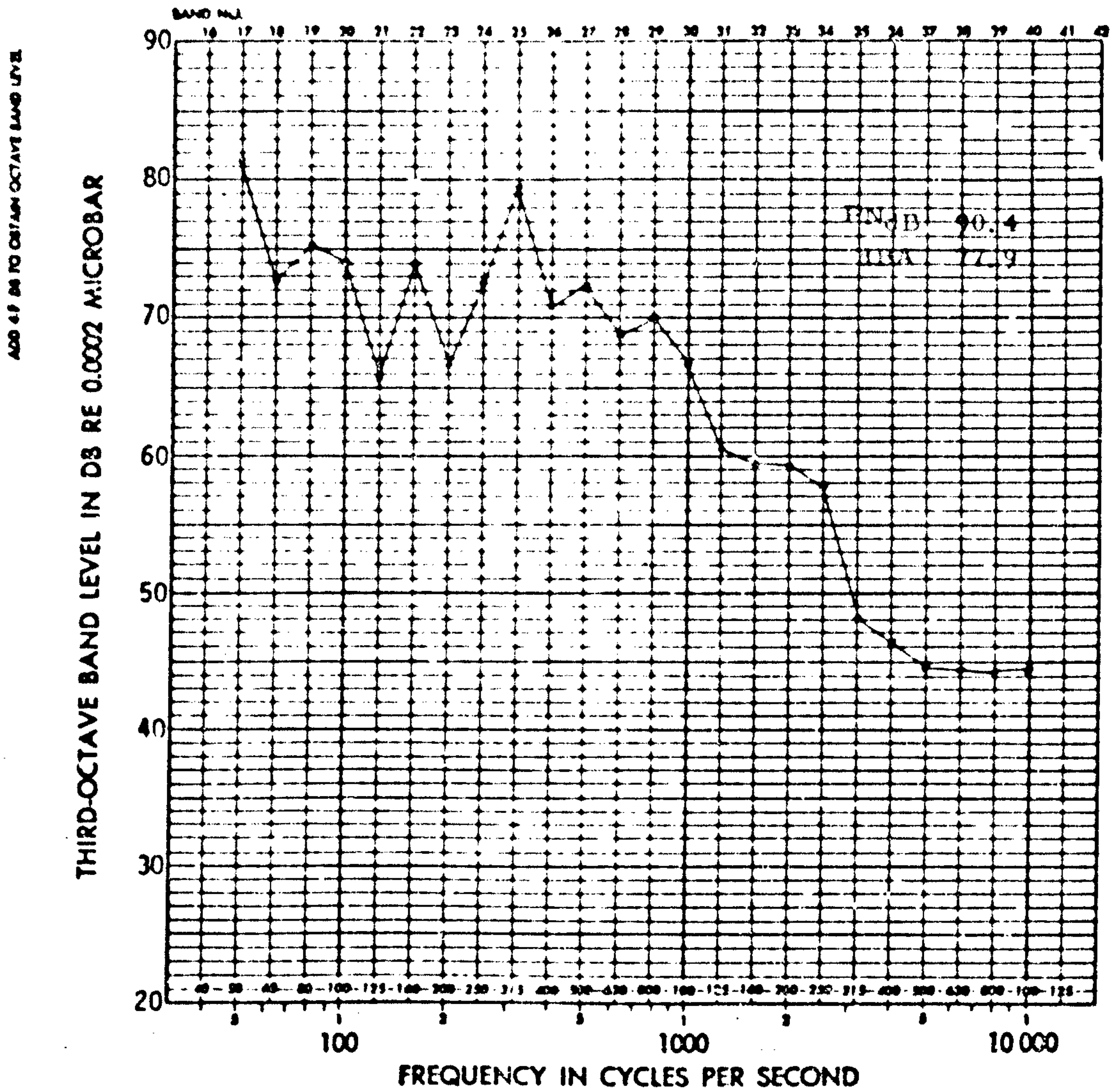



Figure C-11. Peak 1/3-octave band spectrum for Signal No. 11 - Chinook hover - direct and FM recording.

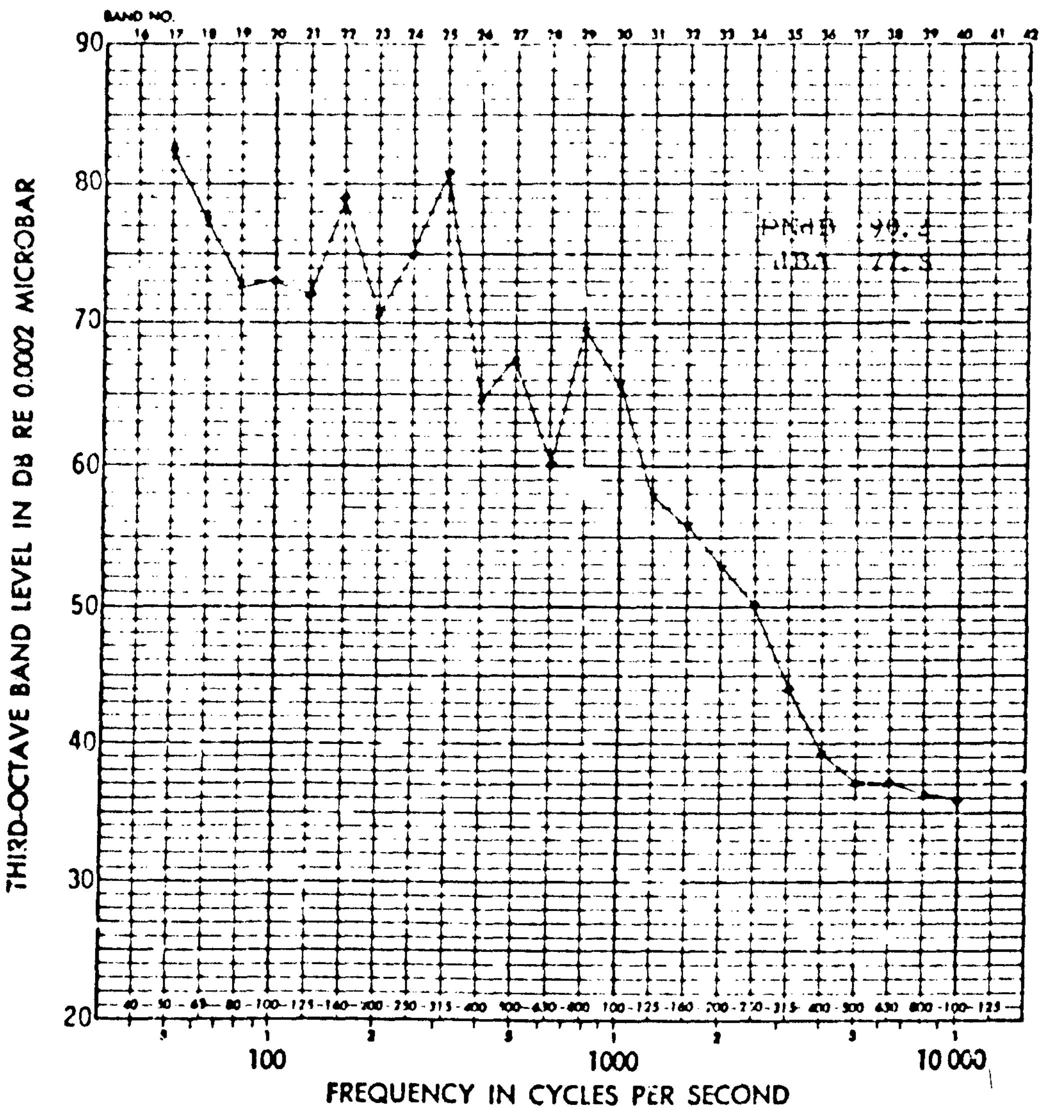



Figure C-12. Peak 1/3-octave band spectrum for Signal No. 12 - Chinook hover - direct and rolled-off FM recording.

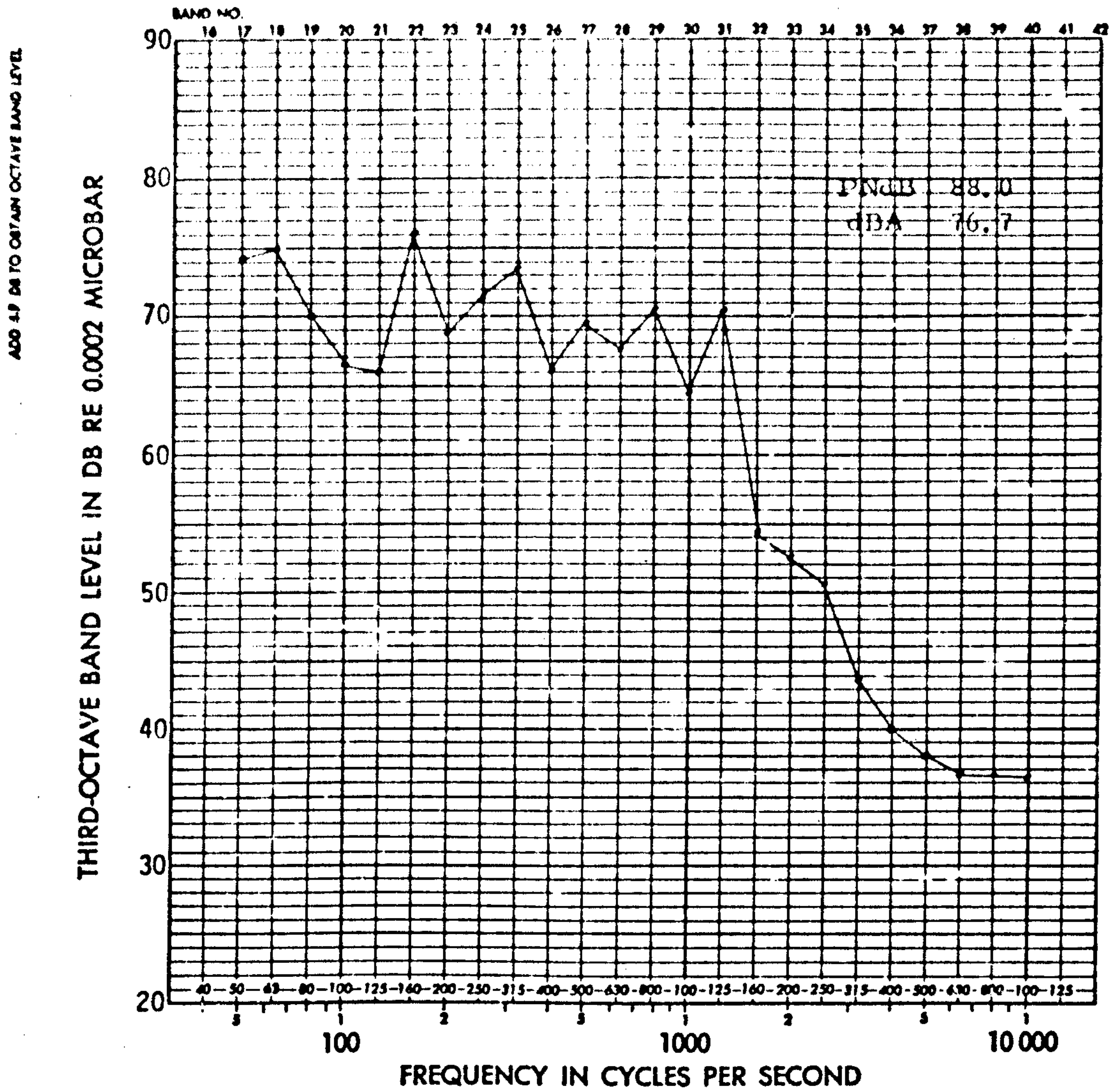



Figure C-13. Peak 1/3-octave band spectrum for Signal No. 13 - Chinook hover - direct recording only (no FM).

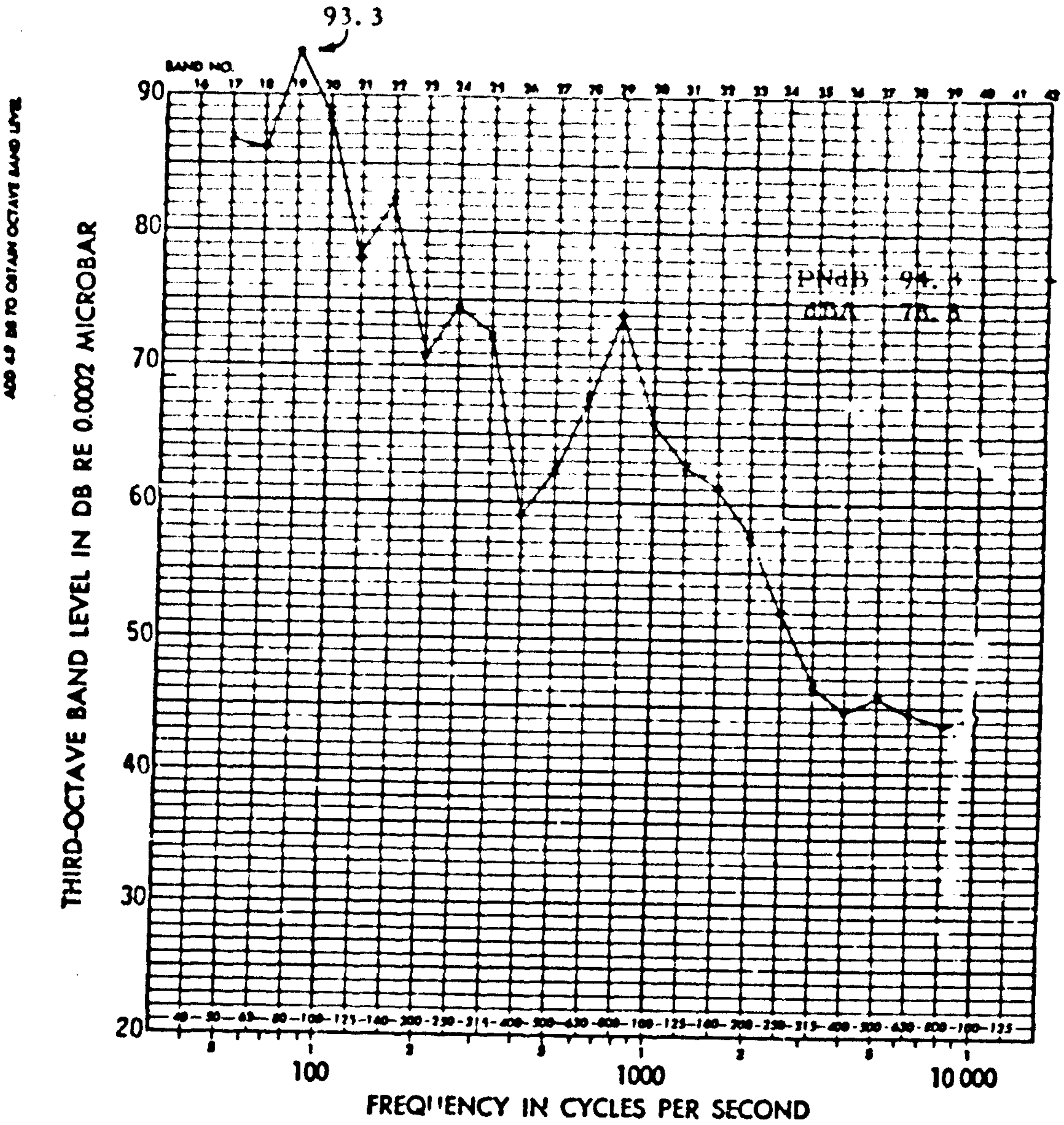



Figure C-14. Peak 1/3-octave band spectrum for Signal No. 14 - Chinook shallow turn - direct and FM recording.

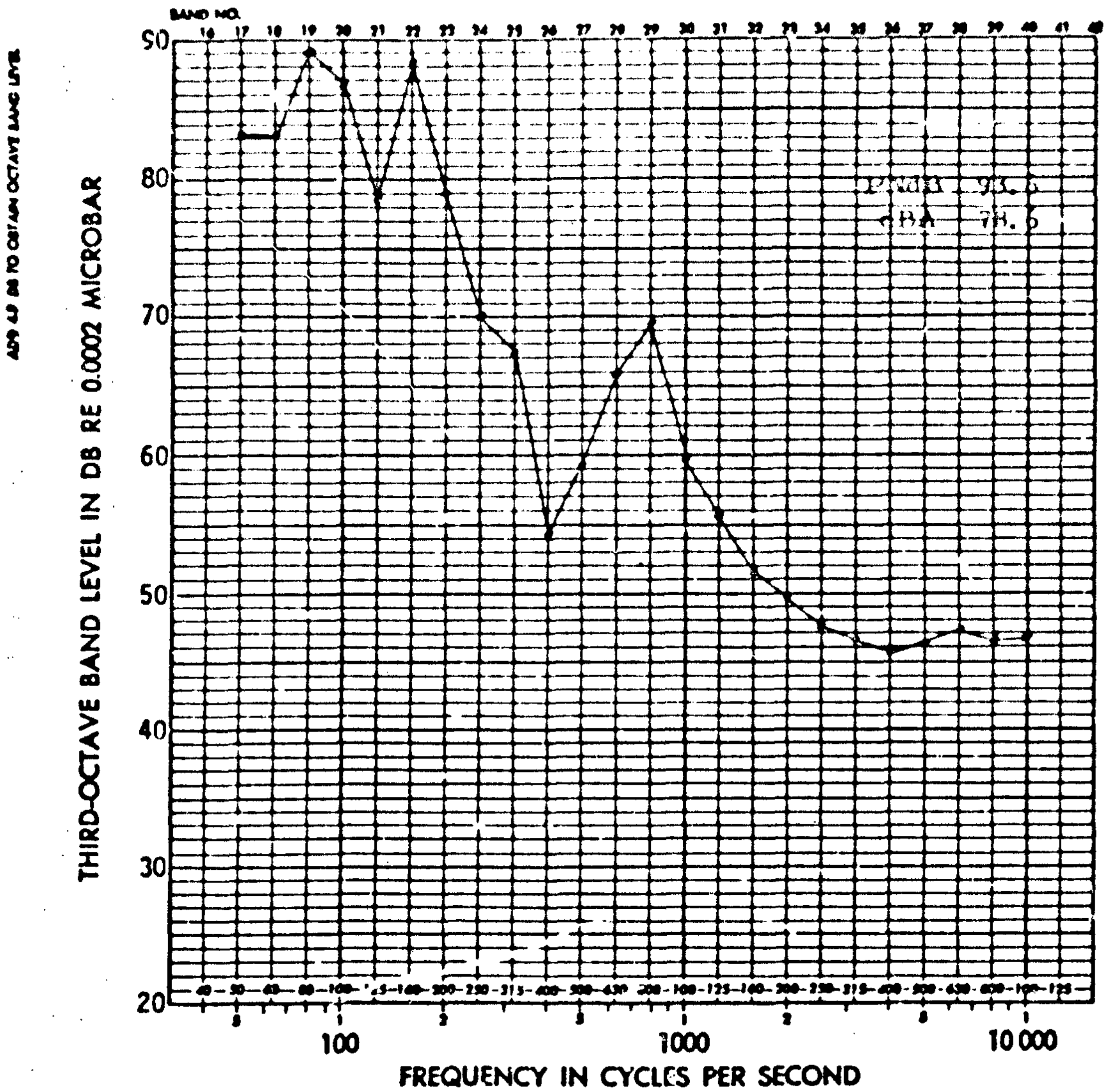



Figure C-15. Peak 1/3-octave band spectrum for Signal No. 15 - Chinook shallow turn - direct and rolled-off FM recording.

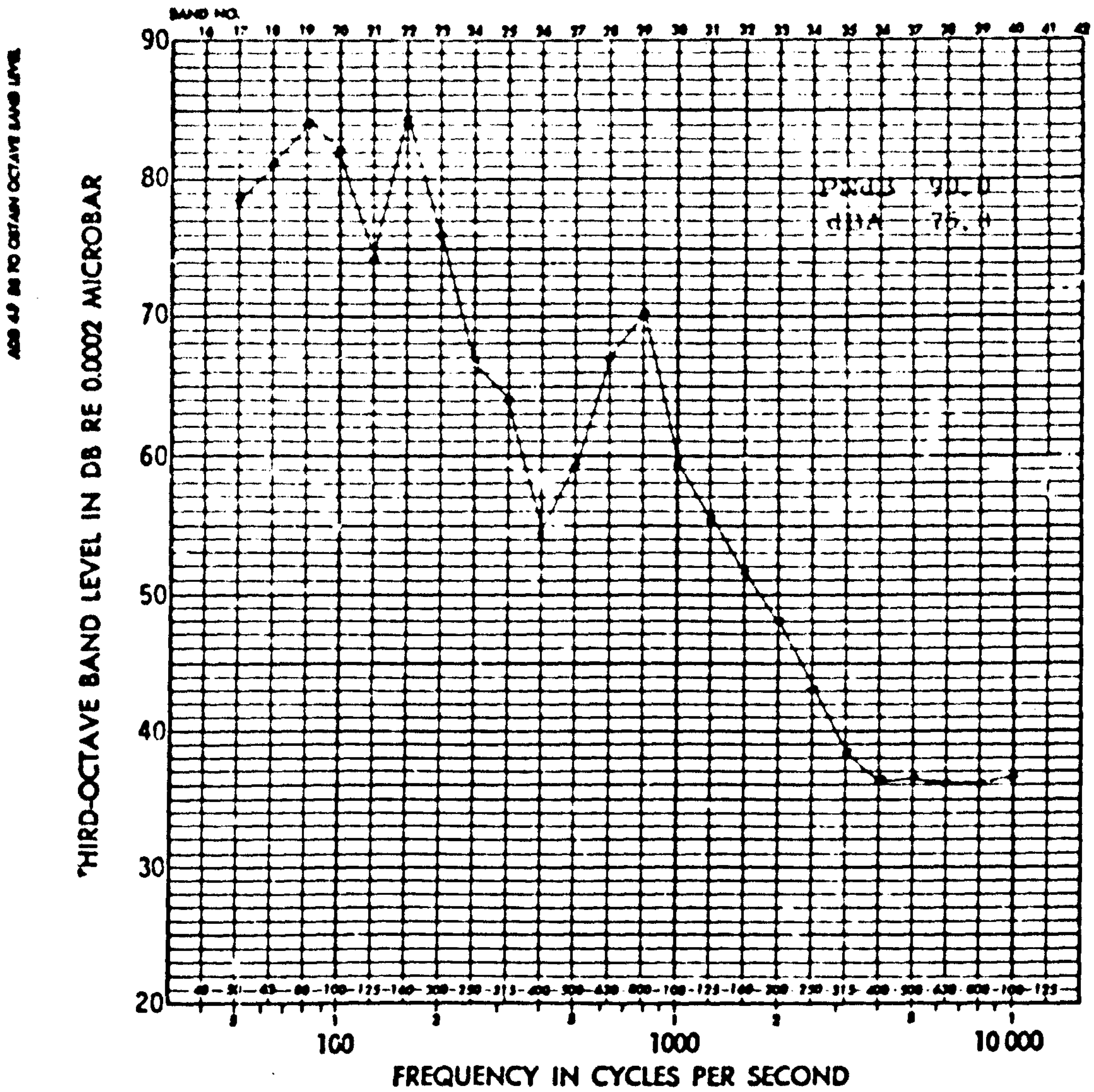



Figure C-16. Peak 1/3-octave band spectrum for Signal No. 16 - Chinook shallow turn - direct recording only (no FM).